

BAUXITE:

Its composition, occurrence, origin, distribution, etc.

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## INTRODUCTION

The object of this paper is to present a general discussion about bauxite, its mineralogical characteristics, geological occurrence, origin, chemical aspects, etc., including also some data about its distribution, production, and uses.

Of course, the discussion is not exhaustive because the paper has been made chiefly based on bibliographical references, using only the publications found in the Main Library and at the Department of Geology Library of this University. On the subject of bauxite and the closely related subject of laterization many articles have been written and a selection of an appropriate bibliography is not easy to make; although, the references used gave an ample information.

No field work was made, but some personal experience in the search for bauxite in Costa Rica, and a recent visit to the bauxite mines in Arkansas have been useful in writing this paper.

Thanks are due to Dr. W. S. McCann, for whom I worked in Costa Rica at the close of the year 1943 and the beginning of 1944, and who invited me to visit the Arkansas mines.

## MINERALOGICAL AND CHEMICAL COMPOSITION

Commonly bauxite is regarded as an amorphous earthy mineral, its formula being  $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ , that is  $\text{Al}_2\text{O}_3$  73.9 per cent, and  $\text{H}_2\text{O}$  26.1 per cent. But it is rather a mixture of varying character "containing large amounts of a colloidal form of  $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . This substance has been called sporogelinite or diasporogelinite, cliachite and alunogel.(1).

L.W.E. Ford, DANA'S TEXTBOOK OF MINERALOGY, New York, John Willey and Sons Inc, 1932, p. 566.

In a more strict sense bauxite is not a specific mineral, but a rock being defined by its chemical and mineralogical composition. "It embraces gibbsite (hydrargillite or alpha trihydrate),  $Al_2O_3 \cdot 3H_2O$ ; dias-pore (beta monohydrate)  $Al_2O_3 \cdot H_2O$ ; boehmite (alpha monohydrate)  $Al_2O_3 \cdot H_2O$ , and mixtures in any proportions of any two of them. Bauxite of the Mesozoic and Tertiary in Europe is predominantly a mixture of gibbsite and boehmite, subordinately a mixture of boehmite and dias-pore, or gibbsite and dias-pore. The bauxite of North and South America, tropical Africa and Asia, consist largely of gibbsite."(2)

P. K. Morse (3), says that for practical purposes bauxite may be defined as an ore which is hydrated oxide of aluminum or a mixture of several hydrates, sufficiently pure to serve as a commercial ore of aluminum and its salts.

Gradations from bauxite to corundum ( $Al_2O_3$ ) exist as a result of metamorphic action.

Several impurities occur in bauxite, such as silica in the form of clay minerals (kaolinite, halloysite, etc.) or quartz, iron oxides (hematite, limonite, goethite), titania (leucosene or rutile), and in some particular cases iron carbonate (siderite), and iron sulphide (pyrite, marcasite), manganese compounds, etc. Of these, especially important in determining the value of the ore are the iron and silicon compounds.

Bauxite belongs to a group of materials called laterites, formed chiefly by surface weathering. Laterites are weathering products composed mostly of aluminum and iron sesquioxides, with some amount of silica, combination water, and other substances present. They have been

2. E. C. Harder, "Bauxite", INDUSTRIAL MINERALS AND ROCKS, New York, Am. Assoc. Min. and Met. Eng., 1937, pp 111.

3. P. K. Morse, THE BAUXITE DEPOSITS OF MISSISSIPPI, Mis. Geol. Survey Bull. 19, 1923, p. 12.

studied by pedologists as a soil group and by geologists as sources of concentration of minerals. Clarke (4) considers that laterite corresponds to the formula  $RO_3H_3$ , which is that of gibbsite. But the residual substance is a mixture of gibbsite, diaspore, and limonite. That is, laterite is identical with bauxite in type, and is merely an iron rich variety of the later. Between the aluminum ore bauxite, and the iron ore limonite, all sorts of mixtures may occur. For instance, in Cuba, a highly ferruginous laterite is found (5).

The relations of the chemical composition of gibbsite, bauxite, and laterite are seen in the following analyses:

Analyses of gibbsite, bauxite, and laterite.						
	A	B	C	D	E	F
Quartz	---	---	---	---	10.52	---
SiO <sub>2</sub>	2.78	.93	3.90	.37	.23	.90
Al <sub>2</sub> O <sub>3</sub>	62.80	67.88	54.80	43.83	35.38	26.27
Fe <sub>2</sub> O <sub>3</sub>	.44	4.09	13.75	26.61	34.27	56.01
MgO	.03	---	---	---	---	.20
CaO	.20	.36	.35	.86	.40	.64
TiO <sub>2</sub>	.04	1.04	.38	4.45	.10	1.59
H <sub>2</sub> O	33.74	26.47	26.82	23.88	19.00	14.39

A; gibbsite, B: bauxite, C,D,E,F: laterite. (6)

C.S. Fox (7) in 1923 stated that bauxite implies chemical purity and laterite carries a genetic significance, and that not all bauxites are lateritic in origin.

Fermor (8) restricted the term laterite to soils containing 90 to 100 per cent of the oxides of Fe, Al, Ti, and Mn, some of them being more or less hydrated.

4. F. W. Clarke, THE DATA OF GEOCHEMISTRY, U.S.G.S. Bull 770, 1924, p.498
5. H.H. Bennett and R.V. Allison, THE SOILS OF CUBA, Washington, Tropical Plant Research Foundation, 1928, p 350.
6. F.W. Clarke, Op. cit. p. 498.
7. C.S. Fox, "Bauxite", ENCYCLOPAEDIA BRITANNICA, 14th edition, 1929.
8. J.S. Joffe, PEDOLOGY, New Brunswick, Rutgers Univ. Press, 1936, p.366.

Physical properties.

In nature bauxite rarely exhibits the characteristics of its constituent minerals, perhaps because much of the alumina is present in colloidal forms, and for the variable combined water content.

The hardness is variable from medium soft to hard. The specific gravity also varies. The less water bauxite has, the greater are its hardness and specific gravity. In some samples, although the hardness and specific gravity are variable, the composition of selected pisolites is essentially the same.

The structure also varies in different localities. It may be fine-grained cellular, porous or compact, and in many places it is characteristically oolitic or pisolitic.

The color ranges from light gray, cream, yellow, brown, to dark red.

#### GEOLOGIC OCCURRENCE OF BAUXITE

Bauxite deposits have been found in different geologic associations which have been grouped by Harder (9) in four main groups:

1. Blanket deposits occurring at or near the surface in sheets or lenses.

These are found in tropical and subtropical climates, on base-levelled surfaces, and they generally have the upper part indurated by the cementation of iron oxide and siliceous material. They range in thickness from 1 to 75 feet, and horizontally they may be extended for several miles.

2. Beds and lenslike deposits occurring at definite stratigraphic horizons interlayered with sediments or between sediments and igneous rocks.

These are surface deposits of past geologic ages that have been submerged after their formation. If the rocks have been subjected to later deformation, the bauxite have suffered changes, i.e. in France,

9. E.C. Harder, Op. cit. pp. 112-115.

Roumania, and Greece, gibbsite has been partially changed to diaspore.

3. Pocket deposits of irregular masses enclosed within limestones and clays. They represent irregularities in the surface upon which bauxite was formed.

4. Detrital deposits. They have been formed by the transportation and redeposition of the material from deposits of the other types.

C.S. Fox (10) makes the distinction between bauxite, laterite, and terra-rossa, discussing the opinion of other authors and claiming certain differences in origin as well as different uses of the terms. He considers two modes of origin and occurrence of bauxite as follows:

a) Terra-rossa type, where the bauxite represents an exceedingly small insoluble fraction of what was a great mass of soluble limestone or dolomite; and which was 1) primary deposited in sheets or irregular cavities, when first liberated, and which may be subsequently eroded; and 2) redeposited with other sediments; and

b) The lateritic type, where the bauxite remains in the locality of the original aluminous rocks, of which it represents the greater part (by volume), and is consequently 1) also a primary or in situ occurrence, which is also capable of being eroded; and 2) redeposited as detrital or secondary material.

The laterite type includes those of India, Gold Coast, British Guiana, Arkansas, etc. The terra-rossa type includes the bauxite of France and the Mediterranean seaboard.

Analyses (11):

	Lateritic bauxite:	Terra-rossa bauxite:
SiO <sub>2</sub>	.25 to 10.00%	.25 to 15.00
TiO <sub>2</sub>	1.00 - 10.00	1.25 - 4.00
Al <sub>2</sub> O <sub>3</sub>	50.00 - 65.00	56.00 - 75.00
Fe <sub>2</sub> O <sub>3</sub>	.25 - 15.00	.50 - 25.00
H <sub>2</sub> O. Comb.	20.00 - 33.00	8.00 - 15.00

The main chemical difference is the content of combined water.

In the discussion about the origin of bauxite some of the geologic relations will be better understood.

10. C.S. Fox, BAUXITE AND ALUMINOUS LATERITE, London, The Technical Press Ltd., 1932, p. 16.

11. C.S. Fox, "Bauxite", ENC. BRIT.

Bauxite occurs in association with rocks of different geological age. The following is a compilation made by Harder (12):

General Age Relations of the Principal Bauxite Deposits:

Pleistocene and Recent. Tropical lateritic bauxite of the Guianas, Brazil, French West Africa, Gold Coast, Nyasaland, India, Dutch East Indies, Australis.

Cenozoic

Pliocene

Miocene

Oligocene

Eocene

Lower

German bauxite (Vogelsberg Mountains).

Irish bauxite (County Antrim).

United States bauxite--underlain by Lower Eocene or Lower Cretaceous.

Dalmatian bauxite-- underlain by lower Eocene and Upper Cretaceous.

Montenegrin bauxite-- underlain by Upper Cretaceous.

Istrian bauxite-- underlain by Upper Cretaceous.

Spanish bauxite-- underlain by Eocene and Rhaetic.

Kashmir deposits-- underlain by Jurassic.

Hungarian bauxite-- underlain by Rhaetic.

Mesozoic

Cretaceous

Upper

Danian

Senonian

Greek bauxite-- underlain by Jurassic.

French bauxite (Herault)- underlain by Jurassic.

Middle

Turonian

Senonian

Albian

Italian bauxite (Central Apennines).

Montenegrin bauxite (Kotor and Niksic)- underlain by Lower Cretaceous.

French bauxite (Var)- underlain by Urgonian, Neocomian and locally Jurassic.

Lower

Aptian

Urgonian

Neocomian

French bauxite (Ariege)- underlain by Jurassic.

Rumanian Bauxite (Bihar)- underlain by Malm.

Jurassic

Malm

Dogger

Lias

Triassic

Rhaetic

Keuper

Lower

Croatian bauxite- underlain by Middle Triassic.

Chinese diasporite (Poshan)- underlain by "Permian-Carboniferous".

Paleozoic

Upper Carboniferous

Lower Carboniferous

Devonian

Missouri diasporite- underlain by U. Carboniferous.

Russian bauxite (Tikhvin)-underlain by Devonian.

Russian bauxite (Ural)- in Middle and L. Devonian.

Some of these bauxite deposits are discussed later with more detail.

ORIGIN OF BAUXITE  
Concentration of aluminum by weathering.

The origin of bauxite deposits have been explained in several ways, based on the geological relations of them. They may be grouped in 1) chemical sedimentation, 2) weathering, and 3) detrital deposition.

1) Chemical sedimentation. It requires the action of solvents because this method of formation is based in the solution and redeposition of the aluminous materials. Various acids and alkalis have been taken into consideration. For instance, T. H. Holland (13) suggests that ~~rather~~ the activity of bacilli or other micro-organisms over the organic matter in the soil may be a source of nitric acid. J. Walther and S. Passarge (13), suggest that the nitric acid may be formed during tropical thunderstorms. Sulphuric acid resulting from the alteration of sulfides may be another solvent.

Hayes (14) interprets the pisolitic structure of the Arkansas bauxite as a proof in favor of the chemical precipitation, suggesting that the material forming the bauxite deposits was in solution or in suspension in a gelatinous form. He considers that the main solvent agent has been water coming from hot springs.

Although the action of chemical agents is needed for the formation of bauxite, the chemical precipitation theory has been disfavored in more recent studies.

2) Laterization. The formation of bauxite by means of the weathering in situ of the protores has been explained by the process called laterization.

Laterization is essentially the progressive hydrolysis of rock minerals (15), which takes place under tropical and subtropical con-

13. F. W. Clarke, Op. cit. p.496.

14. C. W. Hayes, THE ARKANSAS BAUXITE DEPOSITS, U.S.G.S. 21 st Annual Report., 1900, p.461.

15. H. G. Byers, "Formation of Soil", SOILS AND MEN, U.S.D.A. 1938, p973.

ditions, where the rainfall is heavy and the temperature is high. This results in an intensive weathering which, in the aluminum bearing rocks produces the solution and removal of the constituents other than aluminum. In recent years this process of formation of bauxite and laterite has been clearly recognized.

Just as it happens during the formation of kaolin, the process of laterization may be complete or partial, and the typical products appear only when the alteration of the parent rock has been completed.

It may appear that only certain rocks are favorable for the formation of laterite and bauxite, but in general it may be said that any rock, under favorable circumstances, may be laterized. Of course, the rocks of a high aluminum content and a low silica percentage such as nepheline-syenite, phonolite, basalt, shale, etc., are especially favorable for the laterization.

The following is a list of the parent rocks of several bauxite deposits formed in situ:

<u>Rock</u>	<u>Place</u>
Diabase	Surinam (16)
Shale	Netherlands Indies (17)
Shale	Gold Coast (18)
Nepheline-syenite	Arkansas (19)
Phyllites	Gold Coast (18)
Diabase	British Guiana (18)
Basalt	Ireland (18)
Basalt	Germany (20)
Basalt	India (20)

Emmons (21) regards as good protorees of bauxite deposits the minerals sericite, feldspars, and nepheline, due to their high aluminum content.

16. F. W. Clarke, Op. cit. p. 498.
17. R. W. Van Bemmelen, ORIGIN AND MINING OF BAUXITE IN NETHERLANDS INDIES, Econ. Geol. vol. 36 (1941) p. 632.
18. C. S. Fox, "Bauxite", ENC. BRIT. 14th edition.
19. M. N. Bramelette, GEOLOGY OF THE ARKANSAS BAUXITE REGION, Ark. Geol. Sur. Circular 8, 1936, p. 25.
20. P.K. Morse, Op. cit., p. 18.
21. W. H. Emmons, PRINCIPLES OF ECONOMIC GEOLOGY, New York, Mc Grow-Hill Book Company, 1940, p. 459.

The process of laterization has been explained in various ways, and there is still some disagreement among several authors. Clarke (22) points that "the process by which aluminous silicates are transformed into hydroxides has not been determined with certainty". Joffe (23), after a consideration of the different view points of several authors, considers that for the process of laterization it is necessary that the nuclei of kaolin, mica, hornblende, or any other aluminous-silicates complex decompose, the silica be removed and the sesquioxides be left behind. A complete hydrolysis of the silicates takes place. It is possible the existence of an alkaline hydrolysis as a result of the organic matter decay. The silica will go into solution more readily than will the sesquioxides, resulting in an accumulation of the latter in the surface and a simultaneous loss of the former.

According to Van Bemmelen (24), the first stage of leaching is the solution of alkalis due to the  $\text{CO}_2$  dissolved in the ground water, which takes place under certain pH conditions. Then the process consists of the alternating solution and precipitation of the aluminum and iron hydroxides. The important fact is that the solution of silica occurs easily in carbonated alkaline waters.

Several ratios between the chemical components have been studied to see if they give information about the amount of incombined alumina in the ore. Among them, it is valuable to mention the "Ki of Harrazowitz" or  $\text{SiO}_2 - \text{Al}_2\text{O}_3$  ratio (25). "A ki value (molar) below that of kaolinite (2.0) may be said to indicate the presence of free alumina, and can therefore be considered as a safe index of the presence of incombined alumina". There are some exceptions.

22. F. W. Clarke, Op. cit., p. 500.

23. J. S. Joffe, Op. cit., p. 373-374.

24. R. W. Van Bemmelen, Op. cit., p. 631.

25. J. S. Joffe, Op. cit., p. 381.

Data on the pH under which laterization occurs have been widely considered but the information is meager and the opinions on the subject are conflicting.

It has been considered that especial conditions are necessary for the process of laterization. Fox (26) summarizes them as follows:

- 1) A tropical climate subject to alternations of dry and wet seasons of monsoons. ( There is some disagreement about this point).
- 2) A level, or very gently sloping, elevated land surface which is not subject to appreciable mechanical erosion (abrasion by rain and wind).
- 3) The chemical and mineralogical composition of the exposed rocks to be suitable for a supply of lateritic constituents -alumina and ferric oxide-. (This point has already been discussed in this paper).
- 4) The texture of the rock to be (or rapidly become during weathering) sufficiently porous for the entry of percolating water, so that the conditions for chemical action will be at the maximum.
- 5) The infiltrating water to remain in the interstices of the rock for long periods annually; i.e. during the wet monsoon, but eventually to drain away in the dry period, thus giving maximum place to chemical erosion.
- 6) The infiltrating water to contain either an acid or an alkaline substance with which to react on the rock components as well as to constitute an electrolyte and allow electro-kinetic phenomena to operate.
- 7) These annual processes to be in operations continuously for at least a geological epoch or roughly a million years.

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### 3) Detritial deposition.

This type of formation of bauxite and laterite deposits is due to the action of erosion over deposits formed in situ. The materials are transported and sedimented forming deposits of secondary origin.

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Association of bauxite and lignite in relation to the formation of bauxite.

In 1932, C. H. Behre (27), based on his observations on the bauxite deposits of Arkansas, and having in consideration the observations of Stejskal made on the Karlsbad china clay which has been formed by the alteration of granite beneath coal swamps, and on the observations of Freise made on the bauxite deposits of Minas Geraes in Brazil, stated that there must be some relation between the formation of bauxite and the lignite beds which overlie those deposits. In Arkansas, the bauxite deposits and the Tertiary lignite beds are unconformable, but it seems that the sulphate waters, which result from the oxidation of the iron sulphides of the lignite, have had some important action over the bauxite.

Referring to Behre's statement, E. Just (28) says that his observations on the Tikhvin bauxite deposits in the U.S.S.R. are partly corroboratory and partly contradictory. There the bauxite occurs along the Devonian -Carboniferous unconformity. It grades into the Devonian clay beneath, and at the same time it is partially associated with black clay lenses.

A further consideration has been made by Harder (29) who says that the association of bauxite with lignite is not only confined to Arkansas, Brazil, and Russia, but it occurs also in Georgia, Alabama, southern France, the Istria peninsula, etc. Carbonaceous deposits commonly overlie the bauxite and lead to "the supposition that the

27. C. H. Behre Jr, "Origin of Bauxite", ECON. GEOL. vol 27, No 7 (Nov. 1932).

28. E. Just, "Origin of Bauxite Deposits", ECON. GEOL. vol 28, No 5 (Aug. 1933), pp. 506-507.

29. E. C. Harder, "Origin of Bauxite Deposits", ECON. GEOL. vol 28, No 4 ( June 1933), pp. 395-398.

conditions which resulted in laterization and bauxitization, whatever they may have been, were followed in many places by swamp conditions which later gave place to the total submergence." Actually in Surinam the bauxite is ~~mined~~ in several places under swamps.

This does not imply any direct bearing of the carbonaceous sediments on the origin of bauxite and laterite. Apparently these phenomena were superimposed upon the original laterization.

Bauxite deposits under those conditions present certain well-recognized characteristics not possessed by bauxite deposits that have not been associated with lignite. 1) They have iron in ferrous form, either as carbonate, sulphate or sulphide. 2) Sulphur is present as iron sulphate, iron sulphide, or aluminum sulphate. The later is present in the central Urals where alunite occurs in the upper portions of the bauxite deposits.

Chemical and mineralogical changes during the formation of bauxite.

This topic has been already discussed, but here some more detailed information is given.

As it has been explained before, the essential chemical constituents of bauxite are:

Aluminum hydroxide as gibbsite or in colloidal forms.

Ferric hydroxide which is the commonest impurity, also colloidal.

Ferric oxide. As hematite.

Silica. As quartz or as hydrous aluminum silicates.

Titanium. As dioxide or hydroxide.

Manganese. As psilomelane and pyrolusite. Not very common.

Other minor impurities.

In some instances the chemical analysis of the original rock, of the intermediate weathering materials, and of the bauxite, of samples taken along a section in residual deposits, show some of the chemical changes that have operated during the laterization process. Among them, the important ones are the loss of silica and the concentration of aluminum hydroxide. This may be seen in the following analyses of

Arkansas bauxite, taken from Bramelette (30):

	Nepheline-syenite	Intermediate samples		Bauxite
SiO <sub>2</sub>	58.00	52.64	39.80	10.64
Al <sub>2</sub> O <sub>3</sub>	27.10	29.56	37.74	57.48
Fe <sub>2</sub> O <sub>3</sub>	1.86	1.06	1.60	2.56
FeO	3.30	.80	.10	.20
MgO	.25	---	---	---
CaO	1.62	---	---	---
Na <sub>2</sub> O	6.70	4.46	---	---
K <sub>2</sub> O	.25	.44	---	---
Ti <sub>2</sub> O	.40	1.20	3.30	1.20
H <sub>2</sub> O	1.22	9.00	17.00	28.36

If these analyses are taken, and the molecular proportions are found from them, the application of the diagram of Brögger (31) is possible, and the chemical changes are shown diagrammatically (fig. 1).

Table of molecular proportions:

	Nepheline-syenite	Intermediate samples		Bauxite
SiO <sub>2</sub>	966	877	663	177
Al <sub>2</sub> O <sub>3</sub>	265	289	374	572
Fe <sub>2</sub> O <sub>3</sub>	11	6	10	18
FeO	45	11	1	3
MgO	6	-	-	-
CaO	7	-	-	-
Na <sub>2</sub> O	108	72	-	-
K <sub>2</sub> O	2	4	8	-

No further discussion of the chemical changes are made here, although there are some interesting ones such as suffered by the water and titania. Chemical analyses of bauxites from different places are given in following pages.

30. M. N. Bramelette, Op. cit. p. 13.

31. F. Grout, KEMPS HANDBOOK OF ROCKS, New York, D. Van Nostrand Company, 1942, p. 43.

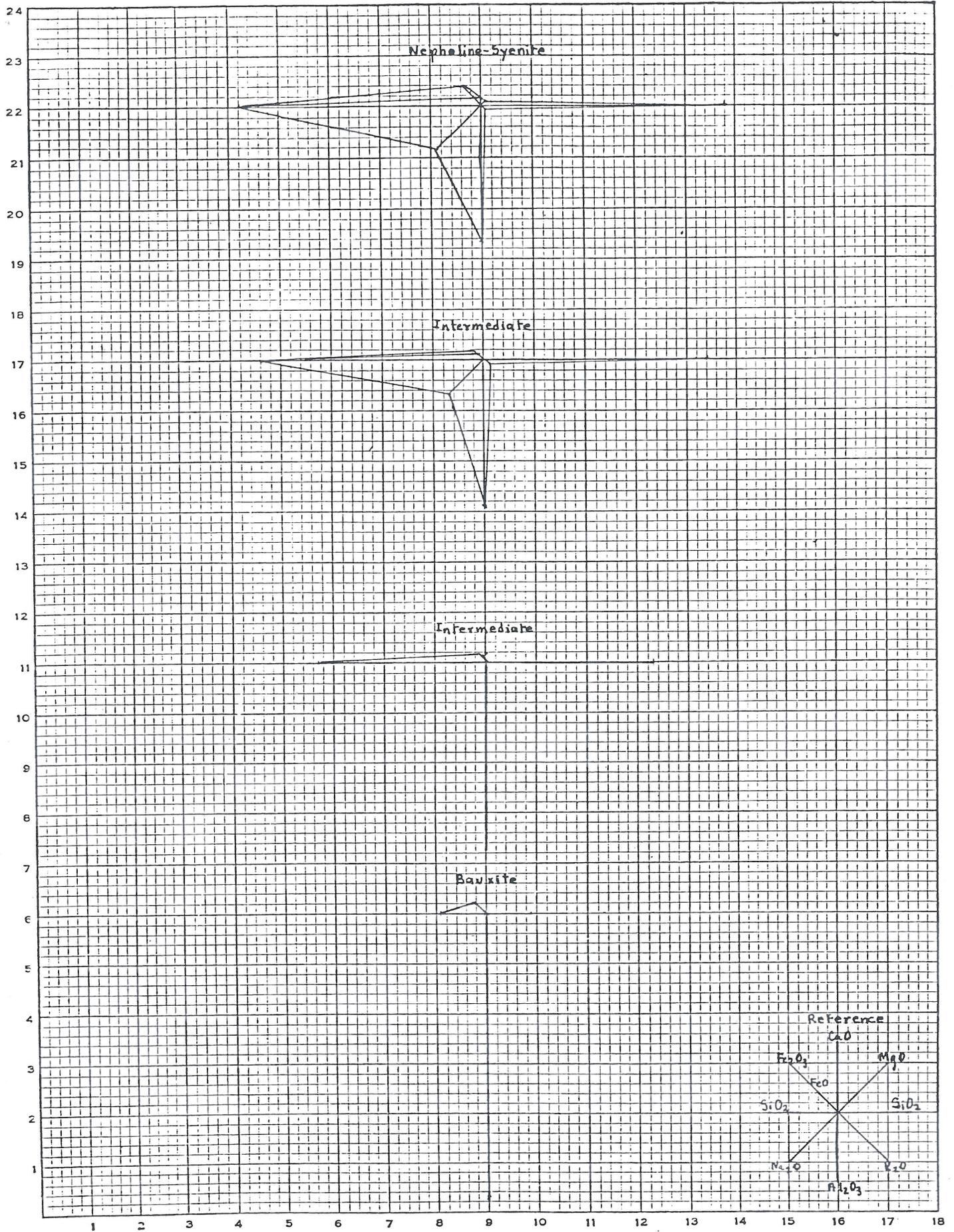


Figure 1.

In reference to the mineralogical changes, Bramlette suggests that the amorphous material has been formed through the solution and redeposition of the crystalline gibbsite. Then he states that the order of alteration of minerals as studied in Arkansas is as follows:

"1) Brown hornblende changes to green hornblende; 2) nepheline changes to analcite, and the feldspars become distinctly cloudy with clay minerals; 3) analcite and apatite disappear through leaching; 4) pyroxenes, amphiboles, and perhaps fluorite disappear; 5) biotite becomes bleached and then disappears, titanite alters to the hydrous mineral xanthitane, and the feldspars are completely altered to clay minerals; 6) magnetite disappears, ilmenite is partially altered to leucoxene, and the clay minerals alter to gibbsite." (32).

Fig. 2 shows diagrammatically the mineral changes.

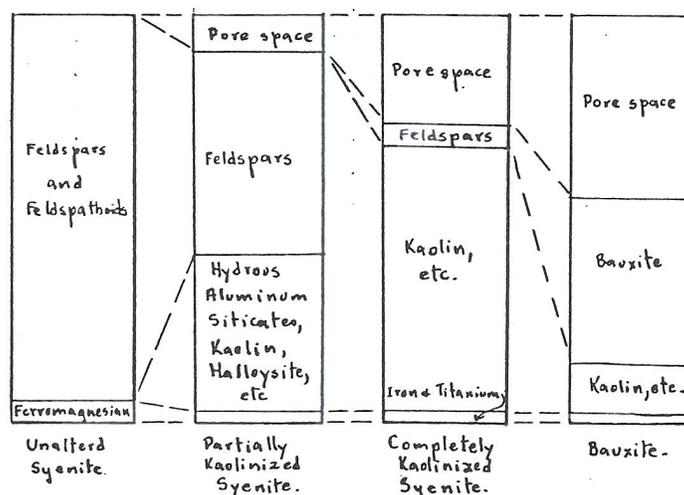


Fig. 2. Diagram showing the in terms of volume the mineral gradation from syenite to bauxite, using samples from a single locality in Arkansas (After Head) (33).

32. M.N. Bramlette, Op. cit. p. 16.

33. W.H. Emmons, Op. cit. p. 459.

## BAUXITE DEPOSITS IN DIFFERENT COUNTRIES

Bauxite and laterite deposits have been found in all the continents. Europe has been the chief producer for many years, and most of the ore that has been mined has come from the famous deposits of France. In North America the principal deposits are in Arkansas, and in South America in Surinam and the British Guiana.

## United States.

Arkansas. (34 - 35). Arkansas produces 90 per cent of all the bauxite produced in the United States. The deposits are found in Saline and Pulaski Counties. They are associated with nepheline-syenite chiefly, but some low grade bauxitic clays occur within Eocene sediments. The bauxite has been regarded as formed through alteration of the nepheline-syenite.

The geologic events of this area, related with the formation of the bauxite, were: 1) intrusion of the nepheline-syenite into folded Paleozoic rocks, before early Eocene (Midway); 2) before Midway time the syenite was exposed by erosion; 3) The Midway rocks were deposited while islands of syenite were altered into kaolin and bauxite; 4) the weathered surface was then buried under the Wilcox continental deposits; and 5) Erosion exposed some of the bauxite as it is found today.

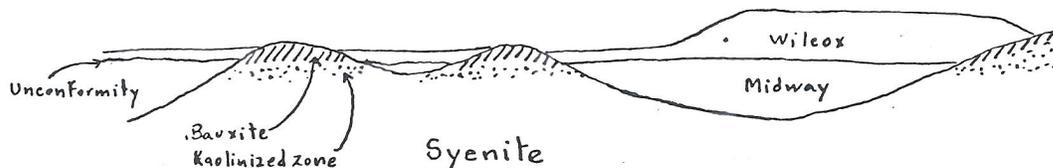


Fig. 3. Sketch of the bauxite deposits in Arkansas showing the geological relations (After Bramelette).

34. C. W. Hayes, Op. cit. pp. 435-472.

35. M. N. Bramelette, Op. cit. pp. 7-10.

Analyses of these deposits were given before in page 13.

Georgia. The bauxite is found in Wilkinson County, in the contact between the Tuscaloosa (Lower Cretaceous), and Claiborne (Eocene) formations, which consist mainly of clay and sands.

Other Georgia deposits are found as the residual alteration products of the Knox dolomite (Lower Silurian). (36).

Tennessee.

Bauxite occurs as residual deposits in the Watanga shales (Cambrian). They are of the same character of those found in Georgia and Alabama.

Analysis of bauxite from Missionary Ridge, Tenn. (37)

Insoluble	12.13
H <sub>2</sub> O	28.97
Al <sub>2</sub> O <sub>3</sub>	57.56
Fe <sub>2</sub> O <sub>3</sub>	1.34

Alabama.

Jones (38) classified the Alabama deposits as follows:

- 1) Cambro-Ordovician contact. In Cherokee County
- 2) Midway-Manfalia contact. In Harbour and Henry Counties.
- 3) Mississippian- Tuscaloosa contact. In Colbert County.

The first group is the more important. The ore bodies are mainly associated with limestones occupying erosional channels, and all the deposits occur at or near unconformable contacts, that is, they were formed during intervals of long duration.

Mississippi (39-40).

The deposits occur in erosion channels in Mississippian limestone that have been partially filled with Tuscaloosa gravel.

36. J.F. Kemp, THE ORE DEPOSITS OF THE UNITED STATES AND CANADA, New York. Mc Grow-Hill Book Company, 1906, p. 405.
37. H. Ries, ECONOMIC GEOLOGY, John Wiley and Sons, 1937, p.638.
38. W. B Jones, THE BAUXITE DEPOSITS OF ALABAMA, Geol. Surv. of Ala. Circular 2, 1929. p.7
39. E. F. Burchard, BAUXITE IN NORTHEASTERN MISSISSIPPI, U.S.G.S. Bull 750, pp. 101-146.
40. P. K. Morse. Op. cit.

## South America.

Laterite in South America occurs chiefly along the coastal region from the Orinoco to the Amazon. Its age is not definitely known but it is thought to be not older than early Tertiary.

## Brazil.

There are several deposits without economic ~~value~~ value, and also some valuable ones, together with lateritic iron deposits. The latter are found near Minas Geraes.

## British Guiana.

The lateritic bauxite of British Guiana is the residual weathering product of diabase and other basic rocks. The high grade deposits are located near the Demerara River, and some of them are intimately associated with kaolin.

## Range in composition of the ore (41):

	Maximum	Minimum
Al <sub>2</sub> O <sub>3</sub>	61.08	57.30
SiO <sub>2</sub>	4.58	1.07
Fe <sub>2</sub> O <sub>3</sub>	3.35	1.30
TiO <sub>2</sub>	4.84	2.66
H <sub>2</sub> O. Comb.	31.62	27.86
Moisture	3.88	.54

The deposits of British Guiana are considered among the best in the world not only in quality but in quantity.

## Dutch Guiana.

These deposits are also extensive and of high grade ore. The mode of occurrence is similar to the British Guiana deposits. Many of them are found under swamps in the coastal plains.

In French Guiana and Venezuela, deposits of lateritic bauxite have been found also.

## Central America and Antilles.

Lateritic deposits have been found but of little if any economic value. In Cuba the laterites have a high iron content, and in Haiti

they have a good alumina concentration as to be used as ores.

In Costa Rica lateritic clays were found as weathering products of volcanic tuffs, but not in commercial quantity. They have, as all the samples taken in Central America and the Antilles, a high iron percentage.

#### Europe.

Bauxite in Europe occurs in various countries: France, Hungary, Italy, Roumania, Yugoslavia, Greece, Germany, Ireland, etc. The following references are in relation only to the main localities.

#### France.

The French bauxite has been extensively worked since 1872. The chief deposits are in the Department of Herault and Var, in association with Cretaceous rocks, and some authors believe that they were formed by the action of thermal waters..

The bauxite deposits have been under the action of dynamic agents, suffering structural changes together with the other rocks.

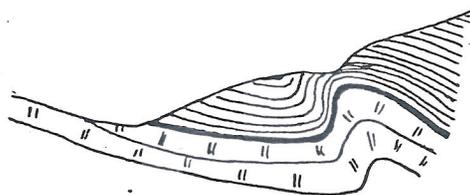


Fig. 4. Sections of bauxite as it occurs in Var, France. (After C. Fox).

Analysis of a French bauxite near Les Baux:

SiO <sub>2</sub>	3.0%	
Al <sub>2</sub> O <sub>3</sub>	60.0	
Fe <sub>2</sub> O <sub>3</sub>	25.0	
H <sub>2</sub> O	12.0	(42).

#### Hungary.

The bauxite deposits of Hungary together with the French ones are the most important in Europe. They are of Lower Cretaceous age and are found between a Triassic dolomite and Tertiary strata. The strata

are faulted and the bauxite occurs mainly in the depressions between the ridges formed by faulting (43), as it may be seen in fig. 5.

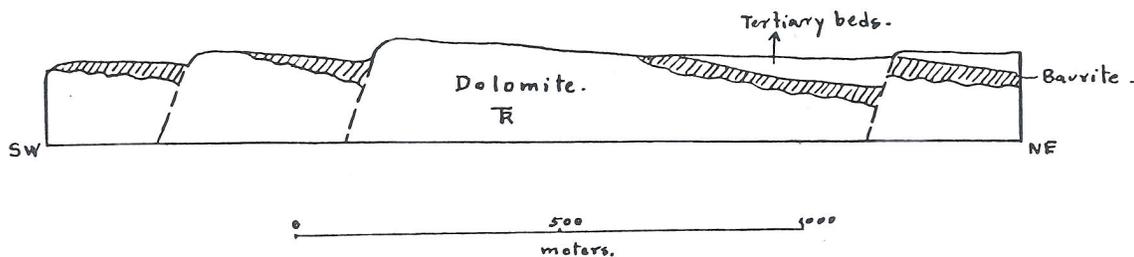


Fig. 5. Sketch section near Gant, Hungary. (After Singewald).

The analyses range between:

$Al_2O_3$	50 to 60%
$Fe_2O_3$	15 to 30
$SiO_2$	2 to 4

#### Roumania.

Bauxite occurs near the Bihar Mountains associated with Upper Jurassic limestone, forming extensive deposits.

Its composition is:

$SiO_2$	12.00
$Al_2O_3$	69.00
$Fe_2O_3$	3.00
$H_2O$	15.00

In many other European localities bauxite has been found; among them there are of interest from the geological point of view those found in Ireland and Germany which are the result of weathering over basaltic lavas.

#### Asia.

The most important locality in Asia where bauxite is found is India. It occurs in several places as a residual product of flat-lying basaltic lavas. Many of the deposits were formed over the Deccan lavas which

43. Q. D. Singewald, "Bauxite Deposits at Gant, Hungary", ECON.GEOL. vol. 33, No 7 (Nov. 1938), pp 732.

are Upper Cretaceous in age.

The relations between the basalt and the bauxite have been very well established as it is shown in fig. 6.

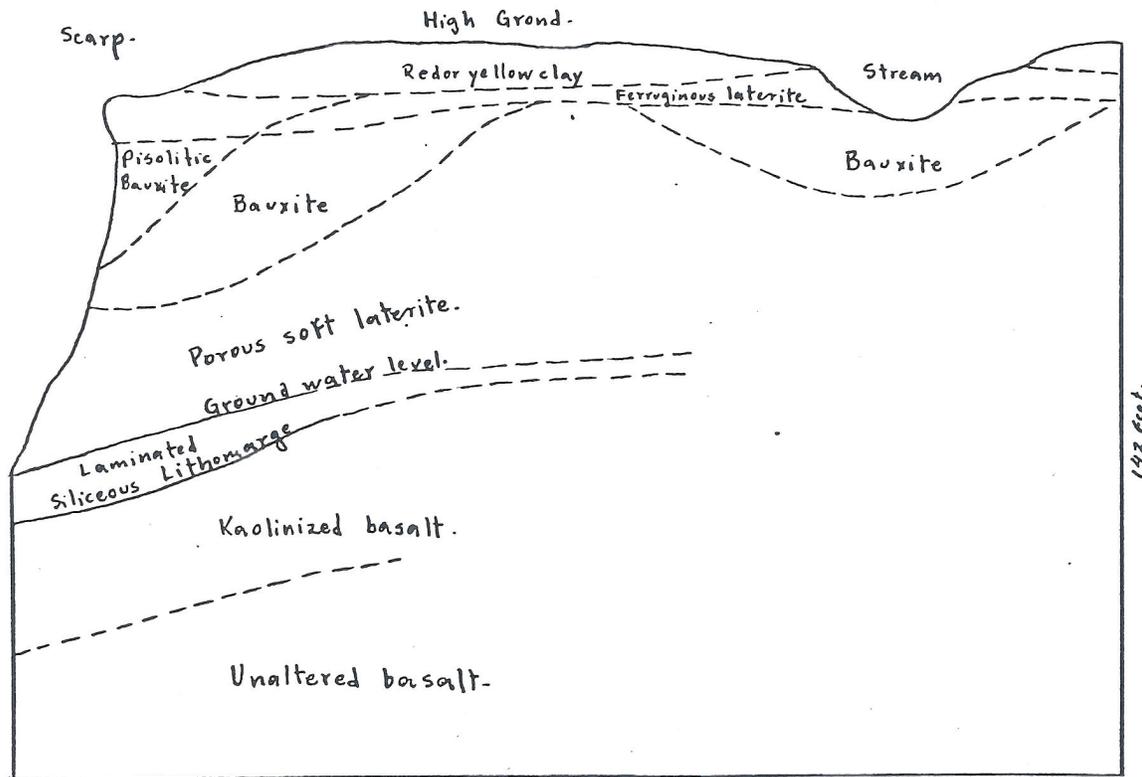


Fig. 6. Diagrammatic section of part of a typical laterite plateau with bauxite. (After Fox).

The following is an analysis of a pisolitic bauxite from India:

SiO <sub>2</sub>	.66
TiO <sub>2</sub>	8.90
Al <sub>2</sub> O <sub>3</sub>	58.40
Fe <sub>2</sub> O <sub>3</sub>	1.31
H <sub>2</sub> O	31.54

Netherlands Indies (44).

Those are the most important deposits of the Far East. The principal ones occur in the island of Bintam. The ores have been referred as aluminous laterites having an average composition as follows:

44. R. W. Van Bemmelen, Op. cit. pp. 630-640.

Al <sub>2</sub> O <sub>3</sub>	53%
Fe <sub>2</sub> O <sub>3</sub>	13.5
SiO <sub>2</sub>	2.5
TiO <sub>2</sub>	1.2

They occur in the top part of granitic rocks, weathered clay-shales, and in contact metamorphic hornfelsic shales.

#### Africa.

Laterite occurs in various places in Africa, particularly in the Atlantic seaboard in the hinterlands of the Gulf of Guinea.

Gold Coast.

This is the most important locality in Africa. The bauxite occurs on the Kwahu plateau as a weathering product of shales, and near Mount Supirri as the laterization product of steeply inclined phyllites and mica-schists.

#### Analysis:

Al <sub>2</sub> O <sub>3</sub>	60.55
Fe <sub>2</sub> O <sub>3</sub>	9.75
TiO <sub>2</sub>	2.21
SiO <sub>2</sub>	1.42
H <sub>2</sub> O	25.59 ((45))

#### Australia.

The laterites found in Australia are both highly ferruginous or highly aluminous varieties. In Western Australia they are associated with granite, diorite, amphibolite, chlorite-schists, etc.

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 The purpose of these references about laterite and bauxite deposits in different places of the world is chiefly to illustrate and give examples of several of the statements that were made at the beginning of the paper. The analyses were given with the purpose of showing how some of the constituents, chiefly water and iron, vary widely from one region to another.

## USES OF BAUXITE

Bauxite has several uses such as manufacture of metallic aluminum, chemicals, abrasives, refractories, cement, etc.

**Metallic aluminum.** The largest amount of bauxite is used for extracting aluminum, being this its principal use.

**Chemicals.** Next in use are the chemicals. The principal ones made from bauxite are: aluminum sulphate (using ore with no more than 2 per cent of  $\text{Fe}_2\text{O}_3$ ), aluminum chloride, aluminum hydrate, sodium aluminate, etc.

**Abrasives.** These are also important products made from certain qualities of bauxite.

**Cement and refractories** made from bauxite are more expensive than those made from other materials, but they are appropriate for certain uses.

## TECHNOLOGY OF ALUMINUM.

This is a broad subject beyond the limits of this paper; thus, only a short reference is made here.

There are several processes to extract the aluminum from bauxite. The earlier ones were based on the reduction of aluminum chloride using sodium amalgam as reducing agent. This method was first used by Henri Saint Claire-Deville in France, as an improvement of the Oersted-Wöhler method which used potassium amalgam.

One of the most outstanding methods, used during most of the years of the aluminum industry, is the Hall process which is based on the fact that alumina is dissolved by molten cryolite ( $\text{Al F}_3 \cdot 3\text{Na F}$ ), at about  $1000^\circ \text{C}$ , and then it can be reduced electrochemically (46).

Since 1941 several methods have been used, trying to obtain aluminum from low grade bauxites and clays. Among the most important advancements in the technology in the aluminum industry is the combination

46. A. Von Zeerleder, THE TECHNOLOGY OF ALUMINUM AND ITS LIGHT ALLOYS, New York, 1936, Gustav Fock, p.5.

of the so called Bayer and lime-soda-sinter processes which is in use at the Government's Hurricane Creek Alumina Plant near Bauxite, Arkansas. This permits the use of low grade bauxite having 13-14 per cent of silica.

#### PRODUCTION

In 1941 the production of aluminum in the United States was 618,134,000 pounds and the consumption was 605,577,231 pounds. "However, 1941 was only the beginning of a new era for aluminum as the Nation prepared for its greatest war, which could not be won unless vast quantities of the light, strong metal were available." (47).

Since then the production and the import of bauxite from other countries, chiefly from Surinam, has supplied the actual needs for the manufacture of warfare implements.

The production in different countries is not discussed here, but the following table gives the data from 1937 to 1941 (48).

World Production Of Bauxite, 1937-41. in Metric Tons:					
	1937	1938	1939	1940	1941
Australia					
New South Wales	6,793	442	820		
Victoria	1,097	1,341	18,279	1,000	1,000
Brazil (exports)	8,770	12,928		82	14,365
Czechoslovakia	846		800,000		
France	688,200	682,440	20,000	700,000	700,000
Germany	18,212	19,703	186,906	20,000	25,000
Greece	137,412	179,886		50,000	50,000
Guiana					
British	305,533	382,409	483,653	700,000	1,089,333
Surinam	392,447	377,213	511,619	615,434	1,198,900
Hungary	532,657	540,718	485,000	647,000	1,000,000
India	15,393	15,005	9,121	15,000	25,000
Indochina	7,000	160	330	118	1,000
Italy	386,498	360,837	483,965	530,000	600,000
Netherlands Indies	198,970	245,354	230,668	247,345	171,821
Portugese East Africa	-----	-----	180	1,030	1,000
Rumania	10,701	11,807	10,460	40,000	40,000
Southern Rhodesia	-----	-----	-----	-----	1,000
Johore	19,305	55,965	93,787	65,787	20,000
U.S.S.R.	230,000	250,000	300,000	300,000	250,000
United States	431,898	511,931	445,958	445,958	908,525
Yugoslavia	354,233	396,368	318,200	290,000	300,000
	<u>5,746,666</u>	<u>3,849,000</u>	<u>4,808,800</u>	<u>4,695,800</u>	<u>6,396,900</u>

47. H.A. Franke, M.E. Trough, BAUXITE AND ALUMINUM, Minerals Yearbook 1941, 48. Ibid.

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