HE HOBART BUTTE HIGH-ALUMINA CLAY DEPOSIT LANE COUNTY, OREGON

By

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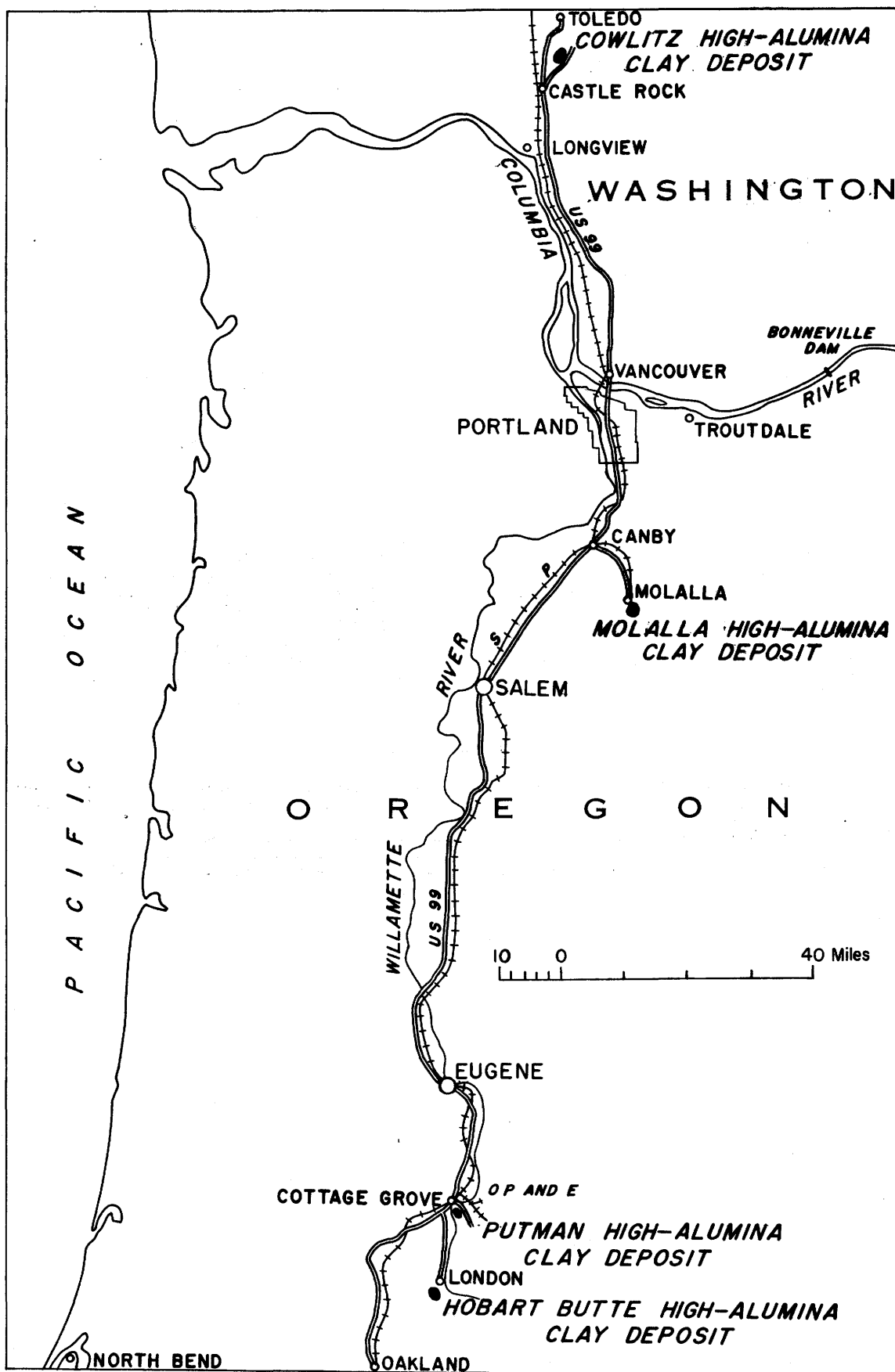and Robert L. Nichols

CONTENTS

ILLUSTRATIONS

Figure 1.--Index map, showing high-alumina clay deposits of western Oregon and Washington.

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LANE COUNTY, OREGON

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ABSTRACT

The Hobart Butte high-alumina clay deposit is in Tps. 22 and 23 S., R. 3 W., and Tps. 22 and 23 S., R. 4 W. It is near the summit of Hobart Butte, Lane County, Oreg., in the Calapooya Mountains, about 1,500 feet above the Coast Fork of the Willamette River. It is 16 miles south of Cottage Grove, approximately 110 miles from the high-alumina clay plant at Salem, and about 15 miles from the Southern Pacific railroad.

The investigation of this deposit was carried out jointly by the U. S. Geological Survey and the U. S. Bureau of Mines between January and November 1943. Forty diamond drill holes, having a total depth of 10,104 feet, were drilled; approximately 300 test pits were sampled; and specimens from 37 localities in the vicinity of the Butte were collected. The Bureau of Mines made more than 8,000 chemical, specific-gravity, moisture, and ceramic determinations.

The ore consists mainly of clay, clay-fragment breccia, and clay-pellet shale, sandstone, and conglomerate. These high-alumina rocks are gray, white, and red. They are found in the Calapooya formation which is probably of late Eocene age; are water-laid, semiflint, and kaolinitic clays a few hundred feet in thickness; and have been folded and perhaps faulted. The ore is largely a transported kaolinitic clay which was probably derived from a weathered surface to the east. In late Miocene time these rocks were invaded by hydrothermal solutions, and realgar, stibnite, pyrite, siderite, scorodite, mansfieldite, dickite-kaolinite, and other minerals were deposited in them. The deposit contains, therefore, both sedimentary and hydrothermal kaolinite, but the latter is only of minor economic importance.

INTRODUCTION

The need for aluminum during World War II was so great that the United States Department of the Interior undertook the investigation of many high-alumina clay deposits as possible sources of alumina. The regional geology, the characteristics of the ore body, and the reserves of the Hobart Butte high-alumina clay deposit were investigated jointly by the U. S. Geological Survey and the U. S. Bureau of Mines in 1942, 1943, and 1944.

The Hobart Butte high-alumina clay deposit is in sec. 36, T. 22 S., R. 4 W., and in sec. 1, T. 23 S., R. 4 W. It lies near the summit of Hobart Butte in the Calapooya Mountains about 1,500 feet above the Coast Fork of the Willamette River and at an altitude of approximately 2,400 feet. It is mainly in Lane County, Oreg., although a small part is located in Douglas County.

The deposit is 16 miles south of Cottage Grove, Oreg. A hard-surfaced county road, approximately 13 miles long, extends from the base of Hobart Butte to Cottage Grove, and a steep, narrow, winding mountain road about 3 miles long leads from the base of the Butte to the deposit. Cottage Grove is on U. S. No. 99, a principal highway in the State; on the Siskiyou line of the Southern Pacific railroad; and about 140 miles from Portland, Oreg. (see fig. 1).

History

Mr. Robert Phillips of London, Oreg., discovered the high-alumina clay deposit at Hobart Butte in 1930. Samples submitted to Professor Hewitt Wilson, University of Washington, were found to be refractory. The deposit was brought to the attention of Mr. O. K. Edwards, president of the Willamina Clay Products Co., and this company purchased Mr. Phillips' interest in the deposit in 1933. A road was built to the deposit near the summit of the Butte, and by 1942, between 12,000 and 15,000 tons of refractory clay had been mined and shipped to the Willamina Clay Products Co. for use in manufacturing refractory brick.

The attention of the U. S. Geological Survey was directed to this deposit by a report on the refractory clays of western Oregon written by Hewitt Wilson and Ray C. Treasher (1938), and published by the State of Oregon, Department of Geology and Mineral Industries. As a result of preliminary examination by the U. S. Geological Survey and U. S. Bureau of Mines, a diamond-drilling program was carried out during 1943.

Because of the findings of the Geological Survey and the Bureau of Mines, the Columbia Metals Corporation of Seattle, Wash., secured a lease on the property in September 1942 with the idea of using the clay as a source of alumina. The lease expired, however, before any mining was done.

Scope of investigation

Forty holes were drilled by the U. S. Bureau of Mines in 1943. The shallowest hole was 56 feet deep and the deepest, 521 feet; the total depth drilled was 10,104 feet. Diamond drills were used, and NX, BX, and AX core was obtained. Approximately 300 test pits were sampled, and specimens from 37 other localities were collected and analyzed. The U. S. Bureau of Mines made more than 8,000 chemical, specific-gravity, moisture, and ceramic determinations. A topographic map of the Butte was made by the U. S. Geological Survey and the U. S. Bureau of Mines to help in the exploration work.

The Geological Survey cooperated in the prospecting program by interpreting the geology, by describing the core, and by sampling and surveying.

Acknowledgments

The chemical analyses, moisture and specific-gravity determinations, and ceramic data were obtained from the U. S. Bureau of Mines. The topographic maps were made by John S. Loofbourow, Jr., U. S. Geological Survey, and Delbert L. Snyder, U. S. Bureau of Mines. Wayne E. Hall of the U. S. Geological Survey assisted on the project.

It is a pleasure to acknowledge the generous cooperation of the men of the Bureau of Mines with whom the writers worked. Special mention should be made of Mr. George H. Coughlin, Project Engineer; Mr. H. G. Iverson, District Engineer of Oregon; and Mr. C. C. Popoff and Mr. Delbert L. Snyder, U. S. Bureau of Mines Engineers. Appreciation is due Mr. Ray C. Treasher of the State of Oregon, Department of Geology and Mineral Industries, who first took R. L. Nichols to the deposit.

GENERAL GEOLOGY

Regional setting

The oldest rocks exposed in the Hobart Butte district belong to the Umpqua formation of Eocene age. They consist of well-bedded shales, siltstones, sandstones, conglomerates, and interbedded lava flows, tuffs, and breccias. (Wells and Waters, 1934.) No high-alumina rocks have been found in the Umpqua formation. It is probably several thousand feet thick, contains marine fossils, and is gently folded. Its distribution is shown on figure 2.

The Calapooya formation unconformably overlies the Umpqua formation. It consists of lava flows, tuffs, breccias, mud flows, and water-laid clays, shales, sandstones, and conglomerates. Transported high-alumina clays belonging to this formation and derived from a kaolinitic weathering profile are found at Hobart Butte and elsewhere. Silicified wood, charcoal, and leaves are found in these clays and other associated rocks. The Calapooya formation is several thousand feet thick and was deposited in a continental environment probably during late Eocene time (Brown, unpublished memorandum). The formation has been eroded, gently folded, and in places faulted. Its distribution is shown in figure 2.

Mafic igneous rocks have invaded both the Umpqua and Calapooya formations. One of these intrusive bodies crops out on the southwest side of Hobart Butte (fig. 2).

Hydrothermal solutions have invaded and in places greatly altered the sedimentary rocks. Cinnabar, realgar, stibnite, pyrite, siderite, calcite, quartz, dickite, and other minerals were deposited. Several quicksilver mines are in this part of Oregon, in formations ranging in age from Paleozoic to Miocene. If the mineralization in the Hobart Butte area took place at the same time as that in the Bohemia district, the mineralization is probably late Miocene in age. (Callaghan and Buddington, 1938, p. 23.)

Geologic history

A generalized outline of the geologic history of the district follows:

Recent and Pleistocene: Formation of present topography. Erosion, rock terraces, river terraces, alluvium, colluvial mantle, weathering.

Pliocene: Uplift and erosion.

Miocene (late):
Hydrothermal activity. Cinnabar, realgar, dickite, etc.
Diastrophism.
Injection of mafic intrusions.

Oligocene: Erosion.

Eocene:
Calapooya formation.
Extrusion of lava, and deposition of pyroclastic rocks and mud flows.
Deposition of water-laid high-alumina clays, sandstones, and conglomerates.
Formation and erosion of a weathering profile.
Diastrophism and erosion.
Umpqua formation.
Deposition of marine shales, sandstones, and conglomerates.
Extrusion of lava and deposition of pyroclastic rocks.

ORE DEPOSIT

Mineralogy

High alumina minerals. --Kaolinite $(Al_2O_3 . 2SiO_2 . 2H_2O)$, the principal clay mineral at Hobart Butte, was identified by petrographic studies of V. T. Allen and by X-ray studies of J. M. Axelrod, of the U. S. Geological Survey. Joseph A. Pask, U. S. Bureau of Mines, made thermal analyses of the clay from the Hobart Butte deposit and considered kaolinite the only clay mineral present. K. G. Skinner of the same organization has orally expressed the opinion that the thermal curves of these clays indicate that kaolinite is the principal clay mineral present, but that minor amounts of dickite $(Al_2O_3 . 2SiO_2 . 2H_2O)$ are included in some
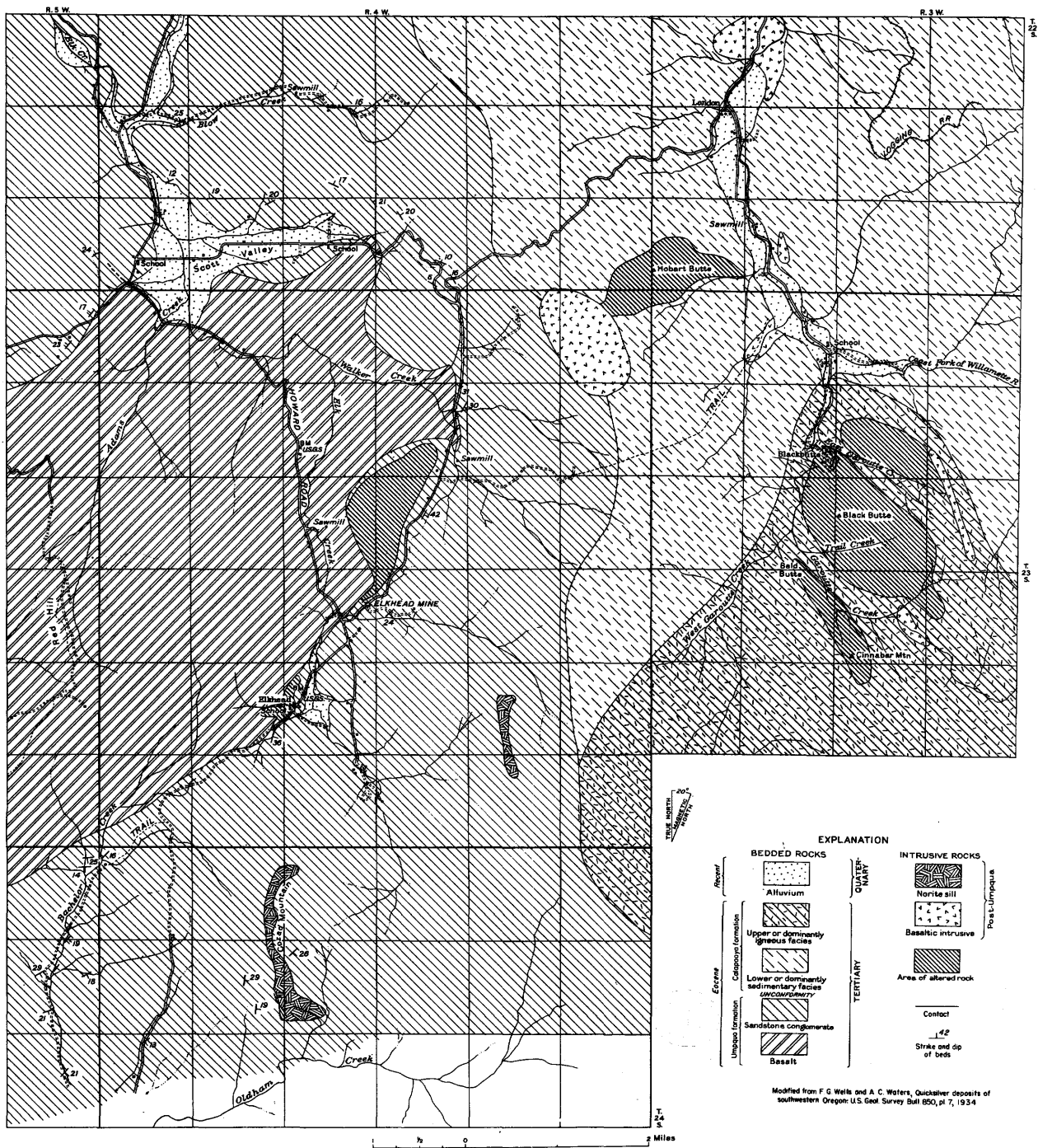
Figure 2. --Geologic map of Hobart Butte, Black Butte, and Elkhead districts, Oregon.

samples. Dickite belongs to the kaolin group of clay minerals, and has the same chemical composition as kaolinite. In the laboratory it has been formed at a slightly higher temperature than kaolinite; its geological occurrence in many districts suggests that it forms by the action of hydrothermal solutions. The optical properties and the mosaic intergrowth of some of the kaolin in the veins and altered rocks at Hobart Butte suggest that dickite may be present. Pask has found that dickite behaves somewhat like kaolinite in the extraction of alumina from calcined clay with 20 percent sulfuric acid (Pask and Davies, 1943, pp. 14 and 27). This simple mineralogy should facilitate the extraction of alumina from the clay.

Other minerals.--Hydrothermal sulfides are distributed throughout many of the beds at Hobart Butte. Realgar and stibnite are most abundant but are probably limited to a few pounds to the ton. They volatilize readily, so the arsenic and antimony may be recovered at an early stage in the metallurgical process selected to obtain alumina from the clay.

Realgar (AsS) occurs principally as: coatings on slickensided surfaces; fillings and replacements of the porous matrix material around pellets and rock fragments; fracture fillings; and irregularly distributed flecks scattered through the host rock. Some of the realgar conforms to the striated grooves of the slickensides and some of the realgar itself is slickensided. This suggests that the clay was slickensided before the hydrothermal solutions brought in realgar, that the slickensided fractures served as one type of opening for the invading solutions, and that movement along slickensides was renewed during the deposition of realgar. The matrix around pellets and rock fragments was permeable enough to be impregnated with realgar. About halfway up one face of the quarry a distinct band of realgar has formed, in which the matrix of the clay, but not the pellets, has been replaced. Small veinlets of realgar cut across early struc tures and small flecks of realgar are scattered through the clay at all depths. The association of realgar with high-alumina clay, particularly in the upper part of the deposit, is related to the porosity provided by these rocks for the invading solutions. At no place is realgar abundant enough to be of economic importance in itself. It is nearly always massive, but a few small crystals have been noted in cavities. Small amounts of orpiment (As$_2$S$_3$) were seen but apparently occur only near the surface.

Stibnite (Sb$_2$S$_3$) occurs in small amounts in some of the clay as tiny acicular crystals and locally forms radiating groups of crystals 3 millimeters in diameter. The greatest concentration of stibnite is along slickensides, where needles of microscopic size form aggrevates about a millimeter thick. Several unidentified alteration products of stibnite were observed.

Large, well-formed pyritohedrons of pyrite (FeS$_2$) are associated with realgar, stibnite, dickite-kaolinite and siderite. Some fine-grained material may be marcasite (FeS$_2$) or arsenopyrite (FeAsS), but these minerals were not identified with certainty.

There are probably several other sulfide minerals at Hobart Butte, but they were not identified during this investigation. A. C. Waters (personal communication) has recognized cinnabar (HgS) and calomet (HgCl) crystals in material from Hobart Butte.

Scorodite (FeAsO$_4$.2H$_2$O) is a common mineral in the clay quarry, and appears as green crusts with spherulitic structure in crevices and replaces the clay. R. M. Denning (1943 pp. 55-57) of Stanford University first reported scorodite at Hobart Butte, and A. F. Rogers and A. C. Waters confirmed the identification. Scorodite was deposited from arsenical waters in Yellowstone National Park (Hague, 1887, pp. 171-175) and probably it was deposited at Hobart Butte by hot ascending waters related to volcanic activity. Rogers and Waters (Waters, March 1943, personal communication) also recognized pitticite (Fe$_2$O$_3$, SO$_3$, As$_2$O$_5$, H$_2$O) with the scorodite at Hobart Butte. V. T. Allen identified a new arsenate (Al$_2$O$_3$.As$_2$O$_5$.4H$_2$O) to which the name mansfieldite has been given (Allen and Fahey, 1946, p. 189; 1948, pp. 122-134).

Siderite (FeCO$_3$) is a common mineral at Hobart Butte, where it occurs as tiny, honey-colored globules, and in barrel-shaped and dumbbell-shaped forms. It is present as disseminated grains, clusters, and fracture fillings. Some simple nodular grains show a radial structure. Siderite nodules in some dickite-kaolinite veins, the crusts of siderite on dickite-kaolinite and pyrite crystals, and the cutting of siderite nodules by stringers of realgar suggest that some of the siderite at Hobart Butte is related to hydrothermal action. The high iron content of some Hobart Butte clays is due to siderite or to iron oxides formed by its oxidation.

Calcite (CaCO$_3$) appears to be of limited occurrence at Hobart Butte. In drill core of hole no. 10, it was found filling interstices of the host rock and also as a vein nearly one-fourth inch in width. It was not found in any high-alumina rocks.

Seams and stains of limonite (2Fe$_2$O$_3$.3H$_2$O) are found in nearly all of the rocks near the surface at Hobart Butte. Limonite is also abundant at considerable depth, where, it is thought, surface waters have penetrated. Some rocks are so thoroughly oxidized and stained by limonite that it is difficult to determine the original nature of the specimen. In the oxidized areas, casts were found that suggest the limonite was derived from pyrite or siderite.

Hematite (Fe_2O_3) and goethite ($Fe_2O_3 \cdot H_2O$) have been identified by X-ray patterns as the minerals providing the color of the red clays.

Quartz (SiO_2) is present in some altered tuffs and volcanic rocks in grains so small that it escapes detection with a microscope. Its presence has been established by X-ray patterns, and in some analyzed samples its presence is confirmed by a higher silica content than that required by the alumina-silica ratio of kaolinite or dickite, with which it is associated. In a few specimens, quartz of microscopic size occurs as prismatic crystals with well-formed terminations in association with scorodite and mansfieldite. This quartz probably resulted from the action of hydrothermal solutions on the invaded rocks. Some of it formed by crystallization of excess silica liberated when the volcanic glass was altered to dickite or kaolinite. The silica for quartz in veins associated with the mosaic intergrowths of kaolinite and dickite, and in the siliceous matrix which surrounds some clay pellets, was probably transported from its place of origin to its present position by hydrothermal solutions.

Analyses

Several thousand chemical determinations were made of drill core, sludge, grab samples, and channel samples. These analyses were made principally by the Northwest Experiment Station, U. S. Bureau of Mines. The determinations included total Al_2O_3, Fe_2O_3, SiO_2, MgO, GaO, Na_2O, K_2O, TiO_2, ZrO_2, P_2O_5, V_2O_5, Hg, Sb_2S_3, WO_3, As_2O_3, organic C, and CO_2; loss on ignition at 700° C. and 950° C.; and available Al_2O_3, Fe_2O_3, and SiO_2.

The available Al_2O_3 is usually between 75 and 100 percent of the total Al_2O_3. The percentage by weight is obtained by treating clay calcined at 700° C. with a 20 percent solution of H_2SO_4 for one hour. The available Al_2O_3 and Fe_2O_3 are calculated from the weight of the sample after drying at 130° C.

The chemical characteristics of the clay are shown by the following analysis of a composite sample of the high-grade part of ore body A.

The loss on ignition and the Al_2O_3 content are closely related to the abundance of kaolinite, and the Fe_2O_3 content to the abundance of siderite, hematite, and limonite. The assay values of available Al_2O_3 for trench, pit, and outcrop samples are shown in plate 1; and the assay values of Al_2O_3 and Fe_2O_3 for drill-core samples, in plate 2.

Analysis of composite sample from high-grade part of ore body A

/Analyzed by U. S. Bureau of Mines/

Total

SiO_2	51.2	Sb_2S_3	0.08
Al_2O_3	30.4	As_2O_3	0.27
Fe_2O_3	3.6	WO_3	0.0
MgO	0.0	Hg	0.0
CaO	0.2	Organic C	0.1
Na_2O	0.2	CO_2	0.7
K_2O	0.1	Ign. loss at	
TiO_2	2.4	700° C.	11.5
ZrO_2	0.0	Ign. loss at	
P_2O_5	0.25	950° C.	11.8
V_2O_5	0.0*		

*Less than 0.05 percent.

Available

Al_2O_3	29.8
Fe_2O_3	3.5
SiO_2	0.6

Lithologic characteristics and genesis

The following outline indicates types of clays that have been recognized at Hobart Butte. The origin assigned to each type is based upon petrographic, X-ray, and chemical determinations.

Types of clay at Hobart Butte

I. Sedimentary clays--kaolinitic clay deposited by streams.

    A. White, gray, yellow, and purple clays; 29.0 to 35.2 percent available Al_2O_3; 0.7 to 3.4 percent available Fe_2O_3.

        (a) Clays containing white to gray pellets in a light-gray to black clay matrix; organic matter ranging from 0.1 to 2.8 percent.

        (b) Water-laid breccias in which angular kaolinitic fragments are embedded either in a clay matrix containing some organic matter (16 G, table 2) or in a yellow, buff, or purple matrix (5, 6, table 1).

        (c) Massive clays.

    B. Red clays; 21.0 to 27.0 percent available Al_2O_3, 3.5 to 11.0 percent available Fe_2O_3.

        (a) Clays containing white or light-colored pellets in a red clay matrix.

        (b) Water-laid breccias in which angular kaolinitic fragments are embedded in a red clay matrix.

        (c) Massive clays.

II. Hydrothermal clays--formed by hydrothermal solutions acting on volcanic rocks; 24.0 to 27.4 percent available Al_2O_3; 0.28 to 9.74 percent available Fe_2O_3.

    (a) Altered welded tuffs--former fragments of pumice distorted by pressure against other volcanic fragments; organic material absent. (1, table 1).

    (b) Altered tuffs--relict shard texture preserved in clay now mainly kaolinite and quartz; organic material absent. (7, table 1).

    (c) Veins of kaolinite-dickite with a mosaic structure, and fine-grained quartz. (3, table 1).

III. Clays of mixed origin; from less than 20 to 34.0 percent available Al_2O_3; 0.50 to 11.0 percent available Fe_2O_3.

    (a) Sedimentary clays cut by veins of kaolinite-dickite and quartz, or bleached by hydrothermal solutions. (16W, table 2).

    (b) Clays which have been silicified by hydrothermal solutions. (10, table 1).

    (c) Clays into which siderite, scorodite, pyrite, and other hydrothermal minerals have been introduced.

    (d) Low-grade clays containing a variety of unaltered siliceous rock fragments.

Chemical analyses of selected samples of these types of clays, made in the chemical laboratory of the U. S. Geological Survey, are listed on p. 7.

During this investigation four principal hypotheses for the origin of the clays at Hobart Butte have been considered: first, the clay is a result of residual weathering; second, the deposit consists of sedimentary clays; third, the clay is the result of hydrothermal alteration of sedimentary rocks in place; and fourth, the deposit consists of both sedimentary and hydrothermal clay.

Recent drilling suggests that the theory of residual weathering is unsatisfactory, because the clay is too thick; many features prove that it is a sedimentary clay; and no profile of weathering is apparent either conformable with the present topography or with any pre-existing topography.

A sedimentary origin for most of the kaolinite is favored by the petrographic studies of Allen, who believes that the flattened pellets of kaolinite, which are common in certain clay beds, are sedimentary structures (Allen and Nichols, 1945, pp. 25-33). The organic matter in the clay surrounding the pellets and breccia fragments (table 2) is proof of deposition in water by sedimentary processes. The presence of charcoal, lignitic material, diatoms, silicified wood, and the abundance of pellets and clay fragments is evidence that the clays containing them are fluvial sediments. The molding of some pellets and breccia fragments against quartz, rock fragments, and pellets indicates that they were deposited as a clay with some plasticity.

This clay had the composition of kaolinite at the time of deposition. Pellets can be formed only from clay fragments that possess a limited plasticity and do not disintegrate in water. Kaolinitic flint clay is known to possess these characteristics. Similar pellets have been observed in the Pennsylvanian rocks of the eastern United States coal fields, the Cretaceous and Eocene rocks of the Atlantic and Gulf coasts, the Cretaceous rocks of Colorado, and the clays of Eocene age in southern California and Washington; at all the known occurrences they are considered sedimentary in origin.

Kaolinitic clays that contain organic matter, such as ball clays, are plastic, and when wet, deform easily. Brown and gray fragments in the clays at Hobart Butte contain more organic matter than the white fragments, and many of these are squeezed and plastically deformed around the white fragments and pellets.

Moreover, the X-ray and petrographic studies of the pellets, the breccia fragments, and the matrix of the clays at Hobart Butte have failed to reveal remnants of another clay mineral from which the kaolinite could have formed. On the

Table 1.—Analyses of main varieties of clay

/M. D. Foster, Analyst_7

	1	3	5	6	7	10
Loss at 130° C.............................	0.44	0.23	0.64	3.97	0.16	0.17
Loss at 700° C.............................	10.15	9.71	10.50	8.26	5.95	8.80
Available Al_2O_3*........................	27.36	26.71	29.41	34.33	24.00	15.54
Available Fe_2O_3*........................	9.74	0.28	1.17	3.00	1.12	0.48
Available TiO_2*.........................	0.14	<.02	<.02	.06	<.02	<.02

*Calculated on dry weight at 130° C.

1. Altered welded tuff, southwest side of Hobart Butte, near summit.

3. Kaolinite-quartz vein, lower part of Hobart Butte.

5. Water-laid breccia with yellow clay matrix, quarry at Hobart Butte.

6. White fragment from water-laid breccia having a purple clay matrix. Fragment is now kaolinite, but retains relict texture of pumice. Quarry, Hobart Butte.

7. Altered vitric tuff with relict shard texture. Volcanic glass has been altered to a mosaic of kaolinite-dickite and fine quartz. W. M. Adams property, sec. 3, T. 21 S., R. 3 W., near Cottage Grove, Oreg.

10. Altered trachyte (?). Altered feldspars are now kaolinite and retain a flow arrangement. They have escaped the intensive silicification affecting the groundmass. Lower part of Hobart Butte.

Table 2. Analyses of clays from the quarry at Hobart Butte

/W. W. Brannock, analyst_7

	16G	16W	15	Q59
SiO_2.....................................	50.80	50.91	....	....
Al_2O_3...................................	33.45	33.67	....	....
Fe_2O_3...................................	.81	.50	....	....
MgO......................................	none	none	....	....
CaO......................................	none	none	....	....
Na_2O....................................	none	none	....	....
K_2O.....................................	none	none	....	....
H_2O (-110° C)...........................	.61	.61	....	....
H_2O (+110° C)...........................	12.11	11.97	....	....
TiO_2....................................	1.92	1.99	....	....
Organic matter........................	.31	.16	1.31	2.80
	100.01	99.81	....	....

16G. Water-laid breccia in which the long axes of white fragments are alined in one direction, and surrounded by dark-gray clay containing organic matter and appreciable iron.

16W. Bleached zone, 2 inches wide, in contact with clay represented by sample 16G, and retaining the same arrangement of fragments as 16G but in a white clay matrix. Some organic matter and ferric oxide have been removed by hydrothermal solutions.

15. Organic matter in a clay-pellet conglomerate forming a 10-foot bed in which white pellets are surrounded by dark-gray clay.

Q59. Organic matter in clay in which white pellets are surrounded by black carbonaceous clay.

southwest side of Hobart Butte, about 200 feet below the summit, kaolinite occurs as books in a leaf-bearing shale. This is the characteristic habit of kaolinite in sedimentary rocks, and suggests that a supply of kaolinite was available in the region during the deposition of the Calapooya formation. Also, fragments of pumice and welded tuffs, now white kaolinite but retaining original structures, are enclosed in a red or purple, iron-stained, kaolinitic matrix at various levels throughout the Hobart Butte area (see 6, table 1). The alteration of volcanic glass to kaolinite must have been completed at the time of deposition, because if it took place after deposition the red matrix would have been bleached.

Many features of the Hobart Butte high-alumina clays suggest that they were derived during the Eocene from weathered rocks, which furnished not only white kaolinite clay for pellets, books, and matrix material but also red clay high in iron for the matrix surrounding the white pellets and the fragments of altered pumice.

Some of the clay at Hobart Butte was formed by hydrothermal solutions that invaded the region, probably in the later part of Miocene time, and deposited realgar, stibnite, arsenates, pyrite, quartz, dickite, and other minerals. The distribution of the sulfides along slickensided surfaces indicates that the fractures in sedimentary clay served as one type of opening for the invading solutions. The hydrothermal solutions altered volcanic glass and rock fragments to kaolinite-dickite. Some of the original texture of the pumice is so perfectly preserved that one receives the impression that the cloudy, isotropic to low-birefringent material is the original glass, but all the specimens isolated and examined have the indices of refraction and the X-ray pattern of kaolinite. In many specimens the formation of kaolinite from glass and rock fragments was accompanied by the crystallization of quartz, which is so fine-grained that it escapes detection except in X-ray patterns. In a few specimens, however, quartz of microscopic size occurs as prismatic crystals with well-formed terminations. At the summit of Hobart Butte, the glass of welded tuffs is altered to an isotropic material giving the X-ray patterns of kaolinite and quartz (see 1, table 1). A vitric tuff near Cottage Grove has been so thoroughly altered to submicroscopic quartz and a mosaic of kaolinite-dickite by hydrothermal solutions (see 7, table 1) that no mineralogic distinction can be made under the microscope between large shards and the fine material surrounding them. The available alumina of these hydrothermally altered tuffs (1 and 7, table 1) is from 27.36 to 24.00 percent, and the available Fe_2O_3 is 9.74 and 1.12 percent, respectively.

Clay of hydrothermal origin fills cracks ranging from 1 to 8 millimeters in width at all altitudes in the Hobart Butte area. Such clay veins are more abundant at lower altitudes, and all of those tested contain finely divided quartz. In thin section the white kaolin mineral in the veins shows the mosaic intergrowth characteristic of the massive dickite from Chihuahua, Mexico,

and Neurode, Silesia; a few small grains have an extinction angle of about 16°, which is indicative of dickite rather than kaolinite. All the Hobart Butte specimens, including one in which a few grains had extinction angles of about 16°, gave the X-ray pattern of kaolinite. This suggests that the amount of dickite is too small to be recorded in the X-ray pattern, and that the temperature of the hydrothermal solutions at first may have been high enough to allow some dickite to crystallize, but soon dropped to a point at which kaolinite crystallized. The available alumina of a typical veinlet giving the X-ray pattern of kaolinite and quartz is 26.71 percent (see 3, table 1), and, like that of clays produced by hydrothermal solutions acting on tuffs, is lower than the available alumina of typical sedimentary clays from the upper part of Hobart Butte.

The possibility that the available alumina in the sedimentary clays was increased by the action of hydrothermal solutions has been considered during this investigation. The addition of veins of kaolinite and quartz to red and light-colored clays decreased the available alumina of the invaded clay. A comparison of the 26.71 percent available alumina of a typical kaolinite-quartz veinlet with the 33 to 35 percent available alumina of the best sedimentary clays at Hobart Butte demonstrates this beyond question. Also, the addition of hydrothermal quartz to the matrix or to the groundmass decreased the available alumina of certain types of clay. In the pellet-bearing sedimentary rock that forms a pinnacle on the south side of Hobart Butte, the matrix, but not the pellets, is silicified. In some volcanic rocks, the feldspar phenocrysts are now kaolinite that escaped the silicification that converted the groundmass to quartz (see 10, table 1). Apparently the pellets and kaolinized feldspars were less permeable than the matrix materials and were not replaced by the silica-bearing solutions. Bleaching of red clays to various shades of pink is noticeable in the lower levels at Hobart Butte. In the quarry, along slickensided surfaces coated with sulfides, gray clays are bleached white, suggesting that hydrothermal solutions caused the bleaching. In a specimen collected from a bleached zone cutting a gray, water-laid breccia in which elongate white fragments are surrounded by a dark-gray clay, the unbleached part was analyzed separately from the bleached zone (16G and 16W, table 2). The bleached zone has a slightly lower content of organic matter and ferric oxide than the adjacent gray clay having the same structure, but its Al_2O_3 content is only 0.22 percent higher, and no additional clay minerals found. The relative increase of alumina is of the order, expected by the removal of the slight amount of organic matter and ferric oxide.

Bleaching of the gray clay was accomplished in the laboratory by heating the specimen to drive off organic matter. After heating, the original white breccia fragments remained white, but the surrounding gray clay showed a fine network of red, iron-stained lines in white material. This indicates that the iron content of the gray carbonaceous clay is higher than that of the white breccia fragments.

In attempting to compare the effects of the early weathering and sedimentation with the effects of the late hydrothermal activity, it should be noted that the best clays at Hobart Butte are confined to the upper 200 feet of the clay deposit, where the features of the clays indicate only a sedimentary origin. During the deposition of the upper sediments of the clay deposit at Hobart Butte, a large percentage of high-grade clay materials was derived from weathered rocks to the east. During deposition of the low-grade clays, fragments of many siliceous volvanic rocks, which either escaped alteration or were silicified, were deposited and now form the lower part of the clay deposit. In many samples the low alumina content can be correlated with the quantity of these siliceous rocks. In other samples low alumina is attributed to intensive silicification connected with the hydrothermal activity during the later part of Miocene time. Also, the addition of siderite, pyrite, and scorodite by hydrothermal processes increased the iron content of some clays and proportionally decreased their alumina content. At many places the hydrothermal effects at Hobart Butte were more detrimental than helpful in producing a clay high in alumina and low in iron.

In summary, most of the high-grade clay at Hobart Butte is sedimentary clay derived from weathered rocks and deposited by streams as kaolinitic clay during the Eocene. The clays formed directly by hydrothermal processes acting on volcanic rocks are lower in available alumina and generally are higher in silica or iron than the sedimentary types. The hydrothermal solutions acting on the sedimentary clays produced no significant improvement in the alumina content of the resulting clay, because where bleaching was accomplished, no new clay minerals were added; where dickite-kaolinite veins were added, the accompanying quartz and iron minerals lowered the available alumina of the clay proportionally.

Ore body

The ore body is near the summit of Hobart Butte and ranges in thickness from less than a foot to 204 feet. In places it crops out at the surface; elsewhere there is an overburden of as much as 130 feet. The overburden consists in large part of low-grade clay belonging to the Calapooya formation but also consists of a colluvial mantle which thickens downward from the crest of the Butte.

The deposit appears to be in a faulted, open syncline, that plunges northeast (pls. 1 and 2). This interpretation is based on strike and dip readings at the surface, on observations of the attitude of bedding in drill core samples, and on lithologic correlations from hole to hole. The rocks dip as much as 25⁰, are abundantly slickensided, and vary in lithology from hole to hole in a way that is characteristic of stream deposits. The boundaries of the ore body are partly concordant with bedding, partly discordant. These relationships can easily be explained in terms of the deposition of kaolinitic and nonkaolinitic material in a terrestrial environment.

Neighboring deposits

High-alumina clay is widely distributed in the vicinity of Hobart Butte and Cottage Grove. U. S. Geological Survey geologists and U. S. Bureau of Mines engineers collected samples at 37 of these related localities. The localities having clay with more than 25 percent available Al_2O_3 are listed in table 3. These potential contributory deposits contain more iron than the deposit at Hobart Butte, however, and are less promising as sources of alumina. Two holes were drilled in high-alumina clay at the Putman locality (see fig. 1), which is the most important neighboring deposit.

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Table 3--Analyses of high-alumina clays containing 25 percent or more available Al_2O_3 near Hobart Butte

Property	Section	Township	Range	Location	Ign. loss	Avail. Al_2O_3	Avail. Fe_2O_3	Lithologic Characteristics
	20	19 S.	2 W.	Cloverdale, Ore.	9.9	28.5	17.7	Ferruginous shale
Mark claim	16	15 S.	1 W.		9.8	30.0	10.0	
Do---	21	15 S.	1 W.		9.8	28.8	14.6	
Do---	21	15 S.	1 W.		8.9	26.7	11.2	
Do---	9	15 S.	1 W.	near Mabel	8.6	25.9	3.1	
Camas Swale Rd.	13	19 S.	4 W.	6.7 miles east of Creswell	9.8	25.2	17.4	Red plastic clay
Cougar Bend, Buck Mt.	13	23 S.	3 W.		10.7	31.3	7.0	Red pebbly shale
Adams	3	21 S.	3 W.		10.5	30.7	4.5	Pinkish-red shale
Do---	3	21 S.	3 W.		10.5	30.5	18.5	Red shale
Sheary	3	21 S.	3 W.		10.5	32.2	10.8	Chocolate pebbly shale
John Woodard	31(?)	22 S.(?)	3 W.(?)	near London	9.0	26.2	16.0	
Snyder	30	20 S.	2 W.	between Cottage Grove & Dorena	9.9	27.1	5.9	Ferruginous clay-pellet shale
Porter	32	19 S.	3 W.		11.0	30.2	13.0	
Do---	32	19 S.	3 W.	Keel Creek	9.8	30.7	15.4	Ferruginous shale
Do---	32	19 S.	3 W.	" "	2.0	36.1	1.0	White shale, clay-pellet shale
Do---	32	19 S.	3 W.	" "	10.1	30.7	11.5	Ferruginous pebbly & sandy shale
Raisers	18	22 S.	3 W.	across bridge from George Bales	9.8	26.5	13.9	
Myers	29	21 S.	2 W.	Mosby Creek 8 mi. from Cottage Grove	9.9	29.7	14.9	Ferruginous shale
Do---	29	21 S.	2 W.	"	9.3	27.7	9.3	Ferruginous pebbly shale
Do---	13	23 S.	3 W.	Woodward logging rd. 6.4 mi. from London-Cottage Grove Rd.	9.3	29.0	8.7	In part, red and white shales
Do---	13	23 S.	3 W.	"	11.3	34.9	5.0	
Do---	13	23 S.	3 W.	"	12.2	35.7	1.5	
Do---	13	23 S.	3 W.	"	11.9	33.5	3.9	
Black Butte mine	16-17	23 S.	3 W.	West 900 adit, 240 ft from portal	13.6	27.9	8.5	

Table 3—Analyses of high-alumina clays containing 25 percent or more available Al_2O_3
near Hobart Butte—Continued

Property	Section	Township	Range	Location	Ign. loss	Avail. Al_2O_3	Avail. Fe_2O_3	Lithologic Characteristics
Black Butte mine—Cont.	16-17	23 S.	3 W.	West 500 adit, 60 ft from portal	10.1	27.4	5.1	
"	16-17	23 S.	3 W.	West 500 adit, east crosscut	11.2	25.0	3.8	
"	16-17	23 S.	3 W.	East 500 adit, 100 ft from portal	7.8	27.5	1.3	
"	16-17	23 S.	3 W.	East 400 adit, 50 ft from portal	10.3	26.8	5.1	
"	16-17	23 S.	3 W.	East 900 adit, 300 ft from portal	10.4	28.3	9.2	
	1	18 S.	4 W.		10.4	30.2	11.8	
	30	18 S.	3 W.	Near Spencer Butte	12.5	35.8	4.4	
	30	18 S.	3 W.	Near Spencer Butte	10.6	29.0	2.9	

Putman deposit assays not listed.