

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

329 SW. Oak Street
Portland, Oregon

G M I SHORT PAPER

No. 2

INDUSTRIAL ALUMINUM: A BRIEF SURVEY

by

Leslie L. Motz
Metallurgical Chemist
Oregon State Department of Geology & Mineral Industries.



STATE GOVERNING BOARD

W. H. STRAYER, CHAIRMAN
ALBERT BURCH
E. B. MACNAUGHTON

BAKER
MEDFORD
PORTLAND

EARL K. NIXON
DIRECTOR

PRICE 10 CENTS

The subject of aluminum is one of frequent mention in the Portland area just now because of the announcement that an aluminum plant is to be located here. This brief thumbnail report is therefore pertinent.

This Department is being more or less deluged with inquiries as to whether or not various types of clays that are present in the Pacific Northwest may be considered as ores of aluminum. The answer in general is "no". The reason is that the high-alumina clays in the Northwest are composed essentially of aluminum silicate rather than aluminum oxide. Only the oxide is desirable as an ore at the present time. Persons may determine the desirability as aluminum ore of clay deposits in which they may be interested by having representative samples assayed for silica. If the percentage is more than 5% or 10% SiO_2 , the material would not be acceptable as aluminum ore under present metallurgical practice.

Earl K. Nixon,
Director

Portland, Oregon,
January 1940.

INDUSTRIAL ALUMINUM: A BRIEF SURVEY

by

Leslie L. Motz
Metallurgical Chemist
Oregon State Department of Geology & Mineral Industries
Portland, Oregon

On December 23rd, 1939, the Aluminum Corporation of America announced its decision to establish a \$3,000,000 plant for the making of aluminum metal, near Vancouver, Washington. The Bonneville Administration announced that this corporation had signed an electric power contract covering 32,500 Kw-yrs. per year for a period of 20 years. It is understood the plant will use alumina shipped from alumina-producing plants at East St. Louis, Illinois, and Mobile, Alabama. It is estimated that the plant will have a capacity of 30,000,000 pounds of aluminum per year.

Aluminum, with a specific gravity of 2.70, is the lightest of the metals used in large quantities. In addition to being light, the metal is silvery white, is quite soft, ranks second in the scale of malleability and sixth in ductility, has a high tensile strength, and melts at 660° C. It was discovered in 1825 but was produced only in small amounts until the invention of the Hall-Héroult process in 1886-7. Even then, it was not until 1896 that aluminum began to come into the metallics field. It is now classed by the U. S. Army and Navy Munitions Board as a strategic material because of its great importance for industrial and military use.

Aluminum is one of the most abundant elements in the earth's crust; it ranks third (7.3%) to oxygen first (49.8%) and silicon second (26.1%). It never occurs in the native state but is always combined: as silicates in clay, mica, kaolin, feldspars, and leucite; as oxide in corundum and bauxite; as fluorite in cryolite; and as sulfate in alunite. As much as 63% alumina (aluminum oxide, Al_2O_3 , which contains 53% aluminum metal) is present in complex silicates; but bauxite, the oxide, with 74% alumina maximum, is the principal commercial ore.

Aluminum is obtained as primary metal from the refining of ores and as secondary metal reclaimed from scrap. Primary aluminum is produced in three grades: (1) special, containing 99.5+% aluminum; (2) grade No. 1 (grade A) containing 99+% aluminum; and (3) grade No. 2 (grade B) containing 98 to 99% aluminum. The substantially pure metal finds a limited use, but its alloys are employed in many fields. Alloys possessing varied physical properties are made from combinations of the metal with magnesium, copper, beryllium, zinc, caesium, cobalt, manganese, silicon, iron, nickel, chromium, tungsten, and molybdenum. Although the scrap metal cannot be refined it is commonly re-alloyed.

The metal in powdered form is used in paints, thermit welding, and explosives; but both metal and alloys are made into sheets, structural shapes, and castings for use in -

- Aircraft, bus, auto, railroad rolling stock, street-cars, ship, and mine equipment construction.
- Electrical transmission cables
- Cooking utensils
- De-oxidation of steel in casting
- Lithographic work
- Building construction.

In the field of electrical transmission it compares favorably with copper, and it will probably be used more extensively if an advantageous price differential can be maintained. For hard-drawn conductors of equal conductance, an aluminum conductor is 64% larger in cross-section than a copper conductor; but the aluminum conductor weighs only half as much as the copper conductor. However, the tensile strength of the aluminum wire is 15% less than that of the copper wire, so the weight of an aluminum conductor of equal strength would be approximately 60% the weight of the copper conductor; and it would conduct approximately 11% more electricity. A rough assumption may be made that if the unit price of aluminum is less than 1.7 times that of copper, it would be cheaper to use aluminum transmission lines. Aluminum metal is quoted at 20¢ per pound and copper at 12¢ (January 22nd, 1940).

The principal aluminum metal- and alloy-producing countries in 1938 were Germany, United States, Canada, U.S.S.R., France, Norway, Switzerland, Italy, United Kingdom, and Japan. In the United States, the metal is processed at Alcoa, Tenn. (40%); Massena, N.Y. (34%); Badin, N.C. (14%); and Niagara Falls, N.Y. (12%). Among the many plants fabricating aluminum and its alloys is the sand foundry and forging plant at Los Angeles, Calif., the only plant west of the Mississippi Valley, which fulfills the demands of the Pacific Coast aircraft industry for aluminum alloys. It is reasonable to expect that with an increase in industrial activity in the Northwest, particularly in aircraft manufacture in the Seattle area, the proposed aluminum plant at Vancouver will have a more local demand for its products. Data on aluminum in the United States for 1938 are given in the following table:

Domestic Aluminum Metal Data

Production	128,000 long tons	286,882,000 lbs.
Imports	7,930 "	17,740,281 "
Exports	5,640 "	12,618,078 "
Apparent primary consumption	130,290 "	292,004,203 "
Production of secondary metal	34,600 "	77,600,000 "

Domestic production of aluminum metal is 98% of the apparent domestic primary consumption, while the apparent domestic primary consumption of aluminum was 27% of the world's production. Of the imports, 2570 long

tons came from Norway, 2360 from France, 1270 from Switzerland, 1080 from Canada, and 385 from the United Kingdom. The price of primary aluminum No.1, 99+%, is 20¢ per pound. An import duty of 3¢ per pound was in effect in 1939.

As mentioned before, bauxite, the oxide, is the principal commercial ore of aluminum. Bauxite forms compact, earthy, and pisolitic masses; but it exists as a rock of mineral aggregate rather than as a specific mineral. The term bauxite embraces gibbsite (hydrargillite), $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ (65.4% Al_2O_3 = 34.8% Al); and boehmite (alpha monohydrate) and diaspore (beta monohydrate), $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ (85% Al_2O_3 = 45% Al). Bauxite rarely exhibits the distinct characteristics of its constituent minerals, but the formula $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ (73.9% Al_2O_3 = 39.2% Al) is usually assumed. Bauxite in appearance is rather a nondescript substance, but the following physical properties will aid in identifying it.

Hardness:	1 to 3
Specific gravity:	2.55
Color:	white, cream, yellow, brown, red, and gray.
Luster:	dull to earthy
Cleavage:	irregular
Transparency:	opaque
Tenacity:	crumbly

Bauxite often contains many impurities - silica as quartz and as silicates in clay, iron oxide, titania (which is always present), iron sulphide, magnesia, and iron and calcium carbonates. Bauxites are graded according to chemical analysis and are sold on that basis. However, since iron oxide imparts color to the material, bauxite may be roughly classified as follows: (1) red varieties, high in iron and low in silica; (2) white or gray varieties, low in iron and high in silica; and (3) cream, buff, or gray varieties, iron and silica contents about the same, either high or low.

Bauxite belongs to the group of loosely consolidated materials, called laterites, formed by surface weathering. Laterites and other residual deposits are usually derived from igneous or sedimentary rocks in tropical countries (at the time of deposition), and the term includes impure siliceous and ferruginous bauxite and siliceous and aluminous iron and manganese ores. Deposits are of many types and associations, but they may be grouped in four general classes:

1. Blanket deposits occurring at or near the surface.
2. Beds and lenslike deposits occurring with sediments and igneous rocks.
3. Pocket or irregular deposits enclosed in limestones or clay.
4. Detrital deposits from the other three classes.

Bauxite occurs commonly with or near clay, limestone, or certain igneous rocks such as syenites, feldspathic schists, and, rarely, basalts. However, the most striking occurrence is its association with old land surfaces. Deposits in the older rocks occur along unconformities

representing long time intervals, while deposits of more recent origin occur on peneplained surfaces that had remained undisturbed for a long time. Deposits of bauxite in Arkansas occur in beds up to 20 acres in areal extent but not over 10 feet thick. In Alabama and Georgia it occurs in pockets and irregular masses up to 50 feet long. The general age of United States deposits is Lower Eocene.

Bauxite is used in manufacturing alumina, chemicals, abrasives, alundum, cement, and refractories; and in oil refining for percolation, filtration, and decolorizing of oil and gasoline. Approximately two tons of bauxite will produce one ton of alumina, two tons of alumina will produce one ton of aluminum, or four tons of bauxite will produce one ton of aluminum metal.

Commercial deposits of bauxite are found in France, Hungary, British Guiana, Yugoslavia, Italy, Surinam (Dutch Guiana), United States, U.S.S.R., and Netherlands India. The principal deposits in the United States are located in Arkansas, Alabama, and Georgia. Arkansas in 1938 produced 95% of the total domestic bauxite production. Data on bauxite are given in the following table, 1938:

Domestic Bauxite Data.

Domestic Production	323,818 long tons
Imports	455,693 " "
Exports	90,341 " "
Apparent Consumption	689,170 " "

Domestic production of bauxite is 47% of the apparent domestic consumption, while the apparent domestic consumption of bauxite is 18% of the world's production. Of the imports, 386,756 long tons came from Surinam (Dutch Guiana), 60,044 came from British Guiana, 8,400 from Greece, and 493 from Netherlands India. New Orleans (for East St. Louis) received 61% of these imports, Mobile 28%, while the remainder went to Chicago, Philadelphia, and Boston.

Prices of bauxite in 1938 ranged from \$2 per ton for crude ore f.o.b. mines to \$40 per ton for activated or chemically treated bauxite. An average of \$5.25 was received for crushed-dried, while calcined bauxite brought \$12.38 per ton.

There are no commercial deposits of bauxite known in the western states; however, there are deposits of high-alumina clays, alunite, and leucite. Alunite is a basic potassium aluminum sulphate, $KAl_3(OH)_6(SO_4)_2$. The following table gives analyses of typical bauxite occurring in many countries and used in the United States during 1939:

	Alumina Al ₂ O ₃ %	Silica SiO ₂ %	Iron Oxide Fe ₂ O ₃ %	Combined Water %
British Guiana	59-61	2.5-4	1-2.5	30-32
France	55-59	2-5	20-25	
	60-70	8-16	4-12	12-14
United States	56-59	5-8	1-6	29-31
U. S. S. R.	35-54	10-20	15-20	10-20
Italy	55-65	2-9	10-25	12-14

The following table gives analyses of high-alumina clays of Oregon and alunite and leucite of Utah:

	Alumina Al_2O_3 %	Silica SiO_2 %	Iron Oxide Fe_2O_3 %	Combined Water %	Others
Oregon clay	15.6 38.4 41.3	79.5 49.7 42.2	0.7 0.6 2.9	3.2 11.2 13.4	
Utah alunite	36.1	1.8	.47	13.1	K_2O 10% SO_3 37%
Utah leucite	24.0	55.3	Tr.		K_2O 21%

In a general way, bauxites range in composition as follows: alumina, 35 to 70%; silica, 2 to 30%; iron (ferric) oxide, 1 to 25%; and loss on ignition (combined water), 12 to 40%.

Specifications for commercial bauxite vary according to the use for which the bauxite is intended. Bauxite used in the manufacturing of aluminum should have high alumina content (over 53%), and should not have more than 6% silica (preferably 4%), not more than 4% titanium dioxide, and not more than 10% ferric oxide. For use in manufacture of chemicals, ferric oxide and titanium dioxide should be less than 2.5% each and silica not over 15%. High-silica bauxites result in low recoveries and high acid consumption. Bauxites containing less than 5% silica, 5% ferric oxide and 4% titanium dioxide are preferred for chemicals.

The bauxite is mined both in quarries or in underground mines (of the room-and-pillar type). It is first crushed to about 3-inch size and is then washed in trommel washers or vibrating screens to remove the clay. If it is desired to ship the crude bauxite, it is dried in rotary kilns to about 3% free moisture content. The product is the commonly used "crushed, washed, and dried bauxite" for the manufacture of aluminum and alloys, chemicals, abrasives, and refractories.

The production of aluminum metal is accomplished in two steps: (1) the production of alumina, aluminum oxide from crude bauxite; and (2) the production of aluminum metal from alumina. The Bayer process for the preparation of alumina has largely supplanted all other processes. The chemical principle involved in this process is the formation of sodium aluminate by the treatment of bauxite with aqueous sodium hydroxide and the subsequent precipitation of aluminum hydroxide followed by the calcination of the aluminum hydroxide to alumina. The process consists essentially of mixing water with finely ground calcined bauxite (thoroughly heated to drive off free and combined water) with aqueous sodium hydroxide. The mixture is heated in pressure vessels for a digestion period of 2 to 8 hours, and about 90% of the alumina in bauxite is thus dissolved. The solution and undissolved portion, "red mud", are separated by filtration and aluminum hydroxide is precipitated from the solution during a 60-hour period. The precipitated aluminum hydroxide is filtered and is then calcined in rotary kilns to yield alumina

for production of metallic aluminum. Alumina is produced from bauxite in the United States at Mobile, Alabama, and East St. Louis, Illinois.

The production of metallic aluminum is based on the Hall-Heroult process developed in 1886-7. The principle involved is the electrolytic dissociation of alumina dissolved in a bath of liquid (fused) cryolite (sodium-aluminum fluoride) and calcium fluoride. Aluminum is produced without appreciable effect on the electrolyte. The aluminum reduction cell consists of a rectangular box of steel lined with a refractory material inside of which is a heavier lining of rammed carbon forming the cathode (negative pole). The lining is inclined toward a tap-hole through which the molten aluminum is drawn off. The anodes (positive pole) are large carbon electrodes suspended in the tank. Thirty or more tanks are electrically connected in series. Cryolite and bauxite in proper proportion are continuously added to the furnace, and the resistance of the bath to the electric current causes heat sufficient to melt the bath. The electric current serves both to keep the bath liquid by generation of heat and to cause electrolytic dissociation of the alumina. Electric power is direct current at 200 to 600 volts and 8,000 to 30,000 amperes. Carbon electrodes are made from petroleum coke or other high-grade type of coke which is ground, mixed with a binder of pitch or tar and oil, pressed into shape, and baked.

For every pound of aluminum metal produced there are required approximately 2 lbs. of alumina, 1 lb. of carbon electrodes, 0.1 lb. of cryolite bath, and 15 kw-hr. of electric current. The principal plants for producing aluminum were mentioned on page 2.

The molten aluminum drawn from the cell is marketed in the three grades mentioned on page 1 and contains in small amounts (less than 1.5% total) impurities such as iron, silicon, copper, alumina, carbides, sodium, nitrogen, and titanium. The chief difficulty in the metallurgy of aluminum is that the metal cannot be refined, so its purity depends upon the purity of the alumina and the bath. Many attempts have been made to refine further the metal, but few have been successful. Silica particularly is detrimental because part of the silica in bauxite is dissolved and unites with alumina in the digestion step; and although certain preventative measures are resorted to, the Bayer process is more efficient with a low-silica bauxite. The process is costly, so a crude ore of as high an alumina content as possible is required. A high-alumina clay not only contains silica and other detrimental impurities, but it is low in alumina. For these reasons it is not economical at this time to use high-alumina clay. Germany is reported to be making aluminum metal from low-grade clays, but the process is expensive and can be used only in an emergency such as now exists.

Various processes for the manufacture of aluminum have been tried and patented, but the Bayer and Hall-Heroult processes briefly described here have been the only commercially successful developments in the United States. However, several processes, both old and recent, merit consideration. The Cowles process patented in England in 1885 employed carbon reduction of alumina in the presence of a metal with which the reduced

aluminum alloyed. It therefore has possibilities in the production of certain alloys. Recent investigations by the United States Bureau of Mines have developed a process whereby both potassium sulfate and aluminum are recovered from domestic alunite ores. The process consists essentially of sintering alunite with boric acid and leaching with water to remove potash and excess boric acid. The alumina thus formed is leached with sulfuric acid, and aluminum is electrolytically precipitated from the acid solution. Other processes for the extraction of aluminum from clays have been tried: one resorts to chlorination of clays with chlorine gas for formation of volatile aluminum chloride, another smelts ores in an electric furnace with carbon to form volatile aluminum carbide, and still another makes in a blast furnace an aluminum-iron-silicon alloy.

REFERENCES

- United States Bureau of Mines
Minerals Yearbook, 1939
Koster, Knickerbocker, Fox and Perry: Recovery of Potassium Sulphate and Alumina from Alunite by Fusion with Boric Acid; R. I 3438; R. I 3322. 1939.
Tilley, Millan, Ralston: Acid Processes for the Extraction of Alumina; Bulletin 267. 1927.
Gandrud and De Vaney: Bauxite. Bulletin 312. 1929.
- Industrial Minerals and Rocks; Amer. Inst. Min. and Met. Engrs., 1937. (Excellent bibliography).
- Modern Uses of Nonferrous Metals; Amer. Inst. Min. and Met. Engrs., 1935.
- Lindgren: Mineral Deposits. McGraw-Hill, 1933.
- Anderson: The Metallurgy of Aluminum and Aluminum Alloys. 1925. (A comprehensive treatise).
- Richards: Aluminum: Its History, Occurrence, Properties, Metallurgy and Applications, Including Its Alloys. 1896 (Written by the pioneer worker in the field of aluminum metallurgy).