STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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# FERRUGINOUS BAUXITES OF THE PACIFIC NORTHWEST

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# FERRUGINOUS BAUXITES OF THE PACIFIC NORTHWEST

## ABSTRACT

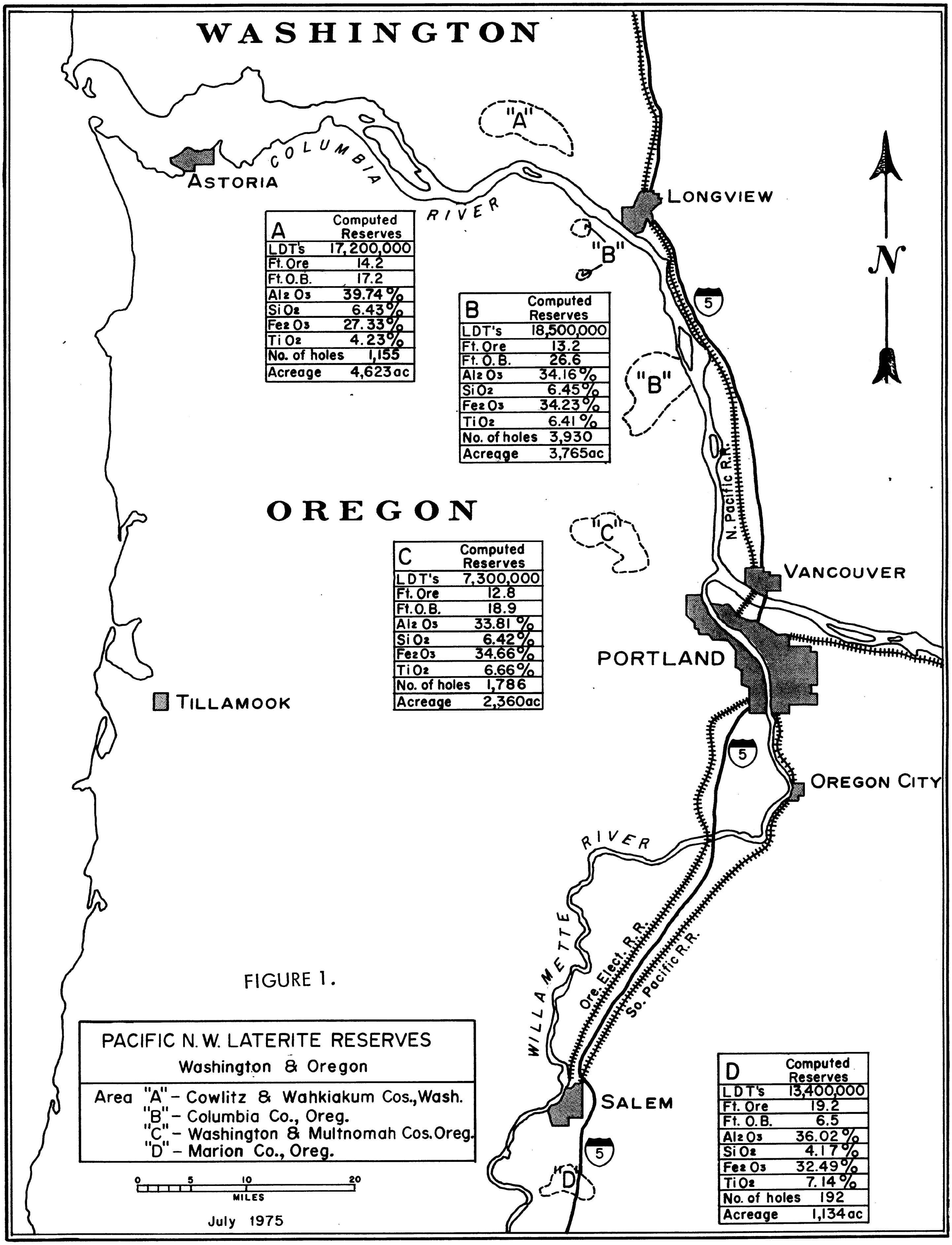
Ferruginous bauxite deposits, formed by the laterization of the upper portion of the Columbia River Basalt occur in Cowlitz and Wahkiakum Counties in Washington and in Columbia, Washington, Multnomah, and Marion Counties in Oregon. The ferruginous bauxite was first identified by the Oregon Department of Geology and Mineral Industries during its investigations of the iron ores in the vicinity of Scappoose, Oregon in 1944. Subsequent exploration drilling, primarily by Alcoa and Reynolds Metals Company, has indicated reserves of 56 million long dry tons, averaging 36.26% $Al_2O_3$, 31.77% $Fe_2O_3$, 5.90% $SiO_2$, and 5.95% $TiO_2$. This grade of ore can be used in existing Bayer process alumina plants, as was demonstrated by a 50,000-ton plant-run sample mined in 1970.

Associated with these low-silica deposits are high-alumina, high-iron clays which contain too much silica to be economic in the Bayer-type alumina plants. It is quite possible that this material would make feed for a Pedersen-type alumina plant, which is less sensitive to the silica content. There are no Pedersen plants in the United States, and the economic limits of grade are unknown. However, if a matrix running as high as 20% silica could be used, the ore reserves would double or triple. In addition, the Pedersen process would recover iron, which would be wasted in the Bayer process. The gray mud waste from the Pedersen process is a valuable raw material for cement.

In 1968, Reynolds Metals Company purchased Alcoa's ferruginous bauxite holdings and now controls 11,882 acres containing most of the known reserves in the Pacific Northwest. Except for the 50,000-ton sample, there has been no production from these deposits. The bauxite properties are presently under timber and agricultural management programs.

The ferruginous bauxite deposits are near the surface, and surface-mining methods are required for their extraction. Excellent reclamation of the land was demonstrated in connection with the mining of the 50,000-ton sample in 1970. A full-scale mining project would affect a relatively small acerage at any one point in time and probably have little more environmental impact than a clear-cut timber operation.

The ferruginous bauxite reserves of the Pacific Northwest are of considerable national importance. Most of the bauxite reserves elsewhere in the country have been mined, and the United States is now heavily dependent on imported ore. Although there are large domestic reserves of high-alumina clay and other aluminum-bearing materials in the United States, no technology for economical extraction has as yet been demonstrated. Thus, Pacific Northwest reserves are a valuable resource that should be protected by prudent land-use planning.


WASHINGTON
OREGON
ASTORIA
COLUMBIA RIVER
LONGVIEW
"A"
"B"
"B"
"C"
"D"
N
N. Pacific R.R.
5
VANCOUVER
PORTLAND
TILLAMOOK
OREGON CITY
RIVER
WILLAMETTE
Ore. Elect. R.R.
So. Pacific R.R.
SALEM
A Computed Reserves
LDT's 17,200,000
Ft. Ore 14.2
Ft. O.B. 17.2
Al2 O3 39.74 %
Si O2 6.43 %
Fe2 O3 27.33 %
Ti O2 4.23 %
No. of holes 1,155
Acreage 4,623 ac
B Computed Reserves
LDT's 18,500,000
Ft. Ore 13.2
Ft. O.B. 26.6
Al2 O3 34.16 %
Si O2 6.45 %
Fe2 O3 34.23 %
Ti O2 6.41 %
No. of holes 3,930
Acreage 3,765 ac
C Computed Reserves
LDT's 7,300,000
Ft. Ore 12.8
Ft. O.B. 18.9
Al2 O3 33.81 %
Si O2 6.42 %
Fe2 O3 34.66 %
Ti O2 6.66 %
No. of holes 1,786
Acreage 2,360 ac
D Computed Reserves
LDT's 13,400,000
Ft. Ore 19.2
Ft. O.B. 6.5
Al2 O3 36.02 %
Si O2 4.17 %
Fe2 O3 32.49 %
Ti O2 7.14 %
No. of holes 192
Acreage 1,134 ac
FIGURE 1.
PACIFIC N. W. LATERITE RESERVES
Washington & Oregon
Area "A" – Cowlitz & Wahkiakum Cos., Wash.
"B" – Columbia Co., Oreg.
"C" – Washington & Multnomah Cos. Oreg.
"D" – Marion Co., Oreg.
0 5 10 20
MILES
July 1975

## INTRODUCTION

This report was prepared as a follow-up of a study for the U. S. Bureau of Mines Minerals Availability System of the ferruginous bauxite resources of the Pacific Northwest. The Minerals Availability System is designed to conduct and maintain an inventory of minerals important to the nation. The report is based largely on drilling and mining data furnished by Reynolds Metals Company and Alcoa and contains ore reserve data which has previously been confidential company information.

It is hoped that this report will furnish planning commissions and other interested parties with a measure of the value of the ferruginous bauxite and the problems involved in its extraction. Since bauxitic types of ore are the only source of aluminum which can be used in existing plants in the United States, and the reserves of bauxite elsewhere in the country are nearly depleated, it is very important that the value of this resource be considered in long-range planning in the Pacific Northwest.

The ferruginous bauxite deposits were first recognized by the Oregon Department of Geology and Mineral Industries during investigations of iron ores near Scappoose, Oregon in 1944. The results of the evaluation by the Department in 1944 and 1945 were published by Libbey and others, 1945. Subsequent evaluation of the deposits in the Salem Hills in Marion County was published by Corcoran and Libbey in 1956. Studies by the Washington Division of Mines and Geology of the ferruginous bauxite deposits of Cowlitz and Wahkiakum Counties were published by Livingston, 1966. Additional publications by the U. S. Bureau of Mines include Kelley (1947), Blake and others (1967), and Fursman and others (1968).

This report supplements the previously published data and adds firm ore estimates from the 6,898 test holes drilled by Reynolds and Alcoa. In addition, some new lines of evidence as to the origin and geology of the deposits are presented. A number of problems remain, particularly in regard to the age relationships of the laterization to the silty clay overburden and the apparent association of the ore deposits with certain youthful topographic forms.

A major economic problem remains in regard to the associated high-alumina, high-iron clays which have too much silica to be used in the Bayer process alumina plants. If this material could be utilized, the ore-reserve estimates would probably triple and might even increase by a factor of 10, depending on the grade limitations. The Pedersen process should be studied in greater depth for this purpose, as it would recover both the alumina and the iron. Unless the iron is recovered, it will create massive waste-disposal problems in addition to the loss of the metal. The technical feasibility of the Pedersen process on Pacific Northwest ferruginous bauxites has been demonstrated by the U. S. Bureau of Mines (Blake and others, 1967 and Fursman and others, 1968), but further research is needed on its economic feasibility.

# LOCATION OF DEPOSITS

The ferruginous bauxite deposits of the Pacific Northwest occur along ridge tops which are underlain by the Columbia River Basalt of Miocene age. The deposits were developed by the weathering of the original basaltic lava flows and possibly in part from overlying sediments. This lateritic process removed much of the original silica, leaving a residium of aluminum and iron oxides. The deposits are found primarily in four major areas: the Cowlitz-Wahkiakum area, the Columbia County area, the Washington - Multnomah area, and the Salem Hills area (see Figure 1).

## Cowlitz - Wahkiakum Area

The deposits in Cowlitz and Wahkiakum Counties, Washington are along the ridge tops north of the Columbia River between the towns of Kelso and Cathlamet.

## Columbia County Area

The major deposits in Columbia County, Oregon are along the ridges west of St. Helens and Columbia City. Minor deposits have been explored near the towns of Apiary and Alston in the northern part of the County.

## Washington - Multnomah Area

The ferruginous bauxite deposits of Washington and Multnomah Counties, Oregon are primarily on Pumpkin Ridge and Dixie Mountain. There are also known occurrences in the Portland Hills but these have not been explored because of the heavy residential development.

## Salem Hills Area

Ferruginous bauxite deposits occur in the Salem Hills Area, Marion County and extend south about 5 miles from Salem. The present city limits are within a quarter of a mile of one of the explored deposits, and there are unexplored occurrences within the city.

## Other areas

Occurrences of ferruginous bauxite are known in the Eola Hills in Polk County, west of Salem, near Mehama in Marion County, the Chehalem Hills in Washington and Yamhill Counties, at Oregon City, and near Estacada in Clackamas County. The bauxites in the Mehama and Estacada areas are not associated with the Columbia River Basalt; they appear to have developed from younger tuffs.

## OWNERSHIP

Most of the known reserves of ferruginous bauxite in the Pacific Northwest are on the nearly 12,000 acres (4,800 hectares) owned or controlled by Reynolds Metals Co. The acreage distribution and type of control are shown in Table 1.

Table 1. Reynolds Metals Company holdings (adapted from Michell, 1975)

| County, State | Fee owned | | Leased: Private | | Leased: State | | Placer Claims | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A* | H** | A | H | A | H | A | H | A | H |
| Cowlitz, Wn. | 480 | 194 | 2,293 | 928 | | | | | 2,773 | 1,122 |
| Wahkiakum, Wn. | | | 1,280 | 518 | 570 | 231 | | | 1,850 | 749 |
| Columbia, Or. | 2,553 | 1,033 | 1,212 | 490 | | | | | 3,765 | 1,523 |
| Washington, Or. | 1,808 | 732 | | | | | 280 | 113 | 2,088 | 845 |
| Multnomah, Or. | 152 | 61 | | | | | 120 | 49 | 272 | 110 |
| Marion, Or. | 1,134 | 459 | | | | | | | 1,134 | 459 |
| Totals | 6,127 | 2,479 | 4,785 | 1,936 | 570 | 231 | 400 | 162 | 11,882 | 4,808 |

*Acres
** Hectares

Additional private farms and timberlands are inferred to have reserves of ferruginous bauxite but few have been confirmed by drilling. Topographic maps in this back-up file show Reynolds properties and the areas of inferred bauxite. The file also contains the 1975 tax maps which show additional details of ownership.

# GEOLOGY

All four of the major ferruginous bauxite areas in the Pacific Northwest have similar geology. The ferruginous bauxite deposits are the result of laterization of the upper portion of the Columbia River Basalt of Miocene age. They are found on the tops of ridges, the remaining upper portion of the basalt flow, in areas which are dissected by youthful drainage. The degree of laterization is variable, but, in general, the narrower ridges between the deeper valleys seem to have the deepest weathering and to have developed the highest grades of ferruginous bauxite.

## General Stratigraphy

The Columbia River Basalt is composed of a series of Miocene lava flows and is more than 500 feet thick in places. In some areas the basalt flows are interbedded with marine sandstones of the Astoria Formation which contain fossils of middle Miocene age. The basalts unconformably overlie Oligocene marine sediments and are covered by a silty clay overburden of questionable age. The stratigraphic relationships are discussed in greater detail by Libbey and others (1945), and Livingston (1966).

## Ferruginous Bauxite Section

The stratigraphic discussion which follows deals with the weathered upper portion of the Columbia River Basalt and the overlying pisolitic clays and silts. This portion of the section is represented in part by sediments and in part by the different zones of laterization in the basalt (Figure 2).

The upper portion of the Columbia River Basalt has a wide variety of weathered products. The progression upward from the unweathered, hard, black basalt to the zones of low-silica ferruginous bauxite is gradational, but a few relatively distinct zones can be recognized. In mapping the 1970 mine pits, the following mappable units were used: Relic Basalt Zone, Fine-grained Zone, Nodular Zone, Pisolitic Zone, and Silty Clay Overburden.

### Relic Basalt Zone

This is a transition zone from the unweathered basalt to the low-silica ferruginous bauxites. It is usually below the water table, and the weathering has produced kaolinitic and halloysitic types of clay. Gibbsitic types of clay are also present and some analyses in the upper portions of this zone show less than 10% $SiO_2$, qualifying it as low-silica matrix. A considerable portion of this zone is high-alumina, high-iron clay and qualifies as high-silica matrix. The lower part of the zone exhibits considerable spheroidal weathering, commonly with fresh basalt forming the centers of the spheroids.

The clays of the upper part of the Relic Basalt Zone are varicolored, usually have a salt and pepper relic-basalt appearance, and are quite soft in comparison to the low-silica ferruginous bauxites above.

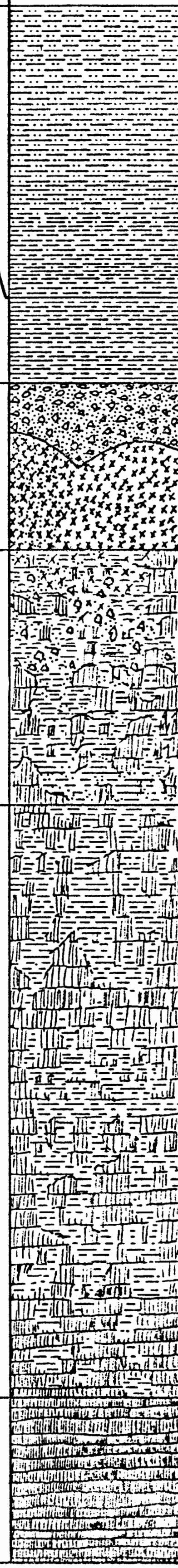
| Thickness range (In feet) | Thickness average | Zone | Composition | Profile | Description |
|---|---|---|---|---|---|
| 0 - 50 | 20 | Silty Clay Overburden | Gibbsite, $Fe_2O_3$ and free silica |  | Tan silt, loose, soft; grades to red silty clay, dense, plastic, with thin silt beds |
| 0 - 9 | 4 | Pisolitic Zone | | | Pisolitic clay, durable, friable |
| 0 - 40 | 12 | Nodular Zone | Gibbsitic clay and $Fe_2O_3$ | | Hard gibbsitic and limonitic nodules or fragments, subrounded to angular |
| | | Fine-grained Zone | | | Fine-grained, brown, ferruginous bauxite with magnetite and ilmenite crystals |
| 0 - 40 | 20 | Upper Relic Basalt Zone | Mixed gibbsite, kaolin clays, and $Fe_2O_3$ | | Varicolored, soft clay with relic basalt texture. Some spheroidal weathering with occasional hard basalt boulders at center of spheroids. Manganese oxides increase toward bottom. |
| 0 - 110+ | ? | Lower Relic Basalt Zone | Kaolinitic type clays and $Fe_2O_3$ | | Clay-altered basalt, dark-gray to brownish with orange to pink halloysite and black manganese oxides in joints. This zone is generally a firm saprolite but may have hard, unaltered basalt boulders. |
| | | Basalt | | | Hard, black basalt |

Figure 2. Generalized section of ferruginous bauxite zones

The thickness of the zone is variable, depending upon the depth of the weathering. Holes drilled to test the low-silica matrix usually stop without reaching the bottom. One deep test in Wahkiakum County cut 93 feet of this material before entering a weathered sedimentary interbed which was 35 feet (10.5 meters) thick (Table 2). An additional 16 feet (5 meters) of the relic-basalt-type material was cut below the sedimentary interbed, at which point the hole was bottomed without reaching hard basalt.

Table 2. Reynolds deep test in Wahkiakum County, Washington (adapted from Jackson, 1974)

| From | | To | | |
|---|---|---|---|---|
| Feet | (Meters) | Feet | (Meters) | Description |
| 0 | 0 | 17 | ( 5.2) | Silty Clay Overburden |
| | | | | Pisolitic Zone - missing |
| 17 | ( 5.2) | 21 | ( 6.4) | Nodular and Fine-grained Zones |
| 21 | ( 6.4) | 51 | (15.5) | Relic Basalt Zone (upper varicolored portion) |
| 51 | (15.5) | 114.5 | (34.9) | Relic Basalt Zone (lower dark-gray to brown saprolite) |
| 114.5 | (34.9) | 133 | (40.5) | Silty-clay sediment |
| 133 | (40.5) | 149 | (45.4) | Clay-altered conglomerate |
| 149 | (45.4) | 165 | (50.3) | Brown, vesicular, basalt-textured clay |
| Bottom at 165 feet | | | | Analyses not available |

A deep test drilled by Alcoa in Oregon (location not given) was reported by Allen (1948). The analyses of this hole were given, but not the log. Table 3 is an interpreted log from the analyses.

Table 3. Alcoa deep test in Oregon

| From | | To | | | Percent | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Feet | (Meters) | Feet | (Meters) | Zone | $Al_2O_3$ | $Fe_2O_3$ | $SiO_2$ | $TiO_2$ | LOI |
| 0 | 0 | 9 | ( 2.7) | Silty clay | | | | | |
| 9 | ( 2.7) | 15 | ( 4.6) | Pisolitic | 37 | 22 | 18 | 5 | 19 |
| 15 | ( 4.6) | 37 | (11.3) | Nodular and Fine-grained | 38 | 32 | 4 | 6 | 20 |
| 37 | (11.3) | 67 | (20.4) | Relic Basalt - upper | 33 | 33 | 13 | 6 | 15 |
| 67 | (20.4) | 177 | (53.9) | Relic Basalt - lower | 26 | 28 | 29 | 6 | 11 |

The analyses of the deep Alcoa test were plotted by Allen (1948) in Figure 3 (the formations as interpreted from the analyses have been added).

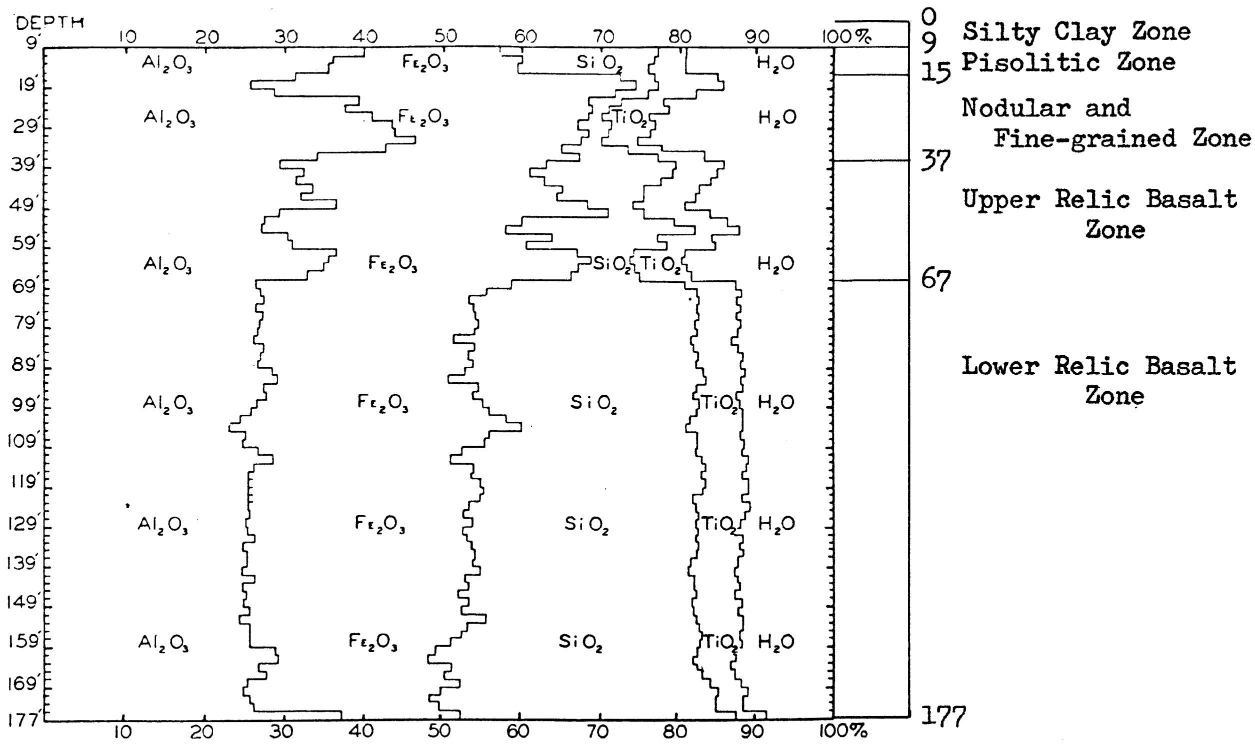



Figure 3. Diagram showing variation in chemical composition with depth in a ferruginous bauxite deposit in Oregon (adapted from Allen, 1948).

Figure 3 shows considerable variation in the analyses of the upper part of the Relic Basalt Zone from 37 to 67 feet, which is normal for the lower portion of most exploration holes. However, the lower portion of the Relic Basalt Zone indicates only minor variations of chemical content and $Al_2O_3$ to $SiO_2$ ratios very close to that of theoretical kaolin. Allen identified the alumina minerals as kaolin and halloysite. This material, averaging about 26% $Al_2O_3$, 28% $Fe_2O_3$, and 29% $SiO_2$, appears to have potential as feed for a Pedersen-process alumina plant. Unfortunately, most of the exploration holes either have not reached this zone or were bottomed in the upper few feet of this zone.

The deep test by Reynolds in Wahkiakum County and by Alcoa in Oregon (presumably Columbia or Washington County) indicate that the weathering can be very deep. If these depths are relatively common and if the material proves to be economic feed for a Pedersen process, the reserve could easily be 10 times that of the low-silica matrix. With a 167-foot thickness, as indicated by the Alcoa hole, the reserves would increase at the rate of 1 million tons per 3 acres. However, because of this very limited data on the lower part of the Relic

Basalt Zone, and because of the marginal nature of the analyses, it is not considered prudent to carry this potential in the MAS estimates. Testing of this lower kaolinitic unit for feasibility in a Pedersen-process plant, to be followed by deep exploration if the material is of economic grade, seems quite justifiable in view of the possible tonnages involved.

The high-silica matrix carried in the MAS estimates is based largely on the mixed gibbsitic and kaolinitic upper portion of the Relic Basalt Zone plus the lower-silica zones above.

## Fine-grained Zone

The Fine-grained Zone is a massive, fine-grained, dark-brown, durable gibbsitic clay with abundant magnetite and ilmenite crystals. The lower part usually grades into the underlying Relic Basalt Zone without a distinct contact. The upper contact of the Fine-grained Zone is distinct but very uneven, forming small rounded hummocks, 5 to 10 feet across and 2 to 4 feet high; the Nodular Zone drapes the tops of the hummocks and fills the deep "V"-shaped depressions between. Both the Fine-grained Zone and the Nodular Zone are usually high in alumina and low in silica, and they account for the bulk of the low-silica matrix. Because of the uneven contact and the similarity of analyses, these two zones are usually considered as a unit, and the combined thickness ranges from 0 to 40 feet (13 meters) and averages about 12 feet (4 meters) in the ferruginous bauxite areas.

## Nodular Zone

The Nodular Zone is made up of hard gibbsite and iron crusts, ranging from sub-rounded nodules to angular fragments, in a reddish-brown clay matrix. The nodules or fragments are reddish brown to mustard yellow, commonly vesicular, and usually have a relic-basalt texture with feldspar laths replaced by gibbsite.

The unusual hummocky contact with the underlying Fine-grained Zone and the collapse-breccia appearance of the Nodular Zone may be the result of shrinkage due to the desilication of the original basalt. Although the nodules or fragments have apparently migrated downward, they do not appear to have been reworked.

The contact between the Nodular Zone with the overlying Pisolitic Zone is usually sharp and even, suggestive of a relatively flat eroded surface. Where the Pisolitic Zone is missing, a similar nearly flat contact exists with the Silty Clay Overburden. The implications of this apparently erosional contact will be discussed later in the section dealing with the origin of the ferruginous bauxites.

## Pisolitic Zone

The Pisolitic Zone consists of pinkish-red pisolites in a durable red-clay matrix 0 to 9 feet (3 meters) thick. The pisolites in this zone consist of concentric bands of gibbsite and iron oxides whereas those in the Silty Clay Overburden above are primarily iron oxides. The pisolites commonly contain grains of quartz, magnetite, and ilmenite. Libbey and others (1945, p 16) reported fragments of altered basalt within some of the pisolites.

The Pisolitic Zone is usually high in alumina, but the silica content is usually above 10 percent, thus eliminating much of this material from the low-silica matrix. However, much of this silica (probably more than half) is non-reactive free silica. The reactive silica, detrimental in the Bayer process is usually less than 10 percent. The ore reserves calculated by Alcoa were based on 10 percent reactive silica and include much more of this zone than those of Reynolds, which were based on 10 percent total silica. Data are insufficient to determine how much potential Bayer-process ore this would add to the reserves calculated by Reynolds, but it is possibly 15 percent or more.

Relatively flat contacts at both the top and bottom of the Pisolitic Zone indicate a sedimentary origin. Livingston (1966) tentatively assigns the Pisolitic Zone, along with the Silty Clay Overburden, to post-Troutdale deposition, but suggests that the pisolitic material is reworked laterite from the Columbia River Basalt. The magnetite and ilmenite crystals and fragments of altered basalt found in the pisolites reinforce this probability.

Jackson (1974, p 53) notes the quartz grains which occur in the Pisolitic Zone but are foreign to the Columbia River Basalt; he makes the following analysis:

> A mineral that has not been given much attention in published bauxite literature (Pacific Northwest area) is quartz. Numerous quartz grains are embedded in the pisolites and bauxite matrix in profile A (pisolitic unit). The grains are mostly silt in size, but some reach 0.75 mm, and are angular to subrounded (Figure 22). The texture of the grains suggest a detrital origin, and do not appear to be formed from weathering processes. The presence of residual quartz grains in the ore zone is not completely understood. During bauxitization, quartz encased in the iron-rich pisolites could be preserved, because limonite is relatively stable. However, it does not seem possible for quartz to survive in the earthy bauxite matrix for a prolonged period of weathering. A possible source rock for the pisolitic unit is the lower portion of the Post-Troutdale silty clay.

Although the Pisolitic Zone has quartz grains in common with the overlying silty clays and magnetite, and ilmenite crystals in common with the underlying ferruginous bauxites, the zone is distinctly different from either.

## Silty Clay Overburden

The Silty Clay Overburden grades from tough, plastic, red silty clay at the base to a soft, loose, tan silty loess near the surface. The uppermost part is mixed with humic topsoils in undisturbed areas. The basal red silty clays commonly contain iron pisolites and are similar in appearance to the Pisolitic Zone, except that the latter has a slightly pinkish cast, is more pisolitic, slightly more durable, and tends to be friable rather than plastic. A thin seam of brownish to greenish silt usually marks the contact, and thin beds of silt are common in the red silty clay. In most sections the change from the red silty clay to the tan loess is very gradual, extending over 20 feet (7 meters) or more in some areas with thick overburden. The silt content gradually increases higher in the section and the color changes from a bright brick red to reddish brown to a buff tan. The intermediate zones commonly exhibit reddish-brown and tan mottling.

Livingston (1966) postulates an aeolian origin for the silty clays, probably derived from glacial outwash of the Columbia River flood plain. Although an aeolian origin seems likely for the tan silt at the top, the thin silty beds near the base indicate water deposition.

Another difficult and unanswered problem is the gradual change from the bright red lateritic silty clay at the base of the Silty Overburden to the apparently unaltered silt at the top. Does this represent a substantial difference in age from bottom to top, a difference in the original material deposited, or increased lateritic action with depth?

Rounded cobbles of chert or quartzite were observed in place in the upper portions of the Silty Overburden during the 1970 mining operations. The occurrences were rare, but several cobbles were observed at different pits in the tan silt zone which otherwise appears to be an aeolian type of sediment. The origin of these cobbles in such a fine-grained sediment is difficult to explain unless they were dropped by some type of animal.

## Stratigraphic Relationships

The full sequence from fresh Columbia River Basalt through the Relic Basalt Zone, Fine- grained Zone, Nodular Zone, Pisolitic Zone, and the Silty Clay Overburden occurs only in the areas which have relatively thick deposits of low-silica ferruginous bauxite. Moving laterally away from the low-silica areas, the Fine- grained, Nodular, and Pisolitic Zones disappear and the Silty Overburden is in contact with the Relic Basalt Zone. In rare instances, the tan silty loess at the top of the Silty Overburden has been found in contact with fresh Columbia River Basalt (Figure 4).

In Wahkiakum County, Washington, the full sequence of stratigraphic units, including the low-silica ferruginous bauxite zones, were found only where remnants of the upper portion of the Columbia River Basalt flows were left on high ridges between the deeply incised valleys of the Mill Creek drainage system (Figure 4-C). Farther up stream, the low-silica zones were missing and the Silty Clay Overburden was in contact with the Relic Basalt Zone (Figure 4-B). At the head of the drainage system, on the high rim along the Columbia River above Cathlamet, where the upper surface of the Columbia River Basalt appears to be uneroded, the upper tan silty loess portion of the Silty Clay Overburden was in contact with hard, fresh basalt (Figure 4-A).

Libbey and others (1945) and Livingston (1966) believe the silty clays were deposited unconformably on an eroded surface of the Columbia River Basalt and point to the draping of the red silty clay over the ridge slopes as evidence. This is well within the realm of possibility if the silty clays are of wind-blown origin as postulated. Certainly the loose, tan, silty, loess-like material of the upper part of the Silty Clay Overburden seems to be aeolian. However, the Pisolitic Zone and the tough red clays of the lower portion of the Silty Clay Overburden seem to be water-laid sediments which would be inconsistent with a draping type of deposit. It seems more likely that the draping of the red clay portion of the Silty Clay Overburden is due to soil-creep down the slopes of the ridges.

## Structure

The intercalation of Astoria marine sandstones with Columbia River Basalt indicates that the lavas poured out on a terrain which was near sea level. The basalt has had subsequent uplift with faulting and minor folding. Slightly tilted fault blocks on the flanks of gentle folds form low-angle dip slopes. Erosion has carved youthful valleys in these slopes. All of the major ferruginous bauxite areas in the Pacific Northwest are on the middle to lower portions

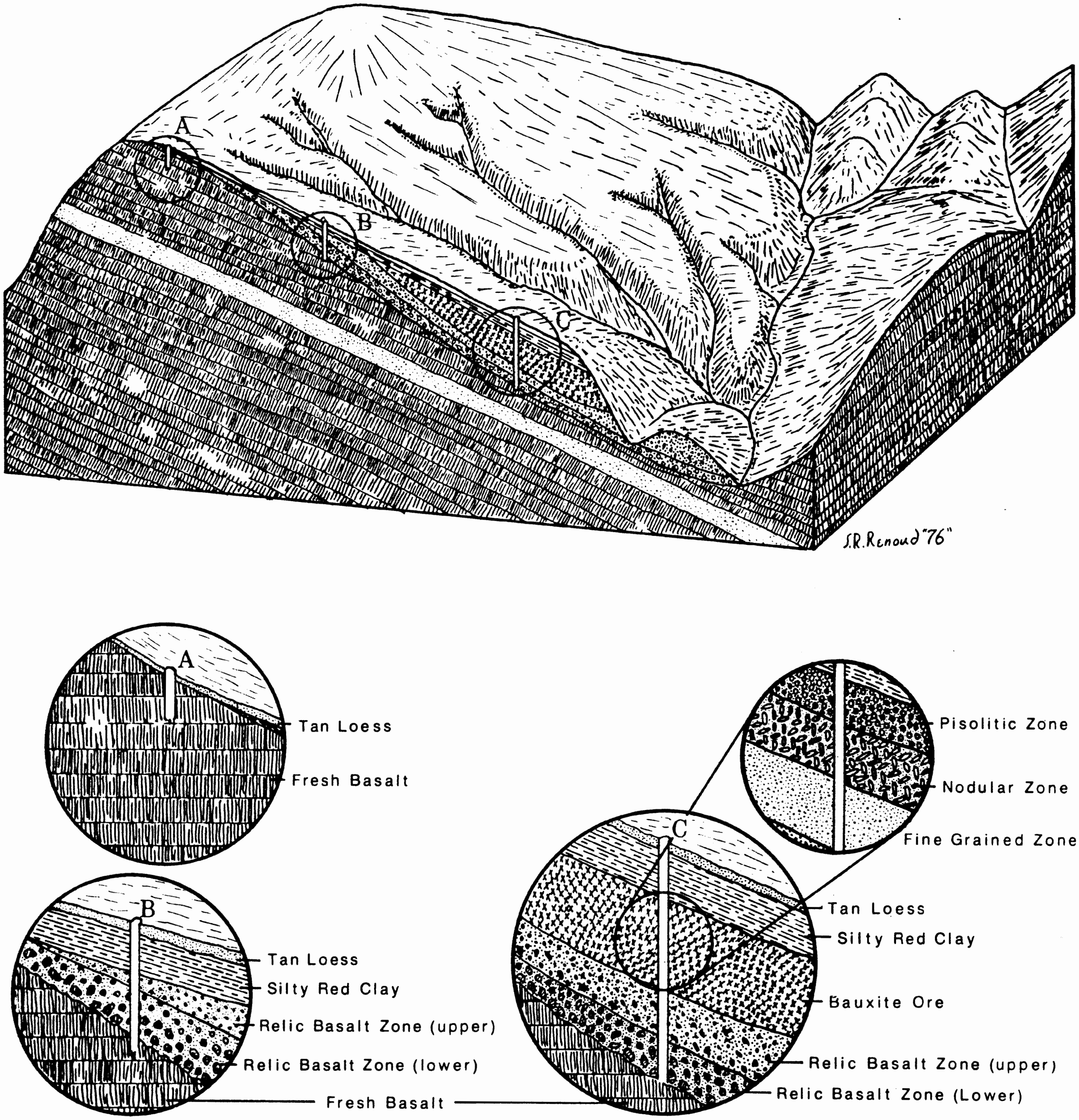



Figure 4. Block diagram of Wahkiakum bauxite area showing three sections in detail.

of dip slopes which have been deeply incised. The thickest and highest grades of ferruginous bauxite are usually found on narrow ridge-top remanents of the dip slope between the deeper valleys (Figure 4).

Examples of these dip-slope structures are: the Wahkiakum County area, where the slope dips east from a high rim along the Columbia River; the Cameron Creek and Mosquito Creek areas of Cowlitz County, where the slope of the Columbia River Basalt dips south from the older volcanics of Abernathy Mountain; the Columbia City area of Columbia County, where the dip slope is south from a high rim; the Dixie Mountain and Pumpkin Ridge areas of Washington and Multnomah Counties, where the dip is generally south to southwest from high rims; and the Salem Hills in Marion County, where the dip slope is a slight, plunging syncline dipping in a northerly direction from a high rim. In all of these areas, the low-silica ferruginous bauxites have been found only on the down-slope portions which have the most highly developed drainage. The rims at the head of the drainage usually have hard basalt at or near the surface.

Because of the silty clay overburden, few faults are exposed in the ferruginous bauxite areas. However, a number of faults can be inferred fromthe topography; off-sets in the dip slopes are indications of faulting. These topographic features are sometimes difficult to recognizė because the dip slopes have been carved by the youthful drainage, and commonly the drainage is along the faults. A fault is recognized along Mosquito Creek in Cowlitz County where the dip slope (and the ferruginous bauxite) is about 100 feet (30 meters) lower on the ridge west of the Creek than on the ridge to the east (the regional dip is south).

Minor faults were exposed in the 1970 mine pits. These faults have well-developed slickensides but apparently very little displacement. An interesting feature of the faults is that they terminate upward in the overburden and the overburden material has worked downward in the fault zone into the ferruginous bauxite.

In the Lisack pit in Cowlitz County, the minor faults extend up through the Pisolitic Zone and the overlying red silty clays to the tan silty loess. The tan loess extends downward in the fault zones to the bottom of the pit at the base of the low-silica matrix. These veins of tan silt are usually less than 1 inch (2.5 cm) wide and taper downward, some pinching out before reaching the bottom of the pit.

In the Fay Olsen pit in Columbia County, the overburden was silty red clay with iron pisolites. This material formed the thin veins in the fault zones.

In the Grabenhorst pit in the Salem Hills, the low-silica ferruginous bauxite was at the grass roots, with about 1 foot (30 cm) of humic topsoil as overburden. In this location, the humic topsoil formed the veins in the faults, many of which extended at least to the bottom of the pit and were rootbound all of the way, 13 feet (4 meters) below the normal surface of the ground. Some veins pinched down to about 1 mm and still had roots, yet the roots did not extend into the ferruginous bauxite walls of the faults.

Subsequent to the observations of the overburden-filled fault zones in the 1970 mining project, a silt-filled fault, in what otherwise appeared to be low-silica ferruginous bauxite, was noted in the core of a test hole in Wahkiakum County. A second hole was drilled 10 feet (3 meters) away and missed the fault. The first hole gave high-silica assays through this zone, but the second was an ore hole with less than 10 percent silica. Thus test holes which accidentally penetrate these narrow veins of silt can give misleading analyses unless recognized as faults.

## Origin of the Ferruginous Bauxite

There is agreement in the literature on the Pacific Northwest ferruginous bauxites that the major deposits are the product of laterization of the Columbia River Basalt. A number of questions remain, however, regarding the time of laterization and the relationships of the Pisolitic Zone and the Silty Clay Overburden.

In the published literature on the district, it has been postulated that the laterization occurred in late Miocene to Pliocene time, prior to uplift, while the Columbia River Basalt was exposed as a low-lying plain and not subject to rapid erosion. Under these conditions it has been assumed that a blanket type of laterization took place over the entire upper portions of the basalt and that the present ferruginous bauxite deposits are the erosional remnants of this laterization.

The theory expressed by Libbey and others (1945, p 14) is as follows:

> 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 may 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.

The possibility of a different origin was indicated when an area which had been presumed to have favorable conditions was drilled and gave negative results. In exploring the Wahkiakum County area, it was found that the broad, gentle, dip slope at the head of the Mill Creek drainage system, presumably an uneroded section of the original Columbia River Basalt, had little or no laterization. The depth of laterization seemed to progress down the dip slope roughly in keeping with the depth of the youthful surface drainage of the area. Low-silica ferruginous bauxites were found only on the lower portions of the dip slope, which had been encised by deep valleys. This evidence was counter to the theory of blanket laterization and led to the speculation that the laterization developed in response to the drainage and thus may be no older than the youthful topography of the dip slope.

The relationship of good drainage to the formation of gibbsite and kaolin minerals was discussed by Allen (1948, p 624).

> The development of gibbsite and ferruginous bauxite in the deposits of Oregon was accomplished by a continuation of the same process of weathering and thorough leaching as that which formed the kaolin minerals. Laboratory experiments demonstrate the effectiveness of carbonic acid solutions in removing silica from clay minerals, and emphasize that removal of silica is facilitated by circulation of solutions. Good drainage conditions are essential in leaching of silica in order to renew the supply of carbon dioxide and to remove the solutions that become partly or wholly saturated with silica.

In discussing the relationship of the Silty Clay Overburden to the ferruginous bauxite deposits, Allen drew the following conclusions:

> The alteration of the silt is less intense than that of the ferruginous bauxite. Thus, the formation of the ferruginous bauxite was completed before the deposition of the overlying silt. The age of this silt has been assigned to the Pliocene. On this basis the period of bauxite formation in Oregon was confined to the interval between the Miocene basaltic eruptions and the Pliocene epoch.

Both of the above statements by Allen seem quite reasonable when taken alone, but together they raise the question of the development of adequate drainage prior to the deposition of the silt. If the silt is of aeolian origin, it could have been deposited over a deeply eroded surface, but if the silt, or a portion of it, was deposited by water, a deeply eroded topography seems very unlikely.

Later evidence from exposures in the 1970 mine pits is counter to the theory that the laterization developed in response to drainage. This evidence is based on the contact relationships of the Pisolitic Zone and the Silty Clay Overburden to the Columbia River Basalt or its laterized equivalent. Except where disturbed by minor faulting, the contacts at the top and bottom of the Pisolitic Zone and the thin silty beds in the basal portion of the Silty Clay Overburden were nearly flat in the mine-pit exposures. These zones appear to have been deposited by water. Furthermore, as Livingston (1966) points out, the Pisolitic Zone seems to have been derived from a Columbia River Basalt source, possibly from a reworking of a laterized portion of this formation. Conditions for this type of deposition could not have existed during the development of the present youthful topography.

Thus the origin of the ferruginous bauxites presents quite an enigma: the Pisolitic Zone seems to indicate a lateritic formation existing prior to dissection by present drainage, yet the major ferruginous bauxite deposits of the Pacific Northwest have been found only in areas which have well-developed drainage.

The distribution of the Pisolitic Zone has not been plotted from drill logs and this would be a useful addition to the present knowledge of the area. In general, however, the Pisolitic Zone seems to be restricted to the near vicinity of the low-silica Nodular Zone which it usually overlies. In many ore holes, the Pisolitic Zone is missing and the Nodular Zone is in contact with the Silty Clay Overburden. If the Pisolitic Zone was derived from the Nodular Zone, the reworked material did not move very far, yet the reworking would have had to have been sufficiently vigorous to produce the nearly flat, nearly knife-edge contacts between these two units. Vigorous reworking with such limited distribution seems unlikely.

An alternative origin for the Pisolitic Zone may be a laterized tuff. Libbey and others (1945) suggested that the pisolitic red-clay overburden in the Salem Hills may be the laterized equivalent of the Fern Ridge Tuff. This is a reasonable possibility for the extensive red silty clays at the base of the Silty Clay Overburden, but the limited extent of the Pisolitic Zone and its apparent coincidence with the Nodular Zone are unlikely for the broad type of deposition characteristic of tuff. However, if tuffaceous deposits on the Columbia River Basalt were laterized along with the basalt in response to drainage, such localization would be expected.

A locally laterized tuff bed or the lower unit of the Silty Clay Overburden would be compatible with the sharp, relatively flat contact with the underlying laterized basalt of the Nodular Zone. However, if the Nodular Zone is a semi-collapse breccia over Fine-grained Zone due to shrinkage from laterization, then its upper contacts should show similar disturbance unless there were an intervening planing by erosion.

In the ferruginous bauxite areas, the water table is usually at or near the base of the low-silica matrix. This coincidence is closely linked to surface drainage because the areas with greater relief have better sub-surface drainage and thus deeper water tables under the ridges. The fact that almost all of the low-silica ferruginous bauxite is above present-day water tables is suggestive of a very recent origin.

In summary, there is evidence for and against both the theory that the laterization occurred following Miocene deposition and the theory that it is of more recent origin, related to the youthful topography of the dip slopes of Columbia River Basalt. However, the coincidence of dip slopes with the low-silica matrix only on the deeply incised lower portions and, for the most part, only above the present water tables, has been a valuable guide to finding ore. On the other hand, projections of ore over the entire dip slopes on the basis of the blanket laterization theory have led to serious overestimates of the resource which have not stood the test of drilling.

## ORE RESERVE ESTIMATES

The ore reserves of Pacific Northwest ferruginous bauxite estimated by Reynolds are based primarily on a matrix which had more than 30% $Al_2O_3$ and less than 10 % $SiO_2$ (Table 4). This low-silica matrix is the assumed limits of feed for a Bayer-process alumina plant.

Table 4. Grade and tonnage estimates of Reynolds Metals Co. ore reserves (Michell, 1975)

| Area | $Al_2O_3$ % | $SiO_2$ % | $Fe_2O_3$ % | $TiO_2$ % | LDT million |
|---|---|---|---|---|---|
| Cowlitz - Wahkiakum | 39.74 | 6.43 | 27.33 | 4.23 | 17.2 |
| Columbia County | 34.16 | 6.45 | 34.23 | 6.41 | 18.5 |
| Washington - Multnomah | 33.81 | 6.42 | 34.66 | 6.66 | 7.3 |
| Salem Hills | 36.02 | 4.17 | 32.49 | 7.14 | 13.4 |
| Weighted | 36.26 | 5.90 | 31.77 | 5.95 | 56.4 |

Additional reserves of the low-silica matrix are known to exist on properties which are not owned or leased by Reynolds, but relatively few of these have been tested by drilling. From an examination of Reynolds properties relative to likely areas of low-silica ferruginous bauxite, it is estimated that the company controls 75 to 80% of the reserves. Thus the total low-silica matrix reserve for the Pacific Northwest is estimated to be approximately 70 million long dry tons.

The low-silica matrix is confined mostly to the Fine-grained Zone, the Nodular Zone, and the Pisolitic Zone. However, the drill holes testing for this matrix usually bottomed in the Relic Basalt Zone, the upper part of which runs about 10 to 20% $SiO_2$ and usually more than 30% $Al_2O_3$. If an economic evaluation of the Pedersen process, or one of the high-alumina clay processes, indicated that this grade of material could be produced profitably, the ore reserves would double or even triple. Probably 150 to 200 million tons of a matrix running less than 20% $SiO_2$ and more than 30% $Al_2O_3$ would be available in the Pacific Northwest.

Very little is known about the total depth of the Relic Basalt Zone. The 177-foot test by Alcoa and the 165-foot test by Reynolds reported in Tables 2 and 3 are the only known deep tests. The lower portion of the Relic Basalt Zone in the Alcoa hole averaged 26% $Al_2O_3$, 28% $Fe_2O_3$, and 29% $SiO_2$ throughout a 110-foot thickness with 58 feet of higher grade material above. If such thicknesses are relatively common, the reserves of this matrix could easily exceed 500 million tons. This is not presented as an ore reserve figure but merely to show the possibility of an enormous resource which should be investigated.

## EXPLORATION

Exploration of the Pacific Northwest ferruginous bauxite deposits was done primarily with churn drills taking drive-core samples. Iwan-type hand augers have also been used. Power augers have been used for fast reconnaissance testing but the samples have been unsatisfactory for reliable grade determination.

### Methods

#### Drive-core sampling

Drive cores give dependable samples and reveal features of the ore such as structure, texture, and durability which are difficult to determine from auger cuttings. The method is fast, economical, and does not require water for drilling. It utilized 4.5-inch (11.43-cm) ID casing attached to the bottom of the jar-hammers. The casing is driven into the bottom of the hole for 1 foot (30.5 cm) or 1.5 feet (45.7 cm) to obtain the sample. The core is pressed from the casing with a piston powered by a hand-operated jack or hydraulic system. Loose material which has sluffed into the hole between runs is easily distinguished from the firm core and is discarded. The core recovery is nearly 100% above the water table, where most of the low-silica matrix is found. Cores are frequently lost when water is first encountered, but recovery improves again below this zone.

#### Iwan-auger sampling

The Iwan is a bucket type of hand auger commonly used for drilling post holes. Short extension joints of pipe are added as the depth increases, and holes 50 feet (15 meters) or more deep are possible. The auger has to be pulled and emptied about every 6 inches (15 cm) and progress is slow, especially as the depth of the hole increases. In some of the more durable ferruginous bauxite, a chopping bit has to be used between auger runs. The sample reliability depends upon how carefully the tools are handled in the hole to reduce sluffing.

Iwan augers were used extensively by Alcoa in the late 1940's and early 1950's when labor costs were lower than they are now. It is hard manual labor and usually done by two men taking turns on the handle. A two-man crew will usually average about one hole per day.

The light, portable Iwan auger is especially useful for reconnaissance drilling in poorly accessible timbered areas. Roads are not required to the drill sites and the timber is not damaged.

### Drilling Costs

The present costs per day, and the average cost per hole, for a two-man crew drilling Iwan hand-auger holes is approximately $64 labor, $18 per diem, and $18 for transportation, equipment and miscellaneous expenses, for a total of $100.

The contract rate for a churn drill with a two-man crew is $27.50 per hour or $220 per 8 hour day, plus $18 per diem. Assuming four holes per day, the cost per hole is about $60. In timbered areas where minimal roads have to be dozed to the sites, the additional cost is about $40 per hole. In addition to being as cheap or cheaper than hand auger drilling, the churn drill is four times as fast and gives better samples.

## MINING AND RECLAMATION

A 50,000-ton, plant-run sample of low-silica matrix was mined from seven different pits representative of the major ferruginous bauxite areas of the Pacific Northwest. The mining was done during the summer of 1970. About 5,000 to 10,000 tons were mined from each pit representing a weighted proportion to the ore reserves of each area. To assure a representative sample, the test block was mined to vertical walls for the full thickness of the ore. The ore control was based on close center drilling with drive cores. The grade of the 50,000-ton sample proved to be very close to the weighted average of Reynold's Pacific Northwest ferruginous bauxite reserve estimate (Michell, 1975) (Table 6).

Table 5. Comparison of low-silica matrix sample with ore-reserve average

| | 5,000-ton sample | Ore-reserve average |
|---|---|---|
| $Al_2O_3$ | 36.35% | 36.26% |
| $SiO_2$ | 6.16 | 5.90 |
| $Fe_2O_3$ | 31.97 | 31.77 |
| $TiO_2$ | 5.25 | 5.95 |
| LOI | 19.67 | ----- |

No unusual or difficult problems were encountered in the mining. The overburden was stripped with bulldozers and the ore mined with end loaders. Some of the more durable zones required ripping, but explosives were not needed. The ferruginous bauxite was compact, durable, and the vertical walls stood well.

The pits were reclaimed immediately after mining. The overburden was returned to the pit, compacted, and contoured for drainage. The top soil, which had been placed in a separate spoil pile, was distributed over the recontoured surface. Two of the pits were in grass-seed fields in the Salem Hills and the remainder were in timber areas or old fields which had been seeded for timber; all were reclaimed to their original use.

The sample was shipped to Reynolds' Bayer-process alumina plant at Hurricane Creek, Arkansas, partly by rail and partly by ship.

## BENEFICIATION

A two-stage process is used to make aluminum from bauxite. The first stage is the refining of the crude ore to alumina ($Al_2O_3$); the second stage is the reduction to aluminum, which is an electrolysis process requiring 7 to 10 kwh of electricity per pound of metal produced. Because hydroelectric power was cheap in the Pacific Northwest, a number of reduction plants were built in the region. However, the Pacific Northwest has no alumina -refining plants; the nearest is at Corpus Christi, Texas. Only under emergency conditions is it likely that the low-grade ferruginous bauxite of the Pacific Northwest would be shipped to an existing alumina plant. Furthermore, all of the existing plants utilize the Bayer process, which recovers only the alumina.

In considering the type of plant needed to process the ferruginous bauxite, most workers have favored the Pedersen process, which recovers both the alumina and the iron and produces a gray mud waste that is a valuable raw material for cement. A disadvantage in the Pedersen process is that it is energy intensive, requiring about 4500 kwh of electricity per ton of alumina produced, plus additional fuel for calcining. The merits of the Pedersen process relative to the Bayer are discussed by Miller and Irgens (1974 p. 790) as follows:

> "With the present high quality bauxite ores in abundance, this process is less competitive than the Bayer process. However, there are two important assets with the Pedersen process which might well give the process a future renaissance, viz.: -
> (i) The Pedersen process enables one to use a wide range of bauxite qualities with high silica and iron content, ranges far beyond the limitations of the present Bayer process.
> (ii) A total elimination of the red mud problem. In fact, the process calls for a complete utilization of the bauxite through the production of high quality pig-iron in the smelting process and further to use the grey mud as an important raw material for cement production."

Additional research is needed to show economic feasibility of the Pedersen process for the Pacific Northwest ferruginous bauxites. Tests by the U. S. Bureau of Mines (Fursman and others, 1968) demonstrated good recovery of both the alumina and iron, but the alumina had too much silica to be cell grade, and the iron had a high (about 1%) phosphorus content. Additional refining may be necessary to remove these impurities. (There is very little data on the phosphorus content of the Pacific Northwest ferruginous bauxites, and the amount of phosphorus in the U.S. Bureau of Mines' samples may or may not be representative of the deposits as a whole.)

Technical feasibility of producing alumina from the Pacific Northwest ferruginous bauxites in a Bayer-process plant was demonstrated by a 50, 000-ton plant-run sample at Reynolds' Hurricane Creek Arkansas plant. A good quality of alumina was produced but the iron was wasted with the red mud. Waste disposal, amounting to about two thirds of the tonnage mined, would be a major problem for a Bayer-process alumina plant in the Pacific Northwest.

In summary, the Bayer process has proven effective for the ferruginous bauxite in a plant-run test. However, the process would recover only alumina, leaving a massive (probably 40 million tons or more) red mud waste product. The Pedersen process, on the other hand, would use all of the resource. In addition, the Pedersen process, which permits a wider range of bauxite quality, might more than double the available reserves.

## ENVIRONMENTAL IMPACT

The major deposits of ferruginous bauxite are on agricultural and timber lands. For the most part, the areas are reasonably remote, but some of the land in the Salem Hills and near St. Helens, Oregon is near highly developed residential areas. During the land acquisition by Alcoa and Reynolds in the 1950's and 1960's, areas with moderate to heavy residential development were avoided because the surface values were greater than the potential value of the ferruginous bauxite. Subsequent urban sprawl around Salem and St. Helens is now crowding some of the acquired land and starting to cover potential ferruginous bauxite resources not under Reynold's control. In the Salem Hills, there are very few hill tops which do not have houses except those owned by Reynolds.

Unless controlled by prudent planning, the expansion of urban development will not only continue to cover valuable mineral deposits but will also cause conflicts when the acquired ferruginous bauxite lands are mined.

### Impact of Exploration

Most of the potential bauxite deposits in the Pacific Northwest have been explored, but some potential ore remains untested. The exploration work is done with auger or core drills.

Hand-operated, post-hole types of augers are used for reconnaissance exploration in poorly accessible areas. The equipment is backpacked to the site and a 4-inch (10-cm) diameter hole drilled to test the resource. The environmental impact is negligible.

The major part of the exploration drilling is done with a truck-mounted churn drill taking drive cores. In agricultural areas, the drilling program is timed to do the least damage to crops and the soil. This is usually in the late summer and fall months after the crops have been harvested and while the ground is still dry enough to support the equipment. It usually takes from 1 to 3 hours to drill a hole. The core material not saved for samples is dumped back in the hole and the hole is plugged. The site is left clean and ready for continued agricultural use.

In timbered areas, a reasonable amount of flexibility is used in the pattern of drilling so that adjustments in the locations of individual holes can be made to fit the site. The sites are picked in natural openings in the timber and minimal winding trails are made through the timber. Existing roads and trails are used as much as possible. The equipment is in compliance with fire regulations, and fire-fighting equipment is kept near the site. These operations cause very little damage to the timber and apparently little disturbance to the wildlife. Each new trail is carefully inspected by the deer as evidenced by their tracks the following morning.

The drilling equipment is quite noisy at the start of a hole because the jar hammers are above ground. At about 20 feet, the jar hammers are in the ground and the noise subsides. The holes are drilled only in the weathered portion of the formations and stopped at or above solid bedrock. The water table is usually encountered but not penetrated deeply enough to disturb ground waters. No drilling muds or other additives are used which might pollute the ground water.

## Impact of Mining

The ferruginous bauxite deposits are near the surface and surface-mining methods are required. The 1970 test-mining project by Reynolds Metals Co. gave an excellent example of the environmental impacts during mining and the residual effects. Seven sites in Oregon and Washington were mined, five in timbered areas and two in agricultural areas. Natural openings were selected in the timbered areas to minimize damage, but the few merchantible trees involved were harvested. The crop of grass seed in the agricultural areas was harvested prior to mining.

The 1970 pit sites were carefully surveyed and spoil pile sites for the topsoil and the remainder of the overburden were planned. Following the extraction of the ore sample, the overburden was backfilled into the pits, compacted and contoured for good drainage. The spoil pile of topsoil was then spread back over the area. The agricultural areas were reseeded with grass, and fir seedlings were planted on the reclaimed sites in timbered areas.

The grass on the two agricultural sites, both in the Salem Hills, has done especially well since reclamation. At both sites, the ferruginous bauxite had been immediately under the topsoil. Except for the soil-filled fault zones described under geology, there had been no root penetration of the ferruginous bauxite zone. The ground disturbed by mining apparently offered better conditions for root development because the grass over the reclaimed sites now remains green later in the summer than over the undisturbed surrounding areas.

The fir seedlings on the reclaimed sites had a high mortality, apparently due to a very lush growth of volunteer wild grass and alder on these freshly exposed soils. The surviving fir however are growing well, and, with cultivation or spraying, there is little doubt that fir could be made the dominant species on reclaimed timber lands.

Some settling has occurred since the pits were reclaimed. This is most evident over the deeper pits. The Adams pit in Columbia County was the deepest, about 30 feet (10 meters), and the settling has been about 3 feet (1 meter). Because the pits were mined to vertical walls, this settling is quite evident adjacent to the unmined ground. However, settling was anticipated and sufficient gradient had been allowed in the recontouring to maintain good drainage subsequent to settling. Except for the sharp line of settling along the up-slope edges of the pits, there is now (5 years later) little evidence that the pits ever existed.

During a full-scale mining operation, production would probably be 2 million long dry tons per year, an amount sufficient to supply alumina to Reynolds' Longview and Troutdale reduction plants. At the average ore thickness of 14.5 feet (4.43 meters), this would require mining about 70 acres (38 hectares) of the low-silica matrix per year or a somewhat reduced area of high-silica matrix. The active mining operations would affect only about 6 acres (2.5 hectares) at any one time, plus the areas utilized for more or less permanent haul roads. Timber harvesting would precede these mining operations. Reclamation would almost immediately follow mining, with probably no more than 1 month lag time.

The 1970 mining was accomplished with bulldozers and end loaders. Explosives were not needed, and noise levels were moderate for the heavy equipment involved. There was little dust in the pits, but the haul roads had to be sprinkled occasionally when the dust became excessive.

The only serious impact of the 1970 mining project was the transportation of the ore. In addition to the dust problem, the trucking caused some damage to county roads and increased the traffic hazard. These problems could largely be eliminated during a large-scale mining project by building private haul roads, as many of the timber companies in this area do. This would not only increase safety, but permit the use of larger trucks than most county roads are designed to handle.

In the timbered areas, the environmental impacts will be little more than those of clear-cutting, and the land can be reclaimed for tree farming. Excessive growth of grass, weeds, and brush may have to be controlled to establish fir trees. No problems are anticipated in reclaiming agricultural lands. In areas where the ferruginous bauxite, leached of almost all of its active minerals, is very near the surface, the fertility is likely to be improved by its removal.

The more serious impact will be in areas of heavy residential density near Salem and St. Helens where the noise and aesthetic disruptions will be a serious problem. Where private haul roads are not practical, such as in the Salem Hills, trucking will have a very serious impact. In addition will be the usual public impression of "strip mining" as something which lays waste the land for all time. An effective public relations program may be needed to prevent public misunderstanding from blocking the utilization of this very valuable resource.

Salem is expanding in the direction of the Salem Hills by design of the city planners. This is the logical direction for expansion because the agricultural productivity of the hills is less than a third that of the fertile valley lands. However, it should be realized that the Salem Hills is one of the few areas in the United States with aluminum ores which can be used in existing alumina plants. It should further be realized that the resource can be extracted and the land shaped for urban development in a single operation and cause little more impact than the urban development alone.

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