STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
702 Woodlark Building
Portland 5, Oregon

Bulletin No. 29

Ferruginous Bauxite Deposits in Northwestern Oregon

by

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Department of Geology and Mineral Industries

1945

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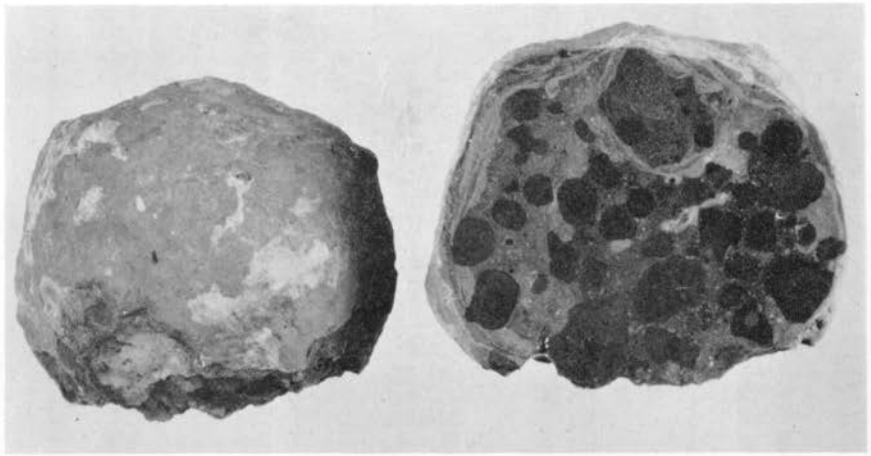

Fig. 1. Two views of a concretion common in ferruginous bauxite deposits. A, surface; B, cross-section showing a typical oölitic texture with oölites within oölites. Natural size.

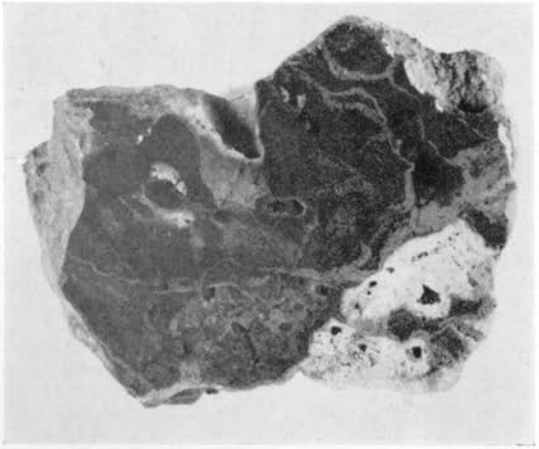

Fig. 2. Hard porous nodule characteristic of nodular type ferruginous bauxite showing a colloform texture and white patches of bauxite. Natural size.

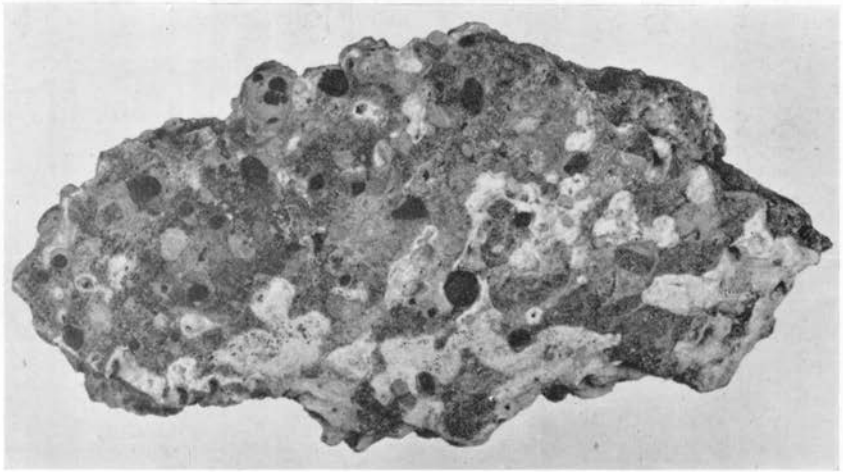

Fig. 3. Porous nodule having textural features common to both oölitic and nodular types of ferruginous bauxite. Natural size.

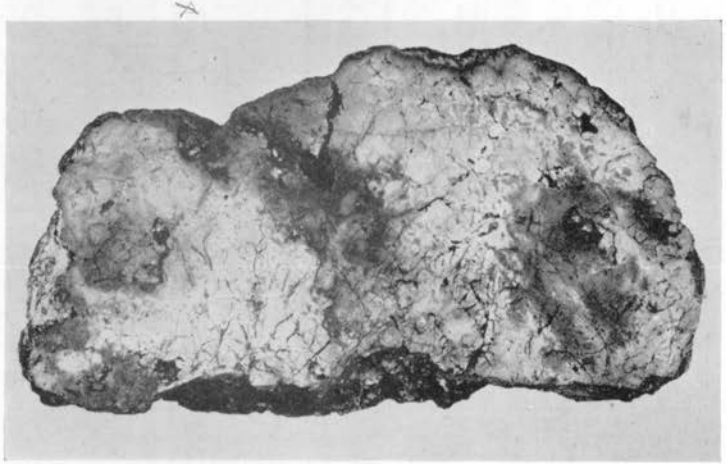

Fig. 4. Section of high-grade bauxite nodule from the Salem Hills. Shaded parts are deep pink; light parts are pink to pinkish-white. Two-thirds natural size.

SPECIMENS OF OREGON BAUXITE

FOREWORD

Since issuing a preliminary report on the ferruginous bauxite deposits of Washington County, Oregon, in August 1944, the Department has done additional field work in the study of these deposits as time and personnel permitted. Areas containing the deposits have been extended into other counties, as described in the accompanying report. All pertinent information so far obtained by the Department, including that contained in the preliminary report, has been assembled in the present volume. It is realized that this is not a complete report on the deposits. It is more of the nature of a progress report. Much more work, some of it beyond the facilities of the Department, must be done in order to give authoritative answers to questions of distribution, extent, origin, composition, and especially commercial application. The bulletin is issued in the hope that the information now available will assist in encouraging commercial development of the deposits, and that substantial postwar employment may result from such development. One large experienced company is already actively engaged in an exploration project on the Washington County deposits.

Economical treatment of this ore is the dominant problem. Compared to bauxite suitable for treatment in a Bayer plant, the bulk of the material described in this report is low-grade in alumina. However, the relatively high iron present is potentially of commercial value, and as it must be separated from the alumina in any event, it should be considered an asset rather than a liability. Weighed against the treatment problem, the deposits have the characteristics of favorable location, large reserves, and low exploration and mining costs. Thus the over-all picture is encouraging. Whether or not the high-grade bauxite in the Salem area occurs in quantity sufficient to influence this picture is not known at present.

One point in connection with the economics of the deposits is worth emphasis; even if the material is not immediately utilized as a source of alumina, the great extent of the deposits provides an invaluable domestic reserve of alumina which might be vital at some future time.

F. W. Libbey
Director

June 15, 1945

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FERRUGINOUS BAUXITE DEPOSITS IN NORTHWESTERN OREGON

Abstract

Extensive deposits of ferruginous bauxite occur in several counties of northwestern Oregon, principally in Washington, Columbia, and Marion Counties. These deposits were formed by laterization of Miocene basalts following their extrusion and before deposition of silts in the Pliocene (?). Probably the laterization occurred before gentle folding and uplift of the region took place sometime in the Pliocene. Conditions preceding and succeeding laterization, especially in the areas both north and south of Salem are not clear, but relief may have been greater in the post laterization period in the Salem area than in Washington and Columbia Counties.

Topography governs outline and areal extent of these nearly flat-lying deposits. Generally they occupy summits of flat hills and the gentle higher slopes. Erosion has dissected and removed a large part of the flows originally laterized.

Thickness of deposits is from 6 to 20 or more feet. Silt overburden is variable in thickness but will range from a foot to 40 or more feet. Average depth of silt overburden is moderate and the ratio of overburden to ore is probably less than 2 to 1.

Texture of the deposits in Washington and Columbia Counties is usually oölitic, especially near the top of the ore section. Lower sections range from earthy to nodular with some nodules containing crystalline bauxite and minor limonite. Nodules made up essentially of whitish bauxite occur as float, and they are widely distributed in the Salem Hills south of Salem.

Exploration by the Department in Washington County alone has indicated more than 5 million long tons of ferruginous bauxite in two localities. An arithmetical average of samples obtained by auger-hole drilling of deposits in these localities is 34.68 percent alumina, 23.12 percent iron, 9.48 percent silica, 4.85 percent titania, and .176 percent phosphorus.

The arithmetical average of the ferruginous bauxite channel-sampled in Columbia County is 38.63 percent alumina, 20.70 percent iron, 9.36 percent silica, and 5.83 percent titania.

In the Salem area the deposits in place appear to be thinner than those farther north; also they appear to lack the oölitic sections found in Washington and Columbia Counties.

High-grade bauxite float is widely distributed in the Salem area, and analyses show 50-60 percent alumina, 2 - 14 percent iron, 2 - 6 percent silica, and 1 - 4 percent titania. Nodules of this float up to a foot or more in diameter are common. No estimate of quantity may now be made.

Although a treatment process to produce alumina competitive with imported high-grade bauxite must be developed before these deposits may be considered commercial, such a process to produce both alumina and iron appears to be feasible, and these deposits, so favorably situated in relation to aluminum reduction plants on the Lower Columbia River, may become an important source of alumina for these plants.

Introduction

In August 1944, G.M.I. Short Paper No. 12, High Alumina Iron Ores in Washington County, Oregon, was published. This was a preliminary report, issued while field work was still in progress. Since then reconnaissance work has been done in tracing deposits of ferruginous bauxite over a wide area in Columbia County, as well as in enlarging the areas underlain by deposits in Washington County. In order to assemble all available information in one volume, the essential parts of G.M.I. Short Paper No. 12 are included in the present bulletin, in addition to the record of results obtained since the preliminary report was issued. After part of the bulletin was in manuscript form, reconnaissance work by the Department in Marion and Polk Counties showed occurrences of ferruginous bauxite in localities both north and south of Salem. Possibly more important was the discovery of high-grade bauxite float distributed rather widely in the Eola Hills north of Salem and especially in the Salem Hills south of Salem. Because the high-grade material appears to occur in quantity that might have commercial importance, results of preliminary studies of these deposits are included in this report. Further study is planned.

The principal exploration work reported in G.M.I. Short Paper No. 12 was done on the Hendrickson farm, and the description of the work is repeated in this report under Locality 5.

Favorable topography indicating the possibility of fairly large tonnage in the area designated as the Hutchison-Nixon project (named after the owners of land at the southeast and northwest ends of the area) was the reason for exploration work described under Locality 8. Some ore was found in test holes in these properties as described in the preliminary report.

Work on other deposits described in this bulletin was of reconnaissance nature only. At places where sections of deposits were exposed in cuts, channel samples were taken. Evidence of many deposits was obtained from grab samples of float material. Occurrence of some deposits was inferred from descriptions of iron deposits obtained from sources named in footnotes. Many of these inferred occurrences have not been verified because of lack of time and personnel.

Laterization which produced the deposits was confined to Miocene basalts, and any area made up of these lavas may possibly contain bauxitic deposits. Therefore such ores may be expected to occur in places farther west in Columbia County, and in outlying districts in the Salem area. An investigation (Wagner, 1945)* of Columbia River basaltic terrane in Eastern Oregon failed to reveal similar deposits there, but this first work does not rule out possible occurrences in areas covered by younger formations.

The name "ferruginous bauxite" has been given to this material for lack of a more definitive term. It is not an iron ore, and "laterite", although defining the origin, does not have mineralogical significance. Bauxite minerals are common and chemical analysis shows that average content of the hydrous aluminum oxides is somewhat in excess of the hydrous iron oxides. "Bauxitic clay", as a name, is not applicable to the deposits as a whole.

Deposits similar in composition and genesis to those in northwestern Oregon are found in New South Wales and Victoria, Australia; in County Antrim, northeastern Ireland; in India; and in the Vogelsberg Mountains, Germany. Concerning deposits in New South Wales resulting from laterization of basalt, Rumbold (1945) states that available analyses show ranges as follows: alumina, 31.43 to 61.46 percent; ferric oxide, 1.99 to 42.21 percent; silica, 0.16 to 29.8 percent; titania, 0.55 to 5.5 percent; "water", 6.85 to 32.68 percent.

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 at a profit.

More than 450 samples obtained in this investigation have been analyzed in the Department's chemical laboratory. The laboratory procedures are included in an appendix as a matter of record. With the exception of the titanium determination which is an original method worked out by L. L. Hoagland, Department chemist, these procedures follow usual standard practice. Spectrographic and petrographic studies of some samples have also been made.

Early in 1945, Alcoa Mining Company began exploration of the deposits in Washington County.

The U.S. Bureau of Mines and the U.S. Geological Survey are engaged (June 1945) in a cooperative investigation of deposits in Columbia County.

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* See bibliography in back.

Acknowledgements

Several members of the Department staff contributed in large measure to the preparation of this bulletin and are listed below:

The topographic mapping on the Hendrickson deposit and the drilling and sampling of the various deposits in Washington County were done by Mr. J. F. Cleaver and Mr. L. C. Swanson. The chemical analyses were made by Mr. L. L. Hoagland, and the spectrographic work was done by Miss Esther W. Miller. Dr. E. M. Baldwin assisted in reconnaissance work on some of the deposits in Columbia County. Typing of the manuscript was done by Miss June Roberts, Mrs. Frances Furniss, and Miss Vida Williams. Mrs. Lillian Owen prepared and multigraphed the plates for the complete bulletin.

The early reconnaissance work was greatly facilitated by Dr. R. P. Nixon, Forest Grove, whose knowledge of the deposits in Washington County was of great assistance. Owners of the various properties examined were uniformly cooperative and in this connection the writers wish to express appreciation of help given by Messrs. Hendrickson, Nelson, Schmidt, Leitzel, Cathey, McKnight, Dudley, Baldwin, Parmele, Gentry, Gaman, Marshall, Lambert, Annicker, Veall, and Hutchison.

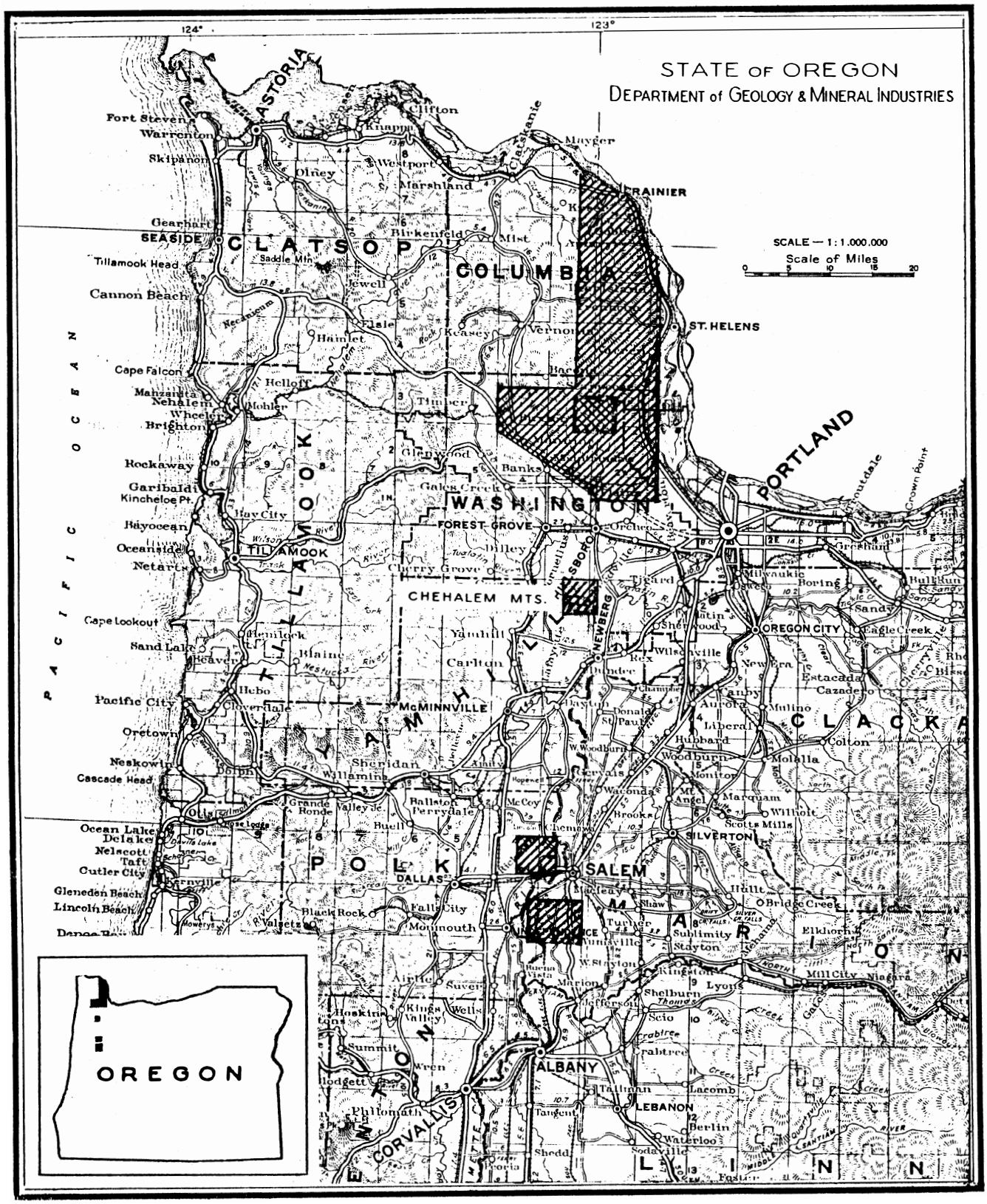
The authors also wish to thank Mr. Hans Norbisrath of the U.S. Geological Survey who gave to the Department information concerning the location of one of the deposits in Columbia County.

Location

The index map on page 5 shows the location of the general areas with which this report is concerned. The localities which are potentially most important are contained in an area of approximately 150 square miles in Washington and Columbia Counties extending from about 25 miles to more than 50 miles northwest of Portland, and in approximately 15 square miles of area in the Eola Hills, Polk County, and in the Salem Hills, Marion County, a few miles north and south respectively of Salem.

Washington County deposits may be reached from Portland by the way of Skyline Blvd. to the Dixie Mt. Road and by the way of Pumpkin Ridge Road north of North Plains. The Columbia County deposits are accessible from Portland by the way of U.S. Highway 30 and branch roads.

Deposits in the Salem area are easily reached by the way of U.S. Highway 99E and branch roads.



Index Map of Northwestern Oregon
Showing Location of Ferruginous Bauxite Deposits
In Washington, Columbia, Polk and Marion Counties

Relief and Drainage

The deposits in Washington, Multnomah, and Columbia Counties lie within the eastward extension of the Coast Range of mountains in northwestern Oregon. The elevation of the areas where the deposits have been found ranges from several hundred feet to nearly 2000 feet. The region as a whole is considerably dissected but numerous extensive flat areas and smooth slopes persist. The deposits occur in these relatively undissected areas.

The Chehalem Mountains on the south, the Tualatin River Valley, and the Portland hills farther north are prominent physiographic features. The northern part of the region lies within Columbia County and is split into two drainages by a north-trending divide which is in most places less than 1500 feet in elevation. Its eastern part, which includes most of the deposits in the area, is drained by tributaries of the Columbia River. The smaller western part is drained largely by the Nehalem and Clatskanie Rivers and their tributaries. A roughly east-trending divide in northern Washington County and southern Columbia County rises in places above 2000 feet and forms the boundary between the northern and southern parts of the region. The southern part is drained largely by the Tualatin River and its smaller tributaries such as McKay Creek and Dairy Creek. The Tualatin River flows eastward into the Willamette River which in turn flows northward into the Columbia River. The region is roughly bounded on the east by the Willamette and Columbia Rivers.

Although the Tualatin River tends to meander on its valley fill, some of its tributaries, such as McKay Creek, have fairly steep gradients in their upper reaches, and their valleys have steep slopes characteristic of youthful topography.

The known deposits in the Salem area are restricted to the Eola Hills and the Salem Hills which are drained by the Willamette River and its tributaries. These hills lie within the Willamette Valley physiographic unit between the Coast and Cascade Ranges. Both the Eola Hills and the Salem Hills rise above 1000 feet in elevation and the relief along their steep western sides is more than 800 feet.

Geology of Deposits in Washington, Multnomah, and Columbia Counties

Stratigraphy

Since publication of the first report (Libbey, Lowry, and Mason, 1944) describing the ferruginous bauxite deposits in Washington County, some additional stratigraphic information has been obtained which clarifies rather than alters the geologic picture of the area.

The Department's recognition of the bauxitic character of certain of the deposits in Columbia County, previously described as being limonitic, makes the geology of the St. Helens quadrangle especially pertinent. Wilkinson's mapping (1941) in the St. Helens quadrangle where a number of these deposits occur, showed that Miocene basaltic lavas more than 500 feet thick in places, unconformably overlie Oligocene marine sediments, which are predominantly tuffaceous sandstones. Additional mapping in the northern part of the quadrangle by W. D. Lowry and E. M. Baldwin of the Department indicates that lower Oligocene sandstone, belonging to the Gries Ranch stage, unconformably overlies a thick series of basic lavas and breccias assigned by them an upper Eocene age.

As far as is known, all the ferruginous bauxite deposits are associated with the Miocene basalts. The deposits are lateritic in origin and occur at the top of the basaltic section. They are not to be confused with the Scappoose-type limonites which are bog deposits within the basaltic series. The ferruginous bauxite deposits occur on flat-topped hills or ridges or on gentle slopes whereas the Scappoose limonite deposits do not have direct relation to the topography and may crop out on steep dissected slopes.

The Columbia River basalts together with the marine sediments that unconformably underlie the basalts are also present in Washington and Multnomah Counties as well as in Columbia County. Disregarding a widespread silt covering, these basalts make up the greater part of the surface in the Washington County area where deposits of ferruginous bauxite occur. The basalts are exposed in places in the Chehalem Mts., Bull Mt. and Cooper Mt., at Jackson Falls quarry, and in McKay Creek as well as at numerous other places. In the youthful valley of McKay Creek a 400-foot section of these basalts is exposed.

The basalts which stratigraphically underlie the Hendrickson deposit and are exposed along McKay Creek are dark gray in color and fine-grained. Thin sections show that they are hemicrystalline. The phenocrysts are plagioclase, augite, and magnetite. The groundmass is either a gray or brown glass which forms some 20 to 25 percent of the rocks. The texture of two of the rocks sectioned is intersertal with the spaces between the divergent

plagioclase laths occupied by augite, magnetite, and glass. The plagioclase is labradorite in the form of laths, averaging 0.4 to 0.5 mm in length and as much as 1.5 mm long. They show albite twinning and a number of them are fractured. Labradorite constitutes about 50 to 55 percent of the rocks. Augite, in many instances in the form of fractured anhedral aggregates, makes up about 25 percent of the sections. The magnetite grains range in size from minute specks to more than 0.6 mm and have anhedral, subhedral, or irregular skeleton crystal outlines and constitute several percent. The groundmass is either a gray or brown glass, in some places partially devitrified, and in the three rocks examined, averages about 20 to 35 percent of the whole. Significant features of these Miocene basalts, as well as those in the Salem area, are their high percentage of plagioclase and their relatively large content of volcanic glass.

A weathered portion of one thin section shows that the glassy matrix alters much more readily than the plagioclase and augite. The magnetite was apparently unaltered. The differential alteration of the glassy groundmass, the fractured nature of nearly all the augite and some of the labradorite, and the intersertal texture of the basalts favor their rather rapid and continuous alteration.

Wilkinson (1941) gives petrographic descriptions of similar basalts from the St. Helens quadrangle and Darton (1909) gives additional petrographic information on Columbia River basalts.

Spectrographic analysis of a sample of Columbia River basalt from the Jackson Falls quarry in the Hillsboro quadrangle gave the following results:

Percentage	Elements*
Greater than 10%	silicon, aluminum, magnesium, calcium
1 - 10%	iron, sodium, titanium
0.1 - 1%	manganese, strontium
0.1 - 0.01%	chromium, vanadium, barium
0.001 - 0.01%	cobalt
Below 0.001%	zirconium, copper, nickel, molybdenum

* A small percentage of sulfur was shown to be present by a qualitative method.

The marine sandstones are exposed in relatively few places in eastern Washington County and in the Portland hills area in Multnomah County. In most places they seem to occupy windows in the overlying basalts. Sandstones occur along the Dixie Mt. Road between Shady Brook School and Wallace School in sec. 18 and reportedly in the SW¼ sec. 5, T. 2 N., R. 2 W., and also in numerous cuts along the Rocky Point Road which leads east from Skyline Blvd. to U.S. Highway 30. Fossils collected from the tuffaceous sandstones along the Rocky Point Road have been identified by H. E. Vokes (Warren, 1945) of the U.S. Geological Survey. According to Walter Warren[1], this fauna has closest affinity with the

[1] Personal communication.

Sooke formation, but inasmuch as Astoria forms are also present, Vokes and Warren think that the Rocky Point beds may be of intermediate age, possibly Vaqueros. Thus these beds are of upper Oligocene or somewhat younger age.

The sandstones on the Rocky Point Road disconformably and probably unconformably underlie Miocene basalts. These sediments seem to occupy a window near the axis of an anticlinal fold in Miocene basalts. The anticline strikes roughly northwest and conforms to the trend of the Portland hills, whose anticlinal structure was pointed out by Treasher (1942).

The Troutdale formation, which Treasher mapped in the Portland area, overlies the Miocene basalts. Chaney (1944) has recently assigned the Troutdale a lower Pliocene age on the basis of fossil leaves. Treasher states that the Troutdale is made up mainly of somewhat consolidated river gravels, sands, and associated silts. He notes that the Troutdale formation and the underlying Columbia River basalts are essentially parallel. An erosional unconformity, which also may be angular, separates them.

On the basis of the evidence available regarding the age of the Columbia River basalts in Oregon, these lavas can be restricted to the time interval between the folding of the upper Oligocene or somewhat younger marine sandstones and the deposition of the Troutdale sands, gravels, and silts assigned by Chaney to the lower Pliocene. Weaver (1937) states that lavas similar to Columbia River basalts on the Washington side of the Columbia River contain intercalated marine sandstone with fossils of the Astoria formation of middle Miocene age.

Treasher states that Boring lavas overlie unconformably the Troutdale sands and gravels. In places the volcanic cone sources of these lavas may still be recognized. Treasher assigns these lavas a late Pliocene or early Pleistocene age and states that they are related to the Cascan formation (Hodge, 1938) of similar age. Boring lavas occur in several places in the Portland hills, and cover an extensive area in the Garden Home and Multnomah districts. Boring lavas near Tigard appear to fill structural as well as erosional depressions in the Miocene lavas and they were probably derived from the cone source known as Mt. Sylvania.

A fine silt overlies the Boring lavas in places but it is not known certainly whether or not this silt is of the same age as that which disconformably overlies the ferruginous bauxite in Washington, Multnomah, and Columbia Counties. This latter silt where exposed in cuts is massive, fine-grained, usually brown in color, and has a loesslike appearance. The color ranges from buff to reddish brown and is often mottled with gray.

Diller (1896) first mentioned the occurrence of a loesslike silt in the Portland hills. Later Darton (1909) gave additional information showing that it occupied much of the Portland hills area. He described it as loess and stated that in places it is more than a hundred feet thick. He noted that the silt in the point of the highland just south of the mouth of Balch Canyon overlies 40 feet or more of gravel which in turn lies on basalt. The gravel

probably belongs to the Troutdale formation. Darton (1909) stated that the silt elsewhere lies in the irregular, and in places decomposed, surface of the basalt.

The silt that overlies the Hendrickson deposit (Locality 5) in Washington County is known to be as much as 40 feet thick in some places, and may be much thicker in a few other places. The grain size of a sample taken near the surface at the Hendrickson locality ranges from 0.3 mm to that of clay which constitutes about 10 percent of the silt. Nearly all the silt fraction is minus 50 mesh and nearly 70 percent is minus 200 mesh. Besides clay and volcanic glass, the silt contains such minerals as plagioclase, microcline, quartz, muscovite, biotite, hypersthene, and magnetite.

The silt is exposed in many roadcuts along Skyline Blvd. on top of the Portland hills. Ferruginous bauxite is exposed beneath the silt in at least one of these cuts. This silt has been mapped in the soil survey of Multnomah County as Powell silt loam (Ruzek, 1922). It is characterized in many places by small pellets, many of which are less than half an inch in diameter. Where they are numerous, they form what is known as a "shot" soil. The "shots" are usually silt particles cemented together with iron oxide.

The massive, unconsolidated character, mineralogic composition, fineness of grain size, light color, and topographic distribution of the silt suggest it was wind-laid. Treasher tentatively assigned a similar silt in the Portland area a late Pleistocene or early Recent age. However, the silt near Sylvan in the Portland hills is sufficiently weathered to be used in making brick and tile, and possibly the extent of the weathering indicates a somewhat older age. One well-rounded quartzite pebble and one basaltic pebble were found on the surface of the pit face at the Columbia Brick Works at Sylvan and according to the operator, such pebbles occur in place in the silt. A well-rounded quartzite pebble was found on the surface at the Anderson place (Locality 14). The presence of these pebbles seemingly in place in the silt indicates that part and possibly all of it may have been laid down in water and subsequently subjected to folding. Probably the same silt as that at the Sylvan clay pit overlies Boring-type lava farther west.

Similar silt is common in Columbia County and disconformably overlies the ferruginous bauxite in the Yankton area where Lowry and Baldwin[1] have tentatively referred it to the Troutdale formation.

River terrace and delta sands, gravels and alluvium of Quaternary age are younger than the silt.

Structure of the Miocene basalts

The topographic distribution of the deposits appears to be directly related to the structure of the Miocene basalts. Reliable dips and strikes in the basalts are difficult to obtain and in most places where they are best shown, only the general direction

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[1] Unpublished report.

of dip may be taken. Along U.S. Highway 99W, south of Rex and north of Newberg, an ash bed between lava flows dips several degrees northward. Other northward dips in the basalts can be obtained elsewhere in the Chehalem Mts.

Diller (1896) noted that the limonite bed at the old Oswego Iron and Steel Co. deposit on the north side of Oswego Lake lies between sheets of basalt that dip northwest 20-30°. The basalts in the Jackson Falls quarry in the Hillsboro quadrangle appear to dip several degrees to the southwest or west-southwest.

In the upper valley of McKay Creek west of the Hendrickson deposit (Locality 5), the basalts strike about N. 65° W. and dip several degrees to the south. Farther east on U.S. Highway 30, 2 miles south of Linnton, the basaltic lavas dip about 10° to the east. According to Williams and Parks (1923) the structure of the limonite deposits near Scappoose closely conforms to that of the enclosing basalts and the deposit at the Colport-Charcoal Iron property, about 2 miles northwest of Scappoose, dips about 3° to the northeast.

Although relatively few dips in the Miocene basalts have been obtained, these dips correspond with the general regional slopes, and it appears that large topographic features in Miocene basaltic terranes are controlled by the structure of the basalts. The attitudes of two of the ferruginous bauxite deposits have been determined by drill holes, and both correspond with the regional slope. The elevations of the ferruginous bauxite deposits may prove to be fairly accurate indicators of the regional structure, especially where a number occur in one area. However, more complete knowledge of the basaltic surface on which the ferruginous bauxite formed is required before full reliance may be placed on them as indicators.

According to Wilkinson (1941) the surface of the St. Helens area at the close of the outpourings of Miocene lavas was a plain, except possibly for some steptoes of older rocks. The surface of that plain may have been similar to some of the younger lava plains in south-central Oregon where extensive flat areas are interrupted only by higher source buttes or feeder cones. Wilkinson states that during the time interval between the late Miocene and the present, the entire region was subjected to climatic conditions which resulted in deep weathering that produced a heavy soil mantle of a lateritic type.

The topographic distribution of the ferruginous bauxite deposits is known to range from about 300 to more than 1600 feet in elevation. There is evidence which suggests that they may be more than 1200 feet below sea level at Hillsboro. The log of the Ray Maling well[1] at Hillsboro shows that 20 feet of "igneous rock" overlies "alternating gray basalt and clay" 1500 feet below the collar of the well. Mr. A. M. Jannsen, who drilled the well, states that a red rock is often referred to by his drillers as "lava" or "igneous rock". The 20 feet of "igneous rock" may be lateritic as it occurs at the top of a section, more than 100 feet thick, of basaltic lavas that are believed to be of Miocene age.

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[1] Geol. Soc. Oregon Country, Geological News-Letter: vol. 3, no. 12, Portland, Oregon, 1937.

The Miocene basalts in the Washington County-Columbia County area have been folded into rather broad synclines, or basins, and anticlines or domes. Faulting has displaced the basalts in places but its extent is not known. The available evidence suggests the following regional structures in the Miocene basalts, but later work may make modifications or revisions necessary.

The basalts in the Tualatin River Valley area appear to form a northwest-trending elongate basin or syncline filled with younger sediments. The Chehalem Mts. form the southern limb of the structure and their much more gentle northeastward slope reflects the attitude of the component basalts. Cooper Mt. and Bull Mt. are just north of the Tualatin River and are made up of these lavas which appear to form a local northwest-trending anticline within the larger structure.

On the basis of stratigraphic and physiographic relationships, a northwest-trending fault is postulated along the proposed course of the Wolf Creek Highway in the Gales Creek area. Its trace would run through Manning and about one mile north of Banks. The southwest side appears to have moved up in relation to the northeast side. Judging from the form of other topographic features, other faults are probably present and further complicate the structure of the Tualatin River Valley.

The basalts which form the northeast limb of the structure rise toward the crest of the Portland hills in Multnomah County where they reverse their dip to form the Portland hills anticline (Treasher, 1942). The anticline trends roughly northwest, and farther north its crest nearly coincides with the drainage divide in northern Washington County. Farther west this structure seems to swing toward the west so that in the vicinity of the Hutchison deposit (Locality 8) it trends nearly west.

In southern Columbia County the structure of the basalts is even less well known than farther south in Washington County. The known dips in the basalts northwest of Scappoose are to the northeast and judging from the regional slopes, the basalts appear to form the southwest limb of a southeast-trending and plunging syncline whose axis runs through the Yankton area. From there, the basalts rise to the northeast.

The age of the folding which produced the regional structures in the Miocene basalts in the areas concerned is difficult to determine. From most of the evidence now available, it appears to have occurred in the Pliocene before the outpourings of the Boring and High Cascade lavas which are assigned a late Pliocene to Pleistocene age.

Laterization of the basalt

The time of formation of the laterite is not known. It was formed after the basalts of the area were extruded in Miocene time and before the deposition of the overlying silt, whose age is still uncertain. The laterization probably took place before the basalts were folded; the rate of formation of laterite would have had to exceed the rate of its removal

by erosion. As it is now generally agreed that the formation of lateritic aluminum hydroxides is caused by the long continued action of ground waters under special conditions of moisture and heat (Lindgren, 1933), it seems logical to assume that erosion was relatively inactive during the accumulation of the Washington County-Columbia County deposits. The association of the Miocene basalts with the marine Astoria formation farther to the northwest indicates that the region formerly had a much lower average relief. Additional evidence is indicated in the pillow structure of probable Miocene basalt located about one mile west of Rainier.

Possibly laterization was taking place while the Scappoose-type bog-iron ores were being deposited after the first extrusions of Miocene basalts. Also these bogs may have been formed in part by the disruption of drainage as a result of the extrusion of lavas on a surface whose relief may have been as much as 500 or 600 feet. Judging from the available evidence, erosion of parts of the bog deposits and deposition of fine silts in channels within and on top of these deposits preceded outpourings of additional basaltic lavas. Some of the limonite deposits, according to Hotz[1], are 500 feet above the contact of the basalt with the underlying Oligocene sediments, and in one place the overburden is said to consist of as much as 160 feet of clay and soft, weathered basalt. Elsewhere the overburden is much less. The known laterites occur at the top of the basaltic section, and, because reliable evidence is lacking, an accurate statement regarding the horizon interval between them and underlying bog-type limonites may not be made. The information available suggests that they may be separated in places by as much as 200 feet. Elsewhere, as at Locality 8, the interval is much less - about 25 feet. Possible explanations for this variation in the interval between the bog deposits and the laterites are:

1. More than one period of laterization.
2. Difference in the thickness of the lavas poured out on the bog-iron deposits.
3. More than one period of bog-iron formation.
4. Formation of the bog-iron deposits at different elevations.
5. Differential erosion of overlying lavas prior to laterization.

As yet no conclusive evidence has been found that indicates more than one period of laterization.

The lavas which poured out after the deposition of the bog-iron ores probably did not flow out on a level surface, and in any event, they could not be expected to form a uniform cover. In places they probably failed to cover part of the earlier basaltic terrane and in such spots laterization may have acted over a somewhat longer period of time.

Although the bog-iron deposits may have formed at different periods, no evidence is available as proof of such an assumption.

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[1] Hotz, P.E., Iron ore deposits near Scappoose, Columbia County, Oregon: Manuscript report, in files of U.S. Geol. Survey.

Drainage was undoubtedly well established prior to the first extrusion of Miocene lavas and was probably disrupted by these outpourings; thus bog deposits might be expected to form at different elevations.

As laterization of the type and extent found in northwestern Oregon would require a long time, geologically speaking, it follows that erosion was not active during this time. The piling up of several hundred feet of lava might be expected to result in gradients sufficient to cause active erosion unless the land sank, or (conceivably) the sea rose, and it may be that subsidence of the land attended the great outpouring of these lavas. Thus after the last flows, the land surface may have been an extensive low-lying plain which allowed the laterite to form at a greater rate than it could be removed by erosion. The rapid development of a dense vegetation on such a plain would aid the process.

Laterization may have been active in forming the ferruginous bauxites in Washington, Multnomah, and Columbia Counties from the time of the outpouring of Miocene lavas to the time of their folding, and mah have produced a relatively continuous blanket over terranes made up of these lavas. The folding of the Miocene basalts is believed to have occurred during the Pliocene, and erosion accompanying and following it was dissecting the deposits until a thick silt was laid down, possibly in later Pliocene or early Pleistocene time. The silt which disconformably and probably unconformably overlies the ferruginous bauxite in the Yankton area (Locality 23) has been tentatively referred to the Troutdale formation by Lowry and Baldwin. Erosion, probably accompanying subsequent or continued warping and uplift, has since removed part of this silt cover and the underlying laterite.

Shape and attitude of deposits

Topography determines the outline of the deposits, which are confined to the generally flat-topped hills and ridges, and gentle slopes. In Washington County the deposits drilled by the Department are overlain by a silt overburden ranging in thickness from a few inches to more than 40 feet. The upper surface of the deposits does not parallel exactly the present topography. The auger drilling of two of the deposits indicates that the present surface, exclusive of the stream valley areas, is not as deeply dissected as that of the pre-silt topography. Erosion was more effective in dissecting the old basalt surface, as the porous character of the silt of the present surface decreased runoff. Also deposition of the silt tended to lessen inequalities of the old surface. However the present topography of areas underlain by ore appears to be somewhat more irregular than the surface of the ore. Except in the main stream valleys the dissection since the deposition of the silt has not been sufficient to expose the older surface, but the present drainage appears to coincide in some places with that established prior to the deposition of the silt.

The deposits have a sheetlike form and the ones so far drilled range in thickness from a few feet to more than 20 feet. The cross sections of the Hutchison-Nixon body (Locality 8)

accompany the discussion of that occurrence in the section describing the individual deposits. The bottom of that deposit is fairly smooth and regular. The drilling of the Hendrickson body (Locality 5) indicated that the lower surface of the hard ore is fairly even, but drilling of more closely spaced holes at both places may show that the bottoms of the deposits are less regular than supposed, as the cut-off of the ore is not well defined in most places.

The sheetlike form of the deposits apparently is the result of the generally uniform laterization of a single basalt flow or several flows. The attitude of the deposits is therefore believed to correspond with that of the flows from which the deposits were derived. The strike of the Hendrickson ore body as determined from the elevations of the bottom contact of the hard ore is approximately N. 75° W. and the dip, 1° - 2° to the south. This attitude is very similar to that of the basaltic lavas exposed in the valley of McKay Creek not far to the west. The strike of the Hutchison-Nixon deposit, a little farther west, as determined by auger drilling, is about N. 85° W. with a dip of 1° - 3° to the south. It is difficult to determine the dip accurately because of the elongate nature of the deposit in a westerly direction. The more westerly strike of the Hutchison-Nixon body seems related to a similar change in the strike of the basalts in that area as judged from the regional structure. As previously noted, the topographic distribution of the deposits is apparently determined by the structure of the Miocene basalts from which the deposits inherit their attitude.

Character of the ore

Color of the ferruginous bauxite in Washington and Columbia Counties ranges from light brown through various shades or red to dark or chocolate brown. A single deposit may contain several textural varieties of ore. The varieties include a hard oölitic or pisolitic type, a softer earthy variety with hard porous nodules or angular fragments, and a hard porous granular type. The oölitic or pisolitic type has been referred to in some reports as a "shot", "cemented shot", or concretionary variety. The somewhat softer porous, nodular type was referred to in G.M.I. Short Paper No. 12 as a pebbly, somewhat nodular and porous variety.

Composition of the several varieties of ore is not greatly different, but the hard porous granular ores which have been encountered largely as float at some localities, contain an appreciably higher percentage of alumina and less iron.

The oölites and pisolites in the concretionary ores are variable in size and may be nearly round, ovoid, or quite irregular in shape. Figure 1B of plate 1 shows an oölitic texture. Most of the oölites and pisolites range in size from less than one sixteenth inch in diameter to about three fourths inch although some concretions at certain of the localities are several inches in largest dimension, and several as much as 5 inches in

diameter have been found, but the larger concretions generally have a "wormy" texture and a higher percentage of iron. Some of the larger oölites and pisolites enclose a number of smaller ones.

The fresh or unweathered fracture surfaces of most oölites have a dark gray to nearly black color and submetallic luster, weathering concentrically to a brownish color. Hardness is somewhat variable but for most oölites is probably 5 to 5.5. Streak is reddish-brown. The matrix has an earthy limonitic appearance and is usually softer and lighter in color than the concretions.

The oölites and pisolites posses various degrees of magnetism; most of them are readily attracted by a magnet. The matrix of these types is much less magnetic, and in one instance nearly half of a sample, finely crushed, from the Hendrickson deposit (Locality 5), consisted of pieces of matrix either very weakly magnetic or nonmagnetic. Residual grains of magnetite and possibly some of ilmenite as much as 0.55 mm in diameter are contained in the oölites as well as in the matrix, and are irregular in outline for the most part. The greater magnetism of certain oölites is believed to be due to the presence of magnetic secondary iron oxide.

Examination of thin sections of the oölitic ore from the Hendrickson deposit shows that many of the oölites have a colloform structure and are isotropic. The interoölitic masses in some sections have an oölitic texture and are anisotropic. They contain residual grains of magnetite. These masses are probably largely gibbsite with some admixed iron oxide.

Although much of the material making up the oölites in a sample from Locality 12 is opaque, the index of refraction of the isotropic matrix ranges from 1.59 to 1.63. It is probably cliachite. A number of features of interest are shown in a thin section of oölitic ferruginous bauxite from this locality. The makeup of the oölites may be quite different as shown in Plate II, figure 1, opposite page 16. Some have a dark gray opaque core surrounded by a rim of reddish-brown translucent material with residual grains of magnetite. The opaque material in these oolites, which are the most magnetic, is largely a magnetic secondary iron oxide. It has a metallic to submetallic luster and a colloform or oölitic texture. The translucent rim, which may be very thin, is slightly birefringent and its index of refraction indicates it is a mixture of gibbsite and an iron oxide. The rim material of one oölite with an opaque core has a well-defined concentric structure. Other oölites in the thin section lack the opaque magnetic secondary iron oxide but have a colloform or oölitic texture with residual grains of magnetite ± 0.1 mm in length. These oölites may have a peripheral zone characterized by a concentric growth structure as shown in Plate II, figure 1. Some contain either crack or cavity fillings of gibbsite and this feature is also shown in the figure noted above. One oölite has a colloform texture with only a few residual grains of magnetite and another is made up almost entirely of gibbsite. One of the larger oölites includes three pieces of altered basalt whose texture has been preserved. The

Fig. 1. Photomicrograph of oölitic ferruginous bauxite from Washington County showing differences in the makeup of certain oölites. The matrix is largely gibbsitic material. The white streaks within the oölite to the left of center are gibbsite. Reflected and plain light. Approx. X 15.

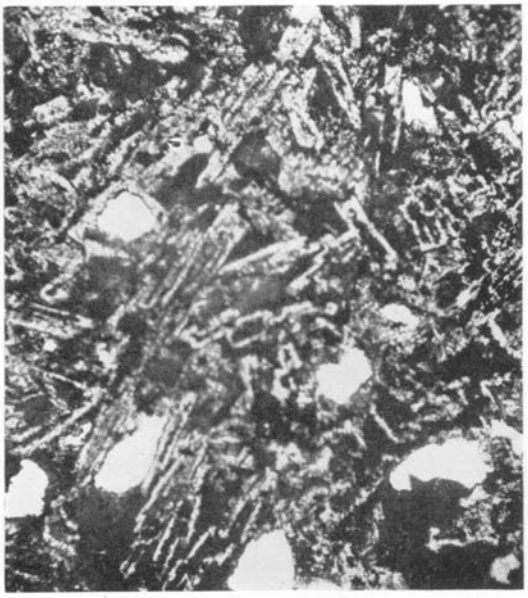


Fig. 2. Photomicrograph of porous granular ferruginous bauxite from Locality 30, Columbia County. Much of the original texture of the parent basaltic rock has been preserved. The white areas are pore spaces. Plain light. Approx. X 45.

Fig. 3. Photomicrograph of gibbsite nodule from Locality 81, Salem Hills, Marion County. Much of the original texture of the parent basaltic rock has been preserved. The original plagioclase laths have been replaced by gibbsite. Plain light. Approx. X 45.

Fig. 4. Photomicrograph of Miocene basalt from Jackson Falls quarry, Washington County. The basalt is made up of labradorite laths, augite, magnetite and glass, and has an intersertal texture similar to those shown in Figures 2 and 3. Plain light. Approx. X 45.

plagioclase laths of the original basalt have been replaced by gibbsite and the residual grains of magnetite retain their original arrangement.

Gibbsite also occurs as a cavity lining in some of the interoölitic areas. These areas are made up largely of gibbsitic material similar in appearance to that of the non-opaque oölites but part is made up of gibbsitic material with a concentric structure and little residual magnetite. Some of the interoölitic areas also contain reddish-brown aggregates of radially arranged fibers with a botryoidallike structure. The fibrous aggregates are probably largely goethite. They appear to constitute the initial fillings between some of the oölites. Magnetic secondary iron oxide similar to that in the opaque cores of some oölites forms a network in some of these aggregates, and gibbsite occurs as a filling within some of them.

Petrographic examination of material from the hard pisolitic horizon at Locality 23 shows that the hard magnetic concretions are predominantly a mixture of magnetite, limonite (including goethite), and brown isotropic material with an index of about 1.71 to 1.72. As no well-defined isotropic, iron-aluminum mineral has a similar index, the material is thought to be an intimate mixture of hydrous ferric and aluminum oxides. Possibly it is cliachite mixed with an iron sesquioxide, such as the material referred to as hematogelite. The concretions also contain a minor amount of gibbsite as well as a minor amount of unidentified material which is probably partially corroded magnetite. The matrix of the concretionary ore is more uniform in composition and is only very slightly magnetic. It is made up largely of the isotropic iron-aluminum material described above as occurring in the concretions. Limonite is a much less important constituent, and probably other minerals are present in small amounts.

Spectrographic analysis of the oölites obtained from a sample at the Hendrickson deposit (Locality 5) shows that they contain more than 10 percent both of iron and of aluminum with the percentage of iron much the greater, approximately 4 percent silica, and about 3 percent titanium. Analysis of the matrix shows the presence of the same elements, and although the aluminum and iron are both more than 10 percent, the percentage of aluminum is greater than the iron. The concretions as well as the matrix contain water of hydration.

In the nodular type of ore from Locality 9 the nodules are quite hard but when broken show patches made up of lighter brown or buff, sometimes gray or nearly white, porous earthy material that is made up mainly of cliachite (?) and gibbsite. The frontispiece, Plate I, figure 2, shows one of the nodules from this locality. The index of the cliachite (?) is about 1.62 to 1.63 which is a little higher than the range usually given for it. Only a few of the nodules contain scattered, hard, dark-colored oölites. However, examination of a thin section of one nodule shows that it contains both oölitic and colloform structures with residual grains of magnetite.

A thin section of a porous, limonitelike specimen from Locality 5 has a colloform structure. It is made up of anisotropic material with an oölitic texture and contains numerous residual grains of magnetite. Chemical analysis shows its similarity in composition to the typically oölitic specimens and it is probably a mixture of iron oxide and gibbsitic material.

The composition of the oölitic and pisolitic variety of ore is fairly well represented by 9 feet of oölitic material in hole 44 at Locality 8. Here the ore is similar to that of the somewhat softer, porous nodular type, but is not as high in alumina as that of the porous granular type found as float at localities 16 and 30. Analyses fairly representative of these two different textural types are shown below:

	Oölitic type (Locality 8, hole 44)	Porous, granular type (Locality 16)
Al_2O_3	36.47 %	56.31 %
Fe	21.65	13.54
SiO_2	7.99	5.30
TiO_2	3.23	2.73
Ign. loss	23.05	24.86

Examination of a thin section of the porous granular type of ore from Locality 30 shows that much of the original texture of the basalt from which it was derived has been preserved. Photomicrographs of this section and one of fresh Miocene basalt from Jackson Falls quarry, Washington County, are shown in Plate II, figures 2 and 4 respectively, opposite page 16. The numerous residual skeleton crystals of magnetite in the porous granular ore retain their original arrangement. The original laths of plagioclase as well as the other constituents have been largely replaced by aggregates of gibbsite. Reddish-brown birefringent iron oxide, probably goethite, is a lesser constituent. Chemical analysis of ore from this locality shows that it contains 46.84 percent alumina, 9.81 percent iron, and 7.26 percent silica.

Pieces of gibbsite and high-alumina limonite are found as float at several of the localities, and chunks of gibbsitic material, in place, have been found at localities 23 and 24. Analyses of some of the gibbsitic pieces show that they contain more than 60 percent alumina.

A cross section or profile of the laterite, representative of the deposits examined, may not be given from the amount of exploration work so far completed. Where the profile could be determined from exposures and drill logs, the upper ore horizon in most places has a quite well-defined oölitic or pisolitic texture. At places as at localities 5, 8, and 21, the oölitic part of the ore is more than 13 feet thick.

In several places where the profile is known the concretionary variety is directly underlain by laterized basalt. At Locality 23 the material beneath the oölitic horizon resembles badly weathered basalt, and there is little doubt that it was derived from basalt.

Although the silica content of the weathered basaltic material tends to increase with depth at Locality 23, and the part sampled is of lower grade than the overlying pisolitic horizon, the laterized basalt includes pieces of gibbsitic material containing more than 60 percent alumina.

Elsewhere the material underlying the hard oölitic and pisolitic horizon has a similar chemical composition but it may have a somewhat lower silica content and a higher percentage of alumina. The material of this horizon is usually a brown, rather soft and earthy material with much harder, irregularly shaped, nodules.

One hole drilled at the Hutchison-Nixon deposit (Locality 8) penetrated 20 feet of ore which contains 38.46 percent alumina, 21.00 percent iron, and 6.82 percent silica. The hole bottomed in ore. The upper oölitic horizon is about 10 feet thick and the lower predominantly non-oölitic horizon is at least 10 feet thick. The silica content of 2½ feet of material 8 feet below the top of the ore was 11.48 percent which is 4 percent more than the samples above and below.

In the cut made at the Hendrickson deposit (Locality 5), more than 9 feet of non-oölitic material has a silica content less than 6 percent and an alumina content of about 38 percent. This material is earthy in texture with numerous hard, irregularly shaped nodules of which some are light-colored and gibbsitic. Probably most of this material underlies about 15 feet of ore encountered in hole 7, nearby, which bottomed in ore. At least 5 feet of the upper 10 feet of ore in hole 7 is oölitic. The total thickness of ore in this vicinity is probably more than 20 feet. The material in the bottom of the cut contains 17 percent silica and it becomes more siliceous with depth.

The reason for the difference in texture of the ore is as yet unknown. As may be seen from the descriptions of the ore at the various localities, the oölitic or pisolitic type is common, and further work may show that many of the deposits have similar profiles. The difference in texture of the ore within a deposit may be marked; the profiles of the several deposits whose profiles are known may be quite similar. The difference in texture of the ore within a single deposit might be partially explained by the effect of laterization on different flows. Although a slight difference in the texture and composition within a single basalt flow and among separate flows might result in a variation in the texture of the ore, this difference is not thought to be the true explanation. The difference in texture of the ore is characteristic of deposits that are widely separated, and such textural and compositional differences in the flows would have had to be present in all of them. Such factors as groundwater level and its seasonal fluctuations may be the most important in effecting the textural differences. The inclusions of oölites within pisolites, and they in turn within larger concretions, show that the ores accumulated over a long period of time. The oölitic or pisolitic section probably represents a zone of

concentration in part by concretion, whereas the underlying section may represent a zone of concentration largely by leaching.

Concentration by both of these processes appears to have taken place in several of the deposits. At Locality 23, the combined alumina and silica content of the pisolitic horizon is about 40 percent (33.20% Al_2O_3 and 6.36% SiO_2) whereas that of the underlying weathered basalt is about 53 percent (38.48% Al_2O_3 and 14.34% SiO_2). The iron content of the pisolitic horizon is 27.83 percent whereas that of part of the underlying horizon is only 19.07 percent. Both horizons have a similar ignition loss.

Thus while leaching of silica from a lower horizon was taking place, iron probably was being added to the overlying horizon. The retention of the original intersertal texture in the porous granular type of ore by replacement of the original constituents with gibbsite indicates that aluminum hydroxide was added to the lower zone from above.

Spectrographic analyses of fairly representative samples of ore from localities 5, 8, and 21 are listed below:

Percentage	Elements*		
	Locality 5 1/	Locality 8 2/	Locality 21 3/
Greater than 10%	aluminum iron	aluminum iron	aluminum iron
1 - 10%	titanium silicon	titanium silicon	titanium silicon
0.1 - 1%	magnesium		
0.01 - 0.1%	manganese zirconium vanadium	manganese zirconium vanadium magnesium barium	manganese zirconium vanadium chromium arsenic
0.001 - 0.01%	chromium barium strontium	chromium	magnesium
Less than 0.001%	molybdenum	molybdenum	molybdenum barium boron

* Small percentages of phosphorus and sulfur were shown to be present by other qualitative methods.

1/ A 43-inch channel from the lower part of the Hendrickson cut.

2/ Composite sample representing 20 feet of ore from hole 50.

3/ A 2.4-foot sample of the hard pisolitic horizon.

Character of the ore at each locality is given later under Description of Deposits.

Origin of the ore

As stated previously the ferruginous bauxite deposits are of lateritic origin, and were formed by the laterization of Columbia River basalts of Miocene age. The origin of these ores is different from that of the Scappoose limonite deposits in Columbia County which were formed in bogs. The Scappoose-type limonites contain much less alumina, more phosphorus and somewhat less titania. The association of sedimentary material and petrified wood with some of the limonite deposits and their stratigraphic position within the basaltic section indicate that they were formed in a different environment and prior to the ferruginous bauxite. Although limonitic material occurs in some of the ferruginous bauxite deposits, the samples analyzed show that it contains a much higher percentage of alumina than the Scappoose type.

Much additional evidence besides the confinement of the ferruginous bauxite deposits to the top of the section of Miocene basaltic terrane indicates that they were derived from the basalt by laterization. Road cut exposures and drill logs show that there is a gradation from bauxitic material to altered basalt. The road cut at Locality 32 shows the original vesicles in the basalt and a spheroidal weathering pattern; that at Locality 4 shows a suggestion of such a pattern. Residual magnetite grains are present in the deposits and some of the grains still retain part of their original crystal outlines. The oölitic or pisolitic and nodular texture of the ores in Washington and Columbia Counties together with the mixed composition and colloform structure of both the oölites and matrix, suggest their colloidal nature and their derivation from basalt. One specimen of oölitic ferruginous bauxite contains inclusions of altered basalt which retain much of their original texture. The porous granular ferruginous bauxite retains much of the original texture of the basalt including the original arrangement of the residual grains of magnetite.

Spectrographic analyses of the ferruginous bauxite from three different deposits show that it contains all the metallic elements present in a specimen from the Miocene basalt series. One of the ferruginous bauxite samples analyzed showed between 0.1 and 0.01 percent arsenic and 0.01 to 0.001 percent boron. Presence of these elements not found in the specimen of basalt analyzed can not now be explained. Nevertheless the presence of 12 elements in the ore which are also present in the basalt similar to those from which the ore was supposedly derived, is undoubtedly more than coincidence.

In summary it seems fairly well established that laterization was accomplished by the leaching action of ground waters which removed silica and other non-aluminous constituents. Much of the silicon and magnesium, and all the calcium and sodium present in the Miocene basalts were thus removed. The laterization in Washington, Multnomah, and Columbia Counties appears to have taken place following the extrusion of the Miocene lavas and prior to their folding which is assigned to the Pliocene. At that time the surface of the basalts probably had a much lower average elevation than now. Additional information on the laterization of the basalt is given on page 12.

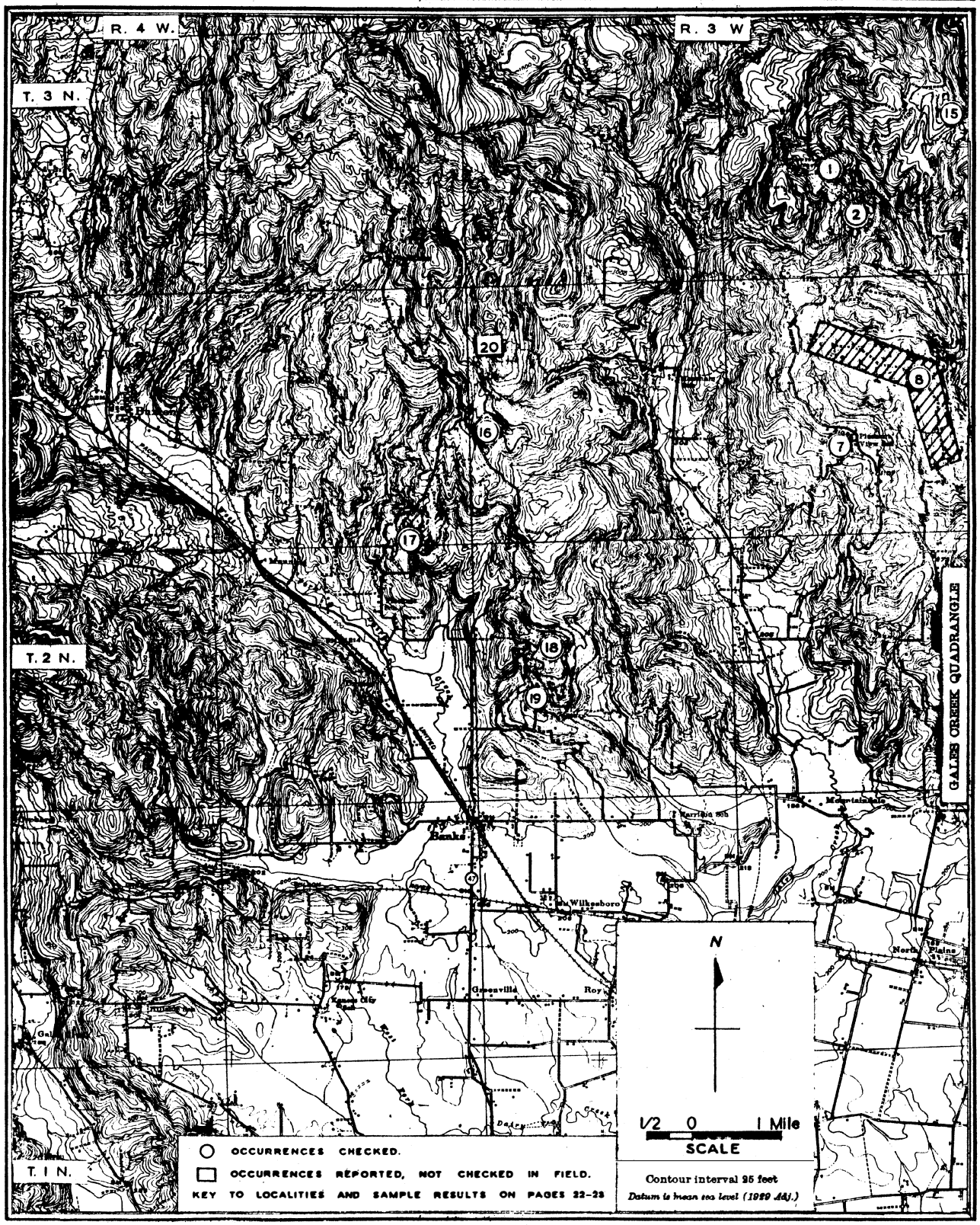
Key to Deposits Shown on Locality Maps
(See pages 24-27)

Locality No.	Map	Name	Type of Sample*	Al_2O_3	Fe	SiO_2	TiO_2	Ign. loss	
1	A	Locality 1	(2)	28.48	13.54	16.80	----	----	
2	A	Railroad Cut			Not analyzed				
3	B	Lazy "W" Ranch			Not analyzed				
4	B	Locality 4			Not analyzed				
5	B	Hendrickson & Extension	(2)	31.85	25.95	8.95	4.5	18.0	(av.)
6	B	Nelson	(2)	32.52	21.66	12.97	----	----	(av.)
7	A	Pearl Smith			Not analyzed				
8	A	Hutchison-Nixon	(2)	34.33	24.46	8.64	----	----	
9	B	Parmele	(2)	32.62	24.22	8.52	----	----	
10	B	Jacobs			Not analyzed				
11	B	Cathey	(2)	22.33	15.93	40.35	----	----	
12	B	Leitzel	(2)	42.08	19.32	8.30	----	----	
13	B	Berger	(3)	34.08	30.41	5.12	4.12	16.57	
14	B	Mrs. A. & Edw. Anderson	(3)	56.36	8.95	3.90	2.89	27.95	
			(3)	44.24	22.26	5.84	2.25	23.37	
15	A	C. E. Ferguson	(3)	22.80	32.08	2.07	5.67	----	
16	A	Bald Mt.	(3)	56.31	13.54	5.30	2.73	24.86	
17	A	Locality 17	(3)	40.28	22.06	6.42	4.49	18.22	
18	A	H. Davies	(3)	31.44	29.31	4.25	4.81	18.17	
19	A	H. Davies	(3)	30.48	29.07	3.39	4.65	18.51	
20	A	Locality 20			Not sampled				
21	B	Gus Nelson			Not sampled				
22	C	E. M. Lambert	(3)	39.95	15.04	16.76	----	----	
23	C	Yankton Railroad Cut	(1)	35.50	26.52	6.66	5.72	16.79	
24	C	John Gaman	(3)	41.11	21.17	7.48	6.11	18.50	
25	C	John Marshall	(3)	22.84	37.59	4.00	4.16	17.97	
26	C	Locality 26			Not analyzed				
27	C	John Gentry	(3)	30.52	29.59	8.08	5.76	16.03	
28	C	Dark Creek Road	(1)	35.56	24.22	6.60	4.50	18.71	
29	C	Happy Hollow School			Not sampled				
30	D	Locality 30	(3)	46.84	9.81	7.26	----	----	
31	D	Fern Hill School	(3)	54.72	8.97	6.70	3.53	29.16	
32	D	U.S. Highway 30, Rainier	(1)	36.12	16.51	21.66	3.37	17.50	
33	D	Locality 33			Not analyzed				
34	B	Locality 34			Not analyzed				
35	C	Locality 35	(3)	22.35	43.65	1.77	2.98	11.85	

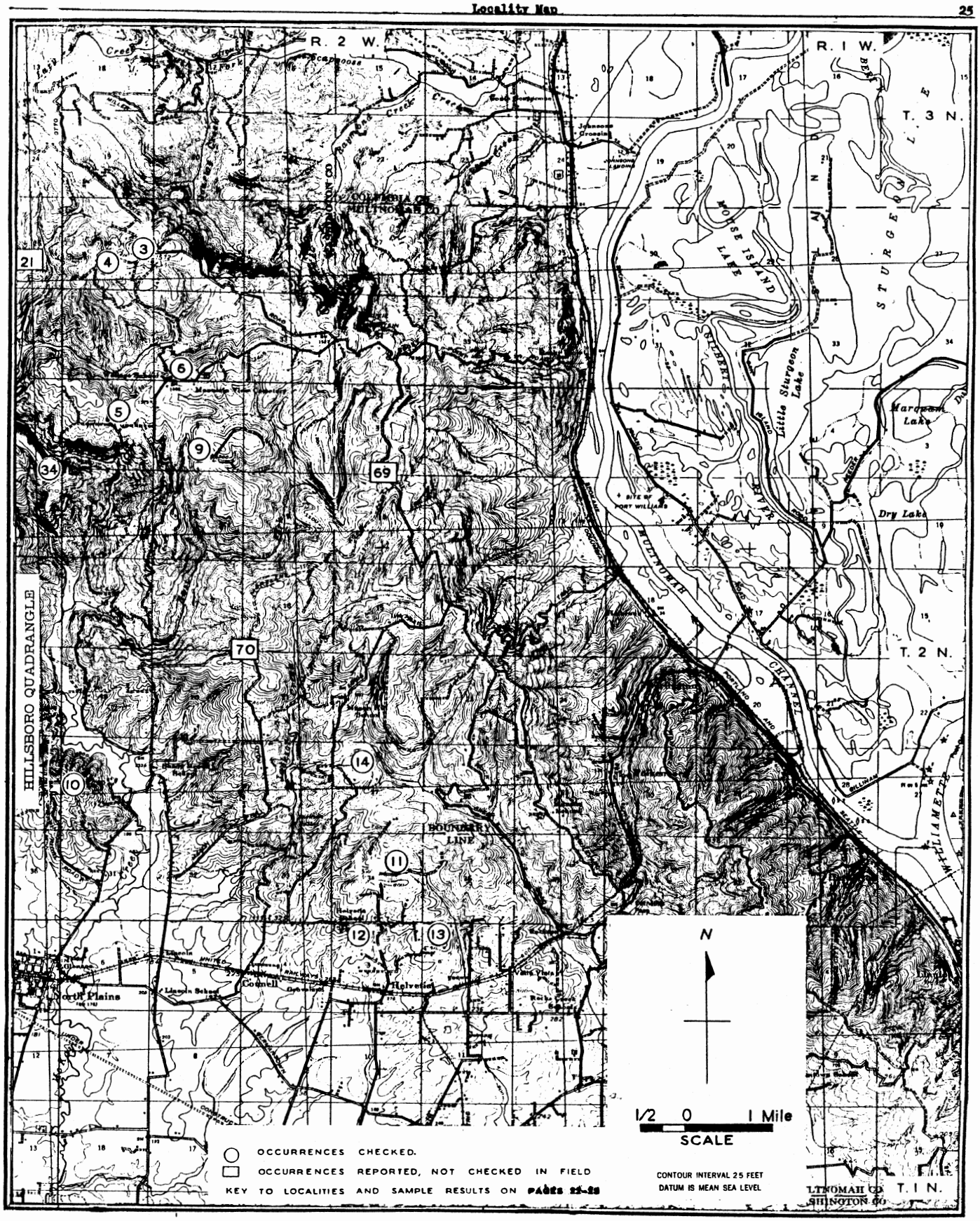
*(1) Channel (2) Drill hole (3) Other

Locality No.	Map	Name	Type of Sample	Al_2O_3	Fe	SiO_2	TiO_2	Ign. loss
36	C	Colport Development Co.			Not sampled			
37	C	Locality 37			Not sampled			
38	C	Oester Road	(1)	38.80	23.46	6.29	1.49	20.65
39	C	Locality 39	(3)	44.47	18.36	5.09	2.08	22.69
40	C	Locality 40	(3)	35.32	17.94	11.21	2.68	21.01
41	C	Locality 41			Not analyzed			
42	C	Locality 42	(3)	33.50	31.66	2.32	2.58	17.73
43	C	Locality 43			Not sampled			
44	C	Locality 44	(1)	36.42	23.83	10.87	1.98	19.18
45	C	Locality 45			Not sampled			
46	C	Locality 46			Not sampled			
47	C	Locality 47			Not sampled			
48	C	Locality 48			Not sampled			
49	C	Locality 49			Not sampled			
50	C	Bunker Hill			Not sampled			
51	C	Serafin			Not sampled			
52	C	Locality 52			Not sampled			
53	C	Trenholm			Not sampled			
54	C	Locality 54			Not sampled			
55	C	Locality 55			Not sampled			
56	C	Locality 56			Not sampled			
57	C	Ironcrest Limonite			Not sampled			
58	C	Ironcrest			Not sampled			
59	C	Ladysmith			Not sampled			
60	C	O. E. DeVaul			Not sampled			
61	C	Spitzenberg			Not analyzed			
62	C	Locality 62	(1)	44.52	12.53	14.30	----	----
63	C	Langlie Place			Not sampled			
64	C	Locality 64			Not analyzed			
65	C	Locality 65	(3)	52.73	6.37	10.99	2.06	26.61
66	C	Oregon Charcoal Iron Co.			Not sampled			
67	C	Locality 67			Not sampled			
68	C	Maple Hill			Not sampled			
69	B	Skyline Blvd.			Not analyzed			
70	B	Moreland Road			Not sampled			
71	*	Chehalem Mts.	(3)	32.80	20.65	13.31	4.27	----
72	*	Chehalem Mts.	(3)	40.35	21.34	3.08	4.46	----

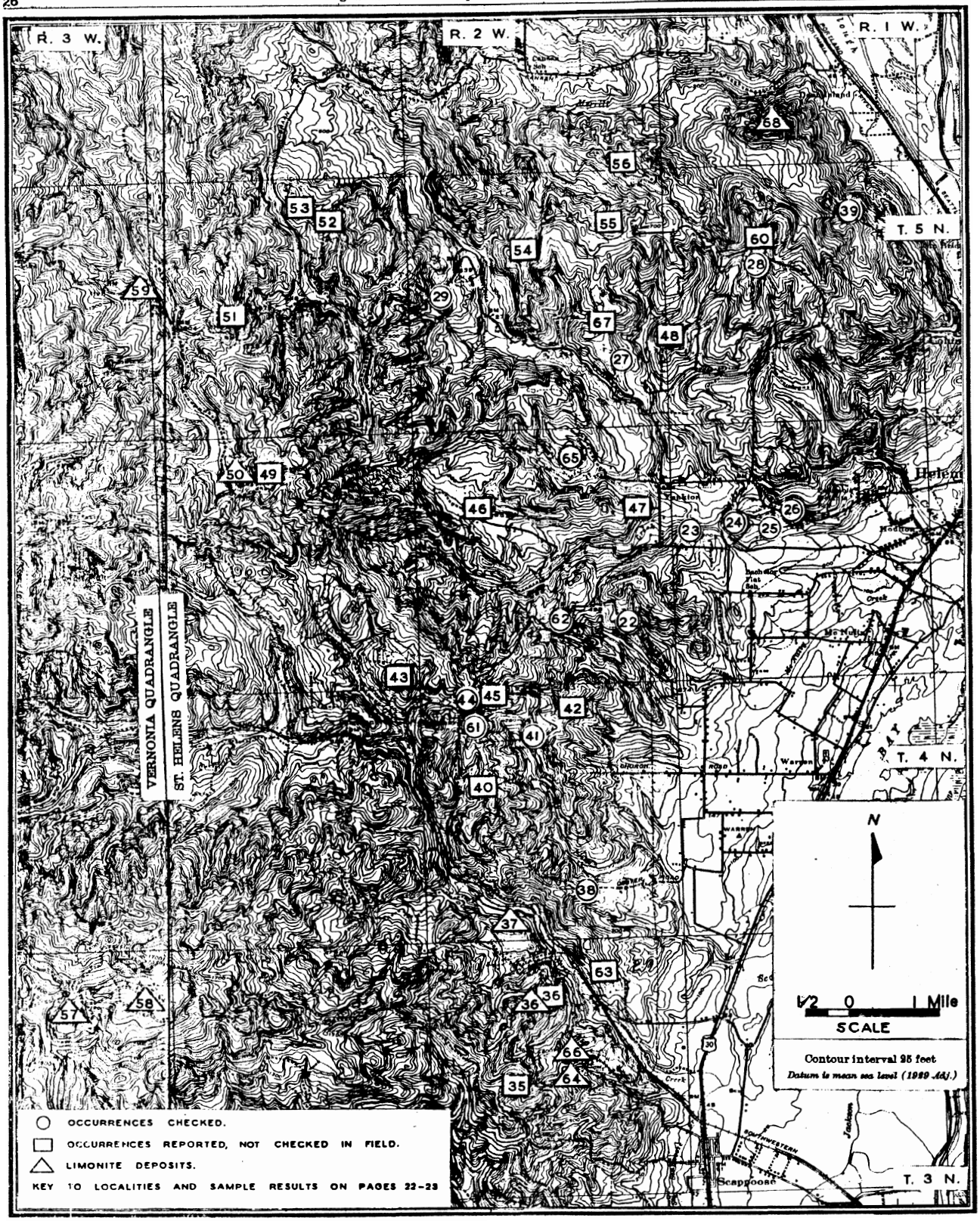
* In Tualatin quadrangle and not shown on any locality map. See index map page 5.



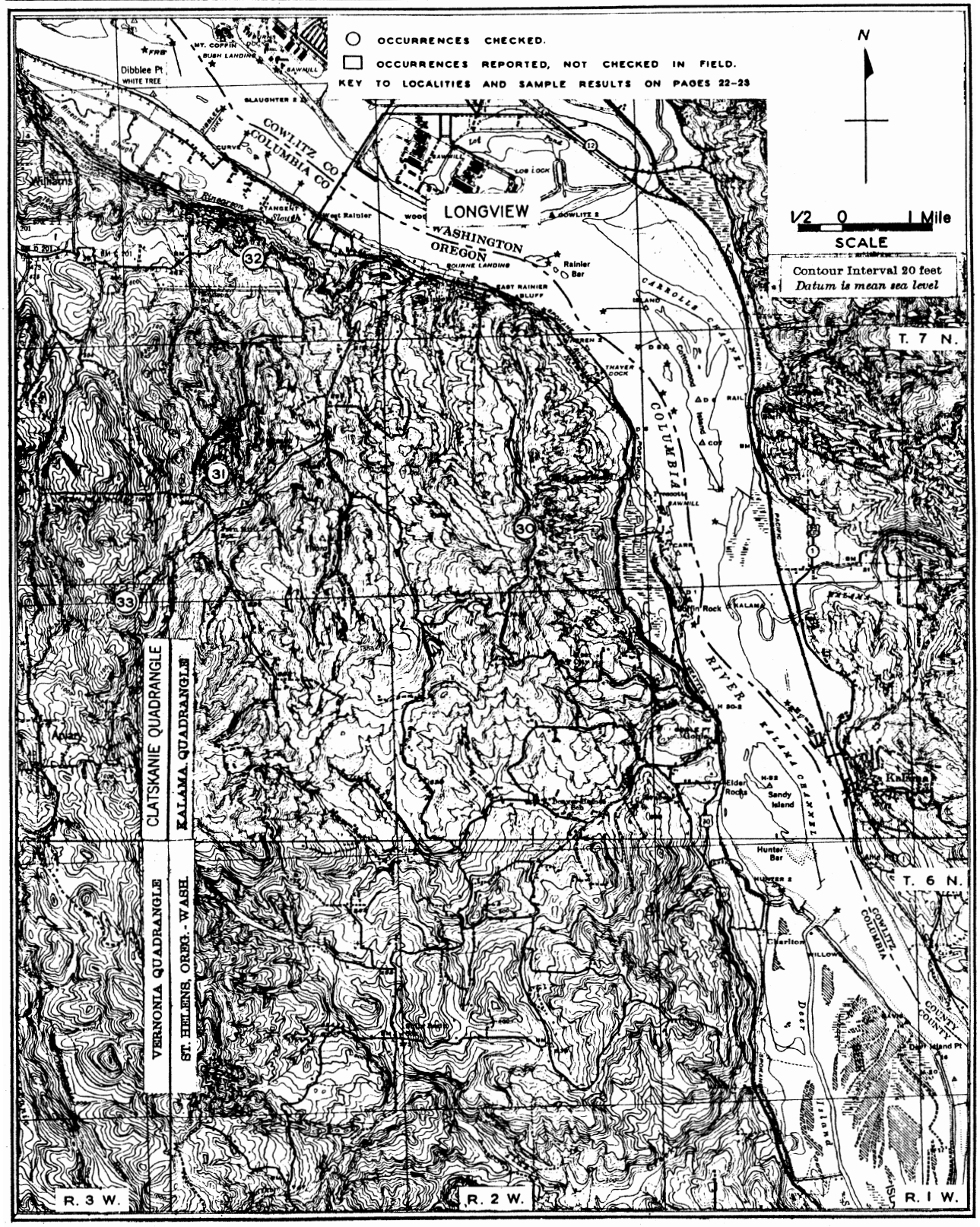
Locality Map A
North-Central Washington County, Oregon
Showing Generalized Location of Ferruginous Bauxite Deposits
Topog. Base by U.S.G.S. and 29th Engineers U.S. Army



Locality Map B
Northeastern Washington County, Oregon
Showing Generalized Location of Ferruginous Bauxite Deposits
Topog. Base by U.S.G.S. and 29th Engineers U.S. Army



Locality Map C
Southeastern Columbia County, Oregon
Showing Generalized Location of Ferruginous Bauxite and Limonite Deposits
Topographic Base by U.S.G.S. and 29th Engineers U.S. Army



Locality Map D
Northeastern Columbia County, Oregon
Showing Generalized Location of Ferruginous Bauxite Deposits
Topog. Base by U.S.G.S. and 29th Engineers U.S. Army

Description of Deposits in Washington, Multnomah, and Columbia Counties

Locality 1, Gales Creek quadrangle

This deposit is 4.6 miles north of the Pleasant View School on the Pumpkin Ridge Road at an elevation of about 1600 feet. A drill hole penetrated 9 feet of reddish-brown material having the following analysis:

Al_2O_3	28.48 %
Fe	13.54
SiO_2	16.80

Nodular type ore was found on the surface near the road.

Locality 2, Railroad Cut, Gales Creek quadrangle

This locality, 4.0 miles north of Pleasant View School by the way of the Pumpkin Ridge Road, is at an elevation of 1550 feet. The bottom of an old railroad cut, about 15 feet deep, shows a 3-foot layer of reddish-brown claylike material containing pieces of typical oölitic ore as much as 4 inches in diameter. No analysis of the material has been made.

Locality 3, Lazy "W" Ranch, Hillsboro quadrangle

Several feet of ferruginous bauxite containing gibbsite nodules is exposed in the road cut just north of the house in the SE¼ sec. 30, T. 3 N., R. 2 W., at an elevation of about 1575 feet. Oölitic ferruginous bauxite occurs as float in the saddle west of the house. No analysis of material from either place has been made.

The weathered basalt associated with the ferruginous bauxite exposed in the cut appears to have a spheroidal weathering pattern.

Locality 4, Hillsboro quadrangle

This locality is about half a mile west of the house at Locality 3. Oölitic ferruginous bauxite and associated limonitic concretions as much as 6 inches in diameter, have been taken from prospect holes in the NE¼ SW¼ sec. 30, T. 3 N., R. 2 W., near the head of a small creek which flows southeast. The ore is at an elevation of about 1550 feet which is a little below the top of the hill. No analysis of the ore has been made. The limonitic concretions, although they resemble the Scappoose limonite, are very similar to those which occur at Locality 23, south of Yankton in Columbia County, in that both have a "wormy" texture. Those from the Yankton area contain as much as 20 percent Al_2O_3 and 34.68 percent iron.

Locality 5, Hendrickson and Hendrickson extension, Hillsboro quadrangle

The Hendrickson farm on Dixie Mt. Road is in the N½ sec. 6, T. 2 N., R. 2 W., at an elevation of about 1300 feet. It was selected for the first exploration project because of its accessibility and also because exposures of the ore formation along an old logging railroad grade indicated a possible large tonnage. Preliminary sampling of the exposures which represented only the top of the ore bed gave the following results:

(Analyses by Lerch Bros., Hibbing, Minnesota)

Sample (A) In railroad cut (1500 N - 4000 E). A 4-ft. channel sample of nodular type ferruginous bauxite.

Alumina	(Al_2O_3)	34.60 %
Iron	(Fe)	28.26
Silica	(SiO_2)	6.22
Phosphorus	(P)	0.170

Sample (B) In railroad cut (1900 N - 5100 E). Top foot of the oölitic ore bed sampled.

Alumina	(Al_2O_3)	24.59 %
Iron	(Fe)	40.92
Silica	(SiO_2)	3.58
Phosphorus	(P)	0.092
Titania	(TiO_2)	4.02

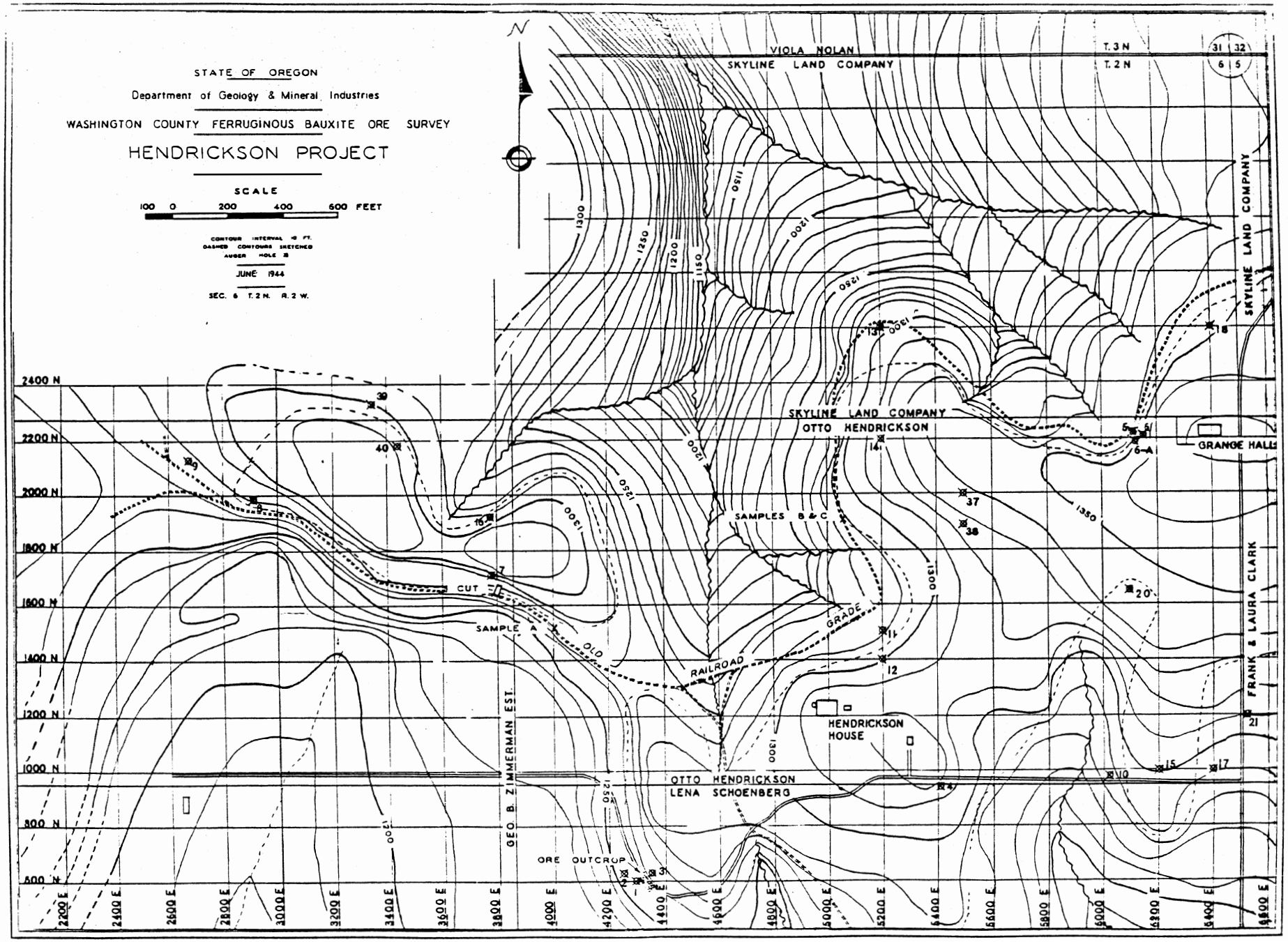
Sample (C) Same location as (B). A 4-ft. channel sample of red silty clay overlying (B).

Alumina	(Al_2O_3)	23.41 %
Iron	(Fe)	14.13
Silica	(SiO_2)	38.27
Phosphorus	(P)	0.098
Titania	(TiO_2)	3.22

A plane-table survey of the Hendrickson locality was made in 1944 and 29 holes were drilled using hand augers and chopping bits for the purpose of sampling the deposit. The topography and the location of drill holes and cuts are shown on the map opposite page 31.

It is believed that some of the holes in ore showed relatively high silica results because too much of the overlying reddish clayey silt was included in the samples.

The material near the bottom of the cut, which is about 35 feet S. 65° E. of hole 7, contains gibbsite in addition to limonite and a minor amount of magnetite. The silica content of this earthy material is somewhat lower than that of the average ore. Analyses of samples from this cut were not included in the calculations of average grade of the deposit. The cut was made to determine the characteristics of a section of the ore, and was sampled to obtain the volume-weight factor for tonnage calculations. Analyses and description of the material in the cut follows:


STATE OF OREGON
Department of Geology & Mineral Industries
WASHINGTON COUNTY FERRUGINOUS BAUXITE ORE SURVEY
HENDRICKSON PROJECT
SCALE
100 0 200 400 600 FEET
CONTOUR INTERVAL 10 FT.
DASHED CONTOURS SKETCHED
AUGER HOLE 25
JUNE 1944
SEC. 6 T. 2 N. R. 2 W.
N
VIOLA NOLAN
SKYLINE LAND COMPANY
T. 3 N
T. 2 N
31 32
6 5
SKYLINE LAND COMPANY
SKYLINE LAND COMPANY
OTTO HENDRICKSON
GRANGE HALL
SAMPLES B & C
CUT
SAMPLE A
OLD RAILROAD GRADE
HENDRICKSON HOUSE
OTTO HENDRICKSON
LENA SCHOENBERG
GEO. B. ZIMMERMAN EST.
FRANK & LAURA CLARK
ORE OUTCROP
2400 N
2200 N
2000 N
1800 N
1600 N
1400 N
1200 N
1000 N
800 N
600 N
2200 E
2400 E
2600 E
2800 E
3000 E
3200 E
3400 E
3600 E
3800 E
4000 E
4200 E
4400 E
4600 E
4800 E
5000 E
5200 E
5400 E
5600 E
5800 E
6000 E
6200 E
6400 E
6600 E

Sample No.	Thickness	Al_2O_3	Fe	SiO_2	Ign. loss	Moisture	Description
	0' - 3'	(Not sampled)					Red clayey silt.
P-2473	3' - 9'	36.48	23.25	5.70	19.8	17.5	Hard reddish-brown ore.
P-2474	9' - 12'7"	42.92	15.81	5.74	----	21.2	Dark reddish-brown ore with gray gibbsitic nodules and white specks.

An arithmetical average analysis of samples of ore from holes drilled on the Hendrickson place is:

Alumina	(Al_2O_3)	31.85 %
Iron	(Fe)	25.95
Silica	(SiO_2)	8.95
Phosphorus	(P)	0.140
Titania	(TiO_2)	4.5
Ign. loss		18.0
Moisture		19.0

The area underlain by ore on the Hendrickson farm is approximately 64 acres. The volume-weight factor for ore in place has been determined as 17 cu. ft. per long ton. Using this factor, the Hendrickson farm would contain in round figures 2500 tons per acre-foot. The average arithmetical thickness of the ore sampled, using 11 holes in ore, is approximately 11 feet; therefore, 1,760,000 long tons of ore (natural basis) is indicated for the Hendrickson property alone. The earthy material underlying the hard ore was thought to be largely clay at the time most of the sampling was done. Since then it has been found that in places this material is bauxitic, and it is probable that further drilling will prove a greater thickness of ore than used in the calculations.

Five of the holes were drilled just south of the Hendrickson farm on the Schoenberg property which adjoins it. Results of this drilling indicate that the same ore body underlies a portion of the Schoenberg farm, although the areal extent is small because of the nature of the terrain.

Hendrickson extension

This locality owned by the Geo. B. Zimmerman Estate lies on land immediately northwest of the Hendrickson deposit and is separated from it by a narrow saddle.

A drill hole penetrated 13 feet of oölitic ore which gave the following values:

Al_2O_3	36.60 %
Fe	23.49
SiO_2	6.94

Any estimate of the extent of this ore body is difficult due to insufficient exploration. However, a flat-topped area possibly 50 acres or more in extent may be underlain by ore.

Locality 6, Nelson deposit, Hillsboro quadrangle

A quarter of a mile northeast of the Hendrickson locality at a somewhat greater elevation (about 1400 feet), six auger holes were put down on the Nelson farm in the SW¼ sec. 32, T. 3 N., R. 2 W. The ore deposits on these two farms, although not connected, could easily be served by one mining operation.

Average analysis of ore from 3 drill holes is as follows:

Al_2O_3	32.52 %
Fe	21.66
SiO_2	12.97

Reserves, based on a 10-foot average thickness of ore for the area lying between the holes in ore are estimated to be 175,000 long tons. By deepening 3 other holes which failed to encounter ore, an additional tonnage might be proved. Increase in areal extent might also be shown by additional drilling. A well at the Dudley house southwest of the Nelson farm and 200 feet southeast of the Wallace School cut several feet of oölitic ore at a depth of about 25 feet. No accurate measurement could be made due to inaccessibility of the well. A petrographic examination of a sample of claylike material from the well dump showed the material to be largely a mixture of gibbsite and limonite. Spectrographic analysis showed the material was mainly aluminum and iron with about 5 percent each of silica and titania.

The silt overlying the ore body is the same as that on the adjoining Hendrickson farm. The horizon of the ore in the drill holes on the Nelson farm is nearly the same as would be obtained by projecting the 1° - 2° dip of the hard ore northeastward from the Hendrickson ore body. Although these two ore bodies were undoubtedly connected originally, they are now separated by the saddle which crosses the road between Wallace School and the Grange Hall. A hole drilled just east of the road at the lowest point in the saddle was in silt which was deposited after erosion had removed the ore. Another hole drilled 120 feet south of a point midway between holes 24 and 25 was likewise barren of ore.

Locality 7, Pearl Smith, Gales Creek quadrangle

This occurrence is on the Pumpkin Ridge Road 0.45 mile north of the Pleasant View School, at an elevation of 1175 feet. Oölitic type float is found both north of the Smith house and in a draw a short distance to the southwest. A well has been dug back of the house at the old Epler place on the other side of the road from, and a short distance north of the Smith house. Oölitic type ore was found on the dump and may be seen also on the walls of the well shaft.

Locality 8, Hutchison-Nixon project, Gales Creek quadrangle

As stated in the Introduction, an area containing the Hutchison and Nixon properties was selected for further exploration by auger hole drilling. These properties were briefly described in G.M.I. Short Paper No. 12.

The area is 14 miles north of Hillsboro and 8 miles north of North Plains by the way of Pumpkin Ridge Road. Elevation of the area ranges from 1100 to 1300 feet. Legal description is secs. 1 and 2, T. 2 N., R. 3 W., and secs. 34, 35, and 36, T. 3 N., R. 3 W. Branch roads, as shown on the localities map, connect the Pumpkin Ridge Road with the area. The Hendrickson deposit lies to the east across McKay Creek.

Preliminary work on the project included plane-table mapping of more than 325 acres on a scale of 200 feet to the inch, with a 10-foot contour interval (see map in pocket). An additional surrounding area, as shown on the map, was sketched in to show drainage.

Drilling of the deposit was done by hand with 2-inch and 3-inch "Iwan" soil augers[1]. Some hard ribs in the ore were encountered which required the use of a chopping bit. More than 230 samples were taken from 23 drill holes totalling 692 feet. As the ore in the auger sample was difficult to distinguish from iron-stained silt which overlies the ore, and from altered basalt into which the ore grades, samples were over 2-foot intervals, but where there was doubt as to the character of material penetrated, samples were taken at 1-foot intervals.

In several holes concentrations of magnetic oölites were encountered in the silt overburden several feet above the ore zone and also above the basalt where the ore was missing. This oölitic material closely resembled the underlying ore and could be regarded as ore except for the high silica content. Petrographic examination of the magnetic oölites shows that they contain included grains of quartz and feldspar $\pm$ 0.08 mm in diameter. These grains are similar to those in the non-oölitic part of the silt and their presence suggests the development in the silt of magnetic oölites of secondary iron oxide.

Cross sections through the deposit showing the relationship between the overlying silt, the ore body, and the underlying basalt are shown in figures 1, 2, and 3 on pages 37, 38, and 39. Although the drill holes are spaced too far apart to determine accurately the outline of the ore body and the thickness of the silt mantle, it is believed that the relationships shown are essentially correct.

The ore body is similar in thickness, attitude, and composition to that at the Hendrickson farm (Locality 5) which lies 1½ miles to the east. The ore is oölitic and pisolitic for the most part, with the lower portion of the bed somewhat less gritty and of a porous-granular texture. The narrowness of the ridge prevented a desirable location for all the drill holes, and thus it was difficult to determine the attitude of the sheetlike ore body, which strikes about N. 85° W. and dips approximately 1° - 3° to the south.

---

[1] "Auger Hole Prospecting", THE ORE.-BIN, December 1944.

Description and analyses of the material in hole 50 which encountered the thickest section of ore follows:

Hole 50

Sample width	Al_2O_3	Fe	SiO_2	TiO_2	Ign. loss	Description
0' - 20'		Not analyzed				Buff and red silty clay with few magnetic oölites, some yellow spots.
20' - 24'	22.76	6.10	57.94	----	10.26	Brick-red clay, few oölites.
24' - 27'	27.28	10.43	44.30	2.84	13.47	Brick-red clay, few oölites.
27' - 32'	36.20	18.04	15.94	----	20.91	Hard, brick-red clay, magnetic oölites and pisolites.
30' - 32'	42.72	19.38	5.54	----	----	Top of ore. Hard, brick-red, oölitic, spotted.
32' - 36'	39.20	23.70	5.76	4.45	23.92	Hard, brick-red and varicolored, gritty, oölitic.
36' - 36'6"	41.00	20.87	6.14	----	23.44	Firm, red-brown, slightly oölitic; thin layer of olive drab, gritty, oölitic.
36'6" - 39'	38.40	18.06	11.48	5.31	21.52	Hard, brown, gritty, slightly oölitic.
39' - 41'	37.88	21.61	7.50	5.55	21.54	Firm, brick-red, sandy textured with oölites.
41' - 42'	34.68	22.49	8.70	4.18	19.04	Firm, brick-red, sandy, slightly oölitic.
42' - 43'	36.92	23.04	3.64	----	23.65	Firm, light brick-red, sandy, non-oölitic.
43' - 44'	34.36	21.25	4.00	----	24.11	Hard, brick-red, gritty, non-oölitic.
44' - 45'	34.72	22.26	7.70	----	20.04	Hard, brick-red, gritty, non-oölitic with white spots.
45' - 49'	39.76	19.01	5.76	----	24.60	Firm, varicolored, gritty, lumpy, spotted.
49' - 50'	34.96	22.48	8.56	----	21.96	Firm, varicolored, olive-drab, spotted.
(Bottomed in ore)						
Weighted Average	38.46	21.00	6.82	----	----	20 feet of ore (30' - 50')

A bed of massive, dark-brown limonite more than 2 feet thick crops out near the bottom of the gully directly below hole 32. The limonite is weakly magnetic, has no oölites, and is typical of the limonite ribs of the Scappoose area. A sample returned 51.34 percent iron, 5.64 percent alumina, and 4.53 percent silica. The outcrop is apparently stratigraphically below a bed of oölitic, high-alumina ore. An indication of the depth to which the basalt underlying the ore zone has been altered is revealed by the outcrop of hard, unaltered basalt in the side of the gully 200 feet vertically below the bottom of the ore in hole 62.

Profiles of all the holes which encountered ore, and the average weighted analysis of the ore are given in figures 4, 5, 6, and 7, on pages 40, 41, 42, and 43. A summary of the holes in ore, giving acreage and acre-feet for each hole, together with average analysis of the ore and depth of overburden is given on page 36.

The Hutchison-Nixon deposit is about 8 miles from the nearest railhead at North Plains on the United Railway (S.P.& S.) line. The nearest probable plant site on deep water would be on the Columbia River north of Portland, approximately 40 miles from the deposit over existing roads.

Reserves:

Calculation of ore reserves was governed by the following factors:

(1) Only material containing approximately 10 percent or less SiO_2 was considered to be ore, although some material which contained somewhat more than 10 percent was included in the estimates. The over-all weighted average analysis of the ore indicated, using the vertical bisector method, is 34.33 percent Al_2O_3, 24.46 percent Fe, and 8.64 percent SiO_2. Moisture determinations were not made for all the ore samples as some holes were drilled below the water table. Moisture content of the ore tested ranged from 15 to 34 percent. Loss on ignition for most of the ore sampled averaged about 20 percent.

(2) Because the ore body crops out at only a few widely separated places, its exact boundaries could not be determined directly. The mantle of silt which covers the area like a blanket of snow is thin on the steeper slopes and as much as 40 feet thick on some flat ridge tops.

(3) Holes 30 and 50 were bottomed in ore and only the thicknesses of ore actually drilled were used in the calculations. A small "island" of ore across the gully to the north of hole 32 has been included in the totals even though it was not drilled. Topography and float found in the immediate vicinity indicate the presence of the ore.

(4) For the purpose of determining the approximate boundaries of the ore sheet, it was assumed that the silt was of uniform thickness in a given local area. The procedure used in determining the ore margins consisted of first determining where the median line of the ore would have cropped out if there had been no silt overburden. Next, this boundary was moved back a distance equal to the product of the thickness of the silt multiplied by the cotangent of the angle of the hill slope. This new boundary was used in determining the areal extent of the ore body, which is estimated to be 111 acres. The thickness of ore used in calculating tonnage ranges from 9.5 to more than 20 feet, with a weighted average of 13 feet. As the ore should average 2500 long tons per acre foot in place, a total reserve of 3,600,000 long tons in place is indicated. This figure does not include all of the potential ore in the adjacent area as the ore body is known to extend northwest from hole 30 for an unknown distance. There is an excellent possibility that the ore may be

present on the ridge across the creek to the north of holes 60, 61, 62, and 30, but this area was not sampled or investigated for want of time. The thickness of overburden ranges from 2 to 30 feet and averages 18 feet. The stripping ratio of overburden to ore is 1.4 to 1.

Tonnage Calculations
Hutchison-Nixon Project

Hole	Acres	Feet of ore	Acre feet	Analysis Al_2O_3	Analysis Fe	Analysis SiO_2	Overburden Depth	Overburden Acre ft.
30	6.38	7*	44.66	33.65	22.70	8.41	6	38.3
32	3.31	14	45.33	33.54	24.84	7.62	10	33.0
44	1.98	12	23.76	35.58	21.87	8.89	22	43.5
48	2.70	16	43.20	38.79	22.41	6.80	29	78.2
50	3.84	20*	76.80	38.46	21.00	6.82	30	115.0
51	1.70	12	20.40	34.34	25.01	8.75	29	49.3
53	6.21	12	86.52	35.81	23.16	9.97	24	149.0
55	10.63	12	127.56	35.24	26.33	7.22	8	85.2
56	12.63	14	176.82	36.83	24.84	5.97	15	189.0
57	13.18	10	131.80	32.72	22.54	13.94	28	396.0
58	23.14	13	300.82	33.73	24.05	8.67	13	562.0
59	11.66	9.5	110.77	33.09	25.60	8.95	10.5	122.0
61	10.77	16	172.32	31.40	24.49	8.88	11	118.2
62	3.64	10	36.40	30.77	27.67	9.38	16	58.2
Totals	111.77		1397.16					2009.00
Weighted average		12.50		34.33	24.46	8.64	18.0	

* Hole bottomed in ore.

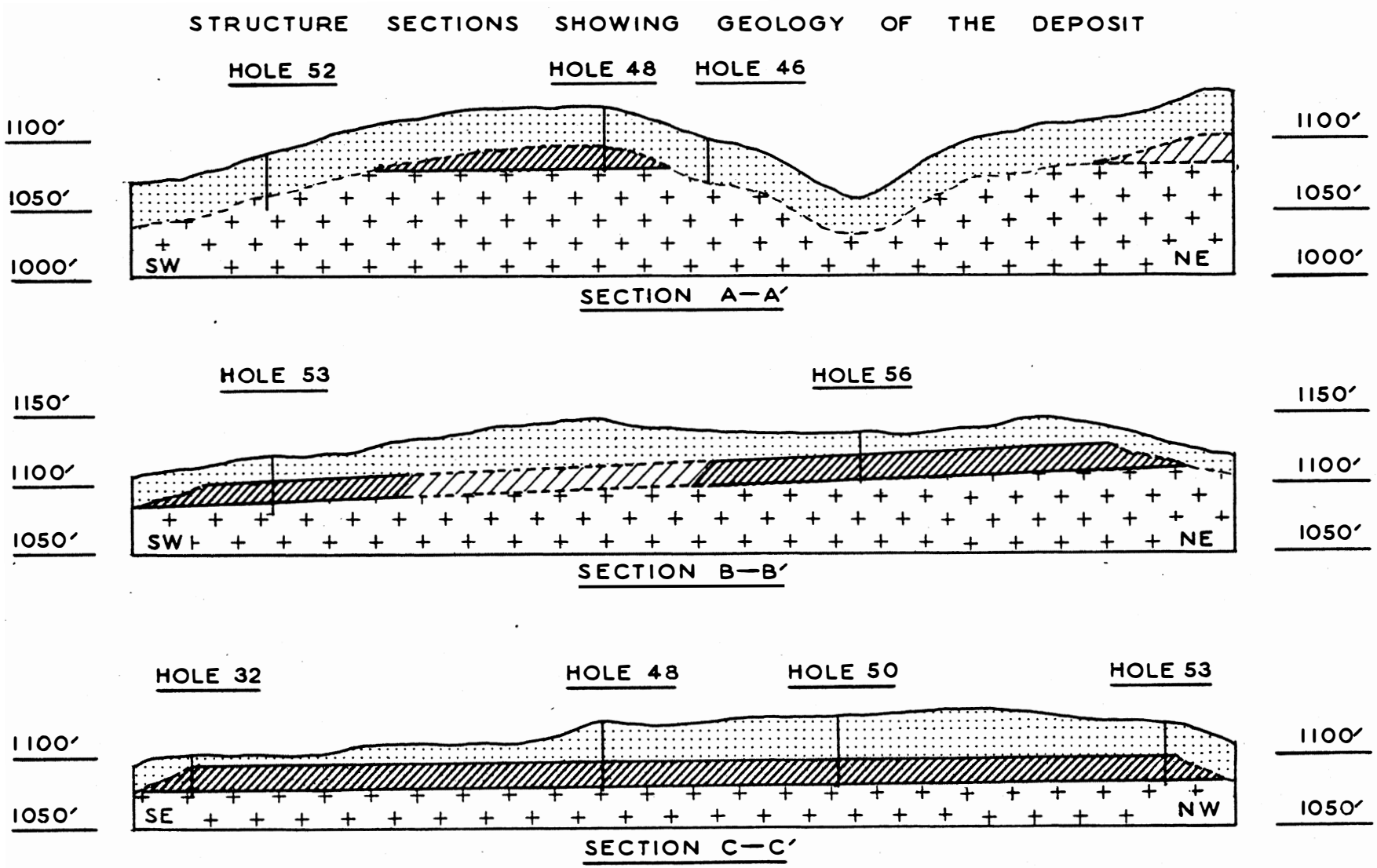

STRUCTURE SECTIONS SHOWING GEOLOGY OF THE DEPOSIT
HOLE 52
HOLE 48
HOLE 46
1100′
1050′
1000′
SW
NE
SECTION A—A′
HOLE 53
HOLE 56
1150′
1100′
1050′
SW
NE
SECTION B—B′
HOLE 32
HOLE 48
HOLE 50
HOLE 53
1100′
1050′
SE
NW
SECTION C—C′
CLAYEY SILT
ORE
BASALT
PROBABLE EXTENSION OF ORE
50
0
100
200 FT.

FIGURE 1

HUTCHISON-NIXON PROJECT

STRUCTURE SECTIONS SHOWING GEOLOGY OF THE DEPOSIT

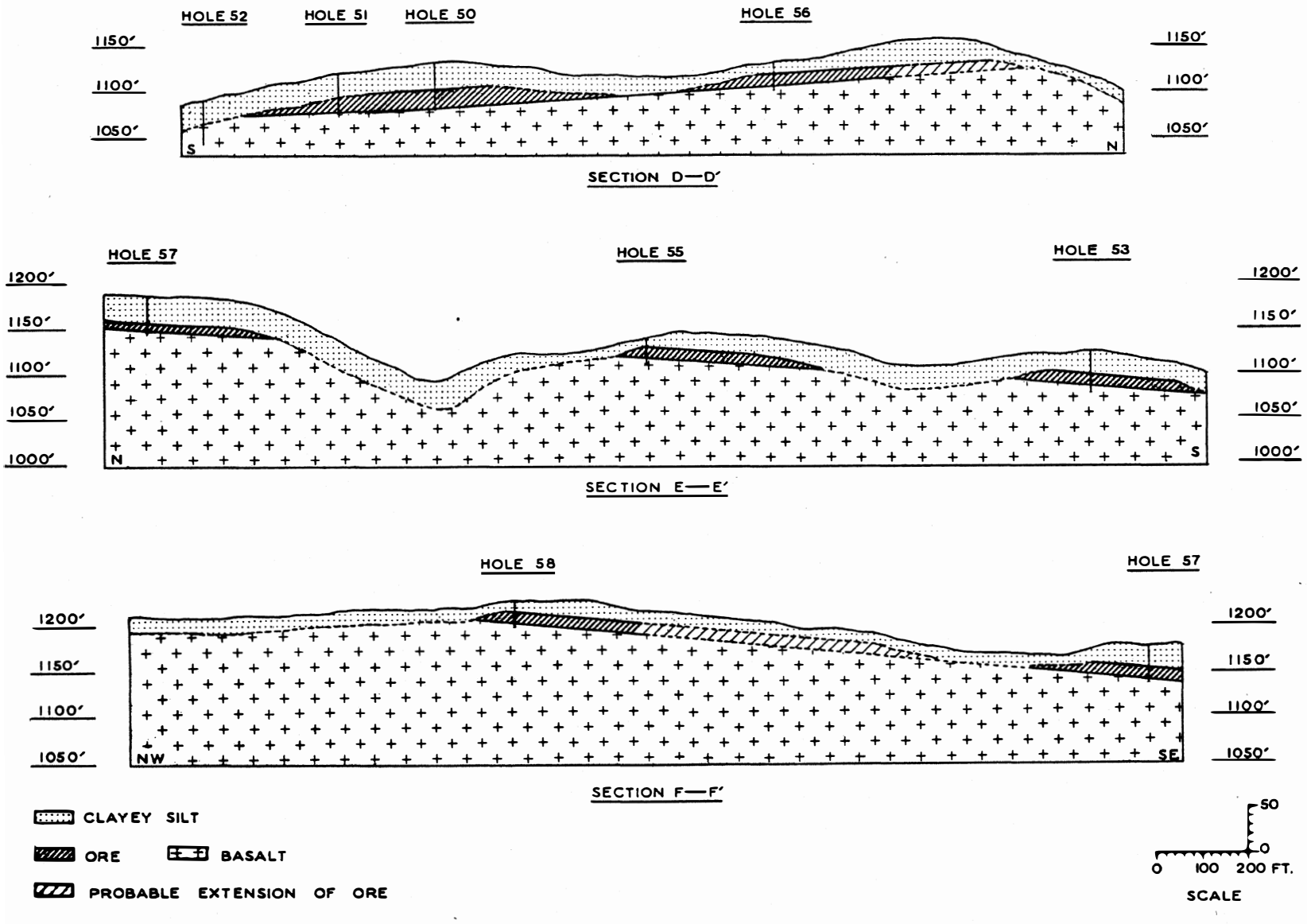
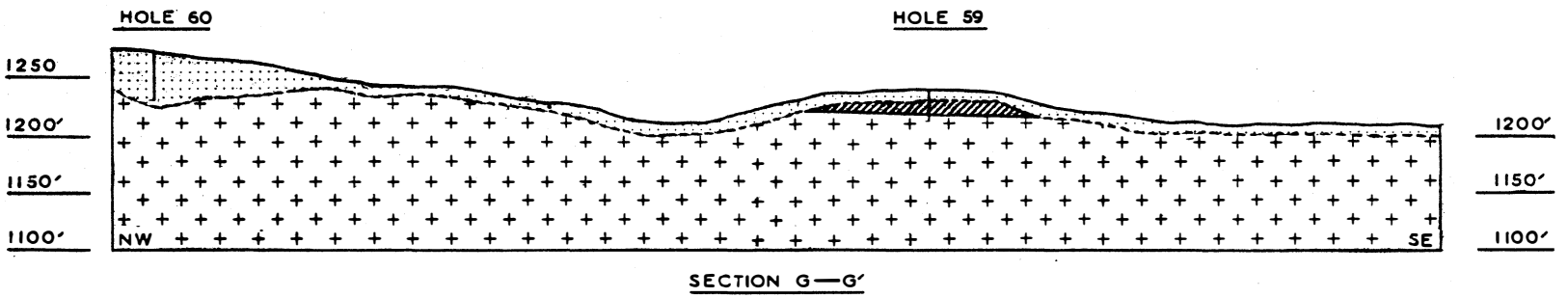


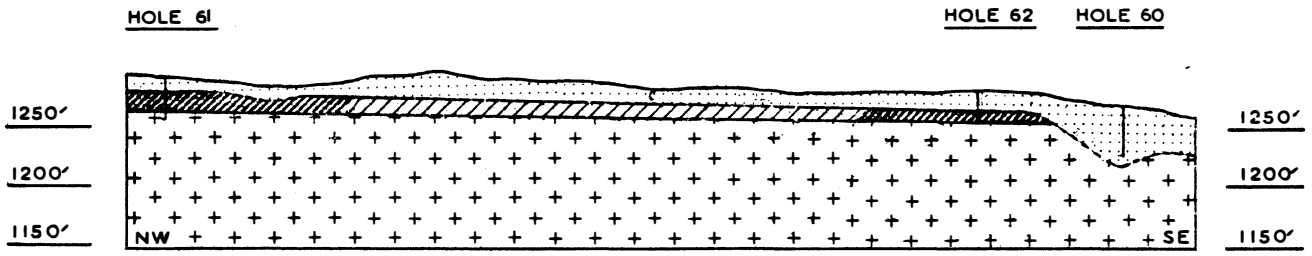
FIGURE 2

HUTCHISON-NIXON PROJECT

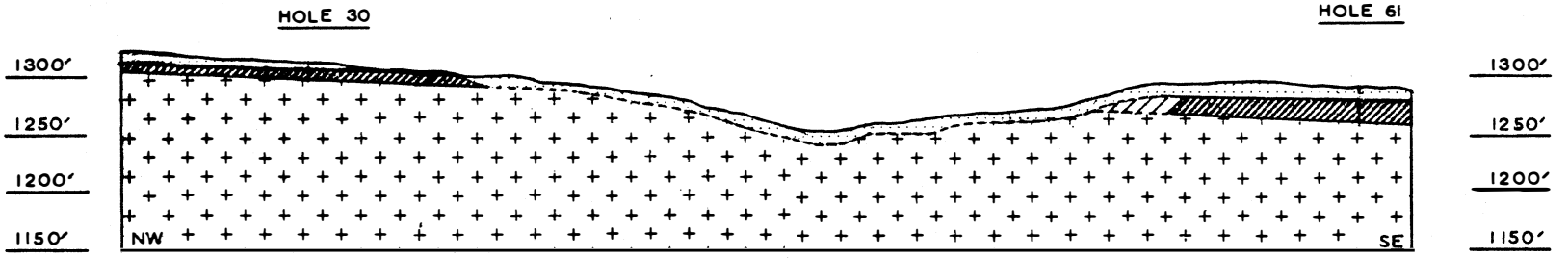
STRUCTURE SECTIONS SHOWING GEOLOGY OF THE DEPOSIT



SECTION G—G'



SECTION H—H'



SECTION I—I'

CLAYEY SILT

ORE

BASALT

PROBABLE EXTENSION OF ORE

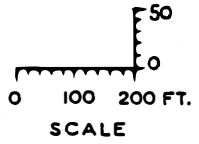


FIGURE 3

HOLE PROFILES, HUTCHISON-NIXON DEPOSIT

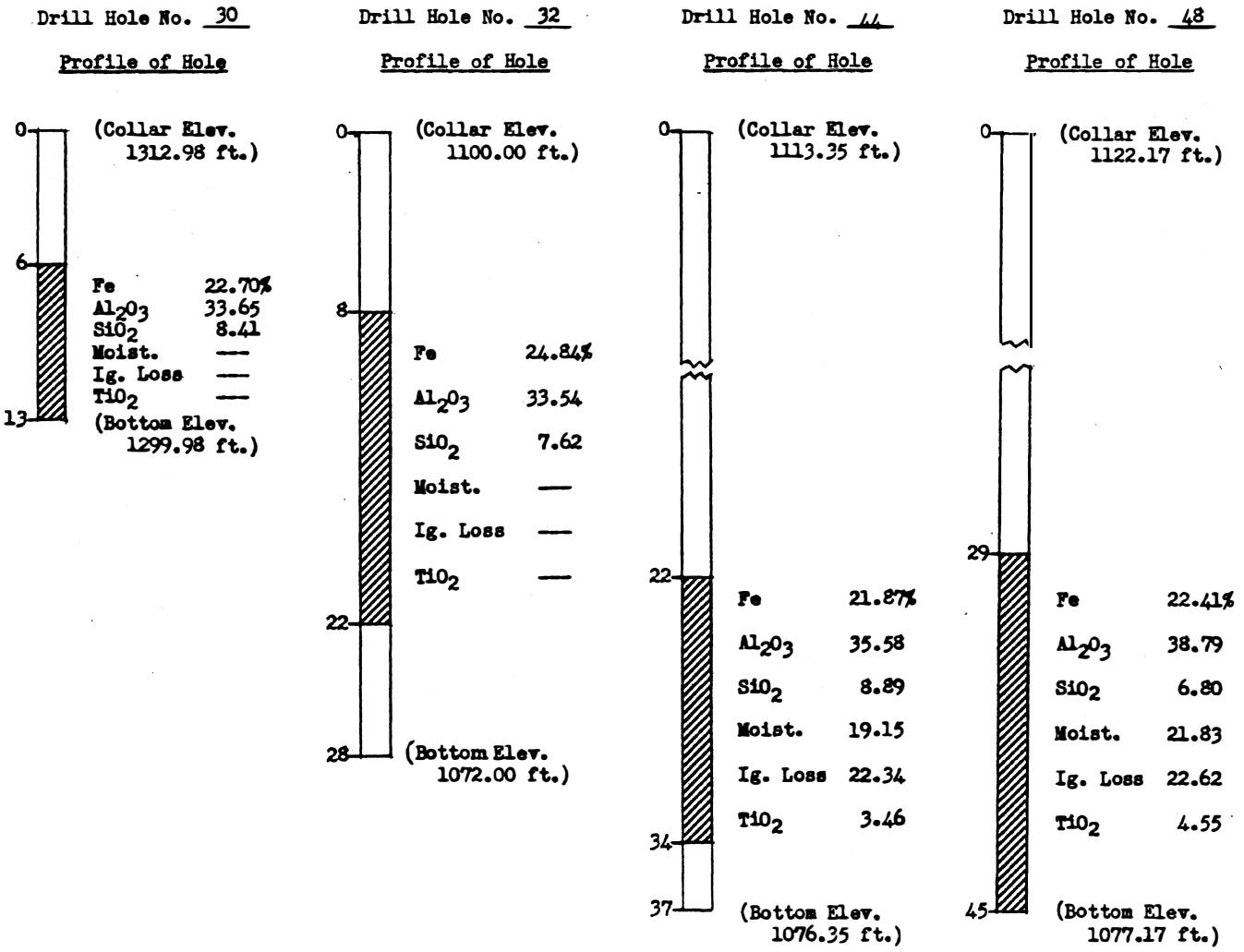


FIGURE 4

HOLE PROFILES, HUTCHISON-NIXON DEPOSIT

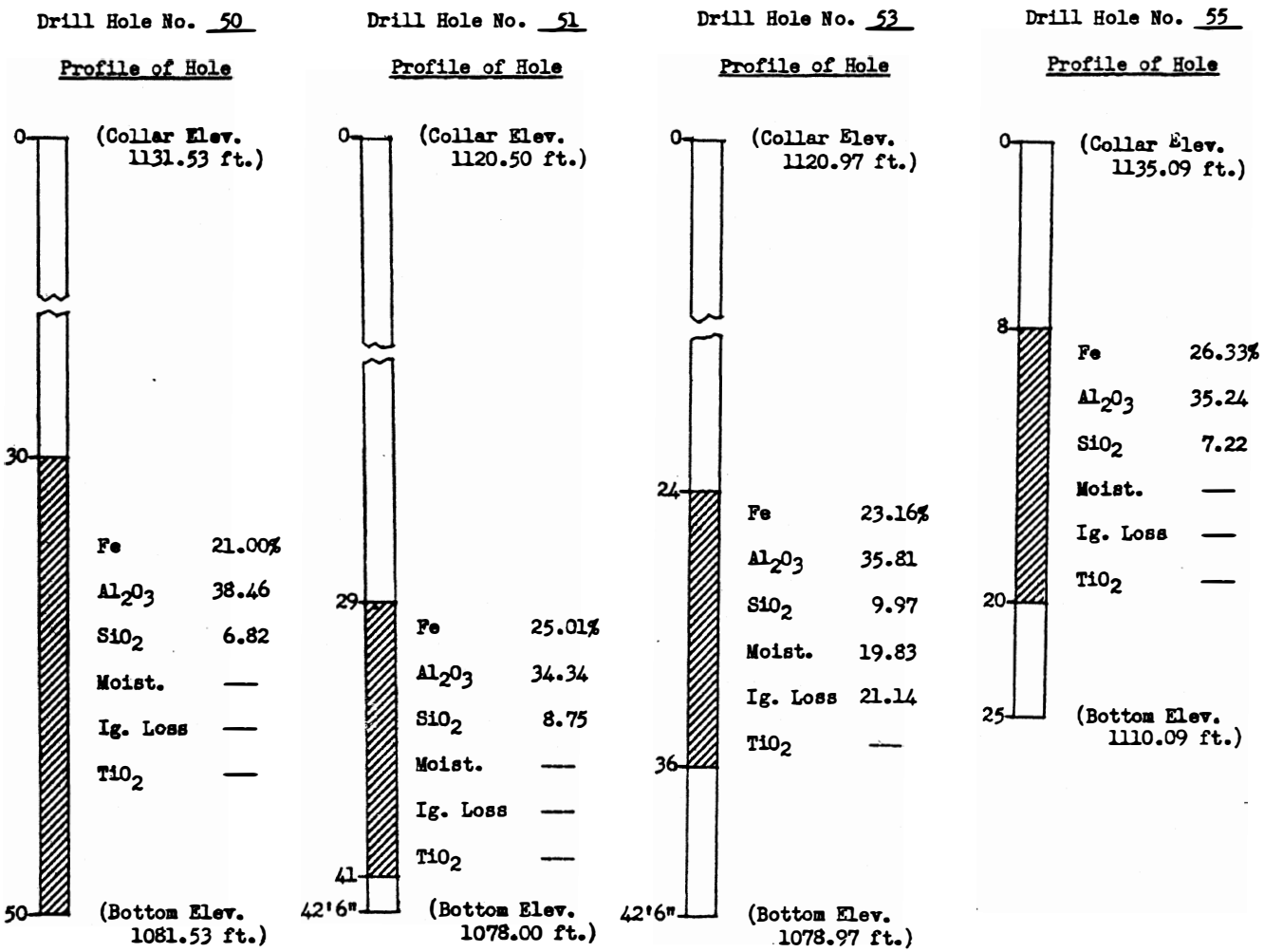


FIGURE 5

HOLE PROFILES, HUTCHISON-NIXON DEPOSIT

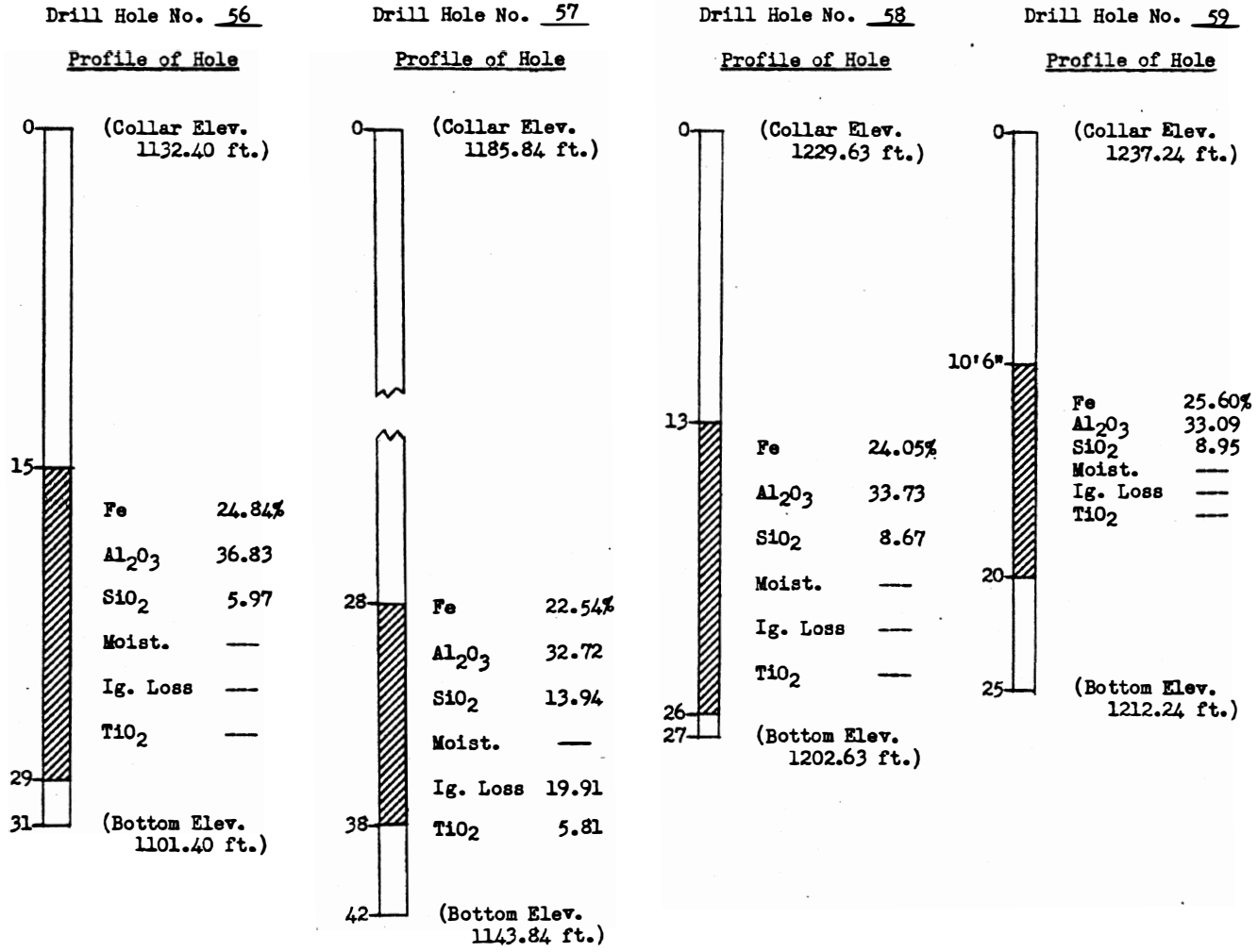
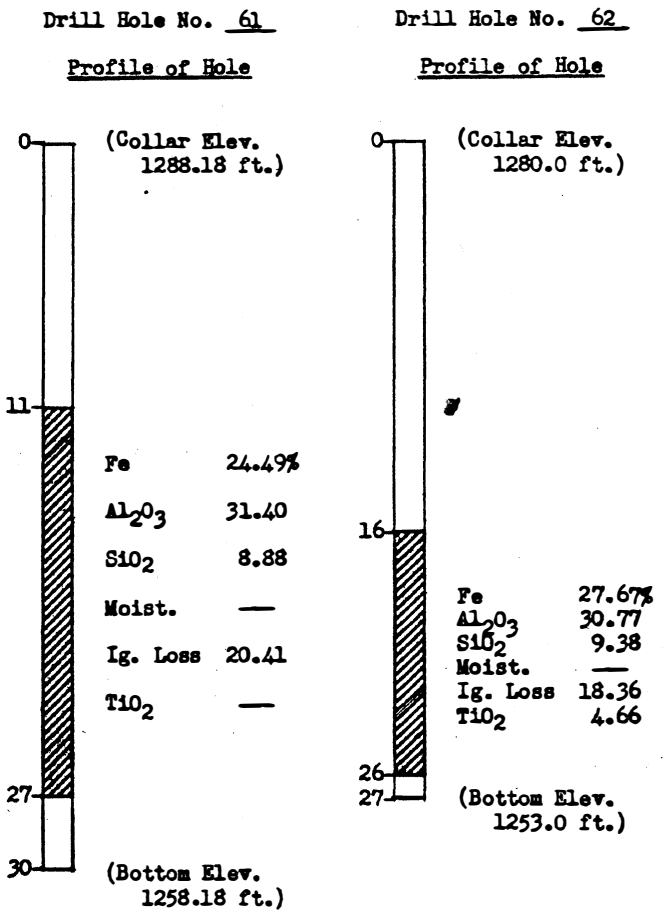


FIGURE 6

HOLE PROFILES, HUTCHISON-NIXON DEPOSIT



NOTE

Holes 31, 34, 45, 46, 47, 49, 52, 54, 60 failed to encounter ore. Some of these probably were drilled in areas of pre-silt erosion of the ore, others proved to have been started stratigraphically below the ore horizon.

FIGURE 7

Locality 9, Parmele, Hillsboro quadrangle

Hard nodular type ore occurs in the S½ sec. 5, T. 2 N., R. 2 W., 0.27 mile east of Dixie Mt. Road. The ore is exposed in a roadcut at the top of the hill at an elevation of about 1240 feet. Hole 29 penetrated 10 feet of ore having the following weighted average analysis:

Al_2O_3	32.62 %
Fe	24.22
SiO_2	8.52

The silica content of the lower 6 feet of ore is somewhat less than that given. Petrographic analysis shows that the white particles in the firm red claylike material of this lower portion are made up of gibbsite with some limonite.

Locality 10, Jacobs, Hillsboro quadrangle

This locality is near the middle of the township line between secs. 25 and 30, T. 2 N., Rs. 3 and 2 W. respectively, and is 0.2 mile east of the Pumpkin Ridge Road and 4.45 miles south of the Pleasant View School. Pieces of oölitic ore and gibbsitic material are scattered over part of the W. O. Jacobs farm. The ore occurs at an elevation of about 525 feet and it may be rather extensive in this general vicinity. No chemical analyses have been made.

Locality 11, Cathey, Hillsboro quadrangle

Half a mile north of the Leitzel farm (Locality 12) and at a higher elevation three auger holes were put down along the county road in the NE¼ sec. 34, T. 2 N., R. 2 W. Two of the holes encountered irony material and the average of the analyses of samples taken from them is given below:

Al_2O_3	22.33 %
Fe	15.93
SiO_2	40.35

The silica content of the material drilled is much too high for it to be classed as ore.

Locality 12, Leitzel, Hillsboro quadrangle

This locality in the southern part of the area in the NW¼ sec. 3, T. 1 N., R. 2 W., at an elevation of about 350 feet was described in O.M.I. Short Paper No. 12 as the Schmidt farm. wnership changed hands and the three holes drilled by the department and one outcrop are located on land owned by John W. Leitzel. Oölitic ferruginous bauxite is exposed in a cut on the north side of the county road on the Wm. Bishop place, north of the Leitzel farm. A preliminary sample of the outcrop on the Leitzel place returned:

Al_2O_3	45.87 %
Fe	18.51
SiO_2	8.16
P	0.150

Three auger holes were put down on this farm. Analytical results of samples from holes 1 and 2 give the following average analysis:

Al_2O_3	42.08 %
Fe	19.32
SiO_2	8.30

A description of a thin section of the ore from this locality is given under the character of the ore on page 16. The topography of this area is such that a considerable acreage might be underlain by ore. Additional holes to determine the extent of the ore body are needed before any tonnage estimates may be made, and to give information concerning average thickness of overburden.

Locality 13, G. F. Berger, Hillsboro quadrangle

Float of oölitic ferruginous bauxite and limonitic material occurs on the slopes of a small hill north of the farmhouse in the NW¼ sec. 2, T. 1 N., R. 2 W., at an elevation of about 450 feet. Near the house at a lower elevation, two shallow shafts were sunk several years ago and penetrated a bed of limonite, pieces of which are piled on the dumps. Results of a sample of oölitic ferruginous bauxite submitted by G.F. Berger follow:

Al_2O_3	34.08 %
Fe	30.41
SiO_2	5.12
TiO_2	4.12
Ign. loss	16.57

Locality 14, Mrs. A. and Edw. Anderson, Hillsboro quadrangle

This occurrence is near the top of the hill in the NW¼ sec. 27, T. 2 N., R. 2 W., about one third mile east of the Logie Trail. The ore occurs at an elevation of about 800 feet and is exposed along the north side of the road near the house, and is scattered over the plowed field just north of the road and west of the house. The material is reported to have been encountered at a shallow depth in the old well near the barn. Gibbsitic, limonite, oölitic, and earthy varieties of ferruginous bauxite are present. Analysis of a sample of the gibbsitic pieces, P-3364, is given in the following table. Petrographic examination of this sample shows that it is made up largely of gibbsite. Analyses of a limonitic piece, P-3363, of an oölitic type, P-3365, and of a somewhat pisolitic earthy type, P-3366, are also given.

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3363	10.48	50.56	4.56	1.76	12.14
P-3364	56.36	8.95	3.90	2.89	27.95
P-3365	44.24	22.26	5.84	2.25	23.37
P-3366	47.36	12.19	4.70	3.69	26.81

Locality 15, C.E. Ferguson, Gales Creek quadrangle

Only a few small pieces of pisolitic irony material were found at this locality on the northeast slope of the ridge in the NW¼ NE¼ sec. 24, T. 3 N., R. 3 W., at an elevation of about 1700 feet. The reported results of a chemical analysis of the material follow:

Al_2O_3	22.80 %
Fe_2O_3	44.04
FeO	1.60
SiO_2	2.07
TiO_2	5.67

Locality 16, Bald Mt., Gales Creek quadrangle

Pieces of bauxite float were found in a cultivated field on the southwest slope of Bald Mt. at an elevation of about 1300 feet. Bald Mt. can be reached from the Wolf Creek Highway by several roads. It is about 4½ miles due north of Banks. The float has a porous granular texture. It is not only porous but retains much of the original texture of the basaltic rock from which it was derived. Results of the analysis of two pieces of the float follow:

Al_2O_3	56.31 %
Fe	13.54
SiO_2	5.30
TiO_2	2.73
Ign. loss	24.86

Unaltered basalt occurs near the edge of the northwest corner of the field.

Locality 17, Gales Creek quadrangle

Ferruginous bauxite occurs on the top of the spur above and about one quarter of a mile east of the road leading northward from near Davies on the Wolf Creek Highway toward Bald Mt. The locality is about 1½ miles north-northeast of Davies and at an elevation of about 650 feet. Numerous pieces of float were found scattered over the slopes around the farmhouse, which is situated on top of the spur, and apparently ore occurs in place near the northeast corner of the house. Several textural varieties are present. Results of the analysis of one of the non-irony types follow:

Al_2O_3	40.28 %
Fe	22.06
SiO_2	6.42
TiO_2	4.49
Ign. loss	18.22

Locality 18, H. Davies, Gales Creek quadrangle

This locality is in the SE¼ sec. 19, T. 2 N., R. 3 W., about 3 miles due north of Wilkesboro. The ore occurs at the edge of the timber on the north side of the ridge at an elevation of about 825 feet.

Results of the analysis of a composite sample made up of two oölitic pieces and one nodular type piece are given below:

Al_2O_3	31.44 %
Fe	29.31
SiO_2	4.25
TiO_2	4.81
Ign. loss	18.17

Locality 19, H. Davies, Gales Creek quadrangle

Numerous small pieces of float occur in the field just east of the house in the NE¼ sec. 19, T. 2 N., R. 3 W., at an elevation of about 600 feet. A few gibbsitic pieces were among them. Results of the analysis of a composite sample made up of oölitic and nodular type pieces follow:

Al_2O_3	30.48 %
Fe	29.07
SiO_2	3.39
TiO_2	4.65
Ign. loss	18.51

Locality 20, Gales Creek quadrangle

Pieces of ferruginous bauxite are reported to occur on top of a long, north-trending ridge at an elevation of 1550 feet, about 5½ miles nearly due north of Banks.

Locality 21, Hillsboro quadrangle

Mr. Gus Nelson reports that ferruginous bauxite occurs on his farm on the top of a ridge in the SE¼ sec. 25, T. 3 N., R. 3 W., at an elevation of about 1400 feet.

Locality 22, E.M. Lambert, St. Helens quadrangle

This locality is in probably the NE¼ sec. 1, T. 4 N., R. 2 W., at an approximate elevation of 500 feet. It is on the Stone Road about half a mile southeast of its intersection with the Spitzenborg-Yankton road. The road here follows an elongate ridge trending and sloping slightly to the southeast. Reddish pisolitic material is found at the bend in the road and, according to Lambert, was encountered in the telephone-pole hole on the southwest side of the road. The results of the analysis of a piece from the roadside is given below:

Al_2O_3	39.95 %
Fe	15.04
SiO_2	16.76

Locality 23, abandoned railroad cut near Yankton, St. Helens quadrangle

This deposit was first mentioned in the report by Williams and Parks (1923). They noted the occurrence of limonitic "shot" ore in an old railroad cut south of Cox Creek about one quarter of a mile south of Yankton (actually about half a mile south-southeast).

The deposit is in the SW¼ sec. 1, T. 4 N., R. 2 W., and can be reached best by walking the old grade from where it intersects the Kappler Road at its intersection with the road leading about three quarters of a mile due north to Yankton. The old railroad grade runs generally northeast about 2200 feet to the cut where the ore is exposed over a distance of 300 feet. The grade then continues eastward nearly half a mile and turns southeast to finally intersect the Kappler Road again about 1 mile east of its other intersection. The grade is situated part way down the north, or Cox Creek side, of a rather flat ridge which is separated from its eastern extension toward localities 24 and 25 by a well-defined saddle.

The elevation of the cut as judged from the topographic map is about 275 feet. As this cut is the best exposure of ferruginous bauxite known, a sketch is given below. The present grade is the result of excavation preparatory to building a road along the former railroad grade.

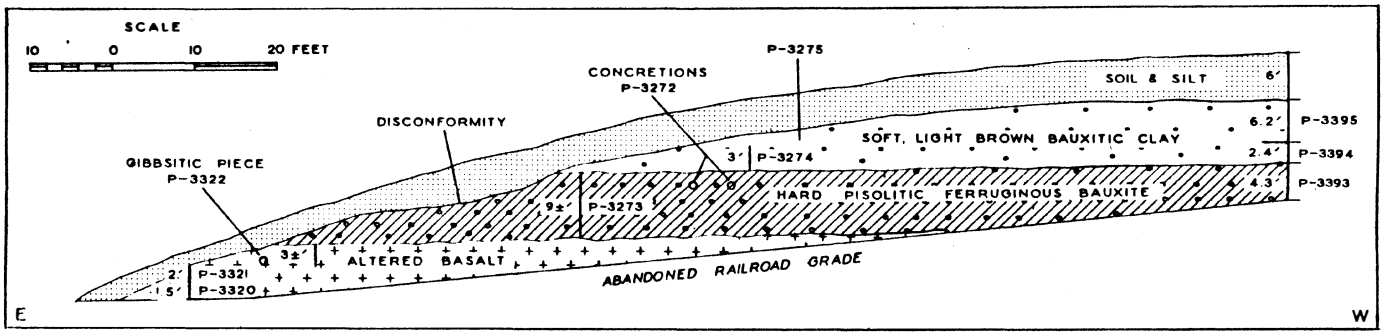


FIG. 8. SKETCH OF YANKTON RAILROAD CUT LOCALITY

The laterite is overlain disconformably by a massive mottled silt which contains grains of hornblende, magnetite, biotite, muscovite, and apatite, as well as other minerals. Channel and grab samples of the horizons and ore types beneath the silt have been taken and their analyses are given in the table on page 49. Three samples from a 12.9-foot vertical channel were taken 140 feet from the east end of the cut. The uppermost horizon sampled is a soft, reddish-brown, slightly pisolitic, bauxitic clay. Sample P-3395 is a 6.2-foot vertical channel sample of this horizon. This grades below into a 2.4-foot thickness of soft, mottled brown and gray, more pisolitic material, represented by sample P-3394. Petrographic examination of material from this horizon shows that it contains gibbsite, quartz, apatite, muscovite, zircon, tourmaline, as well as other minerals. The pisolites of this horizon are magnetic, and petrographic examination shows that they contain rounded and subangular grains of quartz about 0.1 ± mm in diameter. As shown in the above sketch, this bauxitic clay appears to be conformable with the underlying ferruginous bauxite and was deposited prior to the deposition of the relatively unweathered massive silt which disconformably overlies it.

It can not be stated certainly whether the bauxitic clay was formed in place from silt that was deposited on top of basalt prior to laterization or whether it was derived from laterite elsewhere and deposited on top of previously formed ferruginous bauxite now found underlying it. The presence of a rounded pebble or concretion of ferruginous bauxite near the contact with the underlying laterite suggests deposition of the bauxitic clay following laterization of the basalt. The inclusion of quartz grains within the oölites in the bauxitic clay horizon indicates that the oölites were not derived from basalt. As the quartz grains in the oölites are like those in the matrix, it is thought that the oölites were formed after the silt was deposited on top of the basalt prior to laterization of both horizons. It is also possible that the oölites were developed after deposition of a bauxitic clay on top of previously formed ferruginous bauxite.

The magnetic property of the oölites is very likely due to a secondary iron oxide, probably derived from the underlying basalt as the oölites become less abundant upward. Although the bauxitic clay appears to be conformable on the ferruginous bauxite, the evidence is insufficient to establish the relationship.

Markedly different from this horizon is the underlying hard reddish-brown pisolitic zone. Sample P-3393 is a 4.3-foot channel sample of this horizon which continues downward. Analyses of this and other samples are given in the table below:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	P	Ignition loss	
P-3395	6.2 ft.	39.22	12.50	23.36	3.32	0.189	18.10	Lerch Bros.
P-3394	2.4 ft.	33.70	24.85	14.04	4.86	0.232	14.58	Lerch Bros.
P-3393	4.3 ft.	33.06	29.72	6.20	5.48	0.212	15.25	Lerch Bros.
P-3275	grab sample	41.28	10.18	22.52	4.81	-----	20.19	
P-3274	3.0 ft.	34.49	14.51	26.65	4.73	0.212	15.93	Lerch Bros.
		37.30	15.00	22.04	4.94	-----	17.62	Hoagland
P-3273	9.0 ft.	35.50	26.52	6.66	5.72	0.248	16.79	Lerch Bros.
		33.20	27.83	6.36	5.35	-----	19.83	Hoagland
P-3272	large concretion	20.00	34.68	8.38	3.20	-----	15.62	
P-3322	nodule	60.52	3.58	7.66	----	-----	-----	
P-3321	2.0 ft.	28.12	25.62	16.14	----	-----	13.63	
P-3320	1.5 ft.	38.48	19.07	14.34	----	-----	18.46	

Petrographic examination of material from this hard pisolitic horizon (sample P-3273) shows that the hard magnetic concretions are predominantly a mixture of magnetite, limonite (including goethite), and a brown isotropic material with an index of refraction of about 1.71 - 1.72. As no isotropic, iron-aluminum mineral has a similar index, the material is thought to be an intimate mixture of hydrous ferric and aluminum oxides. Possibly it is eliachite mixed with an iron sesquioxide. The concretions also contain a minor amount of

gibbsite as well as a minor amount of an unidentified material. The matrix of this horizon is more uniform in composition and is only very slightly magnetic. It is made up largely of the isotropic iron-aluminum material described above as occurring in the concretions. Limonite is a much less important constituent and probably other minerals are present in small amounts. Some of the concretions or pisolites from this horizon are as much as 5 inches in diameter. They have a porous or "wormy" texture and unlike the main mass of this horizon, are only very slightly magnetic. In the field they were described as being limonite but analysis of a portion of one of the larger ones, sample P-3272, shows it contains 20 percent Al_2O_3. Its analysis is given in the table.

Beneath the hard pisolitic zone near the east end of the cut is a brown, non-oölitic, earthy horizon of laterized basalt. About 6½ feet of this material is exposed. The lower 3½ feet was channel sampled. Sample P-3320 represents the lower 1½ feet and P-3321, the upper 2 feet. A piece of light gray compact material 3 inches long and about 1 inch thick, sample P-3322, was found at the top of the section of sample P-3321. Petrographic examination shows that it is largely gibbsite, and chemical analysis gives 60.52 percent Al_2O_3.

A 3-foot channel sample, P-3274, of the soft bauxitic clay overlying the pisolitic ferruginous bauxite was taken earlier at the place indicated in figure 8 on page 48. It includes all of the material represented by sample P-3394 and the lower part of that represented by sample P-3395. A grab sample, P-3275, of the bauxitic clay about 7 feet above the hard pisolitic zone is equivalent to the upper part of channel sample P-3395. A chip sample, P-3273, of the hard pisolitic material was taken somewhat farther east where the thickness is about 9 feet. Sample P-3393 represents the upper part of this horizon. Analyses of these samples are also given in the preceding table.

Locality 24, John Gaman, St. Helens quadrangle

This deposit, formerly known as the Salzer locality, was first described by Williams and Parks (1923:24). It is in the S½ NE¼ sec. 1, T. 4 N., R. 2 W., about 2½ miles west of St. Helens and about 1 mile southeast of Yankton. Williams and Parks stated that a thin ed of siliceous shot ore is exposed and that such deposits are closely associated with the basalts and that the ore is to be regarded as decomposition products of these lavas. They further stated that none of the "shot" variety of iron ore, described as limonite "shots" held in a fairly hard matrix, thus far prospected has proved to be sufficiently high in iron or large enough in quantity to be given consideration. They, like others, did not mention the presence of a high percentage of alumina in such Columbia County ores.

The ore is exposed in an adit and several old cuts situated part way down on the north side of the hill southeast of Milton Creek, at an elevation probably between 275 and 300 feet. The portal of the adit, which is about 50 feet long, exposes about 10 feet of hard oölitic or pisolitic ore. A grab sample, P-3267, representing the upper 6 feet of oölitic

ore exposed by the portal face and a harder, darker-colored, more "irony" sample, P-3268, from a more compact layer near the top of the portal itself, were taken. The compact "irony" layer is about 4 to 6 inches thick and appears to extend as an uneven horizon from the portal more or less continuously to the face of the adit. Analyses of these samples are given below:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	P	Ignition loss	
P-3266	6 in.	21.60	36.02	4.28	3.68	-----	17.92	Hoagland
P-3267	6 ft.	41.11	21.17	7.48	6.11	0.316	18.50	Lerch Bros.
		38.80	22.05	7.02	6.05	0.347	21.40	Hoagland
P-3268	6 in.	24.66	39.25	4.55	4.61	0.141	12.59	Lerch Bros.
		23.12	40.20	4.64	3.89	0.182	14.29	Hoagland
P-3317	2.5 ft.	40.38	15.55	14.20	----	-----	-----	Hoagland
P-3318		62.32	1.95	2.68	----	-----	-----	Hoagland
P-3319		57.32	4.03	13.10	----	-----	-----	Hoagland

The analysis of a sample, P-3266, of the "irony" layer from the face of the adit is listed in the above table. A more earthy and somewhat softer, brown, nodular material underlies this layer in the face of the cut. The analysis of a 2½-foot channel sample, P-3317, of this lower horizon is given in the table above.

Pieces of light-colored or light buff earthy material as much as an inch in size occur embedded in and just below the "irony" layer in the face. Petrographic examination of this material, sample P-3318, shows that it contains much gibbsite. A light gray earthy material, sample P-3319, occurs at several places in the north wall of the adit. Petrographic examination shows that it too contains much gibbsite. Chemical analyses of these two samples are also listed in the table.

Pieces of oölitic float were picked up along the trail leading from the Gaman house to the adit and cuts to the west. The ore is overlain by a thick silt very similar in appearance and composition to that found in Washington County lying above the ferruginous bauxite deposits there. As exposed in cuts along the Kappler Road, which runs along the southern side of the hill, the silt is seen to be light brown to brown, mottled with gray. It is massive and loosely consolidated. It may be as much as 75 feet thick in places at the Gaman locality. The ore is thought to belong to the same body as that at the Marshall place, Locality 25, about half a mile to the east-southeast. This body may extend either broken or unbroken to Locality 23, about a mile to the west.

Locality 25, John R. Marshall place, St. Helens quadrangle

This locality is in about the center SW¼ sec. 6, T. 4 N., R. 1 W., at an elevation of about 325 feet. It is on the more gentle back or southeast slope of the hill on which the Gaman deposit, Locality 24, is situated. Numerous pieces of hard, dark reddish-brown, irony,

oölitic float were seen on the slope immediately east and below the house. More earthy pieces were found but it is thought that the harder types of ore weather less rapidly and are thus more likely to occur as float. Many pieces of the hard irony type are to be seen in the driveway fill and presumably came from the well near the house. The results of the analysis of sample P-3269 which consists of several pieces of pisolitic float from the slope east of the house are given below:

Al_2O_3	22.84 %
Fe	37.59
SiO_2	4.00
TiO_2	4.16
Ign. loss	17.97

Pieces of oölitic material were found in the field west-southwest of the Marshall house. The overburden here may be thin. Several large glacial erratics may be seen in this area. The U.S. Bureau of Mines is drilling this deposit.

Locality 26, Eber Brown, St. Helens quadrangle

Ferruginous bauxite is exposed along the north side of the Vernonia-St. Helens Highway about 1½ miles east of Yankton at an elevation between 325 and 350 feet. Some of the material has a breccialike appearance. Gibbsite is also present but no analyses of either material have been made.

Numerous pieces of hard "irony" type oölitic bauxite, similar to some of the float at the Marshall place, Locality 25, and more earthy varieties occur on the north side of the Vernonia-St. Helens Highway farther east, about 1 mile west of St. Helens, and a short distance west of its junction with the road leading south to Houlton. The elevation, as shown by the topographic map of the St. Helens quadrangle, is about 300 feet and the float here does not appear to represent an eastward extension of the deposits farther west. Granitic boulders and other erratics are also present.

Locality 27, John Gentry, St. Helens quadrangle

This locality is in the SE¼ sec. 26, T. 5 N., R. 2 W., about 1½ miles north-northwest of Yankton. Grab samples were taken from two southeast-trending spurs of the ridge just north of the Vernonia-St. Helens Highway. Sample P-3264 is from the westernmost spur and was taken near its top at an approximate elevation of 550 feet. It is a hard, rough textured irony material. The other sample, P-3265, was taken from the top of the spur about one quarter of a mile to the east at an elevation of about 525 feet. The sample consisted of several pieces of oölitic float gathered near the toe of the spur. Analyses of these samples are given below:

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3264	29.84	29.87	5.48	4.72	21.72
P-3265	30.52	29.59	8.08	5.76	16.03

Locality 28, Dark Creek Road-Smith Road intersection and vicinity, St. Helens quadrangle

This area is about 2½ miles west of Columbia City and the general elevation is about 750 feet. Wilkinson's survey of the St. Helens quadrangle (1941) noted this locality. A 4½-foot vertical channel sample was taken from the west bank of the Dark Creek Road, about 0.2 mile south of its intersection with the Smith Road. The Marshall house is west of the spot sampled. The upper 3 feet is red and oölitic and the lower 1½ feet is nodular. Results of the analyses of this sample follow:

Al_2O_3	35.56 %
Fe	24.22
SiO_2	6.60
TiO_2	4.50
Ign. loss	18.71

O. E. De Vaul reports that similar material was encountered in most wells in the vicinity of this intersection. A bedded, relatively unweathered volcanic ash with some muscovite underlies the Columbia River basalt in this area.

A specimen of massive limonite was collected by Wilkinson's survey party, and is reported to occur on the east side of the road, a short distance south of the intersection.

Locality 29, Trenholm-Happy Hollow School area, St. Helens quadrangle

Ferruginous bauxite occurs in a roadcut on the Vernonia-St. Helens Highway more than a mile by road west of the Happy Hollow School. No analysis is available.

Locality 30, Kalama quadrangle

This locality is near the center sec. 34, T. 7 N., R. 2 W., at an elevation of about 1150 feet. It is near the high point of the road leading from the Neer City School to Rainier and about 1.6 miles north of its intersection with the only main road leading to the west, a little more than a mile north of the Neer City School. Numerous pieces of float, several inches in diameter, occur below the road on the east side. A few pieces were found along the road. All the pieces have a reddish-brown color and a porous granular texture. Results of the analysis of a sample made up of pieces from five chunks of ore are given below:

Al_2O_3	46.84 %
Fe	9.81
SiO_2	7.26

Locality 31, Fern Hill School area, Kalama quadrangle

Numerous pieces of float occur on the bare, upper surface of the hill in the SW¼ sec. 30, T. 7 N., R. 2 W., at an elevation of about 900 feet. The hill is about three-quarters of a mile nearly due north of the Fern Hill School and less than half a mile east of the road leading north from that school to the Hudson School, 3 miles farther north.

Analyses of samples of white and buff colored gibbsitic material, P-3401, of a brown, slightly oölitic, limonitic piece, P-3402, and a reddish-brown, porous, granular piece, P-3408, are given in the following table:

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	P	Ignition loss
P-3401	55.84	3.59	11.68	3.53	0.089	30.91
P-3402	18.28	41.05	4.44	2.75	---	19.40
P-3408	54.72	8.97	6.70	3.53	---	29.16

Petrographic examination of samples P-3401 and P-3408 shows that both contain much gibbsite.

Locality 32, U.S. Highway 30, roadcuts west of Rainier, Kalama quadrangle

Ferruginous bauxite is exposed in two adjacent roadcuts on U.S. Highway 30, about 2.3 miles west of the Longview bridge junction. These cuts are in sec. 18, T. 7 N., R. 2 W., and are just east of the junction of the highway and a market road leading to the southeast, at an elevation of about 665 feet. The ferruginous bauxite is here overlain by a mottled silt.

Results of the analysis of a channel sample, P-3399, representing the upper section, 2.3 feet in thickness, in the westernmost cut are given below. This section is made up of soft oölitic material red in color with some gray streaks. Some of the overlying silt may have been included in this sample. It did not include any part of the hard oölitic boulders which form a discontinuous layer in this horizon. Results of the analysis of a piece broken from one of these boulders, sample P-3361, are given in the following table.

The middle section of the deposit in this cut, 8.7 feet in thickness, is represented by sample P-3398 and consists mostly of hard, red oölitic material with some soft streaks. The lower part of this horizon contains some small fossil wood fragments.

Below this hard middle horizon there is oölitic, claylike material which was sampled in two sections. Sample P-3397 is from the upper 1½ feet which is red in color and contains some yellowish fragments of fossil wood similar to those in the overlying zone. The lowest section, 3 feet in thickness, is represented by sample P-3396. This lowest horizon is buff-colored and oölitic, and contains some hard spots.

Analyses of samples taken in the west cut, Locality 32, follow:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3399	2.3 ft.	26.00	10.87	24.90	2.75	11.50
P-3361	"boulder"	39.32	18.79	15.00	3.69	17.26
P-3398	8.7 ft.	36.12	16.51	21.66	3.37	17.50
P-3397	1.5 ft.	32.12	13.00	31.70	2.96	13.80
P-3396	3.0 ft.	37.32	5.71	34.92	3.02	15.06

Petrographic examination of material from the upper, hard oölitic horizon, represented by part of sample P-3398, shows that the oölites, which are magnetic, contain quartz grains ± 0.1 mm in diameter. The matrix contains quartz, apatite, and tourmaline (?) as well as other minerals.

Petrographic examination of the light-colored claylike horizon at the base of the cut shows that it contains such minerals as tourmaline, muscovite, biotite, and ilmenite. Chemical analysis shows that the material contains more alumina than silica, which indicates that it is probably bauxitic. It is similar in appearance to the silt which overlies hard pisolitic ore at the Yankton railroad cut, Locality 23.

Although the ferruginous bauxite in this cut resembles that elsewhere derived by laterization of basalt, its silica content is higher, and the presence of detrital minerals and wood fragments indicates its derivation from transported material. It is not known whether laterization took place before or after deposition. The presence of quartz grains in the oölites which are similar to those in the matrix suggest that the oölites were developed after deposition. Lack of stratification and the induration of the upper horizon suggest laterization took place after deposition of the material.

Silty soil also overlies the deposit in the adjacent roadcut east and a few feet lower in elevation. The upper section, 3 feet in thickness, under the silt is represented by sample P-3364. This horizon is composed of rather soft reddish-brown oölitic material, and appears to be part of a fill occupying a channel in laterite. Water-worn pebbles mark the bottom of the well-defined cut and fill structure. A fracture in the laterized basalt on the east side of the structure appears to extend up into the channel filling which, however, does not show the effects of deformation exhibited in the slickensided basalt just below the bottom of the channel. A nearly vertical fault which strikes roughly northeast is shown in the basalt just south of the channel filling. The laterized basalt retains the original vesicles and spheroidal weathering pattern. This lower horizon, 11 feet in thickness, was sampled in two equal sections represented by P-3463 and P-3462. The upper section is generally brownish red with hard angular fragments gray in color and commonly half an inch or more in size. This sample may have included a little of the overlying channel filling. The lower 5½ feet is similar to the material just above, but is more mottled and light reddish and yellowish brown in color. Analyses of these samples follow:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3464	3.0 ft.	38.80	16.26	21.78	4.18	17.02
P-3463	5.5 ft.	38.76	20.07	13.86	4.50	18.44
P-3462	5.5 ft.	38.56	20.52	17.30	4.18	17.07
P-3400	grab sample	43.96	13.01	14.46	3.21	21.70

Also listed in the foregoing table are results of the analysis of a grab sample, P-3400, taken from this cut at an earlier date. It represents hard gibbsitic pieces in the upper part of the lower horizon.

Although fracturing, slickensiding, and faulting of the basalt may have taken place before channeling and filling, it is not known whether laterization of the basalt preceded channeling and filling. If the fracturing and faulting shown mainly in the laterized basalt accompanied deformation of the basalts elsewhere, laterization of the basalt may have preceded channeling and thus the channel filling is largely transported bauxitic material.

As the evidence appears to favor laterization of the transported material in the upper cut after its deposition and that in the lower cut before deposition, additional study of the cuts is necessary before conclusive statements may be made.

Locality 33, Clatskanie quadrangle

Several pieces of altered basalt, sample P-3488, were collected from the bank of the road in front of a house in the NW¼ sec. 1, T. 6 N., R. 3 W., at an elevation of approximately 1000 feet. The locality is about 2 miles north-northeast of Apiary. Petrographic examination shows that the pieces contain much gibbsitic material. No chemical analyses were made.

Locality 34, Hillsboro quadrangle

Numerous pieces of ferruginous bauxite as much as 6 inches in diameter were found on the crest of the spur in the northeast corner sec. 12, T. 2 N., R. 3 W., at an elevation of about 1100 feet. Both nodular and porous granular types are present. No analyses were made.

Locality 35, St. Helens quadrangle

Wilkinson (1941) noted the occurrence of limonitic and pisolitic material from the southeast slope of a hill at an elevation of about 750 feet, 2 miles northwest of Scappoose. Analysis of a pisolitic piece collected by his party and analyzed recently in the Department laboratory gave the following result:

Al_2O_3	22.35 %
Fe	43.65
SiO_2	1.77
TiO_2	2.98
Ign. loss	11.85

Locality 36, Colport Development Co., St. Helens quadrangle

This area, about 2½ miles northwest of Scappoose, contains both a limonite deposit and a "shot" deposit which may prove to be ferruginous bauxite. These deposits were first mentioned in the report by Williams and Parks (1923). The limonite deposit was shown on their

map in the SW¼ sec. 34, T. 4 N., R. 2 W., and was reported to underlie basalt and to be of bog origin. Williams and Parks noted the occurrence of a few feet of residual reddish "shot ore" in a prospect cut near the northeast corner of the Colport Development Company property which included 50 acres in the SW¼ sec. 34, T. 4 N., R. 2 W. They recognized the distinction between the limonitic and the lateritic "shot ore" deposits and stated that the latter did not contain sufficiently high iron to be given serious consideration. This locality has not been checked, but the description of the "shot ore" indicates that ferruginous bauxite may be present in addition to limonite.

Locality 37, St. Helens quadrangle

This locality, 3¼ miles northwest of Scappoose, was noted by Wilkinson (1941). It is designated as a pit in iron ore. The character of the ore is unknown. Possibly it is bauxitic.

Locality 38, Oester deposit, St. Helens quadrangle

This deposit is on the Wm. J. Oester place near the west end of the Oester Road, about 3½ miles north-northwest of Scappoose at an elevation of about 500 feet. It was noted by Wilkinson (1941) and later by Hotz[1] who described the ore as a "cemented shot" deposit exposed in an old cut and adit. Hotz stated that it was reported that some of this material was mined and crushed for paint pigment many years ago. Results of the analysis of a 2-foot channel sample of the pit material below loose boulders of oölitic ferruginous bauxite are given below:

Al_2O_3	38.80 %
Fe	23.46
SiO_2	6.29
TiO_2	1.49
Ign. loss	20.65

Locality 39, McBride, St. Helens quadrangle

Results of the analysis of a 4-inch piece of brick-red, porous-granular bauxite float found on the northeast slope of a ridge at an elevation of about 650 feet, about 1½ miles due south of the Deer Island post office, are given below:

Al_2O_3	44.47 %
Fe	18.36
SiO_2	5.09
TiO_2	2.08
Ign. loss	22.69

Locality 40, St. Helens quadrangle

Concretionary iron ore is indicated by Wilkinson (1941) as occurring near the summit of the northwest side of a hill, 950 feet in elevation, about 1 mile southeast of Spitzenberg.

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[1] Hotz, P.E., op. cit., p. 13.

Results of the analysis of a specimen of brick red, oölitic ferruginous bauxite collected by Wilkinson's party in 1941 and analyzed recently by the Department are given below:

Al_2O_3	35.32 %
Fe	17.94
SiO_2	11.21
TiO_2	2.68
Ign. loss	21.01

Locality 41, St. Helens quadrangle

Hotz[1] reports the occurrence of a small oval body of "cemented shot" ore on top of a hill 825 feet in elevation about 1¼ miles east of Spitzenberg in the NW¼ sec. 15, T. 4 N., R. 2 W. He states that the exposed surface is 200 feet long and about 100 feet wide. He also notes the presence of rounded quartzite and weathered basalt pebbles and suggests that the ridge is part of a once more extensive terrace. Investigation by the Department showed that numerous pieces of oölitic ferruginous bauxite as much as 6 inches in diameter are present on the surface near the top of the hill. No analysis of the material was made.

Locality 42, St. Helens quadrangle

Pisolitic ore was noted by Wilkinson (1941) on the southwest end of a ridge 575 feet high, about 2 miles east of Spitzenberg. Results of the analysis of a composite sample made up of two pieces of oölitic ferruginous bauxite collected by Wilkinson's party and analyzed recently in the Department laboratory are given below:

Al_2O_3	33.50 %
Fe	31.66
SiO_2	2.32
TiO_2	2.58
Ign. loss	17.73

Locality 43, St. Helens quadrangle

A deposit of ferruginous bauxite is reported to form the upper part of the elongate hill which is about 850 feet in elevation and three quarters of a mile north of Spitzenberg. The occurrence of hematite float in this locality was mentioned by Williams and Parks (1923). The deposit has not been investigated by the Department.

Locality 44, St. Helens quadrangle

Numerous pieces of porous granular ferruginous bauxite occur near the crest of the Spitzenberg-Yankton road at its junction with a market road leading southward. The locality is about 1 mile east of Spitzenberg at an elevation of about 1000 feet. Analysis of a 1-foot channel sample taken from the ditch on the northeast side of the intersection returned:

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[1] Hotz, P.E., op. cit., p. 13.

Al_2O_3	36.42 %
Fe	23.83
SiO_2	10.87
TiO_2	1.98
Ign. loss	19.18

Locality 45, St. Helens quadrangle

"Limonitic concretions" are reported by Wilkinson (1941) to occur near the head of an east-flowing creek, a short distance northeast of Locality 44. Limonitic concretions from other localities have been associated with ferruginous bauxite deposits. This occurrence has not been investigated by the Department.

Locality 46, St. Helens quadrangle

Undescribed irony material is reported by Wilkinson (1941) to occur a very short distance northeast of the Dowd School, which is about 2 miles west of Yankton. It is said to occur at an elevation of about 700 feet on the southwest side of a ridge. None of the material is available for analysis. The occurrence has not been checked by the Department.

Locality 47, St. Helens quadrangle

Wilkinson (1941) indicated the occurrence of pisolitic iron ore on the east end of a long east-trending and sloping ridge, about half a mile southwest of Yankton. No analysis of the material is available and the locality has not been examined by the Department.

Locality 48, St. Helens quadrangle

Wilkinson (1941) noted that iron ore float occurs on a hill 525 feet high, about 2 miles nearly due north of Yankton. No other information is available.

Locality 49, St. Helens quadrangle

The occurrence of pisolitic ore at this locality was reported by Wilkinson (1941). The material occurs on a hill, 1550 feet in elevation, which is located about 2 miles south-southwest of Trenholm. No further description was given.

Locality 50, Bunker Hill limonite deposit, St. Helens quadrangle

This deposit of limonite was first described by Williams and Parks (1923) as the Bunker Hill group. It was said to be located in the southwest corner of sec. 31, T. 5 N., R. 2 W., at an elevation of about 1200 feet on the north side of the divide at the head of one of the branches of the Clatskanie River. The ore was described as the soft crumbly variety with some bands of hard ore, and was said to be obviously both overlain and underlain by basalt. An average analysis of the ore is given in the report on the Scappoose Mine, by the U.S. Bureau of Mines (War Minerals Report 186, 1944). This locality is here mentioned as it seems to indicate that although limonite and ferruginous bauxite deposits may occur in nearby areas, the limonite was deposited before the extrusion of later lavas whose upper portion weathered to form ferruginous bauxite. According to the description given,

the limonite deposit mentioned is about 100 feet stratigraphically below the "pisolitic or cemented shot" type of "iron" deposit represented by Locality 51.

Locality 51, Serafin deposit, St. Helens quadrangle

"Cemented shot" ore is reported by Hotz[1] to occur at the Serafin deposit located in sec. 19, T. 5 N., R. 2 W., about 12 miles west of St. Helens, and he states that the deposit occurs along the St. Helens-Vernonia road at an elevation of 1300 feet. In sec. 19, the road does not reach an elevation of 1300 feet, according to the topographic map. Possibly the ore extends northward along the crest of this ridge. Hotz described the deposit as a blanket of unknown size lying on the surface. A shallow pit is said to disclose a thickness of at least 3 feet of ore. The occurrence has not been checked by the Department.

Locality 52, St. Helens quadrangle

Wilkinson (1941) indicated the occurrence of "iron" float on the north end of a long ridge at an elevation of about 1025 feet, approximately three quarters of a mile north of Trenholm. No investigation has been made by the Department.

Locality 53, Trenholm deposit, St. Helens quadrangle

This occurrence was described by Hotz[1] as the Trenholm deposit. He stated that the ore occurs on a flat-topped hill at an approximate elevation of 1000 feet in sec. 20, T. 5 N., R. 2 W., 1 mile north of Trenholm. The location of this occurrence as shown on Locality Map C is probably in error and localities 52 and 53 may be the same. Pieces of "cemented shot" ore as much as 3 feet in size are reportedly exposed in a shallow pit and on the surface. Hotz also noted the presence of pieces of weathered basalt cut by narrow veinlets of hard limonite. No analysis of the material is available.

Locality 54, St. Helens quadrangle

Pisolitic "iron" ore was reported by Wilkinson (1941) to occur near the top of a ridge, about 1 mile north-northeast of the Happy Hollow School on the St. Helens-Vernonia Highway between Trenholm and Yankton. The elevation of the ore is about 800 feet. No analysis of the material is available but its topographic location and the texture of the ore suggest that it is bauxitic.

Locality 55, St. Helens quadrangle

Wilkinson (1941) noted the occurrence of "iron ore" at an elevation of about 600 feet in a draw north of the saddle in a roughly east-trending ridge, about 3 miles north of Yankton. No additional information is available regarding the occurrence, and the deposit may prove to be limonite.

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[1] Hotz, P.E., op. cit., p. 13.

Locality 56, St. Helens quadrangle

The location of this occurrence is not definitely known. Wilkinson (1941) indicated that "iron float" occurs near the top of a northwest-trending ridge at an elevation of about 825 feet, 1½ miles southeast of Canaan School, and also on the southeast slope about half a mile to the west at an elevation of approximately 700 feet. The character of the material from these possibly separate localities is unknown. The one on top of the hill may contain ferruginous bauxite.

Locality 57, Ironcrest limonite deposit, Vernonia quadrangle

This limonite deposit was described by Williams and Parks (1923) as the Ironcrest property. It consisted of a group of claims on the summit of the divide between the North Fork and the South Fork of Scappoose Creek in the southern part of sec. 35, T. 4 N., R. 3 W., at an elevation of 2000 feet. The deposit is reported to rest on a sticky gray clay containing rounded pebbles and silicified wood. One fossil mollusk was reportedly found in this clay. The limonite is overlain by weathered basalt.

This deposit is listed here as a matter of record and to avoid confusion with a possible occurrence of ferruginous bauxite nearby to the east, listed as Locality 58.

Locality 58, Ironcrest property, Vernonia quadrangle

Williams and Parks (1923) reported that some 30 holes were drilled in an area of 140 acres along the saddle in the northern part of the SE¼ sec. 35, T. 4 N., R. 3 W. This area adjoins Locality 57 on the west. Most of the holes reportedly struck ore through a shallow overburden of "weathered basalt" from 2 to 20 feet thick. The bed of ore was reported to have an average thickness of 10 feet. No information concerning the character of the ore was given. Analyses of the Ironcrest ore, as given by the U.S. Bureau of Mines (War Minerals Report 186, 1944) indicate that it is limonitic. However, the report stated that deposits of "shot ore" are present at the Ironcrest, Ladysmith, and Bunker Hill localities. These deposits are described as probably having originated on the surface as products of weathering and leaching of basalt. No analysis of these "shot ores" was given. Some may prove to be bauxitic in character. It may be that some of the area tested by the drill holes is underlain by ferruginous bauxite. This locality has not been investigated by the Department.

Locality 59, Ladysmith deposit, Vernonia quadrangle

Williams and Parks (1923) described this locality and stated that the Ladysmith claims were in the SW¼ sec. 24, T. 5 N., R. 3 W. The occurrences of ore they noted were apparently all limonitic and were overlain by basalt. However, as noted in the description of the Ironcrest locality, "shot ore" is reported by the U.S. Bureau of Mines (War Minerals Report 186, 1944) to occur at this locality. The smaller of two deposits mentioned by the Bureau's report is on a wide flat ridge 50 feet above the other which lies on the hillside. The report stated that the ore consisted of limonitic concretions cemented with iron oxide. Possibly the ore of the higher deposit is bauxitic.

Locality 60, De Vaul place, St. Helens quadrangle

Mr. O. E. De Vaul reports that material identical with that shown at Locality 28, 0.2 mile to the south, was found in a well on his place. The De Vaul house is the second one east of the intersection of the Dark Creek Road and the Smith Road on the north side of the Smith Road. He also reports that similar material was encountered in the wells on the Alfred Nightingale place on the southwest corner of the intersection, and on the Charles Ridgeon place which is the house on top of the hill north of the intersection.

Locality 61, Spitzenberg area, St. Helens quadrangle

Several small pieces of oölitic ferruginous bauxite were found about three quarters of a mile nearly due east of Spitzenberg on the west side of the road 0.4 mile south of its junction with the main road leading from Spitzenberg to Yankton. The material was not analyzed.

This locality is in an area mentioned by Williams and Parks (1923). The report stated that much of the "shot" variety of iron ore crops out in the road about one mile nearly east of Spitzenberg near the summit of the divide at an altitude of about 850 feet.

Locality 62, roadcut between Spitzenberg and Yankton, St. Helens quadrangle

An exposure of ferruginous bauxite, 200 feet long, is shown in the cut bank on the northwest side of the road leading from Spitzenberg to Yankton, probably in the NE¼ sec. 10, T. 4 N., R. 2 W. The roadcut is about 0.3 mile west from the Stone Road intersection, and is at an elevation of about 575 feet. Slightly fractured, weathered basalt is exposed on the north side of the road 0.2 mile farther west at a similar elevation, and weathered, well-bedded tuffaceous sediments, which stratigraphically underlie the basalt, are exposed in the roadcut 0.4 mile farther west at an elevation of about 625 feet. The sediments dip about 15° N. 65° E. and provide evidence that the ferruginous bauxite at this locality is dipping eastward. In this roadcut the deposit, more than 13 feet in thickness, and overlain disconformably by silt, was sampled in 3 sections. Sample P-3324 represents the top horizon, 3½ feet in thickness. It consists of red, somewhat oölitic hard material. Sample P-3325 represents the middle horizon 5½ feet in thickness. This section is soft and earthy with scattered oölites. Sample P-3326 represents the bottom horizon, 4 feet in thickness, and is made up of brown oölitic material, harder than the top horizon, with some pisolites. This bottom horizon extends at least one foot deeper as shown in the drainage ditch along the road. Analyses of these samples are given in the following table:

Sample No.	Thickness	Al_2O_3	Fe	SiO_2
P-3324	3½ ft.	44.52	12.53	14.30
P-3325	5½ ft.	45.48	12.97	9.28
P-3326	4 ft.	29.52	30.54	5.10

Similar oölitic material is exposed along the same road 0.1 mile farther east but analysis of a channel sample shows that it contains a high percentage of silica.

Locality 63, Langlie place, St. Helens quadrangle

Ferruginous bauxite is reported to occur on a southeast-sloping ridge which is about 2 miles north-northwest of Scappoose. The report has not been verified by the Department.

Locality 64, St. Helens quadrangle

Material described as iron ore is shown by Wilkinson (1941) to occur on a spur at an elevation of about 325 feet, 1½ miles northwest of Scappoose. A specimen of the ore collected by his party is massive limonite. The occurrence is noted here as a matter of record.

Locality 65, St. Helens quadrangle

"Iron ore" was reported by Wilkinson (1941) to occur on the southwest slopes of the hill 1 mile west of Yankton, at an approximate elevation of 400 feet. Loose fragments of pisolitic and gibbsitic varieties of ferruginous bauxite together with badly weathered basalt were collected along the upper road in this area.

Results of the analysis of the gibbsitic pieces are given below:

Al_2O_3	52.73 %
Fe	6.37
SiO_2	10.99
TiO_2	2.06
Ign. loss	26.61

Locality 66, Oregon Charcoal Iron Co. limonite deposit, St. Helens quadrangle

This occurrence was noted by Williams and Parks (1923) and described as the Oregon Charcoal Iron Company property located 1½ miles northwest of Scappoose. The ore is limonitic and described as a bog deposit between flows of basalt. It was drilled in 1942 by the U.S. Bureau of Mines (War Minerals Report 186, 1944), and the deposit is mentioned here as a matter of record.

Locality 67, St. Helens quadrangle

Williams and Parks (1923:map) show this locality in the NW¼ sec. 26, T. 5 N., R. 2 W. They state that numerous pieces of "limonite float" as large as "boulders" occur on the hill slope north of Milton Creek. Altered basalt country rock was also noted. This occurrence has not been checked, but as it is less than a mile north of Locality 27 where ferruginous bauxite occurs, the material may prove to be bauxitic. Williams and Parks also mentioned that similar float occurs at intervals to the northwest over a distance of 2 miles along the Milton Creek slope of the divide. Abundant showings were noted as occurring within the loop of Milton Creek and near the summit of the ridge probably in sec. 20, T. 5 N., R. 2 W. This last occurrence may be the same as that mentioned under localities 52 and 53.

Locality 68, Maple Hill, St. Helens quadrangle

As shown by Williams and Parks (1923:map) this occurrence is in the SW¼ sec. 7, and the northern part of sec. 18, T. 5 N., R. 1 W., near the top of the north side of Maple Hill at an approximate elevation of 500 feet. They report that a series of cuts and drill holes failed to prove the presence of a commercial quantity of ore which they described as a bed of limonite. This occurrence has not been checked; it probably is not bauxitic in character.

Locality 69, Skyline Blvd., Hillsboro quadrangle

Numerous small pieces of ferruginous bauxite were found in the roadcut along Skyline Blvd. near the south end of sec. 3, T. 2 N., R. 2 W., at an elevation of about 1300 feet. The area is overlain by silt. Ferruginous bauxite is also reported to occur farther south on Skyline Blvd. in sec. 14, T. 2 N., R. 2 W., near its junction with the Logie Trail.

Locality 70, Moreland Road, Hillsboro quadrangle

Ferruginous bauxite is reported to occur near the junction of the Moreland Road with the Mason Hill Road in the southwest corner of sec. 16, T. 2 N., R. 2 W., at an elevation of about 925 feet.

Locality 71, Chehalem Mts., Tualatin quadrangle (not on locality map - see index map on p.5)

The material is exposed in a roadcut in the SE¼ sec. 30, T. 2 S., R. 2 W., at an elevation of about 1000 feet. Results of the analysis of a 3-foot channel sample of yellow earthy material with some hard lumps, are given below:

Al_2O_3	32.80 %
Fe	20.65
SiO_2	13.31
TiO_2	4.27

Locality 72, Chehalem Mts., Tualatin quadrangle (not on locality map - see index map on p.5)

Ferruginous bauxite is exposed in a roadcut on the top of a northeast-trending and sloping spur in the SE¼ sec. 34, T. 2 S., R. 2 W., at an elevation of 950 feet. This is the farthest south that ferruginous bauxite has been found by the Department in the Washington County area.

Results of the analysis of a composite sample made up of three pieces of oölitic ferruginous bauxite are given below. Gibbsitic and limonitic varieties were also found.

Al_2O_3	40.35 %
Fe	21.34
SiO_2	3.08
TiO_2	4.46

Other indications of ferruginous bauxite

Additional occurrences and indications of ferruginous bauxite deposits not shown on the locality maps are known.

In the Gales Creek quadrangle, ferruginous bauxite is exposed in a roadcut on the Pumpkin Ridge Road about half way between localities 7 and 8 at an elevation of about 1250 feet. Loose pieces of porous, granular ferruginous bauxite occur in the roadcuts a short distance to the south.

In the Hillsboro quadrangle, loose pieces of ferruginous bauxite occur in the roadcut in the southeast corner of sec. 29, T. 3 N., R. 2 W., at an elevation of about 1450 feet.

In the St. Helens quadrangle, loose pieces of porous, granular ferruginous bauxite occur along the road about 2 miles north-northeast of Yankton and about half a mile southwest of Locality 28.

At the road intersection a quarter of a mile south of Locality 50 a laterite section several feet thick is exposed in the roadcut leading north. No information on total thickness is available. Some small nodules of gibbsitic material are embedded in the upper part of the section which consists of soft reddish- brown material. Numerous pieces of porous granular float were found along the road which extends southwestward from this intersection.

The iron content of samples from four open cuts in a hill located about 1 mile northwest of Columbia City in the St. Helens quadrangle is reported to range from 29 to 36 percent. These old cuts, described as the Giltner operation, are reported to be on the east slope of the hill about 40 feet below the top. The composition of the remaining portions of the samples is not known, but the topographic position of the cuts and the percentage of iron in the samples suggest that the material may be ferruginous bauxite.

In the southwest corner of the Kalama quadrangle, several pieces of bauxitic float were found on the upper surface of the ridge about 4 miles due south of Locality 30 at an elevation of nearly 1200 feet.

A piece of pisolitic ferruginous bauxite was found by Mrs. H. Mildred Stockwell on a gravel bar at the junction of the Clackamas and Willamette Rivers, just north of Oregon City. The source of the material is unknown, but as it is rather friable, it may not have traveled far if transported by natural processes, and it may have been derived from a nearby deposit. No attempt to locate its source has yet been made. The results of the analysis of the specimen are given below:

Al_2O_3	45.64 %
Fe	9.12
SiO_2	12.84
TiO_2	2.40
Ign. loss	25.26

Geology of Deposits in the Salem Area - Polk and Marion Counties

Introduction

Ferruginous bauxite and associated nodules of bauxite were found by the Department in the Eola Hills and Salem Hills north and south respectively of the city of Salem. Some further investigation of these two areas has been made since the discovery, and reconnaissance work has been done in the area farther east in the vicinity of Stayton. Many of the higher ridges and slopes in the Salem Hills contain much high-grade bauxite float, but investigations to date show it to be in place at only a few localities. A considerable area, at least several hundred acres, may be underlain by ferruginous bauxite, with bauxite float distributed over the surface, and contained in the overburden.

Stratigraphy

As in Washington and Columbia Counties, the bauxite and ferruginous bauxite deposits in the Salem area are associated with Miocene basalts. These basalts are called Stayton lavas (Thayer, 1939) and tentatively are correlated with the Columbia River basalts. Thayer states:

> "The Stayton lavas overlie the Illahe formation in the Salem Hills, and have been traced eastward continuously to the crest of the Mehama anticline. In the vicinity of Stayton they form dip slopes from which the younger formations have been stripped off. The lavas attain a maximum thickness of about 400 feet in the Salem Hills and apparently increase in thickness toward the northeast; east and southeast of Stayton they average less than 200 feet. The lavas are mainly medium-gray to dark-gray basalts in some of which olivine is visible; andesite flows occur south and east of Stayton.
>
> "The Stayton lavas lie unconformably on the Illahe and Mehama formations. Dips in the lavas average 3°, whereas dips in the Illahe and Mehama formations average 10 to 12°. The irregularity of the basal contact of the lavas indicates that they were poured out on a rolling landscape that had relief of 600 feet or more."

The Stayton lavas are petrographically very similar to the Columbia River basalts in Washington and Columbia Counties, and, as described by Mundorff (1939), are typically fine-grained, even-textured to slightly porphyritic, dense rocks with a gray to nearly black color. The average composition as determined petrographically by Mundorff from 15 representative specimens was given as 54 percent plagioclase, 19 percent augite, 21 percent glass, 5 percent magnetite, and 1 percent miscellaneous minerals. Mundorff stated that the bulk of the plagioclase is basic andesine (Ab_{55} - An_{45}). O'Neill (1939) reported that most of the plagioclase in the Stayton lavas in the Stayton quadrangle is labradorite.

The Illahe formation is made up of tuffaceous marine sandstones which Thayer tentatively correlated with the Eugene or Pittsburg Bluff formations of Oligocene age. In the Molalla area northeast of Salem the Stayton lavas unconformably overlie marine sediments containing fossils assigned by Durham (1942) to the lower Miocene.

According to Thayer the Stayton lavas east of the Salem quadrangle are conformably overlain by the Fern Ridge tuffs of Miocene age. O'Neill later pointed out that the tuffs lie on an erosion surface of the Stayton lavas, and he tentatively referred them to the Pliocene.

The High Cascade lavas occur farther east, and they have been referred by Thayer to the Pliocene and Pleistocene.

Structure of the Miocene lavas

The topographic distribution of the ferruginous bauxite deposits in the Salem area, like those in the Washington County-Columbia County area, appears to be related to the structure of Miocene lavas. For the most part, the deposits occur on flat-topped hills and ridges.

Dips of 3° in the Stayton lavas in the Salem area were noted by Thayer (1939). He states:

> "The Salem Hills are essentially a slightly warped lava-capped mass whose eastward dip is best shown west of Marion. 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 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 Willamette Valley."

Additional information on the attitude of the Stayton lava is given by Allison and Mundorff[1].

> "The apparent strike of the lavas of the Salem and Eola Hills changes from about N. 45°W. in the south to about N. 15° W. toward the north, and the dip of the mass appears to be about 2° toward the east or northeast. . . It is noteworthy that certain of the eastward slopes on the Eola Hills (and less clearly on the Salem Hills) are essentially dip slopes of the component lavas."

Laterization of the basalt

Insufficient work has been done by the Department in the Salem area to date the period of laterization there with certainty, but the evidence indicates laterization took place before the deposition of the Fern Ridge tuffs.

As no bauxitic material was found in several places where the contact between the Fern Ridge tuffs and the Stayton lavas was examined, it appears that if laterization did precede deposition of the tuffs, either the laterite did not form in places or was removed before the tuffs were laid down. If, on the other hand, laterization followed deposition of the tuffs,

[1] Allison, Ira S., and Mundorff, Maurice J., Preliminary geologic map of the Salem quadrangle, Oregon: In manuscript.

then it would be unlikely that any laterite would be found beneath the Fern Ridge tuffs.

O'Neill (1939) states that the Fern Ridge tuffs in the Stayton quadrangle are made up of poorly sorted and poorly bedded, stream-laid deposits of tuff and some pebble conglomerate which unconformably overlie the Stayton lavas and in places the Illahe formation. According to Thayer (1939) the lower part of the Fern Ridge formation is made up mainly of tuffs, sandstones and fine pebble beds, and the upper part comprises coarse andesitic conglomerate with boulders as much as 18 inches in diameter. This information indicates that erosion was active while the Fern Ridge tuffs were being deposited.

If the Fern Ridge tuffs were conformable on the Stayton lavas, as suggested by Thayer, there would be no reason to believe that the lavas in the Salem Hills, where bauxite is present, were not originally buried by the tuffs. Nondeposition there would be hard to explain, as the Fern Ridge tuffs farther east are estimated by Thayer to be as much as 1500 feet thick in places. If the lavas in the Salem Hills had been buried by other than a thin veneer of Fern Ridge tuffs, the laterization would have had to precede deposition of the tuffs, as erosion of such a cover to permit laterization of the underlying basalts would have removed the laterite as fast as it was formed.

O'Neill reports that the Fern Ridge tuffs are unconformable on the Stayton lavas. Thus if laterization had followed deposition of the tuffs, it is conceivable that the lavas in the Salem Hills and Eola Hills were not covered by the tuffs and that laterite could have formed there and not farther east where the lavas were covered. However, there are two possible objections to this thesis. First, the attitude of most of the laterite appears to conform to that of the lavas. This attitude conformable with the flows, and the presence of nearly all of the laterite only on the higher ridges and slopes would be difficult to explain if, as postulated by O'Neill, the erosional break between the Stayton lavas and the Fern Ridge tuffs was the result of folding of the lavas prior to deposition of the tuffs. Second, the red soil covering the laterite in the Salem Hills closely resembles that which is residual from the Fern Ridge tuffs farther east, and if they be the same, the tuffs covered the lavas in the Salem Hills and are represented by this soil cover. A number of rounded, unweathered basaltic pebbles have been found in this soil cover at several places in the Salem Hills where their transport by other than natural agents seems unlikely. Presence of these pebbles indicates that a waterlaid deposit formerly covered the laterite, and these pebbles are tentatively assigned to the Fern Ridge tuffs.

If laterization preceded deposition of the tuffs as is believed, the absence of bauxitic material beneath the Fern Ridge tuffs in the Stayton area can be explained by either nonformation in places or by erosion prior to deposition of the tuffs. Although nonformation is a possibility, there is evidence which indicates that both laterization of the Stayton lavas and subsequent erosion preceded deposition of the Fern Ridge tuffs.

Sediments which O'Neill (1939) mapped as part of the Fern Ridge tuffs overlie unconformably weathered Stayton lavas in a roadcut near the Ed Doerfler place in the NW¼ sec. 21, T. 8 S., R. 1 W., at an elevation of about 500 feet. These sediments appear to be an outlier of the main body of the Fern Ridge tuffs farther east and are similar to them in appearance, lithology, and degree of weathering. A nodule of high-grade gibbsite was found here in the sediments several feet above the contact with the underlying basalt. This indicates not only that laterization preceded deposition of the Fern Ridge tuffs but also that erosion accompanying their deposition in places stripped away laterite which was deposited together with the tuffs. In this roadcut the marked differential weathering shown in the underlying basalt, as well as the erosional unconformity, indicates that part of the lateritic profile was removed by erosion before the overlying sediments were deposited.

Both the tuffs and gravels in the Fern Ridge formation have been weathered in places to form high-alumina clays. It appears that the weathering of the Fern Ridge tuffs represents either a continuation of the conditions which produced laterization of the Stayton lavas, or a later weathering cycle. The tuffs may have been deposited in the Salem area at about the same time as the sediments of the Troutdale formation in the Portland area. Gravels tentatively assigned to the Troutdale formation in the St. Helens quadrangle by Lowry and Baldwin[1] have been similarly weathered, and the clay from the Fransen deposit (Wilson and Treasher, 1938), which may belong to the Troutdale formation, contains as much alumina as silica. This suggests that laterization may have been active during part of Troutdale time.

Shape and attitude of deposits

The presence of much bauxite float on many of the highest ridges and flat hills in the Salem Hills indicates that the deposits were formed from the upper flows in the basaltic section. The surfaces here as well as in the Eola Hills have been described as dip slopes. Most of the roadcuts in that area are not deep enough to expose the underlying basalt, although laterized basalt is shown in one roadcut on the crest of a hill. Thus the outline of the deposits probably is determined by the topography, and their attitude by that of the basalt flows. One apparent exception is the occurrence of ferruginous bauxite and an associated overlying layer of bauxite nodules at Locality 87 on U.S. Highway 99E in the SE¼ sec. 35, T. 8 S., R. 3 W. The bauxite here occurs in a roadcut which is more than 200 feet below the surrounding summits. This suggests that either this deposit has been affected by faulting or slumping or that the area may have had considerable relief while laterization was taking place.

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[1] Unpublished report.

Character of the ore

Preliminary investigation in the Salem area shows that the character of the laterite is somewhat different from that in Washington, Multnomah, and Columbia Counties. The oölitic and pisolitic horizon is missing except at Locality 93*. Elsewhere the laterite appears to have two distinct phases. The upper phase consists of bauxite nodules, ranging in size from small pieces to as much as 2 or 3 feet in diameter, which have been found in most places only as float. The other phase is somewhat earthy laterized basalt. The upper few feet of this phase is equivalent in grade and similar in characteristics to the soft earthy sections in Washington County ore. Below this upper section, the earthy laterite increases in silica content, and grades into weathered basalt. In some places small nodules of bauxite occur near the top of the lower phase, indicating a gradation from one phase to the other.

At two localities where the earthy ferruginous bauxite has been sampled, the laterite has characteristics which show its derivation from basalt. At one, Locality 83, a well-defined spheroidal weathering pattern is preserved, and at the other, Locality 87, the lower part of the red earthy laterite contains a large piece of unaltered basalt. At the first locality, the upper 5 feet is brown with limonitic streaks or seams which are related to the spheroidal weathering pattern. This upper section contains lighter colored gibbsitic material with numerous grains of magnetite, some of which show an octahedral crystal habit. Analysis of channel samples of the upper 5 feet of the laterite section at both localities shows that it contains about:

Al_2O_3	36 %
Fe	21
SiO_2	10.5
TiO_2	2-5

The silica content of the next 3 or 4 feet below at both localities increases to about 17 percent and the alumina drops to about 30 percent.

Overlying the ferruginous bauxite at both localities is a layer of loose bauxite nodules. Although similar nodules have been found in Washington and Columbia Counties, those in the Salem area are much more common and generally larger in size. The nodules are irregular in outline and have a rough surface. Commonly they measure 6-8 inches in diameter. The largest nodule seen so far measured about 3 feet in longest dimension. Color of the nodules when broken, is white, green, pink, light brown, or reddish-brown or variations of these colors. Some of the reddish-brown bauxite nodules have a porous, almost spongy, granular texture with residual grains of magnetite. Some of the larger nodules have a dense texture with irregularly shaped cavities and contain much fewer grains of residual magnetite. They tend to be lighter colored.

* The deposit containing pisolitic ferruginous bauxite was found while the manuscript was being multigraphed; hence its presence could not be noted in the Abstract.

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. A photomicrograph of the section is shown in Plate II, figure 3, opposite page 16. 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 ± 1 mm long and are now filled with aggregates of gibbsite. Many of the skeleton crystals of magnetite are cut through by 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.

A thin section of a brown, more porous nodule from Locality 79 retains only a part of the original texture of the basalt from which it was derived. 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 much 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.

Although most of the gibbsite nodules are loose on the surface or in the overburden, some appear to be in place in laterized basalt at several localities, and high-grade bauxite apparently is in place at Locality 84 where a bed of solid ore about 12 feet long and 1 foot thick is exposed in a roadcut.

The alumina content of the nodules analyzed ranges from 50 to 60 percent; the silica, from 1 to 6 percent; and the iron, from 1 to 14 percent.

At Locality 93, numerous pieces of pisolitic ferruginous bauxite and bauxite nodules occur as float on the surface. At this locality, a few pieces of high-grade pisolitic bauxite were found near the J. Summers' house; one chunk of pisolitic ferruginous bauxite found near the well was nearly 1 foot long. The occurrence of much of the pisolitic ferruginous bauxite northeast of most of the bauxite nodules and at a slightly greater elevation indicates that the pisolitic ferruginous bauxite is stratigraphically higher in the lateritic profile as the dip of the basaltic lavas in the Salem Hills is northeast. Thus the profile in the Salem area may have been quite similar to that in Washington and Columbia Counties where the oölitic and pisolitic horizon is uppermost. The presence of this horizon at only one locality suggests that it has been removed by erosion from the other localities.

The pisolitic ferruginous bauxite at Locality 93 is quite similar in appearance and composition to that in Washington, Multnomah, and Columbia Counties. The pisolites are embedded in a reddish-brown, earthy matrix. They tend to be round and average about three-sixteenths of an inch in diameter. Their fracture surfaces range from a dull, earthy brown to a submetallic, dark gray or nearly black color. The pisolites are magnetic. The pisolitic ferruginous bauxite also contains inclusions of porous granular ferruginous bauxite and dense gibbsite. The porous granular inclusions are reddish-brown in color and as much as 1¼ inches in length. They apparently retain part of the texture of the basaltic parent rock and contain residual grains of magnetite. The dense, light-colored, gibbsitic inclusions are as much as 2 inches in length and some are characterized by smooth, curved surfaces suggesting the colloidal nature of the gibbsite. An analysis of a piece of the pisolitic ferruginous bauxite from this locality, sample P-3987, is given in the tabulation below. Other pieces probably contain more alumina and somewhat less iron as judged by the amount of gibbsitic material included in them. An analysis of a piece of the pisolitic bauxite, P-3988, also found at this locality follows:

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3987	29.15	35.04	2.78	1.39	17.17
P-3988	57.60	6.78	4.07	2.77	30.52

In contrast to the rather thick silt overburden in Washington and Columbia Counties, that in the Salem area appears to be thinner in section, probably less than 10 feet thick. The soil contains mineral particles of silt size, including quartz grains, whose derivation is not yet known. Possibly the soil is the remnant of the Fern Ridge formation.

Origin of the deposits

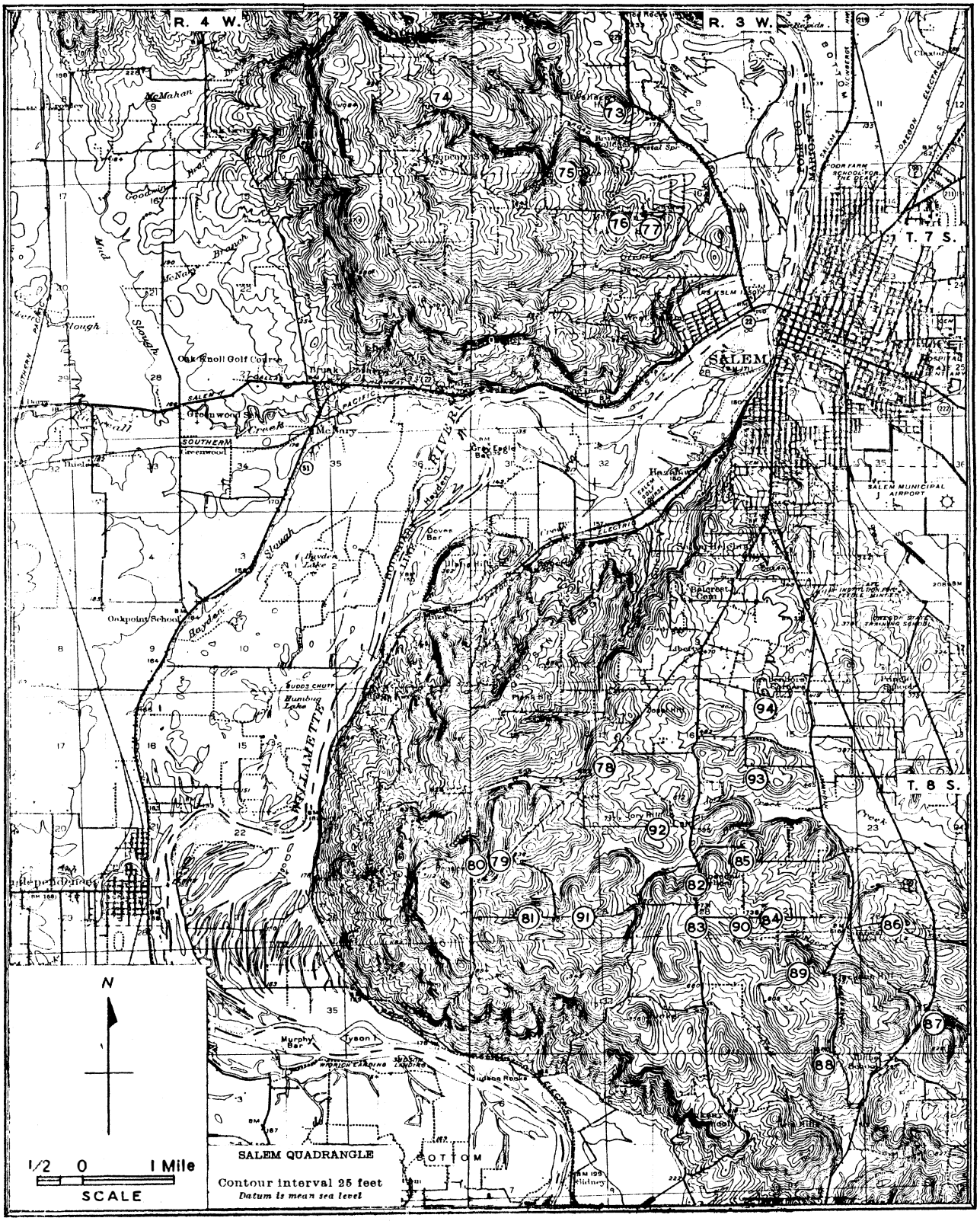
The laterite in the Salem area is the result of the weathering of Stayton lavas of Miocene age over a long period of time which followed the extrusion of the lavas and probably preceded the deposition of the Fern Ridge tuffs of Pliocene (?) age. Derivation of the laterite from the Stayton lavas is unquestionable. The laterite is confined to terrane made up of Stayton lavas. At Locality 83, the original spheroidal weathering pattern of the parent basalt is preserved in the earthy ferruginous bauxite which contains numerous residual grains of magnetite. At Locality 87, the earthy ferruginous bauxite is a laterized basalt which grades downward into less altered material containing fresh chunks of basalt.

The nodules of high-grade bauxite represent a more altered and stratigraphically higher part of the basaltic section. They show a gradation from brown, very porous granular varieties which retain part of the original texture of the parent basaltic rock,

to light-colored, rather dense varieties. The dense varieties retain none or only a suggestion of the original texture and contain only a few residual grains of magnetite which show their original crystal outlines. As described previously, and as shown in Plate II, fig. 3, opposite page 16, a brownish-white nodule from Locality 81 retains much of the original intersertal texture of the basalt from which it was largely derived. However, part of the preservation of the texture is the result of replacement by gibbsite.

The pisolitic ferruginous bauxite at Locality 93, which probably represents the upper section of the laterite profile, contains inclusions of porous granular ferruginous bauxite which retain part of the texture of the parent basaltic rock. Residual grains of magnetite are also present in the pisolitic ferruginous bauxite and further attest to its derivation from the Stayton lavas.

For a more complete discussion of the age of the laterization, refer to the discussion on page ~~3.~~ 67



Locality Map E
Salem Area, Polk and Marion Counties, Oregon
Showing Generalized Location of Bauxite Deposits
Topog. Base by U.S.G.S. and 29th Engineers U.S. Army

Description of Deposits in Salem Area - Polk and Marion Counties*

Locality 73, Wallace Hill, Salem quadrangle

Numerous pieces of porous granular bauxitic float occur on the south slope of Wallace Hill in the SE¼ sec. 8, T. 7 S., R. 3 W., at an elevation of approximately 350 feet. Results of the analysis of a composite sample of several pieces follow:

Al_2O_3	50.90 %
Fe	11.98
SiO_2	3.50
TiO_2	1.82
Ign. loss	28.87

Locality 74, Eola Hills, Salem quadrangle

Pieces of porous granular bauxitic float were found east of the road in the NE¼ sec. 12, T. 7 S., R. 4 W., at an elevation of 750 feet. No analysis of the material was made.

Locality 75, Grice Hill, Salem quadrangle

Numerous pieces of bauxitic float are reported to occur on Grice Hill in Sec. 17, T. 7 S., R. 3 W. The locality has not been visited by the Department.

Locality 76, Chaplin Hill, Salem quadrangle

Pieces of porous granular bauxitic float occur on the crest of the road on top of Chaplin Hill near the center of the SE¼ sec. 17, T. 7 S., R. 3 W., at an elevation of 500 feet. None of the material has been analyzed.

Locality 77, Mountain View School, Salem quadrangle

Numerous pieces of bauxitic float are scattered around a large open cut on the north end of the hill southwest of the Mountain View School, in the southwest corner sec. 16, T. 7 S., R. 3 W., at an elevation of approximately 400 feet. No analysis of the loose pieces was made but a 2-foot channel sample of the material several feet below the top of the excavation returned:

Al_2O_3	34.01 %
Fe	16.62
SiO_2	19.10
TiO_2	3.18
Ign. loss	19.28

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*See locality map.

Locality 78, Salem Hills, Salem quadrangle

Results of the analysis of loose pieces of brown porous granular bauxite which occur in a roadcut of the Liberty-Prospect road in the SW¼ sec. 17, T. 8 S., R. 3 W., at an elevation of 700 feet are given below. The bauxite contains residual grains of magnetite.

Al_2O_3	56.46 %
Fe	7.92
SiO_2	5.57
TiO_2	3.47
Ign. loss	28.39

Locality 79, Prospect Hill area, Salem quadrangle

Both gibbsitic and limonitic varieties of float occur in the roadcut on the east side of the saddle in a north-trending ridge in the SW¼ sec. 19, T. 8 S., R. 3 W., at an elevation of 825 feet. Results of the analysis of a gibbsitic specimen, P-3551, and a limonitic specimen, P-3552, are given below. The gibbsitic specimen was brown and had a porous granular texture; it contained residual grains of magnetite.

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3551	53.35	9.91	1.55	2.68	28.83
P-3552	14.35	42.47	10.18	1.39	13.96

Locality 80, Prospect Hill area, Salem quadrangle

Pieces of gibbsitic material occur in the roadcut on the northwest side of the hill a short distance east of the schoolhouse in the southwest corner of sec. 19, T. 8 S., R. 3 W., at an elevation of 825 feet. No analysis of the material was made by the Department.

Locality 81, Salem Hills, Salem quadrangle

Numerous pieces of gibbsitic float are exposed in the roadcut on top of the spur near the center of sec. 30, T. 8 S., R. 3 W., at an elevation of 825 feet. A specimen of the bauxite has a brownish-white color and a porous granular texture with residual spearlike aggregates of magnetite. A description of a thin section of this nodule is given on page 8. Analysis of the material gave the following results:

Al_2O_3	50.64 %
Fe	13.57
SiO_2	2.23
TiO_2	2.11
Ign. loss	27.07

Locality 82, Rosedale School, Salem quadrangle

Weathered basalt is exposed in the roadcut in the NW¼ sec. 28, T. 8 S., R. 3 W., at an elevation of about 650 feet, about one quarter of a mile south-southwest of the Rosedale School. It is overlain by 4 feet of silty soil containing gibbsitic float.

No analysis of the float was made but analyses of three channel samples of the weathered basalt were made and are listed below. These analyses show gradational changes in the laterite section.

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3569	3 ft.	35.08	18.57	17.71	3.57	20.43
P-3568	3 ft.	29.69	15.10	31.49	3.77	15.73
P-3567	1½ ft.	29.60	12.75	35.03	4.07	15.23

Sample P-3569 represents the upper horizon, 3 feet in thickness, containing brownish-gray material with whitish gibbsitic pieces. Immediately south of the point where this channel sample was taken, an unaltered chunk of dark gray basalt occurs in about the same horizon. Sample P-3568 represents 3 feet of the soft claylike middle horizon, which contains a few oölities in its upper part. It shows no residual basalt texture. Sample P-3567 represents a 1½-foot channel of the lowest horizon sampled. It is a soft, red and gray material which retains the vesicles of the original basalt.

Locality 83, Salem Hills, Salem quadrangle

A layer of brown, porous granular, gibbsitic nodules in the shallow soil overlying laterized basalt is exposed in the roadcut in the NE¼ SW¼ sec. 28, T. 8 S., R. 3 W., at an elevation of 775 feet, about two-thirds of a mile south of the Rosedale School. Results of the analysis of one of the gibbsitic nodules, sample P-3549, are given below. A thin section of one of the nodules shows that only part of the original texture of the parent basalt is retained. Outlines of some of the original plagioclase laths are visible and the original arrangement of the residual grains of magnetite is partially preserved.

The laterized basalt below the overburden is characterized by a spheroidal weathering pattern. The upper 5 feet, channel sample P-3571, is brown with limonitic and gibbsitic streaks. The gibbsitic streaks contain residual magnetite grains some of which show their crystal outline. The less altered lower part of the basalt which is a soft, light brown, earthy material, 4 feet in thickness, is represented by sample P-3570. Analyses of these samples follow:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3549	nodule	50.23	11.02	4.82	3.57	26.11
P-3571	5 ft.	37.46	21.20	10.55	2.78	19.80
P-3570	4 ft.	29.22	24.66	17.33	3.27	16.88

Analyses of the laterized basalt show that although continued laterization has effected a further reduction in the content of silica and titania and an increase in the alumina similar to that which took place at Locality 82, it has reduced the percentage of iron. The

analysis of the gibbsitic nodule, P-3549, shows the continuation of similar changes with the exception of an increase in the percentage of titania. Much of the remaining titania may be present as titaniferous magnetite.

Gibbsitic nodules are exposed in the roadcut about one-third of a mile south of this locality, near the south end of sec. 28. This nodular material has not been analyzed by the Department.

Locality 84, Salem Hills, Salem quadrangle

An exposure of light-colored, porous gibbsitic material about 12 feet long and 1 foot thick is shown in the roadcut about 1 mile southeast of the Rosedale School near the center of the W½ sec. 27, T. 8 S., R. 3 W., at an elevation of about 725 feet. The outcrop appears to be in place. Analysis of a sample of the material returned:

Al_2O_3	52.80 %
Fe	9.98
SiO_2	2.55
TiO_2	2.98
Ign. loss	28.77

Gibbsitic nodules are exposed in a roadcut nearly half a mile to the west of the above outcrop. No analysis of the material was made by the Department.

Locality 85, Salem Hills, Salem quadrangle

Many gibbsitic nodules are scattered over the surface at the bend in the road in the southwest corner of sec. 22, T. 8 S., R. 3 W., at an elevation of about 675 feet. No analysis of the float was made by the Department. Similar gibbsitic nodules occur in the roadcut on the crest of the ridge in the southeast quarter of the same section.

Locality 86, Sunnyside School area, Salem quadrangle

Light-colored, irregularly shaped bauxite nodules as much as 8 inches in diameter were found in the soil horizon in the roadcuts near the center of sec. 26, T. 8 S., R. 3 W., at an elevation of about 750 feet. Analyses of one of the nodules, P-3546, and of a 3½-foot channel sample, P-3536, of the red, nodular material underlying the nodule horizon are given below:

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3546	nodule	59.55	2.59	3.24	1.00	32.85
P-3536	3½ ft.	28.35	14.71	28.70	4.32	16.97

It is thought that the channel sample included part of the silty soil horizon and that possibly the lower part of the channel represents better grade material.

Bauxite nodules were also found along the same road less than half a mile to the west. There the material exposed in place in the roadcut is weathered basalt containing more than 30 percent silica.

Locality 87, U.S. Highway 99E roadcut, Salem quadrangle

A layer of loose irregularly shaped, slightly porous bauxite nodules is exposed in the roadout on U.S. Highway 99E in the NE¼ SE¼ sec. 35, T. 8 S., R. 3 W., about 6 miles south of Salem. The nodules are light-colorod when broken, and lie on top of red laterized basalt in place; they are also distributed over the surface of the slope to the east. The analysis of one of the nodules, P-3532, 1 foot in longest dimension, is given below. Petrographic examination shows that it is made up largely of gibbsite with some cliachite, and a few residual grains of magnetite. The upper 5½ feet of the laterized basalt is represented by sample P-3537. Below this a section of laterite, 3 feet in thickness, is represented by sample P-3573. This lower section shows a marked increase in the percentage of silica. A large chunk of unaltered basalt occurs in or below this horizon a little farther south in the cut.

Sample No.	Thickness represented	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3532	nodule	56.50	1.21	4.87	1.30	32.86
P-3537	5½ ft.	35.27	20.60	10.65	4.62	19.84
P-3573	3 ft.	30.75	21.89	17.77	5.25	16.91

The elevation of the exposure is about 500 feet which is several hundred feet below the nearby hilltops. It is not known whether the presence of laterite here indicates that lateriзation took place while the area had considerable relief or that faulting or slumping is responsible for its position. Bauxite nodules similar to those at this locality, occur in the next two roadcuts less than half a mile to the south. Analysis of a grab sample of the weathered basalt from near the base of the southernmost of these cuts returned about 30 percent alumina and 28 percent silica. A hard red nodule in the weathered basalt exposed in the highway cuts more than a mile south of Locality 87 contains about 15 percent alumina, 38 percent iron, 17 percent silica, and 0.3 percent titania.

Locality 88, George Veall place, Salem quadrangle

Bauxitic nodules similar to those at Locality 87 are embedded in the soil on top of the ridge in the NE¼ sec. 3, T. 9 S., R. 3 W., at an elevation of 675 feet. They are also shown under uprooted trees and in one shallow prospect pit. Many of the nodules are 1 foot in diameter and one of those seen was 3 feet in longest dimension. They have a tough surface, a rather dense though slightly cavernous texture, and a pinkish color. They contain some residual grains of magnetite. A brief description of a thin section of one of these nodules is given on page 9.

Locality 89, Salem quadrangle

Many gibbsite nodules, as much as 2 feet in diameter, occur on top of a northwest-trending ridge near its western end in the NW¼ NE¼ sec. 34, T. 8 S., R. 3 W., at an elevation of 800 feet. Some bauxite float was found along the western extension of this

ridge just west of an intervening saddle.

Locality 90, Salem quadrangle

Gibbsite nodules several inches in diameter were found on the dump of a shallow pit near the southeast corner of the church on the south side of the road in the NE¼ SE¼ sec. 28, T. 8 S., R. 3 W., at an elevation of 725 feet. Nodules were also seen elsewhere in the vicinity of the church.

Locality 91, Salem quadrangle

Loose gibbsite nodules are exposed in the roadcut at the top of the ridge near the center of the W½ sec. 29, T. 8 S., R. 3 W., at an elevation of about 850 feet.

Locality 92, Jory Hill, Salem quadrangle

Bauxite nodules are scattered over the flat upper surface of Jory Hill, most of which lies in sec. 20, T. 8 S., R. 3 W., at an elevation of about 700 feet. A pile of the nodules several feet high, apparently gathered from the adjacent field, is just north of the main road at the northeast corner of the southeast quarter of the section. A well-rounded, unweathered basaltic pebble was found on the surface of the flat south of the road.

Locality 93, J. Summers place, Salem quadrangle

Pieces of pisolitic ferruginous bauxite and bauxite nodules are common over much of the flat surface of the J. Summers place in the SW¼ sec. 15, T. 8 S., R. 3 W., at an elevation of nearly 500 feet. Gibbsite nodules are more common just south of the right angle turn in the road west of the house. Farther east toward the house, at a slightly higher elevation, pieces of pisolitic ferruginous bauxite become more common and chunks as much as a foot in length were found near the well on the east side of the house. A few pieces of pisolitic bauxite were found a short distance back of the house. As the dip of the lavas of the Salem Hills is northeast, the pisolitic material which predominates to the east probably represents the stratigraphically highest section of the ore at this locality.

The pisolitic ferruginous bauxite is very similar to that found in Washington and Columbia Counties and described on page 10. Results of analyses of type specimens at Locality 93, namely a piece of ferruginous bauxite, P-3987, a piece of pisolitic bauxite, P-3988, and a nodule of the porous granular bauxite containing a few attached oölites and pisolites, P-3989, are given below:

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2	Ignition loss
P-3987	29.15	35.04	2.78	1.39	17.17
P-3988	57.60	6.78	4.07	2.77	30.52
P-3989	43.95	15.37	8.46	3.17	-----

A few well-rounded unweathered basaltic pebbles were also found on the surface at this locality.

Locality 94, Grabenhorst Corners, Salem quadrangle

Two horizons of lateritic material are shown in the roadcut in front of the W. D. Olden place on top of the hill about half a mile west of Grabenhorst Corners at an elevation of about 500 feet. The roadcut is in the NW¼ sec. 15, T. 8 S., R. 3 W. Results of analyses of samples from these horizons are given below. Sample P-3990 represents nodular material of porous granular type from the top of the upper horizon. Sample P-3991 represents the upper horizon, 3 feet in thickness, made up largely of brownish nodular material. Sample P-3992 represents the lower horizon, 3 feet in thickness, made up of earthy, brown and white material.

Sample No.	Al_2O_3	Fe	SiO_2	TiO_2
P-3990	44.65	16.20	1.96	3.57
P-3991	29.45	19.39	20.37	----
P-3992	26.50	18.42	27.19	----

Other indications of bauxite in the Salem area

Bauxite nodules were found along the road south of the Ankeny School in sec. 9, T. 9 S., R. 3 W. The nodules do not occur in place, and probably have crept or have been transported a considerable distance. Bauxite nodules were also seen along the Jefferson Highway and U.S. Highway 99E nearer Salem than any of the localities shown on the locality map on page 74.

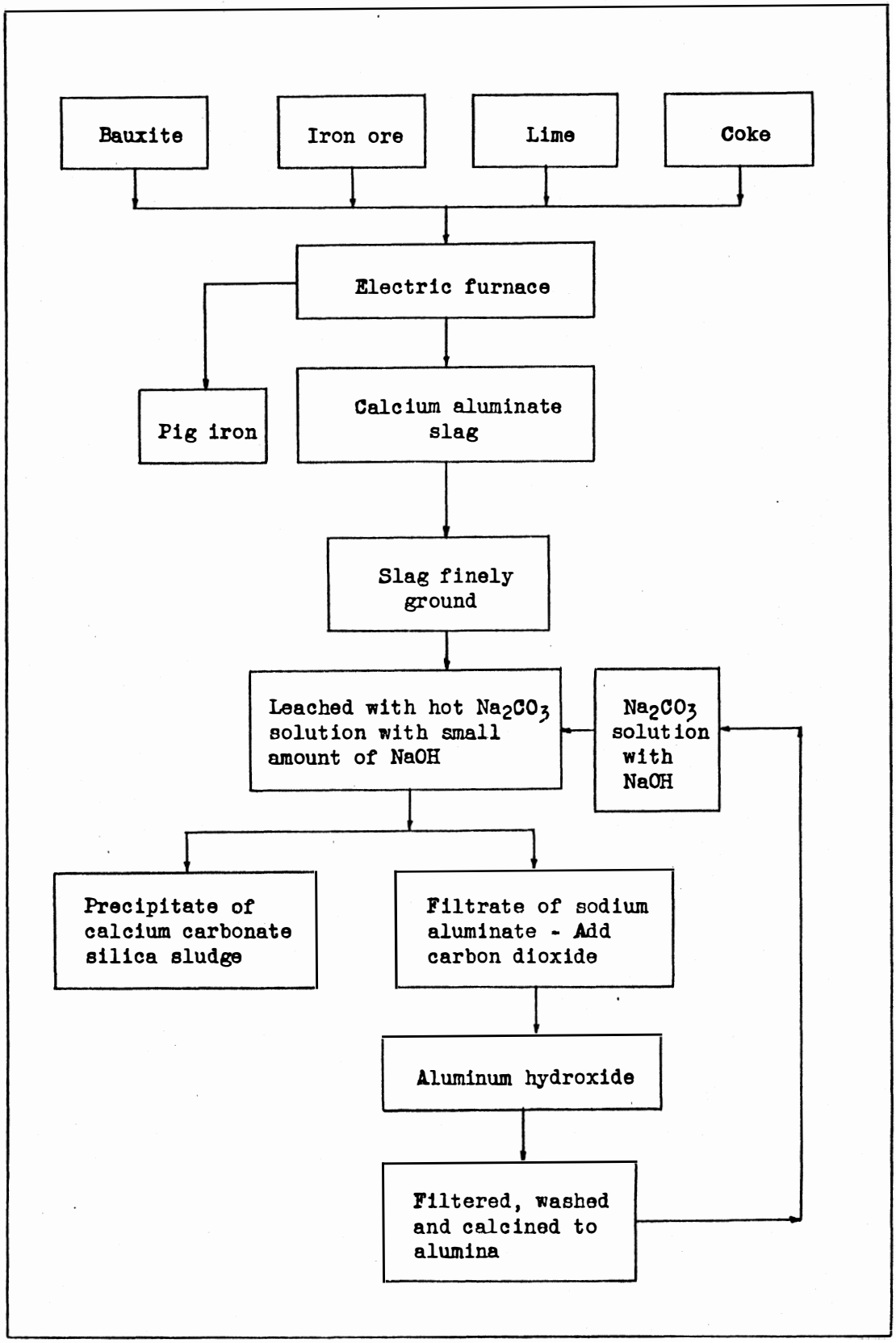
Loose bauxite nodules occur along the road in the SW¼ NW¼ sec. 6, T. 8 S., R. 2 W., about 2 miles southwest of Turner in the Stayton quadrangle. High-grade gibbsite float has been found at several places in the Waldo Hills east of Salem. One piece was found on the south slope of the hilltop in the SE¼ sec. 9, T. 8 S., R. 2 W., at an elevation of about 625 feet. Several pieces were seen in the roadcuts near the Witzel School in the NE¼ sec. 16, T. 8 S., R. 2 W. Numerous gibbsite nodules are scattered over the surface of the flat near the house on the south side of the road in the southeast corner of the NW¼ sec. 15, T. 8 S., R. 2 W. The surface is a little more than 600 feet in elevation and extends northwest nearly a mile.

Bauxite is reported to occur on the surface of the higher elevations of the southeastern extension of the Salem Hills, about 3 miles northwest of Marion.

As previously mentioned under the discussion of the laterization of the basalt on page 69, a high-grade gibbsite nodule was found in a roadcut near the Ed Doerfler place in the NE¼ sec. 21, T. 8 S., R. 1 W. This nodule occurs in sediments overlying Stayton lava. The sediments have been mapped by O'Neill (1939) as part of the Fern Ridge tuffs. The significance of this occurrence is noted in the discussion mentioned above.

An occurrence of limonite in sec. 24, T. 8 S., R. 2 W., is also listed here as a matter of record. Results of the analysis of a sample submitted to the Department by James E. Towle of the Waldo Hills Seedling Nursery, Aumsville, Oregon, are given below:

Fe	51.32 %
Al_2O_3	4.90
SiO_2	3.44
TiO_2	0.39
Ign. loss	16.43



Pedersen Process for Production of Pig Iron and Alumina

Economics of Deposits

Introduction

According to present practice, metallic aluminum is produced from ore in two steps. The first is the production of pure aluminum oxide, or alumina as it is called, from high-grade bauxite by the Bayer process. The second step is the electrolysis of alumina in a fluoride bath to obtain the metal. No other process has so far been used to produce aluminum commercially in this country. Only high-grade bauxite is amenable to treatment by this process; in fact no other aluminous material has so far been competitive with bauxite in production of aluminum, if exception is made of the reported treatment of clays in Germany and Russia, and the small wartime production of alumina from alunite. In these instances, the plants were Government-owned or sponsored and costs of production were probably not comparable with those obtainable by Bayer process plants operated by private industry. However, it is improbable that unit cost of producing aluminum metal from low-grade material such as clay or other silicates has been nearly as low as that obtained in using bauxite of the quality required in Bayer plants. The reason, of course, for treating the lower grade material in Germany and Russia was the lack of bauxite within their own boundaries, and the continual search for means to become self-sufficient in strategic raw materials.

Reserves of high-grade bauxite in the United States, never very large compared to those in some foreign countries, have been greatly reduced because of unprecedented war requirements. New high-grade ore has been found by exploration work (MacPherson, 1945), but the known quantity of reserves of Bayer grade bauxite is far too small to make this country independent of foreign supplies, and it is a truism to state that this country should never again be dependent on foreign sources of supply of any materials essential in prosecuting a war. Therefore either we must maintain huge stock piles of imported high-grade bauxite or develop economic processes to treat domestic low-grade aluminous materials which occur in abundance. It is unnecessary to point out the advantages of developing and maintaining our own industry.

Prior to World War II, because cheap and reliable electric power was available from hydroelectric development of the Columbia River, two privately owned aluminum reduction plants were built on the river, one at Vancouver, Washington, and one at Longview, Washington. These were the first aluminum reduction plants built west of the Mississippi River. Later, because of war needs, three more plants were built in the Northwest with Government funds; one at Troutdale, Oregon; one at Spokane, Washington; and the third at Tacoma, Washington.

Combined rated capacity of the two privately owned plants is 248,000,000 pounds annually; that of three Government-owned plants is 367,000,000 pounds. The total is over 300,000 tons, or twice annual domestic production before 1940.

Under conditions existing in this country, the largest item of cost in aluminum metal production is alumina supply; the second is cost of electric power. However, cost of alumina is less critical in relation to location of plants, as alumina may be transported over long distances without increasing cost of the metal in direct proportion to the distance spanned, whereas electric energy may be transmitted economically over relatively short distances. Dependability of power is also a governing factor in location of plants, as some so-called overhead costs such as amortization, depreciation, administration and the like must be charged whether or not a plant is turning out metal.

Except for a relatively small amount of alumina produced from alunite by a plant at Salt Lake City, no alumina is produced in the West, and it must be transported from Bayer plants in the eastern part of the country to supply northwest plants. Railroad freight is reported to be $8.00 per ton in train lots. Converted into unit cost of metal, this cost of freight is 0.8¢ per pound of aluminum.

Economic characteristics of deposits

The thickness, attitude, friability, and moderate stripping ratio of the deposits in Washington and Columbia Counties all favor cheap mining with earth-moving equipment. It is likely that the ore could be excavated without the use of explosives. The deposits are distributed widely, and aggregate reserves appear to be substantial in millions of tons. Location of the deposits is especially favorable in relation to railroads, highways, the aluminum plants on the Columbia River, and electric power.

Metallurgy

In order to be commercial, the ore would need to be treated to produce both alumina and iron. Results of metallurgical testing work being carried out on low-grade bauxite by public and private agencies are not known to the writers. In the past the Pedersen process was applied on a commercial scale in Norway to treat analogous material, and it is possible that this process or some modification of it may be feasible. As used in Norway where operations were aimed primarily at producing high-grade pig iron, low-silica ferruginous bauxite was imported from France and smelted in an electric furnace with Norwegian iron ore, together with lime as a flux and coke as a reducing agent. An outline of the process is given opposite page 83. Pig iron and calcium aluminate slag were the products from the electric furnace. The finely ground slag was treated with hot sodium carbonate solution containing some sodium hydroxide. Carbon dioxide gas was passed into the resulting sodium aluminate solution to precipitate aluminum hydroxide which was filtered and calcined to produce alumina.

For a number of years the U.S. Bureau of Mines has been carrying on testing work on treatment of low-grade bauxite. Results have not been made available to the public, but it has been reported that a large amount of work has been done in studying the application of the Pedersen process to high-silica and high-iron bauxites.

A process for treating low-grade bauxite or other low-grade aluminous material was developed by the Aluminum Company of America during the war period just past, and applied to treatment of wastes from the Bayer process. As described by Robert F. Gould[1] the new process appears to be chiefly valuable in combination with the Bayer process, and would not seem to be economically suitable for treatment of the high-iron Oregon ores.

Salem deposits

In the absence of exploration work, it is impossible to estimate the economic importance of the occurrences of high-grade bauxite in the Salem area. In some roadcuts and on the surface in several places nodular bauxite occurs in quantities which warrant testpitting to determine the amount present. In one roadcut high-grade material occurs in place as a solid layer about one foot thick. The areal extent of this layer has not been determined.

Bauxite of the quality found in the Salem area might be suitable for uses other than production of alumina. These uses are in making aluminum chemicals, chiefly aluminum sulphate; production of high-grade abrasives; in oil refining; as a refractory; and in making quick-setting cements. Each of these classifications has distinctive specifications.

The low-grade ore which occurs in the laterite section immediately below the high-grade nodular ore, is widespread but appears to be in thinner section than in the corresponding deposits of Washington and Columbia Counties. Silica content increases rapidly with depth below the upper 4 or 5 feet. The change is gradational, and no dividing line may be determined visually between low- and high-silica material. The preliminary study of the deposits has been insufficient to permit definite statements concerning the profile of the laterite section, but from present indications the ferruginous bauxite (exclusive of the high-grade nodular material) in the Salem area is probably of less potential commercial importance than that in Washington and Columbia Counties.

Conclusion

In summation, the ferruginous bauxite deposits of northwestern Oregon appear to contain reserves of sufficiently large size to warrant an alumina industry. Development of an economic treatment process is the critical factor in putting these deposits into production, not quantity of reserves.

Although the Oregon ore is low in alumina compared to bauxite suitable for the Bayer process, the iron contained is potentially of commercial value. If arbitrary values of $45.00 per ton for alumina and $17.90 per ton for iron are taken, the potential gross value of products obtainable from 100 tons of ore (unit taken for convenience), assuming 90 percent

[1] Industrial and Engineering Chemistry, September 1945.

recovery, is $1788.03. The comparable value of alumina produced from 100 tons of Arkansas bauxite would be $2227.50, assuming 55 percent Al_2O_3 and 90 percent recovery. If this alumina is to be used in aluminum reduction plants in the Northwest, its value to the producer is reduced by railroad freight of $8.00 per ton. The comparison is tabulated as follows:

Bayer Process Ore - 100 Tons

55% Al_2O_3, 90% recovery, 49.5 tons alumina at $45[1]	$ 2227.50
Less $8 per ton freight	396.00
Received by producer of alumina f.o.b. lower Columbia River points	$ 1831.50

Oregon Ore - 100 Tons

35% Al_2O_3, 90% recovery, 31.5 tons alumina at $45[1]	$ 1417.50
23% Fe, 90% recovery, 22.5 tons iron at $17.90[2]	370.53
Value of combined alumina and iron	$ 1788.03

The comparison, of course, assumes economic treatment of the Oregon ore. In practice, a lower percentage recovery could be expected in treating Oregon ore, but this disadvantage would probably be offset by cheaper mining costs, and the comparison indicates that there is no great disparity in gross value under the assumptions given above. At the same time it is realized that profit and not gross value governs feasibility.

No value may be assigned the titanium in the Oregon ore but it is believed by the authors that the titanium content may, at some future time, be a commercial by-product in the recovery of alumina and iron, either as titanium oxide or ferrotitanium.

Because of location, probable extent, physical and chemical characteristics, and potential gross unit value of the ore, the Oregon deposits form the most important known reserve of low-silica aluminous ore in the United States.

From the above, the following important points may be emphasized:

1. The Oregon ore is low in silica and therefore may be more economically treated than clays or other aluminum silicates.
2. The iron contained in Oregon ores is an asset which offsets the lower alumina content compared to high-grade bauxite.
3. Location of deposits near aluminum reduction plants, and physical characteristics of deposits which will permit low mining cost, are especially favorable factors in any plan for commercial production from these ores.

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[1] Records of costs of producing alumina are not available. Estimates by Engle, Gregory, and Mosse (1944) range from about $35.00 to about $42.00 per ton as the cost of producing alumina at hypothetical locations in the United States, the principal variable being capacity. The lowest cost estimate is for a plant on the lower Columbia River with a capacity of 500,000 tons per year, and using bauxite brought in from Bintan Island. The highest estimate is for a plant at an inland point in the Southeast with a capacity of 100,000 tons per year, and using bauxite from Dutch Guiana. Based on figures in these estimates it would appear that $45.00 per ton is at least not too low as a selling price for alumina in the Northwest, and therefore does not reflect too low a gross value on high-grade bauxite in comparison with Oregon ore.

[2] Average value per net ton of pig iron at blast furnaces in the United States in prewar year 1940 according to U.S. Bureau of Mines Minerals Yearbook.

Appendix

Analysis of Ferruginous Bauxite Ore
by
L. L. Hoagland[1]

An accurate analysis of alumina ores containing titanium requires more attention and care than is generally appreciated. Even in the most routine methods it is necessary to resort to extreme measures to bring the ore completely into solution, and after this is accomplished the analyst must guard against hydrolysis of the titanium to prevent contamination of the silica and alumina oxides.

For the analysis of ferruginous bauxite ore from Washington and Columbia Counties in the laboratory of the Department of Geology and Mineral Industries, it was necessary to work out a method in which the high titanium content of the ore would not affect the accuracy of the results. The procedure finally adopted requires 3 to 4 days for completion, and eliminates the titanium interferences. It also fits in well with other laboratory work which frequently interrupts the progress of any lengthy analysis for periods ranging from several hours to several days.

Prior to making any chemical analysis, the ores were examined both petrographically and spectrographically, and it was found that aside from very minute quantities of other elements, the ores were essentially hydrated oxides of alumina and iron with silica and titania as accessory components. For the determination of alumina, iron, silica, and phosphorus, parts of standard methods described by Lundell, Hoffman and Bright[2], Scott[3], and Low[4] were incorporated. After trying several standard gravimetric and volumetric methods for the titanium determination, which were described in the works cited above, a volumetric method was worked out in the Department's laboratory. This method requires much less time and gives more accurate results than were possible by gravimetric methods, and compares favorably with results obtained with standard volumetric methods.

In making the analysis, separate portions of the air-dried sample are taken for the moisture and ignition loss, iron, and phosphorus determinations, whereas the silica, alumina, and titania are determined on the same portion. All portions are weighed at the same time in order to eliminate changes that might occur in the moisture content. The following gives the detailed procedures for making the determinations:

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[1] Assayer and chemist, Oregon Department of Geology and Mineral Industries.

[2] Lundell, Hoffman and Bright, Chemical analysis of iron and steel.

[3] Scott's standard methods of analysis.

[4] Low, A.H., Technical methods of ore analysis.

Moisture

Transfer 2 grams of the air-dried sample to a weighed platinum crucible having a tight-fitting cover. Dry at 100° to 105° C. for 3 to 4 hours. Place the cover loosely on the crucible and cool in a desiccator. When cool, cover tightly and weigh. To find the percentage of moisture, subtract the final weight from the original weight and multiply by 50.

Loss on Ignition

After the final weighing in the moisture determination, heat the crucible gently in an oxidizing atmosphere until oxidation changes have taken place; cover and heat for 30 minutes at 1000° to 1100° C. Cool in a desiccator and weigh. Calculate the percentage loss.

Iron

The determination of iron is made by the well-known Zimmermann-Reinhardt method as described by Lundell, Hoffman, and Bright[1]. This method checks very closely with results obtained by much longer umpire methods.

Special solutions required:

Stannous chloride. Dissolve 150 grams of $SnCl_2 \cdot 2H_2O$ in 300 ml of HCl, and dilute to 1000 ml with water.

Titration mixture. Dissolve 200 grams of $MnSO_4 \cdot 4H_2O$ in 1000 ml of water, and add a cooled mixture of 400 ml of H_2SO_4, 1200 ml of water, and 400 ml of syrupy phosphoric acid.

Mercuric chloride. Prepare a saturated solution of $HgCl_2$ in water.

Standard 0.10 normal permanganate. Dissolve 3.16 grams of $KMnO_4$ in 1 liter of water, allow to age, filter through asbestos, and standardize against Bureau of Standards sodium oxalate. One ml $KMnO_4$ is equivalent to 0.005584 grams of Fe.

Procedure: Transfer 0.5 grams of the air-dried sample to a 200-ml beaker; add 10 ml of HCl and 5 ml of stannous chloride solution. Cover the beaker and gently heat on a warm plate for 3 hours with occasional agitation. If any dark particles remain, continue heating until only a white, flotant, insoluble matter remains.

Add a 2.5 percent solution of $KMnO_4$ (drop by drop) until a distinct pink or brownish color appears. Dilute to 25 ml with water; heat nearly to boiling. Add stannous chloride solution dropwise and with stirring until the color of the ferric iron disappears, and then add just one drop more. Wash down the inside of the beaker, and quickly cool in ice water. Add at one stroke 10 ml of saturated solution of mercuric chloride; stir;

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[1] Op. cit., p. 87.

again wash down the inside of the beaker with cold water and allow the solution to stand for 2 to 5 minutes. Transfer the solution to a 600-ml beaker to which 25 ml of the titration mixture and 400 ml of cold water have been added. Stir and add standard permanganate solution from a burette to a definite pink end-point. Run a blank on the reagents through all operations and make proper corrections.

Silica

The titaniferous ores from Washington and Columbia Counties are not entirely decomposed by acids. It is necessary to filter off the insoluble residue after acid treatment, and subject it to evaporation in hydrofluoric and sulphuric acids. The following procedure has been found to be most effective as it yields a very sharp separation and is somewhat more rapid than most umpire procedures.

Procedure: Transfer 0.5 gram of the sample to a porcelain casserole, cover, and add 25 ml of HCl. Digest with frequent agitation on a warm plate or water bath until decomposition appears to be practically complete, then add 1 ml of HNO_3 and evaporate to dryness. Bake at about 110° C. for 1 hour. Cool somewhat, drench the residue with 10 ml of HCl, digest for 2 minutes, and then add 70 ml of hot water. Heat until soluble salts are in solution (preferably not over 5 minutes) and filter. Wash 5 times with hot dilute HCl (1:20) then wash thoroughly with hot water. Evaporate the filtrate and washings to dryness; bake and dissolve the soluble salts as before. Filter, wash the small amount of silica, first with cold dilute HCl (1:100), then with hot water. Reserve the filtrate and washings for the determination of alumina and titania. Ignite the two papers in a platinum crucible, slowly at first, and finally at a temperature of 1200° C. Cool and weigh. Treat with a few drops of dilute H_2SO_4 (1:1) and 5 to 10 ml of HF, evaporate to dryness, and again ignite at 1200° C. Cool and weigh. The loss in weight represents the silica.

Alumina and Titania

For the determination of alumina in ores there are three very accurate gravimetric methods which are frequently used. These methods are as follows:

1. Precipitation of all the oxides with ammonium hydroxide and calculation of the alumina by difference after the various amounts of other elements known to be present have been determined.

2. Precipitation of the alumina as phosphate after removal of the interfering elements.

3. Precipitation of alumina with ammonium hydroxide after the other oxides have been separated from the sodium hydroxide solution.

The last method was adopted because it gives the least contaminated Al_2O_3 precipitate, and also fits in with the scheme for the volumetric determination of titanium in the same portion of the sample.

The volumetric method for titania as worked out in the Department's laboratory gives results that are well within the limits of accuracy, and duplicate results are easily obtained after a little practice to develop speed in the manipulation. Because of the rapidity with which titanium oxidizes after reduction with zinc, most volumetric methods require that the reduction, and manipulation after reduction, be carried out in the absence of air. The procedure described below, although it allows the solution to be in contact with air for a few seconds, gives results which check within the limits of accuracy on standard bauxite samples. As an illustration, Bureau of Standards bauxite sample No. 69 gave 3.01, 3.05, and 3.03 percent TiO_2 as against the certificate value of 3.07 percent.

Procedure:

Alumina. Fuse the non-volatile residue from the silica determination with a small amount of sodium carbonate. Cool, take up the melt in dilute HCl (1:4), and add the solution to the filtrate and washings from the determination of silica. Dilute to 300 ml, heat to boiling, and add NH_4OH cautiously until all the oxides are precipitated. An excess of ammonia must be avoided as Al_2O_3 is slightly soluble in dilute ammonium hydroxide. Boil for 1 to 3 minutes, add 4 drops of methyl red and allow the precipitate to settle partially. If the clear solution is red, discharge the color with a drop or two of NH_4OH. Filter through a No. 40 Whatman or similar paper, and wash 5 times with hot neutral 2 percent solution of ammonium chloride. Wash the precipitate back into the beaker in which the precipitation was made with a strong jet of water and dissolve it in 50 ml of hot dilute HCl (1:4). When dissolved, dilute to 350 ml, add the paper and stir until it is pulped. Repeat the precipitation and washing as before. Transfer the precipitate and paper to a silica crucible, dry at 110 to 120° C., and ignite cautiously until charred, then heat to 900 to 1000° C. to burn off the paper. Cool, pulverize the precipitate in a small agate mortar using care to avoid loss, and return it to the crucible. Clean the mortar thoroughly by grinding several small portions of $K_2S_2O_7$. Add these fractions to the crucible and make up the weight of $K_2S_2O_7$ to about 12 grams. Mix and then fuse over a moderate flame for 20 to 30 minutes. Cool, place the crucible and cover in a 300-ml tall form beaker, add 12 ml of HCl diluted with 70 ml of water, and heat to dissolve the melt. Remove crucible after rinsing with a small volume of water and heat to boiling. Filter off the insoluble, dry the paper, ignite and weigh, then treat the residue with HF and H_2SO_4. The loss in weight is added to the weight of the silica. The solution should not be much greater than 100 ml at this point and should contain not less than 10 percent HCl by volume in order to prevent hydrolysis of the titanium. Heat to near boiling and nearly neutralize the solution with 25 percent NaOH and pour the clear solution slowly and with constant stirring into 250 ml of a nearboiling 5 percent solution of NaOH in a 600-ml beaker. Cool to room temperature, transfer to a 500-ml volumetric flask and dilute to the mark. Return to the beaker, mix well, and allow to settle. Filter through a dry No. 2 Whatman or similar paper. Measure out a 250-ml portion of the filtrate in a volumetric flask. Continue the filtration and after washing the precipitate once or twice, reserve it for the titanium determination.

Transfer the 250-ml aliquot to a 400-ml beaker, add 4 drops of methyl red, acidify with HCl, and add 10 ml in excess. Heat to boiling and precipitate the aluminum by adding NH_4OH until the red color just changes to yellow. Boil for 2 minutes and filter on a paper of loose texture. Wash twice with a 2 percent solution of NH_4Cl. Transfer the paper and precipitate back to the beaker in which the precipitation was made, stir the paper to a pulp, and add 50 ml of hot 1:4 HCl. Digest for a few minutes, dilute to 250 ml, and precipitate and wash as before. Ignite the paper and precipitate and weigh as Al_2O_3. Correct this weight by a blank carried through all steps of the method. The precipitate may also carry some P_2O_5. However, unless the percentage of phosphorus is relatively high in the original sample, nearly all will be lost during the volatization with HF and the fusion with pyrosulfate. In general the amount remaining with Al_2O_3 precipitate is negligible.

Titanium. Place a 200-ml tall form beaker under the funnel and dissolve the precipitate obtained in the NaOH separation above with 10 ml HCl diluted with 15 ml of water. (Solution should be near boiling). As titanium does not dissolve readily on filter paper the solution should be reheated and again passed through the paper. Wash the paper with small portions of hot very dilute HCl until all the color in the paper has been discharged. The volume of solution should not exceed 75 ml at this point, and with the HCl content above 10 percent (to prevent hydrolysis of the titanium) can be set aside for several days while accumulating several samples before continuing with the titanium determination. Transfer the solution to a 100-ml volumetric flask and dilute to the mark, mix thoroughly, return to the beaker, and pipette 50 ml to a 250-ml Erlenmeyer flask. The pipette and flask must be checked to insure that the 50 ml removed is exactly 1/2 the total volume.

The solution remaining in the beaker is heated to boiling, the iron reduced with stannous chloride, and titrated with potassium permanganate as described above in the iron determination. To the solution in the Erlenmeyer flask add 3 ml of HCl and heat to near boiling, remove from the heat and add cautiously 5 grams 20-mesh zinc shot. The iron is reduced to the ferrous condition and the titanium to Ti_2O_3; hydrogen is liberated by the action of the free acid on the zinc and expels oxygen from the flask. Allow the action to continue, heat if necessary until the solution is first colorless and then imparts a violet color (due to reduced titanium). Cool with 50 ml of cold water and quickly place the flask in a cold water bath. Cautiously add 20 ml 1:1 H_2SO_4 which will dissolve the greater part of the remaining zinc shot and allow an excess of sulphuric acid for the titration. Remove from the water bath as soon as the violent action has subsided and allow the action to continue. Before all the zinc is dissolved filter rapidly through a funnel containing a small plug of moist cotton into a 1-liter beaker containing at least 3 inches of cold water. The neck of the funnel should extend to within 1/2 inch of the beaker bottom in order to collect the filtered solution under water. Wash the beaker, funnel, and cotton rapidly with large quantities of cold water, dilute if necessary to 700 ml with cold water, and titrate at once with standard potassium permanganate. Subtract the burette reading obtained in the titration of the aliquot portion reduced with stannous chloride from the reading obtained above. The difference is the volume of permanganate used to oxidize the titanium from Ti_2O_3 to TiO_2. Calculate the percentage of TiO_2. One ml of 0.10 normal $KMnO_4$ is equivalent to 0.00799 grams TiO_2.

Phosphorus

Phosphorus is determined in this laboratory by the so-called "alkalimetric-method" based on the neutralization of the ammonium phosphomolybdate precipitate with a standard solution of sodium hydroxide. It is a very desirable procedure for the routine determination of the moderate amounts of phosphorus found in Oregon ferruginous bauxite ores if the procedure is faithfully followed.

Special solutions required:

Standard 0.10 normal sodium hydroxide. Dissolve 100 grams of sodium hydroxide pellets in 100 ml of distilled water, transfer to a 150-ml test tube of resistance glass, and avoid wetting the top. Stopper tightly with a stopper covered with tin foil and let stand in a vertical position (for several days) until clear. Withdraw carefully 6.5 ml for each liter of solution with a pipette and dilute at once with recently boiled (CO_2 free) distilled water. Standardize against Bureau of Standards standard acid potassium phthalate No. 84.

Standard 0.10 normal nitric acid. Mix 7 ml of clean concentrated nitric acid with 1 liter of water and standardize by comparing with the standard alkali solution.

Molybdic acid reagent. Mix 100 grams of molybdic acid (118 grams of 85 percent acid) to a paste with 265 ml of water. Add 155 ml of NH_4OH (sp. gr. 0.90) and stir until all is dissolved. To this solution add 66 ml of HNO_3 (sp. gr. 1.42) stir well, and then set aside for an hour. In another vessel make a mixture of 395 ml of HNO_3 (sp. gr. 1.42) and 1100 ml of water. Finally pour the first solution into the second, stirring constantly. Age 24 hours and then filter before using.

Procedure: Transfer 2 grams of the sample to a large platinum crucible and mix with 5 times its weight of sodium carbonate. Fuse at the full heat of a Meker or Fisher burner for 15 minutes. Cool and rotate the crucible so that the melt solidifies in a thin layer on the side of the crucible. Place in a 250-ml beaker, extract the melt with 100 ml of hot water. Remove crucible and digest near the boiling point for 15 to 30 minutes; filter and wash with hot water.

Acidify the filtrate with HNO_3 and evaporate to dryness in a porcelain casserole. Cool, add 25 ml of 1:1 HNO_3, heat to boiling, then add 20 ml of hot H_2O and filter into a 250-ml Erlenmeyer flask. Wash the paper a few times with a little hot water. Evaporate the solution to about 45 ml, neutralize with NH_4OH, and add 3 to 4 ml of HNO_3 and 10 grams of ammonium nitrate.

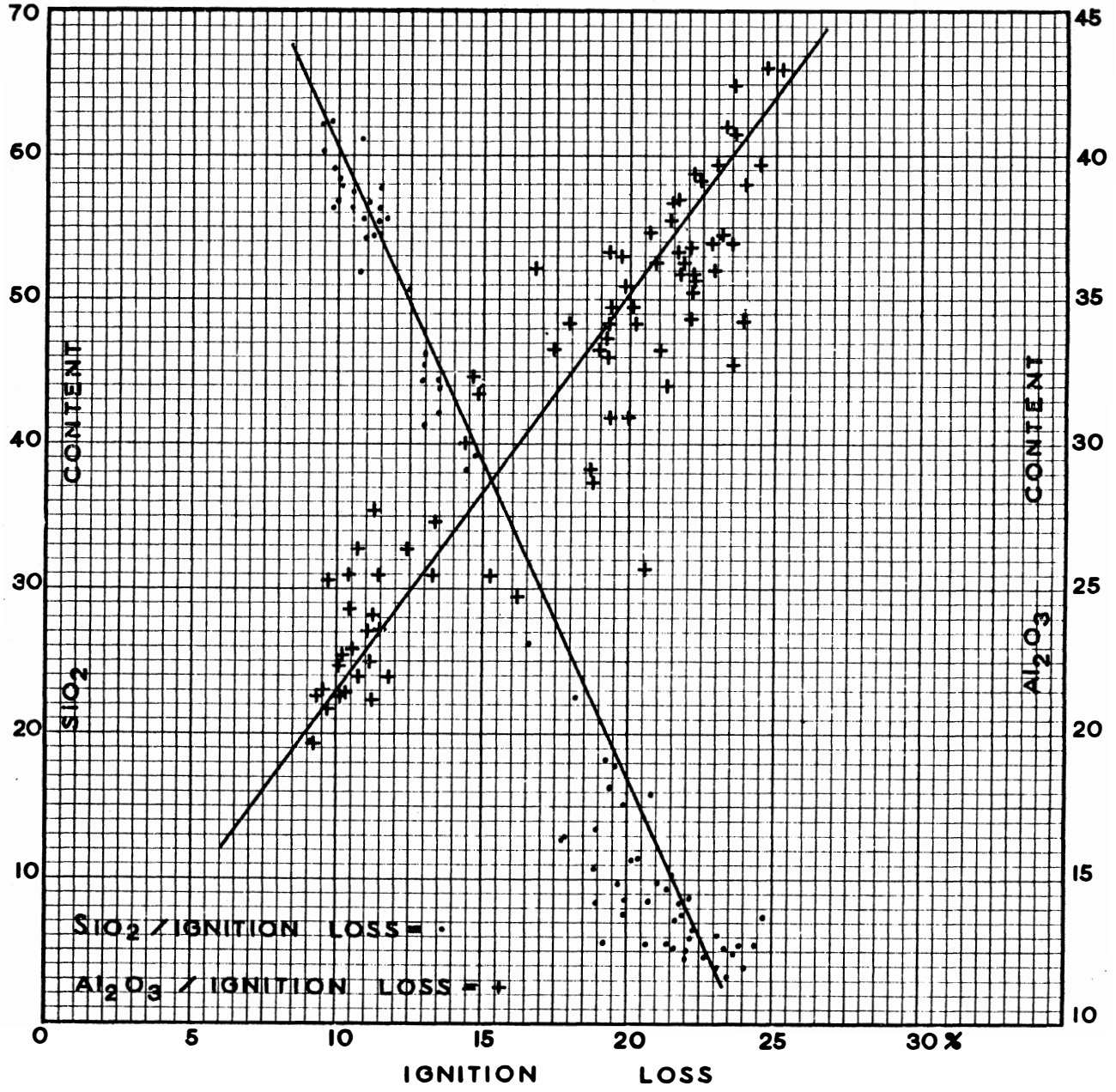
Heat to 40° C.; add 60 ml of molybdate reagent previously heated to 40° C. Stopper the flask and shake for 5 minutes. Allow to stand in a warm place for 15 to 30 minutes, then filter on a 9 cm No. 42 Whatman paper. Wash the flask, precipitate, and paper twice with 5 ml portions of dilute HNO_3 (1:100) and then 5 times with 5 ml portions of a 1-percent solution of KNO_3. Finally wash the paper about 10 times directing the jet of KNO_3 solution around the edge of the paper and then spirally down. Washing is complete when 10 ml of the filtrate will not decolorize 1 drop of the standard alkali to which has been added 1 drop of phenolphthalein.

Return the paper and precipitate to the flask, add a 2 - 5-ml excess of standard 0.10 normal NaOH and 25 ml of water free from carbon dioxide, and shake or stir until the precipitate is dissolved. Dilute to about 125 ml with CO_2 free water, add 3 drops of 0.2 percent phenolphthalein and discharge the pink color with standard 0.10 normal HNO_3. Finish the titration by adding standard alkali until the reappearance of the pink color. One ml of 0.10 normal NaOH is equivalent to 0.000135 gram phosphorus.

Acknowledgment

The writer wishes to acknowledge the assistance given by Miss Esther Miller, spectroscopist for the Department of Geology and Mineral Industries, who made spectrographic analyses of precipitates and filtrates during the experimental period in which these methods were being checked.

GRAPH SHOWING RESULT OF PLOTTING LOSS ON IGNITION AGAINST SiO_2 CONTENT OF 85 ASSAYS FROM HUTCHISON—NIXON DEPOSIT



Glossary

Bauxite - A generic term for rocks rich in hydrous aluminum oxides. An aluminous laterite in which aluminum hydroxides are in greater quantity than other lateritic constituents. Applied commercially to aluminous laterites of ore-grade.

Bauxitic - Containing bauxite minerals.

Bauxitic clay - A clay containing bauxite minerals so that the ratio of alumina to silica is greater than that in kaolinite or halloysite.

Cliachite - A colloidal aluminum hydroxide whose composition has been given as $Al_2O_3\ (H_2O)_x$. It is the main constituent of some bauxites.

Colloform - The rounded, reniform, or more or less spherical form assumed by amorphous or metacolloidal minerals or mineral gels in open spaces. Structure similar to that assumed by colloids.

Ferruginous - An adjective applied to rocks containing iron as an influencing component.

Gibbsite - A mineral consisting of the hydrous aluminum oxide, $Al_2O_3 \cdot 3H_2O$ or $Al(OH)_3$. It is the major constituent of some bauxites and a minor one in others.

Goethite - A mineral consisting of the hydrous iron oxide, $HFeO_2$.

Laterite - A residual surface deposit, often concretionary, formed as a result of the decomposition of rocks by weathering and ground-water action, and consisting essentially of aluminum and ferric hydroxides, which may be crystalline or amorphous.

Laterization - The process by which laterite is formed.

Limonite - Name formerly given to a hydrous iron oxide with the supposed formula $2Fe_2O_3 \cdot 3H_2O$. It has been shown that much of the natural material classed as limonite is cryptocrystalline goethite with adsorbed or capillary water. It is retained as a convenient field or generic term to refer to hydrous iron oxides whose real identity is unknown.

Magnetite - The magnetic oxide of iron, Fe_3O_4 or $FeO \cdot Fe_2O_3$.

Nodular - Having the shape of a nodule or composed of nodules; in tuberose forms; or having irregular protuberances over the surface.

Oölites - Rounded, concretionary grains usually considered to be smaller than a pea.

Oölitic - A textural term for rocks consisting of small round grains or concretions (oölites) cemented together, resembling the roe of a fish.

Pisolitic - A texture coarser than oölitic, the concretions being about the size of, or larger than, a pea.

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STATE OF OREGON

Department of Geology & Mineral Industries

WASHINGTON COUNTY HIGH-IRON BAUXITE ORE SURVEY

HUTCHISON-NIXON PROJECT

SCALE

100 0 200 400 600 FEET

CONTOUR INTERVAL 10 FT.
DASHED CONTOURS SKETCHED
DATUM ASSUMED
AUGER HOLE ■

FEBRUARY 1945

R.S. MASON