Bulletin No. 46

Ferruginous Bauxite Deposits in the Salem Hills, Marion County, Oregon

By

R. E. Corcoran, Geologist,
Oregon Department of Geology and Mineral Industries
and
F. W. Libbey, Mining Engineer

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Price $1.25

STATE OF OREGON
Department of Geology and Mineral Industries
1069 State Office Building
Portland 1, Oregon

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FOREWORD

Bauxite was found in the Salem Hills, Oregon, by the State of Oregon Department of Geology and Mineral Industries in 1945. A brief reconnaissance study was made at that time and a preliminary description of some of the deposits was included in Department Bulletin 29. In 1953 the Governing Board of the Department authorized a follow-up project to obtain more definite information concerning quantity and quality of bauxite in the Salem Hills area, and the accompanying report gives the results of the study. It was felt that the investigation was warranted both because of the need for more information on Oregon's mineral resources and, perhaps more important, because of the national need for increasing domestic reserves of bauxite.

In 1945 it was freely predicted that since aluminum production had been greatly stepped up to supply war needs there was excess capacity, and demand for the metal would fall off as a post-war reaction which would result in a serious decline in production. The prediction was in error. Instead of declining, the demand for aluminum progressively increased. New reduction and fabricating plants were built in the Pacific Northwest as well as in other parts of the country, and the demand continues to increase. This expansion meant, and means, an increased need for bauxite, most of which must be shipped in to the United States from Carribean countries. From a national defense angle, dependence on foreign ore is dangerous. One needs only to point to the sinking of many bauxite ships by German submarines early in World War II when failure of bauxite imports became a serious menace to national security. Therefore finding new reserves of bauxite is greatly to be desired and finding them near established reduction plants, as in the lower Columbia River area, offers added advantages.

In this investigation the Department could not do sufficiently detailed drilling and sampling to evaluate accurately the bauxite reserves in the Salem Hills area because of the cost involved. In addition such detailed work is not a proper function of the Department, which, in such studies, should only point the way by indicating possibilities, leaving the complete exploration to private enterprise.

As an added comment on the project it should be pointed out that Mr. L. L. Hoagland, Department chemist, and his assistants cooperated wholeheartedly with the authors in the important task of preparing and analyzing the large number of samples. Prompt analytical results were essential in planning intelligent exploration and in providing the assay evidence necessary for the completion of the report. The Department is appreciative of Mr. Hoagland's generous, competent help to the authors in the carrying out of the project.

<div align="right">Hollis M. Dole
Director</div>

July 2, 1956

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FERRUGINOUS BAUXITE DEPOSITS IN THE
SALEM HILLS, MARION COUNTY, OREGON

By
R. E. Corcoran and F. W. Libbey

Abstract

Laterization of basaltic lava in the Salem Hills area, 7 to 10 miles south of Salem, formed deposits of ferruginous bauxite. The lava, variously termed Salem basalt or Stayton lava, is believed to be a correlative of Columbia River basalt of middle Miocene age. It overlies the marine sediments of the Eugene formation of Oligocene age, and underlies Fern Ridge tuffs believed to be of Pliocene age as interpreted outside of the laterized area. Quaternary alluvial deposits occupy stream valleys both east and west of the Salem Hills. This range of gently rolling hills which is intersected by the Willamette River continues north as the Eola Hills. The Salem-Stayton lavas in the Salem Hills dip gently to the northeast and form the west limb of a syncline whose east limb is the Waldo Hills.

Probably bauxitization of the Salem-Stayton lavas continued into Pliocene time during which a gibbsite section was formed. Uplift and erosion dissected and removed much of the laterite horizon and the deposits that remain are found at topographic highs. As the result of erosion, relic gibbsite nodules of all sizes as much as 30 inches in diameter are scattered widely over the surface and in the soil. The gibbsitic laterite section is underlain by lithomarge which merges successively into weathered basalt and then fresh basalt. The Salem Hills laterite is analogous to the laterite on Columbia River basalt farther north in Oregon and Washington.

"Draping" of the deposits over some of the rounded hills is indicated by drilling. The most extensive and continuous deposit appears to exist in the Rosedale Church area. The attitude of the deposits corresponds with that of the basalt.

The gibbsitic laterite is reddish brown, granular, and generally soft. An oölitic section is rare in contrast to the deposits farther north. Gibbsite nodules when broken are generally light tan, pink, and gray with a porcelaneous texture. They are dense and hard with a smooth, rounded, irregular surface. A waxy, desert-varnish type of surface is characteristic of many of the nodules. At least one locality has a hard gibbsite layer in place and this layer appears to be unique in showing regular banding.

Auger hole drilling by the Department has indicated that an aggregate area of approximately 1200 acres is underlain with gibbsitic laterite which has an average thickness of 14.4 feet and a weight-volume factor estimated to be 17 cubic feet per ton in place. Average analyses of drill hole samples give a weighted average of 35.0 percent Al_2O_3, 6.7 percent SiO_2, 31.5 percent Fe_2O_3, 6.5 percent TiO_2, and 20.2 percent L.O.I.

The Salem Hills bauxite deposits are low in Al_2O_3 compared with high-grade bauxite, but they have advantages which partially, at least, compensate for this disparity. The average of 6.7 percent SiO_2 is relatively low and that is very desirable in the Bayer process. The high iron content could make a commercial by-product, either pig iron or ferrotitanium. It has been reported authoritatively that there are no metallurgical obstacles to treatment of the ore either by the Bayer or Pedersen processes. The physical characteristics of the deposits are favorable for cheap surface mining, and there are excellent transportation facilities to the lower Columbia River area about 50 miles to the north where aluminum reduction plants are operating. An alumina plant in that area would mean a large saving in the cost of transportation of alumina which now (1956) must be shipped across the continent to reduction plants in the West.
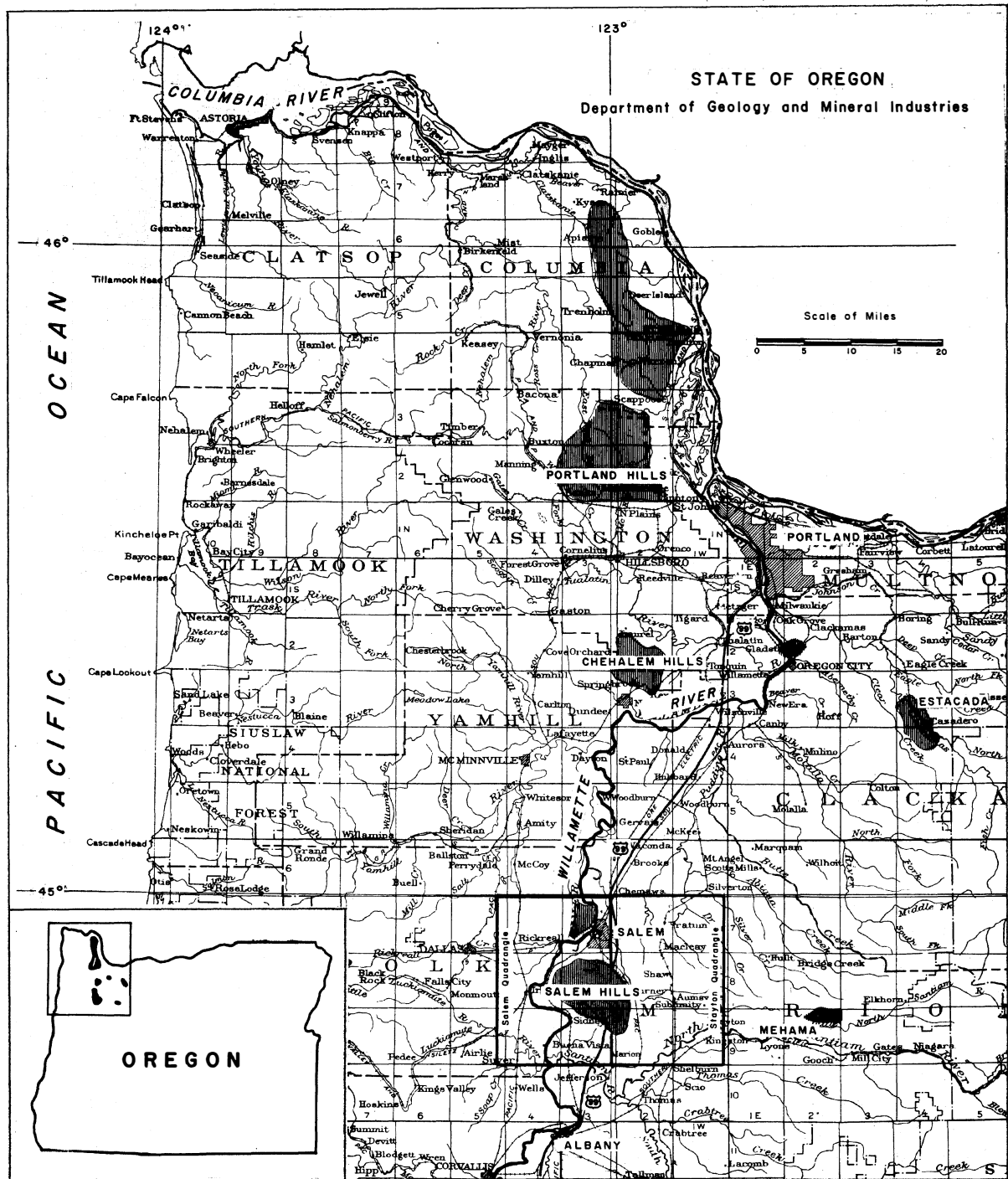
Figure 1 – Index Map Showing Ferruginous Bauxite Deposits in Northwestern Oregon

Introduction

General

Ferruginous bauxite developed on laterized Miocene basalt in the Salem Hills, Marion County, Oregon, was found by the Department in 1945 during an investigation of laterite deposits in the northern Willamette Valley area (see Index Map on opposite page). A brief description of these deposits was included in Department Bulletin No. 29[1] which was primarily concerned with the bauxite deposits in Columbia and Washington counties. At that time when the first reconnaissance work in the Salem Hills was done, it was tentatively thought the laterite section there had undergone considerably more erosion than deposits in Columbia and Washington counties, and that the Salem Hills offered less hope for developing substantial reserves. Assays of some of the material taken from road cuts, however, indicated that the bauxitic laterite in these hills might be of sufficient grade to warrant a more detailed examination.

In the summer of 1953 further work in the Salem Hills area was authorized by the Governing Board of the Department. Preliminary exploration began with a general reconnaissance over most of the area in order to determine, at least approximately, the surface limits of the laterite section. During the course of this examination several of the more promising areas were selected for drilling. The drilling program was begun in the fall of 1953 and continued, when weather conditions permitted, until the fall of 1954. Twenty-five holes were put down by hand auger for a total of 489 feet (see Locality Map, Plate 1, in pocket). The holes were drilled to about 20 feet in depth unless sample results obtained by thermal analysis or assaying showed that greater or less depth was required. Three deeper holes were drilled by power auger in cooperation with the State Highway Department to determine the thickness of the clay section beneath the bauxite and also to investigate the possibility of lower bauxitic horizons.

More than 250 samples obtained in this investigation were analyzed for Al_2O_3, SiO_2, TiO_2, and Fe_2O_3 in the Department's chemical laboratory. Spectrographic, petrographic, and X-ray diffraction studies of selected samples were made either in Department or U. S. Bureau of Mines laboratories in order to supplement the results of the chemical analyses. Differential thermal analyses of drill samples were run during the drilling in order to estimate promptly the amount of gibbsite and kaolinite present in the laterite.

Another part of the laterite investigation was concerned with titanium mineralogy and its possible geochemical significance. In some places samples contained almost 10 percent TiO_2 and the average for the bauxite section is approximately 7 percent. The Department authorized Dr. E. E. Roedder, professor of mineralogy at the University of Utah, to conduct research on samples furnished by the Department, and a report on the results is given in the Appendix. The U. S. Bureau of Mines at Albany, Oregon, also cooperated in the titanium research by making petrographic and X-ray diffraction examinations. Results of the Bureau's studies are given on pages 20 and 21.

Complete chemical analyses of samples of the parent basalt, clay, and bauxite were made at the Rock Analysis Laboratory, University of Minnesota, under the direction of Dr. S. S. Goldich (see Table 2, page 13).

[1] Libbey, F. W., Lowry, W. D., and Mason, R. S., 1945, Ferruginous bauxite deposits in northwestern Oregon: Oregon Dept. Geology and Min. Industries Bull. 29.

In the course of the Salem Hills bauxite investigation, the nearby Eola and Waldo hills were also examined for possible bauxitic horizons. Although some gibbsite nodules were found on the surface and scattered through the soil horizon on the lower slopes in the southern part of the Eola Hills, only deposits of very limited size and scattered distribution were indicated. No drilling was done in either the Waldo or Eola hills, and the possible presence of bauxite horizons of greater extent cannot be ruled out.[2]

As noted in Department Bulletin No. 29, the name "ferruginous bauxite" used in referring to the laterites of northwestern Oregon has been given to this material for lack of a more definitive term. It cannot be classified as an iron ore and the hydrous aluminum oxides are generally in excess of the hydrous iron oxides. Although one drill sample from the Salem Hills contained 44 percent Fe_2O_3, the overall average of the bauxite section is approximately 30 percent. In his investigation of the Antrim laterites, Eyles (1952)[3] also uses the term "ferruginous bauxite" when describing the material developed on basalt similar in composition and age to that in the Salem Hills.

The term "ore" is used in this report for convenience. It is realized that according to a strict definition the material is not ore until it is shown that it may be treated commercially.

Two progress reports on the Salem Hills bauxite investigation have been printed in the Department's monthly publication, The Ore.-Bin (Corcoran, 1954, and Corcoran and Libbey, 1955). The reports included a brief description of the deposits and results of chemical assays for the first 23 drill holes. Early in 1955, Aluminium Laboratories, Limited, began an exploratory drilling program in the areas originally outlined by the Department.

Location

A locality map (Plate 1 in pocket) shows the location of the Salem Hills and surrounding areas. Laterite deposits are situated in the southwestern portion of the hills in a northwest-trending strip approximately 3 miles wide by 6 miles long in T. 8 S., Rs. 2 and 3 W. This area is 7 to 10 miles south of Salem in Marion County and is easily accessible from U. S. Highway 99 over a network of graded secondary county roads. Topographic maps of the Salem and Stayton quadrangles covering the areas of interest may be obtained from the U.S. Geological Survey.[4]

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[2] A small deposit of bauxitic laterite has been discovered in the foothills of the Western Cascades near the town of Mehama approximately 25 miles east of the Salem Hills. Some bulldozing was done by the owner of the mining claims, and samples in the bulldozer cuts were taken and analyzed by the Department. A few samples indicated bauxitic material, but the deposit appears to be of limited extent. The Department plans to continue reconnaissance in the Mehama area.

[3] See bibliography.

[4] Aerial photographs taken in 1948 having a scale of approximately 1667 feet = 1 inch are available from the Agricultural Stabilization and Conservation Service, U. S. Department of Agriculture.

Relief and drainage

The Salem Hills are part of a larger relief feature in this area of the Willamette Valley that is referred to as the Salem-Eola Range. These two groups of hills, Eola to the north and Salem to the south, are structurally continuous but are topographically separated by the Willamette River (see Index Map opposite page 3 and Locality Map, Plate 1, in pocket). The hills owe their height to a capping of lavas 400 to 500 feet thick which are more resistant to erosion than the underlying tuffs and tuffaceous sandstones. The trend of the range changes from approximately N. 60° W. at the southern end of the Salem Hills to northerly in the Eola Hills. The Willamette River flows around the western side of the Salem Hills, and erosion of the nonresistant marine sediments which underlie the lavas has created a fairly steep scarp. The laterized basalt surface on the east side of the Salem Hills, however, has a gentle north-easterly slope of approximately 150 to 200 feet per mile. This slope has been maturely dis-sected by numerous streams, the largest of which are Rodgers and Battle creeks that flow south and east into Mill Creek, a tributary of the Willamette River.

The highest point in the Salem quadrangle is at Prospect Hill (elevation 1121 feet) near the westernmost margin of the ridge. On the whole the topography is rolling but in certain areas the surface is relatively flat (Plate 3). The thickest and most extensive bauxite deposits are located in these flatter areas at elevations between 600 and 1000 feet. Bauxite may also occur in places at lower elevations, but increasing thickness of overburden and lack of outcrops prevent any direct observation of such deposits.

Plate 3 - View of Salem Hills showing typical rolling terrain. Crop land is in wheat.

Climate

The broad lowland of the Willamette River Basin has a relatively equable climate, characterized by warm dry summers and cool wet winters. These characteristics are shown by Table 1 on page 6, which gives averages of temperature and precipitation for the years 1950 through 1954. Over most of the Willamette Valley the yearly average temperature is between 51° and 53° F. The precipitation, rain for the most part, occurs largely in the winter and early spring, with usually no more than 2 to 3 inches falling during the summer months. The table shows this marked seasonal distribution of rainfall and snowfall, which is characteristic of the entire Willamette River Basin. It is interesting to note that during the 5-year period from 1950-1954, the average annual temperature remained fairly constant but there was a considerable variation from year to year in the total rainfall. Studies have been made on the average

annual rainfall in the Willamette Valley over a 40-year period (Piper, 1942) and show that along the middle of the Valley the precipitation has ranged from 60 to 145 percent of the average (37.22 inches for Salem).

Table 1.
Record of Average Temperature and Total Precipitation in the
Willamette River Basin from 1950 to 1954 Inclusive

	Average Temperature - Degrees F.						Total Precipitation - Inches				
	1950	1951	1952	1953	1954		1950	1951	1952	1953	1954
Jan.	30	40	39	47	40		11.7	9.5	6.6	15.4	10.0
Feb.	41	43	41	43	43		6.2	5.4	4.9	4.9	5.9
Mar.	45	41	44	45	43		4.9	4.0	2.6	5.0	3.0
Apr.	48	53	50	49	49		1.9	1.0	1.6	1.6	2.7
May	55	56	56	54	56		1.2	2.5	0.2	3.8	1.3
June	62	64	59	58	57		2.8	Tr.	2.6	1.3	1.3
July	67	67	67	65	63		0.2	0.2	0.0	Tr.	0.3
Aug.	69	65	66	65	63		0.1	0.7	0.0	1.7	0.7
Sept.	62	63	64	62	59		0.8	3.2	0.2	1.6	1.3
Oct.	52	53	57	54	51		10.7	7.3	0.8	3.0	3.5
Nov.	47	45	39	48	49		9.7	7.0	1.7	7.0	5.1
Dec.	47	38	41	43	40		6.1	6.7	8.6	7.8	6.3
Average annual temperature							Average annual rainfall				
	52	52	52	53	51		56.6	47.5	29.9	53.0	41.5

From: U.S. Weather Bureau Climatological Data: Oregon, Years 1950-1954.

Geology

Stratigraphy

The Salem-Eola Range (see Plate 1 in pocket) is underlain by a series of marine tuffs, tuffaceous sandstones, and pebble conglomerates named Illahe formation by Thayer (1939) from exposures in Illahe Hills just north of the Salem Hills. The Illahe formation can be traced southeastward into Oligocene marine beds in the Lebanon area which have been correlated (Allison and Felts, 1956) with the Eugene formation (Schenck, 1927, 1928) farther to the south. The name "Eugene formation" has therefore been adopted for this report because of its priority. In this formation, according to Mundorff (1939), sandstone predominates and is typically composed of feldspar, quartz, and glass with minor amounts of augite, magnetite, olivine, and various rock fragments. The grains vary in size from about .02 mm to 5 mm in different beds, but they are usually quite well sorted within each bed.

In the Salem Hills the general dip of the beds is 4° to 5° NE., varying as much as 12° NE. due to local folding. The best exposures of the Eugene formation are along the steep western escarpment of the Salem-Eola Range which forms the anti-dip slope. The strike of the formation more or less coincides with the present trend of the Range; i.e., approximately N. 6° W. in the Eola Hills to approximately N. 45° W. in the southern part of the Salem Hills. The total exposed thickness is approximately 2200 to 2500 feet.

Plate 4 - Outcrop of Salem-Stayton lavas exposed in quarry on U.S. 99 south of Salem. Note columnar jointing.

Fossils were first collected from these beds by Dall (1896)[*] who assigned a doubtful Oligocene age to them. Later collections by Arnold and Hannibal (1913), Schenck (1928), Thayer (1939), and Mundorff (1939), show that these sediments are of upper Oligocene age and correlate with the Pittsburg Bluff formation (type locality west of Portland, Oregon) and the San Lorenzo formation of California.

The Eugene formation is overlain unconformably by a fairly thick series of basalts called the Salem lavas in the Salem quadrangle by Mundorff (1939) and Stayton lavas in that general region by Thayer (1939). On the west side of the Salem Hills the lavas are at least 400 feet thick and dip gently to the northeast approximately 2° to 3° (Plate 4).

According to Mundorff (1939) the Salem lavas are typically medium to dark gray, fine grained and dense, rarely porphyritic. An average of 15 specimens of the basalts has the following mineral composition: plagioclase - 54 percent; augite - 19 percent; glass - 21 percent; magnetite - 5 percent; olivine, epidote, apatite, and serpentine - each less than 1 percent. Under the petrographic microscope the extinction angle of the plagioclase shows that the predominant feldspar is basic andesine. O'Neill (1939), Barlow (1955),

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[*] See Diller, J. S. 1896.

and Halstead (1955) report that most of the plagioclase in the Stayton lavas in the foothills of the Western Cascades is labradorite.

Thayer (1939) suggests that the Stayton lavas are marginal flows to the Columbia River basalt as the formation thickens to the northeast.   Schlicker (1954) presents evidence to show that the Columbia River basalt and the Salem-Stayton lavas can be correlated on the basis of geographic and stratigraphic position and mineralogic and petrographic similarity.

The Salem-Stayton lavas are therefore almost certainly time-rock equivalents of the Columbia River basalt, if not actually part of the same series of flows, and are assigned a middle Miocene age.

The bauxite deposits in the Salem Hills have been developed on the weathered upper flows of the Salem-Stayton lavas (Plate 5). In the Eola Hills the occurrence of gibbsite nodules in the soil indicates that the bauxite was once present in that area also but has since largely been removed by erosion. The process of bauxitization of these basalts will be discussed in greater detail later in this report.

On the lower slopes of the Salem Hills, a dark-red silty clay occurs in places between the bauxite and the surface soil horizon. The clay varying from 4 to 10 feet appears to increase in thickness northward and is characterized by a somewhat higher silica and lower alumina content than the bauxite im-

Plate 5 - Spheroidally weathered Salem-Stayton lavas in Salem Hills on U.S. 99 south of Salem.

mediately beneath it. Petrographically the silty clay is composed of angular to sub-rounded silt-size to clayey grains of feldspar largely altered to kaolin with a few grains of quartz, ilmenite, magnetite, and hypersthene in a matrix of iron-stained kaolinitic clay. Small pieces of almost pure gibbsite are sometimes found in the silty clay zone. The overlying soil horizon contains rounded, unweathered pebbles of basalt as well as pieces of gibbsite.

The red silty clay has been considered to represent residual material from the Fern Ridge tuffs (Libbey, Lowry, and Mason, 1945) which unconformably overlie the Salem-Stayton lavas in the foothills of the Western Cascades to the east (O'Neill 1939, Barlow 1955, and Halstead 1955). Unfortunately the Fern Ridge tuffs cannot be traced into the red silty clay of the Salem area and there is no apparent petrographic similarity between the two. Another possible age correlative is the Portland silt overlying the bauxite in Columbia and Washington counties to the north (Libbey, Lowry, and Mason, 1945) (Lowry and Baldwin, 1952).   How-

ever, there is not sufficient evidence available at this time to refer the red silty clay in the Salem area to any particular unit in the established stratigraphic column for northwestern Oregon.

Gibbsitic material in the red, silty clay shows that there was a reworking and inter-mixing of the underlying bauxite during deposition of the clay.

Structure

In summarizing the regional structure of the Willamette Valley area, Thayer (1939) states:

"The Willamette Syncline is a broad open fold that plunges somewhat east of north at a very low angle, and is revealed by the dips in the Stayton lavas. The Salem Hills are essentially a slightly warped lava-capped mass whose eastward dip is best shown west of Marion /near the southern edge of the Salem Hills in the Stayton quadrangle/.* The Salem, Eola, and Amity Hills are all part of a single eastward dipping homoclinal block which is transected by the Willamette River west of Salem. Erosion of the soft Illahe /Eugene/* beds exposed below the western edge of the Stayton lavas has given the hills their asymmetrical, cuestalike form. Along the foothills of the Cascades proper, north of Thomas Creek, the lavas slope gently northwestward toward the Wil-lamette Valley. . . . The lavas west of Marion in the south end of the Salem Hills are undoubtedly continuous with those south of Shelburn, 3½ miles to the southeast. North of Turner the lavas can be matched almost flow for flow across Mill Creek Gap, and it is certain that they are parts of a single lava formation, which has been folded along a northeast-southwest line. . . . There is no evidence of the fault along this portion of the Willamette Valley margin suggested by Washburn (1914), and the Western Cascade folds extend unbroken across the Willamette River."

Laterization

General description: The term "laterite" has come to have a variety of meanings since it was first applied by Buchanan (1807) to the red ferruginous soils of India which are composed largely of iron oxides with a slaglike, cellular, or pisolitic structure. Buchanan called this material "laterite" (from L. lateris, a brick) because after it is quarried and allowed to dry it becomes hard enough to be used for building construction. In later studies (Du Preez, 1949; Sherman, 1950) more attention was paid to the various weathering factors involved in producing laterites, and Buchanan's somewhat restricted definition was broadened to include other types of lateritic soils. Most workers today (Eyles, 1952; Sherman, 1952; Owen, 1954) agree that laterization is essentially a de-silication process in which the alkalies and alkaline earths are eliminated along with silica. The other constituents of the parent material from which the laterite was derived, chiefly iron and aluminum oxides, remain in the immediate vicinity. Laterites are found to range in composition from relatively pure iron oxide of the type originally referred to by Buchanan to aluminous varieties almost free from iron (i.e., bauxite). Primary laterite is not a sediment in the ordinary sense of the word but a residual rock formed in situ by the chemical weathering of a parent rock as a result of the special type of weathering known as laterization. Recent studies (Harder, 1949)

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* Insertion by authors.

have shown that with few exceptions any rock type can be laterized if the rate of erosion does not exceed the rate of chemical decomposition.

Products of laterization: Sherman (1949, 1952) shows that during the chemical breakdown of basalt to laterite, a definite sequence of clay types is produced as follows: primary minerals of parent material ——➤ secondary aluminosilicate minerals (montmorillonite-kaolinite) ——➤ free oxides (hydrated iron or aluminum oxide in various proportions). His studies indicate that laterites can form only after passing through the intermediate clay stage. Drilling done in the Columbia County, Oregon, bauxites by Alcoa Mining Company supports this theory, as the samples showed a gradational change from bauxite at the top down through kaolinite (approximately 100 feet thick), weathered basalt, into fresh basalt (Allen, 1948, 1952). Eyles (1952) in his investigation of the Antrim, Ireland, laterites also concluded that these were formed by the chemical breakdown of the parent rock in two distinct stages: first, alteration to lithomarge (a term used in India for the variegated clays under the Indian laterites), which he termed "kaolinization" and second, formation of laterite from the lithomarge, which he termed "laterization."

In the formation of aluminous laterite (bauxite), however, some investigators believe that an intermediate clay stage is not always necessary and, further, kaolinite itself may be an end product of rock weathering.   To support this view, localities are described[5] where the material shows a direct change from fresh rock to bauxite. In the Arkansas and Australian bauxites (Goldman, 1955; Owen, 1954) there are local areas in which kaolinite has apparently been formed by silication of a bauxite zone.   Harder (1949) summarizes various views concerning formation of bauxite and describes areas where bauxite has formed both by direct alteration of the parent material and through desilication of kaolinite or halloysite in the clay zone. He concludes that although bauxite formed from kaolin is common, nevertheless clays formed from bauxite due to silication cannot be ruled out.

Processes of laterization: Sherman (1949) also determined that the type of oxide end products (i.e., aluminous oxides or hydrated iron) formed through laterization are largely the result of two main climatic conditions: (1) continuously wet climates typical of tropical and subtropical areas, and (2) climates having alternating wet and dry seasons.

Aluminous laterites or bauxites, Sherman believes, are formed only in areas having a continuously wet climate.   Under such conditions the silica and iron oxide are leached and the alumina becomes the stable oxide. Titanium oxide increases slightly. (See Fig. 2 on opposite page.)

Ferruginous laterite, on the other hand, is formed in areas where there are fairly distinct wet and dry seasons. Under such conditions the iron and titanium oxides are alternately hydrated and dehydrated and, through capillary action, move upward and become concentrated in the upper portion of the soil horizon. Alumina and silica are removed during the decomposition of the aluminosilicate clay minerals. This process, according to Sherman, is especially effective when there is a fairly large fluctuation in ground-water level between the wet and dry seasons. The dehydration process promotes the formation of minerals of high specific gravity such as anatase and hematite (see Fig. 2).

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[5] Discussion in Problems of Clay and Laterite Genesis: AIME Symposium, St. Louis, Mo., Feb. 1951.
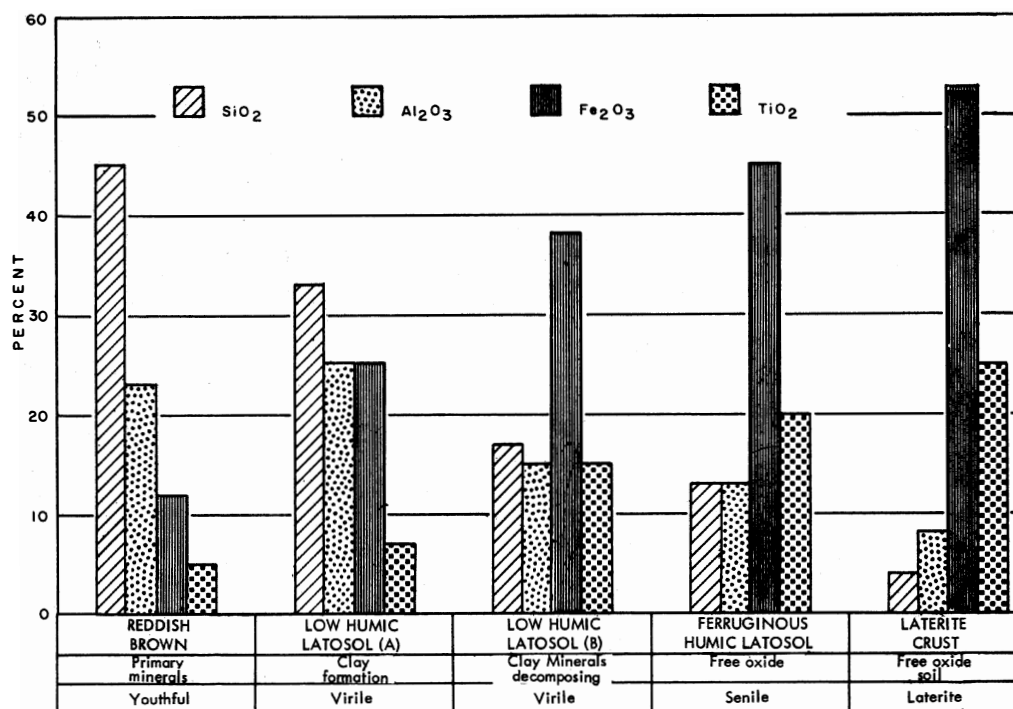
The influence of the lengthening of the wet season of an alternating wet-and-dry-season climate on the chemical composition of the A-horizon of the soil. Wet season increases from left to right. (A) and (B) profiles are two different soils belonging to the low humic latosol.
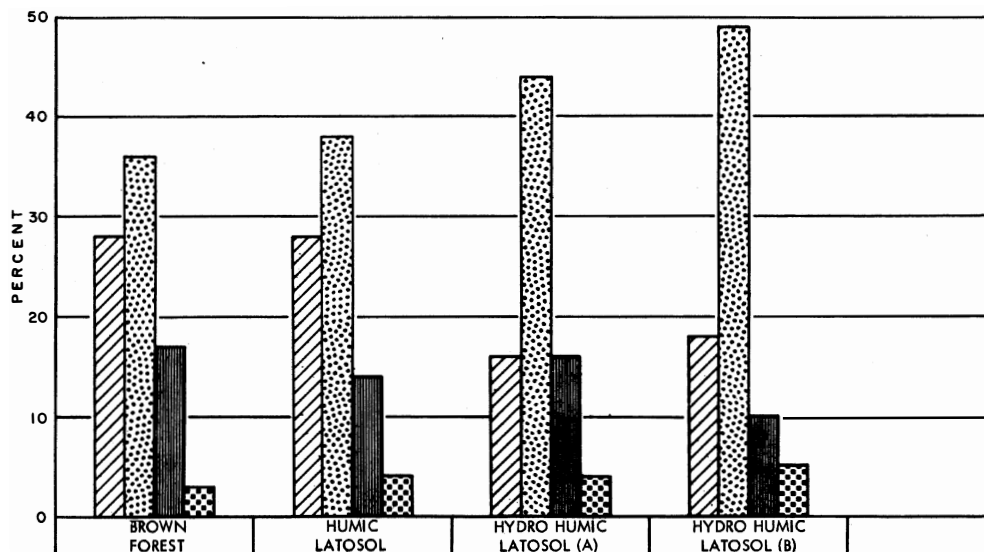
The influence of an increase in annual rainfall on the chemical composition of soils developed in a continuously wet region. Alumina instead of iron becomes the stabilized free oxide.

Figure 2 -   Graphs Showing Progressive Change in Chemical Composition
of Hawaiian Soils in (1) Areas Having Wet and Dry Seasons
and (2) Continuously Wet Regions. (Reproduced from "Factors
Influencing the Development of Laterite and Laterite Soils in
the Hawaiian Islands," by G. D. Sherman, Pacific Science, 1949.)

The theory that aluminous laterites develop only under conditions of continuous rainfall is at variance with the conclusions of some earlier workers (Fox, 1923; Harder, 1949), who maintained that an alternating wet and dry season is necessary for the formation of bauxite. Fox apparently based his reasoning on the fact that the laterites in India are in areas having definite wet and dry seasons and his belief that the bauxite is presently being formed. Harder states: "Some observers claim that, not only is a general warm, moist climate necessary for laterization, but there must be a regular and distinct alternation of wet and dry seasons." Sherman points out that laterization, as used in the general sense for all types of chemical weathering in which desilication is the dominant process, can result from either type of climate but bauxitization can proceed only when the climate is continuously moist. Hosking (1941) studied the clay mineralogy of Australian soils developed on basalts and agrees with Sherman. "Under excessive moisture and dominant leaching conditions, where free drainage is a feature, and there is no approach to drouth conditions for any period of the year, basaltic parent materials give rise to colloids of the kaolinite type. Hydrargillite (gibbsite), goethite, and hematite are a further expression of high sesquioxide content and conditions allowing complete oxidation."

Laterization of the Salem Hills basalt: In the Salem Hills, evidence seen in road cuts and drill-hole samples tends to support Sherman's theory of a two-stage process for laterite formation. New road cuts through the Salem Hills on U.S. Highway 99 in the general vicinity of the bauxite deposits show at least 50 to 60 feet of varicolored clays underlain by darker spheroidally weathered basalt. The higher knobs on either side of the highway contain numerous gibbsite nodules scattered through the soil, although the laterite horizon appears to have been stripped. The presence of a thick clay zone between the bauxite section and the parent basalt is best illustrated in Hole 15, which was drilled to a total depth of 85 feet. The upper 25 feet contains a section of low-silica bauxite. From 25 to 30 feet is a transitional zone of higher silica bauxitic clay. Below 30 feet and continuing to the bottom of the hole, the material is a varicolored high-silica clay which on thermal analysis proved to be predominantly kaolinite-halloysite with some limonite (goethite). The presence of a clay section beneath a laterite horizon has been reported from localities in other parts of the world as well as in Oregon (Fox, 1923; Allen, 1948; Eyles, 1952; Owen, 1954). These reports all show that there is an apparent genetic relation between the bauxite and the underlying clay in accordance with Sherman's conclusions. It seems improbable that the 55 to 60 feet of high-silica clay in the Salem Hills would have formed by silication of bauxite.

Analyses of samples by the Rock Analysis Laboratory, University of Minnesota are given in Table 2 on page 13. They show the chemical changes produced by lateritic weathering of the basalt in the Salem Hills.

Table 2.

Lab. No.	R 2150[1]	R 2151[2]	R 2152[3]
	Basalt	Clay	Ferruginous Bauxite
SiO_2	54.95%	24.13%	4.81%
Al_2O_3	13.47	24.05	30.02
Fe_2O_3	2.26	26.18	33.14
FeO	10.00	2.73	2.79
MgO	3.47	.15	.23
CaO	7.13	.13	.13
Na_2O	3.00	.05	.03
K_2O	1.69	.04	.07
H_2O+	.82	12.43	17.15
H_2O-	.32	2.56	2.59
TiO_2	2.12	6.13	6.76
P_2O_5	.35	.79	1.51
MnO	.20	.31	.36
	99.78	99.68	99.59

[1] Fresh basalt from State Highway Department rock quarry in the southeastern part of the Salem quadrangle near U.S. 99 in $NW\frac{1}{4}$ sec. 2, T. 9 S., R. 3 W. (See Plate 4, page 7.)

[2] From 16' to 20' interval, Hole 14.

[3] From 2' to 6' interval, Hole 14.

Samples R 2150, R 2151, and R 2152 were also analyzed spectrographically in the Department's laboratory and showed the following results:

SAMPLE R 2150

Elements present in concentrations over 10%
Si, Al

Elements present in concentrations 10% – 1%
Fe, Ca, Na, K, Mg

Elements present in concentrations 1% – 0.1%
Mn, Ti

Elements present in concentrations 0.1% – .01%
Ba, Sr

Elements present in concentrations .01% – .001%
Zr, Cr, V, Ni

Elements present in concentrations below .001%
Cu

SAMPLE R 2151

Elements present in concentrations over 10%
Al, Fe

Elements present in concentrations 10% – 1%
Si, Ti

Elements present in concentrations 1% – 0.1%
Mn

Elements present in concentrations 0.1% – .01%
Mg, Na, K

Elements present in concentrations .01% – .001%
Ca, Zr, Cr, V

Elements present in concentrations below .001%
Cu, Ba, Ni

SAMPLE R 2152

Elements present in concentrations over 10%
        Al, Fe

Elements present in concentrations 10% - 1%
        Ti, Si

Elements present in concentrations 1% - 0.1%
        Mn

Elements present in concentrations 0.1% - .01%
        Mg, Ca, Na, K

Elements present in concentrations .01% - .001%
        Zr, V, Ni, Cu, Ba

Elements present in concentrations below .001%
        Cr, Sr

Formation of aluminous laterite in the Salem Hills: The present climate in Oregon is
one of alternating wet and dry seasons. There is usually a period of at least three months
during the summer when the total rainfall does not exceed 3 inches and a period of at least
three months during the winter when the total rainfall is more than 20 inches (see Table 1,
page 6). On the basis of Sherman's conclusions, any laterites that may be forming at the
present time in Oregon should be the more ferruginous type which would contain little, if
any, bauxite. However, the authors have reason to believe, that even in a climate having
a definite dry season, conditions may still be favorable for the formation of aluminous laterite
below the ferruginous zone.

In the Salem Hills, during the course of the drilling, it was noted that the ferruginous
bauxite was damp approximately 10 to 12 feet below the surface even at the end of the summer
dry season (late September – early October). Hole 23 was drilled during this period, and,
although the material was damp below 14 feet, the water table was not encountered in
drilling to bottom at 32 feet. This hole was later inspected in the latter part of December
of the same year about the middle of the rainy season. At that time the water table had risen
in the hole to within 10 feet of the surface.

From the foregoing observations, it can be seen that there is a 20- to 30-foot zone in
which the ground-water table seasonally fluctuates, and the laterite section never becomes
completely dehydrated to allow the iron oxides to be precipitated. The continually wet
section may therefore be an active zone of leaching most of the year and approximate the
conditions Sherman regards as necessary for the formation of aluminous laterite. The laterite
section that has formed in the alternating wet and dry climate of India also tends to bear out
this conclusion. Harder (1952), in his diagrammatic sketch of a typical laterite profile in
central India shows that the bauxite section is usually overlain by a zone of ferruginous
laterite.

The presence of ferruginous bauxite near the surface in the Salem Hills can perhaps be explained by a change in climate since the basalts were first exposed to weathering. Durham (1950) and Cheney (1948) have shown that the climate of Oregon since Eocene time has become progressively cooler and drier. It is therefore possible that a sufficient amount of rainfall occurred throughout the year during the early laterization of the basalt to cause the formation of a fairly thick section of low-iron bauxite. The presence of the residual high-grade gibbsite nodules now scattered through the upper 2 to 3 feet of soil tends to support this conclusion. With the gradual change to an alternating wet and dry climate during post-Pliocene time, the upper part of the remaining original bauxite section in the zone of seasonal dehydration became more ferruginous. Bauxitic clays in the lower part of the laterite section grading upward into ferruginous bauxites near the surface are there-fore the prevailing types in the Salem Hills.

Age of laterization in the Salem Hills: Lowry (Libbey, Lowry, and Mason, 1945) believed that laterization of the basalt took place before deposition of the Fern Ridge tuffs. The tuffs disconformably overlie the Salem-Stayton lavas in the foothills of the Cascades to the east and are generally considered to be of upper Miocene-lower Pliocene age. Lowry suggested that the red silty clay covering the laterite in the Salem Hills might be a residual material from the Fern Ridge tuffs.

In the Mehama, Oregon, area, east of the Waldo Hills (see Index Map, opposite page 3), however, the laterite appears to have developed on massive lithic tuffs which have been mapped as "Fern Ridge" by Barlow (1955). Farther to the north, in the foothills of the Cascades along the Clackamas River near Estacada (see Index Map opposite page 3), an oölitic ferruginous bauxite horizon has been formed on a tuff breccia of the Rhododendron formation. Although no fossils have been found in the Rhododendron formation, its strati-graphic position and general lithology suggest that it is a northern equivalent of the Fern Ridge tuffs. The Rhododendron formation at the Clackamas River bauxite locality is dis-conformably overlain by a basal siltstone of the Troutdale formation of lower to middle Pliocene age according to D. E. Trimble, U.S. Geological Survey.[6] There is a possibility that two separate periods of laterization are represented in the post middle Miocene section of the northern Willamette Valley. It appears more likely, however, that the laterite on the Salem-Stayton lavas and Columbia River basalt, as well as on the Rhododendron-Fern Ridge forma-tions resulted from one period of laterization. This would mean that the older lavas became laterized where they were exposed, but along the foothills of the Western Cascades, the younger formations (Rhododendron and Fern Ridge) which covered the Miocene basalt were subjected to laterization.

The laterite formed on Rhododendron tuffs in the Clackamas River area has somewhat different characteristics from that developed on Salem-Stayton lavas and Columbia River basalt. The Clackamas River bauxite is higher in both alumina and silica and much lower in iron oxide and titania. The important aluminum minerals are gibbsite and a much smaller proportion of kaolin. The color of the bauxitic material varies from reddish brown to brown and is typically oölitic with only a few pisolites observed. Gibbsitic nodules, which are common in Washington, Columbia, and Marion counties, have not so far been found in the Clackamas River deposits.

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[6] Personal communication.

In 1948 the Department drilled six hand-auger holes and sampled road cuts where the bauxitic material was exposed in the vicinity of the Kiggins and Shearer farms, NW¼ sec. 3 and NE¼ sec. 4, T. 4 S., R. 4 E., Clackamas County (Oregon Dept. Geology and Min. Ind., 1948).

Average analysis, on a dry basis, obtained from about 7 feet of section of two auger holes about 1,000 feet apart on the Kiggins farm, is as follows:

Al_2O_3 . . . . 43.0%

Fe_2O_3 . . . . 10.0

SiO_2 . . . . 21.5

TiO_2 . . . . 1.0

L.O.I. 20.0

Moisture 24.0

Shape and attitude of the deposits

The laterite derived from the upper flows of the Salem-Stayton lavas probably was first formed as a blanketlike deposit of fairly large extent. Subsequent uplift of the Salem Hills caused dissection of the bauxite deposit and it now occurs largely as erosional remnants capping the higher knobs. Plate 1 (in pocket) shows the location and approximate boundary limits of the deposits as estimated by field reconnaissance work and drill-hole samples.

Although the surface on the northeast side of the Salem Hills, where the bauxite deposits occur, has been described as a dip slope, drill-hole evidence suggests that the lavas may dip more steeply to the northeast than indicated by surface topography. If so, then the laterite section as well as the overburden would be thicker in that direction.

The average thickness of the ferruginous bauxite section in the Salem Hills as determined from drill samples is 14.4 feet. This figure may be somewhat low as several of the holes in the northeastern part of the laterized area bottomed in low-silica bauxitic material. Two holes especially worthy of mention are 22 (depth 25 feet) and 23 (depth 32 feet). Both holes illustrate the seeming thickening of the bauxite section in a northeasterly direction.

The results of the drilling in the vicinity of the Rosedale Friends Church indicated that this area contained the greatest thickness and greatest areal extent of bauxite in the Salem Hills. Therefore this area was topographically mapped on a scale of 500 ft. = 1 inch to show more accurately the extent of the deposit (Plate 2 in pocket). The limits of the deposit are only approximate as they are based almost entirely on information obtained from seven scattered drill holes; furthermore several of these holes did not completely penetrate the laterite section.

Certain relatively high areas that were expected to contain some bauxite were found to be capped by weathered basalt or clay both of which underlie the laterite section in other places. This is especially well shown in Hole 12 (NW$\frac{1}{4}$ sec. 28, T. 8 S., R. 3 W.) which lies near the north end of a long ridge in the middle of the bauxite area and was drilled to a depth of 20 feet. Chemical analyses showed that the entire section contained high-silica material. Thermal analysis indicated that the dominant mineral was kaolinite-halloysite. Another example of this type of occurrence is the large hill in the NE$\frac{1}{4}$ sec. 34, T. 8 S., R. 3 W., between holes 19 and 21. A bulldozed trench 4 feet deep and 25 feet long has been cut into the hill at its highest point (800 feet elevation). The material exposed in the sides and bottom of the trench is a bluish clay essentially composed of kaolinite. Paradoxically, this hill contains more high-grade gibbsite nodules in the soil than have been found anywhere else in the bauxite area. The reason for this somewhat spotty distribution of the gibbsitic laterite is difficult to explain. One possibility is that the drainage pattern developed on the basalt in the early stages of laterization has changed. After the Salem Hills were uplifted, some of the low places from which the bauxite had been stripped became the high inter-stream areas. Another possibility is that the uplift of the Salem Hills was accompanied by considerable faulting more or less normal to the present strike of the Salem-Stayton lavas. Although displacement may have been comparatively small, the bauxite would have been stripped more rapidly from the higher blocks. The structural relationships of the bauxite deposits are shown in the cross sections of the Rosedale Church area (Plate 2, in pocket). The base of the laterite section if projected across the ridges from Hole 18 to Holes 26 and 23 indicates that some block faulting may have occurred. Unfortunately the drill hole information is not sufficient to show more than the approximate base and attitude of the laterite section, and the apparent offsetting may be caused in part by the line of the cross sections not being parallel to the true dip of the deposits.

Further evidence for post-laterite faulting is indicated by the relationship of Hole 13 to Hole 4 in the southeast part of the bauxite area. Hole 13, elevation 630 feet, contains a 12-foot gibbsitic laterite section averaging 6 percent silica. Hole 4, elevation 828 feet, approximately one mile north of Hole 13, contains a similar laterite section, but was not considered ore because of its somewhat higher silica content (8- to 16-foot interval, 11.89%). Assuming that the laterite in the Salem Hills has a general northerly dip, it appears that the section in Hole 4 has been elevated with respect to the section in Hole 13.

Examination of a freshly dug basement showed bauxitic material in place approximately 28 feet vertically below the top of the knoll on which Hole 1 was drilled. As the chemical analyses of Hole 1 indicated that the thickness of the laterite was not much greater than 20 feet, the bauxite horizon appeared to be "draped" over the topographic high at this locality. To test this possibility in other areas of the Salem Hills, Hole 27 was drilled down slope approximately 250 yards southeast and 37 feet vertically below Hole 23. Chemical analysis of the bottom 2 feet from Hole 27 (Al_2O_3, 31.05 percent; SiO_2, 10.00 percent), which is approximately 57 feet below the top of the hill at Hole 23, shows that the material is still within the bauxite section at that depth and indicates that "draping" may be valid in other places.

Character of the ore

Fresh outcrops of the laterite section in the Salem bauxite area are rare, except in a few road cuts because the material tends to change rapidly to form a soil. Most of the information concerning the deposits has been derived from drill hole samples. One road cut in the NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 28, T. 8 S., R. 3 W., contains a 10-foot exposure of what might be termed "typical" ferruginous bauxite in the Salem Hills. This section is somewhat varicolored, but predominantly yellowish to reddish brown and earthy. It shows a well-defined spheroidal weathering pattern similar to that seen in the underlying weathered basalt exposed in other road cuts (see Plate 5, page 8). The texture of the parent basalt has been preserved in the bauxite at this locality. The section is criss-crossed by numerous veinlets of limonite and lighter colored clayey material (gibbsite and kaolinite?). Angular pieces of gibbsite as much as 3 inches across are scattered through the upper few feet of the bauxite section. Larger, more rounded nodules of gibbsite as much as 8 inches in diameter are also present in the overlying soil.

A 9-foot channel sample was taken in this cut and gave the following results:

	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	L.O.I.
Upper 5 feet	37.46%	30.35%	10.55%	2.78%	19.80%
Lower 4 feet	29.22	35.31	17.33	3.27	16.88

This cut is approximately 600 yards northwest and 40 to 50 feet vertically below the surface at Hole 18 and may represent a portion of the "draped" material that occurs along the flanks of the ridges referred to previously.

Two prospect pits showing lateritic material were excavated along the top of the ridge near the center of sec. 35, T. 8 S., R. 3 W., several years ago by Paul R. Hendricks, owner of the property. These pits, approximately 100 yards apart, are 40 feet long and 10 feet deep at the deepest point (Plate 1, in pocket). The material is very similar in lithology and texture to that exposed in the road cut described above. In the east pit, two channel samples covering 9 feet of depth below 3 feet of soil averaged 40.6*percent Al_2O_3, 25.2 percent Fe_2O_3, and 18.6 percent SiO_2. From the west pit a channel sample representing a section 9 feet thick below 2$\frac{1}{2}$ feet of soil averaged 35.5*percent Al_2O_3, 30.40 percent Fe_2O_3, and 15.4 percent SiO_2. The U.S. Bureau of Mines at Albany, Oregon, recently took a large bulk sample containing approximately 30 tons of the laterite from the east pit for metallurgical testing. The analytical results determined by them for the 30-ton sample are as follows: Al_2O_3 - 33.4 percent; TiO_2 - 2.67 percent; Fe_2O_3 - 26.6 percent; SiO_2 - 17.2 percent; and L.O.I. - 18.03 percent. Their bulk sample was taken from the same 9-foot zone exposed in the bulldozed pit that had been previously sampled and analyzed by the Department. Department Hole 24, near the same pit, showed that low-silica bauxitic laterite occurs at this locality beneath a section, approximately 12 feet thick, of higher silica bauxitic clay. A 5-ton sample was also taken by the U.S. Bureau of Mines from a pit approximately 5 feet deep, about 20 feet west of Hole 11. Analytical results of this bulk sample as reported by the Bureau are as follows: Al_2O_3 - 38.6 percent; TiO_2 - 5.16 percent; Fe_2O_3 - 32.6 percent; SiO_2 - 4.4 percent; and L.O.I. - 20.6 percent.

_____

* Includes approximately 3 percent TiO_2.

The writers have found that samples of ferruginous bauxite taken from weathered out-crops are more clayey and run somewhat higher in silica than material obtained from nearby drill holes at or near corresponding horizons. This is particularly true with respect to the material in the eastern and northeastern parts of the area that lie beneath the clay silt over-burden or soil horizon. The higher silica content in the weathered exposures apparently is due to partial intermixing of the overlying clayey material with the bauxite horizon under-neath. For reasons not clearly understood, the drill-hole samples indicate that the zone of intermixing is much narrower in those areas that have not been exposed to direct surface weathering. This condition is well illustrated in the vicinity of Hole 23. Thermal analysis of a 2-foot channel sample taken from a small road cut 400 yards southeast and approximately 25 feet vertically below the surface at Hole 23 indicated a silica content between 15 and 20 percent. By comparison, the average silica in the 20- to 30-foot interval of Hole 23 is 3.28 percent.

The highest percentage of Al_2O_3 found in the drill-hole samples (61.32 percent) is from the 4- to 6-foot interval in Hole 23. This hole also had the highest Fe_2O_3 and TiO_2 content, 44.70 percent and 10.19 percent, respectively, from the 26- to 28-foot interval. This last analysis apparently reflects a local concentration of ilmenite and titaniferous mag-netite in the bauxite section. The lowest percentage of silica found (1.34 percent) is from the 8- to 10-foot interval in Hole 15.

The U.S. Bureau of Mines at Albany, Oregon, made petrographic examinations of two selected samples from each of three drill holes as shown below. The mineral constit-uents are listed in approximate order of decreasing abundance. Particular attention was concentrated on the identification of any titanium-bearing minerals that might be present because of their possible economic value. Percentage estimates were calculated by em-ploying a combination of grain-count studies, weight determinations of products derived by acid leach, micro heavy-liquid separations, and a series of magnetic separations. Differential thermal analyses confirmed the identity of the halloysite and gibbsite and aided in determining the relative amounts of each. Results of the Bureau's examinations were reported as follows:

Sample No. 3. (6- to 8-foot depth in ferruginous bauxite, Hole No. 22) essentially contains gibbsite, with some associated ilmenite (14 to 17 percent), halloysite, limonite, goethite, and small amounts of leucoxene (2 to 4 percent) and magnetite (including a minor amount of titaniferous magnetite). Also present is a trace of calcite.

Chemical analysis: Al_2O_3 – 29.68 percent, SiO_2 – 10.96 percent, TiO_2 – 9.90 percent, Fe_2O_3 – 35.9 percent.

Sample No. 11. (22- to 24-foot depth in ferruginous bauxite, Hole No. 22) essentially contains gibbsite, with some limonite, goethite, ilmenite (8 to 10 percent), and titaniferous magnetite (6 to 8 percent). Also present are small amounts of hal-loysite, leucoxene (1 to 2 percent), and a trace of calcite.

Chemical analysis: Al_2O_3 – 33.32 percent, SiO_2 – 2.72 percent, TiO_2 – 6.56 percent, Fe_2O_3 – 35.5 percent.

Sample No. 13. (11- to 13-foot depth in ferruginous bauxite, Hole No. 2) essentially contains gibbsite, with some associated limonite, ilmenite (10 to 12 percent), goethite, and small amounts of magnetite (including a minor amount of titaniferous magnetite), and leucoxene (1 to 2 percent). Also present is a trace of sphene.

Chemical analysis: Al_2O_3 - 37.01 percent, SiO_2 - 9.38 percent, TiO_2 - 7.20 percent, Fe_2O_3 - 28.8 percent.

Sample No. 21. (20- to 21-foot depth in bauxitic clay zone beneath ferruginous bauxite, Hole No. 2) essentially contains halloysite, some gibbsite, titaniferous magnetite (8 to 10 percent), and small amounts of limonite, goethite, ilmenite (2 to 5 percent), and leucoxene (1 percent).

Chemical analysis: Al_2O_3 - 36.87 percent, SiO_2 - 23.68 percent, TiO_2 - 3.70 percent, Fe_2O_3 - 17.2 percent.

Sample No. 25. (12- to 14-foot depth in clay zone beneath ferruginous bauxite, Hole No. 14) essentially contains halloysite with some associated ilmenite (7 to 10 percent), limonite, goethite, and small amounts of magnetite (including a minor amount of titaniferous magnetite), and leucoxene (1 to 2 percent). Also present is a minor amount of gibbsite and a trace of feldspar.

Chemical analysis: Al_2O_3 - 23.92 percent, SiO_2 - 22.00 percent, TiO_2 - 6.20 percent, Fe_2O_3 - 32.0 percent.

Sample No. 28. (18- to 20-foot depth in clay zone beneath ferruginous bauxite, Hole No. 14) essentially contains halloysite, some ilmenite (7 to 10 percent), limonite, goethite, and small amounts of magnetite (including some titaniferous magnetite), and leucoxene (1 to 2 percent). Also present is a minor amount of gibbsite and traces of calcite, feldspar, and ferromagnesian minerals.

Chemical analysis: Al_2O_3 - 24.09 percent, SiO_2 - 22.14 percent, TiO_2 - 7.46 percent, Fe_2O_3 - 29.0 percent.

The presence of gibbsite in the bauxite zone and halloysite in the underlying clayey material together with the usual iron oxides conforms with the expected mineralogical composition of lateritic clays. The most interesting fact concerning these samples is the high content of ilmenite, titaniferous magnetite and magnetite, and the almost total absence of any secondary titanium minerals such as anatase or brookite usually found in laterites of this type (Eyles, 1952). The titanium mineralogy of the bauxite in the Salem Hills is discussed in greater detail in the appendix of this report.

With the possible exception of some bauxite found in Holes 22, 23, and 26, all of the bauxitic material in the Salem area is the so-called "earthy" variety (Libbey, Lowry, and Mason, 1945). A pisolitic-oölitic horizon overlying the earthy zone in the Columbia-Washington counties ferruginous bauxite deposits was not encountered with certainty in

any of the holes drilled in the Salem Hills. However, Hole 23, which penetrated the thickest section of bauxitic laterite (32 feet plus) appeared to have a 3- to 4-foot zone (at a depth of 2 to 6 feet) of almost pure gibbsite, which in turn was underlain by a 2- to 4-foot zone (at a depth of 8 to 12 feet) of dark, reddish-brown, earthy laterite that contained numerous dark-red, shotlike pellets. A few pisolitic nodules, all within T. 8 S., R. 3 W., were found in the soil at four scattered localities as follows: NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 35, elevation 725 feet; SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 27, elevation 725 feet; along ridge in SE$\frac{1}{4}$ sec. 16 and SW$\frac{1}{4}$ sec. 15, elevation 600 feet; NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25 on top of Prospect Hill, elevation 1121 feet. These occurrences indicate that a pisolitic horizon in the laterite zone was once present over a fairly large area.

The gibbsite nodules widely dispersed throughout the soil horizon (Plate 6 on opposite page) and in the upper part of the laterite section in the Salem Hills are of two general types based on difference in texture. These are: 1. dense porcelaneous (Plate 7 on opposite page), the more common, and 2. porous granular (Plate 8 on opposite page). The porcelaneous variety is in various shades of white, gray, green, pink, light yellowish-brown, or deep purple and has a characteristic waxy surface texture similar in appearance to desert varnish. They are fairly hard and have a dense to vuggy texture. The porous granular type is medium to dark reddish brown and contains numerous residual grains of magnetite that are visible under the hand lens. Both varieties range in size from about half an inch to more than 30 inches (Plate 9 on opposite page). The lighter colored porcelaneous variety usually has somewhat higher alumina and lower iron than the brownish granular type. The following chemical analyses of the two types, represented by three samples each, illustrate this difference:

Dense Porcelaneous

	Al_2O_3	SiO_2	Fe_2O_3
	59.45%	3.94%	4.29%
	57.91	4.02	6.03
	59.55	3.24	3.72
Average	58.97%	3.79%	4.68%

Porous Granular

	Al_2O_3	SiO_2	Fe_2O_3
	53.35%	1.55%	14.15%
	50.64	2.23	19.40
	50.23	4.82	15.77
Average	51.41%	2.87%	16.44%

Plate 6 – View of gibbsite nodules on surface near Hole 1, Salem Hills.
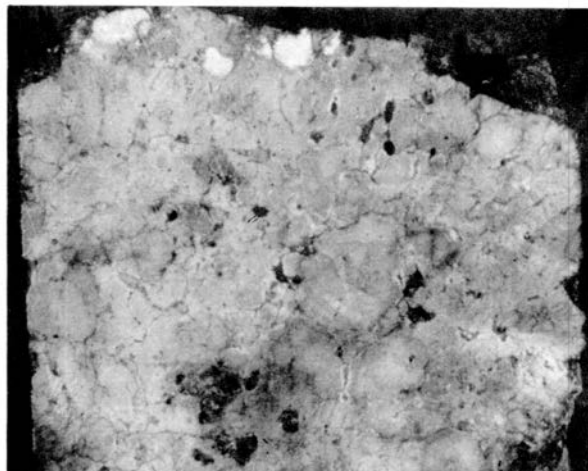
Plate 7 – Section of typical porcelaneous variety of gibbsite nodule from the Salem Hills. Shaded portions are yellowish brown to pinkish. Lighter colored areas are cream to light gray. Actual size.
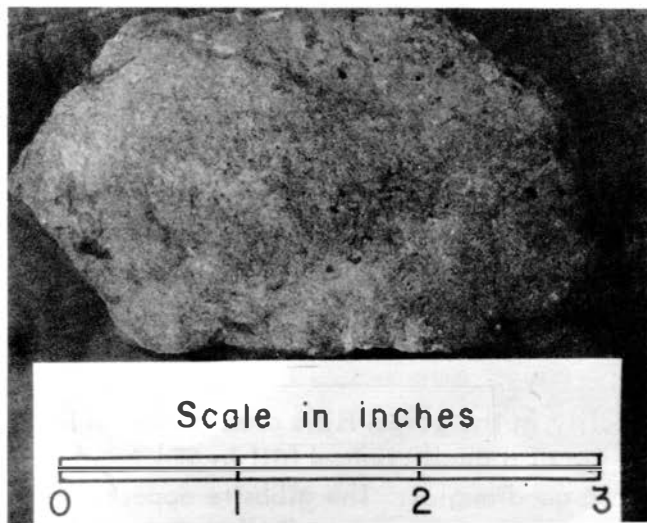
Plate 8 – Section of porous granular variety of gibbsite nodule from the Salem Hills. Color varies from yellowish brown to reddish brown. Minute black specks are grains of magnetite and ilmenite (?).

Plate 9 – Large gibbsite nodules at intersection of Reese Hill Road and Rainbow Drive near Hole 23.

Lowry (1945) studied thin sections of both the dense porcelaneous and porous granular varieties under the microscope and reported:

Dense Porcelaneous

"A thin section of a pink, more dense nodule from locality 88 is made up of a chalcedoniclike aggregate of gibbsite with numerous residual grains of magnetite some of which retain part or all of their crystal outlines. Only in one place does the section show a suggestion of the original texture. Probably much of the iron in the nodule is in the form of residual magnetite grains, most of which are less than 0.2 mm in diameter, the maximum size. Gibbsite forms veinlets cutting through the aggregates and also fills or lines some of the cavities. Very small grains which may be residual apatite are also present." (Plate 10 on opposite page.)

Porous Granular

"A gibbsitic nodule from locality 81 shows white lath-shaped crystals and residual grains of magnetite. Examination of this specimen in thin section under the microscope reveals that much of the original texture of the parent basalt is preserved. . . . The original basalt had an intersertal texture and was made up of skeleton crystals of magnetite and laths of plagioclase in a partially crystallized glassy groundmass. The original laths of plagioclase were $\pm$ 1 mm long and are now filled with aggregates of gibbsite. Many of the skeleton crystals of magnetite are cut through be veinlets of gibbsite. Gibbsite forms other veinlets which cut the original texture and also lines some of the cavities. As pore space makes up less than 25 percent of the section, the preservation of the original texture is not alone the result of alteration in place but is in part due to replacement by introduced gibbsite." (Plates 11 and 12 on opposite page).

A thin zone of almost pure gibbsite approximately 3 to 4 feet thick occurs just beneath the silty clay overburden in the northern portion of the bauxite area. The maximum thickness of this zone was encountered in Hole 23 as previously mentioned, and thinner zones are also present in Holes 22 and 26. Under the hand lens the gibbsitic material in these holes appeared to be of the dense porcelaneous variety.

So far as is known, there is only one other locality in the Salem Hills area where high-grade gibbsite is found in place. This locality is on top of a small conical hill in SE¼ NW¼ sec. 6, T. 9 S., R. 2 W., elevation 500 feet (Stayton quadrangle). The gibbsite appears to be entirely the dense porcelaneous variety, and is probably several feet thick. This small knob lies on the east edge of the Salem Hills and is surrounded on three sides by higher hills, all of which are capped by weathered basalt. The nearest section of bauxite to this conical hill is that in Hole 13 approximately 1 mile to the southeast (elevation 625 feet). Hole 4, approximately 1½ miles due east (elevation 828 feet), contains some bauxitic clay.

Another interesting aspect of this conical knob deposit is the banded character of some of the gibbsite (Plate 13 on opposite page). The rock appears to be concretionary in origin and is typically composed of alternating layers of light brown to pinkish gibbsite 2 to 4 mm

Plate 11 - Photomicrograph of porous granular variety of gibbsite nodule from the Salem Hills. The original texture of parent basalt has been preserved, the plagioclase being replaced by gibbsite. Plain light. Approx. x 55.

Plate 12 - Photomicrograph of Salem Hills lava. Note the textural similarity to the photomicrograph of porous granular gibbsite nodule shown in Plate 11. Plain light. Approx. x 85. Courtesy of M. J. Mundorff.
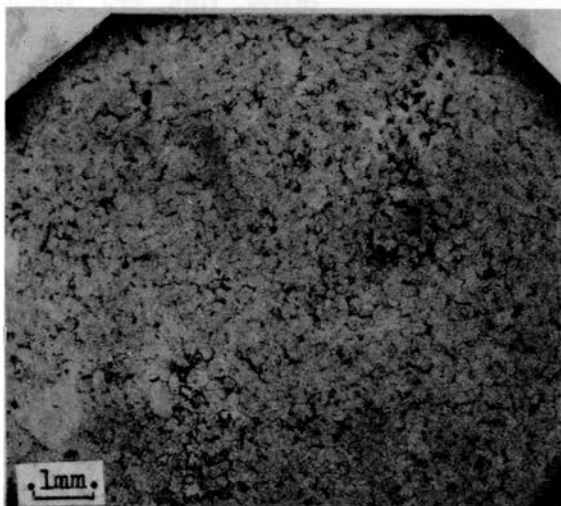
Plate 10 - Photomicrograph, porcelaneous variety of gibbsite nodule from the Salem Hills. None of the original texture has been preserved. Plain light. Approx. x 80. Courtesy of V. T. Allen.
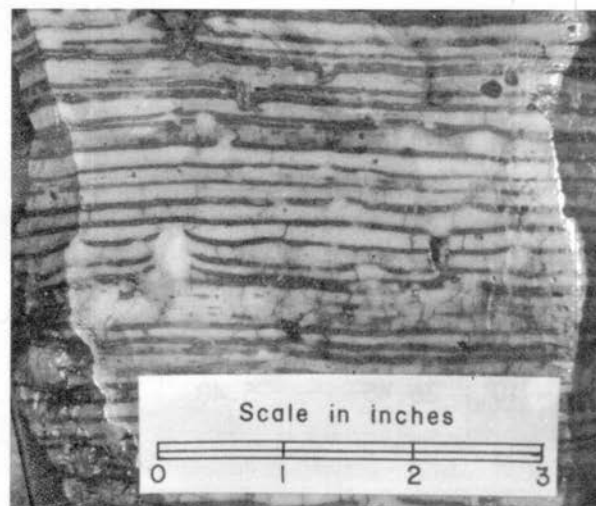
Plate 13 - Section of banded variety of gibbsite nodule from conical hill in SE¼ sec. 6, T. 9 S., R. 2 W.

thick separated by darker brown bands 1 to 2 mm thick. The darker layers may owe their coloration to a somewhat higher iron content. The exact origin of the banding is unknown, but the writers believe that it may possibly be due to cyclic changes in the climate during formation that regularly caused more ferruginous material to be deposited.

On a tonnage basis, the deposit in the conical hill is of minor importance, but its presence may be an indication of other zones of high-grade bauxite that are not exposed at the surface.

Following is a log of Holes 17 and 22 together with analyses of samples to show characteristics of typical laterite sections. Hole 17 shows a section of the bauxite and underlying clay zone. Hole 22 encountered one of the thickest sections of ore in the Salem Hills area.

Table 3.

Hole 17

Sample width	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	L.O.I.	Description
0' - 2'			Not sampled			Soil horizon contains many nodules of gibbsite.
2' - 4'	30.52%	16.96%	26.9%	5.64%	19.98%	Yellow-brown, earthy, gritty, firm, dry, numerous frags. gibbsite, porcelaneous.
4' - 6'	32.64	8.44	33.0	6.93	18.99	Yellow-brown, earthy, gritty, firm, dry.
6' - 8'	33.72	4.42	35.2	7.39	19.27	Yellow-brown to light red, earthy, gritty, firm, dry.
8' - 10'	36.45	5.40	31.8	7.44	18.91	Yellow-brown to light red, earthy, gritty, firm, dry.
10' - 12'	34.64	13.44	32.4	6.80	12.72	Tan to light red, earthy, slightly clayey, gritty, firm, damp.
12' - 14'	29.11	15.02	32.9	6.39	16.58	Tan to light red, white, yellow, red, black spots, earthy, clayey, gritty, firm, damp.

Table 3 (cont.)

Sample width	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	L.O.I.	Description
14' – 16'	33.44%	21.92%	28.3%	5.82%	10.52%	Tan to blue-black, yellow, black, blue spots, clayey, slightly gritty, less firm, damp.
16' – 18'	34.60	27.96	23.8	5.00	8.64	Brown to blue-black, yellow, black, blue spots, clayey, slightly gritty, damp.
18' – 20'	28.16	28.04	25.4	5.33	13.07	Brown to blue-black, yellow, black, blue spots, clayey, slightly gritty, damp.

Hole 22

Sample width	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	L.O.I.	Description
0' – 2'			Not sampled			Soil horizon – gibbsite nodules sparse
2' – 4'	36.24	13.39	16.3	3.38	30.69	Brownish red, hard, earthy, gritty, dry, numerous frags. gibbsite, porcelaneous.
4' – 6'	52.32	8.32	13.0	3.06	23.30	Same as above only harder and more frags. gibbsite, porcelaneous, gritty, dry.
6' – 8'	29.68	10.96	35.9	9.90	13.56	Grayish brown to reddish brown, fewer frags. gibsite, porcelaneous, earthy, gritty, dry.
8' – 10'	45.72	3.42	26.8	7.83	16.23	Tan colored, more gibsite frags., granular, gritty, dry.
10' – 12'	36.80	2.18	31.0	7.40	22.62	Same, but less gritty, damp.
12' – 14'	35.80	5.38	36.3	6.80	15.72	Reddish brown, gritty, earthy, damp, slightly clayey.

Table 3 (cont.)

Sample width	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	L.O.I.	Description
14' - 16'	33.92%	7.00%	37.2%	6.85%	15.03%	Reddish brown, gritty, earthy, damp, slightly clayey.
16' - 18'	28.94	4.70	37.1	7.70	22.80	Same as above.
18' - 20'	35.60	4.96	36.7	5.95	16.79	Same as above.
20' - 22'	35.16	2.98	37.8	7.84	16.22	Same as above.
22' - 24'	33.32	2.72	35.5	6.56	21.90	Same as above.
24' - 25'	32.16	2.40	41.4	7.20	16.84	Tan colored, less gritty, more clayey, quite damp.

The reason for the rather marked variation in silica content from one 2-foot interval to the next in some of the holes is not completely understood (see Figure 3 on opposite page). This problem was also encountered in the Columbia-Washington counties deposits and was discussed in some detail by Libbey, Lowry, and Mason (1945) and Allen (1948). The consensus was that the variations may be caused by one or more of the following: (1) Diffferentiation of some of the basaltic lava flows causing notable variations in the original silica of certain horizons; (2) mechanical rearrangement of detrital fragments; (3) alteration of the glassy groundmass and vesicles provided zones of increased permeability and susceptibility to alteration; and (4) the variable effect of ground-water level and its seasonal fluctuations.

Other occurrences of bauxite in the Salem area

Some field reconnaissance was carried on in the areas adjacent to the Salem Hills in the search for other bauxite deposits. The likeliest area appeared to be in the Eola Hills (Plate 1, in pocket) because they are a northward extension of the Salem Hills. However, topographic highs are capped by fairly large blocks of fresh and weathered basalt and any laterite horizons that may once have existed are now probably stripped. The lower elevations of the Eola Hills, comprising a large part of the northern third of the Salem quadrangle, contains some gibbsite float on the surface and scattered through the soil horizon (Libbey, Lowry, and Mason, 1945). The gibbsite nodules, unlike those found in the adjacent Salem Hills are typically the porous granular variety. Inspection of some freshly dug cellars in the Chapman Hill area (sec. 17, T. 7 S., R. 3 W.) shows that the float in the soil lies directly on pinkish weathered basalt with little or no intervening lateritic horizon. Because of negative evidence in basement excavations and road cuts, as well as at Locality 77 (Libbey, Lowry, and Mason, 1945), no test holes were drilled. However, this does not completely rule out the possibility of bauxite deposits in the area. The low, flat ridges in the southeastern portion of the Eola Hills may be worth further investigation.
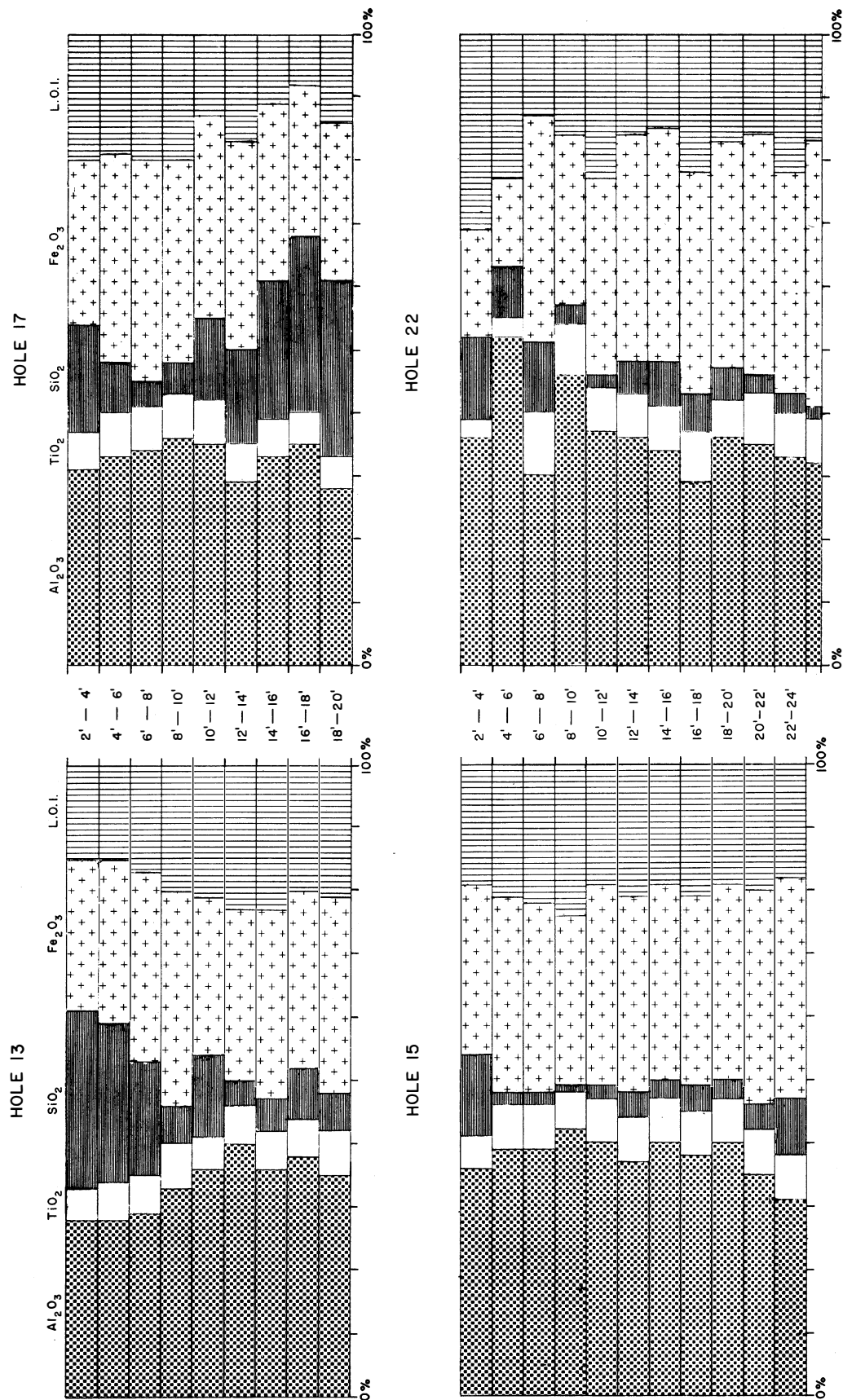
Figure 3 - Graphs of Four Selected Holes Showing Variation in Chemical Composition for Each 2-Foot Interval of Depth.

The west-dipping lavas of the Waldo Hills in the adjacent Stayton quadrangle form the east limb of the "Willamette Syncline" (Thayer, 1939), which has its west limb the lavas of the Salem Hills. Gibbsite nodules have been noted in the soil along the ridge area in secs. 9, 10, and 15, T. 8 S., R. 2 W., but nearby road cuts on State Highway 222 show the underlying rock to be spheroidally weathered basalt. As gibbsite nodules in soil have not been a sure indication of an underlying bauxite horizon in northwestern Oregon, there is as yet no positive evidence of bauxite deposits in the Waldo Hills.

Economics

General

Aluminum ranks today among the primary nonferrous metals produced in the United States. Within the past 20 years the uses of aluminum have multiplied and the tremendous expansion of primary aluminum capacity in this country brought about by World War II and the Korean War, illustrates the great strategic need for this light metal. The increased demand of the aircraft industry and the rising use of aluminum for such nonmilitary purposes as fabrication of railroad cars, automobiles, and in the construction industry assure this metal an unlimited market future.

Although aluminum is the third most abundant element in the earth's crust, following oxygen and silicon, it is commonly combined with them in nature to form a firmly knit silicate. Compared with bauxite, which is essentially a compound made up of aluminum oxides and water, the silicates are much more expensive to treat for production of aluminum oxide. Therefore at present bauxite is the only ore used for large-scale aluminum production.

Of the total bauxite mined in the United States, 85 to 90 percent is used for the production of alumina (aluminum oxide) of which more than 90 percent is eventually reduced to metallic aluminum. The remainder of the bauxite is used for artificial abrasives, chemicals, refractories, cements, and in the steel and petroleum industries. According to Kurtz and Blue (1955), most of the nonmetallurgical uses of bauxite are expanding; however, the scarcity of high-quality domestic ore threatens to retard the future growth of these applications.

United States production of bauxite began in Georgia in 1882. Soon after this the relatively large deposits in Arkansas began to be mined, and since 1914 more than 85 percent of the domestic production of bauxite has come from Arkansas. In the early twenties, the United States was a net exporter of bauxite, but beginning in the latter part of that decade, aluminum ore from the large deposits in Surinam (Dutch Guiana) began to be imported into this country in ever-increasing amounts. Since 1947 the United States has consistently imported more bauxite than it has produced domestically and the discrepancy between domestic production and foreign imports is increasing (see Figure 4 on opposite page). Table 4 (on opposite page) indicates the degree to which the United States has relied on foreign sources of bauxite since 1940 (Kurtz and Blue, 1955). According to the U.S. Bureau of Mines, if the foreign imports were cut off owing to a wartime emergency, much, if not at all, of the higher grade domestic aluminum ore would be exhausted within 5 years and lower grade deposits in this country would have to be utilized to meet the demand. The danger of relying on foreign sources of bauxite (as well as other strategic ores) was brought home to the United States early in World War II when German submarines sank a large proportion of boats loaded with Surinam bauxite.

Table 4.

United States Self-Sufficiency in Bauxite for Selected Years

(Thousand Long Tons)

Years	Domestic production (long tons, dry basis)	Imports (crude and dried, long tons as imported)			Percent self-sufficiency $\left(\dfrac{\text{Domestic production}}{\text{Imports + domestic production}} \times 100\right)$
		Jamaica	South America	Total	
1940	439	---	616	630	41
1943	6,233	---	1,548	1,548	80
1946	1,104	---	851	852	56
1949	1,149	---	2,113	2,688	30
1952	1,667	265	3,214	3,498	32
1953	1,580	1,176	3,202	4,389	26
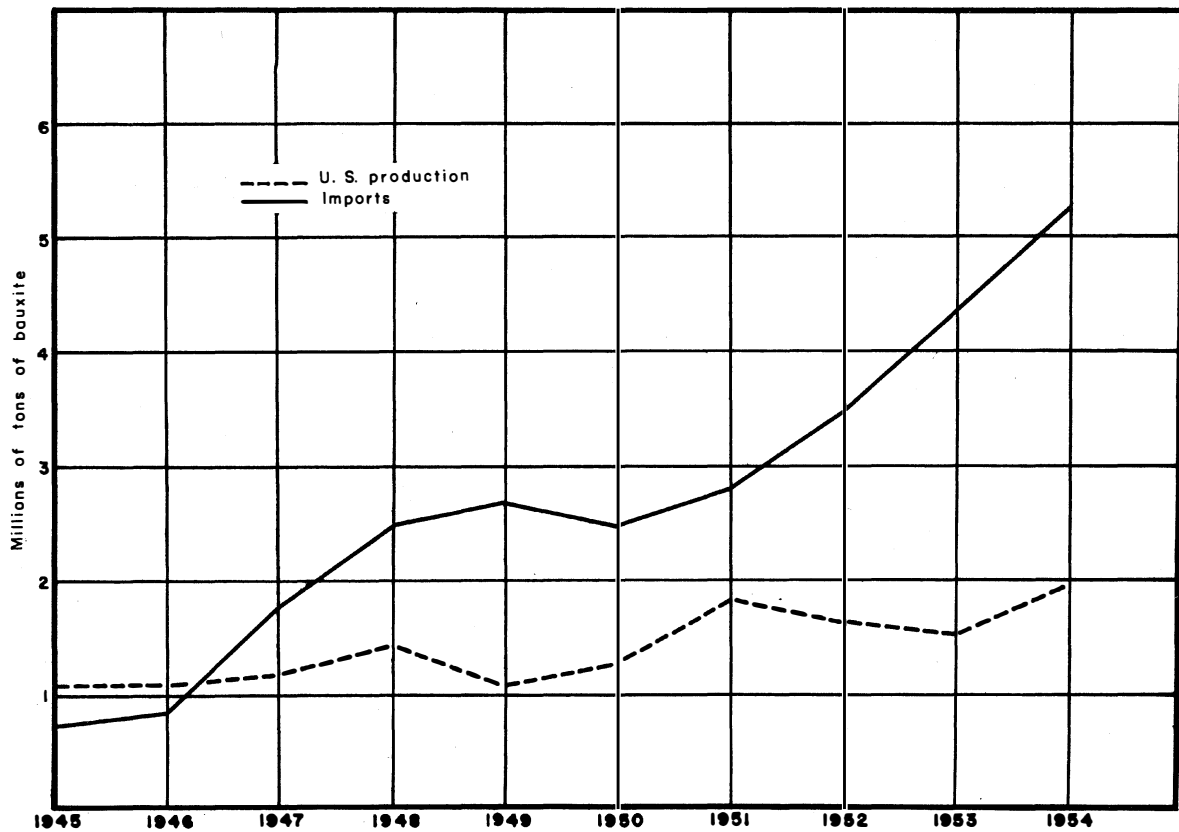
Figure 4 - Graph Showing U. S. Production and Imports.

Foreign production may present serious problems to United States' producers in some countries. There is little doubt that foreign lands will be increasingly reluctant to have their mineral raw materials exported because of a growing world-wide appreciation of their essential and nonrenewable nature. Encouragement is usually given to establish a plant and go into production, but, once established, the operation is then subject to political forces, and these usually mean higher taxes, higher wages, and generally higher operating costs. Also in a war emergency such foreign production is especially vulnerable to sabotage and labor unrest.

Aluminum production

Aluminum metal is produced in two steps requiring two distinct operations. First, bauxite ore which in nature is an impure hydrated oxide of aluminum is treated by the Bayer process to produce pure aluminum oxide or alumina as it is called. The second step is the reduction of the aluminum oxide to aluminum metal. Alumina is fed to a cryolite (Na_3AlF_6) bath in "pots" where it is reduced to aluminum metal by electrolysis using carbon electrodes. The aluminum metal is first tapped into molds to form "pigs" and these may be refined to form "ingots." As a consequence aluminum reduction plants are located near cheap and reliable sources of electric power, and availability of hydroelectric power was the prime consideration in selecting the Columbia River area for Northwest aluminum plants.

All Bayer plants are in the Middle West or South. Thus alumina used in Northwest reduction plants must be shipped across the country. As alumina contains approximately 50 percent aluminum, twice as much alumina by weight must be transported as can be reduced to metal.

The importance of the aluminum industry to the economy of the Northwest and to national defense cannot be overestimated. Beginning with the single plant built by Alcoa in 1940, the industry now (January 1956) has seven plants turning out primary metal with a total plant capacity of about 621,000 tons. In addition, two of the plants have extensive fabricating facilities. The Northwest plant capacity has outstripped hydroelectric developments on the Columbia River system so that in planning for increased domestic production of metal in recent years, other cheap power areas, notably Texas, have gained new plants at the expense of the Northwest.

Total production of primary aluminum in the United States during 1955 amounted to 1,565,000 short tons according to the U.S. Bureau of Mines. This a 7-percent increase over 1954. Net imports(Lipkowitz, 1956) were 197,000 short tons making total aluminum supply of 1,763,000 short tons. Apparent domestic consumption was approximately 1,700,000 short tons. Domestic production of bauxite was 1,818,000 long tons (2,036,160 short tons) 96 percent of which came from Arkansas. Imports for the year were 5,228,000 long tons (5,855,000 short tons) of which 2,528,000 long tons came from Jamaica and 2,463,000 long tons came from Surinam.

Table 5 on opposite page lists the Northwest aluminum plants and gives some of their characteristics.

Table 5.

Characteristics of Northwest Aluminum Plants

Name of Company	Location	Year Reduction Plant Built	Primary Metal Annual Capacity Tons	Remarks
Alcoa	Vancouver, Washington	1940	97,500	Extrusions – rod, bar, wire.
Alcoa	Wenatchee – Rock Island	1952	108,500	
Reynolds Metals Co.	Longview, Washington	1941	54,000	
Reynolds Metals Co.	Troutdale, Oregon	1942	86,500	Designed and built by Alcoa for government as a war measure and subsequently sold to Reynolds.
Kaiser Aluminum & Chemical Corp.	Spokane (Mead and Trentwood)	1942	176,000	Rolling mill for sheet, plate, strip and screen products designed and built by Alcoa for the government in World War II and subsequently purchased by Kaiser.
Kaiser Aluminum & Chemical Corp.	Tacoma, Washington	1942	38,500	Built by government in World War II, operated by Olin Industries and after the war sold to Kaiser.
Anaconda Aluminum Co.	Columbia Falls, Montana	1955	60,000	Power from Hungry Horse Dam.

Total plant capacity, 621,000 tons annually.

Oregon-Washington bauxite

The aluminum industry in the Northwest is growing into an integrated system. More than 265,000 tons of the primary aluminum turned out is fabricated locally. The missing link at the bottom of the system is lack of alumina manufacturing facilities. Alcoa has explored substantial reserves of ferruginous bauxite in Columbia and Washington counties of northwestern Oregon and in Cowlitz County of southwestern Washington. Similar material, as described in this bulletin, has been investigated in Marion County, Oregon, by other groups.

Even though this high-iron bauxite is lower grade in alumina than that treated in Bayer plants elsewhere, the proximity of the deposits to established reduction plants, which would mean a large saving in transportation costs on alumina, places the lower grade material in a more favorable light. Also the iron and possibly titanium in the ore are potential by-products.

Extensive metallurgical testing has been done on Oregon bauxite by Alcoa, and reportedly the ore is amenable to treatment by the Bayer process or a modified Bayer process. At one time it was stated in the press that the company would use the Pedersen process to treat Oregon ore. In this process, which has been used in Norway, the ore is smelted with carbon and limestone to produce pig iron or a ferroalloy and calcium-aluminate slag which could be further treated to produce alumina. It was later stated that the Bayer process rather than the Pedersen was preferred.

Libbey, Lowry, and Mason (1945, p. 86) made an estimate to compare cost of producing alumina at established Bayer plants with a hypothetical plant using Oregon ore. The estimate using certain assumptions showed the cost of producing alumina at a lower Columbia River plant would compare favorably with the cost at plants which then were shipping alumina to the Northwest. Although under 1955 conditions some figures would need to be changed, it appears that because of increased freight rates and a higher probable price for by-product iron or ferrotitanium, a similar comparison now would be more favorable to Oregon ore and a Bayer plant in the Northwest. During the 10 years since the report was written, the production of primary metal in the Northwest has about doubled and the amount of alumina now required is more than a million tons annually.

Salem bauxite possibilities

Table 6 (on opposite page) gives the results of drill-hole sampling in the Salem Hills and shows that characteristics of the Salem Hills bauxite are analogous to those in Washington and Columbia counties in quality and thickness of ore. Overburden in the Salem Hills, however, is considerably less. The oölitic section common in Washington and Columbia counties appears to be lacking in the Salem Hills and, has been mentioned, gibbsitic nodules are common in the Salem Hills whereas they are sparsely distributed in the laterite areas farther north.

An indication of tonnage possibilities may be obtained by using the total of potential ore areas (about 1200 acres) as shown on the locality map (Plate 1, in pocket), and obtaining volume by combining this acreage with the average thickness (see Table 6). The volume-

Table 6 – Average Analyses of Drill Hole Samples in Ore Section of Salem Hills Area

Hole	Depth Feet	Over-burden Feet	Ore Interval* Feet	Ore Thickness Feet	Al_2O_3 Percent	SiO_2* Percent	Fe_2O_3 Percent	TiO_2 Percent	Loss on Ignition Percent	Remarks
1	20	2	2 – 20	18	35.51	8.75	30.9	6.20	18.64	At bottom SiO_2 = 7.66%
2	40	2	2 – 14.5	12.5	38.83	6.92	29.1	3.17	19.50	At 21' SiO_2 = 23.68%; at 14.5' SiO_2 = 4.9%
3	10	---	none	---	---	---	---	---	---	Average SiO_2 = 21.31%
4	20	---	none	---	---	---	---	---	---	Average SiO_2 = 17.14%
5	11.7	2	2 – 10	8	35.74	9.37	29.2	6.21	19.48	At bottom SiO_2 = 20.08%; at 10' SiO_2 = 14.22%
6	14	---	none	---	---	---	---	---	---	Average SiO_2 = 25.41%
7	20	2	2 – 18	16	34.09	8.13	31.2	6.76	19.82	At bottom SiO_2 = 17.04%; at 18' SiO_2 = 5.8%
8	10	2	2 – 8	6	31.01	10.63	32.7	6.91	18.75	At bottom SiO_2 = 20.8%; at 8' SiO_2 = 10.5%
9	3	---	none	---	---	---	---	---	---	In weathered basalt below overburden
10	12	---	none	---	---	---	---	---	---	Average SiO_2 = 23.94%
11	21	2	2 – 21	19	36.47	5.28	32.3	6.13	19.82	At bottom SiO_2 = 7.48%
12	20	---	none	---	---	---	---	---	---	Average SiO_2 = 26.02%
13	20	8	8 – 20	12	35.87	6.23	29.3	6.99	21.61	At bottom SiO_2 = 5.96%
14	20	2	2 – 8	6	32.31	6.48	36.9	6.00	18.31	At bottom SiO_2 = 22.28%; at 8' SiO_2 = 10.50%
15	85	2	2 – 24	22	37.85	4.28	30.9	6.94	20.02	At 24' SiO_2 = 9.02% At 85' Al_2O_3 = 28.9%; SiO_2 = 25.8%; Fe_2O_3 = 25.1%; TiO_2 = 3.3%
16	24	2	2 – 22	20	37.37	4.14	32.4	7.14	18.95	At bottom SiO_2 = 13.74%; at 22' SiO_2 = 10.40%
17	20	2	2 – 12	10	33.59	7.92	33.1	7.00	17.62	At bottom SiO_2 = 28.04%; at 12' SiO_2 = 13.44%
18	20	4	4 – 18	14	32.84	5.85	32.7	6.58	22.03	At bottom SiO_2 = 20.32%; at 18' SiO_2 = 11.28%
19	20	8	8 – 14	.6	33.85	7.51	32.0	6.00	20.64	At bottom SiO_2 = 21.06%; at 14' SiO_2 = 7.68%
20	20.5	8	8 – 21	13	31.20	7.46	33.2	6.80	21.34	At bottom SiO_2 = 8.68%
21	20	4	4 – 18	14	38.02	11.60	22.3	5.34	22.74	At bottom SiO_2 = 12.24%; at 18' SiO_2 = 9.16%
22	25	4	4 – 25	21	36.84	5.12	32.8	6.84	18.40	At bottom SiO_2 = 2.40%
23	32	4	4 – 32	28	35.90	6.03	33.8	7.20	16.80	At bottom SiO_2 = 5.86%
24	25	12.5	12.5-25	12.5	29.62	11.04	32.2	6.63	20.08	At bottom SiO_2 = 12.82%; 12.5' – 17.5' SiO_2 = 8.58%
25	35	12.5	12.5-25	12.5	32.10	8.14	30.0	6.65	22.94	At bottom SiO_2 = 16.9%; 25' SiO_2 = 7.92%
26	20	6	6 – 20	14.0	34.96	4.14	30.8	6.85	25.60	At bottom SiO_2 = 2.44%. Water encountered at 9'; increased to bottom; prevented further drilling.
27	20	2	2 – 20	18.0	31.25	5.46	33.3	6.69	23.28	At bottom SiO_2 = 10.0%
Weighted Average		4.4		14.4	35.0	6.7	31.5	6.5	20.2	

*Since there is no sharp demarcation between the bauxite and the underlying clay zone, the writers have arbitrarily determined the ore thickness by using a cutoff point of 10 percent silica except in Holes 8 (cutoff of 10.63 percent), 21 (cutoff of 11.60 percent), and 24 (cutoff of 11.04 percent).

weight factor was determined for ore in place in Washington County to be 17 cubic feet per
long ton (Libbey, Lowry, and Mason, 1945, p. 31) and this factor could be used as a fair
approximation for Salem Hills ore. Exact figures would not be dependable by this method
in the absence of a much larger amount of exploration work.

The Department did not have the facilities to determine the quantity of high-grade
gibbsite nodules present in the soil horizon and thus obtain an idea of their quantitative
importance. It seems likely, however, that these nodules could be recovered by hand
sorting and coarse screening, possibly combined with washing, and would then constitute
a source of "sweetening material" for upgrading the bauxite below. Testing work to de-
termine the quantity of gibbsite present in the soil and the best method for its recovery
would be necessary before the importance of the nodules could be evaluated.

The bauxitic laterite section could be mined cheaply with earth-moving equipment.
Probably no explosives would be required. As mentioned above, the small proportion of
overburden would probably need some special attention in order to recover gibbsite. It
seems likely that these nodules would more than pay for handling the overburden.

Proximity of the bauxite area to Salem and the desirability of some of the acreage
for suburban living influence the value of the surface for real estate. Part of the area
underlain by bauxite is occupied by farms. Some of these farms appear to have a shallow,
rocky soil and probably would be more profitable for bauxite mining than for crops if ore
is present in economic amounts. Plans for any mining project in the Salem Hills area
should probably include reclamation of the surface after mining. The type of reclamation
would necessarily vary with the amount and quality of soil removed as well as depth and
areal extent of mined-out pits. Partial reforestation might be desirable.

Transportation

The Salem Hills deposits are close to highway, rail, and water transportation. Main
highway arteries run south from Salem and secondary highways crisscross the deposit areas.
The main line of the Southern Pacific Railway as well as its branch lines lies just east of
the deposits, and the Oregon Electric Railway owned by the Spokane, Portland, and
Seattle Railway System runs along the east bank of the Willamette River just west of the
Salem Hills. Water transportation is available on the Willamette River for shallow draft
boats and barges. The distance by water from Salem to the locks at Oregon City is 56.3
statute miles. Distance from the locks to Ross Island Bridge, Portland, is 12.5 statute miles
(see Index Map opposite page 3). Depth of channel between Salem and Oregon City is
6 feet and depth of the channel from the locks to Ross Island Bridge is 8 feet. Dimensions
of the locks at Oregon City are 37 feet wide maximum and 175 feet available in length.
The depth of water at the upper lock is 6 feet at low water.

Probably barge transportation between Salem and Portland on a large quantity of
product in regular shipments would be relatively cheap. Special shallow draft vessels
would be required. At the present time petroleum products (in tank barges), logs (in rafts),
and wood pulp are the principal river-borne products.

Appendix

Exploration techniques

The equipment used for obtaining the samples as tested by the Department in earlier projects (Mason, 1944) combines portability with ease of handling and is especially convenient when working in areas not accessible by car or truck.

The first part of the drilling activity consisted of putting down holes in those areas of the Salem Hills where a ferruginous bauxite horizon was known to exist in order to determine its approximate thickness. Hole 1, for example, was located next to the Rosedale Friends Church because a ditch there exposed at least 4 feet of bauxitic laterite in place. Logs of the first holes indicated a fairly thin overburden and an underlying bauxitic zone usually less than 20 feet thick. Most of the rest of the holes were therefore drilled to depths of 20 feet or less except where thermal analyses or chemical assays showed the base of the bauxite section had not been penetrated. Holes were deepened where a bauxite thickness greater than 20 feet was indicated but usually no attempt was made to penetrate farther than 25 to 30 feet because of the difficulty of hand augering at such depths.

All of the holes, with the exception of those later put down by power auger, were drilled with a 3-inch "Iwan" soil auger (see Figure 5, page 38). The 3-inch drill was threaded to standard 3/4-inch galvanized iron pipe. When the bauxite became too hard to penetrate with the soil auger, usually in the upper few feet of the laterite zone, the material was loosened by replacing the drill with a 2-inch coal-auger bit. The coal auger is a regular hand-twist drill with a 3/4-inch pipe coupling welded to the shank. Occasionally, when the laterite became too hard even for the coal auger, a light forged chisel bit was used as a churn drill and was generally able to break up fairly solid material. Regardless of how the material was broken up, the soil auger was always the sampling tool.

The drill crew consisted of a driller and sampler. As the hole was deepened additional lengths of pipe were added to the drill stem. In order to reduce the number of couplings in the drill pipe, 6-foot lengths were substituted for the 3-foot pieces as the drilling progressed. For depths of much greater than 25 or 30 feet a tripod approximately 25 feet high with a rope block bolted to the peak was usually mounted over the hole to help pull out the drill pipe and to keep it from bending over.

As each auger pod became filled it was brought to the surface and the material deposited on a large canvas mat. Care was exercised when the pod was lifted out of the hole in order to keep side-wall scraping at a minimum. In general, the pod was filled and cleaned five or six times in making 1 foot of hole except in hard material. When the required 2-foot interval of rock had been drilled out and deposited on the mat, it was quartered twice to reduce the quantity, and the material that remained (approximately 5 pounds) was packed in canvas bags for chemical analysis. A small sample of the bottom 2 feet was retained for thermal analysis in order to determine, as soon as possible, if the hole had gone through the gibbsite zone.
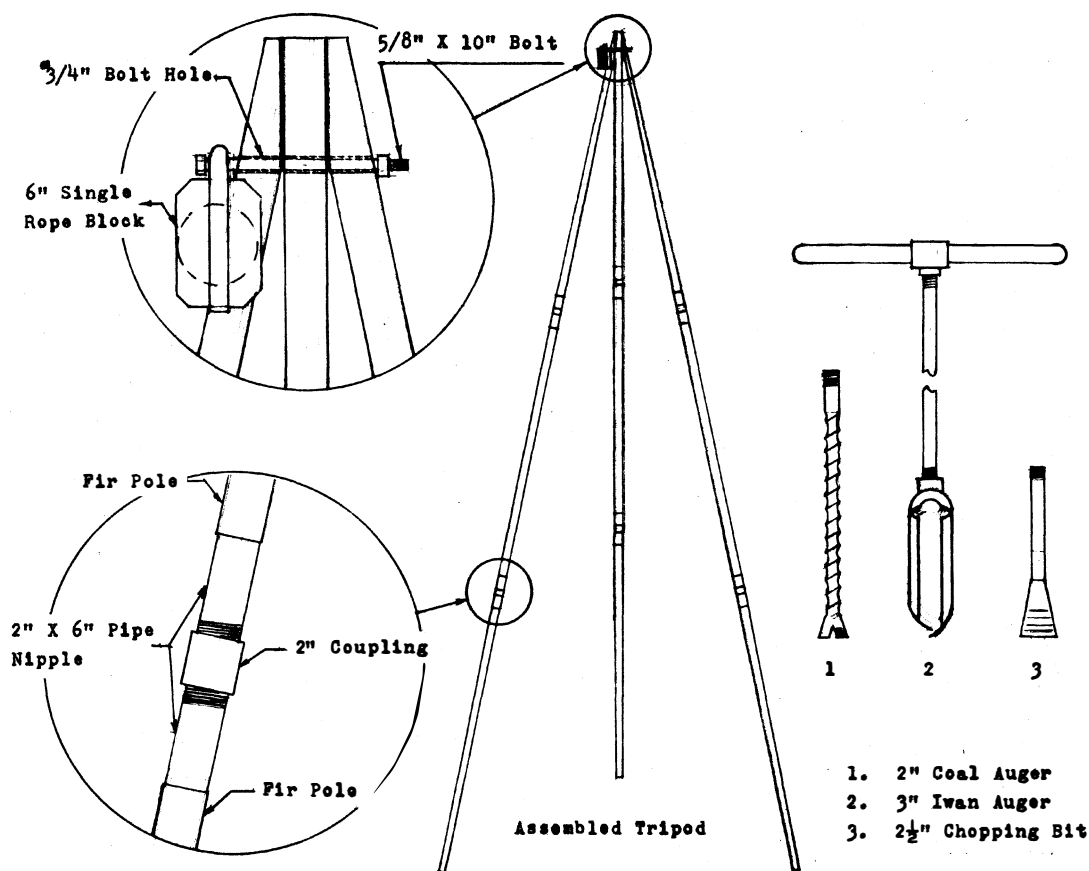
Figure 5 - Diagram of Auger Drill.

As drilling progressed and more chemical analyses were obtained, there was evidence that in a few of the holes a low-silica bauxite horizon lay beneath a section of higher silica bauxitic clay. A truck mounted with a 6-inch power auger capable of drilling to depths of 75 to 100 feet was loaned by the Oregon State Highway Department to determine by drilling the possible presence of any lower bauxitic horizons. Holes 24 and 25 were therefore drilled to depths of 45 feet and 35 feet, respectively. Hole 24 encountered low-silica bauxitic material at 12.5 to 17.5 feet with high-silica bauxitic clay both above and below it. Hole 25 showed a low-silica bauxite zone from 12.5 feet to a depth of at least 25.0 feet. A sample of the material at the bottom of the hole (35.0 feet) taken from the bit showed that it had penetrated moderately high-silica bauxitic clay (see "Remarks" in drill-hole tabulation, Table 6, opposite page 34).

Hole 15 was deepened to 85 feet with the power auger in an attempt to obtain a complete section of the bauxitic laterite and the intermediate clay zone above the parent basalt. Varicolored kaolinitic clay of the intermediate zone was penetrated by the drill approximately 30 feet below the surface. At a depth of 85 feet the material taken from the drill bit was essentially the same type of clay (Table 6) and further drilling was believed to be of no practical value. (Compare with clay in Hole 17, 18 to 20-foot interval; see Table 3 , page 27.)

During the drilling of these three holes (Nos. 15, 24, and 25) vibration of the steel against the wall probably caused some of the side material to work downward and become mixed with that taken from the bottom of the hole. Accuracy of the samples below 25 to 30 feet was therefore questionable because of possible contamination. No samples below a depth of 25 feet (except those taken off the drill bit at the bottom) were submitted for chemical analysis for this reason.

Differential thermal analysis

A differential thermal analysis unit was built by the Department several years ago while making a study of Oregon clays. The unit was particularly useful during the drilling phase of the Salem Hills bauxite project, because of the relative ease in determining by this method whether or not a sample was bauxitic.

The apparatus has a nickel mounting block which contains three holes, 1/4 inch by 3/8 inch (see Figure 6 on page 40). Chromel-alumel thermocouples are cemented part way up into each hole. Holes A and B are packed with calcined alumina which is thermally inert up to 1000° C., and Hole C is packed with the test sample. Furnace temperatures are recorded on a Brown portable potentiometer connected to the thermocouple in Hole A. The temperature difference between the thermocouple in the test sample and the inert substance is measured by a Leeds and Northrup mirror galvanometer. Electric furnace heat is controlled by a 700-watt variable voltage transformer. The furnace-control variac is periodically advanced at a rate which produces a straight line increase in temperature of approximately 18° to 20° C. per minute.

Differential thermal analysis involves the measurement of heat absorbed or given off by a substance upon heating. The material is heated at a standard rate, usually to a maximum of 1000° C., and its temperature compared to that of an inert material by use of a differential thermocouple. It is therefore possible to determine the temperature at which thermal reactions take place in a material, and also the intensity and general character of such reactions. Each of the clay and bauxite minerals shows a characteristic endothermic reaction (absorption of heat) due to dehydration and to loss of crystal structure, and some may show exothermic reactions (evolution of heat) due to the formation of new phases at elevated temperatures. Information obtained by differential thermal analysis usually is presented by plotting the sample temperature against the difference in temperature between the sample and the inert material (see Figure 6, page 40).

Gibbsite, aluminum trihydrate $Al(OH)_3$, was the only bauxite mineral identified on the basis of differential thermal analysis. This was later confirmed by X-ray and petrographic study. Gibbsite shows a characteristically strong endothermic peak at 310° to 330° C., the temperature at which it dehydrates (Figure 6, page 40). The clay minerals associated with the hydrous aluminum oxides in bauxites generally are members of the kaolin group. Kaolinite shows a moderate endothermic reaction at 530° to 560° C. caused by loss of water and a sharp exothermic peak at about 980° C., probably due to the formation of either or both of the compounds gamma Al_2O_3 and mullite $3Al_2O_3 \cdot 2SiO_2$ (Grim, 1953) (Figure 6). Halloysite, also present in the bauxite, differs in composition from kaolinite in that it may contain excess (absorbed) water. Halloysite therefore shows an endothermic effect between 100° and 200° C. The differential thermal curves for halloysite above 200° C. are essentially like those for kaolinite. The bauxite samples were
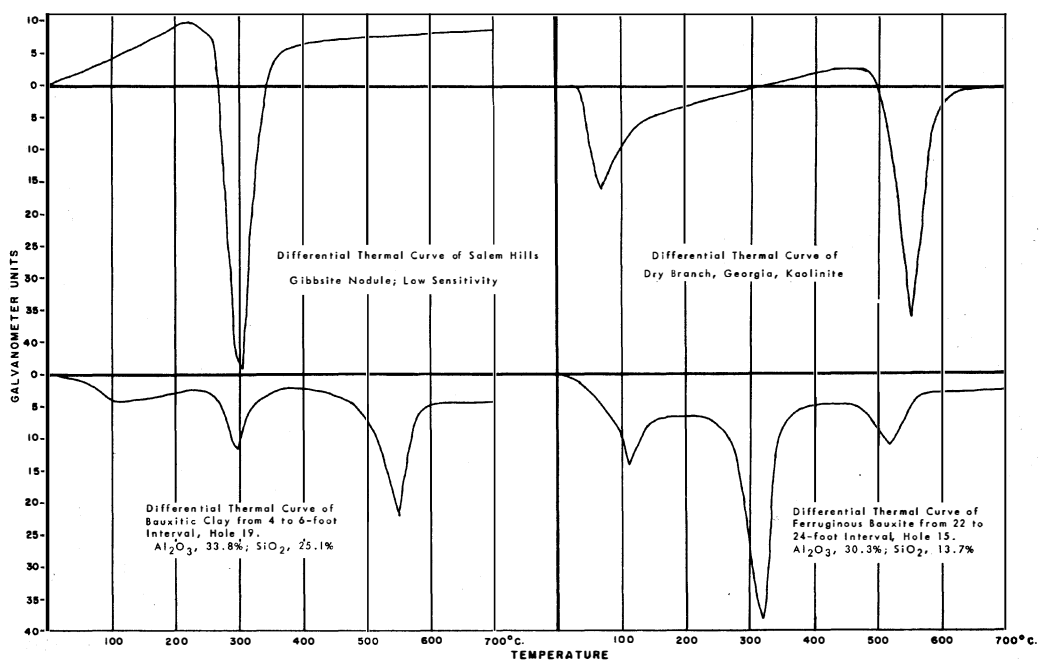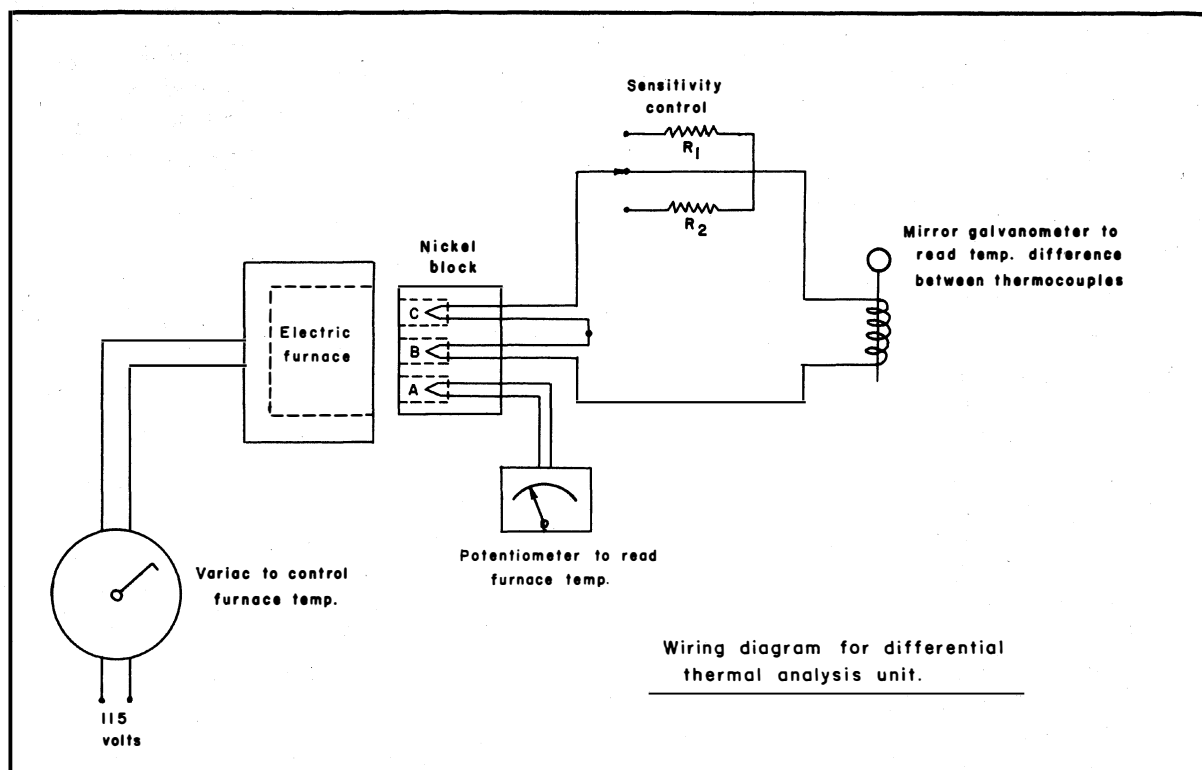
Figure 6 - Diagram of Differential Thermal Analysis Unit Used by the Department and Representative Thermal Curves of Kaolinite and Bauxite

tested after air drying only, so that the loss of moisture at 100° C. probably masked the low-temperature reaction of the halloysite (Figure 6, on opposite page).

Limonite (goethite) is also known to be present in the laterite section, but the characteristic reaction curves for limonite were not recorded by the Department's unit. Two samples of limonite from the bog iron deposits in Columbia and Washington counties, Oregon, were tested and showed only moderate endothermic peaks at 280° to 290° C. These curves are very close to the dehydration peak for gibbsite, and the greater amount and intensity of reaction of the gibbsite in the bauxite samples probably masked the limonite reaction. X-ray and petrographic analyses indicate that perhaps as much as 10 to 15 percent of the Fe_2O_3 in the samples may be attributable to residual ilmenite, titaniferous magnetite, and magnetite, all of which are thermally inert. This would mean that the limonite-goethite content in the Salem Hills bauxite probably does not exceed 20 to 25 percent and is too low to be recorded thermally except by more sensitive instruments.

Several workers (Norton, 1940; Berkelhamer, 1944; and Hendricks, et al, 1946) have investigated various methods for making semiquantitative mineral determinations by differential thermal analysis. Results of their studies showed that there is a direct relationship between the amount and the amplitude of the peak for each of the constituent minerals. It was further noted that although increasing the heating rate resulted in a consequent increase in the amount of deflection of the curve, the total area involved would vary by no more than 3 to 5 percent. Other factors that might affect the curve such as the method of packing the sample in the holder or the sorting and particle size of the material were found to be important only if extreme accuracy was involved. The usual procedure in making the analyses is therefore based on measurement of the areas within the reaction curves representing the different minerals present in the sample.

Semiquantitative work on Salem Hills bauxite using differential thermal analysis methods was done by the Department to guide exploration. This was a great advantage in day-to-day planning because of the large amount of time required to get results of chemical analyses. An outline of the technique used is given below.

The Department's thermal analysis unit was calibrated by running a series of gibbsite-kaolinite mixtures of the following percentages (see Figure 7, opposite page 43):

Kaolinite	Gibbsite
15%	85%
25	75
35	65
45	55
65	35
85	15

The gibbsite used was from a Salem Hills nodule and had the following composition: Al_2O_3, 60 percent; SiO_2, 3 percent; and Fe_2O_3, 8 percent. The kaolinite was from a clay deposit near Dry Branch, Georgia, (provided by the Illinois State Geological Survey), and had the following composition: Al_2O_3, 39 percent; SiO_2, 45 percent; and Fe_2O_3, 0.5 percent. Both the kaolinite and the gibbsite were ground to pass a 100-mesh screen. The areas under the gibbsite and kaolinite endothermic peaks in each standard mixture were calculated and
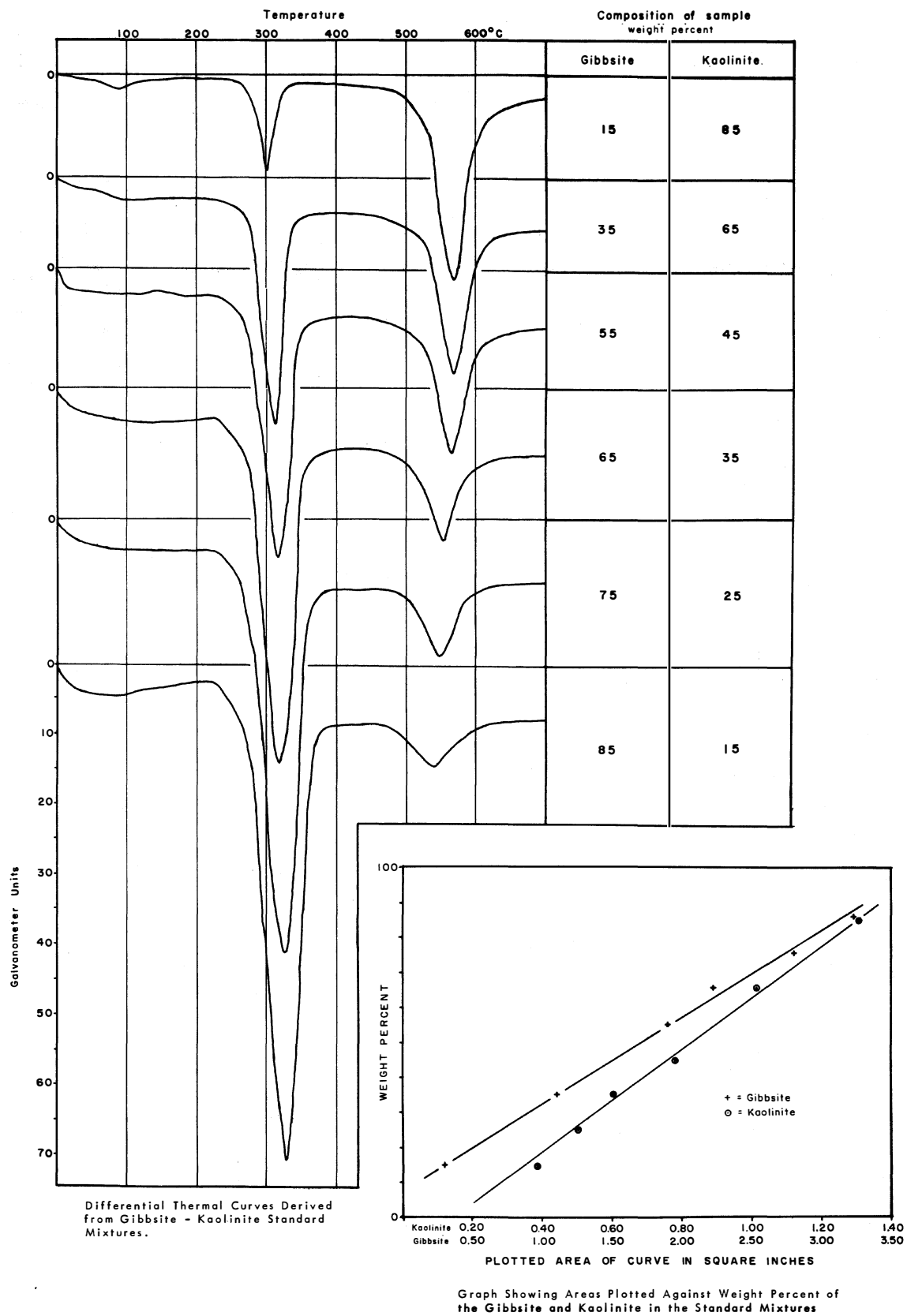
Figure 7 – Differential Thermal Analysis Graphs of
Gibbsite – Kaolinite Standard Mixtures

plotted (see Figure 7 on opposite page). Simplest and most satisfactory method for determining the area of the peak was by counting the squares of the graph paper used in plotting the curves. Samples of the Salem Hills bauxite were next run and their gibbsite-kaolinite content calculated. The amounts of alumina and silica were then calculated from the mineralogical composition by using the determined chemical analyses of the gibbsite-kaolinite mixtures. For purposes of comparison the following tables show the results obtained from a few samples that were tested by this method. Table 7 gives the mineralogical composition of these samples based on their differential thermal curves. Table 8 compares the composition of samples as calculated from differential thermal analysis curves with that determined from chemical analysis.

Table 7.

Sample No.	Weight, percent	
	Gibbsite	Kaolinite
15346 (Salem Hills)	37%	29%
15352 (Salem Hills)	42	20
17226 (Salem Hills)	55	9
15354 (Salem Hills)	33	25
14846 (Mehama)	19	63
14849 (Mehama)	62	19

Table 8.

Sample No.		Weight, percent	
		Al_2O_3	SiO_2
15346	Calculated	33.5%	14.2%
	Determined	33.4	15.3
15352	Calculated	33.0	10.2
	Determined	37.0	9.4
17226	Calculated	36.5	5.8
	Determined	33.3	7.5
15354	Calculated	29.6	12.3
	Determined	33.2	13.5
14846	Calculated	36.0	29.0
	Determined	38.4	30.2
14849	Calculated	44.6	10.4
	Determined	44.0	12.8
Average deviation		2.3	1.4

In general, the silica and alumina content in most of the bauxite samples can be calculated with an accuracy of about 10 to 15 percent of the amount present. The greatest error was found to be in the alumina content and was probably due largely to the inhibiting effect of limonite in the material which was not taken into account in the calculations. It was also found that the thermocouples tended to break down or deteriorate within a relatively short period (10 to 15 hours of actual running time) and would produce erratic results. These variable factors were generally not great enough to affect markedly the differential curves, and the calculated results were usually well within the allowable margin of error for this type of work provided the thermocouples were replaced periodically.

Report on the Mineralogy of the Titanium in Bauxite
From the Salem Hills, Oregon
By
Edwin Roedder
Associate Professor, University of Utah

Statement of the problem

High iron bauxite, averaging approximately 6 percent TiO_2, has developed over Miocene basaltic lavas in the Willamette Valley of Oregon. The problem presented was to determine the major titanium-bearing minerals present, and hence to understand their origin.

Samples submitted

Twenty-one samples of earthy bauxitic material taken from six drill holes in the area were submitted, following an introductory series of three samples including a fresh and a weathered basalt. Chemical analyses for Al_2O_3, TiO_2, SiO_2, and Fe_2O_3, on splits of these samples were also submitted. Each sample was submitted as representative of a two-foot interval in the drill hole.

Previous work

A considerable amount of work has been done on the origin and occurrence of titanium in lateritic soils and bauxites. This has indicated that the titanium mineralogy varied from place to place, as might be expected from the variation in original materials and in lateritization conditions. The possible mineralogical types are: 1, residual minerals such as ilmenite and rutile from the parent rock; 2, newly formed secondary high titanium minerals such as sphene and anatase, as the fine-grained aggregate loosely called ".leucoxene"; and 3, dispersed in colloidal or ionic form throughout some normally nontitaniferous secondary aluminum or iron mineral in the bauxite, such as gibbsite or goethite.

Procedures used

As a result of preliminary work on the introductory series, several different methods of study were used. Straight petrographic techniques on powder mounts of the bauxite and various concentrates were used; some magnetic separations were performed; and a number of samples were separated in Thoulet's solution (density 3.2), with centrifuge, to obtain a high density concentrate.

The bauxite was presumed to contain considerable ilmenite, so a number of chemical methods were also tried in an attempt to concentrate it, quantitatively, for further study. As the major minerals present in any high iron bauxite are gibbsite (or other hydrated aluminum oxide mineral) and "limonite" (goethite, etc.), a solution procedure was developed to obtain the ilmenite, magnetite, rutile, anatase, brookite, and sphene, if any were present, as a concentrated "insoluble residue." Hydrochloric acid, in a concentration and time adequate to dissolve the bulk of the bauxite, was considered too drastic a procedure, in that part or all of the "insolubles" might dissolve under such conditions. Milder solvents were used to remove the bulk of the bauxite first: concentrated NaOH solution, hot, was used first to

dissolve the majority of the aluminum as sodium aluminate, followed by concentrated hot oxalic acid to dissolve the bulk of the limonite as ferric oxalate, then a quick wash with cold dilute HCl, and lastly a minute in concentrated cold HF in platinum to remove any gelatinous silica; it is quite certain that very little, if any, ilmenite will dissolve under these conditions.

Some difficulty was encountered in separating liquid from solid, quantitatively, between the various operations. All such separations were performed by decantation with suction, after considerable dilution. Column heights and settling times were such that all grains of less than 0.050 mm diameter were removed with the solutions. This was an arbitrary value, established for convenience and brevity of operation. Most of the data obtained were on these "insolubles." In each case ten grams of the original air dried sample was taken, after careful coning and mixing. The final residues, which were mainly black sands, were weighed, examined microscopically, and then analyzed chemically and spectrographically for TiO_2 by L. L. Hoagland and T. C. Matthews, respectively, both of the Oregon Department of Geology and Mineral Industries. The weight of these samples was not always as much as desired for the TiO_2 analysis, but was adequate for the purpose of this report.

Results obtained

The petrographic study of the bauxite itself did not reveal any obvious titanium minerals recognizable in transmitted light (rutile, anatase, brookite, or sphene). There were tiny grains, approximately 0.001 mm in diameter, which might have been one of these minerals, but as this is at the limit of resolution of the light microscope, nothing further could be done with the method.

The heavy liquid separations were also rather disappointing, as a result of the high percentage of goethite in the samples, which made up the bulk of the heavy fraction and coated grains of other minerals present.

The "insoluble residues" obtained were found to be opaque black crystalline grains in the size range 0.05 to 0.085 mm. Magnetic tests indicated that there was a small percentage of true magnetite present, and a large percentage showed a slight amount of magnetism. Chemical and X-ray diffraction tests proved conclusively that the bulk of the material was ilmenite, with some magnetite. No other titanium mineral was found in any of the examinations. For various technical reasons, the X-ray diffractions patterns obtained did not permit a determination of the amount of solid solution of magnetite and ilmenite in these minerals.

The results of this work will be found in Table 9 on the opposite page. In summary, the "insoluble residue" varied from 2 to 17 percent, by weight, of the original bauxite, and contained, in most cases, 40 to 45 percent TiO_2, indicating it to be essentially pure ilmenite, with magnetite as the main diluent except in those cases where the TiO_2 content was in the twenties (17231 and 17236), where undissolved gelatinous silica made up the bulk of the residue. The spectrographic determinations made on the residues (see Page 48) reveal amounts of major, minor, and trace elements that are in line with this mineralogy and geochemical environment. Only one element, zirconium, seems out of line, in that it has the uniformly high concentration range of 0.1 to 0.01 percent. As one grain of suspected zircon was found in these residues, and as the nature of the deposit is such as to make inclusion of some detrital

Table 9.

Summary of Analytical Results

Sample No.	Weight-percent TiO_2	Weight-percent residue	Residue percent TiO_2	Weight-percent TiO_2 in bauxite attributable to TiO_2 in residue
15796	9.32	11.65	47.68	5.55
16911	6.90	6.86	48.90	3.35
16912	*6.65	10.01	46.46	4.65
16913	*6.52	11.72	45.91	5.38
17089	7.34	5.91	47.58	2.81
17136	7.48	10.59	42.36	4.49
17137	7.04	8.26	46.91	3.87
17138	5.65	7.38	46.70	3.45
17139	7.24	11.80	41.69	4.92
17140	7.44	11.60	45.36	5.26
17141	7.44	2.86	39.26	1.12
17225	6.55	7.78	46.35	3.61
17226	6.15	6.26	44.90	2.81
17231	6.54	7.42	29.38	2.18
17236	8.43	17.13	27.17	4.65
17304	7.42	10.57	42.14	4.45
17305	8.30	9.77	41.25	4.03
17309	5.74	2.34	46.96	1.10
17543	*7.2	9.40	38.70	3.64

* TiO_2 "calculated" from the analysis for the Fe_2O_3 value and the Fe_2O_3/TiO_2 ratio for other samples in the hole.

Note: Samples 17135, 17657, and 17308 were not analyzed as they did not yield large enough residues.

zircons possible, this is assumed to be the cause for the high values. The columns of Table 9 (page 47) are self explanatory.

Representative spectrographic analysis of titanium concentrates from Salem Hills bauxite:

Elements present in concentrations over 10%.
Ti, Fe

Elements present in concentrations 10% - 1%
Al

Elements present in concentrations 1% - 0.1%
Si, Mg, Na

Elements present in concentrations 0.1% - .01%
Ca, Mn, Zr, Va

Elements present in concentrations .01% - .001%
Cr, Ba, Sr

Elements present in concentrations below .001%
Cu, Ni

Interpretation and conclusions

The interpretation of the results obtained lies in part in Table 9 (page 47). From the preceding data and the table, it is evident that over half of the titanium, on the average, is present in these bauxites as residual ilmenite grains larger than 0.050 mm (about 300 mesh). Certainly some small portion of the ilmenite present did actually dissolve under the conditions of the laboratory treatment, and all grains less than 0.050 mm in diameter were lost as a consequence of the procedure used. Conservative estimates would place the true amount of titanium present in these bauxites as actual residual ilmenite at perhaps 75 percent. The remaining 25 percent may be present in any of several forms, such as well-dispersed very minute secondary titanium oxides ("leucoxene") or phosphates, which would be lost in the processing used, or as an actual part of the almost colloidal secondary hydroxide minerals.

Obviously the concentration of ilmenite in the original basalt, and presumably the grain size, as well as any transportation of materials, would affect the amount of titanium in the final bauxite. The results were plotted in a number of ways, but the residual nature of the bulk of the titanium makes correlation of TiO_2 with other parameters rather indirect, except a good positive correlation of the amount of residue with the percent TiO_2 in the bauxite. Such a correlation is, of course, statistically inevitable, and an even better correlation is obtained between weight-percent insolubles and weight-percent TiO_2 in bauxite attributable to the residue (see figure 8 on opposite page).

Any titanium not present as ilmenite (or titaniferous magnetite) in the original basalt, as for example that in titanaugite, and whatever titanium did dissolve during weathering of the ilmenite, probably oxidized immediately to Ti^{+4} upon release during weathering, regardless of its valence state in the original mineral. Of course the valence state of the titanium
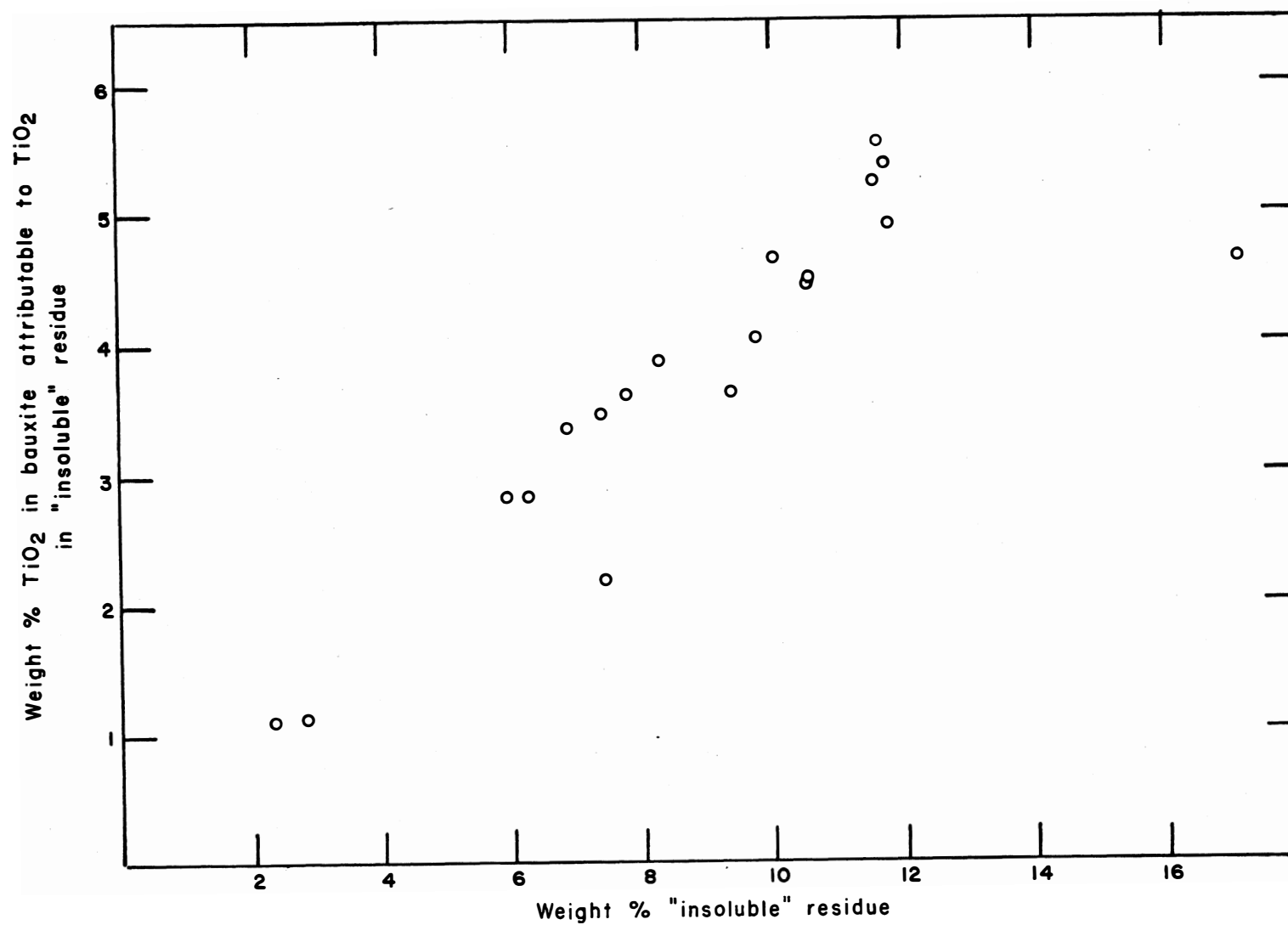
Figure 8 – Graph Showing Result of Plotting Weight Percent Insolubles Against Weight Percent TiO$_2$ in Bauxite Attributable to the Residue

in an insoluble mineral is of no consequence in dealing with ionic potentials and other aspects of the solution chemistry of titanium during weathering, so all the information in the literature of laterization pertaining to such phases of geochemistry is not applicable here, except perhaps in explaining the nature of the remaining 25 percent unaccounted for. The amount of this titanium in forms other than ilmenite was not adequate to be identified by the procedures used in the time available.

Summary

The bulk of the titanium in these bauxites is present as grains of ilmenite and titaniferous magnetite, residual from the original basalt. The remainder of the titanium was not identified. It is not possible to determine, except by further study in the field, whether any of these ilmenite grains might possibly be detrital in any particular sample.

<div align="right">July 30, 1955.</div>

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State of Oregon
Department of Geology and Mineral Industries, 1069 State Office Building, Portland 1, Oregon

PUBLICATIONS

BULLETINS	Price postpaid*

1. Mining laws of Oregon, 4th revision, 1954. Contains Federal placer mining regulations . . . . — $0.50
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7. The gem minerals of Oregon, 1938: H. C. Dake . . . . (out of print)
8. Feasibility of steel plant in lower Columbia area, rev. ed., 1940: R. M. Miller . . . . (out of print)
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11. Geology and mineral resources of Lane County, Oregon, 1938: W. D. Smith . . . . (out of print)
12. Geology and physiography of northern Wallowa Mountains, 1941: W. D. Smith and J. E. Allen, et al (out of print)
13. First biennial report of the Department, 1937-38 . . . . (out of print)
14. Oregon metal mines handbooks: by the staff
      A. Baker, Union, and Wallowa counties, 1939 . . . . (out of print)
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23. Invest. of rpt'd. occurrence of tin at Juniper Ridge, Oregon, 1942: H. C. Harrison and J. E. Allen . . 0.40
24. Origin of the black sands of the coast of southwestern Oregon, 1943: W. H. Twenhofel . . . . (out of print)
25. Third biennial report of the Department, 1941-42 . . . . (out of print)
26. Soil: Its origin, destruction, and preservation, 1944: W. H. Twenhofel 0.45
27. Geology and coal resources of Coos Bay quadrangle, 1944: J. E. Allen and E. M. Baldwin 1.00
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29. Ferruginous bauxite in northwestern Oregon, 1945: F.W. Libbey, W.D.Lowry, and R.S.Mason . . . . (out of print)
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31. Geology of the St. Helens quadrangle, 1946: W.D.Wilkinson, W.D.Lowry, and E.M.Baldwin 0.45
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    J. A. Cushman, R. E. Stewart, and K. C. Stewart 1.00
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        Cushman, Stewart, and Stewart; and one paper on mollusca and microfauna of Wildcat coast
        section, Humboldt County, California, 1949: Stewart and Stewart 1.25
37. Geology of the Albany quadrangle, Oregon, 1953: Ira S. Allison 0.75
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39. Geology and mineralization of the Morning Mine and adjacent region, Grant County, Oregon,
    1948: Rhesa M. Allen, Jr., ... (withdrawn pending revision) . . . .
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GEOLOGIC MAPS

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Geologic map of the St. Helens quadrangle, 1945: Wilkinson, Lowry, and Baldwin (also in Bull. 31) .   0.35
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MISCELLANEOUS PAPERS

1. A description of some Oregon rocks and minerals (prepared to accompany school mineral sets),
    (3rd printing), 1956: Hollis M. Dole 0.40
2. Key to Oregon mineral deposits map (2d printing), 1955: Ralph S. Mason . . . . $ 0.15
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5. Oregon's gold placers, 1954: (Reprints) 0.25
6. Oil and gas exploration in Oregon, 1954: R. E. Stewart 1.00

MISCELLANEOUS PUBLICATIONS

The Ore.-Bin - Issued monthly by the staff as medium for news about the Department, mines, and
    minerals. (Available back issues 5 cents each.) Subscription price per year 0.50
Oregon mineral deposits map (22 x 34 inches) 1951 . . . .   0.30
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Landforms of Oregon: a physiographic sketch (17 x 22 inches) 1941 . . . .   0.25
Index to topographic mapping in Oregon, 1956 . . . .   Free
Index to published geologic mapping in Oregon, 1956 . . . .   Free

TOPOGRAPHIC MAP OF PART OF THE
SALEM HILLS

Marion County, Oregon

Laterized areas

Auger hole

Scale of miles

0   1   2

MAP AREA

GEOLOGIC MAP OF THE
SALEM-STAYTON AREA

Linn, Marion and Polk Counties, Oregon

Quaternary deposits

Salem-Stayton lavas
Miocene

Fern Ridge tuffs
Pliocene

Eugene formation
Oligocene

Geology from M. J. Mundorf (1939) and T. F. O'Neil (1939)

PLATE 2

N

CREEK

JORY

CREEK

BATTLE

CREEK

To Salem 6 mi.

123°3'4"
44°51'47"

Reese Hill Road

Rainbow Drive

Buena Vista Road

RODGERS

CREEK

Rosedale Friends Church

Hylo Road

21 22
28 27

22 23
27 26

T. 8 S.
R. 3 W.

28 27
33 34

44°50'23"
123°3'32"

44°51'23"
123°1'46"

44°50'23"
123°1'44"

Hole 26
Overburden 6'
Ore thickness 14'
Hole 20'
Al₂O₃ 34.96%
SiO₂ 4.14
Fe₂O₃ 30.80
TiO₂ 6.85
L.O.I. 25.60

Hole 23
Overburden 4'
Ore thickness 28'
Hole 32'
Al₂O₃ 35.90%
SiO₂ 6.03
Fe₂O₃ 33.80
TiO₂ 7.20
L.O.I. 16.80

Hole 27
Overburden 2'
Ore thickness 18'
Hole 20'
Al₂O₃ 31.25%
SiO₂ 5.46
Fe₂O₃ 33.30
TiO₂ 6.69
L.O.I. 23.28

Hole 22
Overburden 6'
Ore thickness 21'
Hole 25'
Al₂O₃ 36.84%
SiO₂ 5.12
Fe₂O₃ 32.80
TiO₂ 6.84
L.O.I. 18.40

Hole 20
Overburden 8'
Ore thickness 13'
Hole 21'
Al₂O₃ 31.20%
SiO₂ 7.46
Fe₂O₃ 33.20
TiO₂ 6.80
L.O.I. 21.34

Overburden 2'
Ore thickness 18'
Hole 20'
Al₂O₃ 35.51%
SiO₂ 8.75
Fe₂O₃ 30.90
TiO₂ 6.20
L.O.I. 18.64

Hole 18
Overburden 4'
Ore thickness 14'
Hole 20'
Al₂O₃ 32.84%
SiO₂ 5.85
Fe₂O₃ 32.70
TiO₂ 6.58
L.O.I. 22.03

Salem Hills
Bauxite Investigation
ROSEDALE CHURCH AREA
Marion County, Oregon

Scale in feet
0   500   1000   1500

Contour interval 10 ft.
Datum assumed
Auger hole
Approximate outline of laterite area

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

June 1956

CROSS SECTIONS SHOWING GEOLOGY
ROSEDALE CHURCH AREA

B   North   Jory Cr.   Hole 26   Battle Cr.   Hole 22   Hole 1   Rodgers Cr.   Hole 18   A   South

C   North   Jory Cr.   Hole 23   Hole 20   Hole 1   Hole 18   A   South

Ore
Probable extension of ore
Intermediate clay zone
Basalt