Clay Deposits of Spokane County Washington

GEOLOGICAL SURVEY BULLETIN 1270

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By JOHN W. HOSTERMAN

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A geological, mineralogical, and chemical study

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CLAY DEPOSITS OF SPOKANE COUNTY, WASHINGTON

By John W. Hosterman

ABSTRACT

The clay deposits of eastern Spokane County occur along the eastern and northeastern margin of the Columbia Plateau, where the basalt flows lap onto the older igneous and metamorphic rocks. Five genetic types of clay are available for making clay products, and three of the five types are possible future sources of alumina. The five types are (1) white residual clay derived from pre-Tertiary igneous and metamorphic rocks, (2) bluish-gray residual clay derived from Columbia River Basalt (Tertiary), (3) residual and transported clay beds in the Latah Formation (Miocene), (4) brown clayey silt and silty clay of the Palouse Formation (Pleistocene), and (5) light-greenish-gray silty clay of the glacial lake deposits. Residual clays, derived from igneous and metamorphic rocks, and clays from the Latah Formation would be best for refractory products, filler uses, and as an ore of aluminum. Residual clay derived from basalt would be useful only as an ore of aluminum with a possible byproduct of titanium. The best use of clay from the Palouse Formation and lake deposits is in making building brick.

Five clay minerals have been identified by X-ray diffraction in samples from these deposits. Kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) is found in all types of clay, except residual clay derived from basalt. Halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$) is found primarily in the residual clay derived from basalt, and traces are found in the residual clay derived from pre-Tertiary rocks. Montmorillonite and illite do not occur in residual clay derived from basalt, but do occur in varying amounts in all other types of clay. Nontronite (a high iron montmorillonite) is found only in the residual clay derived from basalt.

The clays formed under similar physical, chemical, and bacterial conditions during Tertiary time. It is likely, therefore, that the mineralogic composition of the unweathered parent rock controlled the type of clay mineral produced during katamorphic alteration. The augite in basalt altered to nontronite, and the ferromagnesian minerals in the pre-Tertiary rocks altered to montmorillonite. The pre-Tertiary rocks contained feldspars and muscovite that altered to kaolinite, and the basalt contained plagioclase (labradorite) that altered to halloysite.

The approximate content of SiO_2 Al_2O_3, Fe_2O_3, MnO, CaO, K_2O, and TiO_2 was determined by a rapid and inexpensive X-ray fluorescence method. The chemical composition of 220 samples indicates that the residual clay derived from basalt has an average Al_2O_3 content of 22 percent with individual samples as high as 39 percent; the Latah Formation, 20 percent with a high of 37 percent; and the residual clay derived from pre-Tertiary rocks, 20 percent with a high of 29 percent. The Palouse Formation loess has an Al_2O_3 content of about 15 percent, and the lake deposits, about 16 percent.

INTRODUCTION

Clays are natural earthy materials composed of fine-grained particles (less than 4 microns) that are chiefly hydrous aluminum silicates, but they may contain small amounts of iron, magnesium, potassium, sodium, calcium, and other ions. Clay deposits consist of material composed largely of one or more clay minerals, such as kaolinite, halloysite, montmorillonite, nontronite, and illite. Nonclay minerals in these deposits occur in varying quantities; the most common are quartz, feldspar, muscovite, and minerals composed of Fe_2O_3, MnO, and TiO_2. The mineral and chemical content, particle size and shape, impurities, and other characteristics of the clay minerals result in a wide range of physical properties that determine the economic possibilities of the deposit. The physical properties of the clay include plasticity, color, refractoriness, specific gravity, porosity, deformation with drying and firing, green and fired strength, viscosity, and gel strength. The purity of the clay enhances the economic value of most clay deposits. However, for some uses, particularly in making face brick, certain nonclay minerals are desirable.

Clay deposits totaling hundreds of millions of tons occur along the eastern and northeastern margin of the Columbia Plateau where basalt flows lap onto older rocks. These deposits are a potential source of alumina as well as a raw material for ceramic products. Interest in these clay deposits of eastern Washington and northern Idaho has continued since World War II, when there was a concentrated effort to find domestic sources of aluminum. In the last few years, clay deposits have been more thoroughly explored and new plants producing clay products have been built. In 1961, the J. R. Simplot Co. completed construction on a plant near Bovill, Idaho, to process clay for the paper industry, silica sand for the glass industry, and mica for insulation. The A. P. Green Co. bought the old Troy Firebrick Co. in 1956 and has rebuilt the firebrick plant at Troy, Idaho, that had been partly destroyed by fire. The International Pipe and Ceramics Co., formerly Gladding, McBean and Co., bought all the holdings of Washington Brick and Lime Co. and in 1960 built a modern brick and firebrick plant to replace the old one at Mica, Wash.

Hosterman, Scheid, Allen, and Sohn (1960) discussed the clay deposits in Latah County, Idaho, and parts of some of the deposits in Spokane County, Wash. The present report describes in detail the mineralogy, ceramic data, and theory of origin of the clay deposits in eastern Spokane County. A method for determining chemical composition of clay samples by X-ray fluorescence is outlined herein.

Spokane County, in eastern Washington, borders the State of Idaho; the northeastern half of the county is in the Northern Rocky

Mountains physiographic province, and the southwestern half is in the Columbia Plateaus physiographic province (Fenneman, 1931, p. 183–273). The Northern Rocky Mountains province is characterized by a fairly rugged topography that resulted from alpine-type glaciation. It is underlain by igneous rocks related to the Idaho batholith of Late Jurassic and Cretaceous age, and by older sedimentary and metamorphic rocks belonging to the Belt Series of Precambrian age. The Columbia Plateau is underlain by nearly horizontal lava sheets of Columbia River Basalt of Tertiary age. Locally, the basalt flows are interbedded with sedimentary material of the Latah Formation. Both the basalt and the Latah Formation are overlain by the Palouse Formation of Quaternary age.

The clay deposits are in two distinct districts within the Columbia Plateaus physiographic provinces. South of the Spokane River is the Palouse Hills district characterized by a rolling surface of broad rounded hills that rise 20–80 feet above the valleys. This area contains the Excelsior, Mica, Freeman, Manito, and Saxby clay deposits and the clay deposits south of Moran Prairie. The Coulee district includes the Spokane River valley and the area to the north. It has wide flat valleys between small, almost level plateaus that are about 500 feet higher in elevation than the valleys. This area includes the Orchard Prairie, Pleasant Prairie, Peone Prairie–Deadman Creek, Fivemile prairie, Deer Park, and Milan clay deposits (fig. 1). The Deep Creek, Latah Creek, and Shelly Lake clay deposits occur in the Spokane River valley. Many of these clay deposits were sampled and described by Glover (1941, p. 229–280).

The clay deposits of Spokane County can be classified into two types depending upon their mode of origin: residual clay and transported clay. The residual clay is called saprolite, a term introduced by Becker (1895, p. 289) that means rotten rock. Saprolite was defined by Overstreet (1961, p. 447) as an earthy decomposed product of the subaerial chemical weathering of any kind of rock in place. All textural, structural, planar, and linear features of the original rock are preserved. Saprolite consists of chemically resistant minerals left from the parent rock, and clay minerals formed from the chemically unstable minerals in the original rock; all residual clays are saprolite. The term "saprolite" has been widely used in the southeastern part of the United States, but it has not been used to any extent for the residual clay deposits in the Northwest. The saprolite is developed on the pre-Tertiary igneous and metamorphic rocks, on the Columbia River Basalt, and to a minor extent on the Latah Formation. The transported clays are part of the Latah Formation and the Palouse Formation.

Fieldwork in this area began in June 1961 and continued during the summer months of 1961 through 1963. In 1961 all clay outcrops and

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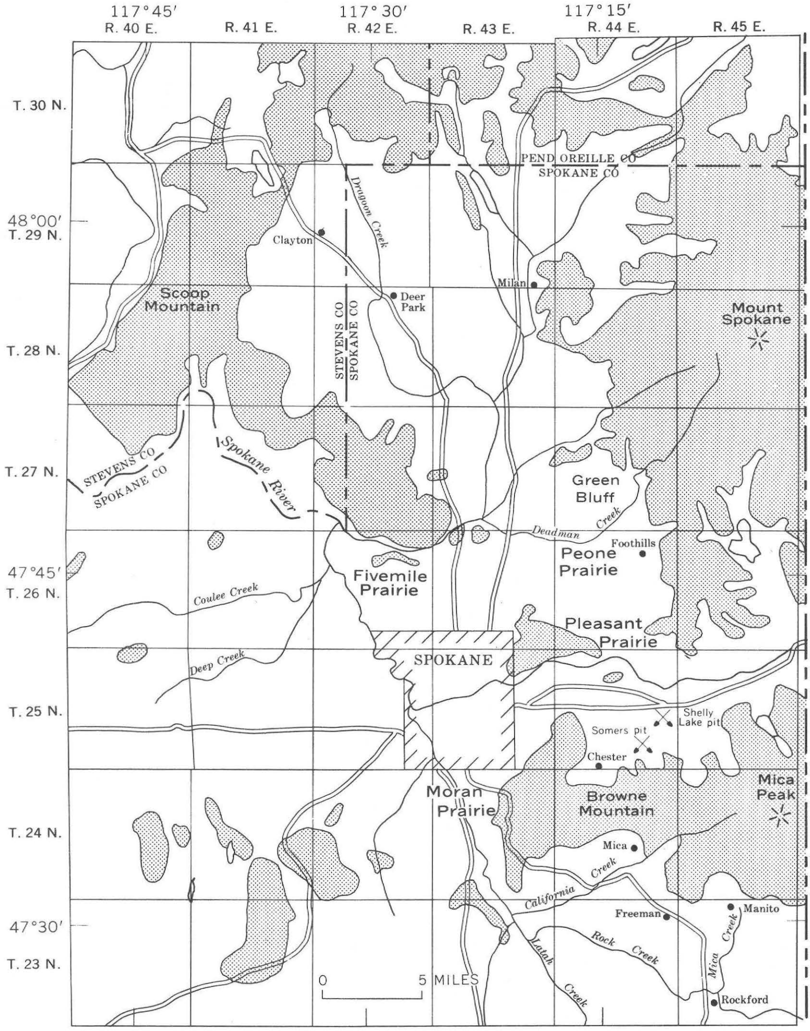

FIGURE 1.—Spokane County and vicinity, Washington. Patterned areas indicate pre-Tertiary rocks. (Geology modified from Huntting and others, 1961.)

pits were sampled in detail. In 1962 and 1963, 206 auger holes were drilled; the total footage was 9,005 feet, an average of about 44 feet per hole. Of the 206 auger holes, 145 were drilled south of the Spokane River in the Mica-Manito area and 61 were drilled north of the river. Logs of all these holes are given on pages 64–90. In addition, 128 auger holes were drilled in the Excelsior-Mica area in 1942 by the U.S. Bureau of Mines; the total footage of these holes was 4,039 feet, an average of about 30 feet per hole. The logs of these holes are given in a report by Hosterman, Scheid, Allen, and Sohn (1960, p. 40–63).

The author acknowledges the help of Thomas Hahn and Dennis Caffrey, who assisted with the auger drilling during the summer of 1962, and of Robert Helming, who assisted with the drilling during the summer of 1963. Diosdado C. Encina, of the Philippines, spent the summer of 1962 with the project as a participant of a training program sponsored by the International Cooperation Administration. The 16 chemical analyses, on which the analyses of X-ray fluorescence are based, were done under the supervision of Leonard Shapiro of the U.S. Geological Survey. The fossil diatoms were identified by K. E. Lohman of the U.S. Geological Survey. The ceramic tests were made at the U.S. Bureau of Mines Electrochemical Experiment Station, Norris, Tenn., under the supervision of the late Howard P. Hamlin and of M. V. Denny. The author gratefully acknowledges the cooperation received from E. C. Stephens, geologist of the Anaconda Co., Ralph I. Clark, geologist of the International Pipe and Ceramics Co., and Ralph A. Watson, geologist of the Great Northern Railway Co.

METHODS OF INVESTIGATION

Auger-drilling equipment was used to sample the clay deposits beneath an overburden of Palouse Formation; data obtained in the sampling program were used to map the clay deposits. The drilling equipment consisted of an auger powered by a four-cylinder engine on a pickup truck. The engine supplied the rotation of the auger through the power takeoff and the force to raise or lower the auger by means of a hydraulic system.

Two methods of sampling the clay with the auger were employed. One method, which produced a disturbed sample, was to drill 5-foot intervals at a time and pull the auger from the hole after each interval. This was repeated until the desired depth of sampling was reached. When the auger was pulled from the hole after each 5-foot interval, the sample was taken from between the whorls of the leading auger flights. A 5-foot interval filled almost two auger flights with sample. Contamination from the walls of the auger hole was easily cut away from the outside of the sample. The second method, which produced an undisturbed sample, was to use a double-tube sampler instead of a bit. The outside of the double-tube sampler consists of an auger, and the inside has a 2-foot-long core barrel 2 inches in diameter. The drilling was done in 2- to 2.5-foot intervals, and the auger was pulled from the hole after each interval. Samples taken from the core barrel were slightly compressed, but they had the textural features of the clay that were lost in the disturbed samples obtained by the other method.

All samples collected were placed in a double thickness of polyethylene bags to prevent moisture loss. Samples taken from the face of the clay pits and from the double-tube sampler were coated with a solution of saran resin dissolved in acetone before being placed in polyethylene bags. The saran resin held in the moisture and also held the sample together so that it could be sawed into cubes for thin sections.

The samples were sent to the laboratory for determination of the mineralogy, chemical composition, and ceramic properties of the clay. The mineral- and chemical-composition studies were made by the author; the ceramic-property studies were made in cooperation with members of the U.S. Bureau of Mines clay testing laboratory formerly at Norris, Tenn. The laboratory procedures used in determining the ceramic properties are given on pages 55–62: the laboratory procedures used in determining the mineral and chemical compositions are described here.

Two splits were made from the original moist sample. One small split was dried at 40°C to be analyzed for chemical composition by X-ray fluorescence. The second split, about 200 grams, was accurately weighed and this weight corrected for moisture content. The split was then dispersed in deionized water, and separated into sand, silt, and clay fractions of the Wentworth scale (Wentworth, 1922). The ratios of clay, silt, and sand were calculated on the basis of dry weight percentage. The description of all the sedimentary samples in this report is based on the weight percentage determined using a system modified from Shepard (1954, p. 157) (fig. 2).

Part of the clay fraction was made into an oriented aggregate using the porous-tile method described by Kinter and Diamond (1956, p. 111–120). This aggregate was exposed to low-intensity copper radiation using a 1.0° beam slit, a fine soller slit, a 0.1° detection slit, and a proportional counter. The clay minerals were identified by the X-ray diffraction traces as discussed on pages 28–35, and their proportions were estimated using the method described by Schultz (1960, 1964).

A rapid, X-ray fluorescence method was used to determine the oxides of some elements. This method permits determination of Fe_2O_3, MnO, TiO_2, CaO, K_2O, SiO_2, and Al_2O_3. MgO and Na_2O cannot be determined with accuracy by this method.

The small split of the whole sample, ground to pass through a 325-mesh screen in a tungsten-carbide mixer-grinder, was pressed into a circular pellet 1 inch in diameter in a hydraulic press at a uniform pressure of 10,000 pounds per square inch for a minimum time of 30 seconds. A layer of powdered boric acid (H_3BO_3) was placed beneath the sample in the mold to provide strength to the pellet.

The following table gives the angle, in degrees, for the $K\alpha_1$ radiation peak and the degrees (2θ) where the background reading was made. According to Zingaro (1958), the background is negligible if the

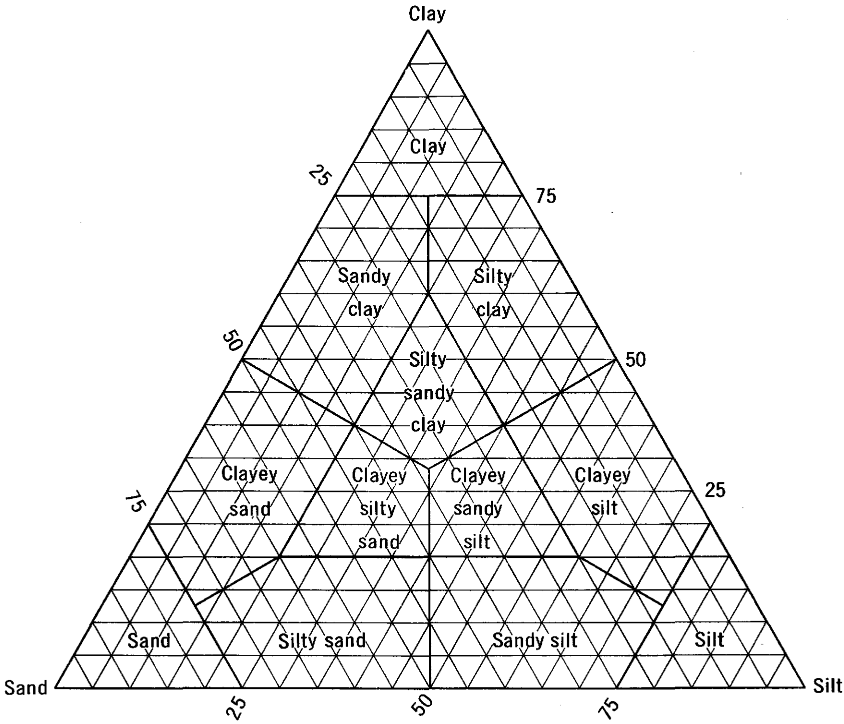

FIGURE 2.—System of sediment nomenclature used in this report. (Modified from Shepard, 1954, p. 157.)

intensity of the peak-to-background ratio is greater than 20:1. Calibration curves are constructed for each element using chemically analyzed samples as standards that have mineral and chemical compositions similar to those of the samples being investigated. The weight percentages of the component elements are expressed in terms of amount of oxides.

Primary X-ray target	Element	$K\alpha_1$ wavelength (A)	Element peak, (degrees 2θ)	Crystal	Element background (degrees 2θ)
Pt	Iron	1.93729	57.52	LiF	61.52
Pt	Manganese	2.10175	62.93	LiF	65.93
Pt	Titanium	2.74841	86.09	LiF	92.09
Pt	Calcium	3.35825	113.02	LiF	108.02
Pt	Potassium	3.74122	136.59	LiF	140.59
Cr	Silicon	7.12528	108.08	EDT	104.08
		----------	108.57	PET	104.57
Cr	Aluminum	8.33669	142.53	EDT	131.53
		----------	143.66	PET	131.46

The method of X-ray fluorescence for determining the chemical composition of a sample is not as accurate as the wet-chemical method owing to variations in sample preparations. However, the weight percentage determined by this method was found to be within 10 percent of the amount of oxide present; this means that if a sample was found to contain 30 percent Al_2O_3, it was accurate to within 3± percent. Rose and others (1962, 1964) have described more complicated sample-preparation procedures that give more accurate results.

GEOLOGIC HISTORY OF THE REGION

The geologic history of eastern Washington is largely conjectural because rocks representing most of geologic time are missing. The oldest rocks of the region are the argillaceous and arenaceous sedimentary rocks that have been slightly metamorphosed. Most of these rocks are correlated with the Belt Series of Precambrian age, but some may possibly be older. In Late Jurassic or Cretaceous time, these rocks were intruded by granodiorite and related rocks that are considered to be part of the Idaho batholith. Eastern Spokane County is in the fringe area of the Idaho batholith, where the regional relationships between these intrusive rocks and the Precambrian rocks are very complex.

Beginning in Miocene time, the lavas of the Columbia River Basalt were extruded as many separate flows over a vast area. These flows dammed the drainage system, and lakes formed in which the Latah Formation was deposited (Kirkham and Johnson, 1929, p. 500). The Latah Formation, therefore, is interbedded and contemporaneous with the Columbia River Basalt. In some areas, the sand, silt, and clay that now form the Latah Formation were deposited in shallow quiet lakes dammed by the basalt. Leaves, along with diatoms and sponge spicules indicative of quiet waters, are abundant in some of these deposits. In other areas, the material that now forms the Latah Formation was swept into the lake by landslides or as the result of mass-wasting. Evidence of this is the coarseness and angularity of the material in the formation, the presence of feldspar which is now kaolinized, and the absence of leaves, sponge spicules, and diatoms.

Sometime during the Tertiary period, chemical weathering caused the development of saprolite or residual clay from basalt and pre-Tertiary rocks. Exactly when the warm humid climate favorable for chemical weathering began is unknown, but it started prior to the first basalt flows inasmuch as pre-Tertiary rock saprolite is found beneath the Latah Formation and older basalt flows. The weathering apparently continued without interruption through Miocene and Pliocene time. The flora found in the Latah Formation in the Spokane River valley indicates a temperate climate with an annual rainfall between 30 and 40 inches. These conditions permitted deep weathering of the exposed rocks on a land surface that had low relief to the west and south and moderate to considerable relief to the north and east. In the center of the Columbia Plateau, the area of frequent lava eruptions, there is little or no basalt saprolite because the time between successive flows was short and individual basalt flows were not deeply weathered. In eastern Washington and northern Idaho, where the lava eruptions were less frequent, at least one long period of time occurred between two basalt flows. Scheid (1947) called the saprolite that developed from basalt during this interval the Excelsior weathering surface, and upon the basis of it divided the Columbia River Basalt into two units.

Lakes formed when basalt flows dammed rivers and streams. Ultimately, these lakes were filled with sediment derived from the weathered pre-Tertiary metamorphic and igneous rocks and with an occasional bed of pillow lava. After the lake basins bacame completely filled with the sediments that are now the Latah Formation, the drainage system was reestablished and dissection continued. Weathering processes then affected the exposed sedimentary rocks and pillow lavas of the Latah Formation as well as basalt, granodiorite, and other rocks; saprolite of sedimentary rocks developed in the Latah. Later, as chemical weathering decreased, erosion continued, and fresh basalt lava was extruded into some of the valleys. Thus, younger, unweathered basalt commonly lies at lower elevations than older, weathered basalt.

During late Pliocene time, diastrophism resulted in the downwarp of the central part of the Columbia Plateau and the uplift of the Cascade Mountains. As a result, the climate in eastern Washington and northern Idaho changed from warm and wet to cool and dry. The drainage system developed to essentially its present form.

During Pleistocene time, eolian material of the Palouse Formation was deposited. The source of the eolian material is unknown, but it is postulated that winds from the north and northeast carried in fine material from uncovered glacial tills, and winds from the west and southwest introduced volcanic dust from the Cascade Mountains. Most of the eolian material was deposited on dry land; however, some of it was deposited in lakes that were left in the wake of the retreating glaciers.

GEOLOGY OF CLAY-BEARING UNITS

All of the rock units exposed in Spokane County contain clay deposits. The pre-Tertiary igneous and metamorphic rocks and the Columbia River Basalt contain deposits of clay in saprolite. The Latah Formation (Miocene) and the Palouse Formation (Pleistocene) contain transported clay as bedded deposits.

The pre-Tertiary rock saprolite is composed of 10–35 percent white kaolinite and 65–90 percent quartz and muscovite. Therefore, beneficiation is required before the clay can be used as a filler, as an ore of aluminum, or as a raw material for ceramic products. Quartz and muscovite are possible byproducts. The bluish-gray basalt saprolite contains 80–95 percent clay, which is halloysite, and 5–20 percent ilmenite and limonite. Basalt saprolite is a potential ore of aluminum with a byproduct of titanium.

The amount of clay found in beds of the Latah Formation ranges from 5 to 95 percent. The color is usually light yellowish white, but various shades of red and brown are common. Clay from the Latah Formation is being used to make refractory brick, building brick, and face brick.

The Palouse Formation loess is composed of moderate-brown silty clay and clayey silt. A small amount of this material is used to make red face brick. The light-gray clayey silt of the Palouse Formation glacial-lake beds has not been used for making brick, but a few truck loads have been used locally to make artware.

PRE-TERTIARY ROCKS

ORIGIN AND DISTRIBUTION

Igneous and metamorphic rocks older than the Columbia River Basalt are found throughout the area as hills that protrude above the relatively flat Columbia Plateau. The metamorphic rocks are intruded complexly by igneous rocks. On Mica Peak and Browne Mountain, metamorphic rocks are more abundant than igneous rocks; on Mount Spokane there are about equal amounts of each; and on Scoop Mountain, igneous rocks are more abundant (fig. 1).

Most of the metamorphic rocks are probably part of the Belt Series (Precambrian), but some almost certainly are older. These are all metasedimentary rocks which now consist mostly of argillite, quartzite, gneiss, and schist. Argillite is found near Fairfield, Whitman County (sec. 30, T. 22 N., R. 45 E.); and quartzite crops out on Browne Mountain, Spokane County (fig. 1), and on Kamiah and Steptoe Buttes about 40 miles south of Spokane in Whitman County. Quartzite, intruded by granodiorite, is exposed in the Freeman clay pit; and mica schist is exposed near the summit of Mica Peak. Quartzose gneiss, biotite gneiss, sillimanite gneiss, and tremolite gneiss crop out in the foothills of Mica Peak and Browne Mountain.

The intrusive igneous rocks in Spokane County are related to the Idaho batholith, which is considered to be Lake Jurassic or Cretaceous. They represent a border phase of the batholith that intruded the older metamorphic rocks. The most abundant rock types noted are granodiorite and quartz monzonite. Other igneous bodies such as granite, tonalite, diabase, and syenite are also associated with the border phase of the Idaho batholith. The typical igneous rock is light gray, medium grained, and granular, but locally the rock becomes aplitic or pegmatitic. The main constituents of all the intrusive igneous rocks, except the syenite, are quartz, orthoclase, plagioclase, muscovite, and biotite.

PRE-TERTIARY ROCK SAPROLITE

Saprolite containing 10–35 percent clay has formed from the pre-Tertiary metamorphic and igneous rocks. The textural and structural features of the original rock are retained in the saprolite. Figure 3 shows an example of such preservation in an igneous body of granitic composition and aplitic to pegmatitic texture that has intruded a bedded quartzitic metasedimentary rock.

Irregularities in the depth and lateral extent of the saprolite depend upon the nature of the parent rock, local structures, texture, permeability, and erosion prior to, contemporaneous with, and subsequent to the time of weathering. Variable depth of pre-Tertiary rock saprolite due to local structures, permeability, and erosion is evident near drill hole 72, where the saprolite gneiss is more than 75 feet thick, yet, 2,000 feet away fresh gneiss is exposed at the surface. The saprolites at low elevations were preserved from erosion and now make up the present deposits of residual clay. The saprolite formed at higher elevations was eroded and now constitutes the transported clay deposits of the Latah Formation.

The deepest saprolite known in eastern Washington and northern Idaho is at the Benson pit, Latah County, Idaho, where a drill hole penetrated 100 feet without striking hard rock (Wilson and Goodspeed, 1934, p. 8). At this pit the saprolite is overlain by basalt and was, therefore, protected from erosion. The granodiorite in this area is uniform in composition and texture; so the gradational differences in the clay mineralogy with depth (Hosterman, 1960, p. 290) are attributed to permeability. No such gradational differences in the clay mineralogy with depth that are due solely to variable permeability were observed in the pre-Tertiary rock saprolite of Spokane County, because the igneous and metamorphic rocks are not uniform in composition and texture.

The development of saprolite from pre-Tertiary igneous and metamorphic rocks is the result of katamorphic alteration. In katamorphic alteration each type of primary mineral breaks down differently under varying conditions of weathering or at different times under the same general weathering conditions. The ferromagnesium minerals, other than biotite, are usually the first to be altered. An example of this sequence can be seen in an old railroad cut near Sharon, Wash. Here a diabase body containing tremolite is in the first stages of weather-

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FIGURE 3.—Structure and texture of pre-Tertiary igneous rock intruding quartzitic metasedimentary rock preserved in saprolite at the Freeman clay pit. The metasedimentary rock contains medium- to fine-grained rounded to subrounded quartz sand. The granitic rock contains angular coarse-grained quartz. Kaolinite, K, has replaced original feldspars; quartz, Q; muscovite, M.

ing. Quartz, feldspar, and biotite are nearly unaltered, but tremolite is being altered to montmorillonite. The ferromagnesian minerals usually alter to montmorillonite, mainly because the leaching processes are not strong enough or have not been active long enough to remove the iron and magnesium ions. Biotite not only is slower to alter than the other ferromagnesium minerals (amphiboles and pyroxenes), but it usually converts to muscovite as an intermediate phase before altering to a clay mineral. Evidence of biotite altering to muscovite in a granodiorite body can be seen in the lower part of the clay pit at Benson, Latah County, Idaho.

The feldspar group minerals usually follow the ferromagnesium minerals in the katamorphic alteration sequence during chemical weathering. It is believed that the plagioclase alters completely to kaolinite before the potassic feldspar alters, because only orthoclase and microcline have been identified in samples of saprolite developed from pre-Tertiary rocks. An excellent example of kaolinization of feldspars in katamorphic alteration can be seen in the clay pit at Freeman where saprolite of both pre-Tertiary igneous and metamorphic rocks is exposed (fig. 3). The quartz and muscovite remain unaltered.

A more advanced stage of katamorphic alteration was recognized in one sample of saprolite collected from immediately below the overburden on the high wall of the Freeman clay pit. In this sample, the feldspars and muscovite are completely kaolinized, and alteration has left only quartz (fig. 4).

Most accessory minerals (table 7) found in the saprolite of the pre-Tertiary igneous and metamorphic rocks remain unaltered in all stages of katamorphic alteration. However, some ilmenite and magnetite have altered to limonite.

Table 1 is a summary of the chemical compositions of 21 composite and single samples representing about 500 feet of pre-Tertiary rock saprolite. The average total alumina content is 20 percent, which agrees closely with the information published by Tullis and Laney (1933, p. 493) and by Hodge (1938b, p. 573). If the clay was beneficiated, the alumina content could be raised almost to the theoretical maximum of 39.5 percent (Wilson and Goodspeed, 1934, p. 39). The average iron oxide content is low (4.6 percent); sample 77E, which has almost 13 percent, is anomalous, perhaps because iron leached by groundwater from the overlying 70 feet of high-iron basalt saprolite has been added. The high calcium oxide content of the composite sample from the railroad cut at Sharon comes from the mineral tremolite, which is in the partly weathered diabase. The loss on ignition at 1,000° C varies according to the percentage of nonclay minerals; in general, the loss on ignition for pre-Tertiary rock saprolite is low because of the high content of nonclay minerals especially quartz.

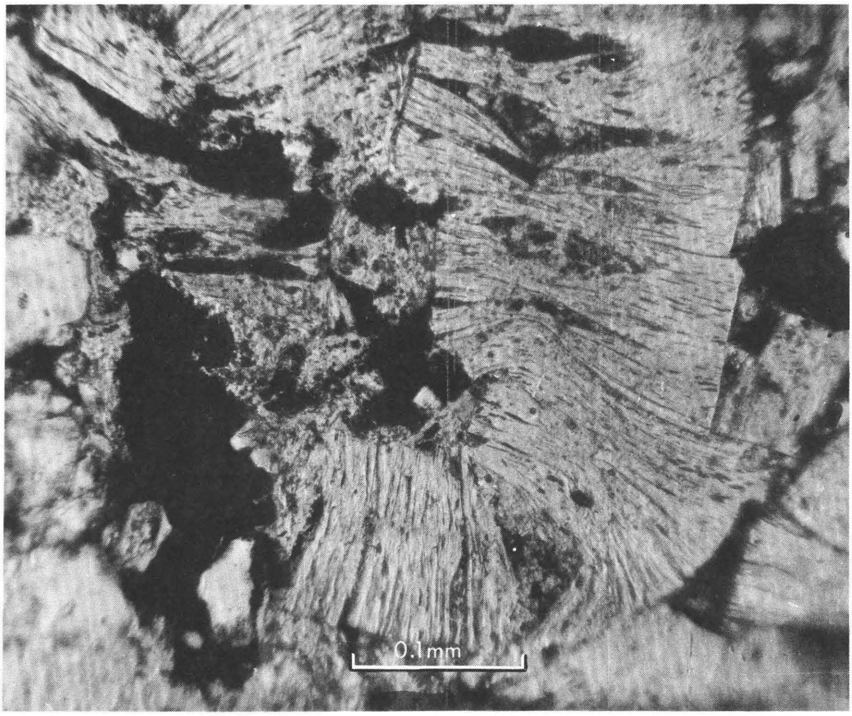

FIGURE 4.—Photomicrograph of vermicular crystals of kaolinite pseudomorphic after muscovite in pre-Tertiary granodiorite saprolite from the Freeman clay pit. Crossed polarizers.

TABLE 1.—*Chemical composition of pre-Tertiary rock saprolite*

[Analyses by X-ray fluorescence method; results in weight percent]

Sample No.,[1] or location	Sample length (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition
13L	12.0	67	21	2.4	0.07	0.2	3.4	0.5	3.4
32A	22.0	65	22	3.9	.04	.4	1.8	.5	5.9
45A–F	73.0	62	22	4.8	.07	.2	3.1	.6	5.7
61A	4.0	70	20	1.1	.11	.6	3.7	.1	2.6
66A,B	24.0	67	19	3.4	.04	.9	2.9	.6	3.9
72A–E	75.0	63	22	3.9	.09	.2	3.5	.5	6.2
74A	20.0	70	21	.9	.07	.2	5.0	.1	2.3
77E	20.0	48	23	12.7	.04	.4	.2	2.0	9.1
105A	15.0	73	17	1.6	.04	1.5	3.0	.2	1.5
112A	12.0	69	17	2.5	.04	.6	4.4	.4	2.4
123A, B	14.0	63	17	5.0	.08	1.0	1.4	.8	6.1
124A	20.0	61	19	4.4	.06	.3	4.2	.8	3.3
128A, B	35.0	58	18	6.6	.10	.6	3.5	.9	4.7
130A	18.0	54	20	9.2	.22	.2	1.0	1.3	7.6
136C	12.0	56	19	7.5	.12	.4	2.6	1.6	6.5
139D	10.0	54	29	1.7	.02	.2	.9	1.1	9.2
147A, B	13.0	52	25	2.6	.02	.3	1.7	1.1	10.1
161A	32.0	57	23	3.4	.01	.2	.8	.6	6.7
Freeman clay pit (A–H)	20.4	68	22	.9	.19	.1	.7	.5	7.3
North clay pit (R)	5.0	66	20	.4	.01	.3	3.5	.6	11.1
Railroad cut at Sharon	44.0	58	15	6.5	.12	5.4	3.1	.9	4.5
Total and averages	500.4	62	20	4.6	.09	.8	2.8	.7	5.5

[1] See auger-hole logs pages 64–90.

COLUMBIA RIVER BASALT (TERTIARY)

Russell (1893, p. 20–22) introduced the term "Columbia lava" to include all lava flows from Eocene to Pleistocene in age in Washington, Idaho, Oregon, and northern California. Merriam (1901) redefined and renamed part of these lava flows the "Columbia River basalt." Subsequent papers have followed this redefinition. The U.S. Geological Survey recognizes the name "Columbia River Basalt" in the Spokane area, where this basalt cannot be divided into formations of the Columbia River Group, as a convenient term including basalt flows of Miocene and possibly Pliocene age.

ORIGIN, DISTRIBUTION, AND LITHOLOGY

According to Waters (1955, p. 707–708), the basalt flows cover an area of about 100,000 square miles in Washington, northern Idaho, and northern Oregon, and have a total volume on the order of 35,000 cubic miles. The thickness of the basalt ranges from several feet at the flanks of steptoes and embayments along the eastern margin of the Columbia Plateau to more than a mile near the center of the plateau, where subsidence was the greatest (Baldwin, 1950, p. 60). Some individual flows averaging more than 100 feet in thickness over large areas indicate that the lava must have erupted quickly and spread very rapidly. Thin soil zones between some flows indicate that there were long periods of time between some eruptions. One source of lave is indicated by a great swarm of dikes located in the Wallowa–Grande Ronde area. These dikes are 10–50 feet thick and can be traced for 5 miles or more. Other probable feeder dikes are found in the Wenatchee Mountains (Chappell, 1936) and in the Teanaway district (Smith, 1904). According to Waters (1955, p. 708), basalt dikes and plugs outside of these areas are rare throughout most of the plateau.

Most flows of the Columbia River Basalt are massive and thick, the maximum thickness being about 200 feet (Hodge, 1938a, p. 848). A scoriaceous zone clearly marks the top of each flow, and vesicular basalt may be found at both the top and the bottom of a flow. Where the basalt is semidecomposed or underlies basalt saprolite, many vesicles are filled with nontronite and halloysite.

The Columbia River Basalt is black or dark gray, dense, and aphanitic. Microscopically the rock has ophitic, intersertal, or diabasic textures. X-ray diffraction traces of the magnetic and nonmagnetic fractions of several samples show that it is composed predominantly of labradorite, augite, and ilmenite. In addition, it contains a considerable amount of glass, not detectable by X-ray diffraction, and abundant slender rods of apatite. Studies made by Waters (1955, p. 708) showed that there is no difference in mineral composition between flows at the bottom and top of many 3,000-foot sections. Peacock and Fuller (1928, p. 361) described two types of basaltic glass: tachylyte, found as a matrix in the massive lava flows and, therefore, more abundant, is dark colored, is high in ferric iron, and is a product of slow cooling; and sideromelane, associated with pillow lavas and usually altered to palagonite, a yellow, tuffaceous-appearing hydrated mineraloid (Fuller, 1950, p. 67), is pale colored, is low in ferric iron, and is a product of rapid cooling in water. Sideromelane in pillow lavas can be found in a roadcut on Palouse Highway near Valleyford and in Deep Creek northwest of Spokane. In the Spokane area, some of the basalt flows are considered to have advanced into a succession of shallow lakes formed by previous flows damming the drainage system.

Chemical analyses of Columbia River Basalt are given in table 2. Relative to the average of 13 samples (1) published by Waters (1955, p. 705), samples 2 and 3, unweathered basalt from Spokane County, are higher in iron oxides, and sample 2 is slightly lower in SiO_2. In all other respects the analyses are in close agreement. Samples 4 and 5 are given to show the decrease in SiO_2 and iron oxides and the increase in Al_2O_3 and TiO_2 as the basalt undergoes katamorphic alteration during chemical weathering.

TABLE 2.—*Chemical comparison of unweathered Columbia River Basalt with saprolite derived from basalt*

[In weight percent]

	Unweathered			Partly decomposed	Saprolite
	1	2	3	4	5
SiO_2	52.31	48.5	52	46.6	38.2
Al_2O_3	14.38	13.0	15	20.6	30.4
Fe_2O_3	2.47	8.8	19 [1]	4.8	2.8
FeO	9.95	7.3	--------	3.5	3.3
MnO	.21	.29	.3	.07	.06
TiO_2	2.10	3.3	3.7	5.8	8.7
CaO	8.37	8.4	8.8	6.7	.83
K_2O	1.26	1.0	1.7	.44	.09
P_2O_5	.36	.82	--------	1.2	.66
MgO	4.46	2.6	--------	.28	.25
Na_2O	2.94	2.6	--------	3.5	.18
H_2O+	.74	2.4	--------	3.4	11.7
H_2O-	.39	1.2	--------	1.8	2.4
Total	100	100.2	100.5	98.7	100

[1] Total Fe is expressed as Fe_2O_3.

1. Average of 13 samples of Columbia River Basalt (Waters, 1955, p. 705).
2. One sample of Columbia River Basalt from sec. 3, T. 27 N., R. 44 E., Spokane County, Wash. Analysis by rapid-rock method; Paul Elmore, Samuel Botts, and Gillison Chloe, analysts, U.S. Geological Survey.
3. One sample of Columbia River Basalt from an outcrop on the road at Mica Creek, sec. 4, T. 23 N., R. 45 E., Spokane County, Wash. Analysis by X-ray fluorescence.
4. One sample of partly decomposed Columbia River Basalt from sec. 3, T. 23 N., R. 45 E., Spokane County, Wash. Analysts same as for 2.
5. Average of six samples of residual clay derived from Columbia River Basalt from sec. 23, T. 24 N., R. 44 E., and sec. 3, T. 23 N., R. 45 E. Analysts same as for 2.

BASALT SAPROLITE

The saprolite formed from the Columbia River Basalt is composed of 80–95 percent halloysite and 5–20 percent ilmenite and limonite. The basalt texture is preserved and is even accented by the uniformly disseminated grains of blue-black ilmenite against the white clay. Figure 5 shows this texture in vesicular basalt.

The katamorphic alteration of the Columbia River Basalt appears to have been controlled largely by ground-water movement. Most of the flows are vesicular and are cut by numerous vertical joints. It seems likely that surface water entered these joints but could not move freely until the basalt began to alter. Under the conditions of poor ground-water movement and poor drainage, the oxidation-reduction reactions probably proceeded at a slow rate, and the alkalies were not removed. The basaltic glass first altered to palagonite; subsequently, the palagonite and augite altered to nontronite which formed in vesicles and cracks (fig. 5). The formation of nontronite increases the permeability by removing some of the SiO_2, Al_2O_3, and Fe_2O_3 from the basalt surrounding the vesicles and cracks. Under these new conditions, ground water moved freely, oxidation took place, alkalies were removed easily, and plagioclase (labradorite) altered to halloysite (fig. 6). As more of the basalt became exposed to

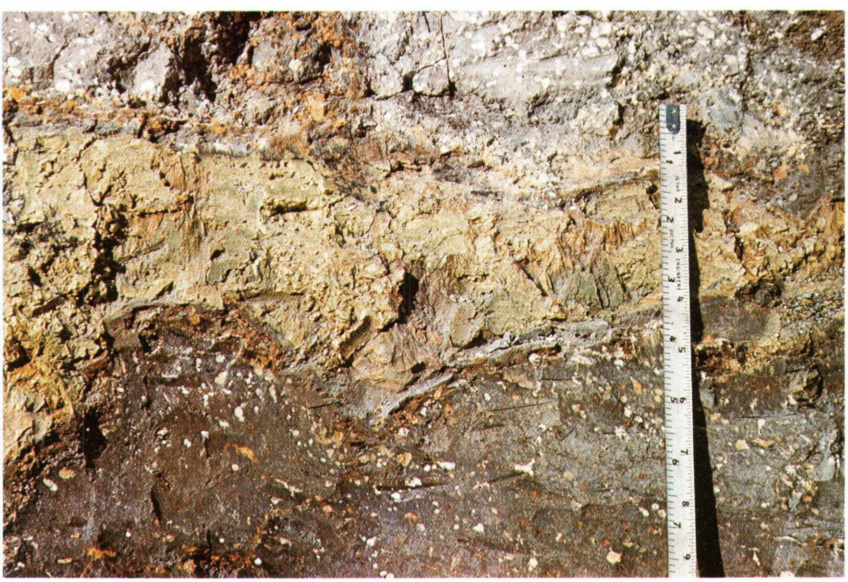

FIGURE 5.—Columbia River Basalt saprolite. White spots are halloysite filling vesicles; greenish-yellow mass is nontronite filling a crack in the basalt. The gray color at the top and the grayish-brown color at the bottom of the photograph are caused by disseminated ilmenite in the basalt saprolite.

FIGURE 6.—Photomicrograph of halloysite pseudomorph after plagioclase in basalt saprolite. Crossed polarizers.

the oxidation process the early formed nontronite was replaced by halloysite.

Evidence for this procedure in katamorphic alteration is provided by the relationships in figure 5, which shows the greenish-yellow nontronite being replaced by white halloysite in the vesicles. The more massive nontronite in the cracks, however, does not show any evidence of being replaced by halloysite. Ilmenite, a very stable mineral does not alter easily except where oxidation is intense over a long period of time; then brown and yellow halos of limonite form around the ilmenite. The gray color of most of the basalt saprolite in figure 5 is due disseminated grains of limenite.

Five gradational zones can be recognized in a typical section of basalt saprolite (Hosterman 1960 p. 12–14). These five zones can be seen in the outcrop of basalt saprolite on the main road at Mica Creek (SW¼SW¼SW¼ sec. 3, T. 23 N., R. 45 E.). Figure 7 shows the variations in content of SiO_2 Al_2O_3, Fe_2O_3, TiO_2, and CaO of the five zones. The upper zone of basalt saprolite is pale brown (2*Y* 6/2)[1]

[1] Color designations from 1954 edition of "Munsell Soil Color Charts," published by Munsell Color Co., Inc., Baltimore, Md.

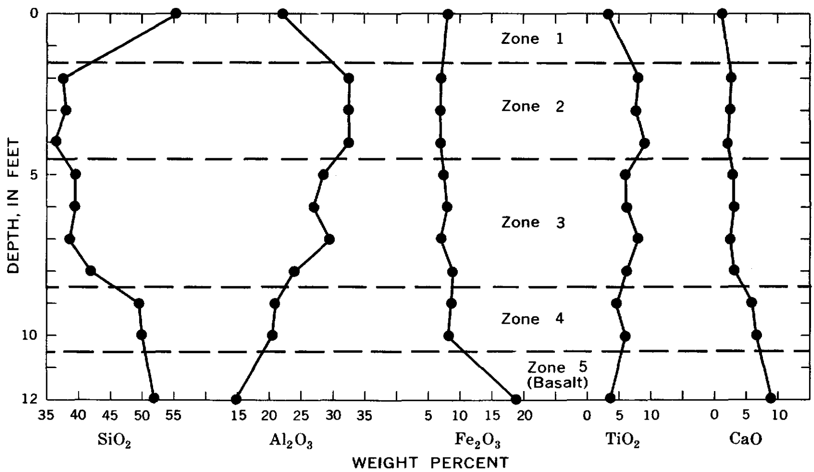

FIGURE 7.—Relationship of chemical variation to depth in basalt saprolite from roadcut at Mica Creek, SW¼SW¼SW¼ sec. 3, T. 23 N., R. 45 E.

and is composed of halloysite and ilmenite; some of the ilmenite is altered to limonite. The cracks are filled with grains of quartz and muscovite that have been transported from the overlying Latah Formation through ground-water movement. This results in the SiO_2 content of the upper zone being high and the Al_2O_3 content being low (fig. 7). The second zone is also composed of halloysite and ilmenite, but since little or no limonite is present, the color is light bluish gray (5*B* 8/1) to light gray (*N*7). All vesicles and cracks are filled with white halloysite. This zone has the lowest SiO_2 content and the highest Al_2O_3 and TiO_2 content (fig. 7). The third zone is weak yellow (5*Y* 7/2) from the small amount of nontronite present. Halloysite and ilmenite are the main constitutents, and with halloysite fills most of the vesicles. The SiO_2 content is a little higher than zone 2, and the Al_2O_3 and TiO_2 contents are a little lower than zone 2 (fig. 7). Zone 4 is pale olive (5*Y* 5/2) to light olive gray (5*Y* 6/1) because of the greater amount of nontronite. Other minerals present are halloysite and ilmenite, with nontronite filling the cracks and vesicles. A few laths of plagioclase are present, but most of them are altered to halloysite. The fifth zone is light gray (*N*7) basalt that is virtually unaltered. This zone is considerably higher in Fe_2O_3 than any of the other zones (fig. 7). The contact with the overlying clay is surprisingly sharp, and the chemical composition is much different.

Table 3 is a summary of the chemical compositions of 19 single and composite samples representing about 435 feet of basalt saprolite. The average total Al_2O_3 content is 22 percent, which is slightly higher than for the saprolite of igneous and metamorphic rocks. The alumina content ranges from about 14 percent in partly weathered basalt to 37 percent in the most weathered basalt saprolite. The Fe_2O_3 content averages 14 percent, and, in general, the iron oxide content varies inversely with the amount of alumina present. Most of the iron oxide is in nontronite, and consequently the samples high in iron oxide contain more of this clay mineral and smaller amounts of halloysite, the alumina-rich clay mineral. The TiO_2, averaging 6 percent, is in ilmenite, a resistant mineral which does not alter easily. The loss on ignition at 1,000° C is considerably higher for basalt saprolite, than for pre-Tertiary rock saprolite. This is due to the high content of halloysite, which contains four molecules of water, and to the absence of quartz. In general, the loss on ignition varies directly with the amount of Al_2O_3 present, which, in turn, reflects the amount of halloysite in the sample.

TABLE 3.—*Chemical composition of Columbia River Basalt saprolite*

[Analyses by X-ray fluorescence method; results in weight percent, Tr., trace]

Sample No.,[1] or location	Sample Length (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition
10A–D	18.0	39	18	19	0.25	1.7	0.1	6.5	12.4
13B–K	68.0	37	27	9	.07	.6	.2	9.7	12.8
33A	13.0	49	16	19	.29	3.0	.5	3.0	8.0
42A	17.0	40	17	24	.12	1.2	.1	5.4	11.4
77A–D	70.0	39	19	21	.20	1.2	.2	6.2	11.2
107A	41.0	38	20	23	.32	.8	.1	5.9	13.0
114A	17.0	45	14	21	.80	3.6	.6	5.0	7.2
116A	12.0	48	36	1.7	.07	.3	.3	3.2	11.8
121A	17.0	48	28	3.5	.02	.4	.9	1.6	11.9
129A and B	21.0	67	17	2.7	.02	.4	.5	.8	12.8
131C–G	28.0	39	24	12	.07	1.5	.2	7.0	10.8
136B	25.0	44	17	22	.31	.8	.5	4.8	10.8
139C	4.0	46	38	0.4	.01	.2	.2	1.7	14.6
143B and C	34.0	48	20	12	.11	.4	.8	5.3	7.9
177B and C	5.0	44	26	7.2	.09	3.5	.3	7.6	10.8
178B	7.0	50	26	2.7	.04	.3	1.1	6.2	10.2
Railroad siding at Mica (A–H)	17.8	40	27	7.8	.07	.5	.1	9.1	13.9
Roadcut at Mica Creek (A–K)	12.0	43	28	7.4	.20	.6	Tr.	4.2	13.1
Excelsior clay pit (L and R)	8.8	37	24	15	.20	.6	Tr.	4.2	13.1
Total and averages	435.6	42	22	14	.18	1.0	.3	6.0	11.5

[1] See auger-hole logs, pages 64–90.

LATAH FORMATION (MIOCENE)

The Latah Formation consists chiefly of clay and shale and some beds of sand and gravel. The name was originally proposed by Pardee and Bryan (1926, p. 1) for a series of beds of fresh-water origin occurring near Spokane, Wash., which contain an abundant lower and middle Miocene flora. Although the formation was originally defined as one deposited before the extrusion of Columbia River Basalt (Pardee and Bryan, 1926, p. 7), Kirkham and Johnson (1929, p. 499) defined the formation as sedimentary material interbedded with basalt flows. In the Spokane River valley, the Latah Formation lies unconformably on basalt and prebasalt granitic and gneissic rocks. Seismic profiles across the Spokane River valley indicate that the formation is more than 500 feet thick in places (Newcomb and others, 1953); Pardee and Bryan (1926, p. 8) stated that the Latah Formation is as much as 1,400–1,500 feet thick. In the area south of Mica Peak, beds of the Latah Formation are interbedded with the basalt flows and are less than 100 feet thick.

LITHOLOGY

The vertical range of the Latah Formation from the Spokane River valley to the town of Mica is approximately 900 feet. The lowest exposure occurs near the mouth of Deep Creek in sec. 7, T. 26 N., R. 42 E. (fig. 1), at about 1,650 feet. The highest occurs near the top of the basalt flows in the area of the Excelsior clay pit, sec. 21, T. 24 N., R. 44 E., 2 miles west of Mica (pl. 1), at about 2,550 feet.

Pardee and Bryan (1926, p. 5) reported the section at Deep Creek to be composed of 35 feet of gray shale overlain by 15 feet of reddish-brown sand. The shale contains abundant plant fossils which have been described in detail by Knowlton (1926) and Berry (1929). The base of the section is not exposed and basalt occurs at the top.

Another excellent exposure of Latah, at an elevation of about 2,080 feet, is at the Somers clay pit at 35th and Adams Streets in sec. 35, T. 25 N., R. 44 E. (fig. 1). Here the Latah Formation is composed of varicolored clay, silty clay, and sand (table 14) and contains a few plant fossils. Neither the bottom nor the top of the section is exposed, but Pardee and Bryan (1926, p. 6) reported that the clay lies on granite schist. The clay is predominantly kaolinite, but illite composes as much as 20 percent of some samples. The heavy minerals found in the sand beds are magnetite, monazite, zircon, and tourmaline.

The Latah Formation is also well exposed at an elevation of about 2,150 feet in the Shelly Lake clay pit in sec. 24, T. 25 N., R. 44E.; and in a Spokane, Portland and Seattle Railway cut, west of Latah Creek, in sec. 36, T. 25 N., R. 42 E. The Latah Formation is similar in lithology at both these places; therefore, only the Shelly Lake section is discussed (table 15). Here the Latah Formation consists of 80 feet of light-olive-gray (5*Y* 5/1) shale with the top 25 feet weathered to a weak yellow (5*Y* 8/2). Neither the base nor top of this section is exposed, and the section is cut by a basalt dike on the west side of the pit. The shale is composed of clay- and silt-size material, and montmorillonite, kaolinite, and illite in a ratio of 5:3:2 make up the clay fraction. The silt fraction is predominantly quartz but contains some feldspar, muscovite, and biotite. The heavy minerals are monazite and magnetite.

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The Latah Formation in the North clay pit, at an elevation of 2,530 feet, is composed of 85.8 feet of interbedded light-gray to white silty sands and clays (table 10), which rest on granite gneiss saprolite, and is overlain by the Palouse Formation. The clay fraction is composed of kaolinite and illite, and the kaolinite ranges from 60 percent of the total clay at the base of the section to 90 percent at the top of the section. The sand and silt fractions are composed predominantly of quartz and muscovite with some feldspar, which was identified by X-ray diffraction as microcline. The heavy minerals found in the sand fraction are magnetite, monazite, spessartine, tourmaline, and zircon. One of the striking features of the Latah Formation at this locality is that some of the kaolinite occurs as pseudomorphs after detrital feldspar measuring to as much as ⅛ by ⅛ by ¼ inch. The feldspars were derived from pre-Tertiary igneous and metamorphic rocks.

The Latah Formation in the Excelsior clay pit, at an elevation of 2,550 feet, is composed of 69.2 feet of interbedded weak-yellow to yellowish-white clay and sand, which are conglomeratic in places (table 9). The formation overlies basalt saprolite and underlies the Palouse Formation. The clay fraction consists of kaolinite and illite; kaolinite composes 95 percent of the total clay fraction at the top of the section, and 80 percent of the clay fraction at the base of the section. The sand and silt fractions are composed predominantly of quartz and muscovite with minor amounts of feldspar (microcline and orthoclase) and biotite. The heavy minerals in the sand fraction are magnetite, monazite, spessartine, tourmaline, and zircon. The Latah Formation in this pit displays two notable features. First, most of the conglomeratic beds contain fragments of clay that are pseudomorphs after feldspar similar to those in the North clay pit section, but these fragments of clay are larger here, measuring up to about ½ by ½ by ¾ inch. Second, a 3.8-foot-thick bed (L, table 9), composed of pseudospherical masses of halloysite rimmed with a thin zone of limonite (fig. 8), represents a pillow-lava flow that has been completely altered to clay. This pillow lava is interbedded with sediments and clearly shows the contemporaneity of the Latah Formation and the Columbia River Basalt.

Table 4 is a summary of the partial compositions of 27 single and composite samples of sedimentary material representing 1,095 feet of the Latah Formation. The average chemical composition of the Latah Formation is very similar to the average chemical composition of saprolite of pre-Tertiary rocks (table 1), and provides additional evidence that the formation was derived predominantly from these rocks. The average Al_2O_3 content is 20 percent, but there is a wide range from about 16 percent in the more sandy and silty clay beds to about 32 percent in the nearly pure clay beds. The SiO_2 content

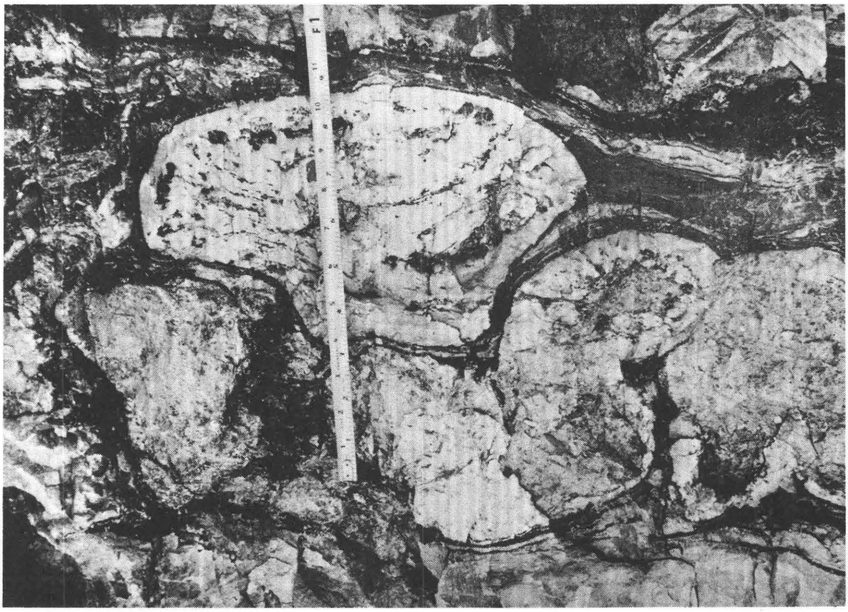

FIGURE 8.—Basalt saprolite with pillow structure at the Excelsior clay pit.

ranges from 49 to 70 percent and averages 62 percent. This variation in SiO_2 content is inversely proportional to the Al_2O_3 variation. The amount of Fe_2O_3 and TiO_2 in the Latah Formation is similar to the amount in the pre-Tertiary rock saprolite but much lower than the amount in the basalt saprolite. Only one sample contains more than 5 percent Fe_2O_3, and only one sample contains as much as 1.5 percent TiO_2. The amount of weight lost on ignition at 1,000°C reflects the Al_2O_3 content, which is controlled by the amount of clay present. However, an abundance of organic matter in the sample will also cause a greater ignition loss.

DEPOSITIONAL ENVIRONMENT

The Latah Formation in the valleys of the Spokane River, Latah Creek, and Deep Creek is the result of sediments being deposited in a shallow quiet lake or series of lakes. These lakes were formed when the Columbia River Basalt dammed the drainage system. At these localities, the formation contains abundant plant fossils, diatoms, and sponge spicules. The plant fossils have been described in detail by Knowlton (1926) and Berry (1929). The common names for the plants found in the Latah Formation are alder, beech, birch, bittersweet, cedar, cherry, chestnut, cypress, elm, fern, fig ginkgo, grass, hemlock, hickory, hornbeam, horsechestnut, laurel, linden, magnolia, maple, moss, oak, persimmon pine, poplar, redbud redwood, sassa-

TABLE 4.—*Chemical composition of sedimentary material of the Latah Formation*

[Analyses by X-ray fluorescence method; results in weight percent]

Sample No.,[1] or location	Sample length (feet)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition
13A	7.0	60	24	2.4	0.02	0.5	1.5	0.8	8.2
92A and B	13.0	66	24	1.1	.04	.2	1.4	1.1	5.8
108A–C	40.0	54	30	1.5	.02	.3	.7	.9	9.6
118A–E	86.0	62	22	.9	.01	.2	2.5	.7	9.9
131A and B	6.0	49	28	4.1	.04	.3	.7	1.5	8.8
136A	3.0	55	27	.7	.01	.2	1.9	1.3	8.6
139A and B	16.0	50	32	2.3	.02	.2	.8	1.0	9.9
143A	9.0	70	18	1.3	.01	.2	2.5	.8	4.6
149A–C	24.0	61	18	4.4	.05	.4	2.5	1.0	6.0
166A–D	47.0	51	22	6.5	.04	.6	1.7	1.0	8.6
167A and B	30.0	57	20	4.9	.01	.5	1.9	1.0	9.1
170A–D	18.0	64	19	2.6	.02	.4	2.1	.7	6.5
177A	10.0	61	22	2.3	.04	2.1	2.3	1.0	9.5
178A	18.0	57	24	1.8	.01	.3	2.0	1.2	9.1
192A–C	79.0	65	20	4.6	.06	.6	2.8	.8	4.4
193A–E	85.0	63	18	4.9	.06	.5	2.8	.7	6.4
199A–C	46.0	65	16	4.0	.05	.6	2.8	.8	2.9
203A–C	72.0	62	16	5.9	.09	.7	2.6	.8	6.0
205A and B	46.0	58	19	4.3	.03	.6	2.1	1.1	6.5
206A	30.0	59	19	3.1	.03	.7	2.3	1.0	4.2
Excelsior clay pit (A–K, M–Q)	74.2	54	21	2.3	.02	.2	1.3	.5	6.5
North clay pit (A–Q)	85.8	65	23	.6	.01	.1	2.2	.6	7.4
South clay pit (A–O)	107.0	68	20	1.5	.03	.3	2.7	.7	5.9
Somers clay pit (A–I)	10.4	56	22	9.4	.03	.2	1.5	1.2	10.1
Shelly Lake clay pit (A–D)	80.0	64	18	5.0	.06	.8	2.7	.8	10.0
Landing clay pit (A–E)	20.0	60	23	3.3	.02	.4	2.1	1.0	10.4
Milan clay pit (A–C)	33.0	67	18	4.1	.06	.5	2.9	.7	7.5
Total and averages	1,095.4	62	20	3.3	.04	.4	2.3	.8	6.7

[1] See auger-hole logs, pages 64–90.

fras soapberry, sweetgum sycamore, tulip, tupelo gum, and willow. In addition to plant fossils, the formation also contains abundant diatoms, some of which were listed by Knowlton (1926, p. 52–53). The following diatoms have been identified by K. E. Lohman of the U.S. Geological Survey in the shale at the Shelly Lake pit (U.S.G.S. diatom locality 5678):

Coscinosidcus subsuladociscoidalis Rattray
Cymbella cistula (Hemprich) Grunow
Eunotia sp.
Fragilaria virescens Ralfs
Frustulia rhomboides (Ehrenberg) De Toni
Gomphonema intricatum Kützing
Melosira granulata var. *curvata* Grunow
Melosira granulata var. *jonensis* Grunow
Melosira cf. *M. italica* (Ehrenberg) Kützing
Melosira cf. *M. solida* Eulenstein
Melosira sp. *A*
Melosira sp. *B*
Melosira sp. *C*
Tabellaria fenestrata Kützing
Tetracyclus ellipticus (Ehrenberg) Grunow
Tetracyclus stella (Ehrenberg) Héribaud and Peragallo
Tetracyclus sp. *A*

The diatoms and sponge spicules found in the Shelly Lake pit and those found by A. Mann (Knowlton 1926, p. 51–55) at other localities in the Spokane Valley are evidence of a quiet water environment, as are the hundreds of fossil leaves of deciduous trees and other plants that have been reported by Knowlton (1926) and Berry (1929). Berry (1929, p. 234) reported that the flora in the Latah Formation indicates a temperate climate with an annual rainfall of 30–40 inches. This paleoflora is similar to the existing flora of the Middle Atlantic States.

The presence of montmorillonite in the shale at the Shelly Lake clay pit indicates that some of the material for the Latah Formation may have been derived from volcanic ash that fell into the lake and was subsequently altered. The kaolinite probably was derived from erosion of the pre-Tertiary igneous and metamorphic rocks that were being subjected to chemical weathering and erosion in the mountainous area to the east. The lithologies of the Latah Formation at the Deep Creek, Latah Creek, and Shelly Lake pits indicate that the sources and the environment of deposition of the materials were similar.

The lithology at the Somers clay pit suggests a deltaic deposit. This is supported by the lenticular beds, cross beds, yellowish-orange and reddish-brown colors, and the lack of fossils. Oxidizing conditions caused the distinctive colors and prevented the formation of montmorillonite; the shallow fast-moving water prevented a large accumulation of leaves and diatoms.

The Latah Formation in the vicinity of Mica differs in lithology and origin from the Latah Formation in the valley of the Spokane River. At both localities, the formation was deposited in a lake or a series of lakes formed when flows of the Columbia River Basalt blocked the drainage system. In the Mica area, however, the subangular quartz grains, the kaolinite pseudomorphs after feldspars, and the poorly sorted fragments indicate that the sediments were derived from nearby outcrops of partially weathered pre-Tertiary rocks and transported into the lake by both floods and landslides. The turbulence caused by the flooding and landsliding prevented the accumulation and preservation of leaf fossils, diatoms, and sponge spicules.

Post-depositional weathering of the Latah Formation was more intense in the Mica area than in the Spokane River valley area because the formation, at a lower elevation in the Spokane River valley, was protected from weathering by overlying basalt flows. The formation at Mica, however, was not covered by basalt and was exposed to chemical weathering. Thus, the Latah Formation in the Mica area is, in part, a saprolite.

PALOUSE FORMATION (PLEISTOCENE)

The Palouse Formation of Pleistocene age was named by Treasher (1925, 1926) to include the loess and glacial-lake deposits that overlie the basalt flows in the region known as the Palouse wheat country. The fertile soil of this area is largely residual material developed on the Palouse Formation, but locally it may include some material that was transported by wind or surface creep. Bryan (1926, p. 22) suggested that the name be changed to "Palouse soil" because he maintained that one origin for the entire formation was doubtful. In subsequent papers, authors have used the original name because the term "soil" as used in soil science has a different connotation from that used by Bryan.

LOESS DEPOSITS

The Palouse Formation loess is massive slightly stratified moderate-brown (10*YR* 5/4) to moderate-olive (2*Y* 4/4) clayey silt characterized by irregular vertical columnar jointing. In many places the base of the formation consists of sand and gravel, usually only a few feet thick but at some places as much as 10 feet thick. A characteristic of the formation is that it maintains vertical faces in roadcuts and streams for many years; however, it slumps very readily when graded at lower angles. The topography in the Palouse region is gently rolling and has an average relief of approximately 250 feet. At the head of each gully, pseudocirques have been formed by erosion (Kirkham, 1931, p. 207). The northeastern slopes of many of these hills are steeper than the southwestern slopes (Tullis, 1944, p. 135), and the flat-bottomed valleys are mostly dry.

The maximum thickness of the Palouse Formation in Washington is more than 250 feet (Treasher, 1925, p. 469). The greatest thickness found by drilling in Spokane County is 76 feet, in auger hole 3, in sec. 20, T. 24 N., R. 44 E. (pl. 1). South of the Spokane River, the Palouse Formation averages 20 feet thick in 141 auger holes, and north of the river it averages 17 feet in 49 auger holes. The Palouse thins northward where there is more topographic relief. All drill holes penetrating more than 30 feet of Palouse were on or near the tops of hills, where erosion had removed less of the material.

Two samples of Palouse Formation were analyzed for grain size and were found to be clayey silt (fig. 2), on the basis of the following approximate proportions: sand, 5 percent; silt, 60 percent; and clay, 35 percent. In both samples, the clay content was mostly montmorillonite and illite in about a 3:1 ratio. Kaolinite was present in a minor amount. The silt- and sand-size fractions are composed of angular quartz and lesser amounts of feldspar and muscovite. Minor heavy minerals found in the sand-size fraction are limonite, monazite, tourmaline, hornblende, garnet, epidote, and apatite. Table 5 gives the partial chemical compositions of the two samples. Their compositions are very similar, even though the samples were collected miles apart. The high SiO_2 and low Al_2O_3 content reflects the high silt and low kaolinite composition. The generally high value for CaO and K_2O reflects the presence of montmorillonite and illite. The average composition of the two samples agrees closely with the compositions published by Treasher (1926, p. 309).

TABLE 5.—*Chemical composition of Palouse Formation loess and glacial-lake clay*

[Analyses by X-ray fluorescence method; results in weight percent]

Sample No.[1]	Sample length (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition
Loess:									
20A	34.0	63	15	5.8	0.13	1.2	2.0	0.9	3.3
175A	50.0	65	16	4.8	.15	1.1	1.6	.9	3.3
Glacial-lake clay:									
183A and B	25.0	67	16	3.1	.03	.5	3.0	.7	3.4
189A	40.0	66	16	5.5	.10	1.7	4.7	.6	4.6

[1] See auger-hole logs, pages 64–90.

The Palouse Formation is of eolian origin. At least two sources for the windblown material are necessary inasmuch as glacial debris is predominant in the lower part of the formation and dust derived from volcanoes is concentrated in the upper part (Rieger, 1952; Campbell, 1962, p. 37–38). The fine glacial debris may have been carried by winds from the area of retreating glaciers to the northeast, and the volcanic dust material may have come from the Cascade region to the southwest. The montmorillonite found in the clay fraction probably represents an alteration product of the volcanic material and is slightly more abundant in the top part of the formation.

Present-day dust storms have redistributed the loess on the surface of the Palouse Formation. An accurate measurement of the amount of dust deposited is difficult to make, but Bryan (1926, p. 43) believed that the present rate of accumulation in some areas greatly exceeds the past rate. During the last several thousand years several feet of windblown dust has been deposited on post-Pleistocene soil zones. Accurate isotopic dates are based on the carbon found in charred wood from Indian camp fires. The buried soils are detrimental to farming because they are impervious to water and result in local perched water tables.

In the area south and west of Mica Peak (fig. 1), the well-drained soils developed on the Palouse Formation are fine- to medium-textured Gray-Brown Podzols and Brunizems. These soils occur on the rolling to hilly uplands under a native cover of grasses and small shrubs. Their principal agricultural use is for growing small grains, peas, lentils, and alfalfa, and for pasture and grazing. The imperfectly drained soil found in the same area is the moderately fine to medium-textured Humic Gley developed on silty alluvium adjacent to the streams and creeks (Ray W. Chapin, written commun., 1964). North of the Spokane Valley, near Pleasant Prairie, Orchard Prairie, Peone Prairie, Green Bluff, and Fivemile Prairie (fig. 1; pl. 2), the soils are chiefly Brunizems and Brown Forest soils, though a small amount of Gray-Brown Podzolic soil is present.

GLACIAL-LAKE DEPOSITS

The glacial-lake deposits of the Palouse Formation occur in the wide flat valleys of the Coulee district north of the Spokane River. These Pleistocene deposits accumulated in lakes that were formed when ice and large glacial debris dammed the creeks and rivers. Mixtures of fine glacial debris and eolian material accumulated in deep lakes, and thick deposits of silty clay and clayey silt were thus formed. Peone Prairie, north of the Spokane River (pl. 2), is underlain by such a deposit. It was studied in detail and found to consist predominantly of clayey silt that is light gray to yellowish gray when dry but has slightly bluish hues when wet.

Three samples of glacial-lake material were studied in the laboratory. According to the grain-size analyses, they range from silty clay to clayey silt (fig. 2). The clay fraction consists of montmorillonite, illite, and kaolinite in an approximate ratio of 5:3:2. The silt- and sand-size fractions consist of angular quartz and muscovite grains with minor amounts of feldspar. Heavy minerals found in the sand fraction are limonite, monazite, tourmaline, biotite, and garnet.

Table 5 gives partial chemical compositions of these samples, and it can be seen in the table that these samples and those from the loess deposits have similar chemical compositions. Relative to the loess, the lake deposits have a slightly higher K_2O content, probably due to the muscovite. The higher SiO_2 and the low Al_2O_3 values reflect the higher quartz content and low kaolinite content. The CaO is probably entirely in the montmorillonite. No samples of glacial-lake deposits were tested for ceramic properties; however, since the mineralogical and chemical compositions of the lake deposits are similar to those of the Palouse Formation, the ceramic properties should also be similar, and, therefore, the lake deposits may be suitable for common brick.

KATAMORPHIC MINERALS

The katamorphic minerals in these deposits are chiefly the clay minerals formed by the alteration of rock-forming minerals in the zone of chemical weathering. Five clay minerals are found in the saprolite developed from metamorphic, igneous, and basaltic rocks, and in the transported clays of the Latah and Palouse Formations. They are kaolinite and halloysite of the kaolin group, montmorillonite and nontronite of the montmorillonite group, and illite of the dioctahedral mica group, Kaolinite, montmorillonite, and illite do not occur in basalt saprolite, but nontronite occurs only in basalt saprolite. Halloysite also occurs chiefly in basalt saprolite, but very small amounts are found in the other saprolites.

Kaolinite has a structural formula of $Al_4Si_4O_{10}(OH)_8$ and a theoretical composition of 46.54 percent SiO_2, 39.50 percent Al_2O_3, and 13.96 percent H_2O. The unit cell is composed of a single silica tetrahedral sheet and a single alumina octahedral sheet (1:1) joined together so that the oxygen tips of the tetrahedral sheet and one layer of the octahedral sheet form a common layer (Gruner, 1932). Normally the basal (001) spacing of the kaolinite unit cell is 7.1 A, but if the bonds between atoms and sheets are weak or if there is a warping of the alumina octahedral sheet by some substitution of titanium or iron for aluminum (Grim, 1953, p. 47), the basal spacing becomes larger and the kaolinite structure is poorly crystalline. Most of the kaolinite in the clay deposits of Spokane County is the poorly crystalline variety with a larger basal spacing; this is shown by the X-ray-diffraction traces in figure 9. Three traces of clay samples containing kaolinite (*A*, *B*, and *C*) show that the peak representing the basal (001) spacing is broad and spaced at 7.2 A, and the peaks representing the prisms (020, 110, 111, . . .) are diffuse or missing. The poorly crystalline kaolinite probably contains titanium and (or) iron in its lattice structure. Kaolinite is usually white but may be gray from titanium or red, brown, or yellow from iron impurities.

A differential thermal analysis curve (fig. 10) of kaolinite verifies the poor crystallinity of the clay mineral. The very broad endothermic reaction at 100°C may be due to a small amount of halloysite. The prominent endothermic reaction resulting from the loss of hydroxyl ions occurs at approximately 560°C and thus indicates that the kaolinite has a poor degree of crystallinity, because in well-crystallized kaolinite the endothermic reation takes place at 600°C. The exothermic reaction, the reaction that takes place at the temperature when the kaolinite structure is destroyed, occurs at about 985°C over a range of about 40°C.

Kaolinite is found as a weathering product of potassium feldspar, biotite, and muscovite and occurs as pseudomorphs after these minerals in residual clay derived from metamorphic and igneous rocks. It also occurs as pseudomorphs after feldspar in the Latah Formation, indicating that the formation, in part, was exposed to chemical weathering after deposition. In addition, the beds of almost pure kaolinite in the Latah Formation indicate that the clay was derived from pre-Tertiary saprolite by erosion and deposition into lakes.

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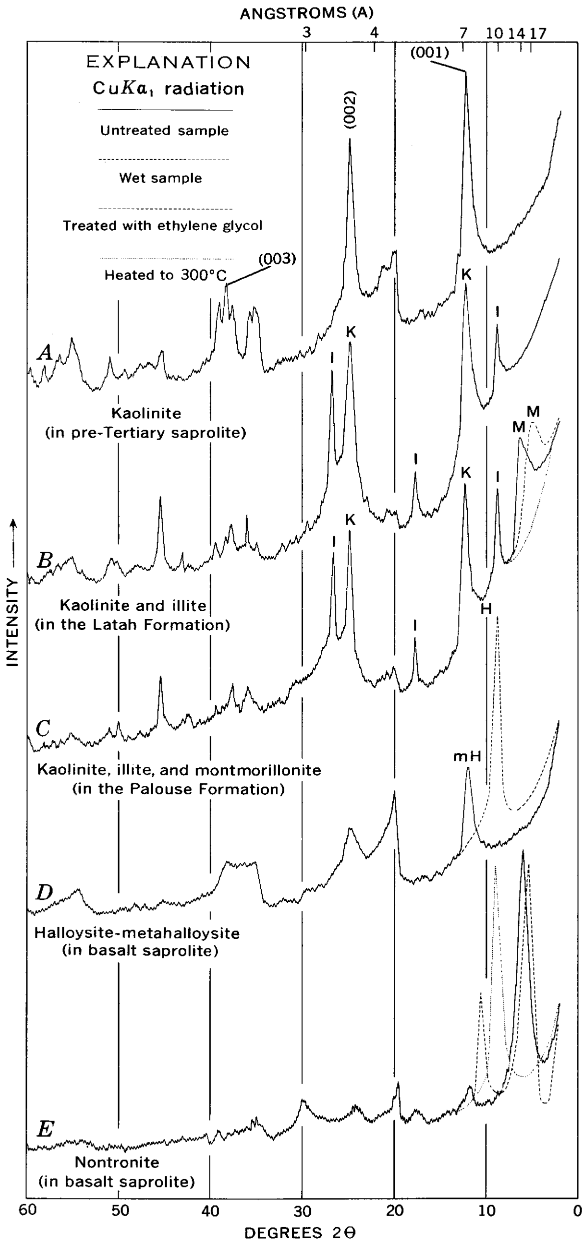

FIGURE 9.—X-ray-diffractometer traces of clay samples from the deposits in Spokane County, Wash.

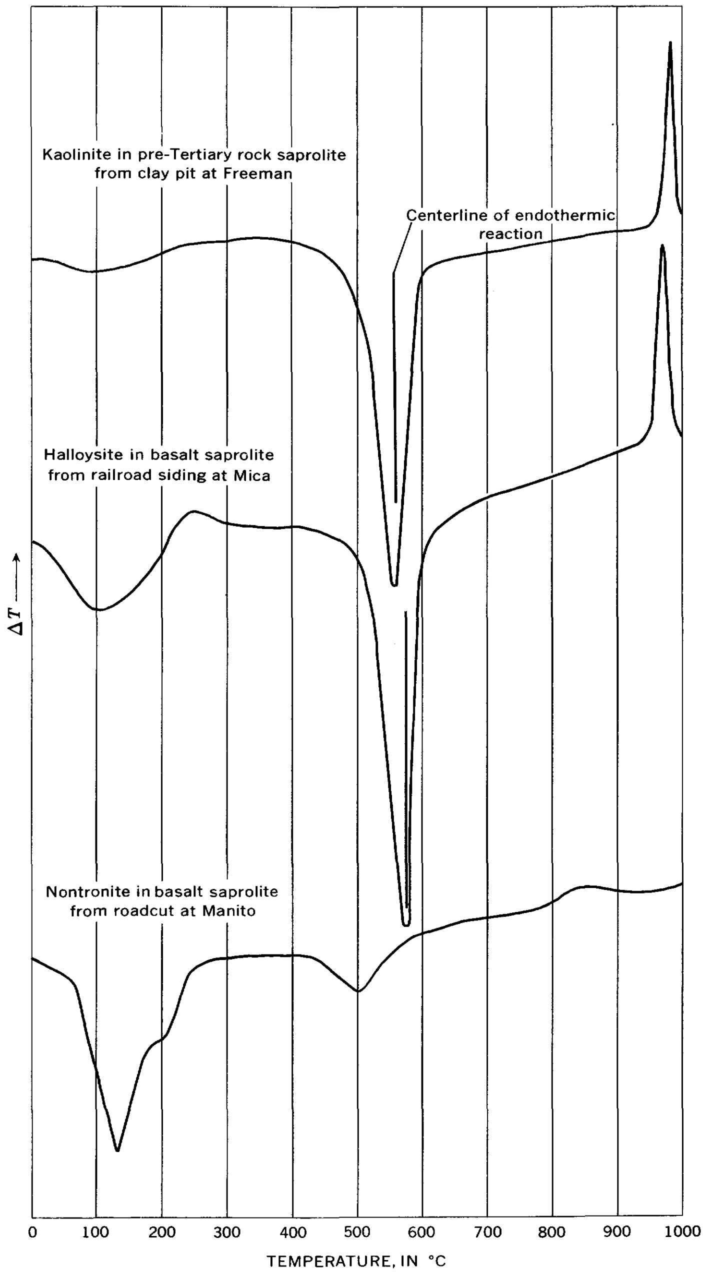

FIGURE 10.—Differential thermal analysis curves of three clay minerals from Spokane County, Wash.

Kaolinite is also found mixed with illite in the Latah Formation and mixed with illite and montmorillonite in the Palouse Formation.

Halloysite [2] has a structural formula of $Al_4Si_4O_{10}(OH)_8.4H_2O$, and a theoretical composition of 40.86 percent SiO_2, 34.66 percent Al_2O_3, and 24.48 percent H_2O. Halloysite has the same single silica tetrahedral sheet and the same alumina octahedral sheet joined the same way as kaolinite. However, these 7.2-A-thick sheets are separated by a single molecular sheet of water 2.9 A thick. This gives halloysite a basal spacing of 10.1 A, which collapses to 7.2 A when the clay mineral dries at relatively low temperatures and the single water molecule evaporates. This dehydrated variety (7.2 A) is called metahalloysite; once the water has been removed it cannot be replaced. The X-ray diffraction trace (*D*, fig. 9) illustrates that the halloysite has a 10 A basal (001) spacing that collapses to 7.2 A (metahalloysite) when the sample is allowed to dry. Comparison of the X-ray diffraction trace of halloysite (*D*, fig. 9) with the traces for kaolinite (*A*, *B*, and *C*, fig. 9) show that halloysite is more poorly crystalline than kaolinite. The peak representing the basal (001) spacing at 7.2 A is very broad, and the peaks representing the prisms (020, 110, 111, . . .) are broad and diffuse.

The differential thermal analysis curve (fig. 10) for halloysite (metahalloysite) shows a reaction similar to that for kaolinite. The halloysite was dried and converted partly to metahalloysite prior to being placed in the DTA furnace. The broad endothermic reaction at about 100°C represents the remaining interlayer water being driven off and would be several times larger if the mineral had not been dried previously. The prominent endothermic reaction at about 575°C results from the loss of hydroxyl ions. The asymmetry of this reaction is characteristic of halloysite and metahalloysite but not of kaolinite. The exothermic reaction—the reaction in which the crystal structure of the halloysite is destroyed—occurs at 970°C and takes place over a range of about 50°C.

Halloysite is found in Spokane County as a weathering product of plagioclase in the basalt. Thin sections of basalt saprolite show halloysite as pseudomorphs after labradorite and as fillings in vesicles that were previously filled with nontronite. Metaholloysite was not found to occur naturally in any of the rock samples collected from Spokane County, although it was found after the samples had air dried. Traces of halloysite occur in beds of the Latah Formation that immediately overlie basalt saprolite, probably because of the reworking by waves. Traces of halloysite are also found in the pre-

[2] The names halloysite for the $4H_2O$ form and metahalloysite for the $2H_2O$ form are preferred by the majority of representatives to the International Mineralogical Association.

Tertiary rock saprolite which originally contained plagioclase in mica-deficient zones that altered to halloysite instead of kaolinite.

Thus, it can be concluded that under similar weathering conditions, feldspars in rocks containing muscovite alter to kaolinite whereas feldspars in rocks that do not contain muscovite alter to halloysite. This conclusion supports the following statement by Sand (1956) in regard to residual kaolins in the Southeastern United States: "Where conditions favor the formation of hydrated halloysite a feldspathic rock high in mica content yields a kaolin clay correspondingly high in kaolinite. Conversely, a rock low in mica yields a clay high in content of hydrated halloysite."

The theoretical structural formula of montmorillonite is $Na_{0.33}(Al_{1.67},Mg_{0.33})Si_4O_{10}(OH)_2 \cdot nH_2O$, and the theoretical dehydrated composition is 65.5 percent SiO_2, 23.1 percent Al_2O_3, 3.7 percent MgO, 2.8 percent Na_2O, and 4.9 percent H_2O. Montmorillonite is composed of two silica tetrahedral sheets with an alumina octahedral sheet between them (2:1) joined so that the tips of the tetrahedrons are attached to the octahedral sheet. A limited number of Al^{+3} ions can replace the Si^{+4} ions in the tetrahedral sheet. In the octahedral sheet, Mg^{+2} and Fe^{+3} ions can replace some of the Al^{+3} ions. If all the Al^{+3} ions are replaced by Mg^{+2} ions, the mineral becomes saponite. The basal (001) spacing of montmorillonite ranges from 9.6 A when the cations and water molecules are removed, to about 14 A when the cations and water molecules are present, to more than 17 A when additions are made in the cation position or when the sample is treated with ethylene glycol (*C*, fig. 9). Montmorillonite in the clay deposits of Spokane County is formed as a weathering product of the ferromagnesian minerals in pre-Tertiary rock saprolite. It is also formed as a weathering product of volcanic ash in the Palouse Formation loess and glacial-lake deposits and as sedimentary material in some beds of the Latah Formation.

Nontronite has a structural formula of $Na_{0.33}Fe_2^{+3}(Si_{3.67},Al_{0.33})O_{10}(OH)_2 \cdot nH_2O$, and a theoretical dehydrated composition of 51.8 percent SiO_2, 4.1 percent Al_2O_3, 37.5 percent Fe_2O_3, 2.4 percent Na_2O, and 4.2 percent H_2O. Nontronite has the same unit-cell structure as montmorillonite, except that all the Al^{+3} ions in the octahedral sheet are replaced by Fe^{+3} ions. The X-ray-diffraction trace (*E*, fig. 9) shows that the basal (001) spacing of nontronite changes from 9.9 A when the interlayer water is driven off by heat, to 14.0 A when the water molecule layer is present, to 17.6 A when the sample is treated with ethylene glycol. Table 6 lists three chemical analyses of nontronite from Spokane County. The natural nontronite contains about four more molecules of water than the theoretical nontronite.

TABLE 6.—*Chemical analyses of nontronite*

	1	2	3
SiO_2	41.63	40.72	40.54
Al_2O_3	8.69	4.96	5.19
Fe_2O_3	25.99	29.57	31.24
FeO		.71	.39
MgO	.33	.74	.06
CaO	1.78	1.98	1.92
Na_2O	.22	--------	.14
K_2O	.32	--------	.24
H_2O+	9.91	6.66	6.00
H_2O-	10.67	15.46	14.75
Total	99.54	100.80	100.47

1. Excelsior, Spokane County, Wash., SE¼SE¼ sec. 16, T. 24 N., R. 44 E. (Allen and Scheid, 1946, p. 297).
2. Manito, Spokane County, Wash., SW¼ sec. 5, T. 23 N., R. 45 E. (Allen and Scheid, 1946, p. 297).
3. Manito, Spokane County, Wash., NW¼NW¼ sec. 8, T. 23 N., R. 45 E. (American Petroleum Institute, 1950, p. 55).

The differential thermal analysis curve of nontronite is shown in figure 10. The sample came from a roadcut at Manito, Spokane County, Wash. The large endothermic reaction at 130°C is the result of the release of absorbed water. According to Mackenzie (1957, p. 143), the size of this reaction is not particularly sensitive to the mineralogical structure of the sample but is influenced by pretreatment of the sample in regard to exchangeable cations and relative humidity. The small endothermic reaction at 500°C is due to loss of the hydroxyl ions. The very small exothermic reaction between 800° and 900°C is probably due to the final breakdown of the structure remaining after the hydroxyl ions have been driven off.

Nontronite forms under poor drainage conditions as a reduction weathering product of ferromagnesian minerals and glass in basalt. It occurs in vugs and cracks of the partly weathered and unweathered basalt underlying the saprolite. Its unusual green color, which fades to a yellowish green when the mineral is dry, makes nontronite prominent when seen against dark basalt (fig. 5).

The term "illite" as used in this report is applied to a dioctahedral clay-size mica. Illite has an approximate structural formula of $K_{1.33}(Si_{6.67}Al_{1.33})(Al_4,Mg_3)O_{20}(OH)_4$, and a theoretical composition of 48.9 percent SiO_2, 14.5 percent Al_2O_3, 9.7 percent Fe_2O_3, 7.7 percent K_2O, 14.8 percent MgO, and 4.3 percent H_2O. The structure of illite is the same as that of montmorillonite (2:1)—two silica tetrahedral sheets and one alumina octahedral sheet. In the silica tetrahedral sheets there is one Al^{+3} ion for every five Si^{+4} ions. In the alumina octahedral sheet the Al^{+3} and Mg^{+2} ions may be partly replaced by Fe^{+3} and Fe^{+2} ions. The potassium ions between the unit layers may be partly replaced by other cations such as Ca^{+2}, Mg^{+2}, or H_3O^+. The basal (001) spacing of illite is 10 A, which does not vary with treatment as it does in montmorillonite or nontronite (*B* and *C*, fig. 9). Illite occurs in several polymorphic forms that are not easily identified unless the mineral is reasonably pure and well crystallized. Illite occurs in Spokane County as a weathering product of mica in pre-Tertiary rock saprolite and as a sediment in the Latah Formation. It is also found as a minor constituent in the Palouse Formation loess and glacial-lake deposits.

Most of the clay-size material occurs as a mixture of two or more clay minerals. One type of mixture consists of discrete grains of one clay mineral mixed with discrete grains of another clay mineral, and the grains show no preferred orientation. In this blend, each clay mineral is easily identified by X-ray diffraction because it retains its natural characteristics, particularly structure. The other type of mixture consists of two intimately interlayered clay minerals. In this mixture, the natural characteristics of each clay mineral are modified by those of the other, so that identification by their structural characteristics is difficult. This second type of clay mixture is termed "mixed layer." There are two types of mixed-layer structures: one in which the interstratification along the *c* axis is a regular repetition of the different clay layers, and another in which there is random interstratification along the *c* axis. The second type of mixed layering is the more common of the two. Mixed layers of illite and montmorillonite with random interstratification are found in the pre-Tertiary rock saprolite, in the Latah Formation, and in the Palouse Formation loess and glacial-lake deposits as a very minor clay-mineral constituent.

The only nonclay katamorphic minerals found in these clay deposits are the iron oxides such as hematite (Fe_2O_3) and limonite ($2Fe_2O \cdot 3H_2O$). These minerals occur in minor amounts, but they are evident by their yellow, red, or brown color. These iron oxide minerals are the weathered products of ferromagnesian minerals, magnetite, and ilmenite. They may also be derived from some of the clay minerals such as nontronite, montmorillonite, and illite.

UNALTERED MINERALS

The unaltered minerals associated with the clay deposits reflect the mineral composition of the parent material. Ilmenite ($FeTiO_3$) is the only nonclay primary mineral in the basalt saprolite. Quartz (SiO_2), muscovite ($KAl_3Si_3O_{10}(OH)_2$), and orthoclase ($KAlSi_3O_8$) are the most common nonclay minerals in the pre-Tertiary rock saprolite, the Latah Formation, and the Palouse Formation. The rest of the nonclay minerals are resistate heavy minerals which range in abundance from a trace to about 0.01 percent of the whole sample.

Table 7 shows the heavy-mineral distribution in all sand-size fractions (table 19) of the samples listed in the auger-hole logs. The minerals of possible economic importance are monazite and ilmenite. Monazite is significant for its thorium and rare earth elements, and ilmenite is important for its content of titanium. An assessment of monazite as a byproduct of these clay deposits has been described by Hosterman, Overstreet, and Warr (1964). There is a possibility, however, that ilmenite could be produced as a byproduct of basalt saprolite. The quartz, feldspar, and muscovite contents in the clay deposits are high enough that these minerals might be byproducts—quartz and feldspar for the glass industry and muscovite for the insulation industry.

TABLE 7.—*Heavy minerals identified in the clay deposits of Spokane County, Wash.*

	Saprolite of pre-Tertiary gneiss and related rocks	Latah Formation	Palouse Formation	Glacial-lake deposits	Basalt saprolite
Biotite	X	X		X	
Limonite	X	X	X	X	X
Magnetite	X	X			
Monazite	X	X	X		
Rutile	X	X			
Tourmaline	X	X	X	X	
Zircon	X	X			
Ilmenite	X	X			X
Spessartine	X	X	X		
Actinolite	X				
Sillimanite	X				
Epidote	X	X	X		
Tremolite	X				
Sphene	X				
Hornblende			X		
Apatite			X		

CLAY DEPOSITS

The descriptions of the clay deposits in Spokane County include data on the mineralogical and chemical compositions of the clay. Emphasis is placed on the alumina content of the deposits because of their possible use as an aluminum ore. Also, the alumina content is an excellent indication of other possible uses of the clay.

Many of the clay deposits in Spokane County were described by Shedd (1910, p. 168–197), Wilson (1923, p. 67–92), Wilson and Goodspeed (1934, p. 35–62), Hodge (1938b, p. 566–608), and Glover (1941, p. 229–280). These publications concentrate on the physical properties of the clay and do not include any information on the mineralogy and very little information on the chemical composition.

The major clay deposits of Spokane County occur in three areas—California Creek area, Mica Creek area, and Spokane River valley area. In the following discussion of the three areas, the terms "clay pit", "clay deposit," and "clay pit and deposit" will be used to define the type of clay deposit. "Clay pit" is used when there is an indication that clay was mined in the past or is being mined at present. The term "deposit" is used to indicate the existence of potential clay resources. "Clay pit and deposit" indicates that the pit is only a small part of the potential clay resources. The limits of the deposit are arbitrary and are based on section boundaries of townships and ranges.

CALIFORNIA CREEK AREA

The area drained by California Creek includes the Excelsior, Mica, and Freeman clay pits and deposits, and the Valleyford clay deposit. Two pits at Mica are currently mined for clay. Abandoned clay pits are at Excelsior, Freeman, and Mica (pl. 1). The Excelsior, Mica, and Valleyford clay deposits are similar in that they contain basalt saprolite overlain by patches of Latah Formation beds. The Freeman clay pit and deposit consists primarily of pre-Tertiary rock saprolite.

EXCELSIOR CLAY PIT AND DEPOSIT

The Excelsior clay deposit is in secs. 20, 21, 28, and 29, T. 24 N., R. 44 E. (pl. 1). State Highway 3H (the Palouse Highway) and several gravel roads traverse the area. The nearest railroad station is about 2 miles east of the deposit at Mica, on the Northern Pacific and the Chicago, Milwaukee, St. Paul, and Pacific Railroads. The small town of Valleyford is immediately southeast of the deposit. A total of 102 auger holes have been drilled in the Excelsior deposit. Auger-hole logs for 84 of these (E–1 to E–50 and M–8 to M–34, M–78 to M–85) have been published (Hosterman and others, 1960, p. 40–54 and 62–63), and logs for the other 18 are in the present report (Nos. 1–18, pages 64–66; pl. 1).

The deposit consists of an almost continuous layer of basalt saprolite overlain by patches of clay of the Latah Formation. There are approximately 160 acres of Latah Formation averaging about 14 feet in thickness and containing an average of about 50 percent clay and 20 percent Al_2O_3. Approximately 1,000 acres are underlain by basalt saprolite averaging 18 feet in thickness and almost 24 percent Al_2O_3. A small amount of saprolite on pre-Tertiary rocks occurs in the northwestern part of the deposit. The Palouse Formation covers the entire deposit to thicknesses ranging from 5 to 76 feet.

The average Al_2O_3 and Fe_2O_3 contents and loss on ignition are given in table 8 for the clay-bearing units in the Excelsior clay deposit. These averages were obtained from 248 assays published by Hosterman, Scheid, Allen, and Sohn (1960, p. 40–63) and 34 fluorescence analyses in this report (table 9, and auger holes 10 and 13, table 19). The Latah Formation and the Columbia River Basalt saprolite contain sufficient Al_2O_3 to be possible future commercial sources of alumi-

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num. The Fe_2O_3 content in the Latah Formation is low enough so that it will not interfere with the alumina recovery. The Fe_2O_3 content in the basalt saprolite could be lowered appreciably by removing the ilmenite. The loss on ignition is an excellent indicator of the amount of clay because there is no material that volatilizes at 1,000°C, and the clays are the only minerals present that contain water.

TABLE 8.—*Average* Al_2O_3 *and* Fe_2O_3 *contents and loss on ignition of clay-bearing units in the Excelsior clay pit and deposit*

[Chemical results in weight percent. Compiled from Hosterman, Scheid, Allen, and Sohn (1960) and tables 9 and 19 of this report]

Unit	Total thickness analyzed (ft)	Number of samples	Al_2O_3	Fe_2O_3	Loss on ignition
Palouse Formation	14. 0	11	13. 5	10. 6	7. 4
Latah Formation	177. 2	37	20. 4	4. 4	7. 8
Basalt saprolite	1, 046. 8	205	23. 6	10. 9	9. 5
Basalt	159. 0	27	13. 9	15. 5	6. 4
Pre-Tertiary rock saprolite	17. 0	2	18. 0	2. 9	3. 8

The Latah Formation exposed in the Excelsior clay pit is 69.2 feet thick and is composed of yellowish-white to yellowish-orange sand, silt, and clay beds ranging in thickness from 1 to 12 feet (table 9). The clay minerals are kaolinite and illite with a ratio of 8.5:1.5. This ratio remains the same regardless of whether the clay minerals are in sand, silt, or clay. The kaolinite, which is pseudomorphic after feldspar, indicates that some of the material from the pre-Tertiary igneous and metamorphic rocks was transported into the basin of deposition unweathered. Postdepositional chemical weathering of part of the Latah Formation has formed a saprolite from sedimentary material. Additional evidence of this is the 3.8-foot-thick pillow lava saprolite (fig. 8) at about the middle of the exposed section (table 9).

The thickest basalt saprolite penetrated in the Excelsior clay deposit by drilling is 68 feet, in auger hole 13 (p. 65). The saprolite is pale blue, yellowish gray, and light olive gray. The basalt saprolite is underlain by pre-Tertiary rock saprolite and overlain by the Latah Formation. The only clay mineral in the basalt saprolite of this auger hole is halloysite; however, nontronite is present with halloysite in auger hole 10.

MICA CLAY PITS AND DEPOSIT

The Mica clay pits and deposit are in parts of secs. 14, 22, 23, and 27, T. 24 N., R. 44 E. (pl. 1). The town of Mica and the brick plant owned by the International Pipe and Ceramics Co. are near the center of the deposit. Both the Northern Pacific and the Chicago, Milwaukee,

TABLE 9.—*Stratigraphic section, chemical composition, and mineralogy of units of the Latah Formation in the Excelsior clay pit, sec. 21, T. 24 N., R. 44 E.*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10, by weight)		
										Sand	Silt	Clay	Kaolinite	Halloysite	Illite
Palouse Formation.															
Latah Formation:															
A. Sandy silty clay, plastic, yellowish-gray (10*YR* 8/1)	1.0	63	23	1.9	0.01	0.5	1.2	0.7	9.2	2.3	2.2	5.5	9.5	--------	0.5
B. Clayey sand, weak-yellowish-orange (2.5*Y* 7/4)	8.0	71	18	3.9	.07	.2	1.3	.4	6.3	4.6	1.9	3.5	8.5	--------	1.5
C. Clayey sand, yellowish-white (10*YR* 9/1)	8.0	75	16	.5	.01	.1	1.8	.3	3.5	6.0	1.8	2.2	8.5	--------	1.5
D. Sandy silty clay, weak-yellowish-orange (10*YR* 7/4)	5.0	60	21	5.0	.03	.3	1.9	1.1	9.0	3.4	2.5	4.1	7.5	--------	2.5
E. Silty clay, weak-yellow (2.5*Y* 8/2)	4.0	55	26	1.9	.01	.2	1.0	1.2	11.7	1.1	2.3	6.6	8.5	--------	1.5
F. Clayey sand, with feldspar fragments altered to kaolinite, pale-yellow (2.5*Y* 9/2)	6.0	70	20	1.0	.01	.1	2.1	.3	5.6	5.3	1.8	2.9	8.5	--------	1.5 2.0
G. Sandy clayey silt, pale-yellow (2.5*Y* 9/2)	3.2	58	25	2.2	.02	.2	2.2	.4	9.4	3.4	3.6	3.0	8.0	--------	
H. Sand, with feldspar fragments altered to kaolinite, weak-yellow (5*Y* 8/4)	2.5	73	17	2.3	.02	.1	2.0	.2	4.9	7.5	1.5	1.0	9.5	--------	.5
I. Clayey silty sand, weak-yellow (2.5*Y* 8/2)	2.0	60	24	2.2	.03	.2	2.1	.5	8.8	3.5	3.1	3.4	9.0	--------	1.0
J. Conglomeratic sand, with feldspar fragments altered to kaolinite, weak-yellow (2.5*Y* 8/2)	3.0	72	18	1.0	.02	.1	1.8	.2	5.6	7.5	1.4	1.1	6.5	--------	3.5
K. Clayey silty sand, weak-yellow (2.5*Y* 8/2)	2.0	66	22	2.6	.02	.1	1.4	.4	7.2	4.8	2.6	2.6	6.5	--------	3.5
L. Saprolite, basalt (pillow lava), weak-yellowish-orange (10*YR* 7/6)	(3.8)	45	27	5.7	.03	.4	.3	1.6	15.3	--------	--------	10.0	--------	10.0	--------
M. Clayey sand, with feldspar fragments altered to kaolinite, white (*N*9)	2.0	73	18	.5	.01	.1	.6	.3	6.7	5.7	1.5	2.8	8.0	--------	2.0
N. Sandy clay, blocky fractured, weak-yellowish-orange (10*YR* 7/6)	1.0	44	26	9.9	.02	.5	.5	1.2	14.1	2.0	1.3	6.7	8.0	--------	2.0
O. Sandy clay, conglomeratic, with feldspar fragments altered to kaolinite, yellowish-white (5*Y* 9/1)	6.5	64	21	.8	.02	.2	.9	.5	8.1	4.0	1.6	4.4	8.0	--------	2.0
P. Sandy silty clay, conglomeratic, with feldspar fragments altered to kaolinite, weak-yellowish-orange (10*YR* 7/6)	12.0	62	21	4.2	.01	.2	1.0	.6	8.6	3.9	2.0	4.1	8.0	--------	2.0
Q. Silty clay, yellowish-white (5*Y* 9/1)	3.0	57	28	1.0	.01	.3	1.1	.5	12.2	1.3	3.7	5.0	9.0	--------	1.0
Base of Latah Formation.															
R. Saprolite, basalt, weak-brown (10*YR* 4/2)	(5.0)	32	21	21.6	.50	.7	Tr.	6.1	11.4	--------	--------	10.0	--------	10.0	--------

St. Paul, and Pacific Railroads serve the town and plant. The deposit presently contains three clay pits: the Mica pit, the North Pit, and the South pit. In 1963, clay from the Latah Formation was mined from the North and South pits for making refractory brick and building brick in a variety of colors and styles, and the Palouse Formation was mined in the South pit for producing reddish-brown building bricks.

A total of 43 auger holes (M–35 to M–77) were drilled in the deposit by the U.S. Bureau of Mines in 1942. Logs and assays of these drill holes were given by Hosterman, Scheid, Allen, and Sohn (1960, p. 55–62). The deposit consists of basalt saprolite overlain by a relatively thick section of the Latah Formation. Pre-Tertiary rocks crop out to the north and east of the deposit. The Palouse Formation covers the entire deposit to depths ranging from 1 to 28 feet, and upper Columbia River Basalt that filled a valley cut into the pre-Teritary basement divides the deposit into two parts.

Excellent exposures of the Latah Formation are found in both the North and South clay pits near Mica (pl. 1). In the North pit, 85.8 feet of Latah Formation overlies pre-Tertiary gneiss saprolite and is covered by the Palouse Formation (table 10). In the South pit, 107 feet of Latah Formation overlies basalt saprolite and is overlain by the Palouse Formation (table 11). At both pits, the Latah is composed of yellowish-orange to white clay and sand that are silty in places. The individual beds range in thickness from 1 foot to 28 feet. The clay minerals in both pits are kaolinite and illite in an average ratio of 8:2. There are about 700 acres of Latah Formation averaging 20 feet in thickness and containing an average of about 30 percent clay and 21 percent Al_2O_3.

Basalt saprolite was penetrated in every auger hole in the Mica clay deposit. It ranges in thickness from 3.5 feet (auger hole M–70) to 46 feet (auger hole M–42). A good exposure of basalt saprolite can be seen along an old railroad siding at Mica below the old Mica clay pit. Description and analyses of units in this section are given in table 12. The basalt saprolite is bluish gray, or pale olive to weak yellow, and is composed chiefly of halloysite and ilmenite. A very small amount of nontronite is visible in some of the samples. Approximately 900 acres are underlain by basalt saprolite. Most of this area is also overlain by Latah Formation. The average thickness of the basalt saprolite is 19 feet; it averages 26.5 percent Al_2O_3, based on the assays by the Bureau of Mines (Hosterman and others, 1960, p. 55–62), and contains 90–95 percent clay-size material.

FREEMAN CLAY PIT AND DEPOSIT

The Freeman clay pit and deposit are in parts of secs. 34, 35, and 36, T. 24 N., R. 44 E., and secs. 1 and 2, T. 23 N., R. 44 E. (pl. 1). State

TABLE 10.—*Stratigraphic section, chemical composition, and mineralogy of units of the Latah Formation in the North clay pit, sec. 14, T. 24 N., R. 44 E*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10, by weight)	
										Sand	Silt	Clay	Kaolinite	Illite
Palouse Formation.														
Latah Formation:														
A. Sandy clay, pinkish-white (5*YR* 9/1) to white (*N*9)	7.6	64	25	0.8	0.01	0.2	1.1	0.7	8.2	3.8	1.7	4.5	8.5	1.5
B. Sand and gravel, pinkish-white (5*YR* 9/1)	1.0	72	18	.3	.01	.2	1.8	.3	3.8	8.3	.4	1.3	8.2	1.8
C. Sandy silty clay, light-gray (*N*8) to white (*N*9)	3.6	64	25	.6	.02	.1	1.3	.8	8.3	3.0	2.0	5.0	8.1	1.9
D. Clayey silty sand, white (*N*9)	1.4	67	22	.5	.01	.2	1.6	.4	6.6	4.6	2.2	3.2	6.2	3.8
E. Silty sandy clay, white (*N*9)	1.6	65	27	.6	.02	.1	1.5	.6	8.9	3.6	2.6	3.8	7.5	2.5
F. Clayey sand, white (*N*9)	1.0	67	23	.4	.05	.1	2.1	.4	5.6	5.4	1.6	3.0	8.0	2.0
G. Clayey silty sand, white (*N*9)	1.6	67	23	.6	.01	.2	1.7	.6	6.6	4.8	2.0	3.1	7.7	2.3
H. Clayey sand, pinkish-white (5*YR* 9/1) to white (*N*9)	6.0	70	21	.6	.01	.1	2.0	.5	5.7	5.4	1.5	3.1	8.0	2.0
I. Sand, light-gray (*N*8)	5.0	73	18	.3	.01	.1	2.6	.2	2.6	7.4	1.3	1.3	8.5	1.5
J. Sandy silty clay, white (*N*9)	5.0	62	24	.6	.01	.2	2.0	.9	7.9	3.5	2.4	4.1	8.5	1.5
K. Clayey silty sand, white (*N*9)	5.0	68	22	.5	.01	.1	2.4	.4	5.6	5.7	2.3	2.0	8.0	2.0
L. Sandy silty clay, plastic, pinkish-gray (5*YR* 7/1)	8.0	60	26	.6	.01	.2	2.1	1.0	9.4	2.1	3.0	4.9	6.5	3.5
M. Clayey silty sand, pinkish-gray (10*R* 8/1)	7.0	70	21	.4	.01	.1	2.5	.5	5.3	5.3	2.2	2.5	8.0	2.0
N. Clayey silty sand, white (*N*9)	10.0	62	25	.6	.01	.1	2.8	.6	7.6	5.0	2.2	2.8	8.0	2.0
O. Clayey sand, white (*N*9)	12.0	70	20	.6	.01	.1	2.8	.4	4.9	5.9	1.7	2.4	7.5	2.5
P. Clayey silty sand, white (*N*9)	1.0	70	22	.7	.01	.1	2.6	.5	6.3	4.0	2.8	3.2	7.0	3.0
Q. Sandy silty clay, carbonaceous, light-brownish-gray (10*YR* 6/1); buried soil	9.0	55	26	.6	.01	.3	2.2	.9	14.4	2.6	3.0	4.4	6.0	4.0
Base of Latah Formation.														
R. Saprolite, gneiss	(5.0)	66	20	.4	.01	.3	3.5	.6	11.1	6.0	2.0	2.0	8.5	1.5

TABLE 11.—*Stratigraphic section, chemical composition, and mineralogy of units of the Latah Formation in the South clay pit, sec. 23, T. 24 N., R. 44 E.*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10, by weight)		
										Sand	Silt	Clay	Kaolinite	Halloysite	Illite
Palouse Formation.															
Latah Formation:															
A. Clayey sand, weak-yellowish-orange (10*YR* 7/3)	6.0	74	18	2.6	0.07	0.2	1.9	0.4	5.0	6.0	1.7	2.3	7.0		3.0
B. Clayey sand, weak-yellowish-orange (2.5*Y* 8/4)	4.0	72	18	2.0	.01	.2	1.7	.7	7.3	4.6	1.5	3.9	9.5		.5
C. Sandy clay, weak-yellowish-orange (10*YR* 7/3)	6.0	65	21	3.6	.04	.3	1.1	1.1	7.9	2.9	1.3	5.8	9.0		1.0
D. Silty clay, white (*N*9)	11.0	54	28	1.5	.02	.4	1.3	1.1	13.0	1.8	1.9	6.3	8.5		1.5
E. Silty sandy clay, light-gray (*N*8)	5.0	55	26	1.8	.02	.4	2.5	1.0	10.5	3.1	2.2	4.7	8.0		2.0
F. Sand, yellowish-gray (10*YR* 8/1)	13.0	72	18	1.6	.04	.3	3.8	.4	3.0	7.5	1.0	1.5	6.5		3.5
G. Sandy clay, yellowish-gray	6.0	60	25	1.3	.03	.4	1.5	1.4	11.3	2.4	1.7	5.9	9.0		1.0
H. Clay, white (*N*9)	4.0	55	30	.9	.02	.3	1.8	1.1	11.2	.6	1.8	7.6	9.0		1.0
I. Clayey sand, white (*N*9)	6.0	74	17	.5	.01	.2	2.8	.5	2.5	7.0	1.2	1.8	7.0		3.0
J. Sand, yellowish-gray (10*YR* 8/1)	8.0	73	17	.9	.03	.2	3.1	.5	2.4	7.4	1.3	1.2	6.0		4.0
K. Silty clay, yellowish-gray (10*YR* 8/1)	1.0	61	24	1.4	.02	.2	2.2	1.0	9.3	2.0	3.8	1.2	7.5		2.5
L. Sand, yellowish-gray (10*YR* 8/1)	6.0	73	17	1.1	.03	.2	2.9	.5	2.3	7.2	1.4	1.4	6.0		4.0
M. Silty sandy clay, light-brownish-gray (10*YR* 6/1)	1.0	58	25	1.0	.03	.3	2.7	1.1	9.9	2.7	2.3	4.9	7.5		2.5
N. Clayey sand, yellowish-gray (10*YR* 7/1)	28.0	72	18	1.1	.03	.2	2.7	.5	2.9	6.7	1.4	1.8	7.0		3.0
O. Silty sandy clay, brownish-gray (10*YR* 4/1); old soil	2.0	58	22	2.3	.03	.4	2.8	.9	12.7	2.8	2.8	4.3	7.0		3.0
Base of Latah Formation.															
P. Saprolite, basalt, light-brownish-gray (10*YR* 6/1)	(10.0)	68	16	2.1	.03	.3	2.5	1.3	9.0		2.0	8.0	2.0	8.0	

TABLE 12.—*Stratigraphic section and chemical composition of basalt saprolite along old railroad siding at Mica, sec. 23, T. 24 N., R. 44 E.*

[Analyses by X-ray fluorescence method; results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition
A. Saprolite, basalt, pale-olive (5*Y* 6/2)	1.5	44	20	12.2	0.19	0.5	0.4	8.0	13.3
B. Saprolite, basalt, pale-olive (5*Y* 6/3)	1.6	40	26	9.7	.05	.4	.1	8.1	15.8
C. Saprolite, basalt, light-bluish-gray (2.5*B* 8/1)	3.6	39	28	7.6	.06	.3	.1	9.1	14.4
D. Saprolite, basalt, light-olive-gray (5*Y* 6/1)	1.8	42	25	7.6	.06	.6	.1	9.6	15.6
E. Saprolite, basalt, bluish-gray (5*B* 6/1)	3.2	39	27	6.1	.05	.4	.1	9.6	14.7
F. Saprolite, basalt, light-bluish-gray (5*B* 8/1)	3.0	38	28	7.6	.06	.4	.1	9.2	12.8
G. Saprolite, basalt, weak-yellow (5*Y* 8/2)	.3	40	28	6.2	.03	.3	.1	9.3	14.2
H. Saprolite, basalt, light-bluish-gray (5*B* 7/1)	2.8	39	28	8.2	.06	.4	.2	9.4	11.6
Total or weighted averages	17.8	40	27	8.1	.07	.4	.11	9.1	13.9

Highway 3H (the Palouse highway) and several gravel roads traverse the area. The town of Freeman is in the center of the area, and it is served by the Northern Pacific and the Chicago, Milwaukee, St. Paul, and Pacific railroads. The clay pit at Freeman was operated for 35 years, from 1902 to 1937, and during this time the clay was washed at Freeman and shipped 11 miles to Dishman or 44 miles to Clayton for processing.

Twenty-seven auger holes were drilled in the vicinity of the Freeman clay deposit (holes 32, 45–59, 71–81, p. 67, 68–69, 71–72). As shown on plate 1, the deposit consists of saprolite developed on pre-Tertiary igneous and metamorphic rocks in the northeastern half of the deposit, and basalt saprolite in the southern half of the deposit. A small amount of Latah Formation overlies the basalt near its contact with saprolite of pre-Tertiary rocks. The entire area is overlain by 10–50 feet of Palouse Formation.

Twenty feet of saprolite of pre-Tertiary igneous and metamorphic rocks are exposed in the east wall of the Freeman clay pit. The lithologic description and analyses of the units sampled are given in table 13. The depth of the saprolite is unknown, but a well 285 feet deep at Freeman reportedly did not strike hard rock (Goodspeed and Weymouth, 1928, p. 688). The original rock types recognizable by textural features (fig. 3) at the Freeman pit are granite, gneiss, quartzite, and aplite and pegmatite dikes. Kaolinite is the predominant clay mineral and is the result of alteration of feldspars and muscovite. Only a minor amount of halloysite is present, indicating that in the presence of muscovite, feldspars alter predominantly to kaolinite (Sand, 1956, p. 39). The biotite has altered to muscovite, and the edges of most muscovite flakes have been kaolinized. Illite and the illitic mixed-layer clay mineral can be found in a few samples, but, in general, kaolinite is more than 90 percent of the clay minerals present. Because of the predominance of kaolinite and the lack of iron oxide minerals, the clay in the Freeman pit is yellowish white to almost white.

The pre-Tertiary rock saprolite in the Freeman clay deposit, which roughly parallels the highway, covers an area of approximately 1,000 acres. Eight auger holes (32, 45, 47, and 71–75) and the Freeman pit penetrate the saprolite to an average depth of 42 feet. None of the auger holes cut hard rock, and drill holes 45 and 72 penetrate more than 80 feet of saprolite. Twenty-one samples from the clay pit and drill holes were analyzed for Al_2O_3, and the average is 22 percent (tables 1 and 13, samples 32A, 45A–F, 72A–E, and 74A).

Twenty feet of pre-Tertiary argillite saprolite was cut in auger hole 77 beneath 70 feet of basalt saprolite and 10 feet of Palouse Formation. The argillite is silty and light brown (2.5*YR* 5/6) and contains about 50 percent clay composed of kaolinite. The thickness and extent of this saprolite are not known because it was found at the bottom of only one auger hole. Similar material is mined by the International Pipe and Ceramic Co. near Fairfield (sec. 30, T. 22 N., R. 42 E.).

The basalt saprolite in the Freeman deposit overlies the pre-Tertiary rocks in the southern part of the area and is below average in quantity and quality of clay. In 11 auger holes (50–57, 76–78) in an area of approximately 1,000 acres, the basalt saprolite averages about 14 feet in thickness. Analyses of four samples from these holes give an average of 18 percent Al_2O_3, 21 percent Fe_2O_3, and 6 percent TiO_2. The basalt saprolite in auger hole 77 is composed of about 60 percent nontronite, 30 percent halloysite, and 10 percent ilmenite. The nontronite gives the saprolite a yellowish-brown color and accounts largely for the high iron content. In section 12, T. 33 N., R. 44 E., south of the Freeman deposit, the basalt saprolite probably contains less nontronite and more halloysite. Here, three auger holes (79–81) show that the light-gray to bluish-gray saprolite is about 24 feet thick over an estimated 300–400 acres. The saprolite was not analyzed, but comparison with clay of similar color and plasticity suggests it probably contains at least 30 percent Al_2O_3 and less than 5 percent Fe_2O_3.

VALLEYFORD CLAY DEPOSIT

The Valleyford clay deposit is in secs. 33 and 34, T. 24 N., R. 44 E., and secs. 3, 4, 9, and 10, T. 23 N., R. 44 E. (pl. 1). The deposit is bordered on the north by California Creek and on the south by Cottonwood Creek, both tributaries to Rock Creek. The town of Valleyford is in the northwestern part of the deposit area. Gravel roads traverse

316-000 O—68——7

TABLE 13.—*Stratigraphic section, chemical composition, and grain-size distribution of pre-Tertiary rock saprolite at the Freeman clay pit, sec. 1, T. 23 N., R. 44 E.*

[Analyses by X-ray fluorescence; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)		
										Sand	Silt	Clay
A. Saprolite, gneiss, clayey sandy silt, yellowish-gray (5*Y* 8/1)	1. 2	51	25	5. 6	0. 60	0. 2	0. 1	5. 8	11. 1	3. 0	4. 2	2. 8
B. Saprolite, granite, clayey silty sand, yellowish-white (5*Y* 9/1)	2. 5	64	25	. 9	. 40	. 2	. 8	. 1	9. 7	4. 5	3. 2	2. 3
C. Saprolite, gneiss, silty sand, yellowish-white (5*Y* 9/1)	2. 6	66	24	. 7	. 10	. 1	1. 3	(1)	8. 8	4. 9	3. 6	1. 4
D. Saprolite, sandstone, silty sand, yellowish-white (5*Y* 9/1)	8. 0	72	20	. 6	. 20	. 1	. 4	. 3	5. 4	6. 4	2. 2	1. 4
E. Saprolite, granite, clayey silty sand, yellowish-white (5*Y* 9/1)	1. 5	72	21	. 9	. 10	. 1	2. 2	. 1	6. 3	5. 6	2. 4	2. 0
F. Saprolite, sandstone, silty sand, yellowish-white (5*Y* 9/1)	1. 0	75	17	. 4	. 10	. 1	. 1	. 3	4. 4	6. 2	2. 2	1. 6
G. Saprolite, aplite, clayey sandy silt, yellowish-white (5*Y* 9/1)	1. 0	64	26	. 7	. 10	. 1	. 1	. 2	9. 8	3. 5	3. 4	3. 1
H. Saprolite, granite, silty sand, yellowish-white (5*Y* 9/1)	2. 6	66	25	. 8	. 20	. 1	. 9	. 1	8. 6	5. 1	3. 5	1. 4

[1] Trace.

the area. The nearest railroad is at Freeman, about 2 miles east of the deposit. There are no clay pits within the deposit area.

A total of 26 auger holes have been drilled in the area. Logs of these auger holes (19–31, 33–44) are given on pages 66–67 and 67–68, and the locations of the holes are shown on plate 1. The deposit consists predominately of basalt saprolite overlain by younger basalt flows that filled the ancestral valleys of California and Cottonwood Creeks. The Palouse Formation covers the area, excluding the creek valleys, to a depth of 30 feet.

Basalt saprolite occurs in four separate areas. One is estimated to be about 80 acres in size (auger holes 19 and 39), another is about 600 acres (auger holes 33, 34, 37, 42, and 44), and two small areas are about 15 acres each (auger holes 28 and 42). The basalt saprolite averages 18 feet in thickness in these auger holes. The Al_2O_3 content in two random samples (33A and 42A) is about 17 percent, a value well below the 22 percent average for basalt saprolite (table 3); the same samples contain approximately 65 percent nontronite, 25 percent halloysite, and 10 percent ilmenite and limonite.

MICA CREEK AREA

The area south of Mica Peak drained by Mica Creek and Lake Creek contains two undeveloped clay deposits (pl. 1), the Manito and Saxby clay deposits which are named after two stations on the Chicago, Milwaukee, St. Paul, and Pacific Railroad. The outline of these two deposits is arbitary, and both deposits contain basalt saprolite and Latah Formation. Pre-Tertiary rocks occur within the deposits, but they are not sufficiently weathered to contain large amounts of clay.

MANITO CLAY DEPOSIT

The Manito clay deposit is in parts of secs. 3, 4, 5, 7, 8, and 9, T. 23 N., R. 45 E. (pl 1). There are no clay pits within the limits of this deposit, but the deposit is well known as a nontronite collecting locality. The area is traversed by Elder Road and other gravel roads. The Mica Creek Church is at the northern edge of the deposit; Mica Creek crosses the deposit from north to south.

Twenty-four auger holes have been drilled in the area of the Manito clay deposit. Logs of these auger holes (82–105) are on pages 72–76, and the location of the holes is shown on plate 1. The deposit consists of flat-lying basalt flows filling a north-trending embayment in pre-Tertiary igneous and metamorphic rocks. The basalt is overlain by isolated patches of sands and clays of the Latah Formation. The basalt and the Latah Formation are covered by 3–42 feet of loess of the Palouse Formation except where exposed in road and railroad cuts.

Alluvium fills the Mica Creek drainage valley, and small patches of fresh, unweathered basalt are found adjacent to the creek (pl. 1) at the same elevation as the basalt saprolite. The basalt represents the last flow that moved into the ancestral valley of Mica Creek. It was probably not thick enough to cover the adjacent ridges, but it did dam the creek and cause a lake to form in which the Latah Formation was deposited. Because fresh basalt is more resistant to erosion than basalt saprolite, the dam was breached at the basalt–basalt saprolite contact, and a new stream valley was formed. This accounts for the occurrence, at the same elevation, of fresh, unweathered basalt cropping out west of Mica Creek and basalt saprolite cropping out east of Mica Creek on Elder Road.

The Latah Formation occurs in three areas near Manito, and several good exposures can be seen in roadcuts along Elder Road and in railroad cuts that parallel the road (pl. 1). One area is west of Manito in the vicinity of the Elder Road-Palouse Highway junction. Here, the Latah is estimated to cover an area of about 300 acres and to average about 6 feet in thickness. Auger holes 84 and 87 penetrated 3 feet of silty clay, but auger holes 82 and 88 penetrated only sand. A larger area of Latah Formation extends from Manito northward and is estimated to cover about 350 acres and to average 22 feet in thickness. The northern part of this area is underlain by clayey sand (auger hole 92), and the southern part, aroun Manito, is underlain mostly by sandy clay (auger holes 94, 95, and 97). The third area underlain by Latah Formation is at the Mica Creek Church site near the southeast corner of sec. 33, T. 24 N., R. 45 E. The Latah Formation here is composed of sandy micaceous clay, is estimated to cover about 40 acres, and seems to be no more than 16 feet thick. Two samples of Latah Formation from the Manito deposit were analyzed. They indicate the Al_2O_3 content of the formation is about 24 percent. The Al_2O_3 content can be increased by beneficiation by washing because of the large amount of sand present in the samples.

The basalt saprolite underlies the entire north-trending Mica Creek embayment, an area of approximately 3½ square miles. In 15 auger holes the average thickness is about 22 feet. Basalt saprolite crops out in two roadcuts on Elder Road. One outcrop is half a mile west of Manito (SE¼ sec. 5, T. 23 N., R. 45 E.) and the other is east of Mica Creek (SW¼ sec. 3, T. 23 N., R. 45 E.). The outcrop west of Manito contains gray basalt saprolite with vugs and vesicles filled with white halloysite and yellowish-green nontronite. Nontronite also occurs as fillings in cracks and crevices (fig. 5). The outcrop east of Mica Creek contains an excellent example of zoning in saprolite due to weathering of basalt (fig. 7). The only samples of basalt saprolite analyzed from the Manito clay deposit were those taken at Mica Creek, and they averaged about 27 percent Al_2O_3, 8 percent Fe_2O_3, and 6 percent TiO_2.

SAXBY CLAY DEPOSIT

The Saxby clay deposit, in parts of secs. 1, 2, 11, and 12, T. 23 N., R. 45 E., and secs. 6 and 7, T. 23 N., R. 46 E., in Washington; and in parts of secs. 1, 12, 13, and 24, T. 48 N., R. 6 W., and secs. 5, 8, 17, and 19, T. 48 N., R. 5 W., in Idaho (pl. 1), is north of Saxby, a station on the Chicago, Milwaukee, St. Paul, and Pacific Railroad. Although no clay has been mined from this deposit, it has been explored by 37 auger holes. Logs of these auger holes (106–142) are on pages 76–82, and the location of the holes is shown on plate 1.

Patches of Latah Formation resting on flat-lying basalt fill two small embayments in the pre-Tertiary rocks around McGowan Butte. The Palouse Formation covers most of the deposit to a depth of 2–30 feet, and alluvium fills the Lake Creek valley. Fresh, unweathered basalt crops out at the edge of the valley. This basalt represents the last flows that moved into the Lake Creek ancestral valley. The basalt dammed the creek and caused a lake to form in which the Latah Formation was deposited. In time, the dam was breached and the present stream valley was formed.

The Latah Formation occurs in four areas north and northeast of Saxby. One area covers about 300 acres in the small embayment on the west side of McGowan Butte. In two auger holes (108 and 109) the formation averages 22 feet in thickness and is composed of sandy clay and clayey sand. In three samples from auger hole 108 the the Al_2O_3 content is about 30 percent. A little-known second area covering about 250 acres is on the south and east flanks of McGowan Butte. In three auger holes (116, 136, and 139), the Latah Formation averages 20 feet in thickness and consists of silty and clayey sand and sandy and silty clay. One sample of reddish-gray silty clay from auger hole 136 contained almost 27 percent Al_2O_3, and two samples of silty clay from auger hole 139 averaged 32 percent Al_2O_3. A third area, about 400 acres, occupies the northern part of the Lake Creek embayment. In seven auger holes (117, 118, 121, 125, 126, 127, and 135), the Latah Formation averages 36 feet in thickness; the maximum thickness recorded is 86 feet in auger hole 118. In this area, the formation contains clay, silty and sandy clay, clayey sand, and sand. Four samples of Latah Formation from auger hole 118 averaged 22 percent Al_2O_3. A fourth area, about 250 acres, is cut by auger holes 131, 133, and 134 on the west side of the Lake Creek embayment. In these auger holes the formation averages 3 feet in thickness. One sample of clayey sand from auger hole 131 contained 22 percent Al_2O_3, and one sample of silty clay contained 32 percent Al_2O_3.

Basalt saprolite underlies the Saxby deposit in an area of at least 5½ square miles. The saprolite, which averages about 17 feet thick in 23 auger holes (106–109, 111, 114–117, 119, 121, 125, 127, 129, 131–136, 139–141), is not exposed at the surface. The color of the saprolite in auger-hole cuttings varies from bluish and yellowish gray and yellowish brown to brownish black and olive black. Eleven samples of basalt saprolite averaged almost 24 percent Al_2O_3 and about 4 percent TiO_2. Two samples of yellowish-gray basalt saprolite (108C and 116A, table 19) contained more than 35 percent Al_2O_3. As both of these samples are from the top unit of the saprolite and as both contain a small amount of kaolinite, they are considered to be contaminated by the Latah Formation.

Data accumulated from the auger holes in the Saxby area indicate the presence of economic clay deposits. The Latah Formation contains appreciable quantities of silty clay which is usable for making building and face brick. Beneficiation of the clay would improve the quality so that the clay would be usable for refractory products, as a paper filler, or as an ore of aluminum. The basalt saprolite contains sufficient halloysite to be used also as an aluminum ore with a byproduct of titanium from ilmenite.

SPOKANE RIVER VALLEY AREA

The commercial clay deposits in the Spokane River valley include the Somers pit near Dishman and the Shelly Lake pit near Veradale. These are called pits rather than deposits because the amount of clay, exclusive of that in the pit, is very limited. The clay from the Somers pit is currently used by the International Pipe and Ceramic Co. in making face and building brick. At the Shelly Lake pit, clay is mined for use by the Ideal Cement Co. in making cement. Other clay deposits are found near the mouths of Latah Creek and Deep Creek. These two clay deposits have not been developed commercially, however, because of their basalt overburden and inaccessible location.

SOMERS CLAY PIT

The Somers clay pit is in the NW¼NW¼SE¼ sec. 35, T. 25 N., R. 44 E. (fig. 1). This pit was previously known as the Chester or Vera pit, and when it was opened many years ago the raw material was hauled 3 miles to be processed into brick at a plant at Chester. The plant is no longer in existence, and at present only a very small amount of clay is mined each year by the International Pipe and Ceramics Co. and hauled 6 miles to their plant at Mica.

According to Glover (1941, p. 253), in 1937 the Somers pit had a 20- to 25-foot working face of Latah Formation that was overlain by 1–5 feet of Palouse Formation. Drilling indicated that the maximum thickness of the Latah Formation was 45 feet. Glover also stated that areal extent of the deposit was not more than 20 acres. Since that time, most of the Latah Formation has been removed. Table 14 gives the stratigraphic sequence and chemical analyses of the Latah Formation remaining in the pit. The formation consists of flat-lying beds of clay and sand. The clay beds and the clay associated with the sand beds consist of 85 percent kaolinite and 15 percent illite.

SHELLY LAKE CLAY PIT

The Shelly Lake clay pit (fig. 1) is on the south side of the Spokane River valley in the NW¼NW¼SW¼ sec. 19, T. 25 N., R. 45 E. The pit is currently mined to supply clay for the Ideal Cement Co. plant at Irwin, Wash., 5 miles away. At the pit, the Latah Formation has a maximum thickness of about 80 feet and covers an area of less than 10 acres with little or no overburden. Undoubtedly the deposit extends under the upper basalt flows and may be several times larger than is known. A basalt dike cuts across the flat-lying formation in the western edge of the pit. Table 15 gives the chemical composition of the Latah Formation as determined by X-ray fluorescence analysis. The large quantity of silt present causes the Al_2O_3 content to be lower than the average for the Latah Formation. The clay fraction averages 55 percent montmorillonite, 30 percent kaolinite, and 15 percent illite. The illite and montmorillonite do not occur as a mixed-layer clay mineral.

OTHER AREAS CONTAINING CLAY

ORCHARD PRAIRIE AREA

Orchard Prairie is a fairly flat area of about 5 square miles northeast of Hillyard and southeast of Mead (pl. 2). Six auger holes (143–148) in the prairie penetrated pre-Tertiary igneous and metamorphic rocks, Columbia River Basalt, and Latah Formation overlain by an average of 24 feet of Palouse Formation clayey silt loess and glacial debris.

The pre-Tertiary rock saprolite at auger hole 147 is more than 83 feet thick and is composed of clay and clayey sand. The clay from the upper part of the auger hole averaged about 23 percent Al_2O_3 and was composed of 60 percent kaolinite, 30 percent illite, and 10 percent montmorillonite (table 19, samples 147A and 147B). Two samples representing 34 feet of basalt saprolite in auger hole 143 (table 19, samples 143B and 143C) averaged almost 20 percent Al_2O_3, 12 percent Fe_2O_3, and 5 percent TiO_2. The basalt saprolite is in an area estimated to be about 100 acres in the NW¼ sec. 23, T. 26 N., R. 43 E. The Latah Formation is in an area of about 300 acres in the NW¼ sec. 23

TABLE 14.—*Stratigraphic section, chemical composition, and mineralogy of the Latah Formation at the Somers clay pit*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-ten by weight)			Clay mineral (parts-in-ten by weight)	
										Sand	Silt	Clay	Kaolinite	Illite
A. Clay, weak-yellowish-orange (2*Y* 8/4)	1.7	56	24	5.1	0.03	0.5	1.3	1.3	11.9	-------	1.0	9.0	9.0	1.0
B. Clay, pale-reddish-brown (10*R* 5/4)	1.7	50	21	16	.03	.2	1.5	1.2	11.2	-------	2.0	8.0	8.0	2.0
C. Clay, weak-orange (5*YR* 6/6	.7	43	19	22	.04	.2	1.5	1.2	11.5	-------	2.0	8.0	7.5	2.0
D. Clay, weak-yellowish-orange (10*YR* 7/6)	.8	50	21	17	.05	.2	1.3	1.3	11.8	-------	2.0	8.0	8.0	2.5
E. Clay, dusky-yellowish-orange (10*YR* 6/6)	.3	12	13	60	.07	.1	1.1	.9	12.3	-------	2.0	8.0	10.0	-------
F. Clayey silty sand, yellowish-white (5*Y* 9/1)	.5	64	25	.6	.01	.1	2.6	1.0	6.1	5.6	2.0	2.4	9.0	1.0
G. Clay, very pale brown (10*YR* 7/3)	2.7	60	24	3.5	.01	.2	1.8	1.4	10.6	-------	2.5	7.5	8.5	1.5
H. Silty sandy clay, very pale orange (7.5*YR* 8/2)	1.0	58	29	1.7	.04	.1	1.4	1.1	10.4	2.0	2.7	5.3	9.0	1.0
I. Sand, weak-yellowish-orange (10*YR* 7/4)	1.0	78	12	3.4	.04	(1)	.9	.2	2.4	8.0	1.0	1.0	7.5	2.5
Base not exposed.														

[1] Trace.

TABLE 15.—*Stratigraphic section, chemical composition, and mineralogy of the Latah Formation at the Shelly Lake clay pit*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10, by weight)		
										Sand	Silt	Clay	Kaolinite	Illite	Montmorillonite
A. Clayey silt, weak-yellow (5*Y* 8/2)	25.0	65	19	3.6	0.03	0.6	2.9	0.8	7.7	0.8	7.0	2.2	2.5	1.5	6.0
B. Clayey silt, light-brownish-gray (10*YR* 6/1); contains wood fragments	15.0	65	18	3.7	.03	.7	2.8	.7	9.8	1.2	6.8	2.0	4.0	2.0	4.0
C. Clayey silt, light-olive-gray (5*Y* 5/1); contains wood fragments	20.0	64	16	6.2	.07	1.1	2.6	.8	10.9	1.5	5.9	2.6	2.5	1.5	6.0
D. Clayey silt, light-olive-gray (5*Y* 5/1); contains diatoms and wood	20.0	61	18	6.7	.09	1.0	2.6	.8	12.1	.7	6.2	3.1	4.0	2.0	4.0
Base not exposed.															

and S½ sec. 24, T. 26 N., R. 43 E., and averages 19 feet in thickness, based on two widely separated auger holes (143 and 146). The formation in three auger holes is silty and sandy clay, clay, clayey silt, and clayey sand. One sample of clayey silt from auger hole 143 contained 18 percent Al_2O_3 (table 19, sample 143A). The Latah Formation clay bed was not sampled and analyzed because it is only 1 foot thick and of little economic importance.

PLEASANT PRAIRIE AREA

Pleasant Prairie, another fairly flat area and east of Orchard Prairie, is about 10 square miles in the southern half of T. 26 N., R. 44 E. (pl. 2). Sixteen auger holes (149–164) were drilled to determine if any clay is present. The prairie is covered by the Palouse Formation loess and glacial debris to a depth of 2–42 feet. Pre-Tertiary igneous and metamorphic rocks occur as saprolite beneath the Palouse Formation in the eastern one-third of the prairie (auger holes 158, 161, and 162). The saprolite is composed of quartz and some clay (table 19, sample 161A). Unweathered basalt, representing the youngest flows of the Columbia River Basalt, underlies the Palouse Formation in most of the western two-thirds of the prairie.

The Latah Formation is found beneath the Palouse Formation in two areas where the younger basalt is not present (auger holes 149, 163, and 164). Auger hole 149 penetrated 95 feet of silty clay, clayey silt, and clayey sand. The highest Al_2O_3 analysis is 19 percent for a silty clay sample (table 19, samples 149A–C). Furthermore, less than 10 acres of Latah Formation is not covered by basalt. Another area of sedimentary material, estimated to be about 100 acres, occurs in the vicinity of auger holes 163 and 164. Here, the Latah Formation is 43 feet thick in auger hole 163 and 7 feet thick in auger hole 164. The material is very micaceous and is composed of silty clay, clayey silt, and clayey sand. No analyses were made, but the Al_2O_3 content is estimated to be less than 20 percent.

FOOTHILLS AREA

The Foothills area is an extension of Pleasant Prairie that covers approximately 5 square miles in secs. 2, 3, 10, 11, 14, and 15, T. 26 N., R. 44 E. (pl. 2). Seventeen auger holes (165–181) were drilled to determine the extent and character of the clay-bearing units. The prairie is covered by the Palouse Formation to an average depth of 19 feet. Pre-Tertiary saprolite rock occurs beneath 3 feet of basalt saprolite in auger hole 165 as clayey, micaceous, and quartzose material 10 feet thick. Unweathered basalt that represents the youngest flows is found in the center of the prairie in auger holes 172, 173, and 174, and around the edges of the prairie in auger holes 169, 179, and 181. Elsewhere, the Latah Formation occurs beneath the Palouse

Formation where the younger basalt is not present. In an area around Foothills and the west-trending ridge to the south, estimated to be about 1,000 acres, the Latah Formation averages 22 feet in thickness (auger holes 166, 167, 168, 170, and 171). In another area, estimated as 600 acres, northwest of Foothills, the Latah Formation averages 12 feet in thickness (auger holes 175, 176, 177, 178, and 180). In the larger area, the Latah Formation contains beds of clay, silt, and sand; in the smaller area, it is composed only of clay beds. Table 19 (samples 166A–D, 167A and B, 170A–D, 177A, and 178A) gives the analyses of 12 samples of Latah Formation which averaged 22 percent Al_2O_3. Basalt saprolite occurs beneath the Latah Formation in eight auger holes (167, 168, 171, 175, 176, 177, 178, and 180) and beneath the Palouse Formation in auger holes 165 and 179. The saprolite averages 9 feet in thickness, and three samples average 26 percent Al_2O_3 and 6.8 percent TiO_2 (table 19, samples 177B and C, and 178B).

PEONE PRAIRIE-DEADMAN CREEK AREA

The Peone Prairie–Deadman Creek area is east of Mead and covers approximately 15 square miles (pl. 2). Fourteen auger holes (182–195) were drilled in the area to determine the existence, extent, and character of the clay-bearing units. Peone Prairie, now a dry lake bed, was formed as a result of glacial ice and debris damming Deadman Creek during Pleistocene time. The maximum depth of the lake deposit is unknown because eight of the nine auger holes (182–190) did not reach the bottom of the deposit. Three samples (table 19, samples 183A and B and 189A) were analyzed and found to be high in SiO_2 (66 percent) and low in Al_2O_3 (16 percent). The lake sediments consist primarily of clayey silt with some sand and gravel beds and very few clay beds. The minerals in the clay fraction are kaolinite (20 percent), illite (20 percent), and montmorillonite (60 percent). Trace amounts of chlorite were found in two samples. The illite, montmorillonite, and chlorite do not occur as mixed-layer clay minerals.

The Latah Formation is penetrated by auger hole 192 (sec. 14, T. 26 N., R. 43 E.) on the south edge of Peone Prairie and crops out on the northern slope of Deadman Creek valley (sec. 27, T. 27 N., R. 44 E.). Auger hole 192 cuts more than 95 feet of clayey silt that averages about 20 percent Al_2O_3 (table 19, samples 192A and C). In the vicinity of auger hole 192, the Latah Formation is limited by basalt on the south and the lake deposit on the north and probably covers about 300 acres. Auger hole 193 on the northern slope of Deadman Creek valley cuts 85 feet of clayey silt averaging about 18 percent Al_2O_3 (table 19, samples 193A–E). A small pit at this locality supplied a few tons of material for use in art pottery, according to the property owner. The Latah Formation in the vicinity of auger hole 193 covers approximately 200 acres, and it is limited to the north by overlying basalt.

North of Peone Prairie, three auger holes (196, 197, and 198) were drilled on Green Bluff to explore for clay. The results were disappointing, and the likelihood of a clay deposit seems dim. The drilling indicated, however, that Green Bluff is underlain directly by Palouse Formation and unweathered basalt. The average depth of the Palouse Formation loess and glacial debris is 24 feet. The Latah Formation may underlie Green Bluff, but if this is so, it is overlain by fresh unweathered basalt.

FIVEMILE PRAIRIE AREA

Fivemile Prairie (fig. 1) is an area of approximately 5 square miles immediately north of the Spokane city limits. It has a fairly flat surface and is at an elevation of about 2,400 feet or approximately 200 feet above the city proper. The prairie is underlain directly by an average of 7 feet of Palouse Formation glacial debris and brown clayey silt. Under this thin cover is a sheet of basalt about 100 feet thick (auger holes 200 and 202). Basalt saprolite was not penetrated by the auger drilling. The Latah Formation underlies the basalt in auger hole 199 on the north side of the prairie, in auger hole 203 on the southeast side, and in a small clay pit on the southwest side. The Latah Formation, where found, is composed primarily of clayey silt with a few clayey sand and silty clay beds. The section exposed in the clay pit consists of 30 feet of white silty clay, 5 feet of coarse sand, and 10 feet of very sandy silty clay at the base. Six samples from the two auger holes (table 19, samples 199A–C and 203A–C) and one sample from the clay pit averaged 16 percent Al_2O_3 and 63 percent SiO_2. The low clay content and the overburden of massive basalt suggest that the Latah Formation at Fivemile Prairie has a very low economic potential.

MORAN PRAIRIE AREA

An area of approximately 4 square miles (secs. 9, 10, 15, and 22, T. 24, N., R. 43 E.) south of Moran Prairie (fig. 1) and west of Browne Mountain is underlain by a thick section of the Latah Formation. The area is covered with the Palouse Formation, which has an average thickness of 8 feet in three auger holes (204–206). The Latah Formation averages 70 feet in thickness and is underlain by basalt in auger hole 206 and by pre-Tertiary gneiss in auger hole 205. The Latah Formation found in the auger holes is composed primarily of silt and clay beds with a few beds of sand. Three samples were analyzed (table 19, samples 205A and B, and 206A) and averaged 19 percent AL_2O_3.

West of Moran Prairie, beds of similar lithology crop out in a cut along Latah Creek. The Latah Formation, as exposed in a railroad cut, is composed of 12 feet of light-gray clay overlain by 10 feet of yellowish-brown clayey silt. The base of the formation is not exposed, and the top of the formation is covered by talus. According to Pardee and Bryan (1926) the Latah Formation here is more than 250 feet thick, if it is stratigraphically continuous from the cut to the base of the overlying basalt.

LANDING CLAY PIT

The Landing clay pit is in sec. 32, T. 30 N., R. 42 E., about 8 miles north of Deer Park (fig. 1). Clay is being mined by the International Pipe and Ceramics Co. for use in their plant at Mica. The clay is almost white and slightly silty and has excellent plasticity and a high alumina content. A 20-foot section was measured and is described in table 16. Five samples averaged 23 percent Al_2O_3 and 3 percent Fe_2O_3. The clay fraction consists of kaolinite, illite, and montmorillonite. Illite constitutes about 20 percent of the clay in all samples; montmorillonite constitutes 50 percent of the clay in the upper two samples only and is not present in the others; and kaolinite amounts range from 30 percent in the upper samples to 80 percent in the lowest sample. The deposit around the pit extends over less than 100 acres, all of which is owned or leased by the brick company.

MILAN CLAY PIT

The Milan pit, in the NE¼NE¼ sec. 10, T. 28 N., R. 43 E., exposes part of the Latah Formation, which is very similar in lithology and chemical composition to that in the Shelly Lake pit. The pit was opened in 1958 to supply raw material for a lightweight-aggregate plant at Mead, about 13 miles to the south. This plant operated for about 1 year and supplied aggregate for the Adams Street bridge in Spokane. Tests by the U.S. Bureau of Mines of material from this pit indicate that it would not make a very good lightweight aggregate (Howard P. Hamlin, U.S. Bur. Mines, written commun., 1962). Table 17 gives the chemical composition of the silt as determined by X-ray fluorescence. The Al_2O_3 content averages about 15 percent, which is low because of the low clay and high silt contents. The clay fraction consists of 20 percent kaolinite, 10 percent illite, 70 percent montmorillonite, and a trace of mixed-layer clay minerals (montmorillonite-illite).

CERAMIC-TEST DATA

Ceramic tests were made on 17 whole samples and five beneficiated samples of pre-Tertiary rock saprolite, Latah Formation, basalt saprolite, and Palouse Formation. Results of these firing tests, as

TABLE 16.—*Stratigraphic section, chemical composition, and mineralogy of the Latah Formation at the Landing clay pit, sec. 32, T. 30 N., R. 42 E.*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10 by weight)			Clay mineral (parts-in-10 by weight)		
										Sand	Silt	Clay	Kaolinite	Illite	Montmorillonite
A. Silty clay, yellowish-gray (10*YR* 8/1)	3.0	60	22	4.4	0.02	0.6	2.2	1.0	12.3	--------	2.7	7.3	2.5	2.5	5.0
B. Silty clay, weak-yellow (2.5*Y* 8/2)	3.0	62	22	2.8	.02	.4	2.3	.9	10.1	--------	2.8	7.2	3.0	2.0	5.0
C. Silty clay, white (*N*9)	3.0	61	24	2.1	.02	.4	2.2	.9	10.4	--------	2.7	7.3	7.0	2.5	.5
D. Silty clay, white (*N*9)	7.0	60	26	1.6	.02	.3	2.0	1.2	10.5	--------	3.1	6.9	7.5	2.5	----------
E. Silty clay, weak-yellowish-orange (10*YR* 7/6)	4.0	60	21	6.8	.03	.3	1.9	.9	9.1	--------	4.0	6.0	8.0	2.0	----------

TABLE 17.—*Stratigraphic section, chemical composition, and mineralogy of the Latah Formation at the Milan pit, sec. 10, T. 28 N., R. 43 E.*

[Analyses by X-ray fluorescence method; chemical results in weight percent]

Description of lithologic units	Thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10, by weight)		
										Sand	Silt	Clay	Kaolinite	Illite	Montmorillonite
A. Silt, light-olive-gray (5*Y* 6/1)	11.0	67	18	4.2	0.06	0.4	3.2	0.7	7.4	1.5	7.0	1.5	3.0	2.0	5.0
B. Silt, pale-brown (2.5*Y* 5/2)	11.0	66	17	4.7	.07	.7	2.8	.7	8.6	2.0	6.5	1.5	2.0	1.0	7.0
C. Silt, pale-brown (10*YR* 6/2)	11.0	68	18	3.4	.04	.5	2.8	.7	6.5	3.0	6.0	1.0	1.0	0.5	8.5

well as the physical properties of the samples, are given in table 18. These ceramic tests were made under the direction of the late Howard P. Hamlin at the U.S. Bureau of Mines Research Laboratories in Norris, Tenn. The following procedure is used to determine whether or not the clay is suitable for ceramic uses.

The clay sample is dried at 110°C and then ground to pass through a 20-mesh screen. A 100-gram sample is used for the Atterberg test (Klinefelter and Hamlin, 1957, p. 20), which is a measurement of the workability of the clay and the minimum amount of water needed for the clay to become plastic (water of plasticity). The water-moist clay is molded into five uniform-size small bricks and allowed to dry slowly. The drying-shrinkage percentage, dry strength, and drying characteristics are carefully measured and noted.

To determine the effects of heat on the clay the five briquets are placed in a furnace and slowly heated from room temperature to 2,300°F. As the temperature of the furnace reaches 1,800°, 2,000°, 2,100°, 2,200°, and 2,300°F, one briquet is extracted at a time and allowed to cool slowly. The above temperatures are chosen because they cover the temperature range used in the ceramic industry. After the briquets cool, the color, hardness, linear shrinkage percentage, percent absorbtion, and apparent specific gravity are measured and noted for each brick.

The pyrometric cone equivalent (PCE) was determined for nine of the raw samples and five of the beneficiated samples. This test is a standard determination used to evaluate the refractoriness of a clay. The PCE of a clay is determined by preparing a pyramidal cone of certain dimensions and heating it along with standard commercial cones of the same size and shape in a specified manner until deformation takes place. The PCE is the number of the standard cone whose deformation takes place at the same time and temperature as that of the clay cone. On the basis of pyrometric cone equivalents, superheat-duty refractories have a cone of 33 or greater (1,745°C, or 3,170°F); high-heat-duty refractories have a cone of 31–33 (1,680°C–1,745°C, or 3,060°F–3,170°F); intermediate-heat-duty refractories have a cone of 26–31 (1,595°C–1,680°C, or 2,900°F–3,170°F); and low-heat-duty refractories have a cone of 20–26 (1,530°C–1,595°C, or 2,790°F–2,900°F). Other ceramic products mature at much lower pyrometric cone equivalents, such as face brick at cone 02 (1,093°C, or 2,000°F), art pottery at cone 06 (1,005°C, or 1,840°F), and stoneware at cone 8 (1,225°C, or 2,240°F).

Grim (1962, p. 52–140) discussed the influence of the clay-mineral composition on properties of fired and unfired clays. The kaolin minerals affect the properties of the unfired clay much less than montmorillonite (nontronite) and illite. Plasticity, drying shrinkage, and

TABLE 18.—*Ceramic-test data*

[Data from U.S. Bureau of Mines]

	Sample	Water of plasticity	Drying shrinkage	Dry (green) strength [1]	Drying [2] characteristics	Pyrometric cone equivalent (PCE)	Percent linear shrinkage						Percent absorption					
							982°C 1,800°F	1,093°C 2,000°F	1,149°C 2,100°F	1,205°C 2,200°F	1,260°C 2,300°F	1,315°C 2,400°F	982°C 1,800°F	1,093°C 2,000°F	1,149°C 2,100°F	1,205°C 2,200°F	1,260°C 2,300°F	1,315°C 2,400°F
Saprolite of pre-Tertiary rocks:																		
Freeman clay pit, composite sample (table 13)	1521–B–1	28.0	5.0	L	G	32+	5.0	5.0	5.0	5.0	5.0	5.0	28.1	27.4	26.7	26.2	24.6	24.7
Same, washed	1521–B–2	57.0	7.5	A	G	34–35	7.5	10.0	10.0	15.0	15.0	17.5	43.1	41.0	37.3	28.4	23.8	20.4
Hole 45, composite sample (A–F)	1551–C	27.6	5.0	F	G	----------	5.0	5.0	7.0	9.5	9.5	9.5	20.8	20.4	20.0	18.1	17.0	16.5
Hole 77, sample E	1551–D	27.1	5.0	F	C	----------	5.0	5.5	9.0	10.0	10.0	10.0	23.1	21.5	19.5	13.9	12.8	11.7
Latah Formation:																		
North clay pit, composite sample (table 10)	1521–C–1	19.0	3.5	L	G	31	5.0	5.0	5.0	5.0	5.0	5.0	18.6	17.6	16.1	14.7	13.2	11.1
Same, washed	1521–C–2	40.0	5.0	A	G	34–35	10.0	12.5	15.0	17.0	17.5	18.5	26.5	17.0	9.5	5.5	2.5	.8
South clay pit, composite sample (table 11)	1521–D–1	21.0	5.0	L	G	28–29	5.0	5.0	7.5	7.5	7.5	7.5	19.2	16.7	16.0	15.8	13.6	12.0
Same, washed	1521–D–2	33.0	5.5	A	G	32–33	5.0	9.0	14.0	16.0	16.0	20.0	23.7	26.6	10.3	4.5	.8	.7
Excelsior clay pit, composite sample (table 9)	1521–E–1	29.0	7.5	L	G	31	7.5	7.5	7.5	9.0	9.0	9.0	24.8	23.1	20.0	19.5	16.3	13.7
Same, washed	1521–E–2	40.4	6.5	A	G	32–33	9.5	10.0	15.0	16.0	20.0	20.0	28.4	23.8	15.2	9.9	7.3	5.5
Landing clay pit composite sample (table 16)	1521–F	35.0	7.5	A	G	26	10.5	15.0	16.5	16.5	19.5	17.5	18.7	7.4	4.8	.6	.3	2.5
Somers clay pit, composite sample (table 14)	1521–H	32.0	5.0	L	G	18	6.0	10.0	10.0	12.5	12.5	12.5	26.1	19.4	17.4	14.7	10.9	7.1
Hole 108, sample B	1551–E	22.1	5.0	G	W	33	2.5	5.0	5.5	10.0	10.0	10.0	19.7	17.3	16.6	11.2	10.4	9.6
Hole 77, sample A	1551–F	30.7	5.0	G	-------	----------	7.0	14.5	14.5	17.5	17.5	20.0	20.4	8.0	7.3	1.5	.6	.8
Hole 167, sample A	1572–B	40.6	9.5	F	G	----------	10.5	14.5	19.5	19.5	20.0	20.0	21.0	12.8	10.8	9.8	5.4	5.0
Saprolite of basalt:																		
Railroad siding at Mica (table 12)	1521–A	44.0	5.0	A	G	27	12.0	12.5	18.0	22.5	22.5	22.5	28.1	24.4	14.6	6.6	6.1	4.2
Roadcut at Mica Creek (table 3)	1521–G–1	40.0	5.0	L	G	18	8.5	10.0	12.5	15.0	15.0	17.5	32.1	25.1	28.8	22.1	15.5	11.7
Same, washed	1521–G–2	37.0	5.0	A	G	23–26	10.0	14.5	15.0	15.0	19.0	20.0	26.5	19.3	18.5	15.8	9.8	5.5
Hole 121, sample A	1572–A	45.6	10.0	F	F	----------	14.0	15.0	17.5	19.5	21.0	21.0	20.2	21.3	16.0	11.0	6.6	5.0
Hole 129, sample A	1572–C	67.2	5.5	F	F	----------	9.0	9.0	10.0	13.5	15.0	20.0	49.2	48.2	38.7	39.7	35.0	27.0
Palouse Formation:																		
Hole 20, sample A	1551–B	24.8	9.5	G	G	----------	9.5	10.5	11.0	14.5	14.5	(4)	12.9	11.0	8.1	2.1	1.7	14.0
Hole 175, sample A	1551–A	21.2	7.5	G	G	----------	7.5	7.5	7.5	10.0	10.0	(4)	14.0	12.0	10.3	6.2	3.3	11.6

TABLE 18.—*Ceramic-test data*—Continued

	Apparent specific gravity						Hardness [3]						Color (Munsell)					
	982°C 1,800°F	1,093°C 2,000°F	1,149°C 2,100°F	1,205°C 2,200°F	1,260°C 2,300°F	1,315°C 2,400°F	982°C 1,800°F	1,093°C 2,000°F	1,149°C 2,100°F	1,205°C 2,200°F	1,260°C 2,300°F	1,315°C 2,400°F	982°C 1,800°F	1,093°C 2,000°F	1,149°C 2,100°F	1,205°C 2,200°F	1,260°C 2,300°F	1,315°C 2,400°F
Saprolite of pre-Tertiary rocks:																		
Freeman clay pit, composite sample (table 13)	2.64	2.62	2.60	2.63	2.61	2.61	SC	SC	SC	SC	SC	SC	5*YR* 9/1	5*YR* 9/1	5*YR* 9/1	5*YR* 9/1	5*YR* 9/1	5*YR* 9/1
Same, washed	2.61	2.59	2.61	2.60	2.63	2.60	SC	SC	FH	H	SH	SH	*N*10	*N*10	*N*10	*N*10	*N*10	*N*10
Hole 45, composite sample (A–F)	2.60	2.62	2.64	2.65	2.66	2.64	FH	H	H	H	VH	VH	5*YR* 6/3	5*YR* 7/2	5*YR* 7/2	5*YR* 6/2	5*YR* 6/2	5*YR* 6/1
Hole 77, sample E	2.86	2.88	2.89	2.87	2.85	2.85	SC	FH	H	H	VH	VH	2.5*YR* 5/4	2.5*YR* 5/4	2.5*YR* 5/4	2.5*YR* 4/2	2.5*YR* 4/2	10*R* 4/1
Latah Formation:																		
North clay pit, composite sample (table 10)	2.62	2.61	2.62	2.60	2.56	2.50	SC	SC	SC	SC	H	VH	10*R* 9/1	10*R* 9/1	10*R* 9/1	5*Y* 9/1	5*Y* 9/1	5*Y* 9/1
Same, washed	2.53	2.56	2.54	2.52	2.46	2.43	SC	H	SH	SH	SH	SH	10*R* 9/1	10*R* 9/1	5*Y* 9/1	5*Y* 9/1	5*Y* 9/1	5*Y* 9/1
South clay pit, composite sample (table 11)	2.63	2.61	2.58	2.58	2.50	2.46	SC	SC	H	VH	SH	SH	5*YR* 8/3	10*YR* 8/3	10*YR* 8/3	10*YR* 8/2	5*Y* 8/1	5*Y* 8/1
Same, washed	2.51	2.51	2.45	2.42	2.34	2.37	VH	VH	SH	SH	SH	SH	7.5*YR* 8/4	7.5*YR* 8/2	7.5*YR* 8/2	10*YR* 8/2	5*Y* 7/1	5*Y* 7/1
Excelsior clay pit, composite sample (table 9)	2.64	2.63	2.61	2.64	2.60	2.56	SC	SC	H	VH	VH	SH	5*YR* 8/4	2.5*YR* 8/2	7.5*YR* 8/4	10*YR* 8/2	2.5*Y* 7/2	10*YR* 8/1
Same, washed	2.60	2.58	2.63	2.57	2.54	2.54	H	VH	SH	SH	SH	SH	2.5*Y* 8/2	5*YR* 8/2	7.5*YR* 8/2	10*YR* 8/2	5*Y* 7/3	5*Y* 7/3
Landing clay pit, composite sample (table 16)	2.59	2.51	2.46	2.36	2.39	2.28	H	SH	SH	SH	SH	SH	2.5*YR* 7/6	7.5*YR* 7/4	7.5*YR* 7/4	10*YR* 6/3	2.5*YR* 6/2	7.5*Y* 6/2
Somers clay pit, composite sample (table 14)	2.82	2.82	2.82	2.76	2.73	2.72	SC	SC	H	VH	VH	SH	2.5*YR* 6/6	2.5*YR* 5/4	10*R* 5/3	10*R* 4/2	5*R* 3/1	10*YR* 2/1
Hole 108, sample B	2.66	2.68	2.63	2.58	2.55	2.54	FH	H	H	VH	VH	VH	7.5*YR* 8/4	10*R* 9/2	10*R* 9/1	10*R* 9/1	10*R* 9/1	5*YR* 9/1
Hole 77, sample A	2.54	2.49	2.50	2.38	2.37	2.36	FH	H	H	VH	VH	SH	10*YR* 9/2	2.5*YR* 8/4	2.5*YR* 8/4	2.5*Y* 7/2	2.5*Y* 7/2	2.5*Y* 7/2
Hole 167, sample A	2.59	2.54	2.48	2.52	2.42	2.46	FH	FH	H	H	VH	VH	7.5*YR* 7/4	7.5*YR* 7/4	7.5*YR* 7/4	10*YR* 7/4	10*YR* 6/4	7.5*YR* 6/4
Saprolite of basalt:																		
Railroad siding at Mica (table 12)	2.69	2.69	2.70	2.69	2.68	2.65	SC	FH	SH	SH	SH	SH	7.5*YR* 7/2	2.5*Y* 7/2	2.5*Y* 7/2	5*Y* 6/2	5*Y* 6/2	5*Y* 5/2
Roadcut at Mica Creek (table 3)	2.84	2.81	2.80	2.80	2.77	2.73	SC	SC	SC	H	VH	SH	10*YR* 7/3	5*Y* 8/3	5*Y* 8/3	5*Y* 7/2	5*Y* 6/1	5*Y* 5/1
Same, washed	2.68	2.66	2.66	2.63	2.65	2.63	H	VH	VH	SH	SH	SH	10*YR* 8/3	2.5*Y* 8/2	5*Y* 8/3	5*Y* 7/3	5*Y* 6/2	5*Y* 5/1
Hole 121, sample A	2.55	2.63	2.57	2.55	2.53	2.50	FH	FH	H	VH	VH	VH	10*YR* 7/3	10*YR* 7/3	10*YR* 7/3	10*YR* 7/3	10*YR* 7/3	10*YR* 6/3
Hole 129, sample A	2.06	2.07	2.21	2.20	2.27	2.26	S	FH	------	H	H	H	5*YR* 9/2	5*YR* 9/2	5*YR* 9/2	10*YR* 9/2	10*YR* 9/2	10*YR* 9/2
Palouse Formation:																		
Hole 20, sample A	2.55	2.60	2.59	2.51	2.26	2.23	FH	H	H	SH	SH	SH	5*YR* 6/6	5*YR* 5/4	5*YR* 5/4	2.5*YR* 4/2	2.5*YR* 4/2	5*YR* 4/1
Hole 175, sample A	2.67	2.69	2.69	2.63	2.57	2.26	FH	H	H	VH	SH	SH	5*YR* 6/6	5*YR* 5/4	2.5*YR* 5/4	2.5*YR* 4/2	2.5*YR* 4/2	5*YR* 4/1

[1] G, good; A, average; F, fair; L, low.
[2] G, good; F, fair; W, warped; C, cracked.
[3] SC, soft crumbly; FH, fairly hard; H, hard; VH, very hard; SH, steel hard.
[4] Expanded.

bonding strength are high for montmorillonite, a little lower for illite, and much lower for kaolinite and halloysite. Therefore, any montmorillonite and illite present in high kaolin clay deposits will change the physical properties of the unfired clays considerably. Samples of less chemically altered saprolite containing abundant montmorillonite and nontronite were not tested for their ceramic properties, because the amount of nonclay minerals is high and the material is not suitable for any ceramic product.

The influence of mineral composition on the properties of fired clay is complicated by the presence of minor elements and impurities in the clay lattice and by nonclay minerals. Iron oxide minerals, and montmorillonite and illite which contain iron, burn red or yellow. The kaolin minerals burn white or light buff. Montmorillonite and illite contain alkalies either within the atomic lattice or as adsorbed-ion impurities. These impurities make montmorillonite and illite generally nonrefractory. Kaolinite, on the other hand, contains little or no alkalies or alkaline earths (fluxes); therefore, this clay mineral makes an excellent refractory product. Halloysite and metahalloysite are very difficult to use in ceramic ware because they do not develop a gradual glassy phase prior to fusion, as kaolinite does. Consequently, clay with a small amount of halloysite tends to crack into small pieces as firing shrinkage develops. However, halloysite and metahalloysite clays are calcined and used as grog in refractory products because heating to 1,000°C (calcining) eliminates the high shrinkage due to the extra molecule of water. Small amounts of halloysite and metahalloysite clays are often used in fine ceramic ware to increase the translucency and whiteness of the ware.

Illite and montmorillonite contain some potassium, sodium, and calcium which act as fluxes and lower the temperature of fusion to the extent that the clay becomes nonrefractory. Iron-bearing minerals, such as ilmenite and nontronite, also reduce the refractoriness of the clay by fluxing the material. Quartz apparently is primarily a diluent and has little or no effect on the fusion but reduces the amount of kaolinite present. In general, therefore, the refractoriness of a clay is directly proportional to the amount of alumina present and inversely proportional to the amount of iron oxide present. However, it does not follow that two samples with the same alumina and iron oxide content will be equally refractory, because the other fluxing materials may be more abundant in one than in the other.

Three whole samples and one washed sample of pre-Tertiary rock saprolite were tested for their ceramic properties (table 18). Sample 1521B, from the Freeman clay pit, shows a low green strength and is soft and crumbly when fired, because it contains abundant quartz and muscovite. However, after beneficiation the green strength was average, and, after firing, the hardness improved. The PCE of the unwashed sample was 32+, but after beneficiation the PCE was 34–35, good enough to make a superheat-duty refractory product. Therefore, on the basis of only one sample, it seems likely that beneficiation of this saprolite can improve the ceramic properties. Sample 1551C (auger hole 45) fires light pink to gray pink and is suitable for decorative tile and art pottery. Sample 1551D (auger hole 77, sample E), which has a high iron content, fires reddish brown to dark red. This color is unsuitable for a refractory product, but the material would make a good building brick or tile.

Four samples of basalt saprolite were tested for their ceramic properties (table 18). The green strength and drying characteristics were fair to good. Samples 1521A, 1521G, and 1572A had excessive linear shrinkage, especially at the higher temperatures. Sample 1572C had an extremely high percentage of water absorption. All samples, however, fired hard to steel hard and had light colors. The PCE tests showed a range from cone 18 to cone 27, indicating that the basalt saprolite is suitable as a low- to intermediate-heat-duty refractory. The washing of sample 1551G did not improve its ceramic properties sufficiently to warrant beneficiation. Clays derived from basalt contain halloysite which is very difficult to use in ceramic ware because, like metahalloysite, it does not become glassy prior to fusion; therefore, it cracks as firing shrinkage develops. Basalt saprolite could be used as calcined grog in refractory products.

Eight samples of Latah Formation were tested for their ceramic properties (table 18). Three of the more sandy samples were washed to evaluate improvement in the ceramic properties after beneficiation. Four of the samples had low green strength, which improved in the three beneficiated samples. The drying characteristics in all samples were good, except in sample 1551E, which warped. All samples fired hard to steel hard with no abnormal change in shape or color. The PCE tests showed a range from cone 26 to cone 35, indicating that the clay would be suitable for intermediate- to superheat-duty refractory products. One sample had a cone of 18, indicating that it would not be suitable for refractory products. This sample was unusual because it contained more iron than is normal in most of the Latah Formation and was, therefore, not representative. Samples 1551F and 1572B have no potential use without beneficiation. Sample 1521H, high in iron, would make a suitable red common brick, and sample 1521F has attractive mottled colors when fired that make it a potential decorative brick product. Sample 1551E warped on drying, and although it had a PCE cone of 33 it would not make a good refractory product; however, it may be suitable for bleaching oil if treated properly (Howard P. Hamlin, written commun., 1963). Samples 1521C, 1521D, and 1521E would make good refractory products, especially if washed. The whiter samples such as 1521C could probably be used in the manufacture of white cement.

Two samples of the Palouse Formation were tested for their ceramic properties (table 18). Both samples were plastic, smooth, fatty, and long working; their green strength and drying characteristics were good. All samples fired hard to steel hard with a slight expansion at 2,300°F. The clayey silt of the Palouse Formation is suitable for making structural brick products. A small amount of the clayey silt is currently being used to make common brick in Spokane County. Although the Palouse material showed some expansion on firing, the expansion occurred at a temperature so high that production of expandable aggregate from this material would not be economical. There may be a possibility of sintering the clayey silt to make aggregate, but lack of coal in the Spokane area may make this unfeasible.

ECONOMIC GEOLOGY

Spokane County is the second largest producer of clay products in the State of Washington. At the present rate of production, the county has sufficient clay reserves to last for many years. Currently, clay is being used in making building and face brick, for refractory products, and in the cement industry. Furthermore, a small amount of clay has been used in the past for ceramic artware products and lightweight aggregate.

The best use of clays in Spokane County is in the manufacture of ceramic products. This category includes all clay products that are molded and baked, such as structural clays used in making building and face brick. Refractory products are made from clays that have a high fusion point (pyrometric cone of 19 or above). The manufacture of portland cement utilizes silty clay. Lightweight aggregate for concrete is made by firing clays that will expand naturally or by sintering. The possible future nonceramic uses of clay in Spokane County are as a source of alumina and as a filler.

The material used in the manufacture of building brick is cohesive and plastic, and it can be dried and fired without distortion. The clay minerals are usually a mixture of kaolinite and illite and occasionally a small amount of montmorillonite. The percentage of nonclay minerals is high to help control the drying and firing shrinkage and to give the finished product a marketable color. Most of the beds, other than sand and conglomerate, in the Latah Formation, and parts of the Palouse Formation and lake deposits are suitable for making common building brick.

The best quality refractory products are made from material containing a large amount of kaolinite and a small amount of illite, montmorillonite, or mixed-layer clay minerals. Saprolite from the pre-Tertiary igneous and metamorphic rocks and most of the Latah Formation generally are of this composition. Much of the material, however, has to be beneficiated to obtain a high-quality refractory product, but the byproducts, quartz and muscovite, may have an economic potential. Basalt saprolite can be used in making refractory products, but it would also require beneficiating and calcining. The beneficiation would yield ilmenite as a byproduct; calcining would be necessary to drive out the water in the halloysite.

The only requirement of clay and shale for the cement industry is that they meet certain chemical specifications dictated by the lime rock being used. The Latah Formation at the Shelly Lake pit meets these specifications. There is an abundance of material similar to that in the Shelly Lake pit in Latah Creek, in Deep Creek, and near Milan.

During and since World War II, interest has been focused on kaolin clay deposits in the United States as a possible source of aluminum. As yet, it is not economically feasible to mine clay for alumina in the Northwest, although alumina is being processed from kaolin clay deposits in Georgia. It is estimated that the Spokane County resources of clay containing more than 20 percent alumina amount to 80 million tons of saprolite from pre-Tertiary rocks, 196 million tons of basalt saprolite, and 225 million tons in the Latah Formation. The best grade clay is in the Saxby area, where approximately 22 million tons of clay in the Latah Formation contains almost 30 percent alumina. The Manito, Saxby, Freeman, and Mica areas have about 163 million tons of basalt saprolite containing more than 25 percent alumina. The deposit at Freeman is the only one in Spokane County that has a large amount of saprolite from pre-Tertiary rocks that contains more than 20 percent Al_2O_3. Benefication of the clay deposits would raise the Al_2O_3 content from 20 percent to almost 35 percent.

Clays are used for fillers in a large number of products such as paper, asphalt, linoleum, rubber, and paint. The most important user of clay as a filler is the paper industry, which uses large tonnages per year. The color and grain size of the clay minerals are very important; only white kaolinite can be used satisfactorily. Kaolinite found in the pre-Tertiary rock saprolite and some kaolinite found in the Latah Formation meet the requirement for paper filler, but probably not for paper coating.

Clay beds in the Latah Formation have been used for making lightweight aggregate in the past. However, the venture was not bery profitable, and, according to the ceramic tests, the aggregate made from clay in the Latah Formation was not very good. The clay could be sintered by using coal as a source of heat, but the process would not be economic because coal is not readily available in Spokane County.

The dry bulk densities of the clay-bearing units and some of the clay minerals are listed below for comparison and for use in calculating clay reserves:

Pre-Tertiary rock saprolite (average of four samples)	1.66
Diabase saprolite	3.37
Basalt saprolite (average of five samples)	1.30
Basalt (average of two samples)	2.48
Halloysite in basalt saprolite	1.49
Nontronite in basalt saprolite	1.75
Latah Formation (average of five samples)	1.71
Palouse Formation	1.85

The bulk densities of the pre-Tertiary rock saprolite and the material from the Latah Formation are very similar. The saprolite from basalt is found to weigh about half as much as the basalt per unit volume, indicating that there is a large weight loss and low volume change when the basalt is chemically weathered. The bulk density of the Palouse Formation is slightly higher than that of the Latah Formation. This is probably due to the tightly packed clayey silt and the montmorillonite content.

AUGER-HOLE LOGS

CALIFORNIA CREEK AREA

Formation	*Sample (table 19)*	*Depth (ft)*	*Description*
			Auger hole 1; elev. 2,540 ft; sec. 29, T. 24 N., R. 44 E.
Palouse		0–25	Silty clay.
Basalt		25–32	Saprolite, olive-black (5*Y* 2/1).
			Auger hole 2; elev. 2,495 ft; sec. 31, T. 24 N., R. 44 E.
Palouse		0–38	Silty clay.
Basalt		38–46	Saprolite, dusky-olive (5*Y* 2/2).
		46	Bedrock.
			Auger hole 3; elev. 2,645 ft; sec. 20, T. 24 N., R. 44 E.
Palouse		0–76	Silty clay.
Pre-Tertiary		76–82	Saprolite, micaceous clayey sand, light-gray (*N*7).
		82	Gneiss.
			Auger hole 4; elev. 2,570 ft; sec. 20, T. 24 N., R. 44 E.
Palouse		0–55	Clayey silt.
Latah		55–61	Sandy clay, light-yellowish-brown (10*YR* 6/4).
		61–63	Clay, yellowish-white (10*YR* 8/1), very plastic.
		63–65	Sandy clay, light-yellowish-brown (10*YR* 6/4).
Basalt		65–74	Saprolite, bluish-gray (5*B* 5/1).
		74	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 5; elev. 2,560 ft; sec. 20, T. 24 N., R. 44 E.			
Palouse		0–56	Clayey silt.
		56–57	Sand and gravel.
Basalt		57–70	Saprolite, bluish-gray (5*B* 5/1).
		70	Rock.
Auger hole 6; elev. 2,515 ft; sec. 20, T. 24 N., R. 44 E.			
Palouse		0–16	Clayey silt, contains some gravel at base.
Basalt		16–20	Saprolite, bluish-gray (5*B* 5/1); white nodules of halloysite.
		20–28	Saprolite, brownish-gray (2.5*Y* 4/4); green nodules of nontronite.
Auger hole 7; elev. 2,535 ft; sec. 29, T. 24 N., R. 44 E.			
Palouse		0–34	Clayey silt.
Basalt		34–41	Saprolite, bluish-gray (5*B* 5/1).
		41	Rock.
Auger hole 8; elev. 2,530 ft; sec. 29, T. 24 N., R. 44 E.			
Palouse		0–33	Clayey silt.
Basalt		33–35	Saprolite, pale-brown (2*Y* 6/2).
		35–41	Saprolite, bluish-gray (5*B* 5/1).
		41–48	Saprolite, pale-olive (5*Y* 5/2).
Auger hole 9; elev. 2,495 ft; sec. 29, T. 24 N., R. 44 E.			
Palouse		0–16	Clayey silt, sand and gravel at base.
Basalt		16–19	Saprolite, bluish-gray (5*B* 5/1).
		19–25	Saprolite, olive-black (5*Y* 2/1).
Auger hole 10; elev. 2,525 ft; sec. 21, T. 24 N., R. 44 E.			
Latah		0–27	Sandy clay, light-gray (*N*8), conglomeratic.
Basalt	A	27–30	Saprolite, bluish-gray (5*B* 5/1).
	B	30–35	Saprolite, pale-brown (2.5*Y* 6/2).
	C	35–40	Saprolite, weak-brown (2.5*Y* 4/2).
	D	40–45	Clay, light-olive (5*Y* 5/1).
		45	Rock.
Auger hole 11; elev. 2,500 ft; sec. 20, T. 24 N., R. 44 E.			
Palouse		0–10	Clayey silt.
Basalt		10–18	Saprolite, dark-bluish-gray (5*B* 4/1).
		18–20	Semidecomposed basalt.
Auger hole 12; elev. 2,535 ft; sec. 28, T. 24 N., R. 44 E.			
Palouse		0–40	Clayey silt.
Latah		40–50	Clay, light-gray (*N*7), plastic.
Auger hole 13; elev. 2,525 ft; sec. 28, T. 24 N., R. 44 E.			
Palouse		0–5	Clayey silt.
Latah	A	5–12	Silty sand, yellowish-white (10*YR* 9/2).
Basalt	B	12–13	Saprolite, pale-blue (5*PB* 6/2).
	C	13–18	Saprolite, greenish-gray (5*GY* 5/1).
	D	18–28	Saprolite, light-olive-gray (5*Y* 6/1).
	E	28–38	Saprolite, weak-yellow (7.5*Y* 7/2).
	F	38–43	Saprolite, light-olive-brown (5*Y* 5/3).
	G	43–53	Saprolite, pale-blue (5*PB* 7/2).
	H	53–63	Saprolite, olive-gray (5*Y* 4/1).
	I	63–73	Saprolite, light-olive-gray (5*Y* 6/1).
	J	73–78	Saprolite, yellowish-gray (5*Y* 8/1).
	K	78–80	Saprolite, light-olive-brown (2.5*Y* 5/4).

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 13—Continued
Pre-Tertiary	L	80–92	Saprolite, micaceous clayey sand, weak-yellowish-orange (2.5*Y* 8/4).
			Auger hole 14; elev. 2,520 ft; sec. 21, T. 24 N., R. 44 E.
Palouse		0–16	Clayey silt.
Basalt		16–19	Saprolite, light-olive-brown (5*Y* 5/3).
		19–24	Saprolite, weak-olive (5*Y* 3/2).
			Auger hole 15; elev. 2,555 ft; sec. 28, T. 24 N., R. 44 E.
Palouse		0–34	Clayey silt.
Basalt		34–45	Saprolite, olive-black (5*Y* 2/1).
		45	Rock.
			Auger hole 16; elev. 2,505 ft; sec. 29, T. 24 N., R. 44 E.
Palouse		0–32	Clayey silt.
Basalt		32–37	Saprolite, olive-black (5*Y* 2/1).
		37	Rock.
			Auger hole 17: elev. 2.465 ft; sec. 28, T. 24 N., R. 44 E.
Palouse		0–7	Clayey silt.
Basalt		7	Rock.
			Auger hole 18; elev. 2,410 ft; sec. 28, T. 24 N., R. 44 E.
Alluvium		0–32	Sandy clay silt.
Basalt		32	Rock.
			Auger hole 19; elev. 2,560 ft; sec. 32, T. 24 N., R. 44 E.
Palouse		0–20	Silty clay.
Basalt		20–39	Saprolite, olive-gray (5*Y* 3/1).
			Auger hole 20; elev. 2,570 ft; sec. 4. T. 23 N., R. 44 E.
Palouse	A	0–34	Clayey silt, pale-brown (10*YR* 6/2).
Basalt		34	Rock.
			Auger hole 21; elev. 2,535 ft; sec. 4, T. 23 N., R. 44 E.
Palouse		0–20	Clayey silt.
Basalt		20	Rock.
			Auger hole 22; elev. 2,610 ft; sec. 5. T. 23 N., R. 44 E.
Palouse		0–67	Clayey silt.
Basalt		67	Rock.
			Auger hole 23; elev. 2,570 ft; sec. 5, T. 23 N., R. 44 E.
Palouse		0–50	Clayey silt.
Basalt		50–52	Saprolite, bluish-gray (5*B* 5/1).
		52	Rock.
			Auger hole 24; elev. 2,520 ft; sec. 5, T. 23 N., R. 44 E.
Palouse		0–12	Clayey silt.
Basalt		12	Rock.
			Auger hole 25; elev. 2,495 ft; sec. 5, T. 23 N., R. 44 E.
Palouse		0–5	Clayey silt.
Basalt		5	Rock.
			Auger hole 26; elev. 2,580 ft; sec. 4, T. 23 N., R. 44 E.
Palouse		0–37	Clayey silt.
Basalt		37	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 27; elev. 2,540 ft; sec. 4, T. 23 N., R. 44 E.			
Palouse		0–37	Silty clay.
Basalt		37	Rock.
Auger hole 28; elev. 2,545 ft; sec. 9, T. 23 N., R. 44 E.			
Palouse		0–35	Silty clay.
Basalt		35–38	Saprolite, bluish-gray (5*B* 5/1).
		38–56	Saprolite, olive-gray (5*Y* 3/1).
Auger hole 29; elev. 2,525 ft; sec. 9, T. 23 N., R. 44 E.			
Palouse		0–27	Silty clay.
Basalt		27	Rock.
Auger hole 30; elev. 2,530 ft; sec. 9, T. 23 N., R. 44 E.			
Palouse		0–49	Clayey silt.
Basalt		49	Rock.
Auger hole 31; elev. 2,495 ft; sec. 27, T. 24 N., R. 44 E.			
Palouse		0–16	Clayey silt.
Basalt		16	Rock.
Auger hole 32; elev. 2,590 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–48	Clayey silt.
Pre-Tertiary	A	48–70	Saprolite, micaceous sandy clay, very pale brown (7.5*YR* 7/2).
Auger hole 33; elev. 2,555 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–31	Clayey silt.
Basalt	A	31–44	Saprolite, pale-brown (2.5*Y* 6/2).
		44	Rock.
Auger hole 34; elev. 2,520 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–24	Clayey silt.
Basalt		24–30	Saprolite, dark-bluish-gray (5*B* 4/1).
		30–40	Saprolite, olive-gray (5*Y* 3/1).
Auger hole 35; elev. 2,530 ft; sec. 33, T. 24 N., R. 44 E.			
Palouse		0–8	Clayey silt.
Basalt		8	Rock.
Auger hole 36; elev. 2,530 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–12	Clayey silt.
Basalt		12	Rock.
Auger hole 37; elev. 2,530 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–24	Clayey silt.
Basalt		24–28	Saprolite, bluish-gray (5*B* 6/1).
		28–40	Saprolite, weak-olive (5*Y* 3/2).
		40–54	Saprolite, pale-olive (5*Y* 6/2).
		54	Rock.
Auger hole 38; elev. 2,490 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–17	Clayey silt, pale-brown (10*YR* 6/2), sand and gravel.
Basalt		17–18	Semidecomposed.
Auger hole 39; elev. 2,550 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–20	Clayey silt.
Basalt		20–22	Saprolite, weak-olive (5*Y* 3/2).
		22	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 40; elev. 2,525 ft; sec. 4, T. 23 N., R. 44 E.			
Palouse		0–33	Clayey silt.
Basalt		33	Rock.
Auger hole 41; elev. 2,530 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–48	Clayey silt.
Basalt		48	Rock.
Auger hole 42; elev. 2,510 ft; sec. 10, T. 23 N., R. 44 E.			
Palouse		0–37	Clayey silt.
Basalt		37–50	Saprolite, brownish-gray (2.5*Y* 3/1).
	A	50–67	Saprolite, pale brown (2.5*Y* 5/2).
Auger hole 43; elev. 2,505 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–37	Clayey silt.
Basalt		37	Rock.
Auger hole 44; elev. 2,535 ft; sec. 10, T. 23 N., R. 44 E.			
Palouse		0–47	Clayey silt.
Basalt		47–59	Saprolite, olive-black (5*Y* 2/1).
		59–63	Semidecomposed.
		63	Rock.
Auger hole 45; elev. 2,550 ft; sec. 26, T. 24 N., R. 44 E.			
Palouse		0–5	Clayey silt.
Pre-Tertiary	A	5–10	Saprolite, micaceous clayey sand, pale-red (10*R* 6/3).
	B	10–15	Saprolite, silty sandy clay, pale-red (5*R* 6/2).
		15–20	Saprolite, micaceous clayey sand, light-yellowish-gray (2.5*Y* 6/4).
	C	20–25	Saprolite, sand, light-yellowish-brown (10*YR* 6/3).
		25–30	Saprolite, micaceous, clayey sand, light-gray (*N*7).
	D	30–60	Saprolite, clayey silty sand, pale-red (10*R* 6/2).
	E	60–63	Saprolite, clayey sand, pinkish-white (10*R* 9/1).
	F	63–88	Saprolite, clayey sand, very pale brown (10*YR* 7/2).
Auger hole 46; elev. 2,560 ft; sec. 35, T. 24 N., R. 44 E.			
Palouse		0–35	Clayey silt.
Basalt		35–37	Saprolite, olive-black (5*Y* 2/1).
		37	Rock.
Auger hole 47; elev. 2,565 ft; sec. 35, T. 24 N., R. 44 E.			
Palouse		0–4	Clayey silt.
Pre-Tertiary		4–5	Saprolite, micaceous clay, pale-red (5*R* 6/2).
		5–37	Saprolite, micaceous sandy clay, medium-gray (*N*6).
		37–47	Saprolite, micaceous clayey sand, brownish-gray (5*Y* 4/1).
		47–50	Saprolite, clayey micaceous sand, pale-brown (10*Y* 7/2).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 48; elev. 2,620 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–45	Clayey silt.
Pre-Tertiary		45	Gneiss.
Auger hole 49; elev. 2,600 ft; sec. 35, T. 24 N., R. 44 E.			
Palouse		0–54	Clayey silt.
Pre-Tertiary		54	Gneiss.
Auger hole 50; elev. 2,530 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–20	Clayey silt, gravel at base.
Basalt		20–29	Saprolite, olive-gray (5*Y* 3/1).
Auger hole 51; elev. 2,505 ft; sec. 34, T. 24 N., R. 44 E.			
Palouse		0–20	Clayey silt.
Basalt		20	Rock.
Auger hole 52; elev. 2,510 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–10	Clayey silt.
Basalt		10–14	Saprolite, dark-bluish-gray (5*B* 4/1).
		14	Rock.
Auger hole 53; elev. 2,575 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–46	Clayey silt.
Basalt		46–56	Saprolite, olive-gray (5*Y* 3/1).
Auger hole 54; elev. 2,570 ft; sec. 3, T. 23 N., R. 44 E.			
Palouse		0–38	Clayey silt.
Basalt		38–56	Saprolite, olive-gray (5*Y* 3/1).
		56–58	Saprolite, olive-black (5*Y* 2/1).
Auger hole 55; elev. 2,525 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–17	Clayey silt.
Basalt		17–27	Saprolite, brownish-black (10*YR* 2/1).
		27	Rock.
Auger hole 56; elev. 2,540 ft; sec. 11, T. 23 N., R. 44 E.			
Palouse		0–45	Clayey silt.
Basalt		45–54	Saprolite, olive-gray (5*Y* 3/1).
		54	Rock.
Auger hole 57; elev. 2,555 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–35	Clayey silt.
Basalt		35–52	Saprolite, olive-gray (5*Y* 4/1).
		52	Rock.
Auger hole 58; elev. 2,555 ft; sec. 2, T. 23 N., R. 44 E.			
Palouse		0–39	Clayey silt.
Basalt		39–40	Semidecomposed.
		40	Rock.
Auger hole 59; elev. 2,510 ft; sec. 11, T. 23 N., R. 44 E.			
Palouse		0–14	Clayey silt.
Basalt		14	Rock.
Auger hole 60; elev. 2,720 ft; sec. 14, T. 24 N., R. 44 E.			
Palouse		0–5	Clayey silt.
Pre-Tertiary		5–30	Saprolite, micaceous sand, light-gray (*N*7).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 61: elev. 2,620 ft; sec. 13, T. 24 N., R. 44 E.			
Palouse		0–16	Clayey silt.
Pre-Tertiary		16–70	Saprolite, clayey micaceous sand, light-gray (*N*7).
	A	70–74	Saprolite, silty sand, yellowish-gray (10*YR* 8/1).
Auger hole 62: elev. 2,570 ft; sec. 14, T. 24 N., R. 44 E.			
Palouse		0–19	Clayey silt.
Pre-Tertiary		19	Gneiss.
Auger hole 63: elev. 2,605 ft; sec. 13, T. 24 N., R. 44 E.			
Palouse		0–18	Clayey silt.
Pre-Tertiary		18–31	Saprolite, clayey micaceous sand, brownish-gray (10*YR* 4/1).
Auger hole 64; elev. 2,490 ft; sec. 13, T. 24 N., R. 44 E.			
Palouse		0–7	Clayey silt.
Pre-Tertiary		7–12	Saprolite, silty sandy clay, light-gray (*N*7).
		12–30	Saprolite, clayey micaceous sand, light-gray (*N*7).
Auger hole 65: elev. 2,495 ft; sec. 18, T. 24 N., R. 45 E.			
Alluvium		0–18	Silty clay, light-olive-gray (5*Y* 6/1).
Pre-Tertiary		18–54	Saprolite, clayey micaceous sand, light-gray (*N*7).
		54	Gneiss.
Auger hole 66; elev. 2,450 ft; sec. 24, T. 24 N., R. 44 E.			
Alluvium		0–10	Silty clay, weak-brown (10*YR* 4/2).
Pre-Tertiary	A	10–24	Saprolite, clayey, sandy silt, light-brownish-gray (10*YR* 6/1).
		24–50	Saprolite, sand and gravel, contains quartz, feldspar, muscovite.
	B	50–60	Saprolite, clayey silty sand, yellowish-gray (10*YR* 8/1).
Auger hole 67; elev. 2,615 ft; sec. 25, T. 24 N., R. 44 E.			
Palouse		0–10	Clayey silt.
		10–15	Sand and gravel.
Pre-Tertiary		15–24	Saprolite, clayey micaceous sand, light-gray (*N*7).
		24	Gneiss.
Auger hole 68; elev. 2,570 ft; sec. 23, T. 24 N., R. 44 E.			
Palouse		0–10	Clayey silt.
Pre-Tertiary		10–19	Saprolite, clayey, micaceous sand and gravel.
Auger hole 69; elev. 2,635 ft; sec. 26, T. 24 N., R. 44 E.			
Palouse		0–5	Clayey silt.
Pre-Tertiary		5–19	Saprolite, clayey micaceous sand, light-gray (*N*7).
Auger hole 70; elev. 2,655 ft; sec. 25, T. 24 N., R. 44 E.			
Palouse		0–10	Clayey silt.
Pre-Tertiary		10–18	Saprolite, clayey sand and gravel, light-gray (*N*7).
		18	Gneiss.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 71; elev. 2,625 ft; sec. 36, T. 24 N., R. 44 E.			
Palouse		0–11	Clayey silt.
Pre-Tertiary		11–18	Saprolite, micaceous silty sand, brownish-gray (*10YR* 4/1).
Auger hole 72; elev. 2,635 ft; sec. 36, T. 24 N., R. 44 E.			
Palouse		0–7	Clayey silt.
Pre-Tertiary	A	7–32	Saprolite, clayey sand, weak-yellow (2.5*Y* 7/2).
	B	32–47	Saprolite, clayey silty sand, yellowish-gray (2.5*Y* 7/1).
	C	47–62	Saprolite, clayey silty sand, weak-yellowish-orange (10*YR* 7/4).
	D	62–72	Saprolite, silty sand, very pale orange (10*YR* 9/2).
	E	72–82	Saprolite, silty sand, weak-yellowish-orange (10*YR* 7/4).
		82–88	Saprolite, micaceous sand, light-brownish-gray (5*YR* 6/1).
Auger hole 73; elev. 2,670 ft; sec. 36, T. 24 N., R. 44 E.			
Palouse		0–20	Clayey silt.
Pre-Tertiary		20–60	Saprolite, micaceous sand, light-brownish-gray (5*YR* 6/1) Quartz and feldspar grains.
Auger hole 74; elev. 2,690 ft; sec. 1, T. 23 N., R. 44 E.			
Palouse		0–7	Clayey silt.
Pre-Tertiary		7–60	Saprolite, micaceous sand, yellowish-gray (10*YR* 7/1).
	A	60–80	Saprolite, silty sand, yellowish-white (10*YR* 9/1).
Auger hole 75; elev. 2,665 ft; sec. 1, T. 23 N., R. 44 E.			
Palouse		0–7	Clayey silt.
Pre-Tertiary		7–10	Saprolite, clayey micaceous sand, pinkish-gray (7.5*R* 8/1).
		10–50	Saprolite, clayey silt, pale-brown (5*YR* 6/2).
		50–70	Saprolite, micaceous clayey silt, weak-brown (5*YR* 4/2), several thin beds of micaceous sand.
Auger hole 76; elev. 2,590 ft; sec. 1, T. 23 N., R. 44 E.			
Palouse		0–7	Clayey silt.
		7–11	Sand and gravel.
Latah		11–15	Sandy micaceous clay, light-gray (*N*7).
		15–24	Clayey sand, yellowish-gray (10*YR* 7/1).
Basalt		24–40	Saprolite, bluish-gray (5*B* 5/1).
		40–60	Saprolite, yellowish-gray (5*Y* 7/1).
		60	Rock.
Auger hole 77; elev. 2,600 ft; sec. 1, T. 23 N., R. 44 E.			
Palouse		0–5	Clayey silt.
		5–10	Sand and gravel.

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 77—Continued
Basalt	A	10–15	Saprolite, moderate-yellowish-brown (10*YR* 5/4).
	B	15–30	Saprolite, light-olive-brown (2.5*Y* 5/4).
	C	30–70	Saprolite, light-olive-gray (5*Y* 5/1).
	D	70–80	Saprolite, light-brownish-gray (2.5*Y* 5/1).
Pre-Tertiary	E	80–100	Saprolite, light-brown (2.5*Y* 5/6).
			Auger hole 78; elev. 2,590 ft; sec. 1, T. 23 N., R. 44 E.
Palouse		0–4	Clayey silt.
		4–9	Sand and gravel.
Latah		9–17	Micaceous sandy, silty clay, light-gray (*N*7).
		17–25	Micaceous sandy, silty clay, weak-yellow (2.5*Y* 7/2).
		25–30	Clayey sand, light-gray (*N*7).
		30–32	Silty micaceous clay, yellowish-white (2.5*Y* 9/1).
		32–35	Micaceous clay, medium-gray (*N*6).
		35–42	Micaceous sandy clay, light-gray (*N*7).
Basalt		42–48	Saprolite, bluish-gray (5*B* 5/1).
		48–54	Saprolite, light-olive-gray (5*Y* 5/2).
			Auger hole 79; elev. 2,575 ft; sec. 12, T. 23 N., R. 44 E.
Palouse		0–39	Clayey silt.
Basalt		39–60	Saprolite, light-gray (*N*7), plastic.
		60–68	Saprolite, olive-black (5*Y* 2/1).
		68	Rock.
			Auger hole 80; elev. 2,560 ft; sec. 12, T. 23 N., R. 44 E.
Palouse		0–19	Clayey silt.
		19–20	Sand and gravel.
Basalt		20–32	Saprolite, yellowish-gray (5*Y* 7/1).
		32	Rock.
			Auger hole 81; elev. 2,610 ft; sec. 6, T. 23 N., R. 45 E.
Palouse		0–14	Clayey silt.
Basalt		14–24	Saprolite, bluish-gray (5*B* 5/1).
		24–34	Saprolite, weak-yellowish-orange (2.5*Y* 7/4).
			MICA CREEK AREA
			Auger hole 82; elev. 2,610 ft; sec. 7, T. 23 N., R. 45 E.
Latah		0–2	Sand and gravel.
		2–7	Clayey sand, moderate-brown (7.5*YR* 4/4).
Basalt		7–12	Saprolite, dark-yellowish-brown (10*YR* 3/4).
		12–17	Saprolite, weak-brown (2.5*Y* 4/2).
			Auger hole 83; elev. 2,605 ft; sec. 7, T. 23 N., R. 45 E.
Palouse		0–7	Clayey silt.
Latah		7–15	Sand and gravel.
Basalt		15–34	Saprolite, brownish-gray (2.5*Y* 3/2).
		34	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 84; elev. 2,595 ft; sec. 6, T. 23 N., R. 45 E.			
Palouse		0–17	Clayey silt.
Latah		17–20	Sand and gravel.
		20–22	Silty clay, weak-yellowish-orange (10*YR* 7/6).
		22–23	Clay, white (*N*9).
Basalt		23–28	Saprolite, bluish-gray (5*B* 5/1).
		28–38	Saprolite, weak-olive (7.5*Y* 4/2).
		38	Rock.
Auger hole 85; elev. 2,640 ft; sec. 6, T. 23 N., R. 45 E.			
Palouse		0–13	Clayey silt.
		13–15	Sand and gravel.
Pre-Tertiary		15–17	Clayey micaceous sand, moderate-yellowish-orange (10*YR* 7/8).
		17–30	Clayey micaceous sand, yellowlsh-gray (10*YR* 8/1).
Auger hole 86; elev. 2,700 ft; sec. 6, T. 23 N., R. 45 E.			
Palouse		0–8	Clayey silt.
		8–10	Sand and gravel.
Pre-Tertiary		10–45	Saprolite, clayey silty sand, pale-yellowish-orange (10*YR* 9/4).
		45	Gneiss.
Auger hole 87; elev. 2,600 ft; sec. 7, T. 23 N., R. 45 E.			
Palouse		0–16	Clayey silt.
		16–19	Sand and gravel.
Latah		19–22	Silty clay, weak-yellowish-orange (10*YR* 7/6).
Basalt		22–25	Saprolite, bluish-gray (5*B* 5/1), white halloysite.
		25–43	Saprolite, weak-olive (7.5*Y* 4/2).
		43	Rock.
Auger hole 88; elev. 2,615 ft; sec. 8, T. 23 N., R. 45 E.			
Palouse		0–3	Clayey silt.
		3–5	Sand and gravel.
Latah		5–15	Micaceous clayey sand, light-gray (*N*7).
		15–20	Micaceous clayey sand, weak-yellowish-orange (10*YR* 7/4).
Basalt		20–30	Saprolite, bluish-gray (5*B* 5/1).
		30–35	Saprolite, weak-olive (5*Y* 3/2).
		35–43	Saprolite, olive-gray (7.5*Y* 3/1).
Auger hole 89; elev. 2,600 ft; sec. 5, T. 23 N., R . 45 E.			
Palouse		0–10	Clayey silt.
Pre-Tertiary		10–38	Saprolite, micaceous clayey sand, weak-yellowish-orange (10*YR* 8/3).
		38–50	Saprolite, clayey silty sand, moderate-reddish-brown (10*R* 4/6).
		50	Gneiss.

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 90; elev. 2,600 ft; sec. 5, T. 23 N., R. 45 E.
Palouse		0–3	Clayey silt.
Basalt		3–30	Saprolite, olive-gray (5*Y* 3/1).
		30–50	Saprolite, moderate-yellowish-brown (10*YR* 4/4).
		50–55	Saprolite, weak-brown (2.5*Y* 3/2).
Pre-Tertiary		55–68	Saprolite, sandy clay, light-gray (*N*7).
			Auger hole 91; elev. 2,655 ft; sec. 33, T. 24 N., R. 45 E.
Palouse		0–13	Clayey silt.
		13–23	Sand and gravel.
Pre-Tertiary		23–60	Saprolite, micaceous clayey sand, yellowish-white (10*YR* 9/1).
		60	Gneiss.
			Auger hole 92; elev. 2,650 ft; sec. 32, T. 24 N., R. 45 E.
Palouse		0–9	Clayey silt.
		9–11	Sand and gravel.
Latah	A	11–17	Clayey sand, yellowish-gray (10*YR* 8/1).
		17–18	Micaceous clayey sand, light-gray (*N*7).
	B	18–25	Clayey sand, weak-yellowish-orange (10*YR* 8/3).
		25–50	Micaceous clayey sand, pale-brown (10*YR* 5/2). Carbonaceous material at base.
Basalt		50–90	Saprolite, olive-gray (5*Y* 3/1).
			Auger hole 93; elev. 2,610 ft; sec. 4, T. 23 N., R. 45 E.
Palouse		0–33	Clayey silt, some sand.
		33–34	Gravel.
Basalt		34–38	Saprolite, bluish-gray (5*B* 5/1).
		38	Rock.
			Auger hole 94; elev. 2,640 ft; sec. 4, T. 23 N., R. 45 E.
Palouse		0–12	Clayey silt.
Latah		12–18	Micaceous clayey sand, weak-brown (10*YR* 3/2).
		18–20	Clayey micaceous sand, light-yellowish-gray (2.5*Y* 6/4).
		20–22	Sandy micaceous clay, yellowish-gray (2.5*Y* 7/1).
		22–25	Sandy micaceous clay, yellowish-white (2.5*Y* 9/1).
Basalt		25–48	Saprolite, olive gray (5*Y* 3/1).
		48	Rock.
			Auger hole 95; elev. 2,620 ft; sec. 9, T. 23 N., R. 45 E.
Palouse		0–6	Clayey silt.
Latah		6–11	Micaceous silty clay, light-gray (*N*7).
		11–16	Micaceous sandy clay, weak-yellowish-orange (2.5*Y* 7/4).
		16–18	Micaceous sand, weak-yellowish-orange (2.5*Y* 8/4).
		18–22	Micaceous sandy clay, weak-yellowish-orange (2.5*Y* 8/4).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 95—Continued			
Latah		22–26	Clayey micaceous sand, pale-yellow (2.5*Y* 9/2).
		26–31	Micaceous sandy clay, pale-brown (2.5*Y* 6/2).
Basalt		31–41	Saprolite, bluish-gray (5*B* 5/1).
		41–56	Saprolite, olive-gray (5*Y* 3/1).
		56	Rock.
Auger hole 96: elev. 2,615 ft; sec. 8, T. 23 N., R. 45 E.			
Palouse		0–42	Clayey silt.
Basalt		42–48	Saprolite, bluish-gray (5*B* 5/1), nontronite streaks.
		48	Rock.
Auger hole 97; elev. 2,600 ft; sec. 4, T. 23 N., R. 45 E.			
Palouse		0–10	Clayey silt.
Latah		10–18	Sandy micaceous clay, light-brownish-gray (10*YR* 6/1).
Basalt		18–22	Saprolite, bluish-gray (5*B* 5/1), white spots and streaks.
		22–60	Saprolite, weak-olive (5*Y* 3/1).
		60–78	Saprolite, olive-black (5*Y* 2/1), semidecomposed.
Auger hole 98; elev. 2,620 ft; sec. 3, T. 24 N., R. 45 E.			
Palouse		0–23	Clayey silt.
		23–24	Sand and gravel.
Latah		24–35	Sandy micaceous clay, weak-yellowish-orange (2.5*Y* 7/4).
		35–38	Sandy micaceous clay, light-gray (*N*7).
		38–40	Sandy micaceous clay, weak-yellowish-orange (2.5*Y* 7/4).
Basalt		40–43	Saprolite, bluish-gray (5*B* 5/1).
Auger hole 99; elev. 2,570 ft; sec. 4, T. 23 N., R. 45 E.			
Palouse		0–23	Clayey silt.
		23–24	Sand and gravel.
Basalt		24–30	Semidecomposed, nontronite specks.
		30	Rock.
Auger hole 100; elev. 2,590 ft; sec. 10, T. 23 N., R. 45 E.			
Palouse		0–11	Clayey silt.
Basalt		11–20	Saprolite, olive-gray (5*Y* 3/1).
		20–32	Saprolite, olive-black (5*Y* 2/1).
		32	Rock.
Auger hole 101; elev. 2,630 ft; sec. 10, T. 23 N., R. 45 E.			
Pre-Tertiary		0–8	Saprolite, clayey micaceous sand, very pale orange (10*YR* 8/2).
		8–15	Saprolite, clayey micaceous sand, weak-brown (10*YR* 4/2).
		15	Gneiss.

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 102; elev. 2,645 ft; sec. 3, T. 23 N., R. 45 E.
Palouse		0–3	Clayey silt.
Pre-Tertiary		3–5	Saprolite, clayey micaceous sand, very pale orange (10*YR* 8/2).
		5–30	Saprolite, micaceous clayey sand, weak-brown (10*YR* 4/2).
		30–40	Saprolite, micaceous sandy clay, medium-gray (*N6*).
		40–55	Saprolite, clayey micaceous sand, light-gray (*N*7).
		55–57	Saprolite, sandy micaceous clay, white (*N*9).
		57	Gneiss.
			Auger hole 103; elev. 2,645 ft; sec. 3, T. 23 N., R. 45 E.
Palouse		0–5	Clayey silt.
Pre-Tertiary		5–9	Saprolite, clayey micaceous sand, light-gray (*N*8).
		9–20	Saprolite, micaceous sand, pale-brown (10*YR* 5/2).
		20	Gneiss.
			Auger hole 104; elev. 2,640 ft; sec. 3, T. 23 N., R. 45 E.
Palouse		0–10	Clayey silt.
Pre-Tertiary		10–20	Saprolite, clayey sand, weak-brown (10*YR* 4/2).
		20–35	Saprolite, sandy micaceous clay, pale-brown (10*YR* 6/2).
		35	Gneiss.
			Auger hole 105; elev. 2,710 ft; sec. 3, T. 23 N., R. 45 E.
Palouse		0–10	Clayey silt.
Pre-Tertiary	A	10–25	Saprolite, clayey micaceous sand, yellowish-white (10*YR* 9/1).
		25	Gneiss.
			Auger hole 106; elev. 2,635 ft; sec. 11, T. 23 N., R. 45 E.
Palouse		0–8	Clayey silt.
Basalt		8–15	Saprolite, olive-black (5*Y* 2/1), streaks of nontronite.
			Auger hole 107; elev. 2,625 ft; sec. 10, T. 23 N., R. 45 E.
Palouse		0–20	Clayey silt.
Basalt	A	20–61	Saprolite, moderate-yellowish-brown (10*YR* 4/3).
			Auger hole 108; elev. 2,620 ft; sec. 2, T. 23 N., R. 45 E.
Palouse		0–10	Clayey silt.
Latah	A	10–18	Sandy clay, weak-yellowish-orange (2.5*Y* 7/4).
	B	18–25	Clayey sand, weak-yellowish-orange (2.5*Y* 8/4).
	C	25–50	Sandy clay, yellowish-gray (10*YR* 8/1).
Basalt		50–75	Saprolite, bluish-gray (5*B* 5/1).
		75–76	Saprolite, olive-gray (5*Y* 4/1).
		76	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 109; elev. 2,645 ft; sec. 2. T, 23 N., R. 45 E.			
Palouse		0–19	Clayey silt.
Latah		19–22	Sandy clay, very pale brown (10*YR* 7/2).
Basalt		22–42	Saprolite, olive-gray (5*Y* 4/2).
		42	Rock.
Auger hole 110; elev. 2,710 ft; sec. 2, T. 23 N., R. 45 E.			
Palouse		0–18	Clayey silt.
Pre-Tertiary		18–70	Saprolite, clayey micaceous sand, yellowish-white (10*YR* 9/1).
		70–75	Saprolite, pale-brown (10*YR* 7/2) gneiss.
Auger hole 111; elev. 2,645 ft; sec. 1, T. 23 N., R. 45 E.			
Palouse		0–15	Clayey silt.
Basalt		15–31	Saprolite, olive-gray (5*Y* 4/1).
		31	Rock.
Auger hole 112; elev. 2,690 ft; sec. 1, T. 23 N., R. 45 E.			
Palouse		0–7	Clayey silt.
Pre-Tertiary		7–15	Saprolite, clayey sand, weak-yellow (7.5*Y* 7/2).
		15–25	Saprolite, clayey sand, pale-brown (2.5*Y* 6/2).
		25–35	Saprolite, clayey sand, pale-olive (5*Y* 5/2).
	A	35–47	Saprolite, silty sand, yellowish-gray (10*YR* 8/1).
Auger hole 113; elev. 2,670 ft; sec. 1, T. 23 N., R. 45 E.			
Palouse		0–9	Clayey silt.
Pre-Tertiary		9–25	Saprolite, clayey sand, pale-olive (7.5*Y* 6/2).
		25–30	Saprolite, clayey micaceous sand, brownish-gray (10*YR* 4/1).
		30–41	Saprolite, clayey micaceous sand, pale-olive (7.5*Y* 5/2).
		41	Gneiss.
Auger hole 114; elev. 2,600 ft; sec. 2, T. 23 N., R. 45 E.			
Palouse		0–15	Clayey silt.
Basalt	A	15–32	Saprolite, olive-gray (5*Y*4/1).
Auger hole 115; elev. 2,610 ft; sec. 12, T. 23 N., R. 45 E.			
Palouse		0–12	Clayey silt.
Basalt		12–13	Saprolite, olive-gray (5*Y* 4/1).
		13–17	Saprolite, brownish-black (10*YR* 2/1).
		17	Rock.
Auger hole 116; elev. 2,680 ft; sec. 12, T. 23 N., R. 45 E.			
Palouse		0–8	Clayey silt.
		8–10	Sand and gravel.
Latah		10–15	Silty clay, dusky-yellowish-orange (7.5*YR* 6/6).
		15–30	Sandy clay, light-yellowish-brown (10*YR* 6/3).
Basalt	A	30–42	Saprolite, yellowish-gray (10*YR* 7/1).
		42–45	Saprolite, bluish-gray (5*B* 5/1).
		45–48	Saprolite, olive-gray (5*Y* 4/1).
		48–60	Saprolite, olive-black (5*Y* 2/1).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 117; elev. 2,595 ft; sec. 31, T. 23 N., R. 46 E.			
Palouse		0–15	Clayey silt.
Latah		15–28	Clayey micaceous sand, weak-yellowish-orange (10*YR* 7/4).
		28–34	Carbonaceous micaceous clay, brownish-black (10*YR* 2/1).
Basalt		34–36	Saprolite, light-bluish-gray (5*B* 7/1).
		36–40	Saprolite, olive-gray (5*Y* 4/1).
		40–50	Saprolite, olive-black (5*Y* 2/1).
Auger hole 118; elev. 2,605 ft; sec. 31, T. 23 N., R. 46 E.			
Palouse		0–14	Clayey silt.
Latah	A	14–20	Silty sandy clay, light-gray (*N*8).
	B	20–40	Clayey silty sand, weak-yellow (2.5*Y* 8/2).
	C	40–60	Clayey sand, yellowish-gray (10*YR* 8/1).
	D	60–85	Clayey sand, yellowish-gray (10*YR* 7/1).
	E	85–100	Silty sandy clay, brownish-gray (10*YR* 3/1), carbonaceous.
Auger hole 119; elev. 2,595 ft; sec. 6, T. 23 N., R. 46 E.			
Palouse		0–10	Clayey silt.
Basalt		10–14	Saprolite, olive-gray (5*Y* 3/1).
Auger hole 120; elev. 2,635 ft; sec. 6, T. 23 N., R. 46 E.			
Palouse		0–4	Clayey silt.
Pre-Tertiary		4–17	Saprolite, pale-brown (10*YR* 7/2) gneiss.
(Auger holes 121 to 142 are in Idaho)			
Auger hole 121; elev. 2,645 ft; sec. 1, T. 48 N., R. 6 W.			
Palouse		0–7	Clayey silt.
Latah		7–10	Micaceous clayey sand, weak-yellowish-orange (10*YR* 7/4).
Basalt	A	10–27	Saprolite, light-brownish-gray (10*YR* 5/1).
		27–28	Saprolite, bluish-gray (5*B* 5/1).
		28–31	Saprolite, olive-gray (5*Y* 4/1).
		31	Rock.
Auger hole 122; elev. 2,630 ft; sec. 32, T. 49 N., R. 5 W.			
Pre-Tertiary		0–5	Saprolite, sand, pale-brown (10*YR* 5/2).
		5–13	Saprolite, silty micaceous clay, very pale brown (10*YR* 7/2).
		13–15	Saprolite, clayey sand, pale-reddish-brown (2.5*YR* 5/2).
		15	Gneiss.
Auger hole 123; elev. 2,620 ft; sec. 32, T. 49 N., R. 5 W.			
Palouse		0–13	Clayey silt.
Pre-Tertiary	A	13–18	Saprolite, clayey sandy silt, weak-yellow (2.5*Y* 7/2).
	B	18–27	Saprolite, silty sandy clay, light-brownish-gray (2.5*Y* 6/1).
Auger hole 124; elev. 2,595 ft; sec. 5, T. 48 N., R. 5 W.			
Palouse		0–30	Clayey silt.
Pre-Tertiary		30–50	Saprolite, micaceous sand, weak-yellow (2.5*Y* 7/2).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 125; elev. 2,615 ft; sec. 5, T. 48 N., R. 5 W.			
Palouse		0–4	Clayey silt.
		4–10	Sand and gravel.
Latah		10–12	Silty clay, moderate-yellow (2.5*Y* 7/6).
		12–16	Clay, light-gray (*N*7).
		16–20	Micaceous silty clay, very pale brown (10*YR* 7/2).
		20–24	Micaceous sand, weak-brown (10*YR* 4/2).
		24–30	Silty clay, pale-reddish-brown (10*R* 5/4).
		30–35	Clayey sand, pale-brown (5*YR* 5/2).
		35–47	Clayey micaceous sand, yellowish-gray (10*YR* 7/1).
		47–57	Silty clay, brownish-black (10*YR*2/1) carbonaceous.
Basalt		57–67	Saprolite, dark-bluish-gray (5*B* 3/1).
Auger hole 126; elev. 2,650 ft; sec. 8, T. 48 N., R. 5 W.			
Palouse		0–6	Clayey silt.
		6–7	Sand and gravel.
Latah		7–12	Sandy micaceous clay, pale-brown (2.5*Y* 5/2).
		12–18	Clayey micaceous sand, moderate-yellowish-brown (7.5*YR* 5/6).
		18–27	Silty clay, moderate-yellowish-brown (10*YR* 5/6).
		27–35	Silty clay, yellowish-gray (10*YR* 8/1).
Auger hole 127; elev. 2,650 ft; sec. 8, T. 48 N., R. 5 W.			
Palouse		0–5	Clay silt, gravel at base.
Latah		5–8	Clayey sand, dusky-yellowish-orange (7.5*YR* 6/6).
		8–10	Sandy silty clay, weak-yellow (2.5*Y* 7/2).
		10–15	Clayey silty sand, moderate-yellowish-brown (10*YR* 5/4).
		15–25	Clayey silt and sand, light-olive-green (2.5*Y* 5/4).
		25–35	Clayey silt, moderate-yellowish-brown (10*YR* 5/4).
		35–60	Silty clay, moderate-yellowish-brown (10*YR* 5/6).
		60–65	Clay, light-gray (*N*7).
Basalt		65–70	Saprolite, olive-gray (5*Y* 3/1).
		70	Rock.
Auger hole 128; elev. 2,680 ft; sec. 5, T. 48 N., R. 5 W.			
Palouse		0–7	Clayey silt.
Pre-Tertiary		7–15	Saprolite, silty micaceous clay, light-yellowish-brown (10*YR* 6/4).
		15–17	Saprolite, micaceous clay, strong-brown (5*YR* 4/8).
	A	17–47	Saprolite, silty sand, weak-yellow (2.5*Y* 7/2).
	B	47–52	Saprolite, silty sand, weak-yellow (5*Y* 7/2).
		52	Gneiss.

Formation	*Sample (table 19)*	*Depth (ft)*	*Description*
			Auger hole 129; elev. 2,580 ft; sec. 9, T. 48 N., R. 5 W.
Palouse		0–12	Clayey silt.
		12–13	Sand and gravel.
Basalt	A	13–24	Saprolite, yellowish-gray (10*YR* 7/1).
	B	24–34	Saprolite, brownish-gray (10*YR* 4/1).
		34	Rock.
			Auger hole 130; elev. 2,620 ft; sec. 9, T. 48 N., R. 5 W.
Palouse		0–6	Clayey silt.
		6–7	Sand and gravel.
Pre-Tertiary		7–10	Saprolite, sandy micaceous clay, weak-yellowish-orange (10*YR* 7/4).
		10–18	Saprolite, silty micaceous clay, yellowish-gray (10*YR* 8/1).
		18–30	Saprolite, clayey sand, weak-yellowish-orange (10*YR* 7/3).
	A	30–48	Saprolite, clayey silty sand, light-brown (5*YR* 6/4).
		48–60	Saprolite, sandy silty clay, moderate-reddish-brown (10*R* 4/6).
		60–70	Saprolite, clayey sand, dark-yellow (5*Y* 6/6).
		70–90	Saprolite, clayey micaceous sand, light-yellowish-gray (2.5*Y* 6/4).
		90	Gneiss.
			Auger hole 131; elev. 2,605 ft; sec. 9, T. 48 N., R. 5 W.
Palouse		0–11	Clayey silt.
Latah	A	11–13	Clayey sand, weak-yellow (2.5*Y* 7/2).
	B	13–17	Silty clay, weak-yellowish-orange (10*YR* 7/4).
Basalt	C	17–19	Saprolite, light-brownish-gray (10*YR* 6/1).
	D	19–31	Saprolite, light-bluish-gray (5*B* 6/1).
	E	31–36	Saprolite, light-yellowish-brown (10*YR* 6/4).
	F	36–41	Saprolite, light-olive-gray (5*Y* 6/1).
	G	41–45	Saprolite, greenish-gray (5*GY* 5/1).
			Auger hole 132; elev. 2,555 ft; sec. 16, T. 48 N., R. 5 W.
Palouse		0–8	Clayey silt.
Basalt		8–22	Saprolite, bluish-gray (5*B* 5/1).
		22–27	Saprolite, olive-gray (5*Y* 4/1).
		27	Rock.
			Auger hole 133; elev. 2,550 ft; sec. 17, T. 48 N., R. 5W.
Palouse		0–9	Clayey silt.
Latah		9–10	Sandy micaceous clay, weak-yellowish-orange (2.5*Y* 7/4).
Basalt		10–13	Saprolite, olive-gray (5*Y* 4/1).
		13	Rock.
			Auger hole 134; elev. 2,665 ft; sec. 8, T. 48 N., R. 5 W.
Palouse		0–10	Clayey silt.
Latah		10–13	Sandy clay, weak-yellowish-brown (2.5*Y* 7/4).
		13–15	Clay, light-gray (*N*7), plastic.

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 134—Continued
Basalt		15–16	Saprolite, bluish-gray (5*B* 5/1).
		16–23	Saprolite, olive-gray (5*Y* 3/1).
		23–24	Saprolite, olive-black (5*Y* 2/1).
		24	Rock.
			Auger hole 135; elev. 2,580 ft; sec. 8, T. 48 N., R. 5 W.
Palouse		0–12	Clayey silt.
		12–15	Sand and gravel.
Latah		15–25	Clay, yellowish-gray (10*YR* 7/1), plastic.
Basalt		25–30	Saprolite, bluish-gray (5*B* 5/1).
		30–34	Saprolite, olive-black (5*Y* 2/1).
		34	Rock.
			Auger hole 136; elev. 2,615 ft; sec. 13, T. 48 N., R. 6 W.
Latah		0–4	Silty sand, weak-yellowish-orange (2.5*Y* 7/4).
		4–8	Silty sand, weak-yellow (5*Y* 7/2).
	A	8–11	Silty sandy clay, reddish-gray (10*R* 6/1).
		11–13	Silty clay, weak-yellow (7.5*Y* 7/2).
		13–20	Clayey sand, dusky-yellow (5*Y* 6/3).
		20–23	Silty clay, light-brown (7.5*YR* 6/4).
Basalt	B	23–48	Saprolite, brownish-gray (10*YR* 4/1).
Pre-Tertiary	C	48–60	Saprolite, clayey silty sand, weak-yellow (2.5*Y* 7/2).
		60–95	Saprolite, micaceous clayey sand, light-olive-brown (2.5*Y* 5/4).
		95	Gneiss.
			Auger hole 137; elev. 2,600 ft; sec. 13, T. 48 N., R. 6 W.
Pre-Tertiary		0–19	Saprolite, clayey micaceous sand, light-olive-brown (2.5*Y* 5/4).
		19	Gneiss.
			Auger hole 138; elev. 2,660 ft; sec. 13, T. 48 N., R. 6 W.
Palouse		0–2	Clayey silt.
Pre-Tertiary		2–33	Saprolite, clayey micaceous sand, light-olive-brown (2.5*Y* 5/4).
		33	Gneiss.
			Auger hole 139; elev. 2,610 ft; sec. 17, T. 48 N., R. 5 W.
Palouse		0–3	Clayey silt.
		3–5	Sand and gravel.
Latah		5–8	Clayey micaceous sand, light-brown (5*YR* 5/6).
		8–10	Clayey micaceous sand, strong-yellowish-brown (10*YR* 5/8).
	A	10–19	Silty sandy clay, weak-yellowish-orange (2.5*Y* 8/4).
	B	19–26	Silty sandy clay, light-gray (*N*8).
Basalt	C	26–30	Saprolite, white (*N*9), halloysite.
Pre-Tertiary	D	30–40	Saprolite, silty sandy clay, weak-yellow (5*Y* 8/2).

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 140; elev. 2,605 ft; sec. 20, T. 48 N., R. 5 W.
Palouse		0–20	Clayey silt.
Basalt		20–30	Saprolite, moderate-yellowish-brown (10*YR* 4/4), halloysite nodules.
		30–50	Saprolite, brownish-black (10*YR* 2/1), nontronite nodules.
		50	Rock.
			Auger hole 141; elev. 2,620 ft; sec. 20, T. 48 N., R. 5 W.
Palouse		0–5	Clayey silt.
Basalt		5–15	Saprolite, bluish-gray (5*B* 5/1).
		15–30	Saprolite, weak-brown (10*YR* 4/3).
		30–35	Saprolite, weak-brown (2.5*Y* 4/2), halloysite nodules.
			Auger hole 142: elev. 2,715 ft: sec. 13, T. 48 N., R. 6 W.
Palouse		0–6	Clayey silt.
		6–8	Sand and gravel.
Pre-Tertiary		8–15	Saprolite, clayey micaceous sand, weak-olive (7/5*Y* 4/2).
		15	Gneiss.

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Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 143: elev. 2,335 ft; sec. 23, T. 26 N., R. 43 E.
Palouse		0–21	Clayey silt.
Latah		21–22	Clay, white.
		22–23	Silty clay, weak-yellow (5*Y* 7/3).
	A	23–32	Clayey silt, yellowish-gray (10*YR* 8/1).
Basalt	B	32–48	Saprolite, greenish-gray (5*GY* 5/1).
	C	48–66	Saprolite, grayish-yellow-green (5*GY* 6/2).
		66	Rock.
			Auger hole 144; elev. 2,320 ft; sec. 23, T. 26 N., R. 43 E.
Palouse		0–12	Clayey silt.
Basalt		12	Rock.
			Auger hole 145; elev. 2,215 ft; sec. 24, T. 26 N., R. 43 E.
Palouse		0–11	Clayey silt.
Basalt		11	Rock.
			Auger hole 146; elev. 2,370 ft; sec. 24. T. 26 N., R. 43 E.
Palouse		0–45	Clayey silt, weak-brown (10*YR* 3/2).
Latah		45–60	Sandy micaceous clay, light-yellowish-brown (10*YR* 6/4).
		60–65	Clayey silt, moderate-yellowish-brown (10 *YR* 5/4).
		65–73	Clayey micaceous sand, light-yellowish-brown (10*YR* 6/3).
Basalt?		73	Rock.

Auger hole 147; elev. 2,180 ft; sec. 25, T. 26 N., R. 43 E.

Formation	Sample (table 19)	Depth (ft)	Description
Pre-Tertiary	A	0–10	Saprolite, silty micaceous clay, yellowish-gray (5*Y* 7/1).
	B	10–13	Saprolite, clay, weak-yellowish-orange (10 *YR* 8/6).
		13–20	Saprolite, clay, pale-brown (2.5*Y* 6/2).
		20–25	Saprolite, clayey micaceous sand, moderate-yellowish-brown (7.5*YR* 5/6).
		25–43	Saprolite, clayey micaceous sand, light-olive-brown (5*Y* 5/3).
		43–83	Saprolite, clayey micaceous sand, weak-olive (5*Y* 4/2).

Auger hole 148; elev. 2,375 ft; sec. 24, T. 26 N., R. 43 E.

Formation	Sample (table 19)	Depth (ft)	Description
Palouse		0–53	Clayey silt, weak-brown (10*YR* 4/2).
Basalt		53	Rock.

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Auger hole 149; elev. 2,280 ft; sec. 29, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Palouse		0–5	Clayey silt.
Latah		5–10	Silty clay, light-olive-brown (2.5*Y* 5/4).
	A	10–20	Clayey silt, yellowish-gray (5*Y* 8/1).
	B	20–28	Silty clay, light-gray (*N*7).
	C	28–34	Clayey sandy silt, light-yellowish-brown (10*YR* 6/4).
		34–37	Clayey sand, moderate-yellowish-brown (10 *YR* 5/6).
		37–50	Clayey sand, light-olive-brown (5*Y* 5/3).
		50–70	Sandy micaceous clayey silt, light-olive-brown (2.5*Y* 5/6).
		70–100	Clayey silt, brownish-gray (5*YR* 3/1), carbonaceous.

Auger hole 150; elev. 2,410 ft; sec. 28, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Palouse		0–24	Clayey silt.
Basalt		24	Rock.

Auger hole 151; elev. 2,433 ft; sec. 29, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Palouse		0–42	Clayey silt, moderate-yellowish-brown (10*YR* 4/4).
Basalt		42	Rock.

Auger hole 152; elev. 2,392 ft; sec. 20, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Glacial till		0–20	Sand and gravel.
		20–30	Clayey sand and gravel.
Basalt		30–38	Saprolite, medium-bluish-gray (5*B* 5/1).
		38	Rock.

Auger hole 153; elev. 2,325 ft; sec. 20, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Glacial till		0-5	Sand and gravel.
Basalt		5	Rock.

Formation	*Sample (table 19)*	*Depth (ft)*	*Description*
			Auger hole 154; elev. 2,360 ft; sec. 17, T. 26 N., R. 44 E.
Palouse		0–20	Clayey silt.
Basalt		20	Rock.
			Auger hole 155; elev. 2,370 ft; sec. 17, T. 26 N., R. 44 E.
Palouse		0–30	Clayey silt.
Basalt		30	Rock.
			Auger hole 156; elev. 2,425 ft; sec. 27, T. 26 N., R. 44 E.
Palouse		0–10	Clayey silt.
Basalt		10	Rock.
			Auger hole 157; elev. 2,440 ft; sec. 27, T. 26 N., R. 44 E.
Palouse		0–3	Clayey silt.
Basalt		3	Rock.
			Auger hole 158; elev. 2,457 ft; sec. 26, T. 26 N., R. 44 E.
Pre-Tertiary		0–12	Semidecomposed granodiorite.
			Auger hole 159; elev. 2,445 ft; sec. 22, T. 26 N., R. 44 E.
Palouse		0–44	Clayey silt.
Basalt		4	Rock.
			Auger hole 160; elev. 2.440 ft; sec. 22, T. 26 N., R. 44 E.
Palouse		0–2	Clayey silt.
Basalt		2	Rock.
			Auger hole 161; elev. 2,429 ft; sec. 23, T. 26 N., R. 44 E.
Palouse		0–7	Sandy silt, pale-brown (10*YR* 6/2).
		7–13	Silty sandy clay, moderate-yellowish-brown (10*YR* 5/4).
Pre-Tertiary		13–28	Saprolite, clayey micaceous sand, weak-yellow (2.5*Y* 8/2), white feldspar, frosted quartz.
	A	28–60	Saprolite, silty sandy clay, micaceous, moderate-orange-pink (2.5*YR* 7/6).
		60–100	Saprolite, clayey micaceous sand, pale-olive (5*Y* 6/2), white feldspar, clear quartz. Gneiss.
			Auger hole 162; elev. 2,480 ft; sec. 23, T. 26 N., R. 44 E.
Palouse		0–10	Clayey silt.
		10–15	Clayey silt, sand and gravel bed near base.
Pre-Tertiary		15–20	Saprolite, silty micaceous sand, yellowish-gray (10*YR* 8/1).
		20	Gneiss.
			Auger hole 163; elev. 2,410 ft; sec. 23, T. 26 N., R. 44 E.
Palouse		0–12	Clayey silt, pale-brown (2.5*Y* 5/2).
		12–15	Sand and gravel.
Latah		15–35	Micaceous clayey silt, moderate-yellowish-brown (10*YR* 5/6).
		35–40	Micaceous silty clay, light-olive-brown (5*Y* 5/3).
		40–58	Micaceous clayey silt, pale-olive (5*Y* 6/2).
Basalt		58–63	Rock, broken.

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 164; elev. 2,365 ft; sec. 23, T. 26 N., R. 44 E.
Palouse		0–5	Clayey silt.
Latah		5–6	Clayey sand, strong-yellowish-brown (10*YR* 5/8).
		6–8	Silty clay, weak-yellow (5*Y* 7/2).
		8–9	Clayey sand, moderate-yellowish-brown (10*YR* 5/6).
		9–13	Clayey micaceous silt, light-olive-brown (5*Y* 5/3).
Basalt		13–15	Rock, broken.

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Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 165; elev. 2,445 ft; sec. 14, T. 26 N., R. 44 E.
Palouse		0–7	Clayey silt.
Basalt		7–10	Saprolite, bluish-gray (5*B* 5/1).
Pre-Tertiary		10–20	Saprolite, clayey micaceous silt, pale-brown (2.5*Y* 5/2).
		20	Gneiss.
			Auger hole 166; elev. 2,410 ft; sec. 14, T. 26 N., R. 44 E.
Palouse		0–8	Clayey silt, some sand beds.
Latah		8–12	Sandy silty clay, moderate-yellowish-brown (10*YR* 5/6).
		12–15	Clay, weak-yellow (7.5*Y* 8/2).
	A	15–26	Silty clay, weak-yellow (5*Y* 7/4).
	B	26–38	Silty clay, yellowish-gray (5*Y* 8/1).
	C	38–45	Silty sandy clay, weak-yellow (5*Y* 7/3).
	D	45–62	Clayey sandy silt, weak-yellow (7.5*Y* 7/2).
Basalt		62	Rock?
			Auger hole 167; elev. 2,410 ft; sec. 14, T. 26 N., R. 44 E.
Palouse		0–15	Clayey silt, some sand beds.
Latah		15–22	Clayey silt, yellowish-gray (10*YR* 7/1).
		22–28	Silty clay, light-olive (10*YR* 5/6).
	A	28–48	Clay, weak-yellow (5*Y* 8/3).
	B	48–58	Clay, weak-yellow (5*Y* 8/2).
Basalt		58–63	Semidecomposed, dark-gray (*N*3) rock.
			Auger hole 168; elev. 2,405 ft; sec. 15, T. 26 N., R. 44 E.
Palouse		0–24	Clayey silt.
Latah		24–25	Clay, moderate-yellowish-orange (10*YR* 7/8).
Basalt		25–32	Saprolite, bluish-gray (5*B* 5/1).
		32–35	Semidecomposed rock.
		35	Rock.
			Auger hole 169; elev. 2,405 ft; sec. 15, T. 26 N., R. 44 E.
Palouse		0–22	Clay silt.
Basalt		22	Rock.
			Auger hole 170; elev. 2,380 ft; sec. 14, T. 26 N., R. 44 E.
Palouse		0–15	Clayey silt.
Latah	A	15–24	Clayey silty sand, yellowish-gray (5*Y* 8/1).
	B	24–30	Clay, yellowish-white (5*Y* 9/1).
	C	30–32	Clay, yellowish-gray (10*YR* 7/1).
	D	32–33	Clayey silt, light-gray (*N*8).
		33–34	Silty clay, moderate-yellowish-brown (10*YR* 5/4).

Formation	Sample (table 19)	Depth (ft)	Description
			Auger hole 171; elev. 2,380 ft; sec. 11, T. 26 N., R. 44 E.
Palouse		0–15	Clayey silt.
Latah		15–25	Sandy clay, strong-yellow-brown (10*YR* 5/8).
Basalt		25–27	Saprolite, bluish-gray (5*B* 5/1).
		27–32	Saprolite, olive-gray (5*Y* 3/1).
		32	Rock.
			Auger hole 172; elev. 2,360 ft; sec. 11, T. 26 N., R. 44 E.
Palouse		0–5	Clayey silt.
Basalt		5	Rock.
			Auger hole 173; elev. 2,412 ft; sec. 11, T. 26 N., R. 44 E.
Palouse		0–4	Clayey silt.
Basalt		4	Rock.
			Auger hole 174; elev. 2,395 ft: sec. 2, T. 26 N., R. 44 E.
Palouse		0–13	Clayey silt.
Basalt		13	Rock.
			Auger hole 175; elev. 2,416 ft; sec. 2, T. 26 N., R. 44 E.
Palouse	A	0–50	Clayey silt.
Latah		50–55	Clay, light-gray (*N*7).
Basalt		55–64	Saprolite, bluish-gray (5*B* 5/1).
		64	Rock.
			Auger hole 176; elev. 2,405 ft: sec. 3, T. 26 N., R. 44 E.
Palouse		0–45	Clayey silt.
Latah		45–50	Clay, light-gray (*N*7).
Basalt		50–54	Saprolite, bluish-gray (5*B* 5/1).
		54–56	Saprolite, olive-gray (5*Y* 3/1).
		56	Rock.
			Auger hole 177; elev. 2,380 ft; sec. 3, T. 26 N., R. 44 E.
Palouse		0–5	Clayey silt.
Latah	A	5–15	Clay, yellowish-gray (10*YR* 8/1).
Basalt	B	15–17	Saprolite, pale-blue (5*PB* 7/2).
	C	17–20	Saprolite, yellowish-gray (5*Y* 7/1).
	D	20–22	Rock.
			Auger hole 178; elev. 2,420 ft; sec. 3, T. 26 N., R. 44 E.
Palouse		0–50	Clayey silt.
Latah		50–54	Silty clay, weak-yellow (5*Y* 8/2).
	A	54–72	Silty clay, light-gray (*N*8).
Basalt	B	72–79	Saprolite, bluish-gray (5*B* 8/1).
			Auger hole 179; elev. 2,410 ft; sec. 3, T. 26 N., R. 44 E.
Palouse		0–25	Clayey silt.
Basalt		25–28	Saprolite, olive-gray (5*Y* 3/1).
		28	Rock.
			Auger hole 180; elev. 2,425 ft; sec. 3, T. 26 N., R. 44 E.
Palouse		0–15	Clayey silt, moderate-brown (7.5*YR* 4/4), gravel at base.
Latah		15–35	Clay, yellowish-white (10*YR* 9/1).
		35–57	Clay, light-gray (*N*8).
Basalt		57–60	Saprolite, bluish-gray (5*B* 5/1).
		60–62	Saprolite, olive-gray (5*Y* 3/1).
		62	Rock.

Auger hole 181; elev. 2,358 ft; sec. 2, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Palouse		0–8	Clayey silt.
Basalt		8	Rock.

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Auger hole 182; elev. 1,880 ft; sec. 5, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Clayey silt, moderate-yellowish-brown (10-*YR* 4/3).
		10–30	Clayey silt, light-olive-brown (5*Y* 5/3).
		30–70	Clayey silt, yellowish-gray (5*Y* 8/1).

Auger hole 183; elev. 1,900 ft; sec. 4, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–30	Sand and gravel, weak-brown (10*YR* 4/2).
		30–45	Clayey silt, pale-olive (5*Y* 6/3).
		45–50	Silty clay, moderate-brown (7.5*YR* 4/4).
	A	50–65	Silt, yellowish-gray (5*Y* 8/1).
	B	65–75	Clay, yellowish-gray (5*Y* 8/1).

Auger hole 184; elev. 1,905 ft; sec. 32, T. 27 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Clayey sandy silt, weak-brown (2.5*Y* 4/2).
		10–24	Sand and gravel, weak-brown (10*YR* 4/2).
		24–38	Sandy silty clay, moderate-yellowish-brown (10*YR* 4/3).
Basalt		38	Rock.

Auger hole 185; elev. 1,880 ft; sec. 31, T. 27 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Silt, moderate-yellowish-brown (10*YR* 4/3).
		10–44	Clayey silt, moderate-olive (2.5*Y* 5/4).
		44–75	Silty clay, yellowish-gray (5*Y* 8/1).

Auger hole 186; elev. 1,870 ft; sec. 2, T. 26 N., R. 43 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Clayey silty sand, weak-brown (10*YR* 4/2).
		10–17	Clayey silt, yellowish-gray (5*Y* 8/1).
		17–30	Silty clay, yellowish-gray (5*Y* 8/1).
		30–50	Clay sand, weak-brown (10*YR* 4/2).
		50–75	Sand and gravel.

Auger hole 187; elev. 1,850 ft; sec. 6, T. 26 N., R. 44 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Clayey silt, moderate-olive (2.5*Y* 4/4).
		10–25	Silty clay, weak-olive (5*Y* 4/3).
		25–40	Silty clay, moderate-brown (5*Y* 4/4).
		40–100	Clayey silt, yellowish-gray (5*Y* 8/1).

Auger hole 188; elev. 1,875 ft; sec. 11, T. 26 N., R. 43 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Sandy silt, light-olive-brown (5*Y* 5/3).
		10–20	Clayey silt, moderate-olive (2.5*Y* 4/4).
		20–25	Silty clay, yellowish-gray (5*Y* 8/1).
		25–30	Clayey sand, pale-olive (5*Y* 5/2).
		30–75	Sand and gravel.

Auger hole 189; elev. 1,850 ft; sec. 13, T. 26 N., R. 43 E.

Formation	Sample (table 19)	Depth (ft)	Description
Lake deposit		0–10	Clayey silt, moderate-olive (2.5*Y* 4/4).
		10–30	Silty clay, light-olive-brown (5*Y* 5/3).
	A	30–70	Clayey silt, yellowish-gray (5*Y* 8/1).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 190; elev. 1,885 ft; sec 8, T. 26 N., R. 44 E.			
Lake deposit		0–35	Sand, weak-brown (10*YR* 4/2).
		34–45	Clayey sand, moderate-yellowish-brown (10*YR* 5/4).
		45–50	Silty clay, yellowish-gray (5*Y* 8/1).
		50–75	Clayey sand, light-olive-brown (5*Y* 5/3).
Auger hole 191; elev. 1,940 ft; sec. 13, T. 26 N., R. 43 E.			
Palouse		0–13	Clayey silt, weak-brown (2.5*Y* 4/2).
Basalt		13	Rock.
Auger hole 192; elev. 2,005 ft; sec. 14, T. 26 N., R. 43 E.			
Palouse		0–5	Clayey silt, weak-brown (10*YR* 4/2).
Latah	A	5–20	Clayey silt, yellowish-gray (10*YR* 8/1), diatoms.
	B	20–58	Clayey silt, light-brownish-gray (10*YR* 5/1), diatoms.
		58–70	Clayey micaceous sand, pale-brown (10*YR* 6/2).
		70–74	Clayey silty micaceous sand, yellowish-brown (10*YR* 5/4).
		74–100	Clayey silt, light-brownish-gray (10*YR* 5/1).
Auger hole 193; elev. 2,060 ft; sec. 27, T. 27 N., R. 44 E.			
Palouse		0–15	Clayey silt.
Latah	A	15–25	Clayey silt, yellowish-gray (10*YR* 8/1).
	B	25–35	Clayey sandy silt, yellowish-gray (10*YR* 8/1), diatoms.
	C	35–50	Sandy silt, weak-yellow (2.5*Y* 7/2), diatoms.
	D	50–85	Clayey silt, pale-brown (2.5*Y* 5/2), diatoms.
	E	85–100	Silty clay, light-olive-gray (5*Y* 6/1), carbonaceous.
Auger hole 194; elev. 1,960 ft; sec. 27, T. 27 N., R. 44 E.			
Palouse		0–20	Silty clay.
Pre-Tertiary		20–80	Saprolite, gneiss.
Auger hole 195; elev. 2,000 ft; sec. 22, T. 27 N., R. 44 E.			
Palouse		0–10	Clay silt.
Pre-Tertiary		10–75	Saprolite, gneiss.

GREEN BLUFF AREA

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 196; elev. 2,360 ft; sec. 20, T. 27 N., R. 44 E.			
Palouse		0–19	Clayey silt, moderate-olive (2.5*Y* 4/4).
Basalt		19–30	Saprolite, olive-gray (5*Y* 3/1).
		30	Rock.
Auger hole 197; elev. 2,360 ft; sec. 19, T. 27 N., R. 44 E.			
Palouse		0–20	Clayey silt, moderate-yellowish-brown (10*YR* 4/4).
Basalt		20	Rock.

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 198; elev. 2,405 ft; sec. 19, T. 27 N., R. 44 E.			
Palouse		0–32	Clayey silt, weak-brown (10*YR* 3/2).
Basalt		32	Rock.

FIVEMILE PRAIRIE AREA

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 199; elev. 2,120 ft; S½SE¼NW¼NE¼ sec. 13, T. 27 N., R. 42 E.			
Palouse		0–10	Clayey silt.
Latah	A	10–24	Clayey sandy silt, weak-yellow (5*Y* 8/2).
		24–25	Sand, reddish-brown (10*R* 4/5).
	B	25–35	Clayey sandy silt, weak-yellow (2.5*Y* 7/2).
		35–42	Clayey sandy micaceous silt, weak-brown (10*YR* 4/2).
		42–60	Clayey micaceous sand, moderate-yellowish-brown (10*YR* 5/4).
	C	60–82	Clayey silt, weak-yellow (5*Y* 8/2).
Basalt?		82	Rock.
Auger hole 200; elev. 2,380 ft; E½SE¼SE¼NE¼ sec. 14, T. 27 N., R. 42 E.			
Palouse		0–4	Clayey silt.
Basalt		4	Rock.
Auger hole 201: elev. 2,395 ft; NE¼NE¼NE¼NE¼ sec. 23, T. 27 N., R. 42 E.			
Palouse		0–7	Clayey silt.
Basalt		7	Rock.
Auger hole 202; elev. 2,365 ft; NE¼NE¼NE¼NE¼ sec. 23, T. 27 N., R. 42 E.			
Palouse		0–9	Clayey silt.
Basalt		9	Rock.
Auger hole 203; elev. 2,150 ft; NE¼SW¼NE¼SE¼ sec. 25, T. 27 N., R. 42 E.			
Latah		0–5	Clayey silt, dusky-yellow (5*Y* 6/3).
		5–15	Silty micaceous clay, moderate-yellowish-brown (10*YR* 4/4).
		15–28	Clay micaceous silt, dusky-brown (10*YR* 2/2).
	A	28–50	Clayey silt, brownish-gray (2.5*Y* 4/1).
	B	50–75	Clayey silt, brownish-gray (2.5*Y* 4/1).
	C	75–100	Clayey silt, brownish-gray (2.5*Y* 4/1).

AREA SOUTH OF MORAN PRAIRIE

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 204; elev. 2,260 ft; N½SE¼NE¼SE¼ sec. 22, T. 24 N., R. 43 E.			
Palouse		0–6	Clayey silt, moderate-olive (2.5*Y* 4/4).
Latah		6–10	Clayey sand, pale-olive (5*Y* 5/2).
		10–11	Clayey silt, dusky-yellow (5*Y* 6/3).
		11–20	Clayey sand, light-olive-brown (5*Y* 5/3).
		20–28	Silty clay, pale-olive (5*Y* 5/2).
		28–60	Clayey sandy silt, pale-olive (5*Y* 6/2).
		60–75	Carbonaceous clay, dusky-brown (10*YR* 2/2).

Formation	Sample (table 19)	Depth (ft)	Description
Auger hole 205; elev. 2,270 ft; N½SW¼SW¼NE¼ sec. 15, T. 24 N., R. 43 E.			
Palouse		0–8	Clayey silt, weak-brown (2.5*Y* 4/2).
Latah		8–12	Micaceous silty clay, yellowish-white (5*Y* 9/1).
		12–16	Silty clay, pale-brown (2.5*Y* 5/2).
		16–20	Clayey silt, strong-yellowish-brown (10*YR* 5/8).
		20–22	Silty clay, dark-yellowish-brown (10*YR* 3/3).
	A	22–55	Silty micaceous clay, brownish-black (10*YR* 2/1).
	B	55–68	Clay, black (*N*2).
Pre-Tertiary		68	Gneiss.
Auger hole 206; elev. 2,300 ft; SE¼NW¼SW¼SW¼ sec. 10, T. 24 N., R. 43 E.			
Palouse		0–10	Clayey silt, weak-brown (2.5*Y* 4/2).
Latah	A	10–40	Clayey sandy silt, light-olive-gray (5*Y* 5/1).
		40–65	Silty micaceous clay, brownish-black (10*YR* 2/1).
		65–75	Clayey silty sand, strong-yellowish-brown (10*YR* 5/8).
		75–93	Clayey sand, moderate-yellowish-brown (10*YR* 4/4).
Basalt		93–97	Semidecomposed.

TABLE 19.—*Chemical composition, grain-size distribution, and clay minerals in selected samples from auger holes*

[Location and description of samples given on pages 64–90; chemical analyses by X-ray fluorescence method, in weight percent; Tr., trace]

Sample	Unit	Sample thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10 by weight)					
											Sand	Silt	Clay	Kaolinite	Halloysite	Illite	Montmorillonite	Nontronite	Mixed layer
10A	Basalt saprolite	3.0	34	26	8.3	0.07	0.4	0.1	10.5	12.6		2.0	8.0		10.0				
10B	do	5.0	70	17	23	.19	1.4	.1	5.7	13.0		3.0	7.0		4.0			6.0	
10C	do	5.0	38	16	21	.08	1.2	Tr.	6.6	10.1		3.0	7.0		2.5			7.5	
10D	do	5.0	42	16	20	.57	3.4	.2	4.9	14.0		4.0	6.0		1.5			8.5	
13A	Latah Formation	7.0	60	24	2.4	.02	.5	1.5	.8	8.2	7.0	1.5	1.5	9.0		0.5			0.5
13B	Basalt saprolite	1.0	44	33	7.0	.03	.6	.2	4.8	13.7		2.0	8.0	1.0	8.0				
13C	do	5.0	26	22	14	.10	.7	.1	19.8	13.9		4.0	6.0		10.0				
13D	do	10.0	38	30	7.4	.08	.7	.1	10.8	12.4		4.0	6.0		10.0				
13E	do	10.0	40	30	7.9	.07	.6	.4	7.7	14.2		3.5	6.5		8.0			2.0	
13F	do	5.0	34	19	19	.08	1.1	.1	8.2	14.0		2.5	7.5		7.0			3.0	
13G	do	10.0	36	30	8.1	.07	.6	.1	10.2	12.4		4.0	6.0		10.0				
13H	do	10.0	32	24	11	.04	.6	.1	9.6	13.0		3.5	6.5		10.0				
13I	do	10.0	38	29	6.8	.03	.6	.2	9.6	13.5		2.0	8.0		10.0				
13J	do	5.0	43	31	1.8	.18	.6	.6	7.4	13.1		2.5	7.5		10.0				
13K	do	2.0	39	20	11	.05	.6	.1	9.7	13.4		3.0	7.0		10.0				
13L	Pre-Tertiary saprolite	12.0	67	21	2.4	.07	.2	3.4	.5	3.4	5.5	1.5	3.0	8.0		1.5			.5
20A	Palouse Formation	34.0	63	15	5.8	.13	1.2	2.0	.9	3.3	.5	6.0	3.5			4.5	5.5		
32A	Pre-Tertiary saprolite	22.0	64	22	3.9	.04	.4	1.8	.5	5.9	3.0	1.0	6.0	6.0		4.0			
33A	Basalt saprolite	13.0	49	16	19	.29	3.0	.5	3.0	8.0		3.5	6.5		3.0			7.0	
42A	do	17.0	40	17	24	.12	1.2	.1	5.4	11.4		3.5	6.5		3.5			6.5	
45A	Pre-Tertiary saprolite	5.0	64	21	4.9	.03	.1	2.4	.7	5.0	6.5	1.5	2.0	8.0		2.0			
45B	do	5.0	50	26	9.1	.02	.5	.3	1.6	9.9	3.5	3.0	3.5	10.0					
45C	do	5.0	60	22	5.0	.11	.1	4.7	.5	4.9	8.0	1.0	1.0	7.5		2.5			
45D	do	30.0	60	22	5.8	.06	.2	2.9	.6	5.9	5.5	1.5	3.0	7.5		2.5			
45E	do	3.0	66	24	.8	.03	.1	4.0	Tr.	4.2	7.0	1.5	1.5	8.5		1.5			
45F	do	25.0	64	22	3.2	.09	.2	3.5	.3	5.0	6.0	1.5	2.5	7.5		2.5			
61A	do	4.0	70	20	1.1	.11	.6	3.7	.1	2.5	6.0	2.5	1.5	7.0		3.0			
66A	do	14.0	66	17	5.0	.05	1.5	2.7	.8	4.4	3.5	3.5	3.0	2.0		2.0		6.0	
66B	do	10.0	70	21	1.1	.02	.1	3.3	.3	3.1	5.0	2.0	3.0	9.0		1.0			
72A	do	25.0	66	19	4.4	.10	.1	3.6	.6	4.5	7.0	1.0	2.0	7.5		2.5			
72B	do	15.0	60	25	2.4	.09	.3	3.6	.2	7.8	4.5	2.5	3.0	9.0		1.0			Tr.
72C	do	15.0	56	23	5.9	.14	.4	2.6	.8	8.5	4.0	2.5	3.5	9.0		.5			.5
72D	do	10.0	63	23	2.9	.08	.3	3.7	.3	6.6	5.5	2.5	2.0	8.5		1.0			.5
72E	do	10.0	67	20	3.1	.05	.3	4.0	.5	4.4	6.5	2.0	1.5	7.5		1.5			1.0
74A	do	20.0	70	21	.9	.07	.2	5.0	.1	2.3	6.5	2.0	1.5	7.0		3.0			
77A	Basalt saprolite	5.0	30	19	26	.07	.6	.3	5.3	11.8		2.5	6.5		7.5	2.5			
77B	do	15.0	39	19	21	.27	1.0	.1	5.7	11.2		3.0	7.0		5.5			4.5	
77C	do	40.0	40	18	21	.19	1.4	.2	6.5	11.1		3.0	7.0		3.5			6.5	
77D	do	10.0	40	19	20	.23	1.1	Tr.	6.2	11.3		3.0	7.0		3.5			6.5	

TABLE 19.—*Chemical composition, grain-size distribution, and clay minerals in selected samples from auger holes*—Continued

Sample	Unit	Sample thickness (ft)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	TiO_2	Loss on ignition	Grain-size distribution (parts-in-10, by weight)			Clay mineral (parts-in-10 by weight)					
											Sand	Silt	Clay	Kaolinite	Halloysite	Illite	Montmorillonite	Nontronite	Mixed layer
77E	Pre-Tertiary saprolite	20.0	48	23	13	0.04	0.4	0.2	2.0	9.1	3.0	2.0	5.0	8.5	1.5	--	--	--	--
92A	Latah Formation	6.0	61	27	.8	.03	.3	1.3	1.3	7.1	6.0	1.0	3.0	8.5	--	1.5	--	--	--
92B	do	7.0	71	21	1.4	.04	.2	1.5	.9	4.8	5.5	1.0	3.5	7.5	--	2.5	--	--	--
105A	Pre-Tertiary saprolite	15.0	72	17	1.6	.04	1.5	3.0	.2	1.5	8.0	1.0	1.0	3.0	--	2.5	4.5	--	--
107A	Basalt saprolite	41.0	38	20	23	.32	.8	.1	5.9	13.0	--	3.5	6.5	--	6.0	--	--	4.0	--
108A	Latah Formation	8.0	56	26	1.8	.02	.3	.7	.9	9.3	3.0	2.0	5.0	6.5	--	3.5	--	--	--
108B	do	7.0	59	25	1.9	.01	.2	.7	.7	7.4	4.5	1.5	3.0	6.5	--	3.5	--	--	--
108C	do	25.0	50	35	.9	.01	.2	.6	1.1	11.3	2.0	2.0	6.0	9.5	--	.5	--	--	--
112A	Pre-Tertiary saprolite	12.0	69	17	2.5	.04	.6	4.4	.4	2.4	7.0	2.0	1.0	2.0	--	4.0	4.0	--	--
114A	Basalt saprolite	17.0	45	14	21	.80	3.6	.6	5.0	7.3		3.0	7.0	--	--	--	--	10.0	--
116A	do	12.0	48	36	1.7	.07	.3	.3	3.2	11.8	--	1.0	9.0	--	10.0	--	--	--	--
118A	Latah Formation	6.0	54	21	1.2	.01	.2	1.6	1.2	7.3	3.5	2.5	4.0	7.0	--	2.5	--	--	0.5
118B	do	20.0	57	27	1.2	.01	.2	1.9	1.0	7.4	4.0	2.0	4.0	8.0	--	2.0	--	--	--
118C	do	20.0	62	23	1.0	.02	.2	3.0	.6	5.2	6.0	2.0	2.0	8.0	--	2.0	--	--	--
118D	do	25.0	72	19	.7	.01	.2	3.0	.4	3.7	7.5	1.0	1.5	7.5	--	2.5	--	--	--
118E	do	15.0	53	21	.6	.01	.5	2.5	.7	30.9	3.0	3.0	4.0	5.5	--	4.5	--	--	--
121A	Basalt saprolite	17.0	48	28	3.5	.02	.4	1.0	1.6	12.0	--	.5	9.5	--	8.0	--	--	2.0	--
123A	Pre-Tertiary saprolite	5.0	65	16	4.3	.15	.9	1.5	.8	5.1	3.0	4.0	3.0	4.5	--	1.0	4.5	--	--
123B	do	9.0	62	17	5.4	.04	1.0	1.4	.8	6.6	2.0	3.5	4.5	3.5	--	Tr.	6.5	--	--
124A	do	20.0	61	19	4.4	.06	.3	4.2	.8	3.3	7.5	1.5	1.0	1.0	--	7.5	--	--	1.5
128A	do	30.0	59	18	6.1	.09	.2	3.9	.9	4.7	6.5	2.5	1.0	3.5	--	6.0	.5	--	--
128B	do	5.0	55	16	9.3	.16	3.1	1.3	.8	4.9	6.5	2.5	1.0	5.5	--	3.0	1.5	--	--
129A	Basalt saprolite	11.0	68	18	2.7	.02	.4	.6	.9	8.2	--	3.0	7.0	--	9.5	--	--	.5	--
129B	do	10.0	70	16	2.7	.02	.5	.4	.6	10.9	--	1.0	9.0	--	10.0	--	--	--	--
130A	Pre-Tertiary saprolite	18.0	54	20	9.2	.22	.2	1.0	1.3	7.6	4.0	3.5	2.5	5.5	--	4.5	--	--	--
131A	Latah Formation	2.0	57	22	4.2	.06	.4	1.6	1.1	3.5	5.5	1.5	3.0	9.5	--	.5	--	--	--
131B	do	4.0	44	32	4.1	.02	.2	.1	1.8	12.0	1.5	1.5	7.0	10.0	--	--	--	--	--
131C	Basalt saprolite	2.0	47	30	2.7	.02	.4	.4	2.2	13.4	--	1.0	9.0	1.5	8.5	--	--	--	--
131D	do	12.0	36	30	4.6	.06	.3	.1	9.5	12.6	--	3.0	7.0	--	10.0	--	--	--	--
131E	do	5.0	32	17	31	.07	.6	.2	5.5	11.7	--	4.0	6.0	--	10.0	--	--	--	--
131F	do	5.0	40	20	18	.13	2.8	.3	6.0	9.4	--	4.0	6.0	--	9.0	--	--	1.0	--
131G	do	4.0	48	14	13	.09	5.8	.5	5.1	4.3	--	4.0	6.0	--	--	--	--	10.0	--
136A	Latah Formation	3.0	55	27	.7	.01	.2	1.9	1.3	8.6	3.5	3.0	3.5	9.5	--	--	.5	--	--
136B	Basalt saprolite	25.0	44	17	22	.31	.8	.5	4.8	10.8	--	3.5	6.5	--	3.5	--	--	6.5	--
136C	Pre-Tertiary saprolite	12.0	56	19	18	.12	.4	2.6	1.6	6.5	5.0	3.0	2.0	3.0	--	5.5	1.5	--	--
139A	Latah Formation	9.0	49	28	3.7	.02	.2	.8	1.1	9.0	3.0	2.5	4.5	9.5	--	.5	--	--	--
139B	do	7.0	50	37	.5	.01	.2	.7	.9	11.0	3.0	3.0	4.0	9.5	--	.5	--	--	--
139C	Basalt saprolite	4.0	46	38	.4	.01	.2	.2	1.6	14.6	--	.5	9.5	--	10.0	--	--	--	--
139D	Pre-Tertiary saprolite	10.0	54	29	1.7	.02	.2	.9	1.1	9.2	3.5	2.5	4.0	9.0	--	.5	.5	--	--
143A	Latah Formation	9.0	70	18	1.3	.01	.2	2.5	.8	4.6	1.5	6.0	2.5	8.5	--	1.5	--	--	--

143B	Basalt saprolite	16.0	54	22	4.3	.02	.2	1.2	5.3	8.5		3.0	7.0		8.5			1.5	
143C	do	18.0	43	18	19	.18	.5	.4	5.2	7.3		4.0	6.0		6.5			3.5	
147A	Pre-Tertiary saprolite	10.0	51	25	2.4	.02	.3	1.7	1.1	10.4	.5	4.5	5.0	5.5		3.0	1.5		
147B	do	3.0	57	20	3.4	.02	.5	2.0	1.2	9.0		1.0	9.0	4.0		3.5	2.5		
149A	Latah Formation	10.0	63	18	2.7	.01	.4	2.6	1.0	5.4	1.0	6.5	2.5	3.0		1.0	6.0		
149B	do	8.0	61	19	2.5	.01	.4	2.2	1.1	7.0		3.0	7.0	3.0		4.0	3.0		
149C	do	6.0	58	17	9.7	.15	.3	2.6	.8	5.8	3.0	4.0	3.0	5.0		3.0	2.0		
161A	Pre-Tertiary saprolite	32.0	57	23	3.4	.01	.2	.8	.6	6.7	3.5	3.0	3.5	9.0		1.0			
166A	Latah Formation	11.0	50	22	7.9	.03	.4	1.6	1.1	9.4	1.0	3.0	6.0	5.0		2.5	2.5		
166B	do	12.0	54	28	2.2	.02	.3	1.4	1.2	8.8	2.0	3.0	5.0	9.0			1.0		
166C	do	7.0	53	17	14	.02	1.0	.7	1.1	7.9	1.0	4.0	5.0	1.0			9.0		
166D	do	17.0	49	21	6.1	.07	.8	2.5	.9	8.3	3.0	4.0	3.0	5.0		2.5	2.5		
167A	do	20.0	59	19	4.8	.01	.5	2.1	1.0	8.9		2.0	8.0	6.5		.5	3.0		
167B	do	10.0	55	21	5.2	.02	.5	1.6	1.1	9.5	.5	1.0	8.5	3.5		1.0	5.5		
170A	do	9.0	67	17	2.9	.02	.4	3.3	.6	4.1	5.0	2.5	2.5	6.5		3.5			
170B	do	6.0	61	20	2.5	.01	.3	.6	.8	9.2		1.5	8.5	8.0		2.0			
170C	do	2.0	56	23	2.3	.01	.3	1.0	1.1	10.1		1.5	8.5	7.5		1.0			1.5
170D	do	1.0	66	19	1.3	.01	.3	2.5	.8	4.8	1.5	5.5	3.0	5.5		4.5			
175A	Palouse Formation	50.0	65	16	4.8	.15	1.1	1.6	.9	3.3	.5	6.0	3.5	.5		2.5	7.0		
177A	Latah Formation	10.0	61	22	2.3	.04	2.1	2.3	1.0	9.5		2.5	7.5	7.0		3.0			
177B	Basalt saprolite	2.0	38	32	7.2	.08	.3	.2	9.8	12.3		4.0	6.0	.5	9.5				
177C	do	3.0	48	23	7.2	.09	5.7	.4	6.2	9.8		2.5	7.5		10.0				
177D	Basalt	2.0	54	14	17	.29	8.1	1.1	3.3	2.5									
178A	Latah Formation	18.0	57	24	1.8	.01	.3	2.0	1.2	9.1		3.0	7.0	7.0		3.0			
178B	Basalt saprolite	7.0	50	26	2.7	.04	.3	1.1	6.2	10.2		4.0	6.0		10.0				
183A	Lake deposit	15.0	66	17	3.1	.03	.6	2.9	.7	3.0		8.0	2.0	1.0		1.5	7.5		
183B	do	10.0	68	16	3.2	.03	.4	3.0	.6	4.0		2.0	8.0	2.0		2.0	6.0		
189A	do	40.0	66	16	5.5	.10	1.7	4.7	.6	4.6		5.5	4.5	2.0		3.0	5.0		
192A	Latah Formation	15.0	67	20	3.2	.03	.6	2.8	.8	3.3	1.0	7.0	2.0	3.0		1.5	5.5		
192B	do	38.0	65	20	5.1	.06	.6	2.8	.8	4.8	.5	7.0	2.5	1.5		1.0	2.0		.5
192C	do	26.0	65	19	4.6	.07	.6	2.7	.8	4.4	1.5	7.0	1.5	3.0		2.0	5.0		
193A	do	10.0	63	19	3.4	.02	.3	3.0	.8	5.6		6.0	4.0	2.5		.5	7.0		
193B	do	10.0	70	15	3.1	.05	.6	3.2	.6	3.9	3.5	4.5	2.0	2.5		.5	7.0		
193C	do	15.0	68	16	4.0	.07	.7	2.9	.6	4.2	3.0	5.0	2.0	2.5		.5	7.0		
193D	do	35.0	61	18	6.3	.08	.5	2.6	.8	7.6	1.5	6.0	2.5	4.5		1.5	4.0		
193E	do	15.0	59	20	4.6	.05	.4	2.9	1.0	8.2		3.0	7.0	3.5		1.5	4.5		.5
199A	do	14.0	64	16	4.7	.03	.6	2.4	.8	3.5	2.5	4.5	3.0	2.5		1.5	6.0		
199B	do	10.0	64	17	3.9	.06	.7	2.7	.8	3.2	3.0	4.5	2.5	2.5		2.5	5.0		
199C	do	22.0	66	16	3.6	.05	.6	3.1	.7	2.5	.5	7.5	2.0	2.5		3.0	4.5		
203A	do	22.0	63	15	5.0	.07	.7	2.6	.8	5.6	2.0	5.5	2.5	3.0		1.5	5.5		
203B	do	25.0	62	16	5.7	.07	.7	2.4	.8	6.0	1.0	6.0	3.0	3.0		1.0	6.0		
203C	do	25.0	61	16	6.9	.13	.6	2.8	.8	6.5	.5	6.0	3.5	2.5		3.5	2.5		1.5
205A	do	33.0	58	19	3.9	.03	.6	2.2	1.1	6.7	.5	5.0	4.5	6.0		2.5	1.5		
205B	do	13.0	58	18	5.2	.04	.7	1.9	1.2	5.9	1.5	3.5	5.0	6.5		2.5	1.0		
206A	do	30.0	59	19	3.1	.03	.7	2.3	1.0	4.2	2.5	4.5	3.0	5.5		2.5	2.0		

REFERENCES CITED

Allen, V. T., and Scheid, V. E., 1946, Nontronite in the Columbia River region: Am. Mineralogist, v. 31, p. 294–312.

American Petroleum Institute, 1950, Analytical data on reference clay minerals: Am. Petroleum Inst. Proj. 49, Clay mineral standards, Prelim. Rept. 7, 160 p.

Baldwin, E. M., 1950, Summary of the structure and geomorphology of the Columbia River basalt: Northwest Sci., v. 24, no. 2, p. 56-64.

Becker, G. F., 1895, Reconnaissance of the gold fields of the southern Appalachians: U.S. Geol. Survey 16th Ann. Rept. pt. 3, p. 251–319.

Berry, E. W., 1929, A revision of the flora of the Latah formation: U.S. Geol. Survey Prof. Paper 154–H, p. 225–266.

Bryan, Kirk, 1926, The "Palouse soil" problem * * *: U.S. Geol. Survey Bull. 790–B, p. 21–45.

Campbell, C. D., 1962, Introduction to Washington geology and resources: Washington Div. Mines and Geology Inf. Circ. 22R, 44 p.

Chappell, W. M., 1936, The effect of Miocene lavas on the course of Columbia River in central Washington: Jour. Geology, v. 44, no. 3, p. 379–386.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., 534 p.

Fuller, R. E., 1950, Structural features in the Columbia River basalt: Northwest Sci., v. 34, no. 2, p. 65–73.

Glover, S. L., 1941, Clays and shales of Washington: Washington Div. Geology Bull. 24, 368 p.

Goodspeed, G. E., and Weymouth, A. A., 1928, Mineral constituents and origin of a certain kaolin deposit near Spokane, Washington: Am. Ceramic Soc. Jour., v. 11, no. 9, p. 687–695.

Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill Book Co., 384 p.

——— 1962, Applied clay mineralogy: New York, McGraw-Hill Book Co., 422 p.

Gruner, J. W., 1932, The crystal structure of kaolinite: Zeitschr. Kristallographie, v. 83, p. 75–88.

Hodge, E. T., 1938a, Geology of the lower Columbia River: Geol. Soc. America Bull., v. 49, no. 6, p. 831–930.

———1938b, Market for Columbia River hydroelectric power using Northwest minerals, sec. IV, Northwest clays: War Dept. Corps Engineers, U.S. Army Office Div. Engineers, North Pacific Div., Portland, Oreg., 804 p.

Hosterman, J. W., 1960, Geology of the clay deposits in parts of Washington and Idaho, *in* Swineford, Ada, ed., Clays and clay minerals—proceedings of the 7th National Conference on Clays and Clay Minerals, Washington, 1958: New York, Pergamon Press, p. 285–292.

Hosterman, J. W., Overstreet, W. C., and Warr, J. J., 1964, Thorium and uranium in monazite from Spokane County, Washington *in* Geological Survey Research 1963: U.S. Geol. Survey Prof. Paper 475–D, p. D128–D130.

Hosterman, J. W., Scheid, V. E., Allen, V. T., and Sohn, I. G., 1960, Investigations of some clay deposits in Washington and Idaho: U.S. Geol. Survey Bull. 1091, 147 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Olympia, Washington Div. Mines and Geology, scale 1:500,000.

Kinter, E. B., and Diamond, Sidney, 1956, A new method for preparation and treatment of oriented aggregates of soil clays for X-ray diffraction analysis: Soil Sci., v. 82, no. 2, p. 111–120.

Kirkham, V. R. D., 1931, Origin of Palouse Hills topography: Science, n. ser., v. 73, p. 207–209.

Kirkham, V. R. D., and Johnson, M. M., 1929, The Latah formation in Idaho: Jour. Geology, v. 37, no. 5, p. 483–501.

Klinefelter, T. A., and Hamlin, H. P., 1957, Syllabus of clay testing: U.S. Bur. Mines Bull. 565, 67 p.

Knowlton, F. H., 1926, Flora of the Latah formation of Spokane, Washington, and Coeur d'Alene, Idaho: U.S. Geol. Survey Prof. Paper 140–A, p. 17–81.

Mackenzie, R. C., ed., 1957, The differential thermal investigation of clays: London, Mineralogical Society (Clay Minerals Group), 456 p.

Merriam, J. C., 1901, A contribution to the geology of the John Day basin: California Univ. Dept. Geol. Bull. 2, p. 269-314.

Newcomb, R. C., and others, 1953, Seismic cross-sections across the Spokane River valley and the Hillyard Trough, Idaho and Washington: U.S. Geol. Survey open-file report, 15 p.

Overstreet, W. C., 1961, Saprolite, *in* Yearbook of Science and Technology: New York, McGraw-Hill Book Co., p. 447–448.

Pardee, J. T., and Bryan, Kirk, 1926, Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Washington: U.S. Geo'. Survey Prof. Paper 140–A, p. 1–16.

Peacock, M. A., and Fuller, R. E., 1928, Chlorophaeite, sideromelane, and palagonite from the Columbia River plateau: Am. Mineralogist, v. 13, no. 7, p. 360–382.

Rieger, S., 1952, Development of A horizon in soils of the Palouse area: Pullman, Wash., Washington State Coll., Dept. Agronomy, Ph. D. thesis, 87 p.

Rose, H. J., Adler, Isidore, and Flanagan, F. J., 1962, Use of La_2O_3 as a heavy absorber in the X-ray fluorescence analysis of silicate rocks *in* Geological Survey Research 1962: U.S. Geol. Survey Prof. Paper 450–B, p. B80–B82.

Rose, H. J., Cuttitta, Frank, Carron, M. K., and Brown, Robena, 1964, Semimicro X-ray fluorescence analysis of tektites using 50-milligram samples *in* Geological Survey Research 1963: U.S. Geol. Survey Prof. Paper 475–D, p. D171–D173.

Russell, I. C., 1893, A geological reconnaissance in central Washington: U.S. Geol. Survey Bull. 108, 108 p.

Sand, L. B., 1956, On the genesis of residual kaolins: Am. Mineralogist, v. 41, p. 28–40.

Scheid, V. E., 1947, Excelsior surface—an intra-Columbia River Basalt weathering surface [abs.]: Geol. Soc. America Bull., v. 58, no. 12, p. 1224–1225.

Schultz, L. G., 1960, Quantitative X-ray determinations of some aluminous clay minerals in rocks, *in* Swineford, Ada, ed., Clays and clay minerals—Proceedings of the 7th National Conference on Clays and Clay Minerals, Washington, 1958: New York, Pergamon Press, p. 216–224.

——— 1964, Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale: U.S. Geol. Survey Prof. Paper 391–C, 31 p.

Shedd, Solon, 1910, The clays of the State of Washington, their geology, mineralogy, and technology: Pullman, Wash., Washington State Coll., 341 p.

Shepard, F. P., 1954, Nomenclature based on sand-silt-clay ratios: Jour. Sed. Petrology, v. 24, no. 3, p. 151–158.

Smith, G. O., 1904, Description of the Mount Stuart quadrangle, Washington: U.S. Geol. Survey Geol. Atlas, Folio 106.

Treasher, R. C., 1925, Origin of the loess of the Palouse region, Washington: Science, n. ser., v. 61, p. 469.

——— 1926, Stratigraphic aspects of loess of Palouse region: Pan-Am. Geologist, v. 46, no. 4, p. 305–314.

Tullis, E. L., 1944, Contributions to the geology of Latah County, Idaho: Geol. Soc. America Bull., v. 55, no. 2, p. 131–164.

Tullis, E. L., and Laney, F. B., 1933, The composition and origin of certain commercial clays of northern Idaho: Econ. Geology, v. 28, no. 5, p. 480–495.

Waters, A. C., 1955, Volcanic rocks and the tectonic cycle, *in* Poldervaart, Arie, ed., Crust of the earth—a symposium: Geol. Soc. America Spec. Paper 62, p. 703–722.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, no. 5, p. 377–392.

Wilson, Hewitt, 1923, The clay and shales of Washington and their technology and uses: Washington Univ. Eng. Expt. Sta. Bull. 18, 224 p.

Wilson, Hewitt, and Goodspeed, G. E., 1934, Kaolin and china clay in the Pacific Northwest: Washington Univ. Eng. Expt. Sta. Bull. 76, 184 p.

Zingaro, P. W., 1958, Statistics in X-ray intensity measurements: Norelco Reporter, v. 5, p. 99–100.

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