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. ¼ 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

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[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.

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[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

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[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

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[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.

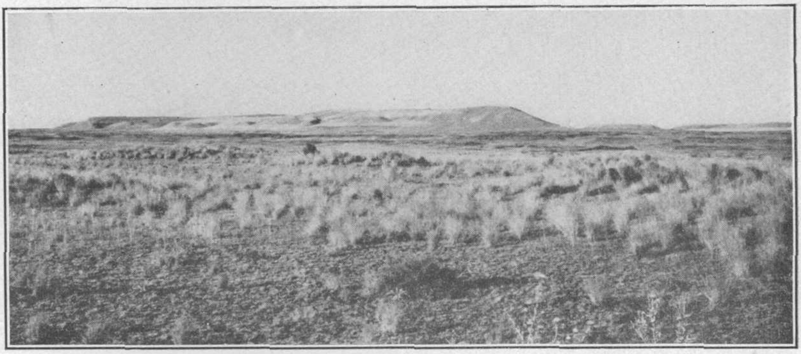
larger part of the core of the intricate maze of hills and ridges characteristic of the areas in which the "soil" occurs. The upper soil, which is from 3 to 10 feet deep, is wind-borne material, as admitted by all writers on the subject. Though part of it may have arisen from a superficial reworking 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.

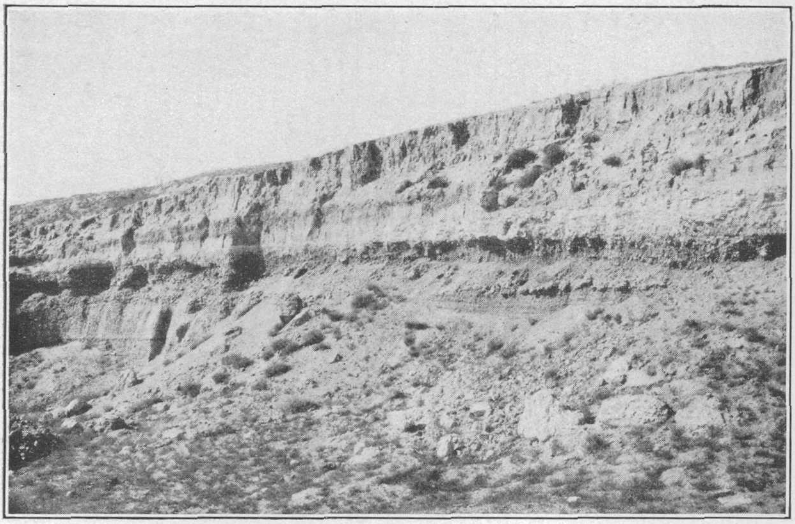
The lower 50 feet of these hills is basalt, generally masked by slump of soil from above. Photographed in 1923

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

Photographed by J. T. Pardee, 1923

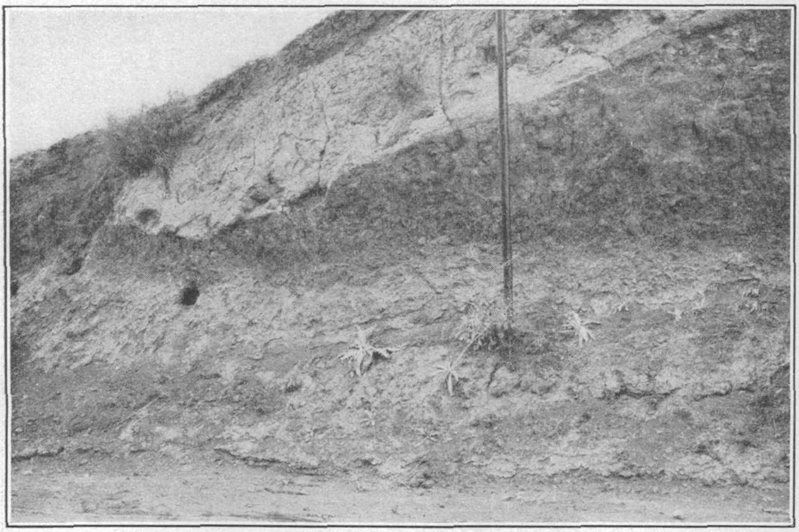
C. ROLLING TOPOGRAPHY AT OLD MAID COULEE, WASH.

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.

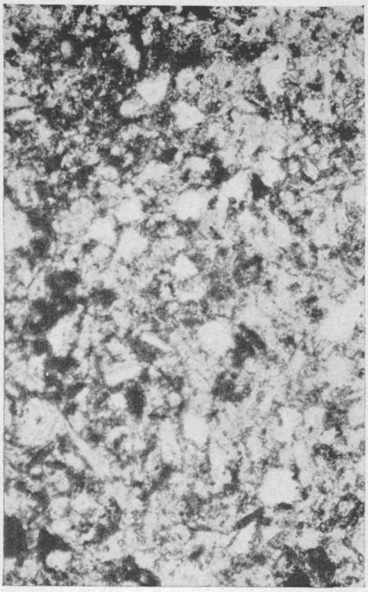
Exposing well-rounded stream gravel overlain by fine-grained loess. Photographed in 1923



B. ROAD CUT AT FISHTRAP, WASH.

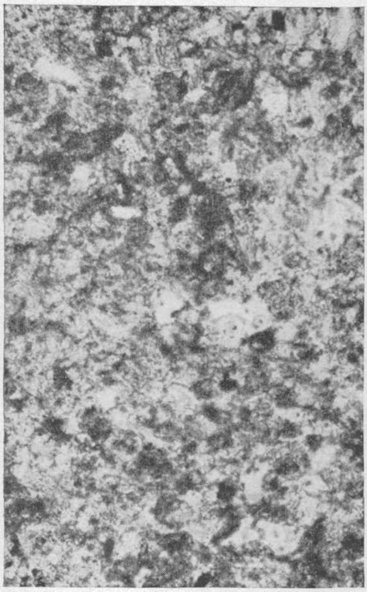
Showing veneer of loess overlying reddish compact fine-grained material that may be old loess. Photographed in 1923

A



B

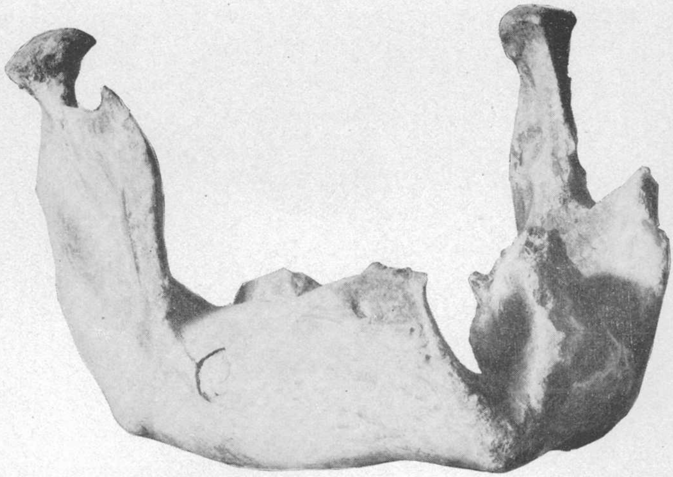
C



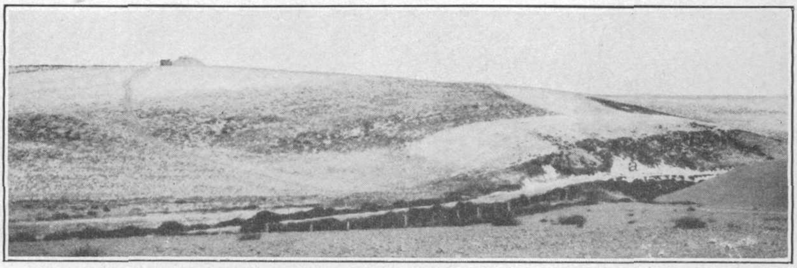
D

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

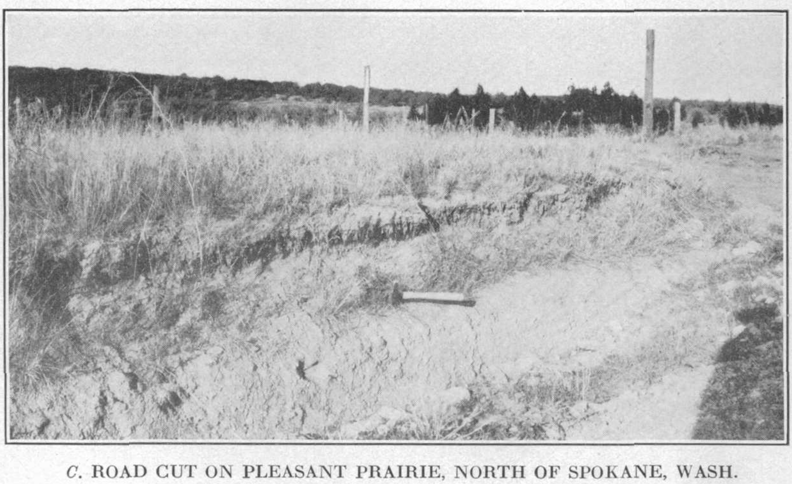


A. LOWER JAW OF ELEPHAS *COLUMBI* FROM WIND-BORNE SOIL ON THE COLUMBIA PLATEAU, WASH.



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.

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