DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 790

CONTRIBUTIONS TO THE GEOGRAPHY OF THE UNITED STATES 1926

MARIUS R. CAMPBELL
GEOLOGIST IN CHARGE

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the chapters for advance publication]

ILLUSTRATIONS

CONTRIBUTIONS TO THE GEOGRAPHY OF THE UNITED STATES, 1926

PEDESTAL ROCKS FORMED BY DIFFERENTIAL EROSION

By Kirk Bryan

INTRODUCTION

Isolated rocks consisting of a larger mass above resting on a smaller base or pedestal and known generally as pedestal rocks form one of the most spectacular types of natural monuments. The processes by which such forms are produced are doubtless as numerous as the agents of rock destruction, and it is probable that all the varied methods of weathering and of abrasion play a part in the formation of some of these rocks. In two preceding papers [1] of these contributions the origin of certain pedestal rocks has been attributed to abrasion of the base of the rock by running water or to rain wash and differential weathering. In this paper additional examples of rocks formed in arid climates by differential weathering are described. The nice cooperation of chemical and mechanical weathering in Washington and the differential weathering of sandstone in New Mexico produce rocks that can, by detailed study, be distinguished from rocks described in the preceding papers that are due to differential rain wash or to abrasion by running water.

Pedestal rocks may be produced by the abrasive action of the water and suspended matter in streams, or by the work of waves of seas or lakes, or by the scour of wind-driven sand. The favorable conditions for the production of the form in a stream are (1) the introduction of a block of rock into the channel by its fall from above or by the lowering of the channel on both sides of a mass of rock in place; (2) a fairly constant flow of water without excessive floods which might in their violence snap off the pedestal; (3) sufficiently short duration of the process.

Abrasion and solution by streams are given by Martel [2] as the sole causes of pedestal rocks, of which he has described a large number in

[1] Bryan, Kirk, Pedestal rocks in the arid Southwest: U. S. Geol. Survey Bull. 760, pp. 1–11, 1925; Pedestal rocks in stream channels: Idem, pp. 123–130. See also Bryan, Kirk, Pedestal rocks: Eng. and Min. Jour. Press, vol. 119, pp. 172–173, 1925.

[2] Martel, E. A., L'érosion des grès de Fontainebleau: Services carte géol. France Bull. 127, 1910. In this bulletin several earlier papers dating back to 1886 are summarized.

various parts of France. He vigorously combats the idea that rain and wind erode such rocks, and he describes three rocks whose form has been produced by stream action—a rock in the bed of Velon River [3] that stands in the bottom of a partly destroyed pothole; a rock in a limestone cavern at Furfoos, Belgium,[4] protected from weather, rain, and wind, but so fragile that it can not be subject to abrasion and must be due almost wholly to solution; and a rock in Gibbon River, Yellowstone National Park,[5] also described by me.[6] He contends that rivers with strong and turbulent currents once flowed at the level of the plateaus of France and particularly over the plateau of Fontainebleau. Although these streams date back to Pleistocene or Pliocene time, their channel features still persist in the form of potholes, arches, and pedestal rocks. In limestone areas subterranean streams flowing through caverns also produce these forms, partly by solution and partly by abrasion, and subsequently erosion has brought them to the light of day.

The effectiveness of stream erosion in the making of such rocks is somewhat limited, as set forth above, and this conclusion is confirmed by the rarity of occurrences in the beds of present streams. Although the three examples cited by Martel seem entirely valid, his position in regard to other rocks in France represents a point of view which is not concurred in by others,[7] who attribute the rocks of Fontainebleau and Montpellier-le-Vieux to the work of weathering and rain wash.

The formation of isolated masses by the abrasive and plucking action of waves against a cliff is common, and such masses, to which the term stack is applied, have been described by a number of writers.[8] The notched stack is such a mass somewhat undercut by the waves. Ordinarily the notch is on the side exposed to the waves, but on some stacks the notch, because of a weakness of the rock at

---

[3] Martel, E. A., op. cit., pp. 15–16, fig. 16.

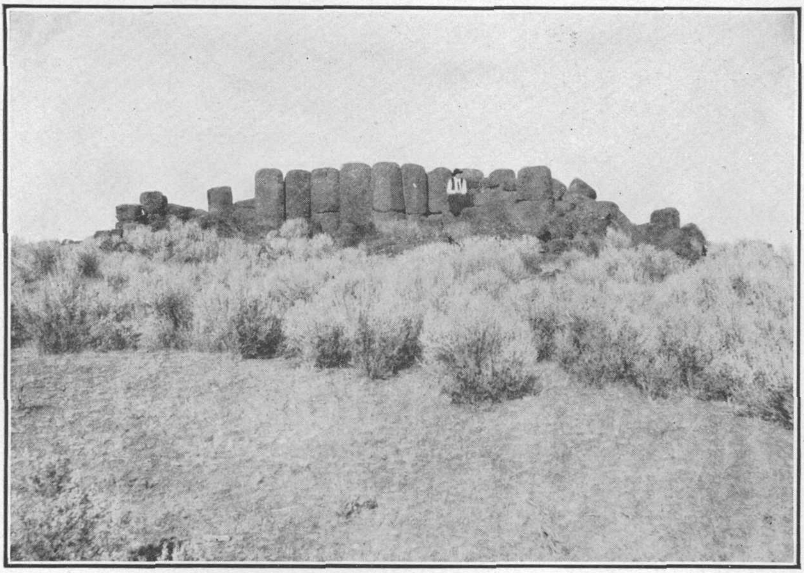
[4] Broeck, E. van den, Martel, E. A., and Rahir, E., Cavernes et les rivières souterraines de la Belgique, vol. 2, pp. 822–824, fig. 234, 1910.

[5] Martel, E. A. [Concerning the torrential origin of peduncular rocks]: Compt. Rend., vol. 159, pp. 87–89, 1914.

[6] Bryan, Kirk, Pedestal rocks in stream channels: U. S. Geol. Survey Bull. 760, p. 127, 1925.

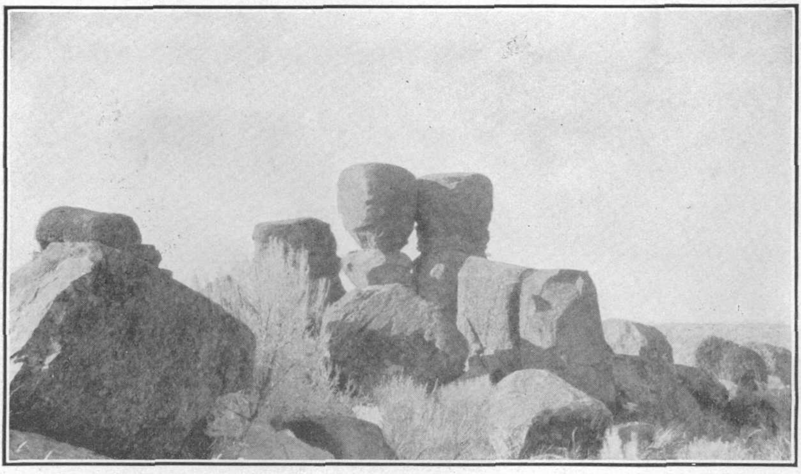
[7] Douvillé, H., Étude sur les grès de la forêt de Fontainebleau: Soc. géol. France Bull., 3e sér., vol. 14, pp. 471–481, 1886. Barré, O., Le relief de la forêt de Fontainebleau: Annales de géographie, vol. 11, pp. 295–314, 1902. De Lapparent, A., Leçons de géographie physique, 3d ed., pp. 90–91, Paris, 1907. Haug, E., Traité de géologie, vol. 1, p. 379, Paris, 1921.

[8] Geikie, Archibald, The scenery of Scotland, etc., pp. 67, 71, London, 1887. Fairbanks, H. W., Practical physiography, p. 411, fig. 342, Boston, 1906. Arber, E. A. N., The coastal scenery of North Devon, pp. 107–108, London, 1911. Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, p. 92, pls. 5, *B*; 9, *B*; and 12, *B*, 1911. Hobbs, W. H., Earth features and their meaning, p. 234, figs. 252–254, 1912. Johnson, D. W., Shore processes and shore-line development, pp. 278–279, pls. 34, 35, New York, 1919. Cotton, C. A., Geomorphology of New Zealand, pt. 1: New Zealand Board Sci. Art. Manual 3, p. 378, fig. 369, 1922. Dalmage, V., Post-Pliocene volcanics of the British Columbia coast: Jour. Geology, vol. 32, p. 41, fig. 4, 1923.



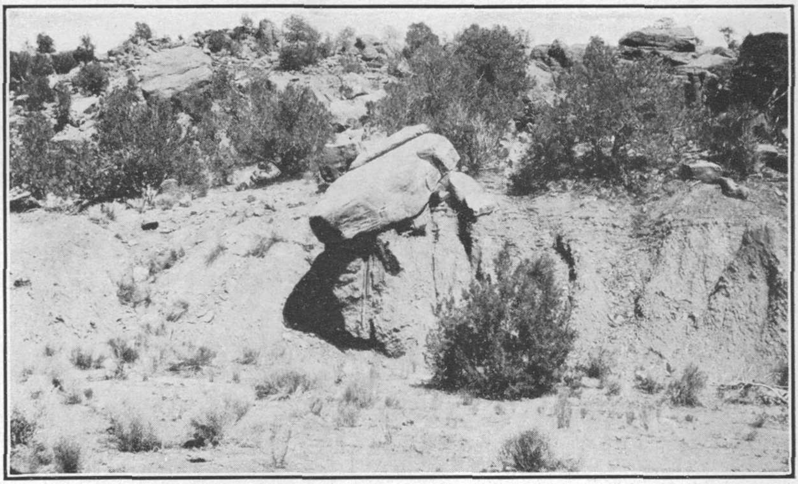
A. HILLOCK OF BASALT COLUMNS 6 MILES NORTH OF WHEELER, GRANT COUNTY, WASH.

A column on the left has the form of a pedestal rock. Photographed in 1923

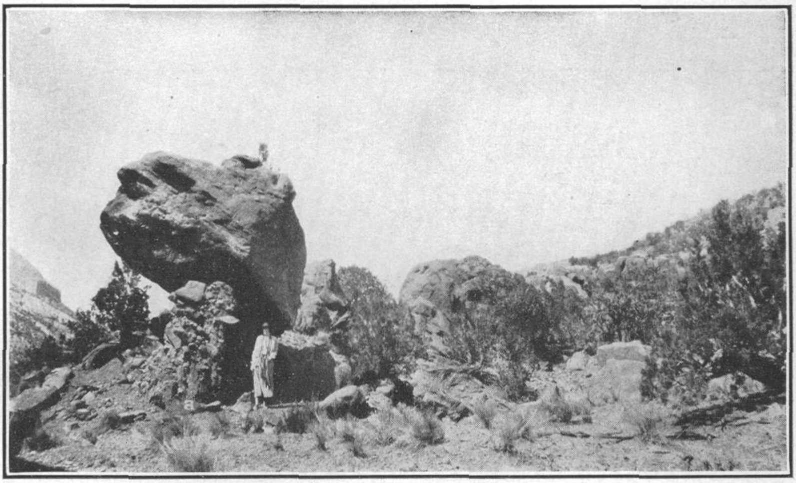


B. PEDESTAL ROCK FORMED BY MECHANICAL DISRUPTION OF BASALT COLUMN

Photographed in 1923



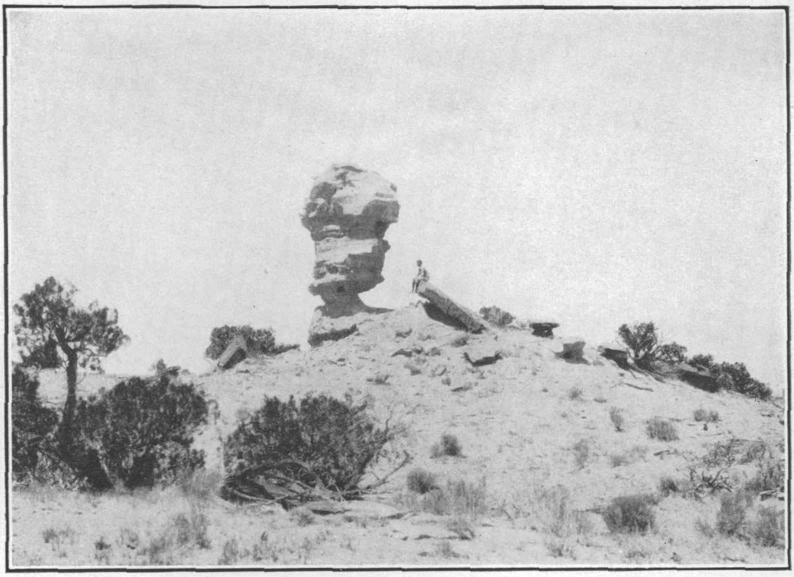
A. SANDSTONE BLOCK RESTING ON PEDESTAL OF SHALE DETACHED FROM THE BANK OF WHICH IT ONCE FORMED A PART



B. SANDSTONE BLOCK RESTING ON RUBBLE OF OLD TALUS ELSEWHERE STRIPPED FROM A SHALE SLOPE

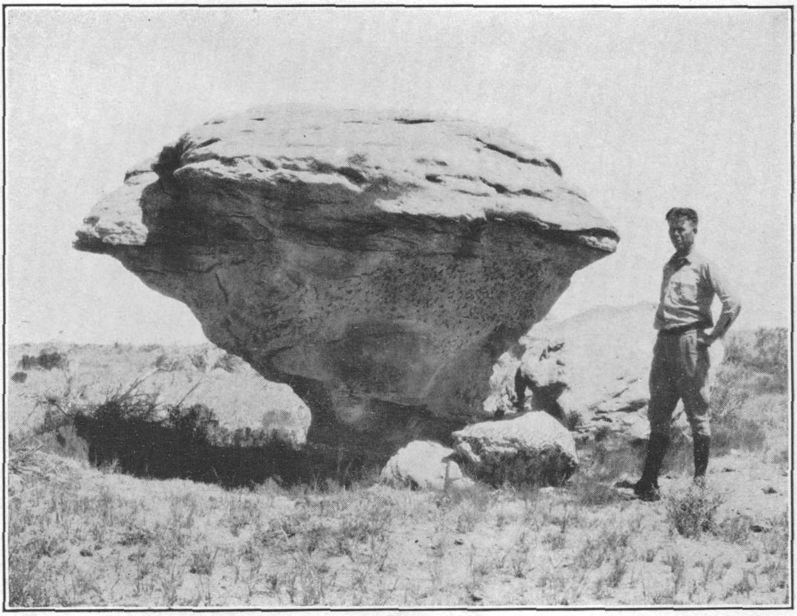
PEDESTAL ROCKS IN CANYON OF JEMEZ CREEK, N. MEX.

Photographed in 1923



A. PEDESTAL ROCK OF SANDSTONE NEAR SEVEN LAKES, McKINLEY COUNTY, N. MEX.

Photographed in 1924



B. PEDESTAL ROCK OF SANDSTONE NEAR McGILLVRAY'S RANCH, McKINLEY COUNTY, N. MEX.

Photographed in 1924

the position of greatest scour, extends all the way around the stack. Such notched stacks have the same form as pedestal rocks. Obviously, these rocks are structurally weak and are easily destroyed by the high waves of great storms. Direct abrasive action of wind-blown sand is asserted by a number of writers [9] to be the agent in the formation of pedestal rocks in deserts. Neither the descriptions nor the photographs presented by these writers are wholly convincing, except those of a rock on the coast of the Red Sea described by Wade [10] and of one in Southwest Africa described by Harger.[11] There is no inherent reason why the form can not be produced by this process, provided that winds and sand operate for a sufficient length of time on a favorably located mass.

The pedestal should show the marks of abrasion by wind-blown sand, but the possibility of polish by the pelts of grazing animals should be eliminated, as Karl Walther [12] has pointed out in describing a pedestal rock of granite which was produced by differential weathering in the plains of Uruguay.

Pedestal rocks in areas having various types of climate are due to differential weathering, and the object of this paper is to describe the particular processes of differential weathering which have produced certain pedestal rocks in areas having climates that differ in type but are comparatively arid. The examples from the State of Washington were studied incidentally in the course of a geologic examination of the Columbia Basin irrigation project in 1923. The rocks in the canyon of Jemez Creek, N. Mex., were seen while I was on leave in the same year, and the rocks in McKinley County, N. Mex., were visited during a geologic study of the recent deposits of Chaco Canyon for the National Geographic Society in 1924.

PEDESTAL ROCK IN BASALT

The pedestal rock in basalt here described is by no means perfect in form, but it is due to so curious a combination of circumstances that a description will doubtless be interesting to those concerned with the processes of arid regions. The rock lies at the north end of a small hillock 12 miles southwest of Adrian and 6 miles north of Wheeler, Grant County, Wash. This locality is in the west-central part of the Columbia Plateau. Quincy Basin, a structural depression, lies to the west, and the lavas of the plateau in this vicinity dip

---

[9] A fairly complete list is given in U. S. Geol. Survey Bull. 760, p. 1.

[10] Wade, Arthur, Some observations in the eastern desert of Egypt, with considerations bearing on the origin of the British Trias (with discussion): London Geol. Soc. Quart. Jour., vol. 67, p. 248, pl. 14, fig. 2, 1911.

[11] Harger, H. S., Denudation in South Africa: South Africa Geol. Soc. Proc., 1913, p. xxxiv, and especially fig. 1.

[12] Estudios geomorfológicos y geológicos: Montevideo Inst. hist. geog. Revista, vol. 4, p. 109, footnote, 1924.

almost insensibly westward and pass under the gravel and sand that form this plain. Several waterless gorges extend westward from the higher land and fade out in the basin. Near the mouth of one of these gorges, Black Rock Coulee, long ago deserted by the glacial waters that excavated it, there is an area with numerous rocky hillocks projecting from the plain. The irregular rock surface, of which the hillocks are the high points, was doubtless carved by the glacial waters from Black Rock Coulee. Over this floor wind-blown dust from the flats of Quincy Basin or rehandled loess from the surrounding plateaus has settled.

The hillock with the pedestal rock consists of a group of basalt columns each of which is from 18 inches to 3 feet across. The columns are mostly six-sided and are unusually even and symmetrical. As shown in Plate 1, *A*, each column is separated from the neighboring ones by a space about 2 inches wide, yet each column, though it has the irregularities normal to such columns, fits its neighbors and evidently has not been displaced since its formation. At the base of the columns and below the ground surface the rock is continuous from column to column except for a medial crack. For an inch on each side of this crack the rock is soft, is greenish gray with rusty crevices, and gives the appearance of having suffered from chemical decomposition. The space between the columns, above ground, is obviously due to the removal of rock weakened in the same way. The projecting columns, though diminished in size, are hard and sound, and their faces are smooth and regular. They are little affected by corrosive processes but suffer disruption by spalling. The dense, tough rock breaks in spalls and chips, and to this spalling is due the pedestal rock shown at the left in Plate 1, *A*, and in more detail in Plate 1, *B*. This column has two incipient cross joints, and, as is well shown in Plate 1, *B*, spalling to these joints has produced the narrow neck that is surmounted by a block the full size of the column. The neighboring column is suffering from the same process, and some of the adjacent columns also show spalling from the corners. A few columns have lost from the sides, as well as from the corners, numerous thin rock chips, which litter the ground. These chips and the larger fragments broken from the corners appear to be fresh rock and ring when struck by the hammer.

Chips collected from the surface and dug out from between the columns have been studied by Clarence S. Ross, who has furnished the following statement:

The chips from the columnar basalt when studied under the microscope, both in thin section and as small grains embedded in immersion oils, show interesting characteristics, some of which were not suspected before examination. The rock is a normal basalt but little altered and is composed of calcic plagioclase, augite, and sparse olivine and magnetite.

The chips collected above ground have a dull weathered and pitted surface, but 1 millimeter below the surface they appear to be fresh, and they have the sharp metallic ring of a fresh rock.

The chips collected below the ground surface have a dirty greenish-gray appearance, and the laminae and cracks are filled with alteration products, among which opal is the most abundant. They do not ring but give a dull sound when tapped, and they present an appearance of rock decay.

In the chips collected above ground the plagioclase grains are entirely unaltered chemically, the augite grains are nearly as fresh, and the sparse olivine is only partly decomposed. A red-brown mineral secondary to olivine is present, but it was probably developed during the final cooling of the rock and is not a product of later weathering. A very small amount of limonitic material has developed which gives the rock a rusty appearance under the hand lens. This material lies in the cracks and cleavage planes of the minerals and as viewed under the microscope is a pale yellow-brown stain which accentuates the fractures and cleavage planes. The most striking characteristic is the development in the plagioclase and augite of countless small fractures, which are far more abundant and conspicuous than in a fresh basalt. On the surface of the chips minerals that appear nearly fresh under the microscope have become so fragile that they can not be picked up with the forceps, but just below the surface, although the fractures are nearly as conspicuous, the minerals are not so fragile. The fractures in general cut across the augite and olivine grains in random directions, but in most of the plagioclase grains they make an angle of 45° with the cleavage or follow a cleavage plane for a distance and then break across at an angle of approximately 45° to another cleavage plane, so as to form a rather regular network of fractures.

The minerals of the rock chips collected below the ground surface are surprisingly fresh considering the appearance of the rock in the hand specimen. The plagioclase grains are unaltered chemically, but the augite and olivine grains show distinctly more alteration than these minerals in the chips collected above ground. Both the plagioclase and the augite have only a few more fractures than are characteristic of the minerals of normal fresh basalt, and they do not have the abundant fractures shown by these minerals in the chips collected above ground.

The greater amount of weathering by chemical decomposition in the rock chips collected below the ground surface observed by Mr. Ross is confirmed by chemical tests carried out in the chemical laboratory of the Geological Survey by J. G. Fairchild. The results may be tabulated as follows:

Partial analysis of weathered basalt from hillock 6 miles north of Wheeler, Grant County, Wash.

	Sample taken above ground	Sample taken below ground
	Per cent	*Per cent*
Ferrous iron (FeO)	10.3	9.24
Loss on ignition (total H_2O)	1.06	2.32

The relative loss in content of ferrous iron of the rock chips from below the surface indicates that the olivine and augite have begun to break down, as is to be expected in the decay of basalt; and the increase in water content indicates that hydrous clayey minerals have been formed as a result of the decomposition of these minerals and perhaps also of the plagioclase, although under the microscope this mineral gives no sign of decomposition.

The intimate fracturing of the mineral grains of the rock chips from the surface brought out by Mr. Ross's study can be safely attributed to mechanical disruption, because the absence of decomposition products except for the small amount of iron oxide testifies to the almost complete lack of chemical change. The physical forces that can have caused the disruption are frost action and thermal expansion and contraction under the diurnal and annual fluctuations of air temperature. It seems improbable that sufficient water could penetrate into the mass of these otherwise unaltered mineral grains to disrupt them on its expansion in freezing, though no data are available in support of this contention. The fractures are, however, of a type that should arise if the grains were subjected to the stresses due to thermal expansion or contraction when at the same time they were confined by and stressed by other grains affected by the same forces. As the diurnal changes of air temperature are not only more numerous but because of their short period produce greater ranges of temperature in adjacent parts of the rock, they have doubtless been more effective than the annual changes in temperature in producing the cracks. It should also be noted that just below the ground surface the fracturing is absent, although there the annual changes in temperature should be just as effective.

The spalling of small chips and larger masses, to which the pedestal rock is largely due, is also a mechanical process. Spalling of this type is ordinarily attributed to thermal expansion and contraction, but Blackwelder [13] has recently expressed the doubts which it is evident from a review of the literature have lingered in the minds of geologists as to the validity of this process.

In this relatively arid locality conditions are favorable for numerous and rapid changes in air temperature, which, if such changes can disrupt rock, should produce the spalling that has been observed. Even if the changes in temperature of this locality are insufficient to disrupt a rock of normal strength the outer part of these basalt columns has already suffered from a minute internal rupture of its component minerals and therefore lacks part of the original strength and may have other quite distinct physical properties.

Frost action also can not be wholly eliminated, because the locality has a cold winter during which moisture that had collected in the fractures of the mineral grains might freeze and cause the spalling.

[13] Blackwelder, Eliot, Exfoliation as a phase of rock weathering: Jour. Geology, vol. 33, pp. 793–806, 1925.

The relatively small amount of chemical weathering observed below the ground surface and between the columns may possibly be due to forces operative in the past. A little decomposition of this sort is evident in all the outcrops of basalt in the Columbia Plateau. Cliffs that are thought to have been formed by streams issuing from the ice of Wisconsin time appear to consist of fresh rock, but a close inspection shows that they have many zones of soft decomposed rock along vertical joints. The minerals that once filled the vesicles of the basalt have been leached out, and bands of opal in the cracks are more or less decomposed. Ordinarily, in the Columbia Plateau, surfaces formed in pre-Wisconsin time are underlain by rock that is softened and discolored by unmistakable chemical weathering. It may be that the chemical weathering of this locality began in the early Pleistocene and has been inherited from a time preceding the occupation of Black Rock Coulee by glacial waters,[14] which have removed at this place only a moderate thickness of rock. On the other hand the glacial channel in Black Rock Coulee may belong to the intermediate glaciation (Spokane of Bretz) or some earlier ice advance, and if so there has been ample time for chemical weathering to take place since the channel was formed. Chemical weathering may even be going on at the present time, for, although the climate is arid, the fine-grained soil is retentive of moisture.

The rock has formed in an arid climate, within the "dry spot" of Washington, a nearly circular region about 50 miles in diameter, in which the annual rainfall is less than 8 inches. The published observations of the United States Weather Bureau at Wheeler, 6 miles to the south and at about the same altitude, indicate, from an incomplete 7-year record, a mean annual precipitation of 7.12 inches. Most of this precipitation takes place in the winter months, November to February, though showers are also common in May and June. The moisture stored in the ground in winter, together with the spring rains, is sufficient to support sagebrush and a fair cover of grass. The vegetation has been sufficiently luxuriant to retain the fine loess-like soil. The capacity of this soil to hold moisture may, as already stated, provide suitable conditions below the ground surface for the small amount of chemical decomposition that has taken place between the columns.

Above the ground surface, however, the rain readily washes away the parts of rock that have been chemically decomposed even in a minor degree. During the long dry summer insolation has full play,

[14] Bretz, J. H., Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., vol. 34, pp. 573–608, 1923. The map of fig. 1 does not show Black Rock Coulee as a glacial channel. See, however, Bretz, J. H., The channeled scablands of the Columbia Plateau: Jour. Geology, vol. 31, pp. 617–649, 1923, especially p. 644 and pl. 3.

and the alternate contraction and expansion of the dense fine-grained basalt of the columns causes near the surface intimate fracturing of the component minerals. The same forces tend to bring about the flaking of chips from the sides and the spalling of the corners of the columns, but here frost action may come into play and may possibly be the dominant factor in disrupting the rock.

Thus this pedestal rock has attained its form by the action of both chemical and mechanical weathering on a basalt column having two incipient cross fractures. The combination of conditions necessary for the production of this rock is not wholly exceptional, for 3 miles northwest of Adrian there is a somewhat similar pedestal rock formed in an identical manner.

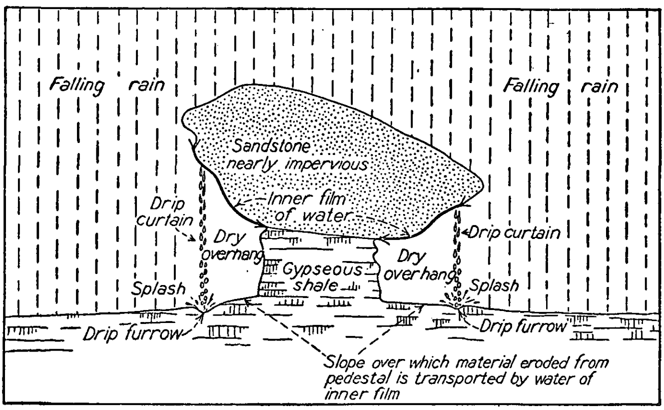


FIGURE 1.—Diagram illustrating differential rainwash on a pedestal rock consisting of an impervious block resting on an easily eroded mass below

DIFFERENTIAL RAINWASH

The violent showers characteristic of most arid climates will produce pedestal rocks by differential rainwash where blocks of impervious material rest on easily eroded material. The mechanism of this process was observed near Lees Ferry, Ariz., and has been described in an earlier paper.[15] The process is shown diagrammatically in Figure 1. The main work of producing the pedestal is done by the drip curtain, which excavates an annular groove around the rock. An inner film of water, however, clings by adhesion to the overhang of the rock and reaches the pedestal. It is largely the work of this film which erodes and thins the pedestal back of the drip curtain. In the rain observed at Lees Ferry the inner film reached just to the pedestal and wet its top. That this inner film may not only reach the pedestal but may, under suitable circumstances, cause erosion is evident from a pedestal rock in the canyon of Jemez Creek between the

[15] Bryan, Kirk, U. S. Geol. Survey Bull. 760, pp. 1–11, 1925.

towns of Canyon and Jemez Hot Springs, N. Mex., about 150 miles east of Lees Ferry, Ariz. The rock consists of a loose block of dense red sandstone, derived from outcrops farther uphill, that rests on a pedestal of red shale, as shown in Plate 2, *A*. On the face of the pedestal is a vertical roll of hardened mud similar in form and origin to the rolls of mud that form on the inside of an adobe house when the roof leaks. Obviously, the inner film of water traveling on the overhang, as shown in Figure 1, has reached and eroded the pedestal. Such a movement of water can have little scouring action, but if continued will lead to the removal of any material on the pedestal that is already loosened by weathering.

A rock near by (pl. 2, *B*) consists of a block of sandstone resting on a mass of rubble that in turn rests on red shale. The rubble and, doubtless, also the underlying block are the last remnants of a talus that once mantled the mountain side. The block has partly protected the underlying rubble in the process of differential erosion by rainwash, but the vertical grooves in the rubble bear mute testimony to erosion by water dripping over the face of the pedestal as an inner film. At the point marked "a" the rubble overhangs and protects the red shale which forms the lower 8 inches of the pedestal. The rubble is therefore more resistant to rainwash than the shale.

The climate of the area in which these rocks occur is not very different from that at Lees Ferry, except for lower temperature and greater precipitation, due to an altitude 2,500 feet higher. The mean annual rainfall amounts to 17.13 inches at Jemez Hot Springs, according to the record of the United States Weather Bureau over a period of 14 years, as compared to 5 inches, the estimated mean at Lees Ferry. This mean rainfall of 17.13 inches places the locality well within the arid zone as usually considered, yet it is evident that the rock shown in Plate 2, *B*, differs from the form of natural monument called earth pyramid, earth pillar, or demoiselle, only in having a larger block in proportion to the size of the pedestal. There seems, therefore, to be no essential difference in origin or method of erosion between earth pillars and pedestal rocks of this type. Yet earth pillars are generally admitted to be normal forms of erosion in humid regions, although they are doubtless less numerous there than in arid regions, where a slower rate of erosion gives each of them a longer life.

DIFFERENTIAL SAPPING

The overlying block in a pedestal rock formed by differential rainwash is relatively impervious to rain. If the upper block is porous, however, and absorbs part or all of the rain that falls on it, the circulation of water within the mass of the rock promotes weathering by solution. Sandstone is particularly susceptible to attack by water absorbed from rain. Generally, the water dissolves the cement and, traveling on original lines of easiest passage, emerges at the sides or base of the rock, where it runs out or is evaporated. At or near the point of emergence the rock crumbles into its original sand grains, which fall away or are carried off by rainwash. The intricacies produced by this process are truly marvelous. In general an excavation or eating back of the original mass takes place, and the process will here be called differential sapping.

Although characteristic also of the weathering of sandstone in humid regions the forms produced by this process in arid regions have been attributed by many to wind erosion. Gregory,[16] however, has invoked differential sapping as the method of formation of niches under dry waterfalls, of rock shelters, of windows, and of arches in sandstone in the dry climate of the Navajo country. Certain rock shelters and niches [17] in the Papago Saguaro National Monument of southern Arizona, where the mean annual rainfall is about 7 inches, have also been ascribed to this process.

PEDESTAL ROCKS IN SANDSTONE

LOCALITY AND CLIMATE

In northwestern New Mexico, in the areas underlain by sandstone and shale of Upper Cretaceous age, pedestal rocks are numerous. At each outcrop of sandstone one or more pedestal rocks may be found. These rocks are special forms of those monuments of erosion customarily isolated in the recession of cliffs. Their shape is due to the cooperation of a variety of structure in the original rock and several processes. The rocks that are most symmetrical in form are due to a nicety in this cooperation that may be considered fortuitous, but the great numbers of pedestal rocks which exist in this region indicate that certain conditions are dominant. The nature of the rock structure and the processes which act upon it in the production of pedestal rocks in the southern part of the San Juan Basin, near Crown Point, McKinley County, N. Mex., will be described in the following paragraphs.

The climate of the area is moderately arid and marked by cold winters and hot summers. An incomplete weather record extending over 11 years at Crown Point, where the altitude is 6,800 feet, as published by the United States Weather Bureau, gives a mean annual precipitation of 10.9 inches. In the five consecutive years for

[16] Gregory, H. E., Geology of the Navajo country, a reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey Prof. Paper 93, pp. 133–134, 1912.

[17] Bryan, Kirk, The Papago country, Arizona, a geographic, geologic, and hydrologic reconnaissance, with a guide to desert watering places: U. S. Geol. Survey Water-Supply Paper 499, pp. 91–93, 1925.

which this record is complete the precipitation ranged from 5 to 16.99 inches, indicating to some extent the great droughts and correspondingly wet years to which the area is subject. A large part of the winter precipitation is in the form of snow, and in the spring the ground is usually sufficiently moist to permit the growth of vegetation. In May and June rain sufficient to wet the ground is rare. In July the so-called rainy season begins. Heavy cumulus clouds drift over the country, and from these clouds fall violent local rains or cloudbursts. The areas in which these rains fall are sometimes small, but the heavier rains usually cover extensive areas. From a half to two-thirds of the annual precipitation falls during the rainy season, but this period of rain is uncertain in time and place. In years of generally high rainfall some areas receive little rain, and in many years the summer rains are delayed until September. In spite of the severity of these conditions for the growth of plants, the loamy and clayey soils developed on shale or on the overflow areas of ephemeral streams have a good growth of deep-rooted perennial grass, which makes its principal growth during the summer rains. The sandstone beds usually crop out as bare rock and have little soil except patches of wind-blown sand. Scanty grass grows on the sand, but the hardy juniper (scrub cedar) thrives in scattered groves, even on the bare rock.

The mean annual temperature at Crown Point so far as determined is about 50° F. The absolute range in temperature, however, is large, from −8° on January 2, 1919, to 95° on July 1, 1917. The daily range, especially early in the summer, is also large, probably amounting to as much as 60° or 70°.

This relatively severe climate, with its long periods of drought and violent rains, hot summers and cold winters, warm days and cold nights, has corresponding effects on erosive processes.

THE ROCKS

One of the most picturesque pedestal rocks of this area stands about half a mile off the road from Crown Point to Chaco Canyon near Seven Lakes. As shown in Plate 3, *A*, this rock rises from a small knoll in an area with a sparse vegetation of small bushes, grass, and junipers. The knoll lies in a small amphitheater in low cliffs of horizontal sandstone that is identical with the material of the pedestal rock. The rock is thus an erosion remnant between small valleys working headward into the cliffs and is remarkable only in the details of its form. An inspection of the photograph shows that joint faces are not entirely obliterated from the massive sandstone at the top, and the implication is that the isolation of the rock is due to erosion by weather and streams, along vertical joints. The remarkably slim pedestal is composed of laminated, somewhat clayey sandstone, and the constricted portion halfway up is of similar material. The capping sandstone is massive, as are the other projecting portions of the mass. It seems obvious that the laminated and clayey beds have suffered more from weathering than the remainder of the rock, and that the form is due to the distribution of the less resistant beds and the summation of the differences in the rate of weathering. That differential sapping, as defined on page 10, is the most active process, seems evident; first, because of the selective work against certain beds, which is effective irrespective of their thickness or position above the ground surface, and second, because at the time of visit, a few days after a rain, the surface of the slimmest part of the pedestal was damp, whereas that of the rest of the rock was dry and powdery.

Differential rain wash can not be solely accountable for this rock, because the differences in resistance of the different sandstone beds are too slight and the porous upper mass must absorb at least part of every rainfall. However, it seems likely that the inner film of water that creeps over the rock face during rainstorms is effective in removing loosened grains from all the intricate reentrants of the mass. Doubtless many of these loosened grains simply fall by gravity, and others are perhaps shaken loose during high winds. That the scour of sand carried by wind has any appreciable effect can be denied, for the base of the rock is too high above the ground for wind scour to be effective. All authorities are agreed that 2 to 3 feet above the ground surface is the limit of effective wind scour.[18]

The rock illustrated in Plate 3, *B*, stands near the road from Crown Point to Chaco Canyon, about 20 miles northeast of Crown Point. To the right of the view there is a rounded boss of sandstone eroded from the same horizontal sandstone bed, but the pedestal rock stands detached in a plain of sandy soil that within the area of the view merges into an alluvial sandy loam. Apparently the rock was once a mass approximating a cube in shape that was isolated along vertical joints, but the present form seems to be due to differential sapping. The upper part of the rock is separated from the remainder by a bedding plane, and it seems fair to assume that this upper sandstone has always been somewhat harder than the remainder of the rock. It is porous, however, and has a crumbly surface. Obviously it absorbs rain water, which emerges lower down from the pores of the sandstone of the pedestal. The surface of this lower portion is notably soft and friable, particularly near the ground. Here individual sand grains are loosened and fall by gravity or are

[18] Among others, see Hobbs, W. H., The erosional and degradational processes of deserts, with especial reference to the origin of desert depressions: Assoc. Am. Geographers Annals, vol. 7, p. 33, 1918.

washed off by the inner film during rains. Not only does the pedestal disintegrate into sand by the relatively slow solution of its cement but periodically large pieces fall off, as is attested by their presence at the base of the rock and by the scars left on the pedestal into which some of them can almost be fitted. It seems likely that frost action, when the pedestal is saturated after rains, aids in detaching these blocks. The wide range in temperature and the severity of the winter have been noted above.

Between the scars of recent falls there are somewhat more ancient surfaces that are minutely pitted. Each pit is about three-eighths of an inch in diameter and half an inch deep. Some of them contain dead insect pupae. It seems evident that wasps bore these holes as nests for their young under the overhang of the rock, where they are protected from the direct impact of rain. Thus animals contribute, in slight degree, to the erosion of the rock.

It seems impossible that wind scour can have had any important part in the formation of this rock. The pulverulent surface of the pedestal testifies to differential sapping; the scars, to frost action; and the pitted surfaces, to insect erosion. None of these surfaces could retain their characteristics under the sand blast, and they are in marked contrast to the firm, harsh surfaces of similar rocks in the region that are unquestionably scoured by wind-driven sand. The surrounding area is sandy, as might be expected where the local débris is all derived from the erosion of sandstone. Near by there are small accumulations of wind-blown sand, 6 inches to 2 feet thick, which are, however, more or less prevented from moving by the growth of grass. Near the pedestal rock sand is not moving in large amount or with violence, else the grass and sagebrush would be cut away, and the rock fragments lying at the foot of the pedestal rock would be shaped by wind scour.

PEDESTAL ROCKS IN HUMID REGIONS

The pedestal rocks described in this paper are all located in arid regions, yet the processes by which they have arisen are operative in humid regions. From a review of geologic textbooks one would gain the impression that pedestal rocks are characteristic of arid regions and do not occur in more humid lands. Aside from notched stacks on coasts and pedestal rocks formed in streams, whose origin is apparently independent of climate, a considerable number of pedestal rocks in humid regions have been described. In England [19]

[19] Hughes, T. McK., On some perched blocks and associated phenomena: Geol. Soc. London Quart. Jour., vol. 42, pp. 527–539, 1886; Notes on the geology of parts of Yorkshire and Westmoreland: Geol. Polytechn. Soc. West. Rid. Yorkshire Proc., vol. 4, p. 574, 1867. Bonney, T. G., The work of rain and rivers, p. 18, Cambridge Press, 1912.

and Ireland[20] certain pedestal rocks consist of glacial erratics of compact and insoluble rocks resting on limestone. Solution of the limestone except where partly protected by the erratic block has produced the forms. Estimates[21] of the age of the pedestal rocks and therefore of the time since glaciation, by comparison of the height of the pedestal with the rate of solution of limestone, have not been wholly satisfactory.

The mushroom rocks of New Red sandstone in Devonshire are thought by Kinahan[22] to be in part due to the work of rain driven horizontally by the wind, and the sandstone crags of Kinder Scout[23] provoked a discussion as to the relative effect of the scour of wind-driven sand and of differential erosion, and apparently no later investigator has published a definite conclusion.

In Indiana,[24] Illinois,[25] Arkansas,[26] and Wisconsin[27] are good examples of pedestal rocks that may be attributed to differential weathering and the subprocesses differential rainwash and sapping.

The life of pedestal rocks in humid regions is relatively short because of the rapidity of rock decay and, in the colder countries, because of the increased effectiveness of frost action due to the presence of moisture. Not only are the forms less persistent, but the presence of vegetation inhibits rainwash and much of the vertical cutting of minor streams, so that the rocks ordinarily occur as the result of exceptional conditions, such as the imposition of blocks of dense insoluble stone on limestone, or else in areas of porous sandstone and limestone. The erosion forms of porous sandstone in humid lands reproduce many of the spectacular features of arid regions, because areas of such rock resemble arid regions in having a scanty, sterile soil, a sparse vegetation, and a low water table. These features are well brought out in the literature on the Fontainebleau sandstone already referred to and in numerous works on the Quadersandstein and Buntsandstein areas of Germany. Similarly, limestones, particularly in areas having the Mediterranean type of climate, may

---

[20] Kinahan, G. H., Valleys and their relation to fissures, fractures, and faults, pp. 53–54, London, 1875. Wynne, A. B., Notes on some physical features of the land formed by denudation: Ireland Roy. Geol. Soc. Jour., vol. 1, p. 258, 1867.

[21] Mackintosh, D., Results of observations in 1882 on the position of boulders, etc. (abstract with discussion): Geol. Soc. London Proc., Feb. 21, 1883, p. 67.

[22] Kinahan, G. H., op. cit., p. 83.

[23] Discussion of paper by Enys, J. D., Geol. Soc. London Quart. Jour., vol. 34, pp. 86–88, 1878.

[24] Dryer, C. H., Jug Rock, near Shoals, Ind.: Indiana Acad. Sci. Proc. for 1898, pp. 268–269, 1899. Logan, W. N., Geologic conditions in the oil fields of southern Indiana: Indiana Dept. Conservation Pub. 42, fig. 1, 1924.

[25] Bonnell, Clarence, The variety of physiographic material in a few counties of southern Illinois: Illinois Acad. Sci. Trans., vol. 9, p. 207, 1917.

[26] Hopkins, T. C., Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 4, p. 343, pl. 17, 1893.

[27] Alden, W. C., The Quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, p. 4, pl. 16, *A*, 1918.

produce somewhat similar forms, although in climates like that of the eastern United States areas of this type of rock are usually mantled by a deep soil.

CONCLUSIONS

The foregoing description of pedestal rocks in the widely separated States of Washington and New Mexico calls attention to the variety of processes involved in the formation of these minor but distinctive forms and emphasizes the accumulating evidence that many pedestal rocks, even in arid regions, are attributable primarily to other processes than wind erosion. The examples cited are due to processes which are also operative in humid regions. The fact that a relatively larger number are found in arid regions is probably due not so much to differences in the nature of the processes of weathering and erosion as in their rate, for in humid regions the formation of soil by chemical weathering and the growth of vegetation inhibit the formation of pedestal rocks in favorable places or rapidly destroy them when formed.

33377°—27——3

CHANNEL EROSION OF THE RIO SALADO, SOCORRO COUNTY, NEW MEXICO

By Kirk Bryan

Deepening and widening of stream channels in the Southwest is a phenomenon that has taken place within the memory of men now living. It began at different dates from 1860 on and has progressed at different rates on several streams, as summarized in a recent paper.[28] The flood plains of numerous minor streams are yet undissected, but nearly every one of them is menaced by a deep channel, or arroyo, which visibly increases headward each year. These channels, or arroyos, not only grow headward through the smooth flood plains of the valleys but constantly widen by lateral cutting and the growth of minor tributaries. It seems inevitable that the present flood plains will eventually disappear and new flood plains will form at lower levels.

The consequences of these processes to native life and to agriculture, stock raising, and other activities of man are numerous and important. Interesting scientific problems are also raised. The various theories that have been advanced to account for this accelerated erosion are reviewed in the paper already cited.

Valid conclusions as to the merits of these theories can not be reached until historical data on the time at which erosion began have been accumulated. Knowledge of the date of the beginning and progress of this spectacular change in the regimen of streams is particularly necessary in arriving at a decision as to the effect on erosive processes of the introduction of cattle and sheep and the overgrazing that in most localities ensued. This paper presents, as a contribution to the necessary body of data, historical evidence, based on two reliable surveys made in 1882 and 1918, on the changes in the channel of a comparatively minor stream in New Mexico.

The Rio Salado, a tributary of the Rio Grande from the west, rises on the north side of the Datil Mountains and has a general

[28] Bryan, Kirk, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, new ser., vol. 62, pp. 338–344, 1925. See also Swift, T. T., Date of channel trenching in the Southwest: Idem, vol. 63, pp. 70–71, 1926; Wynn, Fred, The West Fork of Gila River: Idem, vol. 64, pp. 16–17, 1926.

eastward course north of that range and thence through a narrow gap between the Socorro Mountains and the Sierra Ladron to a junction with the Rio Grande at the village of San Acacia. The Rio Salado is formed by the junction of Alamosa Creek, also locally known as Rio Salado, and a large stream from the north. The total length of this drainage line, if Alamosa Creek is considered the main stem, is 75 miles, and the basin drained by it lies almost wholly in Socorro County. The village of Puertecito lies 2 miles above the junction of the two streams, and Santa Rita (Riley post office), 7 miles below.

When Lorenzo Padilla, the first settler, who is still living at Santa Rita, came to the valley in 1880, the channel of the Rio Salado was inconsiderable, and the broad flat of the valley seemed a propitious place for farming. Consequently, others followed Padilla, and according to the survey notes of Daniel Curry, who in 1882 subdivided the townships into sections, Santa Rita had by that time grown to a town of 100 inhabitants. Curry recorded the width of the stream bed as ranging from 11.88 to 48.84 feet on a number of section lines.

Because the town of Santa Rita lies in one of the odd-numbered sections which was granted to the Atlantic & Pacific Railroad and therefore belonged to its successor, the Santa Fe system, the inhabitants of the town had a defective title to the land. In support of an application by them to the United States General Land Office to have this land declared a public town site, Paul B. Moore, of Magdalena, N. Mex., was employed to make a survey. The information contained in this note was supplied by Mr. Moore, whose interest in New Mexican geology is large and whose help in this and other matters is hereby acknowledged. During this survey in 1918 he found the course of the river radically different from that shown in Curry's survey of 1882, his measurements ranging from 330 to 550 feet in the same stretch of stream channel where Curry found widths of 11.88 to 48.84 feet. Some of these differences are tabulated below.

Width of Rio Salado at different points in T. 2 N., R. 4 W., 1882 and 1918

Location	1882	1918
	Feet	*Feet*
On line between secs. 23 and 24	13.20	525.0
14 and 23	18.48	330.1
14 and 15	11.88	441.3
15 and 16	48.84	550.0

According to the testimony of the local inhabitants to Mr. Moore, there was an exceptional rain and flood in 1883, which washed out a road and formed a new stream channel. Since that time the channel has constantly widened, and most of the agricultural land in the valley has been destroyed.

Unlike many similar streams in New Mexico, which have not only widened their channels but deepened them in the same period, the Rio Salado, at least in the vicinity of Santa Rita, has even yet banks that are only 3 to 10 feet high and average about 5 feet high. It is obvious, however, that the whole regimen of the stream is much different from that which existed in 1880.

But little is known of the progress of this erosion upstream. However, W. T. Thom, jr., during a survey of the Alamosa Creek valley,[29] witnessed, in August, 1923, headward erosion on Felipe Gilbert Creek, a tributary of Alamosa Creek. According to his notes, generously furnished for this paper, at a point in sec. 10, T. 2 N., R. 7 W., 12 miles west-southwest of the village of Puertecito, the arroyo of this stream worked headward into the undissected valley flat a distance of 40 to 75 feet as a result of a single storm, destroying the road crossing and necessitating a detour by the party to avoid the steep-sided gully. From this record we may conclude that the progress of the erosion begun near Santa Rita in 1883 has been, as measured in years, fairly slow and has not yet, 43 years later, affected all the minor tributaries.

Thoughtful men must naturally consider whether it is possible to check such erosion and whether it would be profitable or otherwise advantageous to do so. One of the necessary items of information on which such a decision must be based is the relative value of the land in a dissected or undissected flood plain. Many writers have deplored the destruction of these valley bottoms, but no one has attempted to put a monetary value on the loss that has occurred, yet such an estimate is necessary before it is worth while to consider remedial measures.

---

[29] Winchester, D. E., Geology of Alamosa Creek Valley, Socorro County, N. Mex., with special reference to the occurrence of oil and gas: U. S. Geol. Survey Bull. 716, pp. 1–15, 1921.

THE "PALOUSE SOIL" PROBLEM

WITH AN ACCOUNT OF ELEPHANT REMAINS IN WIND-BORNE SOIL ON THE COLUMBIA PLATEAU OF WASHINGTON

By Kirk Bryan

INTRODUCTION

Wheat is the great crop of eastern Washington. Grown on an extensive scale with all the ingenuity of modern labor-saving devices, it forms the basis for the stable prosperity of the "Inland Empire" which has its commercial center at Spokane. Deep, rich soil is the controlling factor in the growth of wheat in this area, for the rainfall is light, though advantageously concentrated in the winter season. The system of summer fallow is necessary to conserve the moisture of one season into the next, but thereby one-half the land lies plowed and idle. The wheat region, therefore, is a checkerboard of bare brown rectangles of plowed land alternating with rectangles of wheat that are green, gold, or buff according to the season.

The great Columbia Plateau, underlain except in a few small areas by basalt flows several hundred feet thick, has nearly everywhere a mantle of so-called soil, deep and retentive of moisture, the basis of this great wheat growing industry. This "soil"[1] is a fine-grained mass that is intimately dissected into hills and valleys. (Pl. 4, *A* and *B*.) The little valleys are usually cut to or just below the level of the underlying basalt, so that the height of the hills, from 100 to 150 feet, measures the thickness of this "soil." This material is locally known as "Palouse soil," from the rich wheat-growing area along Palouse River south of Spokane, which is popularly known as the "Palouse country."

The Bureau of Soils, as shown in the summary of the history of the subject, on pages 22–26, recognizes in the region a number of soil series, only one of which bears the name Palouse. All the names

[1] The word soil is used throughout this paper in the ordinary sense both for the mantle of unconsolidated material overlying the hard rocks and for the upper part of this material, in which crops are grown, and not in the sense of "solum" as defined by Frosterus (Frosterus, B., and Glinka, K., Zur Frage nach der Einteilung der Böden in nordwest-Europas Moränengebiet: Finland geol. Komm. geotek. Meddel. Nos. 11–14. 1914). See also Veatch, J. O., Geology as a factor in soil classification: Michigan Acad. Sci. Papers, vol. 5, pp. 287–296, 1926.

refer, as is the custom of the bureau, solely to the upper 6 feet or so of what is here called the "Palouse soil," although in places the material below is of exactly the same character. As this material is everywhere of about the same thickness and conforms to the slopes of the plateau, the assumption is justified that it once formed a continuous cover and has since been dissected. As it also has great extent and considerable thickness, it is a geologic body that would be worthy of a formation name if all parts of the mass were known to have had a common origin and age. Treasher [2] has recently proposed the name "Palouse formation," but, as is brought out in this paper, the common origin and age of the material is doubtful, and therefore it seems best to use the local term "Palouse soil" without implication that a formation name is being established.

Much remains to be learned about this widespread and economically important deposit, and the present paper is intended merely to outline briefly the current theories as to its origin, to present facts gained in the course of somewhat desultory field work, and to reconcile, so far as practicable, the known facts with the theories. The results may be summarized in the statement that the bulk of the "Palouse soil" is wind-borne dust or loess, though other material is included in its mass; that this loess is definitely of Pleistocene age, as shown by the occurrence of elephant remains in one of its later phases and by its association with glacial till; and that the present dust storms of the region are phenomena of the last few decades only and have contributed an inappreciable quantity of material to the Pleistocene loess.

The field observations here recorded were made as part of the geologic work done for the Federal investigation of the Columbia Basin irrigation project, conducted by the Bureau of Reclamation in 1923, and were supplemented by a two-day visit to localities at and near Spokane in 1924. Data on dust storms, collected at the Spokane office of the United States Weather Bureau, have been put in tabular form, with the addition of rainfall data, by Mr. E. M. Keyser, whose generous cooperation is here acknowledged. Mr. J. T. Pardee has contributed notes on his observations in the eastern part of the Columbia Plateau, and Mr. Clarence S. Ross has described samples collected by Mr. Pardee. Messrs. A. T. Strahorn and M. H. Lapham, of the United States Bureau of Soils, have read the manuscript critically and contributed valuable suggestions.

HISTORICAL REVIEW

The "Palouse soil" has been of interest to geologists and soil scientists for many years, and its distribution and attributes can

[2] Treasher, R. C., Origin of the loess of the Palouse region, Wash.: Science, new ser., vol. 61, p. 469, 1925.

be best set forth in the course of a review of the numerous papers in which it is described and its origin considered.

Russell,[3] in his report on the eastern part of the Columbia Plateau, appears to have been the first to describe the characteristics of the "Palouse soil" and discuss its probable mode of origin. He believed that the "soil" was primarily due to the decay of the underlying basalt, but that it had, after the devlopment of the present intricate drainage pattern, been reworked superficially by wind—an agent that had also slightly modified the form of some of the hills. These conclusions he supported by evidence obtained four years later from the adjacent region in Idaho.[4] Calkins,[5] after a reconnaissance of the western part of the plateau, contended that the "soil" was deposited by wind and that the material was not derived from the underlying basalt but from water-laid deposits on the southwestern margin of the plateau. He held, however, that the "soil" was once a continuous layer and has been since dissected.

Since these papers were written several soil surveys have been made in the region by the United States Bureau of Soils. In Franklin County, in the western part of the plateau, the Ritzville series of soils was recognized in 1914.[6] Of this series the silt loam is the most widely distributed and is described as a light-brown compact silt loam of a uniform texture to a depth of 6 feet or more. The underlying material is of similar character and extends to basalt bedrock at depths of 50 to 100 feet. Mechanical analyses show that 50 per cent is silt and only 2 to 4 per cent clay. One of the samples was examined for its constituent minerals and found to contain orthoclase, quartz, biotite, hornblende, plagioclase, and traces of isotropic materials of low refractive index. In 1916 the Ritzville series was found also in Benton County, west of Columbia River, and here it forms the surface of a large part of Horseheaven Plateau.[7] Farther east, however, in the Palouse region, darker soils form the surface. In this region the Palouse series was recognized, and the name Palouse appears to have been first used for a soil series as a result of the survey of Latah County, Idaho, in 1915.[8]

The Palouse silt loam, as described in the report cited, consists of 8 to 14 inches of dull-brown or dark-brown silt loam lying on

[3] Russell, I. C., A reconnaissance in southeastern Washington: U. S. Geol. Survey Water-Supply Paper 4, pp. 57–69, 1897.

[4] Russell, I. C., Geology and water resources of Nez Perce County, Idaho: U. S. Geol. Survey Water-Supply Paper 53, pp. 81–83, 1901.

[5] Calkins, F. C., Geology and water resources of a portion of east-central Washington: U. S. Geol. Survey Water-Supply Paper 118, pp. 44–49, 1905.

[6] Van Duyne, Cornelius, and others, Soil survey of Franklin County, Wash.: U. S. Dept. Agr. Bur. Soils Field Operations for 1914, pp. 45 et seq., 1917.

[7] Kocher, A. E., and Strahorn, A. T., Soil survey of Benton County, Wash.: U. S. Dept. Agr. Bur. Soils Field Operations for 1916, pp. 26–32, 1919.

[8] Agee, J. H., and others, Soil survey of Latah County, Idaho: U. S. Dept. Agr. Bur. Soils Field Operations for 1915, pp. 14, 17–18, 1917.

brownish-yellow or light-brown silt loam which extends to a depth of 36 to 40 inches and which in turn rests on a tawny-yellow substratum of homogeneous and unstratified material that has a thickness of 50 feet or more and rests on the basalt bedrock. The substratum is considered to be of loessial origin and to be the source of the agricultural soil. The Helmer series of soils in the same area are also thought to be of wind-borne origin, but these soils have a thickness of 2 to 5 feet only and rest on decomposed granite.

As a result of the soil survey of Spokane County, Wash., somewhat more diverse materials were included under the term Palouse series.[9] Four soil types are described.

The Palouse sandy loam is 1 to 5 feet thick and overlies a fine-grained subsoil derived from the weathering of granite.

The Palouse fine sandy loam consists of 8 inches of friable dark-brown fine sandy loam with a subsoil about 3 feet thick of loose light-brown to yellowish-brown sandy loam. The subsoil is underlain by material of similar color and texture about 10 feet thick that rests on basalt. This substratum is derived from lake deposits or glacial till.

The Palouse loam is a dark-brown loam, 10 inches thick, with a subsoil of brownish-yellow fine sandy loam 10 feet or more thick. The subsoil rests on a very compact reddish-brown material similar to the substratum of the Palouse silt loam next to be described. Granitic and basaltic boulders, some of which bear glacial striae, occur on the surface and in the soil.

The Palouse silt loam consists of 10 inches of dark grayish-brown friable silt loam with a subsoil of yellowish-brown to brown heavy silt loam or silty clay loam 3 feet thick. Below the subsoil is a substratum of unstratified compact reddish material about 50 feet thick that lies on basalt but in places overlaps on granite and schist. In these places the residual character of the substratum is evident.

In their general sections the authors of the report cited[10] take the stand that the Palouse soil series, particularly the Palouse silt loam, is derived from the mantle of fine-grained material overlying the basalt and that this material is of wind-borne origin. They consider that there is no gradation through decomposed to unaltered rock except where the material rests on granite and schist. The dissection of the "soil" mantle is ascribed to stream erosion during some previous period, but in places the hills are thought to be modified by wind action so as to give steep northern and more gentle southern slopes. Except in the matter of the residual character of the substratum, these authors are in accord with Russell. They

[9] Van Duyne, Cornelius, and others, Soil survey of Spokane County, Wash.: U. S. Dept. Agr. Bur. Soils Field Operations for 1917, pp. 35 et seq., 1920.
[10] Idem, p. 35.

note the widespread superficial redistribution of soil material during dust storms, with evidence of some accessions from outside sources, and the tendency for calcium carbonate to accumulate in the soil below the surface. They make the first published statement that much of the "soil" mantle accumulated prior to the last glacial invasion.

In the soil survey of Nez Perce and Lewis Counties, Idaho,[11] three series of residual soils were distinguished, of which two, the Tolo and Waha series, are derived from basalt. Both are thin soils, and the Waha, 20 to 30 inches thick, occupies slopes below the flat summits of plateaus overlain by "Palouse soil." Three loessial soils are distinguished—the Palouse, Nez Perce, and Southwick. The Palouse soil series here is much like that in other areas. The Nez Perce and Southwick are less than 15 feet thick but except for difference in color are very like the Palouse.

In Kootenai County, Idaho,[12] in addition to the Palouse soil series, a loessial series known as the Helmer is distinguished. It was originally forested and for a depth of 10 inches below its surface is much lighter in color than the typical Palouse silt loam. Generally there are four distinct layers differing in color in the first three feet. The Helmer soil attains a thickness of 50 feet and overlies basalt.

It is evident from the foregoing review that there are large differences in the "soil" mantle of the Columbia Plateau, which seems at first glance so homogeneous and characteristic. In the upper 3 feet the soil is universally fine grained and is generally a silt loam or loam. There is, however, a gradation in color from tawny yellow in the western part of the plateau to dark brown in the Palouse country and even an ashy gray farther east in Idaho. This change is largely due to change in humus content coincident with increased rainfall and heavier natural vegetation in the eastern part of the plateau. The principal differences noted are in the substratum below the upper 3 feet. In the succeeding sections some of these differences are further considered.

Bretz[13] describes the "soil" in general terms and brings forward physiographic evidence to show that the main body of the material is older than the stage of ice advance preceding the Wisconsin, to which he has given the name "Spokane." He also notes that the loessial soil near Cheney rests in places on glacial till, which he suggests

[11] Agee, J. H. and Peterson, P. P., Soil survey of Nez Perce and Lewis Counties, Idaho: U. S. Dept. Agr. Bur. Soils Field Operations for 1917, pp. 18 et seq., 1920.

[12] Lewis, H. G., and Denecke, W. A., jr., Soil survey of Kootenai County, Idaho: U. S. Dept. Agr. Bur. Soils Field Operations for 1919, pp. 35 et seq., 1923.

[13] Bretz, J. H., Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., vol. 34, pp. 573–608, especially p. 577, and footnote pp. 588 and 589, 1923: The channeled scablands of the Columbia Plateau: Jour. Geology, vol. 31, pp. 623–634, 1923.

may belong to a still older glaciation. This observation is confirmed by Freeman,[13a] who reports the finding near Cheney of elephant bones in "loess" overlying well-weathered till attributed to this early glaciation. It is obvious from Bretz's work, as supported by evidence in the present paper, that there are at least three bodies of glacial till in this area, representing as many glacial advances. In this paper the terms early, intermediate, and Wisconsin are applied to these bodies of till and corresponding glacial stages.

Recently MacMacken [14] has given a general popular treatment of the problem, and Treasher,[15] in a short note, advocates the hypothesis of accumulation of an original laminated silt in ephemeral sheets of glacial water as "water-laid loess," and later rehandling of this material by wind.

Short notes by Peterson [16] and by Larsen [17] record the present accumulation of dust in the region and regard the "soil" as a loess still in process of formation.

OBSERVATIONS

In general, only the upper part of the "Palouse soil" can be seen. This surface portion is a tawny brown in the western part of the plateau and a deep brown, almost black, in the Palouse country and farther east in Idaho. The names Ritzville, for the Franklin County area, and Palouse, for the Spokane County and Idaho areas, used by the Bureau of Soils, carry a valid distinction. In the western part of the Columbia Plateau numerous contacts on undecomposed though not wholly fresh basalt can be found, and all of Calkins's observations of fact confirmed. However, in a cut on the new State highway from Lind to Connell, in the SE. 1/4 sec. 20, T. 14 N., R. 32 E., about 2 miles north of Connell, finely laminated gray-brown silt is exposed. This material forms the core of the hill, and the exposed portion has a thickness of about 10 feet. The usual loesslike soil mantles the silt in a layer about 5 feet thick that conforms to the shape of the hill. The silt is evidently water-laid and resembles beds near the top of the Ringold formation as exposed in the White Bluffs northeast of Pasco and at other localities. Whatever its origin, the silt is an ideal formation from which the upper soil might have been derived by

[13a] Freeman, O. W., Mammoth found in loess of Washington: Science, new ser., vol. 64, p. 477, 1926.

[14] MacMacken, J. G., Eolative soils of Washington wheat lands: Pan-Am. Geologist, vol. 43, pp. 177–184, 1925.

[15] Treasher, R. C., Origin of the loess of the Palouse region, Wash.: Science, new ser., vol. 61, p. 469, 1925.

[16] Peterson, P. P., Rate and mode of soil deposition in Palouse area of Washington and Idaho: Science, new ser., vol. 55, pp. 102–103, 1922.

[17] Larsen, J. A., Soil shifting and deposits: Science, new ser., vol. 55, p. 457, 1922; Dust storms of northern Idaho and western Montana: Monthly Weather Review, vol. 52, p. 110, 1924.

redistribution through the agency of wind, provided that it were favorably exposed and free of vegetation.

Loesslike soil not only occurs on the broad surfaces of the Columbia Plateau, but similar material of a younger stage lies on the terraces that are typical of certain canyons cut into the plateau surface. The gulch known as Old Maid Coulee, 5 miles south of Connell, has a southwesterly course across the plateau (Pl. 4, *C*), and receives numerous tributaries proportioned in size to their length, which with the main gulch form a dendritic pattern. Old Maid Coulee seems, therefore, to be a normal stream valley and to be sharply distinguished from Esquatzel Coulee, to which it is tributary. Esquatzel Coulee belongs to the group that were deepened and modified by the great streams diverted across the plateau during glacial time, whereas Old Maid Coulee was developed by normal erosion before the diversion of the glacial waters that formed Esquatzel Coulee. Old Maid Coulee has a well-marked but discontinuous terrace rising about 50 feet above the floor of the gulch. This terrace is floored by coarse, fairly well waterworn gravel, evidently deposited by a shifting but not necessarily turbulent stream. The gravel is well exposed in a pit opened on the west side of the State highway in the NE. ¼ sec. 14, T. 13 N., R. 31 E. Here, as shown in Plate 5, *A*, the gravel is overlain by soil that is indistinguishable from the rest of the "Palouse soil." This soil ranges in thickness from 2 feet near the margin of the terrace to 12 feet or more at the back end of the pit. About 18 inches above the gravel there is a well-marked zone of calcareous nodules about 2 feet thick. It seems evident that the soil has accumulated on the terrace by local redistribution of the previously formed soils that rest on the undissected plateau surface above. Slump, soil creep, rain wash, and wind have doubtless all played parts in this process. Similar gravel terraces with like soil coverings were observed in Rattlesnake Coulee and in Smith Canyon.

The larger coulees of the plateau are of two types—those which resemble normal stream valleys and those which were evidently cut by the headward erosion of large rivers. Of the first group Lind Coulee, Third Coulee, and the upper part of Black Rock Coulee have rather smooth slopes of partly weathered basalt more or less covered with soil that seems to have accumulated in a manner similar to that on the terraces of Old Maid Coulee. The coulees of the second type have bold and ragged walls of nearly fresh basalt, yet even here there are scattered small areas of soil evidently due to redistribution by wind of the original soil of the plateau. Washtucna and Esquatzel Coulees, which are typical of this group,

[18] Bretz, J. H., Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., vol. 34, p. 587, 1923.

were cut by glacial waters, although, as Bretz[18] has pointed out, they were probably formed during the intermediate and not the latest stage of glaciation.

Over the general plateau surface the depth of the soil is known only from rather unsatisfactory well records, and the lower part is rarely exposed. Generally, as observed by Strahorn,[19] there is below a depth of 3 feet a limy layer in which the soil is firmly cemented and contains seams, threads, and nodules of calcium carbonate. The upper 3 feet of soil mapped by Strahorn as Ritzville, whether belonging to the main mass or to the terrace, contains so little lime that it will not react with acids.

In this western part of the plateau the main body of the "Palouse soil" is exposed in only a few places, being generally covered by a veneer of wind-borne material, but similar material occurs also on the terraces and in small bodies on the coulee walls. This wind-borne material has been formed in at least five ways in one or all of as many different stages—(*a*) formed from the substratum or forming the substratum before the small valleys were cut; (*b*) formed by redistribution by wind and also by soil creep during and after the period of formation of the terraces in gulches of the Old Maid Coulee type; (*c*) formed by wind distribution on the rocky slopes of coulees cut during the intermediate or some earlier stage of pre-Wisconsin glaciation or perhaps during more than one such stage; (*d*) formed by wind distribution during the Wisconsin stage of glaciation; (*e*) formed by redistribution of previously deposited material with possible additions of foreign material since Wisconsin time.

In the eastern part of the plateau there is the same upper skin or veneer of soil over a more compact substratum. As described in the soil reports, the upper 6 inches is dark, and the subsoil in general is light in color. The thickness of the veneer is doubtless variable, and only a few road cuts show the underlying substratum. The opportunities of the writer to make observations in the area have been so meager that only a few details can be given, which are, however, supplemented by observations and collections made by Mr. J. T. Pardee.

West of the railroad station of Fishtrap a road cut exposes the veneer of soil and the substratum as shown in Plate 5, *B*. The humus layer is dark brown, and the subsoil below it is tawny yellow. Both are fine-grained silts and have an inconspicuous vertical structure. That both these layers are composed of wind-borne dust seems probable. They rest unconformably on the substratum and form a shell corresponding to the slopes of the hill, and thus, before the road cut was made, they completely hid the substratum. The substratum

[19] Strahorn, A. T., letter dated November 4, 1925.

is a light brick-red or pink mass without stratification, composed of material as fine as the overlying soil. It is more compact and has an obscure horizontal structure that is like an imperfect shale parting. Calcareous nodules from 1 to 3 inches in diameter are scattered through the mass and are visible in Plate 5, *B*, as white spots. The contact of this material with the basalt is not exposed.

A number of road cuts near and south of Rosalia show a somewhat similar substratum, but the contacts with the veneer above and the basalt below are obscure. The extent of this reddish substratum is not known, but it corresponds to the substratum of the Palouse silt loam as described in the soil survey of Spokane County (see p. 24) and doubtless has a considerable areal extent. The origin of this material is also uncertain, but from its general appearance there seems to be no good reason why it can not be interpreted as an old loess once similar to the overlying soil but more compacted and oxidized. Except for the lime nodules, it is similar to the tawny-yellow clay at localities a few miles distant described below by Mr. Pardee.

Treasher[20] reports laminated water-laid silts in the substratum from this general area. Russell,[21] in places in this eastern part of the plateau, found complete transitions between basalt, decomposed basalt, and the top soil. On the other hand, J. T. Pardee, in October, 1922, collected a suite of samples that indicates that the different layers of the soil are distinct from the decomposed basalt and are partly at least of distant origin. The following description of the specimens is furnished by Mr. Pardee:

Decomposed basalt.—At a quarry 2 miles north of Plaza soft greenish-gray to lead-gray material that shows the texture and jointing of basalt is exposed to a depth of 15 feet. No fresh rock is visible in the quarry face, but spheroidal cores of hard black basalt can be broken out of the joint blocks, which are 6 inches or more thick. A heap of these cores which had been divested of their decomposed shells by means of a rock crusher looked not unlike so many cannon balls of different sizes. The altered shell shows concentric rings or zones which mark steps in the progress of the weathering and the change of rectangular blocks into spheroids. The altered material is lightly spotted and streaked with iron and manganese oxides, and it contains numerous small bodies of a yellowish-green, apparently noncrystalline substance which W. T. Schaller has identified as an iron-bearing silicate of the chlor-opal group, probably nontronite. There is no gradation between fresh rock and altered rock, the change from one to the other being sharp and abrupt.

In the lower part of the quarry face several seams and joints are filled with a reddish-brown material that ranges in composition from an iron-rich clay to limonite (hydrated iron oxide). The occurrence of this material suggests that the decomposition of the basalt was accompanied by the solution and removal of some of the iron. The decomposed basalt is overlain by a few feet of soil that appears nowise different from the top soils that occur in the general area.

[20] Treasher, R. C., op. cit., p. 469.
[21] Russell, I. C., op. cit., pp. 59–63.

A quarry west of St. John shows altered basalt like that just described, underlain by undecomposed basalt, the two being separated by a thin layer composed of iron oxides. Apparently this layer is at the parting between two flows. Above the altered basalt is a layer of clay mixed with basalt fragments, apparently an old surface mantle, and above this is several feet of typical "Palouse soil."

On the plateau just beyond the end of the long grade north of Colfax a road cut exposes 6 feet of altered basalt that shows the characteristic gray shades, vesicular texture, streaks and spots of iron oxides, and bodies of the green mineral. Here the decomposition is complete, no unaltered cores remaining. Obviously this material, which now can be cut with the finger nail, was once hard basalt, a conclusion that is confirmed by the microscopic examination made by C. S. Ross of a representative sample (specimen 78) as described on page 31 and illustrated in Plate 6, *A*.

From the foregoing statements it appears that in the region north and west of Colfax the basalt at some former time has been rather deeply weathered, but that locally at least the residual product is quite distinct from the "Palouse soil." Furthermore, so far as observed, this material is apparently absent in places and where present is of comparatively small bulk and ordinarily would be classified as part of the basalt formation.

"Palouse soil."—Road cuts at the upper end of the long grade north of Colfax expose 20 feet or more of the typical buff, tawny, or brownish-yellow clay (pl. 6, *B*), overlain by the typical dark surface soil. Near the top of the grade this material rests on a gently sloping surface of partly decomposed basalt. The separation between the two is distinct, and the clay was apparently deposited after the basalt had been somewhat cut away by erosion. At this locality the clay is fine and rather tough, with closely spaced vertical joints and numerous small tubelike cavities and irregular vesicles. So far as their vesicular texture is concerned some specimens of the clay are difficult to distinguish from the decomposed basalt; their color, however, is different and they lack the characteristic greenish substance.

In a road cut on the Inland Empire Highway 3 miles south of Spangle specimens were collected representing 16 feet or more of typical "Palouse soil." The section exposed is made up of the following beds:

Section in road cut 3 miles south of Spangle

	Feet
1. Top soil of light-brownish or reddish-yellow color, loosely compacted and showing an indistinct wavy lamination (pl. 6, *C*)	3–8
2. Dark-gray, almost black subsoil, rather firm and tough, laminated like No. 1	2
3. Reddish-brown tough claylike layer exhibiting vertical joints 2 or 3 inches apart; grades downward into No. 4	3
4. Brownish-yellow to buff rather compact clay, but not so hard or so tough as No. 3. Contains a few small concretions cemented with manganese and iron oxides, and with the aid of a hand lens many fine specks that look like scales of a colorless mica can be seen	8+
Bottom not exposed.	

Specimens 65 to 68 represent, respectively, layers 1 to 4 in the above section. Specimens 77 and 77a represent the "Palouse soil" exposed at the top of the long grade north of Colfax, and specimen 78 represents the decomposed basalt in the road cut a little farther north.

As a result of petrologic studies of some of the samples from the exposures described above, Mr. Clarence S. Ross has prepared the following statement:

Thin sections that preserved the original structure were made from the specimens collected by Mr. Pardee by the use of a relatively new hardening process in preparing sections for microscopic study.[22] By ordinary washing the larger grains were freed from clay, and the individual minerals were identified by the method of obtaining the index of refraction through immersion in liquids whose index is known.

Specimen 78, of the Colfax suite, is an altered basalt that retains without change the vesicular and mineral structure of the original rock, as easily seen in the photomicrograph, Plate 6, *A*. Plagioclase, augite, and olivine are all recognizable, but the plagioclase has altered to a very fine grained aggregate of kaolin-like minerals, and augite and olivine have been changed to a material resembling serpentine.

Specimens 67 and 68, of the Spangle suite, and 77 and 77a, of the Colfax suite, are similar to each other and are composed of fine siltlike material of a yellow-buff color, consisting of angular mineral grains embedded in a brown clayey material. This material has the characteristics of substances that crystallize from gel-like colloids (metacolloidal habit) and possesses optical properties that indicate it to be an iron-bearing beidellite.[23] Most of the grains embedded in the beidellite range from 0.01 to 0.05 millimeter in diameter, but a few measure 0.1 millimeter. They consist predominantly of quartz, but orthoclase, plagioclase, muscovite, biotite, and green hornblende are not rare. Less abundant are brown hornblende, garnet, tourmaline, apatite, and zircon. The texture of these specimens is well shown in Plate 6, *B*.

Specimens Nos. 65 and 66, of the Spangle suite, are alike in mineral composition and differ from each other in color only. No. 65 is brownish gray, and No. 66 is dark brown, and both contain much more organic material, to which the color is due, than specimens 67, 68, 77, and 77a. The grains are angular and are embedded in brown clayey material and beidellite. About 90 per cent of the grains range in diameter from 0.01 to 0.05 millimeter and consist of quartz, orthoclase, plagioclase, hornblende, biotite, muscovite, garnet, zircon, and apatite. That is, the bulk of the grains and the inclosing groundmass are identical in habit, origin, and mode of deposition with the material represented in specimens 67, 68, 77, and 77a.

However, a small part of the grains, estimated as 5 to 10 per cent of the total, are about 10 times the ordinary size and range from 0.1 to 0.3 millimeter in diameter. They consist of andesine having about the composition of $Ab_{60}An_{40}$, brownish-green hornblende, augite, and magnetite. Quartz grains of this size are entirely absent. These grains, as may be seen in Plate 6, *C*, are predominantly euhedral in outline, and the feldspar is strongly zoned.

The characteristic material of the tawny-yellow clay and the predominant material in the dark upper soils, as represented by these specimens, is fine grained, angular, and rather evenly sorted. Its composition indicates that it is not derived from the underlying basalt or decomposed residual material but is made up of minerals of diverse origin, some of which are characteristic

---

[22] Ross, C. S., A method of preparing thin sections of friable rock: Am. Jour. Sci., 5th ser., vol. 7, pp. 483–485, 1924; Methods of preparation of sedimentary material for study: Econ. Geology, vol. 21, pp. 454–468, 1926.

[23] Larsen, E. S., and Wherry, E. T., Beidellite, a new mineral name: Washington Acad. Sci. Jour., vol. 15, pp. 465–466, 1925. Ross, C. S., and Shannon, E. V., The chemical composition and optical properties of beidellite: Idem, pp. 467–468.

of silicic igneous and metamorphic rocks. All this indicates rather clearly that the material was deposited by the wind. The metacolloidal habit of the clayey material shows that much of it was formed by the breaking down, after decomposition of the mass, of unstable minerals of unknown origin into a colloidal material which was later crystallized into beidellite.

The two groups of minerals in specimens 65 and 66 are in mineral composition entirely distinct, and no grains transitional in size were present. The smaller grains consist of angular fragments, predominantly of quartz and in less degree of orthoclase, and differ not at all from the grains of the tawny-yellow clay specimens. The larger grains contain no quartz and no orthoclase but consist of andesine, hornblende, augite, and magnetite that are strikingly euhedral. These grains have all the characteristics of phenocrysts derived from volcanic rocks of andesitic composition. Their lack of rounding and retention of crystal form indicate that they came to place without wear and doubtless were deposited directly from the air. They probably were never deposited elsewhere but settled here as the result of a shower of volcanic dust from a distant source.

Specimens 67, 68, 77, and 77a may contain a little volcanic material, but if present it is far less abundant than in specimens 65 and 66, and there is no marked difference in size between the crystals and crystal fragments of such origin and the other wind-blown grains, by which a discrimination between the two classes can be made.

A sample typical of the well-known loess at Council Bluffs, Iowa, was supplied by W. C. Alden and subjected to the same analysis. As well shown in Plate 6, *C*, this material has grains similar in size, freshness, and angularity to those of the tawny-yellow loess from Spangle and Colfax, although differing in mineral character. So far as these observations are critical, the features of the admitted loess from Iowa confirm the opinion given above as to the origin of the "Palouse soil" samples.

These observations and studies indicate that the close resemblance between the clayey lower part of the "Palouse soil" and the decomposed basalt, which in places in the eastern part of the Columbia Plateau, as at Colfax, underlies the "soil," is wholly superficial. The extent to which this yellow clay forms the lower part of the "Palouse soil" was not determined, but according to the observations of Mr. Pardee, it is present throughout a considerable area. The description of the substratum of the Palouse silt loam in the soil survey of Latah County indicates that it extends into Idaho (p. 23). In the localities described by Mr. Pardee the tawny-yellow soil is composed of mineral grains that originate in granitic, gneissic, and metamorphic rocks. The nearest outcrop of such rocks is in the encircling mountains to the north and east, yet the prevailing winds come from the west and south, as perhaps did also those of Pleistocene time. The coarsest eolian soil (Ritzville type), which as indicated on page 23 has a somewhat similar mineral composition, blankets the plateau to the southwest in the direction of the prevailing winds. It seems possible only to suggest that this material was carried from the mountains in the channels of the ancestral Snake and Columbia Rivers and has since been returned from the vicinity of their junction by wind action. Understanding of the details of the processes by which this transfer was accomplished, however, awaits fuller knowledge of the sequence and character of Pleistocene events in this region.

The discovery by Mr. Ross of volcanic débris in the upper dark-colored layers suggests the possibility that correlation of soil layers from place to place on the basis of a content of volcanic dust may eventually be possible. That volcanic explosions have occurred in this general region in very late geologic time has long been recognized. Russell[24] has described a deposit of volcanic dust that lies in sheltered places in Latah County, Idaho, and must be due to recent dust showers. A deposit of volcanic dust of very late date occurs in Oregon.[25] It has been largely washed from the hillsides and now lies in the valleys and in small alluvial fans at the mouths of gulches, where it is from 1 to 10 feet deep. To the southwest, near Umatilla, Oreg., Hewett[26] has found a similar deposit of very late though prehistoric date.

In the soil survey of Spokane County already mentioned the loesslike upper soil was observed overlying a substratum of reddish material similar to that observed by the writer at Fishtrap, but there is no reason to believe that this reddish substratum is essentially different from the yellow clay found by Mr. Pardee in the same region.

The Bureau of Soils, however, recognized below the top skin of loessial soil a substratum made up of glacial till and even of decomposed crystalline rock, although in these localities the total thickness of unconsolidated material is generally less than 20 feet. Freeman[26a] has confirmed this observation by finding "loess" overlying ancient till near Cheney.

On Pleasant Prairie, in areas covered by soils of the Palouse series, as mapped by the Bureau of Soils, a fine gray to light-brown soil 18 inches to 3 feet thick lies above a compact and somewhat decomposed glacial till. (Pl. 7, *C*.) This till is distinguished by its state of weathering and position from that of the intermediate glacial stage as observed by the writer and described by Bretz.[27] (See also p. 42.)

It is evident from the foregoing statements that the so-called "Palouse soil" in many localities consists of a relatively thin veneer over a substratum of unconsolidated material that makes up the

[24] Russell, I. C., Geology and water resources of Nez Perce County, Idaho: U. S. Geol. Survey Water-Supply Paper 53, pp. 33–34, 1901.

[25] Pardee, J. T., and Hewett, D. F., Geology and mineral resources of the Sumpter quadrangle, Oreg.: Oregon Bur. Mines Mineral Resources, vol. 1, No. 6, p. 17, 1914. Grant, U. S., and Cady, G. H., Preliminary report on the general and economic geology of the Baker district of eastern Oregon: Idem, pp. 143–144.

[26] Hewett, D. F., personal communication.

[26a] Freeman, O. W., op. cit., p. 477.

[27] Bretz, J. H., Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., vol. 34, p. 580, 1923.

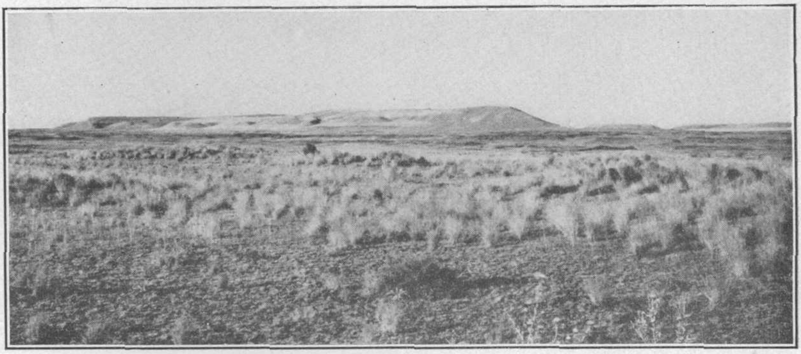
larger part of the core of the intricate maze of hills and ridges characteristic of the areas in which the "soil" occurs. The upper soil, which is from 3 to 10 feet deep, is wind-borne material, as admitted by all writers on the subject. Though part of it may have arisen from a superficial reworking of the underlying material by wind, as Russell suggested, the work of Mr. Ross shows that in places it contains mineral grains from distant volcanic explosions. The establishment of this fact leads to the inference that other parts not discriminated also had a distant source.

The underlying material is to be seen only in artificial exposures. Many of these are road cuts on the flanks of hills, where the veneer is thick. In the western part of the plateau some of these cuts, if not all, lie in the more recent soil corresponding to that which overlies the terrace in Old Maid Coulee. As suggested on page 37, the fossil elephant bones described in the next section probably occur in soil of this kind. Thus the underlying materials composing the substratum have been exposed in only a few places, and here they are of one or more of three kinds—a stratified and obviously water-laid silt, a compact unstratified reddish or yellow silt or clay, perhaps wind-borne, and an ancient glacial till. The observations of Mr. Pardee and the studies of Mr. Ross indicate that possibly none of the true substratum is residual from basalt. That these different materials were contemporaneous in their accumulation seems unlikely, as the period of time in which they may have accumulated extended from the last outpouring of basalt in Miocene time [28] to some part of the Pleistocene epoch. The patches of decomposed basalt that in places underlie the "Palouse soil" required time for their formation, and this fact shortens to some extent the time available for the deposition of the "Palouse soil."

DISCOVERY OF FOSSIL BONES

While making an inspection of the soil survey of the Columbia Basin irrigation project A. T. Strahorn, in charge of the soil survey, E. J. Carpenter, soil scientist, and M. H. Lapham, western inspector, all of the United States Bureau of Soils, found, on September 12, 1923, fragments of large bones and the jaws and skulls of rodents in a road cut in Franklin County. The writer was summoned from Spokane by long-distance telephone, and on the 13th, with the assistance of these gentlemen and Prof. F. J. Sievers, began excavations. On the following four days the writer, with a local helper, continued the work and recovered about 800 pounds of fossil bones.

[28] For recent data on the age of the basalt flows, see Pardee, J. T., and Bryan, Kirk, Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Wash.: U. S. Geol. Survey Prof. Paper 140, pp. 1–16, 1925.



A. HILLS OF "PALOUSE SOIL" RISING ABOVE THE SCABLAND NEAR HILLCREST, WASH.

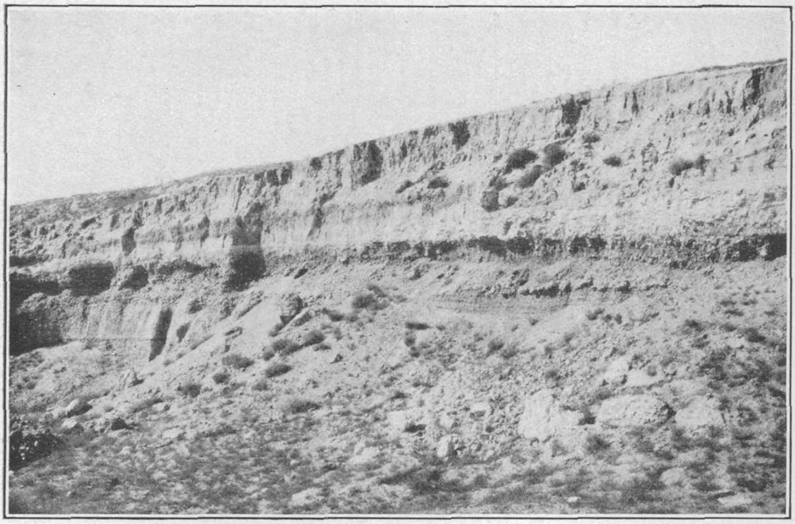
The lower 50 feet of these hills is basalt, generally masked by slump of soil from above. Photographed in 1923

B. ROLLING TOPOGRAPHY OF A "PALOUSE SOIL" AREA IN WHITMAN COUNTY, WASH.

Photographed by J. T. Pardee, 1923

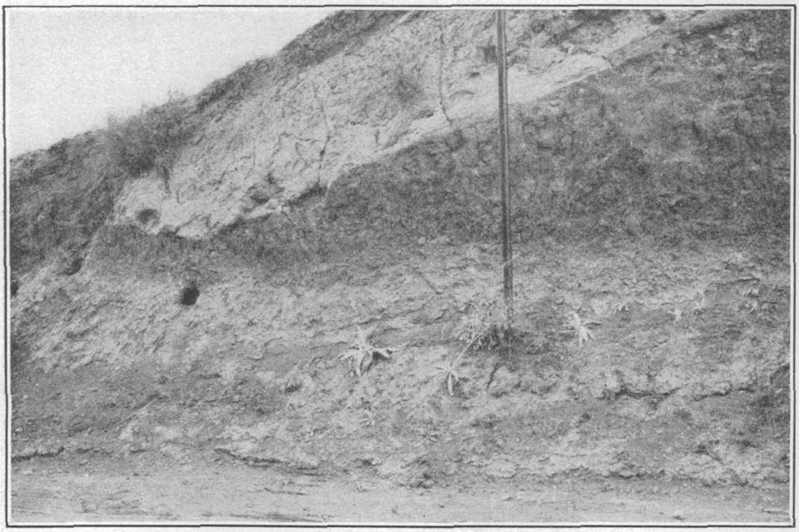
C. ROLLING TOPOGRAPHY AT OLD MAID COULEE, WASH.

The "Palouse soil" is 75 feet thick on the upland, but a mantle of similar though younger material covers the slopes and terraces of the valley. Photographed in 1923



A. GRAVEL PIT IN THE TERRACE ON OLD MAID COULEE, WASH.

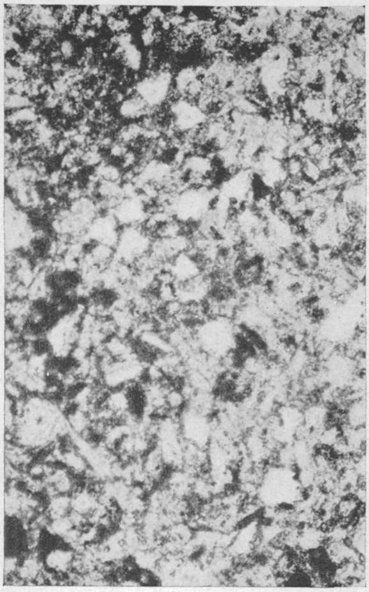
Exposing well-rounded stream gravel overlain by fine-grained loess. Photographed in 1923



B. ROAD CUT AT FISHTRAP, WASH.

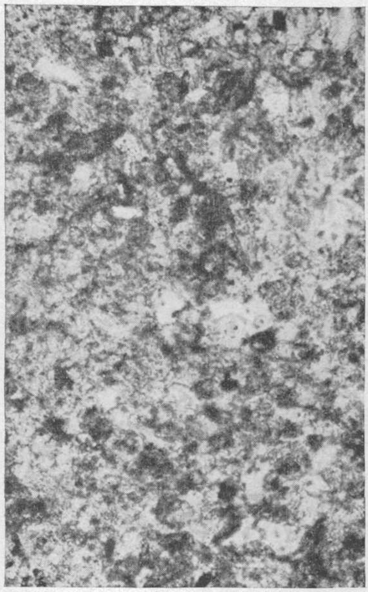
Showing veneer of loess overlying reddish compact fine-grained material that may be old loess. Photographed in 1923

A



B

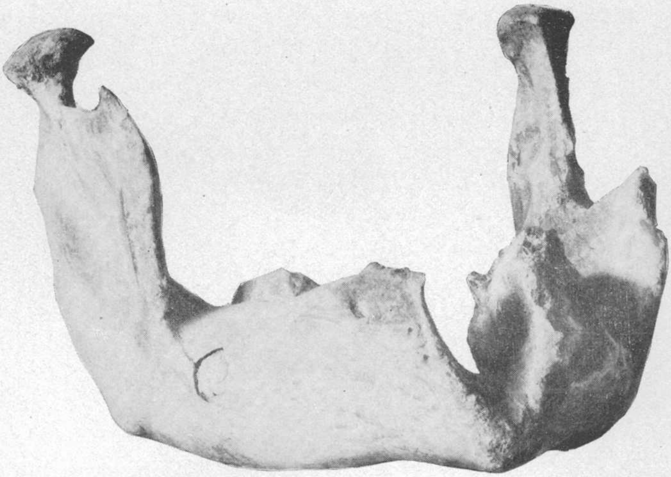
C



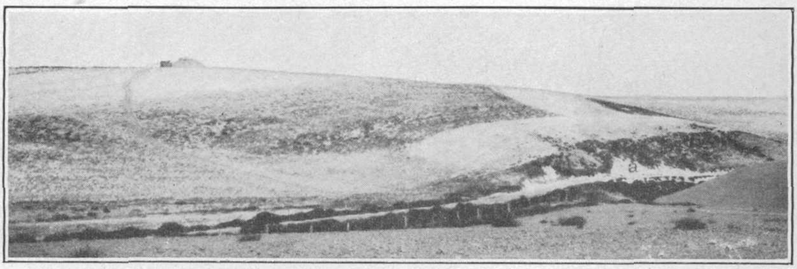
D

PHOTOMICROGRAPHS ILLUSTRATING CHARACTERISTICS OF SOIL RESIDUAL FROM BASALT, SUPPOSED LOESS, AND LOESS

A, Decomposed basalt from road cut north of Colfax, Wash., specimen 78; *B*, typical tawny-yellow clay of the lower part of the "Palouse soil" from road cut north of Colfax, Wash., specimen 77; *C*, typical brownish upper layer of the "Palouse soil" from road cut south of Spangle, Wash., specimen 65; *D*, loess from Council Bluffs, Iowa. [All enlarged 105 diameters

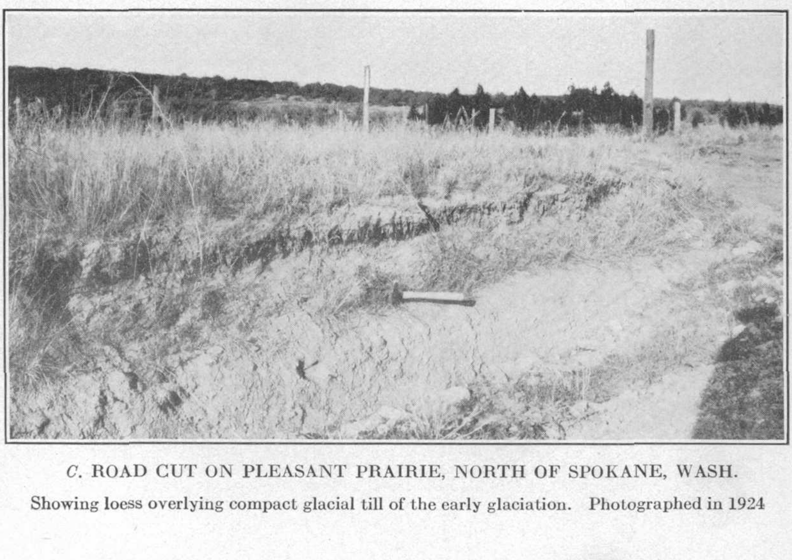


A. LOWER JAW OF ELEPHAS *COLUMBI* FROM WIND-BORNE SOIL ON THE COLUMBIA PLATEAU, WASH.



B. ROLLING HILLS OF COLUMBIA PLATEAU AT ELEPHANT LOCALITY, 15 MILES SOUTHWEST OF KAHLOTUS, WASH.

Photographed in 1923



C. ROAD CUT ON PLEASANT PRAIRIE, NORTH OF SPOKANE, WASH.

Showing loess overlying compact glacial till of the early glaciation. Photographed in 1924

The bones were found in two adjacent road cuts on the Pasco-Kahlotus highway, in the SW. ¼ sec. 27, T. 12 N., R. 33 E., in Franklin County, Wash. This point is 2½ miles west of Snake River, 30 miles northeast of Pasco, and about 10 miles southwest of Kahlotus. As shown on the Wallula topographic map, the altitude of the cut is about 1,350 feet, and that of the top of the adjacent hill is about 1,500 feet. A general view of the locality is given in Plate 7, *B*.

The two road cuts are about 50 yards apart, and both contain elephant bones, rodent remains, and shells that appear to be those of air-breathing gastropods. As the cuts are nearly at the same altitude and the matrix is similar it is assumed that they represent the same horizon. Preliminary work showed that the southern cut was the more promising, and effort was concentrated at this place. At the end of the five days of excavation a hole had been dug in the bank 10 feet wide, 8 feet deep, and having a back face 12 feet high. Bones were being obtained with decreasing frequency, and when this high face caved work was abandoned.

The bulk of the bones belonged to a single elephant. All the major bones were recovered except the skull. This material has been examined by Drs. O. P. Hay and J. W. Gidley, who point out that the individual was very old, as shown by the condition of the teeth. The right side of the lower jaw had suffered a lesion, well shown in the photograph reproduced as Plate 7, *A*. The lesion appears to have been a pus cavity and extended into the tooth, part of which was lost by decay during the animal's life. The age of the animal and this pathologic condition make identification of the species difficult, but Doctors Hay and Gidley believe that the remains are those of an elephant identical with or near to *Elephas columbi.*

The horse tooth found in the northern cut and the invertebrate shells have not yet been identified. The rodent material, though not studied in detail, seems according to Doctor Gidley to belong to species yet living in the region.

It is evident that these fossil remains are of Pleistocene age, but unfortunately *Elephas columbi*, as at present defined, is not characteristic of any particular part of the Pleistocene epoch. Of the rodent remains some are the bones of animals like those that to-day make burrows in the soil to depths of 4 or 5 feet. Others were found as single isolated bones, generally the relatively durable lower jaws, in undisturbed ground and were contemporaneous with the elephant, whose bones, as noticed below, are gnawed by similar animals. That Pleistocene forms of rodents are indistinguishable from those of the present day in the imperfect material collected does not, however, seem remarkable.

ARRANGEMENT OF THE FOSSIL BONES

The lack of definition in age is unfortunate, but the arrangement of the bones has real significance in relation to the origin of the "Palouse soil." At this locality the soil is a light-buff or pale-brown very fine sand and would be classed with the Ritzville soil series in a soil survey by the Bureau of Soils. It has so little clay that it lacks cohesion when dry and handles much like dry Portland cement. There is no stratification nor vertical structure except in a zone about 5 feet thick that conforms to the hill slope. Here there is a pseudovertical structure similar to that noted by the Bureau of Soils as general in the Ritzville series. In this zone the burrows of small rodents are numerous. The upper 2 feet is somewhat more compact than the lower 3 feet, perhaps because of alternate wetting and drying. The whole zone is somewhat more pulverulent than the material below, which, however, is similar in grain and color. In places the grains of the lower part are agglutinated in limy nodules, and there are a few irregular seams of calcium carbonate. Cementation is so incomplete, however, that all the material can be excavated with a shovel. Only one pebble was found. It is of irregular shape with rounded edges, about 1½ inches on the major axis, and composed of basalt.

In this mass the bones of the elephant had a vertical range of 6 feet and a horizontal range of 10 feet along the face of the road cut and of 8 feet into the interior of the hill. They were arranged without order or system. For instance, the lower jaw was upside down and under one shoulder blade; single foot bones and vertebrae were found in various parts of the excavation. When buried most of the bones were in nearly perfect condition except one shoulder blade, most of the ribs, which were found in separated pieces, and the tusks, of which fragments were found scattered throughout the excavation. The skull was missing. The pelvis was imperfect, but this condition is probably due to surface weathering since burial and to damage in the excavation of the road cut.

The bones must have lain on a surface for some time after the animal's death, for many of them retain the marks of gnawing by rodents. These marks alone seem adequate proof that the bones lay on a dry land surface. The scattered fragments of tusks and of bones seem also proof that the skeleton lay on the surface long enough for some weathering of the bones. The bones were, however, entombed and placed in position before fossilization and while yet retaining some resiliency, for one entire rib, free from cracks, was found in a nearly vertical position. In its present state it can hardly bear its own weight in this position and could stand no rotation or creep in the inclosing sand. It must have attained the vertical position and have been inclosed in the sand while yet retaining the tensile strength of green bone.

Thus the arrangement and characteristics of the bones indicate that the elephant died on a land surface. The very fine sand of the inclosing matrix is similar to that found in hummocky areas where constant shifting by wind takes place. Doubtless each bone formed an obstruction to the wind, and a pit was dug out below it on the windward side into which it fell and was buried. This process may have taken place several times, but some of the bones were quickly buried, or they would not have been preserved in such perfect condition. In most sandy areas of this type it is difficult to determine whether there is more erosion than deposition, but deposition must have been dominant at the time in this area, for not only were the bones buried in the wind-blown sand but more material of similar character was accumulated to a minimum height of 10 feet.

If it is granted that the foregoing analysis is correct and that the elephant died and was buried in an eolian deposit, it follows that the land in this area had a scanty vegetative cover and that the climate was doubtless arid. The elephant is, however, a gross feeder and must live in areas of heavy vegetation. This individual may have been merely passing through the region or may have come to this place to die, as is the reported habit of African elephants.

As further collecting at this locality will doubtless produce other bones, some of which may have a greater stratigraphic value than these elephant bones, it is worth while to consider whether the wind-borne material of this locality represents the "Palouse soil" or only a part of it. An inspection of Plate 7, *B*, shows that the road cut lies at the base of a poorly defined terrace, about 150 feet below the top of the adjacent hill. The nearest outcrops of basalt are a quarter of a mile away. If the top of the adjacent hill represents the top of the plateau and if the road cut is in the "Palouse soil," we must assume that this original mantle is 150 feet thick in this locality. Well records and other observations in the vicinity indicate that it is not more than 70 to 100 feet thick, and consequently it seems probable that the road cut was made in a terrace that is composed largely of wind-worked material and lies below the general level of the original mantle of "Palouse soil." Such vaguely defined terraces may be seen on many minor streams and seem to correspond to the pause in erosion marked by the gravel terraces of Old Maid Coulee. (See p. 27 and Pls. 4, *C* and 5, *B*.)

Old Maid Coulee and similar valleys were formed in a cycle of erosion that antedated the great coulees produced by the diversion of glacial waters over the plateau. By this line of reasoning the terraces and specifically the terrace from which the elephant bones were dug are pushed far back into Pleistocene time.

Speculation on the geographic conditions of that time is in the present state of knowledge necessarily hazardous, but it may well be that in those days the deep canyons of Columbia and Snake Rivers did not exist. The valleys of these great rivers may have been broad and shallow. The flood plains, periodically overflowed and with a high water table, may have supported a broad strip of dense vegetation. Here the elephants may have lived in oases in a land as arid or even more arid than that of central Washington to-day. In the area between these river flats fine sand, derived from the original "Palouse soil" and from the broad river channels in the long period between the annual floods, may have been shifted to and fro by the wind, and in this sandy area an elephant who lived in the near-by wooded river flat may have died and left his bones.

PRESENT ACCUMULATION OF LOESS

DUST STORMS

Remarkable dust storms are features of the climate of eastern Washington. These storms and the inferred wind work indicated by the asymmetric shape of the hills, as first noted by Russell,[29] have led to the theory of accumulation of the "Palouse soil" as wind-borne dust through a period extending into the present.

Peterson [30] collected and weighed dust that fell on measured areas of new snow near Moscow, Idaho, in four storms within a period of 55 days. The individual falls ranged from 140 to 585 pounds to the acre for the period. Assuming a similar rate of fall throughout, he obtained a rounded figure of 7,500 pounds to the acre as the yearly accumulation of dust. As the observations extended over a period of only 55 days in only one year, the figure of 7,500 pounds to the acre involves violent assumptions. However, in continuance of Peterson's argument, if this rate of fall is projected into past time the soil has been accumulating at the rate of 4 inches a century. Under this assumption a thickness of 75 feet would require, for its accumulation, 25,000 years.

A slightly greater daily fall is recorded by Larsen,[31] who measured the dust that fell in a single day's storm in March, 1917, in northern Idaho, and obtained a figure of 600 pounds to the acre.

It is unfortunate that systematic measurements of dust falls have not been made, for all observers agree that the fall of dust is very irregular in amount even in recognized "dust" storms, and there is also an invisible fall of dust which takes place daily during the

---

[29] Russell, I. C., op. cit.

[30] Peterson, P. P., Rate and mode of soil deposition in Palouse area of Washington and Idaho: Science, new ser., vol. 55, pp. 102–103, 1922.

[31] Larsen, J. A., Soil shifting and deposits: Science, new ser., vol. 50, p. 457, 1922; Dust storms of northern Idaho and western Montana: Monthly Weather Review, vol. 52, p. 110, 1924.

summer. The observations of Peterson and Larsen, which are tabulated below, have their principal value in giving the order of magnitude of the quantity of dust that falls in single storms:

Summary of measured dust falls in Idaho, 1917

Locality	Observer	Date	Amount (pounds to the acre)
Moscow, Idaho	Peterson	Jan. 29, 1917	140
Do	do	Mar. 21, 1917	196
Do	do	Mar. 22, 1917	184
Do	do	Mar. 23, 1917	585
Northern Idaho	Larsen	March, 1917	600

The average fall is 341 pounds to the acre for each storm, equivalent to a depth of 0.00013 foot, or 0.0016 inch.

A record of the principal dust storms at Spokane, Wash., has been kept at the local office of the United States Weather Bureau as part of the daily written notes on incidental phenomena of the weather. Through the kindness of Mr. E. M. Keyser, the local forecaster, this information with other pertinent data has been tabulated and put at the writer's disposal. Although the recording of dust storms is not a part of the forecaster's required task, Mr. Keyser believes that all the important storms have been recorded but that storms of minor intensity may easily have been missed.

Dust storms at Spokane, Wash., 1905–1925

[Recorded by E. M. Keyser, United States Weather Bureau]

Year	Date	Observer's statement	Wind		Accumulated rainfall from Jan. 1 to date given (inches)	
			Velocity (miles per hour)	Direction	Normal	Actual
1905	Aug. 27	Dust and rain	39	SW.	11.23	11.18
1910	June 1	Dust	35	SW.	8.65	5.84
1911	May 5	Dust and rain	25	SW.	7.23	2.78
1913	Mar. 29	Dust preceded by rain	30	SW.	5.59	5.06
1913	Apr. 21	do	36	SW.	6.61	5.92
1913	July 6	Dust and rain	28	W.	10.54	9.09
1913	Oct. 13	do	39	W.	13.07	12.79
1914	Aug. 6	Dust preceded by rain	23	SW.	10.98	8.68
1915	Oct. 31	do	44	SW.	13.87	10.83
1916	June 18	Dust and rain	23	SW.	9.64	8.48
1917	Mar. 23	Dust of unusual intensity and light rain	40	SW.	5.27	3.08
1918	May 30	Light dust and light rain	30	SW.	8.55	4.90
1918	June 9	Light dust	26	SW.	9.04	4.90
1918	July 9	Dust of unusual intensity and light rain	38	SW.	10.61	5.34
1918	Aug. 8	Light dust and light rain	24	W.	11.00	5.59
1918	Aug. 26	Light dust	26	W.	11.20	5.85
1918	Oct. 11	Intense dust	31	SW.	12.97	6.28
1919	Apr. 24	Light dust and light rain for 1 hour	27	SW.	6.75	7.64
1919	July 5	Light dust	27	SW.	10.46	8.44
1920	Apr. 5	Dust	23	W.	5.92	2.42
1920	Apr. 7	do	28	SW.	6.00	2.42
1920	May 17	Dense dust preceded by rain	39	SW.	7.92	4.10
1920	May 21	Dust	24	SW.	8.12	4.10
1920	June 22	Some dust during afternoon	26	S.	9.86	4.97

Dust storms at Spokane, Wash., 1905–1925—Continued

Year	Date	Observer's statement	Wind		Accumulated rainfall from Jan. 1 to date given (inches)	
			Velocity (miles per hour)	Direction	Normal	Actual
1920	June 23	Dust and rain	22	S.	9.90	4.97
1920	June 24	Dust settled during morning	18	S.	9.94	4.97
1921	Apr. 21	Dust and rain, much dust brought down	20	SW.	6.61	5.81
1921	Apr. 22	do	28	W.	6.66	5.86
1921	Apr. 29	Great clouds of dust	33	SW.	6.95	5.91
1921	Aug. 14	Dust and rain	39	SW.	11.06	6.58
1921	Sept. 26	Dust	33	SW.	12.26	7.96
1921	Sept. 27	do	39	SW.	12.29	7.96
1922	Aug. 19	Heavy dust	28	SW.	11.11	6.71
1923	Mar. 16	Dust and light rain	30	N.	4.95	4.02
1923	Mar. 19	Dust	40	SW.	5.07	4.05
1923	Oct. 16	Dust and rain (driving in automobile difficult)	29	SW.	13.22	12.77
1924	Apr. 18	Dust storm and sprinkles	30	SW.	6.46	3.20
1924	Aug. 3	Light dust storm	23	NW.	10.85	4.64
1924	Sept. 8	Dense dust storm, light rain	36	S.	11.73	5.55
1925	July 24	Light dust, light rain	30	S.	10.83	7.94

NOTE.—The record is complete to October 15, 1925.

As described in notes by Mr. Keyser, the dust storm of August 19, 1922, began in the middle of the forenoon and lasted until after sunset. The dust was so dense that it shut out the sky, and the sun had the appearance of a very pale moon. At Newman Lake, east of Spokane, the view across the lake was obscured as by a dense fog.

The storm of October 16, 1923, was seen by the writer. The dust was so thick as to have the appearance of a yellow fog, and in combination with the clouds, from which rain shortly fell, it produced a yellow darkness in which it was nearly impossible to see one's way. Automobiles were abandoned because of the difficulty of driving. When the rain began the first drops were liquid mud, which made great brown patches on umbrellas and clothing. The window panes in Spokane, the next morning, were so dirty that it was impossible to see through them, and for several days the roofs of buildings retained a thin coat of mud acquired during the storm.

It is obvious from the foregoing accounts that the dust storms of the eastern portion of the Columbia Plateau are extraordinary phenomena. During these storms immense quantities of dust are taken into the air, to be later deposited. The storms are well worth further study to determine more precisely the direction of movement of the dust, the places where it is picked up, and the places where it is deposited.

The Spokane record furnishes the only available group of facts to confirm general observation. From this record the following conclusions can be reached:

1. The wind velocity during storms ranges from 18 to 44 miles per hour.

2. The wind is generally from the southwest, sometimes south, and sometimes west. Only one dust storm had wind from the north, and there were none with wind from the east.

3. Every storm, except that of April 24, 1919, occurred when there was a deficiency of rainfall, as shown by the two columns at the right in the table on pages 39–40, giving the normal accumulated precipitation from January 1 to the date of the storm and the actual accumulated rainfall for that year.

4. In the 21 years 1905 to 1925 covered by the record there were 19 storms recorded as "dust and rain," or an average of about one such storm a year.

The dust storms originate to the southwest of Spokane, but how much of the dust comes from a distance is uncertain, particularly as the incidence of the storms coincides with deficient rainfall at Spokane. However, general testimony of persons familiar with the region indicates that some storms originate in northern Oregon and sweep across the whole of the Columbia Plateau. From the same source it is learned that the dust storms were unknown before the settlement of the country west of Spokane and the Palouse region. Vast areas once protected from the wind by a natural growth of sagebrush and grass have been plowed and many roads have been made in the Big Bend country since about 1900. Here the movement of dust can be seen on any windy day. In places roads have been filled to the tops of the fences with fine sand derived from adjacent fields. The great area of plowed ground left exposed to the wind from spring until fall under the system of summer fallow for the production of wheat, together with the dryer climate of the western portion of the plateau, provides a source for a large quantity of dust. It is natural to expect, therefore, a transfer of dust from this dryer area to the more humid area in the east.

RATES OF ACCUMULATION AT PRESENT AND IN THE PAST

If, as seems reasonable, the dust storms of the present time tend to deposit dust in the eastern section of the Columbia Plateau, it does not follow that such accumulation is the sole cause of the formation of the "Palouse soil" or that the present rate of deposition is a measure of the time involved in the process, as argued by Peterson.

The unconsolidated mantle over the basalt is apparently as thick in the western part of the plateau as in the eastern part, yet at the present time most of the dust picked up by wind in the western part of the plateau arises from roads and fields in the "Palouse soil" areas. This fact alone would indicate that the main body of the "soil" was deposited at some time in the past and that the present action merely modifies the distribution of soil brought about by that past action.

However, there is another group of facts which throws light on the problem. The unequal thickness of wind-borne or loessial soil in the eastern part of the plateau has been noted in the several soil surveys. On the basalt plateau there is above the inner core of the hills, which consists in places of reddish or yellow fine-grained material, thought to be old loess, and of ancient till, 3 to 6 feet or more of soil. A similar material of the same or less thickness but resting directly on the rock is found on the flanks of plateaus, and generally on granite and gneiss.

Still more significant, however, is the almost total absence of such soil on the terminal moraine of the intermediate glaciation and on the ground moraine and rock surfaces attributed to the ice of that stage in the area between Cheney and Spokane. Similarly, the top of the outwash gravel[32] of the intermediate ice, which was left as a terrace along Latah (Hangman) Creek, has no dust cover. On the successive terraces, carved from this outwash gravel by Latah Creek, there is 1 inch to 6 inches of dust. Remnants of the Wisconsin outwash plain show as a terrace along Spokane River, and on this surface there is no accumulation of dust.

On Pleasant Prairie, a plateau remnant north of Spokane, there is a loessial soil mapped as part of the Palouse series in the soil survey. This soil underlies the flat areas between minor streams that lie 50 to 200 feet below the surface of the plateau. The soil is absent, however, from the terraces and heaps of gravel that border these valleys and from a large gravel terrace on the south side of Pleasant Prairie. Glacial till that lies in patches on the slopes, particularly the north slopes of the prairie, is also free of dust. All these accumulations of gravel and till can be attributed to the intermediate glacial ice, which seems to have surrounded Pleasant Prairie without overriding the main part of it. The gravel appears to have been largely deposited by streams that ran across the surface of the little plateau from one part of the surrounding ice to the other.

Between the small valleys with their bordering heaps of gravel loessial soil to a depth of 18 inches to 3 feet forms smooth plains and overlies a compact glacial till. As may be seen in Plate 7, *B*, the soil is generally dark, and its friable nature is in marked contrast to that of the underlying till, which is rusty, compact, and much decomposed. Many well-striated and soled pebbles occur in the till, which is an unmistakable glacial product and long antedates

[32] For a brief description of the gravel at Spokane, see Pardee, J. T., and Bryan, Kirk, Geology of the Latah formation in relation to the Columbia Plateau: U. S. Geol. Survey Prof. Paper 140, pp. 15–16, 1925.

the intermediate glacial stage, representing some earlier glacial advance. Similar loess overlying old till can be seen along the new county highway on Fivemile Prairie.

Thus, near Spokane 18 inches to 3 feet of loess overlies an early till, but no dust has accumulated on the intermediate till or on the Wisconsin terrace. In the sheltered depression of the Latah Creek valley a small amount of dust overlies the recessional terraces cut by the creek in the outwash plain of the intermediate ice.

The city of Spokane lies in an area covered by perennial grass and containing open forests of pine trees, where wind-borne dust should be and probably is deposited easily, yet the deposition of dust near Spokane has in the past been at a moderate rate, and almost none has been deposited since the disappearance of the ice of the intermediate glaciation.

Owing to the lack of quantitative observation on dust falls, the present rate of deposition can be merely approximated, but even under the most conservative assumptions it is obvious that the present rate greatly exceeds that of the past. Those dust storms in which rain accompanies the dust should be the most effective in deposition, for the rain carries the dust as mud down to the ground, where it can be entangled in the grass. The gravelly surface of the Wisconsin terrace is flat and has no surface run-off, so that it is an excellent place to receive the dust from such storms, and the dust once deposited should remain in place. As shown in the tabulated record of the dust storms at Spokane (pp. 39–40), there has been an average of one of these storms a year. No direct measurement of the quantity of dust deposited by storms at Spokane is available. The observations of Peterson and Larsen, the only measure of the quantity of dust deposited, were made many miles distant from Spokane. It may be also that, being made in January and March, they do not apply to all the storms listed in the Spokane record, most of which occurred in the summer and fall. However, the average of their observations, 341 pounds to the acre, or 0.0016 inch in depth, is doubtless of the correct order of magnitude and may be considered the minimum yearly rate of dust falls in Spokane.

The length of time during which the Wisconsin terrace at Spokane has been exposed to the fall of dust is of course uncertain. It is reasonably well established that the last Pleistocene glaciation of the northern Rocky Mountains coincides with the Wisconsin glaciation, as known in the Middle West. Most authorities place the final retreat of the Wisconsin ice front in North America and Europe at a time 10,000 to 20,000 years ago.

As the outwash plain on Spokane River was deserted by glacial water shortly after the ice began to recede, it would be safe to assume that this plain has been prepared to receive dust from the beginning rather than the end of ice retreat. However, for the sake of conservatism 10,000 years may be assumed as the available time. At the rate of deposition of 0.0016 inch to each storm, obtained by the use of the data of Peterson and Larsen, and on the assumption of one storm a year, the total deposit on the Wisconsin terrace should be 16 inches, whereas actually no dust can be detected. This calculation also takes no account of dust storms unaccompanied by rain, though doubtless these storms also deposit dust, and there is probably also a continuous invisible fall during the summer.

By this line of reasoning, therefore, it is apparent that the present dust storms probably deposit dust at a greater rate than at any time since the Wisconsin glaciation. The times following both the intermediate and the Wisconsin glaciations must have witnessed very little fall of dust, else dust would be found on the till and outwash plains of the intermediate glacial stage. We are, therefore, almost forced to conclude that the original deposition of dust took place under conditions of topography and climate that may have been markedly different from those prevailing to-day or at any time since the intermediate glaciation.

In the western part of the Columbia Plateau the amount of soil shifting since the time of the intermediate glaciation may have been somewhat greater, especially near large tracts of "Palouse soil." The so-called scablands[33] are generally bare or have only scattered patches and circular mounds of wind-borne soil. If most of these scabland areas date back to the intermediate glaciation, as contended by Bretz, then the foregoing argument as to past rates of deposition near Spokane applies also to the western part of Columbia Plateau.

CONCLUSIONS

In the foregoing discussion of the "Palouse soil" problem some new facts are brought forward, but these facts are insufficient to give a complete analysis of the genesis of these interesting and economically important deposits. The data are presented to clarify the issues and to make available to others the facts that have been gathered. The inner core of the "Palouse soil" hills remains as much a mystery as ever, but it is obviously a complex and relatively ancient deposit whose story, if known, would illuminate the history of Pleistocene time on the Columbia Plateau.

The following conclusions seem justified:

1. The soil that is useful in agriculture (Palouse, Ritzville, Helmer series, etc., as defined by the Bureau of Soils) consists of a top

[33] Bretz, J. H., The channeled scablands of the Columbia Plateau: Jour. Geology, vol. 31, pp. 623–634, 1923. See also Freeman, O. W., Scabland mounds of eastern Washington: Science, new ser., vol. 64, pp. 450–451, 1926.

skin, or veneer, that is largely wind borne throughout the plateau and rests on material of various sorts.

2. Where the unconsolidated material, or so-called "Palouse soil," is thick the inner core of the hills composing the intricate topography is largely unknown. At various places this inner core consists of (1) laminated silt, (2) almost structureless reddish compact silt with limy concretions that may be a loess, (3) yellow clay and clay silt that seem with little doubt to be loess, (4) ancient glacial till (older than the intermediate till of this region), and (5) very doubtfully a residual soil derived from basalt.

3. In the western part of the plateau there is in numerous valleys a well-defined terrace in part underlain by gravel. The valleys and the terrace antedate the great coulees formed by glacial waters.

4. The soil on these terraces is a definite wind-deposited material, as shown by the arrangement of the bones of an extinct elephant.

5. The soil on the terraces is younger than the unknown inner core of the adjacent "Palouse soil" hills but is of Pleistocene age.

6. In the eastern part of the plateau thin and discontinuous layers of gray to green-gray material residual from basalt underlie yellow clay composed of minerals foreign to the basalt and having all the characteristics of loess.

7. In one place at least the top layer of soil or veneer contains volcanic ash.

8. The present rate of deposition of dust in the vicinity of Spokane is an accelerated rate induced by the cultivation of immense areas of loessial soil to the west and south.

9. Deposition of loess since the Wisconsin and intermediate bodies of till were laid down has been moderate in amount, and the great period of deposition of wind-borne soil antedates these later advances of glacial ice.

INDEX