United States Department of the Interior
Geological Survey
Strategic Minerals Investigations

PRELIMINARY REPORT

ON

THE KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS

by

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PRELIMINARY REPORT

ON

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ABSTRACT

Six high-alumina clay deposits have been investigated in King County, Washington. They lie in the Cedar Lake and Snohomish quadrangles between latitudes 47°15' and 47°32' and longitudes 121°50' and 122°05'. They are only a few miles from Durham, Kanaskat, Kangley, Black Diamond, and Issaquah; are within 5 miles of a railroad; and with one exception are within 50 miles of Seattle and Tacoma.

The investigation of these deposits was carried out jointly by the Geological Survey and the Bureau of Mines, United States Department of Interior, between October 1943 and February 1945. Twelve diamond drill holes having a total footage of 1724.5 feet were drilled.

The high-alumina clay is interbedded with late Eocene sandstone, siltstone, shale, and coal. It is usually between 10 and 30 feet thick, in most places it has a dip of more than 20 degrees, and it is commonly buried by landslide and glacial deposits. The ore minerals are mainly kaolinite and boehmite but gibbsite and alumina gel are also present. Siderite is in places abundant and it has an erratic distribution. The clay is grey, fine-grained, flint and semi-flint, and the total Al_2O_3 content may be as high as 50 percent. It was deposited mainly as kaolinitic clay in a lacustrine environment. It is not known whether the boehmite and gibbsite were deposited with the kaolinite, were formed from it by alteration after deposition, or resulted from the operation of both processes. Some of the kaolinite was probably derived from a weathering profile to the east.

The reserves have been calculated by the perpendicular bisector method. There are 1,747,000 dry tons of measured ore with 33.0 percent available Al_2O_3 and 11.17 percent available Fe_2O_3 and 2,048,000 dry tons of indicated ore with 33.0 percent available Al_2O_3 and 11.39 percent available Fe_2O_3. Geologic data suggest that there are 20,000,000 dry tons of inferred ore of approximately the same grade. Underground mining will be necessary.

INTRODUCTION

Purpose

Due to the great need for aluminum during the present war emergency and in anticipation of a possible shortage of bauxite, many high-alumina clay deposits have been investigated as possible sources of alumina by the United States Department of Interior. The general geology, the characteristics of the ore bodies and the reserves of the King County, Washington, high-alumina clay deposits are briefly considered in the present report. The investigation of these deposits was carried out jointly by the Bureau of Mines and the Geological Survey, United States Department of Interior, between October 1943 and February 1945.

Location and Accessibility

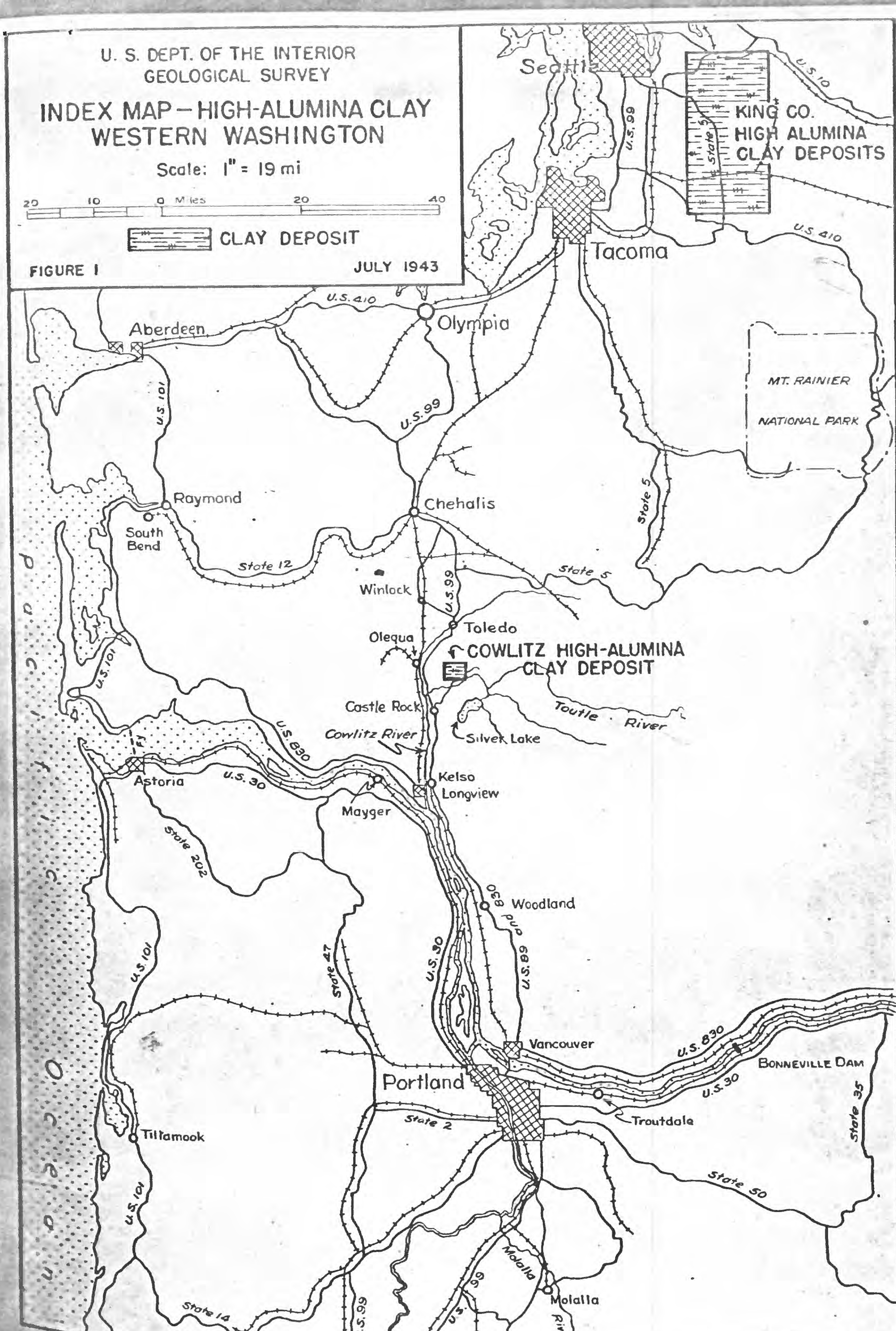
The Durham, Kanaskat, Kangley, Blum, and Kummer deposits are in the Cedar Lake quadrangle; the Harris deposit is in the Snohomish quadrangle; and all have been investigated in the present project (figs. 1 and 2). The Blum and Kummer deposits are in the Puget Trough physiographic section, the others are in the Northern Cascade Mountains province, and all are between latitudes 47°15' and 47°32' and longitudes 121°50' and 122°05'.

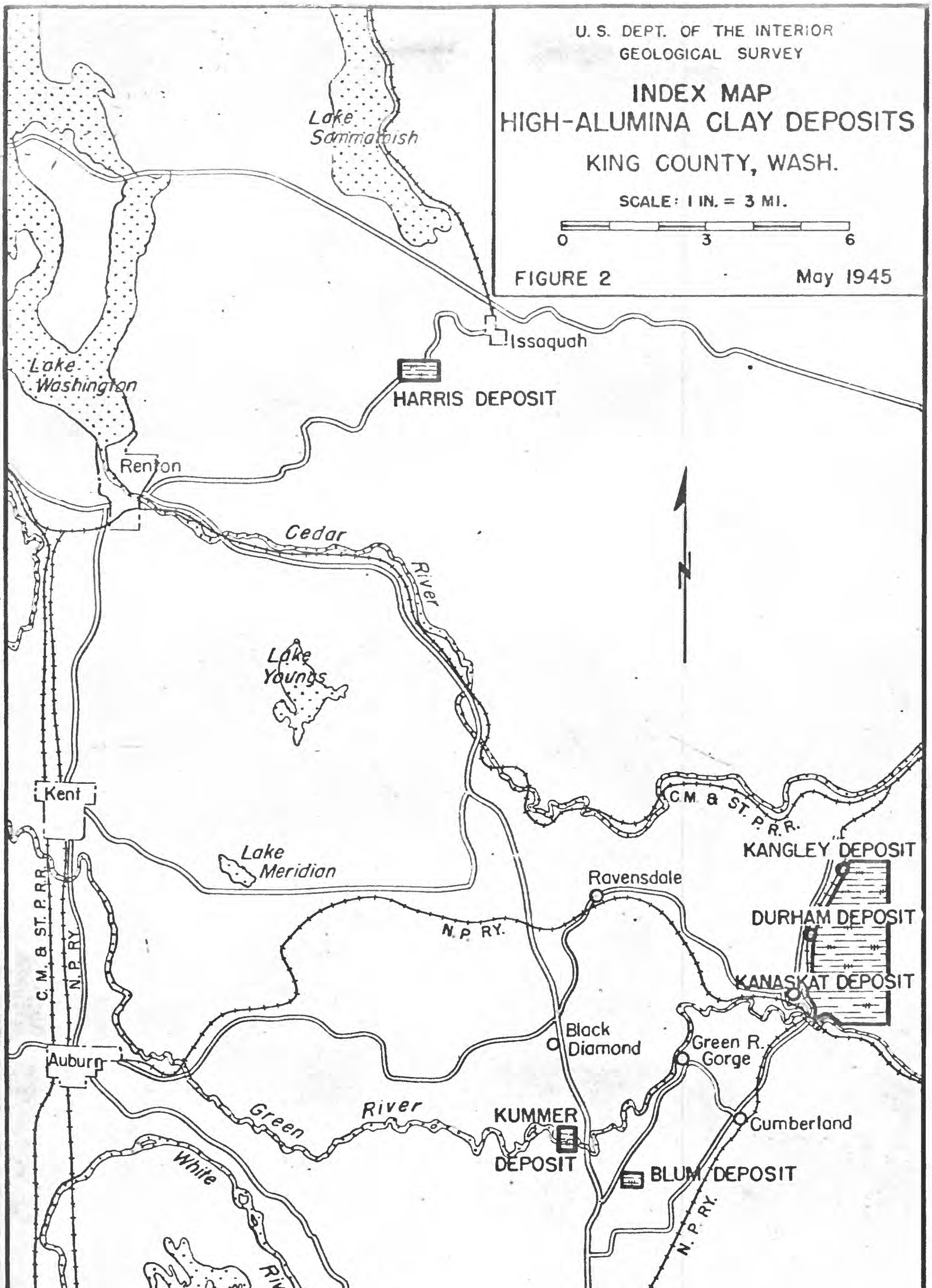
The Durham deposit is in secs. 35 and 36, T. 22 N., R. 7 E. and secs. 1 and 2, T. 21 N., R. 7 E., approximately 2 miles by a mountain road from the Northern Pacific and the Chicago, Milwaukee, St.Paul, and Pacific railroads. The Kangley deposit lies in the SE$\frac{1}{4}$ sec. 26, T. 22 N., R. 7 E., about 1000 feet from the Northern Pacific and the Chicago, Milwaukee, St. Paul, and Pacific railroads. The Kanaskat deposit is in the middle part of sec. 12, T. 21 N., R. 7 E. approximately 2 miles by a gravel road from the Northern Pacific and the Chicago, Milwaukee, St. Paul, and Pacific railroads.

The Blum deposit lies in the NW$\frac{1}{4}$ and SW$\frac{1}{4}$ sec. 31, T. 21 N., R. 7 E. and in the NE$\frac{1}{4}$ sec. 36, T. 21 N., R. 6 E., a few thousand feet from the highway between Franklin and Enumclaw and about 5 miles from the Pacific Coast railroad at Black Diamond. The Kummer deposit is found on the north and south sides of the Green River Gorge in the E$\frac{1}{2}$ sec. 26, T. 21 N., R. 6 E., approximately half a mile from the main highway between Black Diamond and Enumclaw and between 2 and 3 miles from the railroad at Black Diamond. The Harris deposit is located in the SE$\frac{1}{4}$ sec. 32, T. 24 N., R. 6 E., near the main highway between Renton and Issaquah, and approximately 3 miles from the Northern Pacific railroad at Issaquah. It is being mined at the Harris clay mine.

History

The Kummer high-alumina clay bed was found by Jacob Sants on August 15, 1888. A claim was located and filed by Sants et al. in May 1889 and later the deposit was named for George Kummer, ceramist and operating engineer for the Denny Clay Company. Mining started about 1893 and was continued intermittently until 1937 when increased costs made it unprofitable. The Puget Sound Fire Clay Company, the Denny Clay Company, the Denny-Renton Clay and Coal Company, and Gladding, McBean and Co. have operated this deposit; and between 20,000 and 50,000 tons were taken out by underground mining. In addition to the fire clay, coal and shale were also mined. The clay was used to make fire brick and the shale to make sewer pipe. That part of the bed which is on the north side of the Green River was mined for several hundred feet along the strike. The south side was prospected but never worked.


U. S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
INDEX MAP – HIGH-ALUMINA CLAY
WESTERN WASHINGTON
Scale: 1" = 19 mi
20 10 0 Miles 20 40
CLAY DEPOSIT
FIGURE 1
JULY 1943
Seattle
U.S. 10
KING CO.
HIGH ALUMINA
CLAY DEPOSITS
U.S. 99
State 5
Tacoma
U.S. 410
Olympia
Aberdeen
U.S. 101
MT. RAINIER
NATIONAL PARK
Raymond
South Bend
Chehalis
State 12
State 5
Winlock
Toledo
Olequa
COWLITZ HIGH-ALUMINA
CLAY DEPOSIT
Castle Rock
Toutle River
Silver Lake
Cowlitz River
U.S. 830
Astoria
U.S. 30
Mayger
Kelso
Longview
State 202
Woodland
U.S. 99 and 830
State 47
Vancouver
Portland
U.S. 830
Bonneville Dam
U.S. 30
Troutdale
State 2
State 35
Tillamook
State 50
Molalla River
Molalla
State 14
Pacific Ocean


U. S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
INDEX MAP
HIGH-ALUMINA CLAY DEPOSITS
KING COUNTY, WASH.
SCALE: 1 IN. = 3 MI.
0
3
6
FIGURE 2
May 1945
Lake Sammamish
Lake Washington
Issaquah
HARRIS DEPOSIT
Renton
Cedar River
Lake Youngs
Kent
Lake Meridian
C. M. & ST. P. R.R.
KANGLEY DEPOSIT
Ravensdale
N. P. RY.
DURHAM DEPOSIT
KANASKAT DEPOSIT
Black Diamond
Green R. Gorge
Auburn
Green River
KUMMER DEPOSIT
Cumberland
BLUM DEPOSIT
White River
Lake Tapps
Enumclaw

Lawrence Harris, operator of the Harris coal mine, was responsible for the discovery of the Harris high-alumina clay bed. He noticed that some clay on a coal dump burned white and realized that it was low in iron and might be refractory. He submitted samples to Gladding, McBean and Co. They found them to be refractory, acquired title to part of the bed, and started mining in 1932. Operation has been continuous and approximately 50,000 tons have been mined by underground methods. The clay is used at the Renton plant of Gladding, McBean and Co. to make refractory products.

Richard Farrow, operator of the Blue Blaze mine, found the Blum high-alumina clay deposit and brought it to the attention of Gladding, McBean and Co. They tested the clay, found it to be refractory, and prospected the bed during 1937. The deposit has never been mined, however, as most of the clay is high in iron, and the low iron portion is too thin and irregular.

Flint clay 1/ was found at Durham during logging operations. This clay was used as road metal because it was hard and not plastic when wet. One of the loggers, who had lived in Missouri, noticed the similarity between the Missouri and Durham flint clays and sent a sample to Gladding, McBean and Co. Tests showed the clay to be refractory; and in 1941 trenches were dug, the outcrop was bulldozed, and the bed was drilled by Gladding, McBean and Co.

William Peak of Kanaskat found flint clay approximately $1\frac{1}{2}$ miles southeast of the Durham locality in March 1941 while working on a coal seam. L. J. Francis of Kanaskat called this locality to the attention of Gladding, McBean and Co. who prospected the area by means of trenches, pits, and tunnels during the spring of 1942. The presence of flint clay in the Kanaskat area, however, was known to J. W. Woodford, Seattle engineer, as early as 1917. In a report for the Glen Ellen Coal Company dated July 2, 1917, he wrote, "On section 12 I have seen clay beds of great promise but thus far no one has developed them. Grab samples I took showed a high grade of fire clay."

No clay has been commercially mined at either Durham or Kanaskat as the ceramic tests and field work showed that most of it contained too much iron to be of value for refractories.

The Kangley deposit was found by R. M. Grivetti of the Geological Survey and C. C. Popoff of the Bureau of Mines.

Because of the high-alumina content of the King County clays the Bureau of Mines and the Geological Survey became interested in them in the fall of 1943. C. C. Popoff and C. P. Purdy, Jr., of the Bureau of Mines, and the writer were taken on September 23, 1943, by R. M. Grivetti to the Durham, Kanaskat, and Kummer deposits. In October 1943, C. C. Popoff started a prospecting program for the Bureau of Mines which consisted of trenching, test pitting, and bulldozing. This was followed

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1/ Industrial Minerals and Rocks, American Institute of Mining and Metallurgical Engineers, New York City, 1937, p. 223.

by diamond drilling. Wayne E. Hall and the writer arrived in Enumclaw to work on this project on May 4, 1944, a short time before the diamond drilling was started.

Scope

Twelve holes were drilled by the Bureau of Mines between May 1944 and December 1944. Nine holes having a total footage of 1302.8 feet were drilled in the Durham area, 8 of which penetrated the clay bed; and 3 holes having a total footage of 431.7 feet were drilled in the Blum area. The shallowest hole was 84 feet; the deepest 251 feet; and the total footage was 1724.5 feet. Diamond drills were used and NX and BX core was obtained. One half of the core was used for chemical analyses and the other half for specific gravity and moisture determinations; lithologic, petrographic, and X-ray examinations; ceramic tests; and thermal analyses.

The geological work necessary to guide the drilling program was done by both the Bureau engineers and the Survey geologists assigned to the high-alumina clay and coal programs.

Acknowledgments

The clay and coal analyses, moisture and specific gravity determinations, and some of the ceramic data were obtained from the Bureau of Mines, United States Department of Interior.

The topography on the maps is based on surveys by the Geological Survey and the Bureau of Mines. The geologic maps of the Harris, Blum, and Kummer deposits were made by Messrs. Walter C. Warren, H. Norbisrath, R. M. Grivetti, and S. P. Brown, of the Geological Survey. The Durham map was made by Mr. C. P. Purdy, Jr., Bureau of Mines, and Mr. Wayne E. Hall, Geological Survey. Other acknowledgments are made in the title blocks of the individual maps.

It is a pleasure to acknowledge the friendliness, helpfulness, and generous cooperation of Mr. C. C. Popoff, Bureau of Mines Project Engineer, and Mr. C. P. Purdy, Jr., Assistant Project Engineer. Many long discussions with Mr. Walter C. Warren and Mr. C. C. Popoff on various aspects of the problem were very profitable. Mr. R. M. Grivetti and Mr. H. Norbisrath were also helpful in this regard. Thanks are due to Mr. Gordon Adderson of Gladding, McBean and Co.; Mr. Sheldon L. Glover, Supervisor Division of Mines and Mining, State of Washington; Professor Charles E. Weaver, University of Washington, and to Dr. John S. Vhay and Mr. Roy P. Full of the Spokane office of the Survey.

The work was done under the supervision of Mr. Victor T. Allen and Mr. John J. Collins. Both contributed many valuable suggestions and much help for which the writer is grateful. It is also a pleasure to acknowledge the help of Mr. Wayne E. Hall who worked with the writer at Enumclaw, Washington, from May 4, 1944, to August 6, 1944.

GENERAL GEOLOGY 2/

Regional Setting

The high-alumina clay is interbedded in the Puget group, which is of late Eocene age. Late Eocene marine sedimentary rocks (Cowlitz ? formation) and late Eocene volcanic rocks are stratigraphically below the Puget rocks in the Preston-Issaquah area; and the Keechelus endesitic series and Miocene-Oligocene sedimentary beds overlie it in the Durham-Black Diamond area. These formations have been folded, faulted, and eroded. They are usually veneered with glacial drift, landslide deposits, or alluvium.

Bedrock

The Cowlitz (?) formation near Preston consists mainly of shale and sandstone with some lenses of conglomerate and beds of coal. It is late Eocene in age, and at least 2000 feet thick although the base is not exposed. The lower portion is in part marine; whereas, the upper portion appears to be entirely continental.

A volcanic series consisting of tuffs and breccias overlies the Cowlitz (?) formation. Between Preston and Issaquah the volcanic rocks are between 6000 and 7000 feet thick; whereas, near the head of Raging River they are only 2000 feet thick. Cowlitz fossils are present in tuffs near the top of the series, and the volcanic rocks are, therefore, of late Eocene age and interfingered with the Cowlitz(?) formation.

The Puget group lies on the late Eocene volcanic series in the Preston-Issaquah district; but at Black Diamond, Durham, and elsewhere the base of the Puget is not exposed. It consists mainly of shale and sandstone together with numerous coal seams and at least one bed of high-alumina flint clay. It is approximately 3100 feet thick at Newcastle and exceeds 6500 feet at Black Diamond. The Puget group at Durham and Black Diamond may be equivalent to the Cowlitz (?) formation, the late Eocene volcanic series, and the Puget rocks in the Preston Issaquah area. In the Durham area it has been invaded by numerous dikes and sills which are presumably of Keechelus age. The Puget is thought to be upper Eocene.

The Keechelus andesitic series consists mainly of flows and pyroclastic rocks. It is several thousand feet thick, and it rests on the Puget group. The Puget was slightly deformed before the formation of the Keechelus ~~series~~ rocks. The Keechelus is thought to range in age from middle Oligocene to early Miocene.

The Miocene-Oligocene sedimentary beds are mainly marine, in part tuffaceous, and they may be as much as 8000 feet thick. These beds and the underlying Puget group are slightly unconformable near Renton. They are thought to be the marine equivalent of the Keechelus andesitic series.

2/ Warren, Walter C., oral communication.

Surficial Deposits

Glacial drift of Wisconsin age covers much of the area. It is fresh and unweathered. The existence of an earlier period of glaciation is shown by a section exposed near the Mud Mountain dam east of Enumclaw. Here till, varved clays, and outwash gravel of Wisconsin age bury glacial deposits which have been deeply weathered. This weathered glacial material may be of Kansan or Nebraskan age. The glacial deposits are in places more than 600 feet thick. Landslide deposits are found close to the area being prospected near Durham and along the Green River near Black Diamond. The deposit near Durham is probably more than 100 feet thick, and it resulted in part from oversteepening due to glacial erosion. That near Black Diamond resulted from oversteepening due to the cutting of the Green River Gorge. Alluvium is found along the stream channels.

Structure

All of the rocks with the exception of the surficial deposits have been folded into a series of plunging anticlines and synclines. Faulting is common. The deformation is mainly post-Keechelus in age.

Geologic History

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

	Preston-Issaquah area	Black Diamond-Durham area
Late Eocene	1a. Deposition of Cowlitz (?) formation sandstone and shale - marine and continental 1b. Deposition of ~~Eocene~~ volcanic series andesitic tuffs and breccias 1c. Deposition of Puget group shale, sandstone, coal, and high-alumina clay clastic sediments derived from east	1. Deposition of Puget group

2. Diastrophism
   resulting in very gentle dips

3. Erosion

Middle Oligocene to Early Miocene	4. Keechelus andesitic series flows, dikes, sills, and pyroclastic rocks	contemporaneous
	5. Miocene-Oligocene sedimentary beds tuffaceous, mainly marine	
	6. Diastrophism folds, faults	
	7. Erosion	
Kansan to Wisconsin	8. Multiple glaciation deposition, erosion, weathering	
Post-Wisconsin	9. Landslides due to glacial oversteepening	
	10. Erosion cutting of Green River Gorge	
	11. Landslides due to oversteepening by Green River	
	12. Erosion	

ORE DEPOSITS

Mineralogy 3/

Ore Minerals

Kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and boehmite ($Al_2O_3.H_2O$) are the most important ore minerals. They have been identified petrographically, by thermal analysis, and by X-ray investigations. Chemical analyses indicate that some of the clay contains more than 35 percent boehmite. Small amounts of dickite ($Al_2O_3.2SiO_2.2H_2O$), diaspore ($Al_2O_3.H_2O$), and gibbsite ($Al_2O_3.3H_2O$) have been identified by thermal analysis. Thermal and chemical data suggest that some alumina gel may be present.

Other Minerals

Siderite ($FeCO_3$) is the most abundant mineral in the deposit with the exception of kaolinite (fig. 3). In places it noticeably increases the specific gravity of the clay. Elsewhere it may be either absent or present only in minor amounts. It is most abundant near the top of the clay in hole 1, near the bottom in hole 2, and in the middle of the

3/ Identifications made by V. T. Allen, Geological Survey; K. G. Skinner, Bureau of Mines; and the writer.

clay bed in hole 3 (fig.3). It occurs as concretions which are about 1 millimeter in size. They are usually spherical, cylindrical, or dumbbell-like in shape. Veins as much as 6 millimeters in width are also common. Structures found in one vein suggest that it was formed before the clay had lost its plasticity. If this interpretation is correct the veins are probably due to ground water rather than to hydrothermal activity. Some of the clay near the surface contains small spherical and cylindrical holes which were formed by the removal of siderite.

Near the surface the clay is commonly stained with limonite (hydrous iron oxide [s]) which resulted in part from the oxidation of siderite. A few limonite veins cut the clay in some holes and trenches. A small amount of hematite (Fe_2O_3) and ilmenite ($FeTiO_3$) is present.

Pyrite (FeS_2) occurs as small spherical concretions and thin films along fractures.

One occurrence of chalcopyrite ($CuFeS_2$) was noted. The clay from hole 1 contained a few flakes of realgar (As_2S_3). A small amount of realgar was mined along the Green River in sec. 17, T. 21 N., R. 7 E.; and it also was found in secs. 8 and 10, T. 21 N., R. 7 E. Both the chalcopyrite and realgar are ous of hydrothermal origin and probably are related to Keechelus intrusi~~ves~~.

Mica, feldspar, and quartz are present, especially in the Kangley deposit.

Chemistry

Approximately 400 chemical clay determinations were made of drill core samples from the Durham and Blum deposits, and about 700 additional determinations were made of grab and channel samples from all of the deposits. These analyses were made principally by the Northwest Experiment Station, Bureau of Mines, United States Department of Interior. The determinations included total Al_2O_3, Fe_2O_3, TiO_2, SiO_2, MgO, CaO, Na_2O, K_2O, P, and S; loss on ignition at 700° C. and 950° C.; and available Al_2O_3 and Fe_2O_3. The available Al_2O_3 is usually between 75 and 100 percent of the total Al_2O_3. It is the percentage by weight that is obtained in 1 hour by a 20 percent solution of H_2SO_4 on clay calcined to 700° C. The available Al_2O_3 and Fe_2O_3 are calculated on the weight of the sample after drying at 130° C.

The chemical characteristics of the clay are well shown by the following analysis which was made on a large sample taken from the main pit at Durham.

Analyzed after Drying at 130° C. by
the Salt Lake Laboratory, Bureau of Mines, U. S. Department of Interior

Total											Avail.	
Al_2O_3	Fe_2O_3	SiO_2	MgO	CaO	Na_2O	K_2O	P	S	free H_2O	comb. H_2O	Al_2O_3	Fe_2O_3
45.6	11.05	24.0	0.5	0.1	0.12	0.13	.054	.02	1.1	15.65	38.0	10.45

Estimated to contain 51 percent kaolinite, 34 percent boehmite, and 14 percent limonite.

The loss on ignition at 700° C. for the high-alumina clay which was diamond drilled varies from 10.7 to 20.1 percent. It depends mainly on the abundance of the hydrated aluminum silicates, aluminum hydrates, siderite, and organic material.

Total and available Fe_2O_3 is dependent chiefly upon the presence of siderite, as the other iron bearing minerals are usually present only in minor amounts. The available Fe_2O_3 for the high-alumina clay which was diamond drilled varies from 1.0 to 26.8 percent. The average available Fe_2O_3 for the Durham deposit is 12.15 percent, for the Blum deposit 8.87 percent, and for the Kanaskat deposit 12.68 percent.

The percentage of total and available Al_2O_3 is dependent principally upon the abundance of kaolinite and boehmite, as the other hydrated aluminum silicates and aluminum hydrates are present only in insignificant amounts. The highest available Al_2O_3 for the high-alumina clay which was diamond drilled is 44.5 percent. The average available Al_2O_3 in the Durham deposit is 33.05 percent, in the Blum deposit 32.97 percent, and in the Kanaskat deposit 32.92 percent.

The presence or absence of the aluminum hydrates can usually be determined from the chemical analyses.

Lithology

The clay varies from white-grey to black and some of it is brown. The color is probably controlled in large part by the amount of carbonaceous material present. This in turn is dependent upon the initial carbon content and the quantity removed by bleaching. The brown clay is due to the presence of abundant siderite.

A thin layer which is black enough to be called carbonaceous is generally found near the top of the clay bed. Thin coal seams usually less than 5 millimeters wide and several centimeters long are common in this layer.

Generally the clay is not stratified; but with a hand lens lamination can be seen around some clay fragments and pellets. It usually breaks with a sub-conchoidal fracture and much of it is flint. The clay at Durham and Kanaskat ordinarily does not slack; that at the Harris and Blum deposits does. The clay is in places slickensided; some of it is refractory; the apparent specific gravity is approximately 2.6; and the moisture content is about 4 percent.

Some of the clay has been bleached. Irregular masses of dark-grey clay are associated with the white-grey clay from the drill holes. The white-grey clay resulted from bleaching. The Blum clay obtained by drilling, some of which is black, was found between 45 and 170 feet below the surface. The Blum clay cut by trenches, however, is usually light-grey and never black. The occurrence of lighter colored clay at the surface than at depth results largely from bleaching processes which are active near the surface. Clay which has been exposed for several months is usually lighter colored than when freshly exposed. This probably results from low temperature atmospheric oxidation of carbonaceous material. The clay immediately above the sandstone footwall in hole 10 is bleached. This may have resulted from the movement of ground water. In other areas bleaching may have been caused by hydrothermal activity.

The clay is fine-grained although inconspicuous clay pellets are in places scattered through it. They can best be seen on a clean surface with a hand lens. The majority of them are approximately 1 millimeter in diameter; however, those found in the Blum deposit may be as much as 3 millimeters in diameter. They are round and sub-round; usually black, white, or grey; and in places there is a complete gradation from round pellets to sub-angular and angular clay fragments which are approximately the same size. These pellets are similar to those found ~~in~~ the Hobart Butte, Oregon, and Castle Rock, Washington, high-alumina clay deposits.

Tan colored porous masses are abundant in the Blum clay (holes 10 and 12; fig. 3), and somewhat similar features were found in the Kummer clay. They may be as much as 5 millimeters in diameter, and samples of clay containing them are high in available Al_2O_3 (fig. 3). The high available Al_2O_3 suggests that the porous texture may be due to desilicification. These masses may originally have been fragments which were more permeable than the clay matrix and were, therefore, more easily altered. Siderite is found in the clay containing them. If they have been desilicified the siderite was probably deposited after the alteration.

Irregular masses as much as 5 millimeters in diameter are common in the clay from holes 1, 3, and 5. They are light-grey when dry, about the same color as the clay, and difficult to see. When wet, however, they are dark and easily seen. Their irregular shapes prove that they are not fragments. The lamination of the clay close to these irregular masses is parallel to their surfaces indicating that they are not due to bleaching. They are probably concretionary. Their composition was not determined.

Round and sub-round white bodies less than 1 millimeter in diameter are common in hole 7 and elsewhere (fig. 3). They are soft, do not effervesce, some are rimmed with a brown mineral, but their composition was not determined. They may be concretionary. Thin veins of the same material are also present.

Hydrothermal solutions have in places invaded the clay. This is indicated by the following: (1) small amounts of realgar, dickite ?, and chalcopyrite are found in the clay; (2) the deposits of alunite, realgar, cinnabar, and other hydrothermal minerals in the Puget group and Keechelus series 4/; (3) that part of the Puget group in which the clay is found has been invaded by sills and dikes. The hydrothermal

andesitic

4/ Callaghan, Eugene; Alunite Deposits near Enumclaw, King and Pierce Counties, Washington, U. S. Geol. Survey, Unpublished Manuscript. See also Mackin, J. H.; Relation of Geology to Mineralization in the Morton Cinnabar District, State of Washington, Dept. of Conservation & Development, Division of Mines and Mining, Report of Investigations No. 6.

activity has only academic interest, however, as it caused little alteration, and so has no significance with regard to the genesis or exploitation of the clay.

Stratigraphy

The flint clay is immediately interbedded with coal, boney coal, bone, shale, siltstone, and sandstone and with minor amounts of conglomerate, coal fragment breccia, clay fragment breccia, and low-alumina clay. Most of the clastic rocks are quartzose and micaceous; some appear to be bentonitic and tuffaceous; and they are commonly carbonaceous and in places sideritic. They may be stratified, massive, crossbedded, channelled, and contemporaneously deformed; plant remains are common. All of these rocks are continental deposits formed in fluvial, lacustrine, and swamp environments.

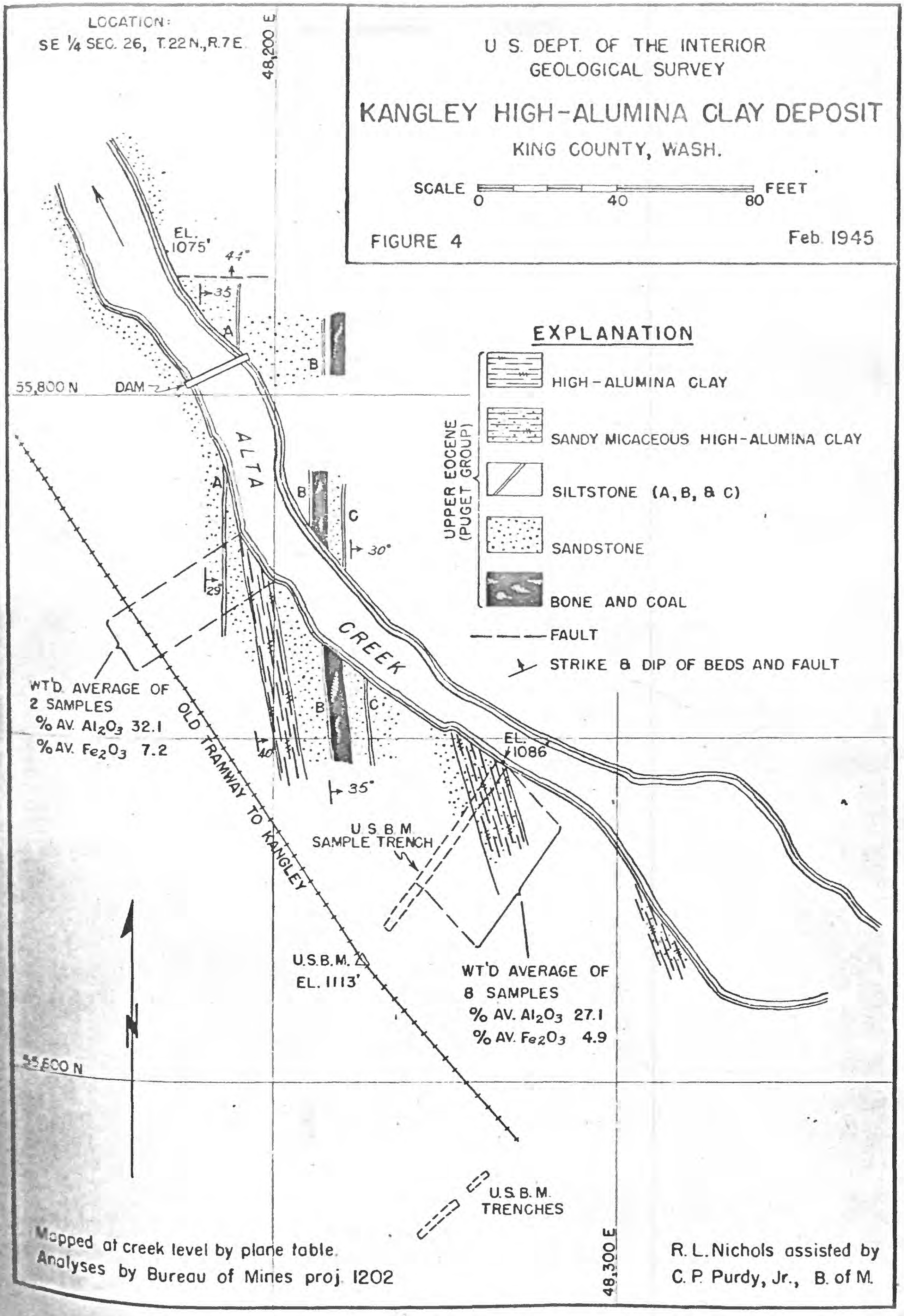
In the Kanaskat, Blum, and Durham areas there is a zone of carbonaceous rocks immediately above the clay. This zone is between 15 and 40 feet thick and it consists of coal, boney coal, bone, coal fragment breccia, and carbonaceous shale. Siltstone or sandstone usually underlies the clay, but at Kummer and in hole 6B the clay rests on boney coal.

There is in general only one bed of high-alumina clay at any locality, and it is sharply differentiated both chemically and lithologically from the sedimentary rock above and below it. However, at Kangley there are two beds which are separated by approximately 28 feet of carbonaceous, white-yellow, and clay-grey sandstone; siltstone and shale; together with bone and boney coal. The upper bed is approximately 20 feet thick and the lower bed, 6 feet (fig. 4).

Ordinarily no material is interbedded in the clay bed. However two feet of clay pellet and clay fragment sandstone is interbedded in the clay in hole 2; four lenses of low-alumina sandstone, coal fragment breccia, and coal and clay fragment breccia are interbedded in the clay in hole 8 (fig. 3); and six feet of siltstone and coal fragment siltstone are interbedded in the Durham clay at trench 8.

The stratigraphic thickness of the clay varies from 3.5 to 33 feet. The average obtained from drill holes in the Durham deposit is 11.9 feet, in the Kanaskat deposit 20.2 feet, and in the Blum deposit 12.2 feet.

The stratigraphic thickness of the Kanaskat deposit varies from 3.5 to 33 feet within a distance of about 500 feet (fig. 6). This is probably due to irregularities in the floor on which the clay was deposited. The presence of clay-fragment breccia interbedded in and immediately above the clay in hole 8 suggests that the clay may have been thinned elsewhere by intra-Puget erosion. It is understood, of course, that the true thickness of the clay will not be present in places because of faulting and the intrusion of sheet-like bodies.


LOCATION:
SE 1/4 SEC. 26, T.22 N., R.7 E.
48,200 E
U. S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
KANGLEY HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASH.
SCALE 0 40 80 FEET
FIGURE 4
Feb. 1945
EL. 1075'
44°
35
A
B
55,800 N
DAM
ALTA CREEK
A
B
C
30°
29
EXPLANATION
UPPER EOCENE (PUGET GROUP)
HIGH-ALUMINA CLAY
SANDY MICACEOUS HIGH-ALUMINA CLAY
SILTSTONE (A, B, & C)
SANDSTONE
BONE AND COAL
FAULT
STRIKE & DIP OF BEDS AND FAULT
WT'D. AVERAGE OF
2 SAMPLES
% AV. Al_2O_3 32.1
% AV. Fe_2O_3 7.2
OLD TRAMWAY TO KANGLEY
B
C
40
35°
EL. 1086'
U.S.B.M.
SAMPLE TRENCH
U.S.B.M.
EL. 1113'
WT'D AVERAGE OF
8 SAMPLES
% AV. Al_2O_3 27.1
% AV. Fe_2O_3 4.9
55,600 N
U.S.B.M.
TRENCHES
48,300 E
Mapped at creek level by plane table.
Analyses by Bureau of Mines proj. 1202
R. L. Nichols assisted by
C. P. Purdy, Jr., B. of M.

Ore Bodies

Durham Deposit

This deposit is in secs. 35 and 36, T. 22 N., R. 7 E. and secs. 1 and 2, T. 21 N., R. 7 E. The bed has been traced for more than 4000 feet (fig. 7). In general it crops out along a mountain slope which trends northward and faces the west.

The lithologic characteristics considered above apply to the Durham deposit. Chemical data will be found in tables 1 and 2.

The clay is interbedded in the main with sandstone, shale, and siltstone into which a sill-swarm has been intruded. It is stratigraphically above the Durham, Mammoth, and Hiawatha coal zones; and it is immediately below a zone consisting mainly of carbonaceous shales, coal and bone which in places is 40 feet thick (figs. 5 and 7). In the areas near holes 2 and 8, sandstone, siltstone, and a coal fragment breccia are interbedded in the clay (fig. 3). The clay where measured ranges in thickness from 5 to 15 feet. The Keechelus-Puget contact, on a basis of mapping by Walter C. Warren and others, is from 250 to 900 feet stratigraphically above the clay[5/]; but down the dip some clay may have been removed by erosion before the extrusion of the Keechelus.

The clay bed commonly strikes north and dips 20° - 30° E.(fig.5 The clay was faulted in hole 4, there may be a fault close to hole 3, and several faults were noted in outcrops. All these faults probably have displacements of less than 20 feet. Two dikes occur near hole 2, but no others were observed.

It will be difficult to extend the bed southward by prospecting because of the presence of a thick landslide deposit. The prelandslide topography immediately south of trench 11, which is now buried by the landslide, was contoured (fig. 8). From this it appears that the landslide 500 feet south of trench 11 may be 100 feet thick, and 1000 feet south approximately 200 feet thick. North of hole 7 the clay is buried by till, outwash, and varved clays the combined thickness of which may be more than 40 feet. These surficial deposits together with a dense vegetative cover, make geologic mapping of little value in prospecting for the clay.

Kanaskat Deposit

The Kanaskat deposit is located in sec. 12, T. 21 N., R. 7 E. The clay bed has been traced for approximately 1100 feet. It crops out along a mountain slope which faces the southwest and has a northwest trend (fig. 6). The lithology and chemical characteristics of the clay are similar to those at Durham (table 3). A coal seam which has been worked in a small way overlies the clay, and sandstone or siltstone underlies it.

The clay varies much more in thickness than that in the other

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5/ Mapped in connection with a study of the King County, Wash., coal fields and clay deposits.

deposits. It is approximately 33 feet thick in trench 5; whereas, in trench 8, only 520 feet away, it is only 2.5 feet thick (fig. 6). This difference is probably due to irregularities in the floor on which the clay was deposited.

The Keechelus-Puget contact is about 350 feet stratigraphically above the clay. The fact that the clay is so close to this contact, and that the Puget and Keechelus are slightly unconformable suggests that some of the clay may have been removed by erosion before the deposition and extrusion of the Keechelus. An analysis of figure 6 indicates that this might have happened southeast of the area prospected.

The clay bed usually strikes north and dips 20° - 25° E. Several faults with displacements of less than 3 feet were observed in the tunnels. A tabular intrusion several feet wide was cut by trenches 7 and 8, and another was seen in the Thomas coal mine.

It will be difficult to extend the bed by prospecting because of the presence of landslide deposits to the northwest and glacial deposits to the southeast.

Kangley Deposit

The Kangley clay deposit which has an altitude of approximately 1000 feet below that at Durham is found along Alta Creek in sec. 26, T. 22 N., R. 7 E. (fig. 4). As indicated above, there are two high-alumina clay beds between which approximately 28 feet of sedimentary rock are interbedded. The lower bed is about 6 feet thick, the upper bed 20 feet (fig. 4). They are about 500 feet stratigraphically below the Kangley coal, and a massive bed of sandstone lies beneath them. The lower bed is lithologically and chemically somewhat similar to the clay at Durham; whereas, the upper bed contains considerable mica and quartz and in general is coarse grained. The chemical characteristics of the two beds are shown in table 4. The lower bed is not found on the north bank of Alta Creek. It is not known whether this is due to: (1) faulting; (2) removal by erosion during Puget time; (3) the lens-like shape of the clay bed. The section in which the clay occurs strikes north and dips 30° - 40° E.

Blum Deposit

The Blum deposit is located about 1 mile south of the Green River, on a relatively flat area close to the Blue Blaze mine; in the $NW\frac{1}{4}$ and $SW\frac{1}{4}$ of sec. 31, T. 21 N., R. 7 E.; and in the $NE\frac{1}{4}$ of sec. 36, T. 21 N., R. 6 E. (fig. 9). Chemical data for the deposit is found in table 5. Lithologically it is similar to the Durham clay except that it slacks more readily and near the surface it is lighter colored (fig. 3). Thermal analyses by K. G. Skinner, of the Bureau of Mines, show that it is characterized by only a trace of boehmite, whereas, the Durham deposit may contain as much as 30 percent. It is mainly kaolinite with a small percentage of gibbsite and possibly some alumina gel.

The Blum clay deposit is interbedded with siltstone, sandstone, shale, and coal; it is approximately 200 feet stratigraphically below the Blue Blaze coal seam; a coal zone about 20 feet thick immediately overlies it; and it is underlain by sandstone. It is approximately 1500 feet from the top of the Puget group. The clay varies in thickness from 6 to 13 feet in the diamond drill holes. It is on the west limb and nose of a plunging anticline the crest of which has been truncated by erosion. Dips vary from 18 to 48 degrees. No dikes, sills, or faults were seen.

The bed has been traced by means of trenches for approximately 2000 feet. High-alumina clay float said to be similar to that at the Blum deposit was found along the old railroad between Black Diamond and Franklin. The clay was not found, however, in the Green River Gorge. This may be due to: (1) faulting; (2) the bed is concealed by talus and slump material; (3) the clay is altered beyond recognition by calcining due to the burning of adjacent coal beds; (4) the bed pinches out in the area around the Gorge; (5) the clay was removed by erosion in Puget time.

The clay is buried by glacial drift and, to the south perhaps by the Miocene-Oligocene sedimentary beds. The glacial drift may be more than 100 feet thick in places and it might make additional prospecting difficult.

Kummer Deposit

The Kummer deposit is found on the north and south sides of the Green River Gorge in the E½ sec. 26, T. 21 N., R. 6 E. (fig. 10). The clay on the south side is approximately 1500 feet from that on the north side.

The ore is mainly grey flint clay. Siderite is very common and black crystals (ilmenite?) are found in the upper half of that part of the bed which is north of the river. A layer containing a great abundance of porous fragments is present in the clay on both sides of the river. Chemical data ~~is~~ are found in table 6. Thermal and chemical analyses show that this clay contains kaolinite, gibbsite, and probably alumina gel.

Generally the clay is interbedded with sandstone, shale, and coal. It immediately underlies shale and coal and overlies carbonaceous shale, bone, and sandstone. It is approximately 11 feet thick. On the south side of the river it is about 30 feet below the coal seam which is being worked by the Johnson Coal Company. The clay is approximately 1500 feet stratigraphically below the top of the Puget group.

The section in which the clay occurs strikes approximately N. 15° E. and dips E. 40° - 50°. It is on the west limb of the Kummer syncline. A fault with a displacement of 2 feet was observed but no dikes or sills were seen.

Prospecting for this clay will be costly as it is covered with thick glacial and landslide deposits and perhaps by the Miocene-Oligocene sedimentary beds and Keechelus andesite series. The presence of an interglacial course of the Green River immediately south of the deposit decreases the reserves somewhat, and the thickness of the glacial drift is greater here than elsewhere.6/

To agree with other headings, omit clay

Harris ~~Clay~~ Deposit

The deposit is located in the SE$\frac{1}{4}$ sec. 32, T. 24 N., R. 6 E. (fig. 11). The lithologic characteristics of the clay are somewhat different from those in the other deposits. It varies in color from light grey to dark grey. It is kaolinitic, fine-grained, carbonaceous, and semi-flint, in places sideritic, massive in hand specimen, and some of it fires light-grey. It commonly contains minute seams of coal, readily slacks on exposure to the weather, and it has in general a pyrometric cone equivalent of between 29 and 31. In places it contains soft kaolinitic pebbles and cobbles 7/, and it varies in refractory characteristics along the strike. It is as much as 55 feet thick, but the bed which is being mined is 7 to 12 feet thick, the average being approximately 9 feet. Analyses made by the Bureau of Mines are found in table 7.

The clay is located on the north side of the Newcastle anticline; it strikes E. 20° S., and dips 30° - 35° N. (fig 10). It occurs at the base of the Puget group, below the Jones coal bed, and immediately above what may be a weathering profile formed on the Eocene volcanic series before the deposition of the Puget group. Late

High-alumina clay is found in the bed of the unnamed creek which flows northeast from Squak Mountain and joins Issaquah Creek close to the B. and R. Issaquah mine (sec. 33, T. 24 N., R. 6 E.; fig. 10).

This clay is immediately below the Jones coal bed and is, therefore, on the same stratigraphic horizon as that at the Harris mine. It is grey, sideritic, and semi-flint. Some of it is a clay breccia, and it readily slacks. Chemical analyses of it are found in table 7.

The presence of clay at the base of the Puget group here and also in the Harris mine, suggests that high-alumina clay may be found elsewhere at this horizon.

Correlation of the King County High-Alumina Clay Deposits

The Kummer clay deposit on the north side of the Green River Gorge correlates with that on the south side. This is proved by: (1) They are lithologically, chemically, and mineralogically similar; (2) a well defined and unusual layer is found in the clay on each side of the river; (3) the stratigraphic sections in which the clay is found are

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6/ Warren, Walter C., et al.; Coal fields of King County, Washington, unpublished manuscript.

7/ Allen, Victor T.; Personal communication.

similar on both sides of the river; (4) only one bed of high-alumina clay has been found on each side of the river; (5) they have approximately the same thickness; (6) they are on the same strike.

The Kummer and Blum clay deposits which are only $1\frac{1}{2}$ miles apart are thought to be synchronous. The evidence for this is: (1) they are similar lithologically, chemically, and mineralogically; (2) a layer containing porous fragments is found in each clay bed; (3) the stratigraphic sections in which they are found are similar; (4) only one high-alumina clay bed has been found in each area; (5) they have approximately the same thickness; (6) they are approximately 1500 feet from the top of the Puget group in the Black Diamond area.

The Durham and Kanaskat deposits, which are about one mile apart, are considered to be of the same age. Their lithologic, chemical, and mineralogic characteristics are more or less identical; only one high-alumina clay bed has been found in each area; and they are both in the upper part of the Puget group. Both deposits are overlain by coal and in general underlain by sandstone, and they are on the same strike.

The correlation of the Durham-Kanaskat and the Kangley deposits is not as well established. The stratigraphic, structural, lithologic, mineralogic, and chemical data and the close proximity of these deposits suggest that they may be equivalent.

For somewhat similar reasons the Kummer and Blum deposits are correlated with those at Durham, Kanaskat, and Kangley. The exact stratigraphic relation between the Harris deposit and the others was not established.

Origin of the High-Alumina Clay

A study of the origin of the Durham-Kanaskat-Kangley high-alumina clay involves a consideration of the environment in which the high-alumina sediments were deposited and an analysis of the source and origin of the kaolinite and boehmite.

It is thought that this clay bed was deposited principally as kaolinitic clay and that the kaolinite did not result from alteration in place. This is indicated by the following: (1) the presence of minute lamination and pellets 8/ of kaolinite in clay; (2) the fine-grained texture of the deposit suggesting that it was originally clay; (3) the lack of quartz and mica in the clay suggesting that it was not formed in a profile developed on the Puget rocks because they are usually quartzose and micaceous; (4) the sharp contact between the clay and the rocks immediately below it.

The distribution of the Puget rocks and the upper Eocene marine rocks, together with a consideration of the mineral composition of the average Puget rocks, indicates that the Puget sediments were derived mainly from the east. The kaolinite was probably derived from a weathering profile in the same area.

8/ Allen, V. T., and Nichols, R. L.; Clay-Pellet Conglomerates at Hobart Butte., Lane County, Oregon, Jour. Sed. Petrology, vol. 15, pp. 25-33, 1945.

In places the high-alumina clay is composed of more than 30 percent boehmite, however, for the bed as a whole there is less than 10 percent. The boehmite is concentrated in the upper half of the bed approximately 5 feet below the top (tables 1 and 2). It is not known whether this distribution resulted from sedimentary processes or whether it is due to a greater local initial permeability of the original sediments which would tend to concentrate here any boehmite formed by alteration in place. No significant hiatus in the clay or between the clay and the coal immediately above it was recognized.

Several theories for the origin of the boehmite have been considered. They are: (1) the boehmite was deposited with the kaolinite; (2) it was formed from the kaolinite in an Eocene weathering profile; (3) it was formed from the kaolinite in a profile developed on the present topography; (4) the boehmite was derived from the kaolinite by the action of ground water; (5) substances derived from the coal were responsible for the alteration of some of the kaolinite to boehmite; (6) two or more of the above processes were effective in the formation of the boehmite.

There are several valid arguments which prove that the boehmite was not formed from kaolinite in a profile developed on the present topography. It suffices to say, however, that the boehmite is as plentiful in the high-alumina clay which is 200 feet below the surface as it is in clay which crops out at the surface. No definitive statement with regard to the origin of the boehmite can be made, but the problem may be solved by a petrographic study which will soon be made by V. T. Allen of the Geological Survey.

The origin of the kaolinite and aluminum hydrates in the Blum and Kummer deposits was probably similar to that of the kaolinite and boehmite in the Durham, Kanaskat, and Kangley deposits.

The Harris deposit rests on a kaolinitic weathering profile developed on the underlying volcanic rocks 9/. It is thought that the Harris clay was derived from that part of this profile which was outside of the area where the Harris clay was deposited. Due to rapid deposition and the absence of local isostatic balance these volcanic rocks undoubtedly stood for a time above the surrounding country so that a weathering profile was developed on them where the physiographic conditions were favorable. Lateral planation by Puget coastal-plain streams of the more exposed parts of this profile and deposition of this eroded clay on the less exposed parts may have been responsible for the Harris clay. The fact that the Harris clay bed is much thicker than the Durham-Blum beds is also evidence of a local source.

The Puget group consists of several thousand feet of sandstone, siltstone, shale, and coal. All of it is of continental origin and was deposited on a coastal plain mainly by westward flowing streams. Differential downward tectonic movements were such that all of the Puget sediments were deposited near sea level 10/. The high-alumina clay is very fine-

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9/ Allen, V. T., and Norbisrath, H., Personal communication.

10/ Weaver, Charles E., Tertiary Stratigraphy of Western Washington, and Northwestern Oregon, Univ. of Wash. Publ. Geol., vol. 4, pp. 53-74, 1937.

grained, and the clastic rocks above and below are siltstone and sandstone.

Silt and sand were carried at times into the Durham-Kangley area while the clay was accumulating. This is indicated by: (1) the presence of sandstone and other rocks which are interbedded in the clay; (2) the lack of a hiatus between the clay and the rocks above and below it; (3) the presence of sand and silt sizes in the upper clay bed at Kangley.

It is thought that the clay is mainly lacustrine. Under these conditions sand and silt in appreciable amount would be deposited with the clay only at lake margins. The interbedded sediments and the fact that the clay is thin and overlain by coal suggest that the lake was not deep.

At Kangley the presence of the rocks which are interbedded with the clay and the abundant mica in the upper bed indicate fluvial conditions. The Durham and Kangley deposits are, therefore, lacustrine and fluviatile. The Blum, Kummer, and Harris clays were deposited in somewhat similar environments.

The pellets in the clay present somewhat of a problem. They are common where quartz and mica are absent. This suggests that they were not carried into the lake after being formed elsewhere. If the level of the lake fluctuated they may have been formed along its shoreline.

The exact origin of the lake or lakes in which the clay accumulated is not known. They might have been formed by volcanic or tectonic processes, or they might have been deltaic or levee-basin lakes. It seems unlikely that the clay accumulated in a marine or lagoonal environment as it contains no marine or brackish water fossils. The fact that the Blum clay may have covered an area more than 2000 feet long and 2000 feet wide signifies that the basin was probably not an abandoned river channel Additional consideration of the genesis of the lake basin yields no data on the continuity of the clay between areas.

The abundance of coal and carbonaceous rocks in the Puget group suggests that the water from which the clay was deposited may have contained considerable quantities of plant-tissue extracts. If so, their presence was probably a factor in the precipitation of the clay 11/

Coal

Eighteen samples of coal obtained by drilling were analyzed. The analyses show that the ash content of this coal is in general considerably higher than the average of the King County coal 12/. For this

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11/ Boswell, P. G. H.; The action of colloids in precipitating fine-grained sediments, Geological Magazine, vol. 67, pp. 371-81, 1930.

12/ Ash, S. H.; Analyses of Washington Coals, U. S. Bureau of Mines Tech. Paper 491, Table 12, 1931. Yancey, H. F.; and Geer, M. R.; Analyses of Washington Coals, U. S. Bureau of Mines Tech. Paper 618, Tables 15 and 19, 1941.

reason it is unlikely that under present conditions this coal has any economic value.

Coal Ash

Generally coal ash is composed of relatively large proportions of SiO_2 and Al_2O_3 and small proportions of the other oxides. The SiO_2 commonly constitutes 40 to 60 percent of the ash and the Al_2O_3 20 to 35 percent 13/. The SiO_2 content is, therefore, approximately twice that of the Al_2O_3.

Seven out of 26 analyses of ash from the King and Pierce County coals 14/ have Al_2O_3 to SiO_2 ratios greater than that of kaolinite (table 8). These 7 coals probably contain kaolinite together with small amounts of boehmite, gibbsite, and/or alumina gel. Analysis No. 3 is of coal taken from the McKay bed which is between 2000-2500 feet stratigraphically below the Kummer high-alumina clay 15/. A comparison of these ash analyses with the statement made above about average ash analyses shows that these are unusually high in alumina.

Coal ash on the basis of its fusibility is divided into 3 classes. Class I is refractory, Class II is of medium fusibility, and class III is easily fusible. A study of the fusibility of the ash of King and Pierce County coals shows that nearly half of the samples tested fall in the refractory class 16/. This also implies that the ash of the King and Pierce County coals is high in Al_2O_3.

There are 3 possible origins for the high Al_2O_3 content. They are: (1) hydrated aluminum silicates and hydrated aluminum oxides were deposited where the coal-forming material was accumulating; (2) aluminum silicates and/or hydrated aluminum silicates were deposited with the coal-forming material, and later they were altered because of vegetable acids and other substances; (3) both processes operated.

In a study of the under clays of Illinois, V. T. Allen showed that their alumina content was not genetically connected with the overlying coal 17/. If the geologic conditions in Illinois and Washington

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13/ Selvig, W. A., and Fieldner, A. C.; U. S. Bureau of Mines Bull. 209, p. 2, 1922.

14/ Ash, S. H.; Analyses of Washington Coals, U. S. Bureau of Mines Tech. Paper 491, Table 13, 1931. See also Fieldner, Arno C., et al; The Fusibility of Coal Ash and the Determination of the softening Temperature, U. S. Bureau of Mines Bull. 129, Table 2, sample no. 94, p. 28, 1918.

15/ Warren, Walter C.; Geology of the Coal Fields of King County, Wash., U. S. Geol. Survey Unpublished Manuscript.

16/ Yancey, H. F., and Geer, M. R., p. 37

17/ Allen, V. T.; Petrographic and Mineralogical Study of the Underclays of Illinois Coal, Amer. Ceramic Soc. Jour., vol. 15, pp. 564-573, 1932.

were the same the high-alumina content of the ash of the Washington coal was probably original and not due to alteration after deposition.

Coal containing high-alumina ash may be helpful in suggesting places to search for high-alumina clay.

Refractoriness

The chemical composition of the clay suggests that some of it should be refractory. As mentioned above, clay for refractories has been mined at Kummer and is now being mined at Harris.

Refractory tests were made on a sample collected in pit I at Durham. The pyrometric cone equivalent was found to be 37, the cone color after firing was white, and the refractory classification based on the pyrometric cone equivalent was super-duty. This material was lower in iron, however, than the deposit as a whole. Additional data on refractoriness will be found in figure 3.

Iron is a deleterious substance in refractories as it adversely affects the color of the fired product and it lowers the fusion point. For each percent of available Fe_2O_3 which is present, the deformation point is lowered approximately one cone 18/. It was, therefore, assumed that clay with less than 5 percent available Fe_2O_3 and more than 30 percent available Al_2O_3 is refractory. It will be seen in figure 3 that less than one-third of the Durham and Blum deposits is refractory according to this assumption. The refractory clay would be costly to mine because of its erratic distribution.

If the iron (siderite) could be removed cheaply there is enough refractory clay in the Durham, Kanaskat, and Blum deposits to supply the Northwest for scores of years at the present rate of consumption.

Geologic Factors Affecting Mining and Metallurgy

The ore deposits are tabular persistent bodies. Strike and dip may vary considerably within short distances. As the dip of the clay is generally less than 30 degrees gravity alone may not be sufficient to move the ore down chutes.

A fault was crossed in hole 4, and the rocks near hole 3 may also be faulted. A fault of several feet displacement was noted north of pit 2 at Durham and many occur in the Kangley and Alta mines (fig. 7). The loss of coal beds due to faulting has resulted in the abandonment of several coal mines in this district. The outcrop at Durham has been traced nearly continuously for more than 4000 feet indicating that no faults of large displacement are present. Faults with stratigraphic throws greater than the thickness of the clay bed are to be expected. The fact that the footwall section, however, is

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18/ Wilson, Hewitt; Ceramics, McGraw-Hill Book Co., Inc., New York City, p. 197, 1927.

commonly different from that of the hanging wall may help to solve fault problems encountered in mining. Faults will increase the cost of mining.

Coal and bone immediately overlie the clay in many places. As much of it is undoubtedly poor roof rock, timbering may be necessary. Tunnels cut in clay have remained open for several years. If the workings are kept entirely in clay, extensive timbering will not be necessary.

Tabular intrusives were cut by holes 2 and 4 at Durham; one occurs in trenches 7 and 8 at Kanaskat; and another is found in a nearby tunnel. Others may be encountered in mining. They should not greatly affect either the mining or the reserves.

Usually it is easy to differentiate the high-alumina clay from the rocks immediately above and below. It is, however, more difficult to estimate the percentage of available Fe_2O_3 in the clay. In order to keep the available Fe_2O_3 low, it will be necessary to discard clay which is high in iron. As the iron is mainly in the form of siderite which can easily be distinguished, the operators should be able to do this.

Sandstone, coal fragment breccia, and other low-alumina rocks are interbedded in some of the clay. These are distinct lithological units, and it should be easy to identify and discard them.

No problem is anticipated in the grinding of the clay either because of hardness or plasticity.

Correlation of Western Washington and Oregon High-Alumina Clay Deposits

The Hobart Butte high-alumina clay deposit 19/ occurs in the Calapooya formation which, on a basis of structural and paleobotanical evidence, has been tentatively assigned to the Eocene by Wells and Waters 20/.

Roland W. Brown of the Geological Survey studied a group of fossil plants collected on Hobart Butte. He identified the following 21/:

- *Anemia delicatula* Brown
- *Hemitelia pinnata* MacGinitie
- *Equisetum* sp.
- *Potamogeton* sp., probably new
- *Populus* sp., probably new
- *Quercus nevadensis* Lesquereux
- *Cercidiphyllum*, cf. *crenatum* (Unger) Brown
- *Liquidambar californicum* Lesquereux
- *Cinnamomum dilleri* Knowlton
- *Cryptocarya praesamarensis* Sanborn

19/ Loofbourow, John S. Jr.; Preliminary Report as of July 23, 1943, on The High-Alumina Clay Deposit at Hobart Butte, Lane County, Oregon, U. S. Geol. Survey Unpublished Report, 1943.

20/ Wells, Francis G., and Waters, Aaron C.; Quicksilver Deposits of Southwestern Oregon, U. S. Geol. Survey Bull. 850, pp. 15-16, 1934.

21/ U. S. Geological Survey memorandum dated Jan. 1, 1944.

Rhus mixta Lesquereux
Thouinopsis myricaefolia (Lesquereux) MacGinitie
Platanophyllum angustiloba (Lesquereux) MacGinitie
? Cercis sp., probably new
Unidentified dicotyledonous fragments
Unidentified fruit

Concerning this collection, Mr. Brown wrote 22/:

"As some of the species listed here are represented by only one specimen, which, like most of the material, may be fragmentary and poorly preserved, definite or complete identifications cannot be given. Many of these species occur in the Chalk Bluffs flora of the Sierra Nevada in California, said by MacGinitie to be of middle Eocene age. Others occur in the late Eocene or early Oligocene of western Oregon and Washington. My inclination, pending receipt of more definite stratigraphic data, is to call the collection late Eocene."

It should be noted that although Mr. Brown calls the collection late Eocene in age there is a suggestion that it might be as young as early Oligocene.

The high-alumina clay found on the property of William E. Buswell, Toledo, Washington,23/ is similar lithologically and chemically to the Cowlitz high-alumina clay 24/. As high-alumina clay is an uncommon rock type in southwestern Washington it seems likely that the Buswell clay deposit correlates with the Cowlitz deposit. According to Professor Charles E. Weaver 25/ the Buswell clay probably belongs to the Gries Ranch formation, but it might be part of the Cowlitz or Keasey formations. The Gries Ranch formation is early Oligocene, the Cowlitz formation is late Eocene, and the Keasey is late Eocene and early Oligocene 26/. The best available data on the age of the Cowlitz high-alumina clay deposit indicates, therefore that it is either late Eocene or early Oligocene.

Fossil plants and animals have been collected from rocks somewhat lower stratigraphically than the Cowlitz high-alumina clay deposit. These may yield when identified additional data on the age of this deposit.

The King County deposits, as stated above, are found in the Puget group. The Puget group, on a basis of structural and paleobotanica

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22/ U. S. Geological Survey memorandum dated Jan. 1, 1944.

23/ Nichols, Robert L.; Memorandum on High-Alumina Clay Exposure Buswell Farm, Toledo, Lewis County, Washington, June 1943, U. S. Geol. Survey Unpublished Report.

24/ Nichols, Robert L.; Preliminary Report on the Cowlitz High-Alumina Clay Deposit near Castle Rock, Cowlitz County, Wash., U. S. Geol. Survey Unpublished Report, 1943.

25/ Oral communication.

26/ Weaver, Charles E., et al.; Correlation of the Marine Cenozoic Formations of Western North America, Geol. Soc. Amer. Bull., Vol. 55, Chart No. 11, 1944.

evidence, is thought to be mainly, if not entirely, Eocene. In discussing the age of the Puget group, Prof. Charles E. Weaver writes 27/:

> "The marine faunas occuring at Duwamish which are interstratified with continental beds of the Puget group are definitely of upper Eocene age and represent a time equivalent to that of the Tejon formation of Southern California.... It is probable that the lowest strata in the Puget group date back into early Eocene and that the entire sequence was deposited during the middle and late Eocene and possibly to a small extent in the very earliest part of the Oligocene epoch."

The Harris clay deposit is found at the base of the Puget group in the Issaquah area. Here the Puget rests on volcanic rocks which in turn lie on marine beds. These marine beds are thought to be equivalent to the Cowlitz formation 28/. Therefore, the Harris clay deposit is probably late Eocene. The Durham, Kenaskat, Kangley, Blum, and Kummer deposits occur near the top of the Puget group. Apparently they are also late Eocene in age.

The Hobart Butte, Cowlitz, and King County high-alumina clay deposits are, therefore, roughly contemporaneous and either late Eocene or early Oligocene. They are also transported deposits. This suggests that sometime in the Eocene a weathering profile of considerable areal extent and containing kaolinite was developed in eastern Oregon and Washington. This profile was eroded, the kaolinite was transported by streams westward, and where conditions were favorable, deposition took place, so that these and probably other high-alumina transported clay deposits were formed. Although all of these deposits were derived from the same profile, it is not to be expected that they would be exactly the same age. A profile as extensive as this one would not necessarily be eroded everywhere at the same time; and the deposits, although derived from the same profile, may have had different transportational histories. As suggested above, the Harris clay deposit may have been derived from a local profile developed on the volcanic rocks beneath the Puget group.

The Molalla high-alumina clay deposit is definitely younger and, therefore, belongs to a different paleophysiographic regime 29/.

RESERVES

Specific Gravity, Moisture, Analyses, and Grade

Seventeen apparent specific gravity determinations for the ore in the Durham deposit were made. Complete data for the ore in

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27/ Weaver, Charles E.; Tertiary Stratigraphy of Western Washington and Northwestern Oregon, Univ. of Washington Publications in Geology, vol. 4, pp. 54-55, 1937.

28/ Warren, Walter C.; U. S. Geol. Survey, Oral communication.

29/ Nichols, R. L.; Preliminary Report on the Molalla High-alumina Clay Deposit near Molalla, Clackamas County, Oregon, U. S. Geol. Survey Unpublished Report, 1944.

holes 3 and 5 and nearly complete data for hole 6 were obtained. The determinations for holes 3, 5, and 6 were weighted on a basis of the footage which they represented; and the averages obtained were used in calculating the reserves for the blocks controlled by these holes. The weighted average of all the Durham data was used for the other blocks as well as for the Kanaskat deposit.

Ten determinations of the apparent specific gravity of the ore in the Blum deposit were made. Complete data for holes 11 and 12 were obtained, but no data are available for hole 10. The weighted averages of the determinations for holes 11 and 12 were used in calculating the reserves for the blocks controlled by these holes. The weighted average of all the Blum determinations was used for hole 10. The data used for apparent specific gravity cannot be in error by as much as 20 percent.

Moisture data were obtained for the same holes and footage intervals. They were handled in the same way as was the specific gravity data. Any error in the reserves resulting from inaccurate moisture data is probably less than 5 percent.

The data on available Al_2O_3 and Fe_2O_3 were used in calculating the grade of the ore body. A study of check analyses for the Cowlitz 30/ and Molalla 31/ high-alumina clay deposits indicates that the error in the determinations of available Al_2O_3 for the King County deposits is considerably less than 20 percent. The length of core sampled for available Al_2O_3 and Fe_2O_3 was between 0.8 and 5.0 feet, and the average length was 2.3 feet. The core recovery was between 61 and 96 percent, the average being approximately 84 percent. The average calculated assay for each hole was determined by weighting the individual assays on a basis of the footage they represented. The average grades for the Durham and Blum deposits were obtained from the weighted averages of the holes. The assays of samples from the trenches, pits, and outcrops were not used in calculating the grade of the Blum and Durham deposits because: (1) surface samples, due to alteration, are not representative of the ore at depth; (2) in many cases it is impossible to determine exactly the thickness of the ore body which is represented by any sample; (3) the total thickness of the ore body was not cut by many of the trenches and pits. The average grade of the Kanaskat deposit was obtained from the weighted averages of samples taken from trenches 5, 6, and 8 and tunnel 2.

Cut-offs

Clay with 25.5 percent or more available Al_2O_3 was considered to be ore; that with more than 20.3 percent available Fe_2O_3 was not considered to be ore; and beds too thin to be easily mined were discarded (fig. 3).

30/ Nichols, Robert L.; Preliminary Report on the Cowlitz High-Alumina Clay Deposit near Castle Rock, Cowlitz County, Wash., U. S. Geol. Survey Unpublished Report, 1943

31/ Nichols, R. L.; Preliminary Report on the Molalla High-Alumina Clay Deposit near Molalla, Clackamas County, Oregon, U. S. Geol. Survey Unpublished Report, 1944.

Area, Volume, Weight, and Grade of the Ore Body

The perpendicular bisector method was used in calculating the volume, weight, and grade of the Durham, Blum, and Kanaskat deposits 32/.

The boundaries of the Durham deposit are: (1) the trace of the hanging wall of the ore body and topography; (2) a line joining points 400 feet down the dip from each hole; (3) two lines perpendicular to the strike and 200 feet from holes 4 and 7 measured along the strike; (4) two lines parallel to the strike which run from points 400 feet down the dip from holes 4 and 7 to the two lines described immediately above under 3 (fig. 8).

The boundaries of the Blum deposit are: (1) the trace of the hanging wall of the ore body and topography; (2) a line joining points 250 feet down the dip from each hole; (3) two lines perpendicular to the strike and approximately 500 feet from holes 10 and 12 measured along the strike; (4) two lines parallel to the strike which run from points 250 feet down the dip from holes 10 and 12 to the two lines described immediately above under 3 (fig. 9).

The boundaries of the Kanaskat deposit are: (1) the trace of the hanging wall of the ore body and topography; (2) a line joining points 200 feet down the dip from the hanging wall of the ore body in trenches 5, 6, and 8 and 200 feet down the dip from the trace of the hanging wall and the floor of tunnel 2; (3) two lines perpendicular to the strike and 100 feet north of trench 8 and south of the trace of the hanging wall and the floor of tunnel 2 measured along the strike; (4) two lines parallel to the strike which run from points 200 feet down the dip from the hanging wall of trench 8 and 200 feet down the dip from the trace of the hanging wall and the floor of tunnel 2 to the two lines described immediately above under 3 (fig. 6).

The fundamental assumption underlying the perpendicular bisector method is that the ore body has continuity. That this assumption is justified in the present case is indicated by the following: (1) the ore is more or less uniform in thickness; (2) the grade of the ore in the various holes and trenches is nearly the same; (3) the lithology of the high-alumina clay in the holes, trenches, and tunnels is similar; (4) not only is there a good correlation of ore from place to place but the beds above and below also correlate in a general way; (5) when the distribution and uniformity of the high-alumina clay bed are considered the holes and trenches are relatively close; (6) a lacustrine origin such as is suggested by the lithology should result in a relatively high degree of continuity.

The areas are conservatively estimated because each ore body is assumed to extend only to the trace of the hanging wall and topography rather than to the trace of the medial plane of the ore body and topography (fig. 8). The position of the trace of topography and the hanging wall of each ore body was drawn whenever possible in such a way that a conservative figure for area was obtained.

32/ Jackson, Charles F.; and Hedges, J. H.; Metal Mining Practice, Bull. 419, U. S. Dept. Interior, Bureau of Mines, pp. 68-69, 1939.

The thickness of the ore in each block was assumed to be equal to that in the hole, trench, or tunnel controlling the block except in the case of that controlled by hole 4. The total thickness of the bed was not penetrated in hole 4 because of faulting, and the arithmetic average of the thickness in the hole and in trench 11 was used.

Measured, Indicated, and Inferred Ore

The Durham deposit has an area of 60.26 acres when measured in a horizontal plane. Eight holes were drilled through it; and there is, therefore, one hole on the average for every 7.53 acres. In addition more than 12 pits and trenches cut the clay. The weighted calculated available Al_2O_3 content of the holes varies from 31.2 to 35.95 percent and the available Fe_2O_3 from 5.28 to 14.58 percent. The true thickness of the ore in the holes varies from approximately 7 to 14 feet. Tabular intrusions were cut by holes 2 and 4, and others may be present. The ore in hole 4 was faulted, one faulted outcrop was noted, and faults are common in the Kangley and Alta mines. Sandstone is interbedded with the ore in holes 2 and 8, and a coal fragment breccia is interbedded with the clay which is cut by trench 8. Elsewhere these lenses might decrease the thickness or the tonnage of ore which could be economically mined. In view of these data the reserves have been classified as measured (50 percent) and indicated ore (50 percent).

Three holes were drilled in the Blum deposit. It has an area of 27.0 acres when measured in a horizontal plane and one hole, therefore, for every 9 acres. In addition to the 3 holes, 6 trenches also cut the clay bed. The weighted calculated average available Al_2O_3 content of the holes varies from 32.41 to 33.81 percent and the available Fe_2O_3 from 7.33 to 9.51 percent. The true thickness of the ore in the holes varies from 5.5 to 14.0 feet. It is thought that the accuracy in estimating tonnage and grade might be close to that prescribed for measured ore, but in the interest of conservatism the reserves have been classified as measured (50 percent) and indicated ore (50 percent).

The data for the Kanaskat deposit were obtained from one tunnel and 3 trenches. The deposit has an area of 4.36 acres measured in a horizontal plane. As it is divided into 4 polygonal ore blocks, there is one trench or tunnel on the average for every 1.09 acres. The bed varies in true thickness from approximately 30 feet in trench 6 to 3.3 feet in trench 8, a distance of approximately 400 feet. The weighted calculated average available Al_2O_3 content of the trenches and tunnel varies from 28.6 to 34.0 percent and the average available Fe_2O_3 varies from 11.5 to 13.3 percent. As the high-alumina clay bed is more or less chemically homogeneous and as it is not thought that the thickness of the polygonal ore blocks are greatly in error, the reserves have been classified as indicated ore.

The Durham clay deposit extends along the strike for more than 4000 feet (fig. 8). For the purpose of tonnage calculations, it was assumed that the bed extended from the outcrop down the dip between 320 and 890 feet. It seems likely, however, that the ore extends down the dip for greater distances. The Kanaskat bed has been followed along the outcrop for approximately 1000 feet. In the tonnage calculations it was assumed to extend about 200 feet down the dip from the outcrop. Here, too, it seems probable that the ore extends beyond this limit.

In view of the fact that the Kanaskat, Durham, and Kangley deposits are thought to be on the same horizon, it seems likely that high-alumina clay is present between these deposits.

Similar reasoning suggests that the Blum bed extends for a greater distance down the dip than the 250 feet assumed in the calculations. The presence of the Kummer deposit more than a mile to the northwest of the Blum deposit and the fact that high-alumina clay drift was found along the railroad between Franklin and Black Diamond according to Mr. Miller of Gladding, McBean and Co. Seattle, Washington., suggest great tonnages of inferred ore in this area.

The presence of high-alumina clay in sec. 33, T. 24 N., R. 6 E. and also at the Harris mine indicates great potential reserves for this area.

These data, together with the regional geology, suggest that there may be 20,000,000 or more dry tons of inferred ore in the King County district. The tonnages and grades of the measured, indicated, and inferred ore are found in tables 9, 10, 11, and 12.

The grades, tonnages, and ore classifications are in very close agreement with those made by Mr. C. C. Popoff, project engineer for the Bureau of Mines, United States Department of Interior.

CONCLUSIONS, ECONOMIC CONSIDERATIONS, AND RECOMMENDATIONS

Four important high-alumina clay deposits in western Oregon and Washington have been studied and drilled by the Geological Survey and the Bureau of Mines, United States Department of Interior. These deposits are in Molalla, Oregon; at Hobart Butte near Cottage Grove, Oregon; near Castle Rock, Washington; and in King County, Washington. The important features of the King County deposits, and a comparison of them with the others follow.

(1) There are 1,747,000 dry tons of measured ore with 33.03 percent available Al_2O_3 and 11.17 percent available Fe_2O_3; 2,048,000 dry tons of indicated ore with 33.01 percent available Al_2O_3 and 11.39 percent available Fe_2O_3; and 20,000,000 dry tons of inferred ore with approximately the same grade.

(2) The reserves of measured and indicated ore are smaller than at Castle Rock, Hobart Butte, or Molalla.

(3) The reserves of inferred ore are smaller than at Molalla, but probably greater than at Hobart Butte or Castle Rock.

(4) The available Al_2O_3 content is higher than at Castle Rock, Hobart Butte, or Molalla.

(5) The available Fe_2O_3 is higher than at the other deposits.

(6) The Salem, Oregon, high-alumina clay plant was designed for clay with an available Al_2O_3 to available Fe_2O_3 ratio of approximately 6 to 1. The King County clay has a 3 to 1 ratio.

(7) The moisture content is approximately 4 percent. It is about the same at Hobart Butte but much higher at both Molalla and Castle Rock.

(8) The ore will have to be mined underground; whereas, that at Molalla, Castle Rock, and Hobart Butte can be strip-mined.

(9) All of the King County deposits are within 5 miles of a railroad, and with the exception of the Harris deposit, all are within 50 miles of Seattle and Tacoma.

(10) The reserves at Blum, Durham, and Kanaskat could easily be increased by additional drilling.

(11) Somewhat less than one-third of the reserves are refractory. The irregular distribution of this material would make mining costs high.

Respectfully submitted,

Robert L. Nichols

Enumclaw, Washington
April 17, 1945

TABLE 1

HOLE 1
DURHAM HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

HIGH-ALUMINA CLAY DATA

Sample No.	Interval feet	Ign. loss, 700° C.	Ign. loss, 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	% Total SiO_2	% Total TiO_2	Apparent specific gravity	Moisture percent as-rec'd basis	Refractoriness	Mineralogy from chemistry	Lithology	Ore
TC 1	17 - 20	4.2			6.9		4.9					non-refractory		no data	
TC 2	58.2 - 62.0	6.1			8.6		4.0					non-refractory		grey siltstone	
TC 3	115.2 - 116.9	5.2			7.9		1.0					non-refractory		coal fragment siltstone	
TC 4	150.5 - 152.1	17.1	18.1	38.4	35.1	16.7	16.1	22.2	2.5			non-refractory	K and * B, G, or A	light grey flint clay siderite	ore
TC 5	152.1 - 157.1	18.2	19.2	38.1	32.3	18.7	18.1	20.1	2.5			non-refractory	K and B, G, or A	light grey flint clay siderite	ore
TC 6	157.1 - 160.1	16.0	16.3	33.1	32.5	11.6	10.9	35.3	2.3			non-refractory	K and B, G, or A	light and dark grey flint clay siderite	ore
TC 7	160.1 - 162.1	17.3	17.9	30.8	29.3	15.9	15.4	31.8	2.1			non-refractory	K and B, G, or A	light and dark grey flint clay siderite	ore
TC 8	162.1 - 165.0	15.3	15.7	30.2	29.7	11.6	10.9	38.9	1.8			non-refractory		grey flint clay siderite	ore
TC 9	165.0 - 167.1	8.0			18.8		4.0					non-refractory		grey micaceous siltstone	
TC 10	167.1 - 172.1	8.8			18.5		4.8					non-refractory		grey micaceous siltstone	
TC 11	172.1 - 177.1	14.3			18.2		2.6					non-refractory		bone, carb. shale, grey siltstone	
TC 12	177.1 - 182.1	10.7			15.8		3.6					non-refractory		grey siltstone	
TC 13	182.1 - 185.2	13.9			9.6		14.3					non-refractory		grey siltstone	

Vertical thickness of ore 14.5 feet
Weighted average available Al_2O_3, 31.72 percent
Weighted average available Fe_2O_3, 14.58 percent
Weighted average specific gravity 2.61
Weighted average moisture 3.56 percent

* K = kaolinite
B = boehmite
G = gibbsite
A = alumina gel

TABLE 2

HOLE 7
DURHAM HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

HIGH-ALUMINA CLAY DATA

Sample No.	Interval feet	Ign. loss, 700° C.	Ign. loss, 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	% Total SiO_2	% Total TiO_2	Apparent specific gravity	Moisture percent as-rec'd basis	Refractori-ness	Mineralogy from chemistry	Lithology	Ore
TC 78	138.8 - 140.3	37.5			17.1		1.5					non-refractory		bone and carb. shale	
TC 79	140.3 - 141.8	15.0	15.4	37.2	32.7	12.2	8.9	31.2	2.4			non-refractory	K and B,G, or A*	black-grey flint clay siderite	ore
TC 80	141.8 - 145.1	19.6	20.0	41.1	31.0	15.8	14.9	19.0	2.4			non-refractory	K and B,G, or A	bone, dark-grey flint clay siderite	ore
TC 81	145.1 - 149.0	17.6	17.7	35.5	32.0	16.0	15.2	26.9	2.4			non-refractory	K and B,G, or A	carb. flint clay siderite	ore
TC 82	149.0 - 150.1	17.5	17.6	28.9	26.9	15.2	14.7	34.4	2.0			non-refractory		black flint clay	ore
TC 83	150.1 - 152.4	17.5			24.7		15.5					non-refractory		black flint clay	
TC 84	152.4 - 153.8	13.3			21.4		11.1					non-refractory		grey flint clay siderite	
TC 85	153.8 - 154.9	14.4			23.7		11.9					non-refractory		black flint clay siderite	

* K - kaolinite
B - boehmite
G - gibbsite
A - alumina gel

Vertical thickness of ore 9.8 feet
Weighted average available Al_2O_3, 31.20 percent
Weighted average available Fe_2O_3, 14.08 percent
Weighted average specific gravity 2.61
Weighted average moisture 3.56 percent

TABLE 3
KANASKAT HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

Chemical Data

Sample No.	Location	Ign. loss 700° C.	Ign. loss 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	Total SiO_2 %	Total TiO_2 %
CCP 53	Tunnel 2 (bottom)	12.7			36.0		14.7		
CCP 54	"	12.4			32.4		15.2		
CCP 55	"	12.3			33.6		13.4		
CCP 56	" (top)	12.5			33.5		6.7		
CCP 45	Trench no. 3 (bottom)	12.8			34.2		10.2		
CCP 46	"	12.9			33.3		9.9		
CCP 51	"	12.5			35.5		4.8		
CCP 52	" (top)	10.6			28.1		7.6		
CCP 44	Trench no. 4 (bottom)	12.6			34.6		5.0		
CCP 43	" (top)	12.8			32.1		12.9		
CCP 50	Trench no. 5 (bottom)	12.1			35.7		3.1		
CCP 49	"	12.2			37.3		3.0		
CCP 48	"	12.0			28.5		24.1		
CCP 42	"	11.8			31.1		16.5		
CCP 41	"	12.7			31.8		13.8		
CCP 40	"	12.7	13.4	43.5	38.9	16.5	15.8	24.8	2.0
CCP 39	" (top)	11.9			31.4		9.6		

TABLE 3
KANASKAT HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

Chemical Data

Sample No.	Location	Ign. loss 700° C.	Ign. loss 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	Total SiO_2 %	Total TiO_2 %	Apparent specific gravity	Moisture % as-rec'd basis
CCP 30	Trench no. 6 (top)	11.1			26.5		12.8				
CCP 31	"	12.9			33.4		11.4				
CCP 32	"	13.4	14.5	42.5	38.5	17.5	16.6	23.4	2.1		
CCP 33	"	12.7			31.4		16.3				
CCP 34	"	12.4			34.8		13.4				
CCP 35	"	11.6			32.6		17.2				
CCP 36	"	12.2			32.7		12.8				
CCP 37	" (bottom)	12.3	13.0	38.0	36.1	3.3	3.2	44.5	1.5	2.45	4.9
CCP 133	Trench no. 8	12.2			33.3		7.9				
CCP 134	"	10.8			27.0		20.6				
CCP 139	Outcrop near Thomas coal mine (clay bed 3.5' thick)	13.0			35.4		5.9				
CCP 140	Thomas coal mine 0.0-2.2' (measured vertically) (top)	13.1			36.6		4.3				
CCP 141	Thomas coal mine 2.2'-6.4' (measured vertically) (bottom not reached)	12.6			32.1		13.9				

TABLE 4
KANGLEY HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

Chemical Data

Sample No.	Location	Ign. loss 700° C.	Ign. loss 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	Total SiO_2 %	Total TiO_2 %
				UPPER BED					
CCP 57	In trench on south side of Alta Creek immediately above ss.	9.4			26.7		1.6		
CCP 58	Next to 57	11.8			29.7		9.9		
CCP 59	Next to 58	9.6			26.9		1.8		
CCP 60	Next to 59	8.7	8.8	24.2	22.7	4.3	4.0	59.7	1.3
CCP 61	Next to 60	12.0			33.4		2.5		
CCP 62	Next to 61	10.4			27.9		4.2		
CCP 63	Next to 62	11.4			29.6		6.1		
CCP 64	Next to 63	11.1	11.4	21.8	19.9	9.5	9.2	53.7	1.4
				LOWER BED					
CCP 137	Bottom 3 feet of lower bed	16.4			29.1		12.9		
CCP 138	Top 3 feet of lower bed	12.9			34.2		3.2		

TABLE 5

BLUM HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

HIGH-ALUMINA CLAY DATA

Sample No.	Interval feet	Ign. loss, 700° C.	Ign. loss, 950° C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	% Total SiO_2	% Total TiO_2	Apparent specific gravity	Moisture percent as-rec'd basis	Refractoriness P.C.E.	Mineralogy from chemistry	Lithology	Ore
TC 110	147.4 - 148.6	45.2			22.8		2.3			1.69	8.7	non-refractory		bone and light-grey flint clay	not ore
TC 111	148.6 - 150.9	15.6	16.0	37.1	36.4	4.5	4.3	39.8	1.8	2.39	6.4	refractory 32-	K and B, G, or A	light-grey flint clay	ore
TC 112	150.9 - 154.3	18.5			33.8		12.4			2.43	7.1	non-refractory 12		light and dark grey flint clay	ore
TC 113	154.3 - 156.1	16.1	16.8	41.3	40.3	1.9	1.7	37.3	2.1	2.31	6.7	refractory 33+	K and B, G, or A*	dark-grey flint clay	ore
TC 114	156.1 - 158.8	19.1			32.4		10.7			2.46	5.4	non-refractory		black flint clay siderite	ore
TC 115	158.8 - 160.8	20.1			30.1		14.2			2.49	5.2	non-refractory		black flint clay siderite	ore
TC 116	160.8 - 162.6	18.4			30.3		11.5			2.55	4.3	non-refractory		black flint clay siderite	ore
TC 117	162.6 - 163.5	21.2			24.5		21.1			2.65	2.6	non-refractory		black flint clay siderite	not ore
TC 118	163.5 - 165.8	19.3			27.2		18.6			2.57	4.4	non-refractory		light-grey flint clay siderite	not ore
TC 119	165.8 - 168.4	22.6			21.7		26.8			2.74	4.0	non-refractory		white-grey flint clay siderite 30%	not ore
TC 120	168.4 - 170.1	14.1	14.4	37.3	36.2	3.7	3.5	41.8	2.1	2.46	4.6	refractory 32+		light-grey flint clay	not ore

Vertical thickness of ore 14.0 feet
Weighted average available Al_2O_3, 33.81 percent
Weighted average available Fe_2O_3, 9.51 percent
Weighted average specific gravity 2.44
Weighted average moisture 5.97 percent

* K = kaolinite
B = boehmite
G = gibbsite
A = alumina gel

Chemical Data

Sample No.	Location	Ign. loss, 700°C.	Ign. loss, 950°C.	Total Al_2O_3 %	Avail. Al_2O_3 %	Total Fe_2O_3 %	Avail. Fe_2O_3 %	Total SiO_2 %	Total TiO_2 %	Apparent specific gravity	Moisture percent as-rec'd. basis	Refractoriness	Mineralogy from chemistry	Lithology	Ore
							South Side of Green River								
CCP 127	top of bed	18.8			28.0		18.0					non-refractory		grey flint clay siderite	not ore
CCP 128		17.5	18.2	34.4	33.8	15.1	13.9	29.2	1.9			non-refractory	K and * B, G, or A	grey tuffaceous (?) flint clay "white bodies" siderite	not ore
CCP 129		18.6	19.3	30.6	30.6	17.7	15.8	28.8	1.8			non-refractory	K and B, G, or A	grey flint clay "white bodies" siderite	not ore
CCP 130	bottom of bed	18.5			36.6		1.1					refractory		dark grey & carb. flint clay	ore
							North Side of Green River								
CCP 119	top of bed	16.1			38.4		1.2					refractory		dark grey flint clay black crystals	ore
CCP 120		17.2	18.0	32.4	32.4	17.3	16.2	28.7	1.8	2.42	5.0	non-refractory	K and B, G, or A	grey flint clay much siderite	not ore
CCP 121		18.0	18.9	37.3	36.3	14.3	13.9	26.4	1.6			non-refractory	K and B, G, or A	tuffaceous (?) flint clay 1/3 altered tuff. frags.	not ore
CCP 122		15.3			37.7		3.5					refractory		dark grey flint clay	ore
CCP 123		20.6			25.6		26.0					non-refractory		grey flint clay much siderite	not ore
CCP 124		15.0			38.2		1.4			2.30	6.9	refractory		dark grey flint clay	ore
CCP 125		41.8			23.9		0.6					non-refractory		carb. shale, bone, & coal	not ore
CCP 126	bottom of bed	8.7			22.1		1.7					non-refractory		grey micaceous siltstone	not ore

* K = kaolinite
B = boehmite
G = gibbsite
A = alumina gel

TABLE 7
HARRIS HIGH-ALUMINA CLAY DEPOSIT
KING COUNTY, WASHINGTON

Chemical Data

Sample No.	Location	Ign. loss 700° C.	Available Al_2O_3 %	Available Fe_2O_3 %
	Harris Mine			
CCP 142	Approximately 1540 feet from portal at the working face, lower part of clay, true thickness 7.5 feet.	13.0	19.1	8.6
CCP 143	Overlying sample CCP 142, true thickness about 3 feet.	14.0	30.0	8.9
CCP 144	About 50 feet up a chute which is 1260 feet from the portal, lower part of clay, true thickness 3 feet.	11.5	28.7	1.4
CCP 145	Overlying sample 144, true thickness 4 feet.	11.8	26.6	2.9
	Squak Mountain Locality			
CCP 115	Outcrop in unnamed creek north of Squak Mt., sec. 33, T. 24 N., R. 6 E.	13.2	25.8	8.9
CCP 116	Same	12.2	32.8	3.6

TABLE 8

KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS

Ash Analyses of King and Pierce County Coal[1]

County and Town	Mine	Bed	Analyses of Ash SiO_2 %	Analyses of Ash Al_2O_3 %	Analyses of dry coal Ash %
King					
Renton	New Black Diamond	Jones	33.7	39.0	11.5
"	"	"	47.8	42.5	11.0
Ravensdale	Dale-McKay	McKay	38.3	40.2	7.2
Pierce					
Fairfax	Fairfax	No. 3	31.2	32.3	9.8
Wilkeson	Wilkeson	No. 8	23.2	31.9	7.0
"	"	No. 7	30.4	40.0	7.3
"	"	No. 4	31.8	44.1	8.5

1 Ash, S. H., Analyses of Washington Coals, U. S. Bureau of Mines Technical Paper 491, Table 13, 1931.

TABLE 9
KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS
DURHAM DEPOSIT

Reserves

Hole No.	Area Hor. Proj. Sq. Ft.	Thickness Vertical Feet	Volume Cubic Feet	Tonnage Factor	Moisture Content %	Wet Ore Tons	Dry Ore Tons	Avail. Al_2O_3 %	Avail. Fe_2O_3 %
1	423,600	14.5	6,142,200	12.28	3.56	500,179	482,373	31.72	14.58
2	462,800	13.2	6,108,960	12.28	3.56	497,472	479,762	31.29	10.07
3	415,600	11.3	4,696,280	11.96	3.10	392,666	380,493	35.95	13.63
4	242,000	7.9	1,911,800	12.28	3.56	155,684	150,142	33.0	13.0
5	420,400	11.0	4,624,400	12,33	3.22	375,053	362,976	34.26	11.66
6	248,600	15.8	3,927,880	12.52	4.12	313,728	300,802	33.79	11.56
7	223,600	9.8	2,191,280	12.28	3.56	178,443	172,090	31.20	14.08
8	188,400	8.2	1,544,880	12.28	3.56	125,805	121,326	33.48	5.28
Totals and Averages	2,625,000	11.9	31,148,000	12.27	3.51	2,539,000	2,450,000*	33.05	12.15

* [illegible]

TABLE 10
KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS
BLUM DEPOSIT

Reserves

Hole No.	Area Hor. Proj. Sq. Ft.	Thickness Vertical Feet	Volume Cubic Feet	Tonnage Factor	Moisture Content %	Wet Ore Tons	Dry Ore Tons	Avail. Al_2O_3 %	Avail. Fe_2O_3 %
10	463,600	14.6	6,768,560	13.03	5.25	519,460	492,188	32.41	9.18
11	392,100	7.9	3,097,590	12.87	3.98	240,683	231,104	32.98	7.33
12	320,300	14.0	4,484,200	13.14	5.97	341,263	320,890	33.81	9.51
Totals and Averages	1,176,000	12.20	14,350,000	13.03	5.20	1,101,000	1,044,000*	32.97	8.87

* 50 percent measured and 50 percent indicated ore.

TABLE 11
KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS
KANASKAT DEPOSIT

Reserves

Workings	Area Hor. Proj. Sq. Ft.	Thickness Vertical Feet	Volume Cubic Feet	Tonnage Factor	Moisture Content %	Wet Ore Tons	Dry Ore Tons	Avail. Al_2O_3 %	Avail. Fe_2O_3 %
Tunnel 2	51,600	14.0	722,400	12.28	3.56	58,827	56,732	34.0	13.3
Trench 5	38,600	36.0	1,389,600	12.28	3.56	113,159	109,130	33.7	12.7
Trench 6	49,900	31.0	1,546,900	12.28	3.56	125,969	121,484	32.2	12.5
Trench 8	50,100	3.5	175,350	12.28	3.56	14,279	13,770	28.6	11.5
Totals and Averages	190,200	20.16	3,834,000	12.28	3.56	312,000	301,000*	32.92	12.68

* Indicated ore

TABLE 12
KING COUNTY, WASHINGTON, HIGH-ALUMINA CLAY DEPOSITS
SUMMARY OF RESERVES

Deposit	Area Hor. Proj. Sq. Ft.	Thickness Vertical Feet	Wet Ore Tons	Dry Ore Tons	Avail. Al_2O_3 %	Avail. Fe_2O_3 %
			MEASURED ORE			
Durham	1,312,000	11.9	1,270,000	1,225,000	33.05	12.15
Blum	588,000	12.2	551,000	522,000	32.97	8.87
Totals and Averages	1,900,000	12.0	1,821,000	1,747,000	33.03	11.17
			INDICATED ORE			
Durham	1,312,000	11.9	1,270,000	1,225,000	33.05	12.15
Blum	588,000	12.2	551,000	522,000	32.97	8.87
Kanasket	190,000	20.2	312,000	301,000	32.92	12.68
Totals and Averages	2,090,000	12.74	2,133,000	2,048,000	33.01	11.39

INFERRED ORE

Geologic data suggest that there are 20,000,000 dry tons of inferred ore of approximately the same grade.