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WORLD RESERVES AND REQUIREMENTS FOR ALUMINIUM RAW MATERIALS 1/

by

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1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO.

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

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SUMMARY

Aluminium is the most widely spread element of the earth crust that has an industrial importance. Its content in the earth crust is 7.45 per cent. At present bauxites are practically the only raw material from which aluminium is being extracted. These rocks are relatively widely spread on the earth.

In different countries, rocks characterised by considerable variations in their composition are regarded as bauxites. Bauxite is an economical rather than a petrographic notion. The absence of an objective criterion for the determination of the term bauxite is the reason for various estimations of its spreading on the earth and different calculation of its reserves. Two main types of bauxites are known; residual-homogenic autochtonous and sedimentary-homogenic allochtonous.

At present the largest bauxite reserves are known on the African continent, in Australia, in the Caribbean basin and in the northern part of South America. On the whole, bauxites are open mined for the aluminium industry. In the Union of Soviet Socialist Republics, and in a considerably lesser extent in the United States, Yugoslavia, France and Hungary, bauxite is mined from underground drill holes and pits.

The absence of a generally acknowledged term, bauxite, restricts the possibilities of an estimation of bauxite rocks in separate regions, as well as of their prediction. Equatorial Africa, Australia, Central and South America, Hindustani peninsula have the greatest perspectives of discovering surface deposits. The ancient epochs of bauxite formation and the "buried" deposits connected with them, are studied quite insufficiently, so that it is difficult to make a prediction of their resources.

The world aluminium industry applies on the whole the Bayer process, using temperatures of digestion. Bauxites, having a high silicon content, are processed by means of sintering. Other numerous patents on the extraction of aluminium oxide from bauxites have not found any practical application.

The improvements of the technology of the extraction of Al_2O_3 from bauxites, the improvement of economical conditions in developing regions and new countries will allow to change in a great extent the requirements made to bauxites, decreasing their content of Al_2O_3 and increasing their content of SiO_2 and Fe_2O_3.

Bauxite reserves, which meet the average world requirements, may be estimated as eight to ten milliard tons; the reserves of ores, suitable for their processing to alumina, will constitute not less than 25 milliard tons in case of improvement of economic conditions and technology. The non-uniformity of spreading of bauxite rocks on the earth, stipulated by geological causes, must not limit the development of the aluminium industry in countries which are in "bauxite-less" zones. For the alumina production it is necessary to use nepheline and leucite syenites, kaoline clays and argillites, disthen (andalusite, sillimanite) - containing rocks.

A favourable factor for processing these rocks is the presence of alkalies (Na and K) in them, which are used in the technological process and are a separate commercial product as well. The spreading of alumosilicate alkaline rocks in the lithosphere is not large and it is even less than that of bauxites. The greatest areas occupied by them are in the northern hemisphere. Almost all nepheline rocks are utilised only in the Union of Soviet Socialist Republics. These rocks are least spread in the countries of the southern hemisphere. The reserves of alumo-containing alkaline rocks in zones, which are perspective for their utilisation, may be estimated as several scores of milliard tons.

The requirements for this new type of raw material have not yet become stable. Conditionally, taking into account the regional economy in the Union of Soviet Socialist Republics, it is considered to be profitable to process rocks containing about 27 per cent of Al_2O_3 and 14 - 18 per cent of alkalies.

For the production of aluminium-silicon alloys, it is rational to use ores, in which the aluminium-to-silicon ratio is near to that which is required for the alloys (disthen, andalusite, sillimanite, kaolinite). These rocks are spread in the lithosphere in a much larger extent than the alkaline alumosilicate rocks. They are known in regions, composed by the most ancient formations, where there are neither bauxites, nor alkaline quartz-free eruptive rocks. Such regions are in particular the southern part of the African continent and the northern regions of Europe and North America. Kaolinite clays are rocks which are widely spread in different climatic zones of the earth.

The industrial production of alumosilicon alloys and silumine from the kaolinite concentrate is organised in the Union of Soviet Socialist Republics. The reserves of the kaolinite raw material constitute many milliard tons.

The alumosilicate alkali-free raw material (content in the concentrate) must meet the following requirements - Al_2O_3, SiO_2, Fe_2O_3:

	Al_2O_3	SiO_2	Fe_2O_3
Disthen (sillimanite, andalusite) concentrate:	56%	37.5%	0.5%
Kaolinite concentrate:	36%	47%	0.5%

For the utilisation of alumosilicates as a raw material for the production of alumosilicon alloys, as well as aluminium, it is necessary to work out technical-economical efficient methods of their beneficiation. Maintaining the present level of rates of development of the aluminium production and even greatly increasing it on condition of using different aluminium-containing rocks, the world would be supplied with raw materials for the aluminium production for many centuries.

Contents

Tables

I. ALUMINA AND ITS COMPOUNDS

1. Aluminium is the most widely spread element of the earth crust that has an industrial importance. According to Fersman's estimation, its content in the earth crust is 7.45 per cent, almost twice as much as iron, (4.16 per cent) the most used element.

2. Almost all rocks composing the earth crust contain aluminium. According to Vinogradov's estimation, the average aluminium content in clay rocks is 10.45 per cent and in eruptive rocks it is as follows: medium rocks, 8.85%; basic rocks, 8.76% and acid rocks, 7.70%. In other rocks composing the earth crust the aluminium content is not high: in sandstones, 2.57%; in ultrabasic rocks, 1.74% and in limestones, 0.43%. Aluminium forms chemical compounds with oxygen, silicon, iron, sulphur, phosphorus, hydrogen and chlorine. More than 300 known minerals contain aluminium as a component: 200 silicates; 57 phosphates; 25 sulphates; 20 oxides; 14 haloid compounds and three carbonates.

3. In the rock composition of the lithosphere only 94 minerals mentioned above have quantities of aluminium of significance: 82 silicates; 5 oxides; 3 sulphates; 2 phosphates; 1 carbonate and 1 halogen.

4. Aluminium oxides have the richest content: corundum, 53%; diaspore and boehmite, 45%; gibbsite, 34.5%; of the silicates: nepheline, 17%; plagioclases, 10 to 19.5%; leucite, 12.5%; mica (biotite, muscovite), 16 to 20%; zeolites, 8.5 to 15%; disthen and alusite, sillimanite, 33.5% and of the sulphates: alunite, 19.5%.

5. Bauxites have the maximum concentration of these minerals and are composed of diaspore, boehmite and gibbsite which contain on the average 25 per cent aluminium. Nepheline rocks of the urtite type contain about 15 per cent aluminium and disthen schists (andalusite and sillimanite ones) contain about 18 per cent.

6. World industry uses practically only bauxites for alumina production. In the Union of Soviet Socialist Republics, besides bauxites, alunite and nepheline rocks are also processed, and for the nproduction of alumosilicon alloys kaolin is used.

7. Bauxite output is being constantly increased and from only scores of tons in 1882 in the United States of America, (1885 in France) output now exceeds millions of tons.

8. Because of the specific character of aluminium, it was used until comparatively recently mainly as a strategic metal. This has been the cause of abrupt decreases of of its production (and hence of bauxite) after the First and Second World Wars.

II. ECONOMIC FACTORS

Alumina and aluminium consumption

9. A prediction of future needs of bauxites can be made only approximately. The average growth rate of aluminium production for the last few years in countries which are the main producers of this metal, can probably serve as a criterion for such a prediction.

10. The increase in aluminium production in the United States of America in 1965 amounted to a 7.9 per cent increase compared to the previous year, and a 7.8 per cent increase in 1966, over 1965. According to an estimation carried out by American experts Landsberg, Fishman and Fisher, Resources of America in the Future, the increase of metal output in the period from 1960 to 2000 will be 3.1 per cent. However, the part of aluminium consumption in the total consumption of main metals will increase from 5.7 per cent in 1960 to 11.2 per cent in 1980 and will amount to 17 per cent in the year 2000. It is supposed that the gross consumption of aluminium will increase on the average of 3.5 times in 1980 (minimum 2.1 and maximum 6.3 times). Hence, for providing production of such a quantity of aluminium, about 15 million tons of bauxite will be necessary according to a minimum estimation; about 25 million tons according to an average estimation, and about 40 million tons according to a maximum estimation.

11. According to a prediction of the same experts, aluminium consumption in the United States of America must increase on the average of about 2.6 times (minimum 1.94 times and maximum about 3 times) during the next twenty years. About 125 million tons of bauxite will be necessary for the production of such a quantity of aluminium using the same quality ore being used at present.

12. The increase of aluminium output in the Union of Soviet Socialist Republics during the post-war five-year period was supposed to be 2.0; 2.6; 2.1 and it is determined as 1.9 to 2 times at present.

13. The progressive nature of the Union of Soviet Socialist Republics national economy indicates that the average rate of increase amounting to 2.5 times during a five-year period will not only be maintained but will probably increase. Hence, the consumption of aluminium raw material will greatly increase. We take into account, that the greatest part of aluminium will be produced outside the United States of America, which will increase considerably the importation of alumina.

14. The world rate of increase of consumption of aluminium raw material will probably be still higher, taking into consideration the great difference in the consumption of economically developed countries and countries which are just on their way to

independent economical development. It would be incorrect to compare aluminium consumption in economically developed countries (the United States of America, Federal Republic of Germany and others) with that of the countries of Equatorial Africa for instance. But even comparing the consumption of aluminium in countries of Western Europe one can imagine what large volume the world aluminium industry would have to have to equalise the provision of people's demands in any country.

15. The realisation of these predictions requires the organization of bauxite mining in new regions as this industry's production lags behind that of countries producing aluminium.

Foreign trade in bauxites

16. Foreign trade of bauxites is constantly increasing, although practically no "free" market of bauxites exists, as many aluminium companies extract raw materials for their enterprises in other countries, either themselves or through branch companies. At present the importation of bauxites satisfies the demand for raw materials in the United States of America, 85 per cent; in the Federal Republic of Germany, Canada, Norway, Holland, Switzerland, England and Japan 100 per cent.

World aluminium industry

17. The present world aluminium industry can be divided into three groups:

(a) Countries that have a developed aluminium industry but not their own raw material resources, having partly or entirely to use imported raw materials such as the United States of America, the Federal Republic of Germany, Canada, Japan, Scandinavian countries, Italy and Switzerland.

(b) Countries that have a developed aluminium industry and are provided with native raw materials, some being also able to export bauxites: the Union of Soviet Socialist Republics, France, Hungary, Rumania, Turkey and Greece.

(c) Countries that export bauxites in large quantities, (some building an aluminium industry of their own) such as Jamaica, Surinam, Dominican Republic, Haiti, Ghana and Australia.

There are also some countries that have bauxite resources which are not being exploited; these are mostly countries of Equatorial Africa

III. BAUXITE RAW MATERIALS AND THE ALUMINIUM INDUSTRY

Bauxite

18. Bauxite is commonly known as a rock consisting mainly of aluminium and ferric hydroxides together with a small quantity of an impurity of aqueous alumosilicates, mostly kaolinite, and minerals of titanium dioxide and calcium oxide, as well as some very small amounts of magnesium, chromium, vanadium, phosphorus and gallium.

19. There are no common criteria for bauxite. Requirements for the content of the useful component aluminium oxide or the harmful impurities such as silicon, ferric and calcium oxides are not defined by objective geological factors. They depend on the level of technological processing, on economic conditions of bauxite deposits, on a country's bauxite demand and on bauxite availability. Bauxite is therefore, rather an economical than petrographical determination. On these grounds in various countries rocks characterised by considerable variations of bauxite-forming oxides are considered to be bauxites.

20. It often happens that even in various regions of one country different requirements are applied to bauxites. In the United States of America state of Alabama bauxites are divided into two grades: I - Al_2O_3 - 55%, SiO_2 - 7%; II - Al_2O_3 - 50-55%, SiO_2 - 15%; in Arkansas into three grades: I - Al_2O_3 - 58%, SiO_2 - 6%; II - Al_2O_3 - 52%, SiO_2 - 10%; III - Al_2O_3 - 50%, SiO_2 - 9%.

21. The following requirements of bauxite for alumina production are worked out in the United States of America using the National Stockpile Purchase Specification P - 5a - R_2:

Table 1

Requirements of bauxite for alumina production

	Content of ignited matter in percentage	
	Trihydrate ore Surinam type	Compound trimono-hydrate ore Jamaica type
Al_2O_3 min.	55.0	47.0
SiO_2 max.	5.0	4.0
FeO max.	3.0	3.0
P_2O_5 max.	1.0	1.0
Alkalies max.	1.0	1.0
$MnO_2 + Cr_2O_3 + V_2O_5$ max.	2.0	2.0
loss on ignition	50 per cent from the active Al_2O_3.	40 per cent from the active Al_2O_3.

22. In Yugoslavia red bauxites are divided into three classes: I - $Al_2O_3 > 55\%$; $SiO_2 < 4\%$; II - $Al_2O_3 > 48\%$; $SiO_2 < 4\%$; III - SiO_2 from 4 to 8%. Bauxites with a content of SiO_2 higher than 11 per cent are considered as low-grade.

23. White bauxites of Tchernogorija are divided into four grades:

		I		II		III and IV
Al_2O_3	>	55%	>	55%	<	55%
SiO_2	<	9%		10 to 22%		10 to 22%
Fe_2O_3	<	3%	<	5%	<	10%

24. In the Union of Soviet Socialist Republics requirements applied to bauxites are defined by the State Standard. The Standard determines the minimum content of aluminium oxide along with the silicon modulus; the latter implies the weight ratio between aluminium oxide and silicon oxide contained in the bauxites.

25. The Standard sets requirements for bauxites which undergo processing according to three principal flowsheets used in the Union of Soviet Socialist Republics. Bauxites of B-2 brands and higher can be processed by the Bayer process at the temperature of 225°; bauxites of B_7 and B_8 brands are processed by the same method but at the temperature of 150°; and bauxites of B_3 and B_5 brands are processed by

Bauxite extract from the State Standard

26. The following is the bauxite extract from the State Standard:

(a) Bauxite is delivered in the following brands:

Table 2

Bauxite brands - qualitative composition

Bauxite brands	Qualitative composition: Content of Al_2O_3 (calculated dry) in per cent	Qualitative composition: Weight ratio of $Al_2O_3 : SiO_2$ in per cent	approximate application
BV	52	12.0	Production of electrocorundum
B-0	52	10.0	Production of alumina, electro-
B-1	49	9.0	corundum and alumina cement
B-2	46	7.0	Production of alumina, molten
B-3	46	5.0	refractories, and alumina cements
B-4	42	3.5	Production of alumina and
B-5	40	2.6	refractories
B-6	37	2.1	Production of refractories and open-hearth production
B-7	30	5.6	Production of alumina and alumina cement
B-8	28	4.0	Alumina production

(b) For bauxite intended for alumina production the following sulphur content limits are set:

Brands B-1, B-2, B-7, B-8 - not more than 0.7%.

Brands B-3, B-5, B-4 - not more than 1.0%.

(c) Bauxite of brands B-1, B-2, B-7, B-8 is produced in two sorts, depending on the content of carbon acid : the first one has carbon acid content up to 1.3%; the second one has carbon acid content of more than 1.3% from the weight of dry bauxite.

(d) It is permissable to have a smaller content of aluminium oxide at the expense of a higher content of calcium carbonate in bauxite designed for alumina production by means of sintering (brands B-3, B-4, B-5).

(e) The following content of calcium oxide is fixed for bauxite used for the production of electro-corundum: for bauxite of brands BV and BO - not more than 0.5%; for bauxite of brand B-1 - not more than 0.8%. Sulphur content is not more than 0.3%.

(f) The sulphur content in bauxite for an open-hearth production must not exceed 0.2%, the phosphorus content - 0.6% calculated for P_2O_5.

(g) The content of calcium oxide in bauxite for the production of molten refractories must not exceed 1.5%; the sulphur content - 0.5%.

(h) The sulphur content in bauxite for the production of an alumina cement must not exceed 0.5%.

27. As a result of improved technology it is possible to decrease the content of Al_2O_3 in bauxites being processed. In 1930 in the United States of America the average content of Al_2O_3 was 60 per cent; in 1963 it was less than 50 per cent.

28. Published figures on bauxite reserves are seldom trustworthy since methods and common criteria of their estimation differ. In many countries mining regulations do not prevent stock companies from claiming for purely speculative purposes, high mineral deposits without sufficient and reliable exploration. World bauxite reserves as a whole, as well as bauxite reserves of separate countries (except the Union of Soviet Socialist Republics and some other centrally planned economy countries) have never been submitted to consideration by authoritative national geological organizations, nor at any international congress, nor any other international geological organization. Experts estimates of world bauxite reserves differ considerably. Figures of some experts do not differ greatly because of their use of common sources.

Bauxite deposits

29. Present bauxite deposits were either exposed on the surface or were easily detected. The "buried" bauxite deposits of the world reserves are not large. Special prospecting of them seems to be carried out now only in the Union of Soviet Socialist Republics. Most bauxites of the world are open mined; only a comparatively small part is mined underground. In the Union of Soviet Socialist Republics it constitutes 65 per cent; in France, 80 per cent and in the United States of America (Arkansas), 12 per cent.

30. The bauxite genesis is not an "academic" question of interest chiefly to scientists. It has an entirely practical significance to which geologists and economists working in the aluminium industry are not indifferent.

31. Up-to-date knowledge of the conditions of bauxite formations makes it possible to divide them into two main types:

(a) residual - chemogenic, autochthonous; and
(b) sedimentary - chemogenic, allochthonous.

The first are formed on various alumo-containing eruptives and seldom on metamorphic and sedimentary rocks in the process of their lateritic weathering. Deposits of present and other cycles of chemical weathering are known. Bauxites of the second type represent redeposited products, resulting from a lateritic weathering of the mentioned rocks, accumulated in different water basins and bauxitized at the place of accumulation.

32. Sedimentary, chemogenic deposits are divided into three subtypes:

(a) Bauxite contacts with limestone in a flat wall, directly or through clay streaks and overlapped by lime-argillaceous sediments, partly containing minerals of free alumina which gradually makes transit into the limestone (Jamaica, France, Yugoslavia, Turkey, China and North Vietnam).

(b) Bauxites occurring in clay rock and connected with it (especially underlaying rock) by gradual transition.

Bauxite-bearing strata occurring in limestone or at the place of contact between limestones and eruptive rock (the Union of Soviet Socialist Republics).

(c) Bauxites occurring among clay rocks, usually variegated ones. Bauxite-bearing strata directly underlaid with sand-clay deposits or crystalline rocks (the Union of Soviet Socialist Republics, North-Western regions, Surinam, British Guiana).

33. Deposits of residual chemogenic origin are confined to the crust of weathering of various eruptive rocks of alkaline and medium rocks, and also of crystalline schists, containing alumosilicate minerals (West Africa, Indonesia, Malaysia and French Guiana).

34. It is known that there are bauxite regions where deposits of both types are very close to each other, having the same mother-bauxite source (the Union of Soviet Socialist Republics, North Onega; the United States of America, Arkansas; Brasil, Minas Gerais).

35. A third type of deposit of unindustrial, or restricted industrial, significance may be pointed out. These are eluvial, eluvial-deluvial, deluvial and alluvial deposits, formed by fragmental completely formed bauxite. These deposits are very close to indigenous lodes. The gross quality of the rock is very low. For practical utilisation, beneficiation is necessary, that is, separating fragments of bauxite from clay, rock waste and pebbles (some deposits in Hungary, Rumania and North Vietnam).

36. In the deposits of a sedimentary-chemogenic type, bauxites occur in the form of layers and lens-shaped lodes of various dimensions, thickness and complex configuration. Sometimes the thickness of lodes is greater than their extension and width. Shapes and dimensions of lodes are defined by the shapes and dimensions of depressions

of the ancient relief of rocks to which the lodes are confined. The pre-ore relief of limestone, as a rule, is of karst origin and sometimes with overlapping of errosive processes. The length and width of large lodes is confined to fields and valleys or to errosive-karst depressions amounting to several kilometres in length and up to several kilometres in width.

37. Various thicknesses up to 50m or more is typical of this kind of lode; bulges are confined to axial parts of negative karst forms. Lodes, controlled by sizes of karst depressions, have various sizes from several scores up to 150 to 200 m, with a thickness up to 10 m or more. There are some lodes shaped with a thickness about one half of their length and width. Deposits are usually represented by a various number of lodes amounting to several scores. In the Union of Soviet Socialist Republics in the Kazakhstan region, located on an area of 150 square kilometers, more than 60 lodes have been found confined to small and middle size karst depressions.

38. In Rumania the deposit Lunka Sprie is comprised of 170 lodes, located at various distances from each other. They are completely isolated from each other or are connected by a bauxite streak of small thickness which is usually of a low-grade type. In lodes of deposits of sub-type "a", "windows" may be rather often found which are penetrating protrusions underlaying bauxites of limestone.

39. The bottom surface of lodes of this sub-type is very uneven and represents, by itself, carrs; the top surface is comparatively even. In deposits of a sedimentary-chemogenic type, except the main bauxite horizon, there are, in some places, second horizons, represented by "blind" lodes.

40. The lodes in the deposits of sub-type "b" are more complicated than those of sub-type "a". They can be represented by one or several beds of bauxite, separated by low-grade bauxite, rich and kaolinic clays. Contrary to the lodes of the deposits of sub-type "a", in the lodes of sub-type "b", usually on their out-wedgings, there are some cleavages of bauxite bed and its substitution by bauxite and ordinary clays.

41. The position of lodes in sub-type "b" is generally determined by an ancient relief of carbonaceous rock foundation. The location of lodes is usually central in relation to ancient depressions, but they often lie on the slope of depressions, depending on the nature of the drainage of ground water.

42. The complexity of the lodes in sub-type "b" increases because of the frequently occurring clumpy character of the bauxite bed itself. A typical bauxite, usually of high quality, is included in the clay mass in the form of grains, debris, or blocks, having a cross-section from only millimetres wide up to several metres in width. The proportion between these two parts of lodes determines the quality of

bauxite as a useful mineral. Bauxites are represented by several varieties such as hard, soft or clay.

43. The ratio of lithological differences of bauxite in deposits varies to a great extent. Varieties of bauxites have different chemical compositions and also differ by the proportion of bauxite-forming minerals. As a rule, hard bauxites are of the best quality since they have a high silicon ratio and hence a higher content of minerals of free aluminium hydroxide. Clay bauxites are of low quality.

44. The distribution of bauxite varieties is governed by a certain law: hard bauxites having a high silicon ratio are located in the central parts of lodes, and clay bauxites at the periphery. Among bauxites of sub-type "a" varieties are distinguished. Subdivision is made mainly according to colour: red and grey or green and multi-coloured. Red bauxites are sometimes divided into varieties according to texture, physical properties and shades of colour.

45. Bauxites of the sedimentary-chemogenic lodes are represented by all mineralogical types: diaspore, boehmite-diaspore, boehmite-gibbsite and gibbsite. The gibbsite type is often characterised by the presence of corundum. The following deposits belong to this particular type: in the Union of Soviet Socialist Republics (the Urals, Kazakhstan), Rumania, Hungary, Greece, Italy, France, Jamaica, the island Espaniol, North and Central China and North Vietnam. Deposits of this type are the main suppliers of bauxite to the world market. They constitute about 33 per cent of all authentic and probable bauxite reserves and produce about 65 per cent of the world output.

46. As far as the period of formation is concerned, certain surface deposits are found to be of the quarternary and tertiary periods and sometimes are not overlapped by any other rocks except a soil layer. Reserves of deposits, which were formed in the ancient epochs of bauxite formation, total about 40 to 45 per cent, and 15 to 28 per cent possibly of world reserves.

47. Deposits of only ancient epochs of formation are known in Europe and in South America. Deposits according to geological period are found in the following countries:

Quarternary	-	Asia (excluding USSR) Australia, Africa
Tertiary	-	Asia (excluding USSR) Australia
Oligocene	-	United States, Union of Soviet Socialist Republics
Eocene	-	United States, Union of Soviet Socialist Republics
Cretaceous	-	France, Greece, Italy, Rumania, Turkey, Yugoslavia
Triassic	-	Asia (excluding USSR)
Carboniferous	-	United States, Union of Soviet Socialist Republics, Asia
Devonian	-	United States, Union of Soviet Socialist Republics
Pre-Cambrian	-	Union of Soviet Socialist Republics

48. Discovery of bauxite surface deposits is far from being exhausted; this is confirmed by explorations in Africa, Somali, new regions in Mali and in other countries of the continent where ancient deposits hide a great many possibilities. A good example is the discovery of bauxites related to the ancient carboniferous crust of weathering of Proterozoic deposits in the European part of the Union of Soviet Socialist Republics.

49. Improvement of the technology of discovery is an important factor for the estimation of raw material resources for aluminium production. This is extremely important for old regions of bauxite where there appears to be large settlements and on which the fate of thousands of people depends.

The Bayer process

50. At present it is known that the world aluminium industry applies mainly the Bayer process, using different temperatures of digestion depending on the mineralogical shape of the free aluminium hydroxide which forms bauxite. However, this method is economically justifiable only for bauxites with a low content of silicon. It is more expedient to process bauxites with a high silicon content by sintering them with limestone and soda in rotary kilns, followed by extraction of aluminium oxide from the sinter by means of alkaline solutions. Depending on the bauxite composition, it is possible to combine these two methods consecutively or parallel.

Sintering and other methods

51. Methods of sintering and combined methods are being used at present only in the Union of Soviet Socialist Republics, China, and the United States of America where two plants utilise Arkansas bauxites of comparatively low quality. A great number of different patents for extracting aluminium oxide from bauxites including those with a high content of silicon and iron, are known, but all of them, except the ones mentioned, have not yet had a practical application. Methods of iron recovery and acid methods are the most important.

52. Development of the technology of extracting Al_2O_3 from bauxites, specially low-grade bauxites and improvement of economic conditions in developing regions and countries, will allow change to a great extent in requirements for these rocks both in reducing the Al_2O_3 content and in increasing the content of SiO_2 and Fe_2O_3.

53. Because geological data are unsatisfactory, it is not possible to estimate the actual volume of deposits as data takes into account only the part that meets modern technical-economical requirements of the industry. Low-grade rocks that contain free aluminium oxide are not taken into account.

Bauxite compounds - deposits of low-grade and economic bauxites

54. The ratio between low-grade and economic bauxites is quite variable in different deposits and it is defined by the conditions of origin and formation. This ratio reaches one to five in favour of the present low-grade ores. In France the reserves of low quality bauxites and bauxite clays are estimated to be one milliard tons. Some low-grade bauxite is used nevertheless by mixing it with ores of high quality provided it does not lower required standards. To save low-grade bauxites for future generations is the task of experts on the exploitation of deposits.

55. The prediction of the quantity of bauxite-bearing rocks and, hence, of world resources of this raw material is found to be difficult because of the absence of a generally acknowledged point of view on the formation of bauxites.

56. The question of the genesis of bauxites has not been worked out very sufficiently. Unmistakable damage to the knowledge of the distribution of bauxites in the world was caused by antagonism towards the water-sedimentary and lateritic theory of formation of these rocks. Denying for a long time the great significance of laterization for the formation of economic bauxite deposits in the Union of Soviet Socialist Republics the geologists did not prospect bauxites connected with crusts of weathering of eruptive and metamorphic rocks. In western countries, on the contrary, sticking on the whole to the lateritic theory and to the theory "terra rossa", geologists ignored the possibility of formation, and, hence, the possibility of discovering deposits formed during the bauxitization of redeposited material. At present "the antogonists" have changed greatly their point of view and have surrendered their position. The largest deposits of Jamaica have turned out to be sedimentary-chemogenic, and typical lateritic bauxites were discovered in the Union of Soviet Socialist Republics (the Ukraine and the European part of the R.S.F.S.R.).

Complex utilisation of bauxites

57. Besides the constant and quite natural genetic association of bauxites with bauxitised and kaolinite clays, ores with an intermediate composition between bauxite and iron ore are known. These ores formed either after alumosilicate eruptive rocks of the trappean type, or represent a facial transition between sedimentary iron ores and sedimentary-chemogenic bauxites. Such ores are known in the Union of Soviet Socialist Republics (Kazakhstan) and contain 55 to 70 per cent Fe_2O_3 and 30 to 20 per cent Al_2O_3, in Turkey (Fe_2O_3 - 70 to 80 per cent; Al_2O_3 - 10 to 12 per cent), in the United Arab Republic (Fe_2O_3 - 60 to 65 per cent; Al_2O_3 - 5 to 10 per cent), in Guinea and some other countries. These ores must be utilised as a complex raw material for cast iron and alumina production; the wastes serve as a raw material for

cement manufacture. In general, the problem of a complex utilization of bauxites has great economic importance, as the production of additional products together with alumina may change essentially the estimation of deposits, the exploitation of which is considered unprofitable. It is known that the aluminium industry is one of the principal industries, and in some countries it is the unique supplier of gallium.

58. The possibilities of a simultaneous receiving of this element are enormous and the problem of its sale and use arises at present. The aluminium industry can also simultaneously produce vanadium, chrome and their salts. The extraction of vanadium from bauxites and chrome was carried out in Germany during the Second World War, and at present it is organized in the Hungarian People's Republic, where there is no raw material basis for organizing a special production of this metal. In the Union of Soviet Socialist Republics, the production of a technical V_2O_5 is carried out as a measure for purification of alkaline aluminate liquors at one of the alumina plants. Simultaneously with vanadium, phosphorus is separated, which, considering its high content in the bauxites, becomes a commercial product. Fluorine can be obtained from the same initial product. A concentrate, containing up to 70 per cent of NaF, can be processed to cryolite.

59. Good prospects have the presence of iron, contained in quantities exceeding 30 to 35 per cent in bauxites of certain deposits, that is, its content is of the same level as in proper iron ores. But the content of ferric oxide in red muds often exceeds 40 per cent, great quantities of V_2O_5, TiO_2, Cr_2O_3, P_2O_5 and other elements are also concentrated in them.

60. The possibility of cast iron production from red muds has been established. Foundry cast iron can be produced by the Thomas process, and by processing muds by reduction melting it is possible to obtain vanadium cast iron. During this process the alumina muds will be a source of supplementary yield of alumina and a raw material for cement production.

Extraction of titanium

61. The extraction of titanium contained in bauxites is of great interest. The content of titanium dioxide in bauxites of certain deposits amounts to 9 to 10 per cent (the USSR, India etc.). Consequently, it increases in slurries up to 18 to 25 per cent, greatly exceeding the content in many proper titanium ores.

62. However, the extraction of titanium dioxide both from bauxites and red mud has not yet been decided upon from the technological point of view. Probably, titanium concentrates, obtained from certain bauxites, can be a source for the extraction of niobium.

Beneficiation of bauxites

63. The use of bauxites with a relatively low content of free aluminium hydroxide for industrial purposes requires development and wide introduction of mechanical beneficiation which must pursue the following:

(a) decrease the absolute content of silica in bauxite ore and, hence, increase the relative content of aluminium;

(b) decrease the ferric oxide content;

(c) decrease the calcium oxide which is extremely important when using bauxites as a raw material for the production of abrasives, and decrease ferric oxide;

(d) extract titanium dioxide and niobium pentoxide connected with minerals from bauxite or red mud.

64. Beneficiation is used at present to decrease silica content of bauxites in Guinea, Surinam, Guiana and Indonesia. At present the beneficiation of bauxite ores for a decrease of their silica content is carried out only for those ores which represent blocks and nodules of proper bauxite, cemented by clay or by low-grade clay bauxite (Indonesia, Guinea); coarse crystalline quartz can be removed easily. During the beneficiation of homogeneous compact bauxites, in which silica is represented only by small flakes of kaolinite tightly aggregated with gibbsite, boehmite and diaspore, satisfactory results have not yet been obtained.

65. Because of an intimate intergrowth of rock-forming minerals, beneficiation of bauxites can result in great loss of alumina which passes into the mud together with silica and ferric oxide. The yield of the beneficiated part is not high and does not exceed 70 per cent. In Indonesia up to 30 per cent of the ore mass is lost during washing.

66. One may also consider as beneficiation the reduction of wetness of bauxite and the content of water of crystallization which is used in the bauxite mining industry. This type of beneficiation has great economic importance for lowering expenses on transportation of bauxites which are sometimes carried great distances (from Jamaica, Surinam, Guiana to the United States of America and Canada). Drying of bauxite also increases the capacity of units. In the case of supplying bauxites for abrasives, cement and other branches of industry, bauxite is subjected to calcination for reducing not only wetness, but also the content of the water of crystallization.

IV. REQUIREMENTS FOR EXPLORING ALUMINIUM RAW MATERIAL

Bauxite deposits

67. Bauxite deposits being exploited at present characterised by their large dimensions are outcroppings of the earth's surface, and are of considerable constancy of chemical composition. Most of the large deposits are being worked under

conditions which are favourable to economic development: proximity to sea transport routes (Jamaica, Guiana, Surinam, Guinea) and location in economically powerful, industrially developed countries (France, Yugoslavia, Hungary and the United States of America). Special prospecting and exploring of bauxite deposits in economically undeveloped regions, chiefly in former colonies and dependent countries, has practically not been carried out.

68. Discovering of new deposits has been usually accidental and has taken place during regional geological investigations. For the purpose of cutting expense connected with exploring, correction factors are usually introduced for determination of reserves. Without any exact calculation this provides an amortisation period for the bauxite mining enterprise and the alumina plant. Generally acknowledged norms for the volume of exploring work and providing the reliability of bauxite reserves in a deposit are probably absent in all countries except the Union of Soviet Socialist Republics.

69. In the Union of Soviet Socialist Republics the selection of a method of exploring bauxite deposits depends on their condition of occurrence, shape and dimensions. According to these features the deposits are divided into four types:

Type I - large layer-shaped bodies, slightly inclined or having a slope of 10 15° with great length and relatively constant quality of bauxite; average thickness is from 0.8 to 5 m.

Type II - large lens-shaped lodes, usually of considerable thickness and length. The composition of the ores is not constant because of the presence of streaks of clay in the bauxite. Along the periphery of the lodes bauxite is substituted by clay bauxites and clays. In the vertical sections of the lodes a zonal spheroidal structure can be detected; the bauxites of a better quality are usually found in the central parts of the lodes. The configuration of the lodes is intricate. The length of the lodes is within 0.4 to 1 km, and their thickness is 1 to 20 m. Sometimes bulges are observed which have a length of several scores of metres. The lodes are usually tectonically simple.

Type III - small lens-shaped lodes, often having considerable thickness from 1 to 2 m. to 10 to 15 m. The horizontal dimensions of the lenses vary from 70 to 100 m. to 300 to 400 m. and the areas of lodes are from 1 to 2 to 10 to 12 ha. correspondingly. The lodes are located individually, but sometimes they are located in groups of two or three or more. The lodes represent in a section an interdigitation of bauxites of different lithological types and different chemical compositions with low-grade ores and streaks of clay of any thickness. The outlines of economic ores are marked only according to the data of sampling.

Type IV - lens-shaped and nest-shaped lodes in holes of ancient karst. The ore bodies have a small extension, but they often have a very large thickness. The composition of the lenses, even located close to one another, can be very different.

70. Exploration is carried out by means of drilling, cutting pits and small shafts, and in mountainous regions with an extremely complex relief (the Union of Soviet Socialist Republics - Buryatia, Tajikistan and Uzbekistan; and Turkey) by galleries. Prospecting drill holes and pits are usually located along a rectangular net for stretched lodes; and a square net for lodes having an isometric shape. The quantity of prospecting drill holes and pits (density of the exploratory net) is determined by the features of the structure of the deposit.

71. The exactness of exploring deposits is determined by the type of the deposit and by the tasks which are set before it. At the first stage of exploring, when it is necessary to determine the economical value of the given deposit, the density of the exploratory net (distance between the drill holes or pits etc.) must be as follows: for Type I - 300 to 350 x 300 to 350 m; for Type II - 100 to 200 x 100 to 200 m; for Type III - 50 to 70 m. At the second stage, when the decision to exploit the deposit is taken, the density of the exploratory net is usually for Type I - 50 to 100 m; for Type II - 35 to 50 x 35 to 50 m; for Type III - 20 to 25 x 20 to 25 m. At the first stage of exploring the general structure of the deposit is determined, as well as its area, average thickness, shape, chemical and mineralogical composition and main features of hydrogeology.

72. At the second stage the average quality of bauxites is determined with an accuracy that ensures a correct determination of the industrial grades of bauxite, the form and dimensions of lodes; the tectonics defined; and the volume weight of bauxites determined. Maps are drawn on a scale of 1:2000 or 1:1000 and for small lodes, 1:500; tests for establishing the technology of processing bauxites of the given deposit are carried out.

<u>Non-bauxite aluminium raw material</u>

73. The irregularity of distribution of bauxites on the earth, stipulated by geological causes, must not limit the development of the aluminium industry in countries, which are in "bauxiteless zones". Especially since there are in these regions countries with highly developed industries, including the aluminium industry, working on raw materials such as bauxites and alumina imported from remote countries.

74. In 1966, 32 million tons of the world output were exported to countries which have no bauxite deposits of their own. The natural wish of these countries to be economically independent and produce aluminium from domestic raw materials presents the task of using non-bauxite alumo-containing rocks for this purpose. As stated above the nepheline and leucite rocks, alkaline gabbroids, kaolinite clays and argillites, disthen (andalusite, sillimanite), containing schists, have the highest content of Al_2O_3.

Nepheline, leucite and feldspathic raw materials

75. The average content of Al_2O_3 in urtites is 27 per cent, in kaolin concentrate - 34 per cent, in argillites - 32 to 34 per cent, in disthen (andalusite, sillimanite) concentrate - 55 to 57 per cent. The factor, which is favourable to the utilisation of these rocks and concentrates, is the possibility of producing some by-products besides alumina during their processing. This determines the high economic value of their utilisation. For the above-mentioned eruptive rocks the most important factor is the possibility of a simultaneous extraction of alkalies (potash and soda), the price of which is about 90 per cent of the price of produced alumina.

76. The wastes of processing from all the alumosilicate rocks during alumina production is bellite slurry, a raw material for cement production. Eight to ten tons of bellite slurry are obtained from one ton of alumina, which constitutes about 10 per cent of the price of the main product, alumina. At present for the extraction of alumina practically only nepheline rocks are used and only in the Union of Soviet Socialist Republics. Alumina produced from these rocks in relation to all alumina produced in the Union of Soviet Socialist Republics, is constantly increasing. An increase up to 44 per cent is expected by 1975. Two types of nepheline product- nepheline concentrate, obtained during a beneficiation of apatite-nepheline rock, as well as urtite are being processed in the Union of Soviet Socialist Republics. The content of Al_2O_3 in both these products is about 28 per cent.

77. The requirements claimed for this new raw material for alumina production have not yet become stable. Under the regional plan of economics in the Union of Soviet Socialist Republics it is considered profitable to process nepheline rock containing not less than 27 per cent of Al_2O_3 and not less than 14 to 18 per cent of alkalies. Ferric oxide is a component, the content of which is limited and must not exceed 5 per cent. For the characteristic of the nepheline raw material, two indices are introduced which represent the molecular ratio: SiO_2: Al_2O_3 not more than 3.0 (silicon modulus); R_2O: Al_2O_3 not less than 0.7 (alkaline modulus).

78. Nepheline rocks are encountered as large massives, as well as shoots, dykes and sometimes laccolites in association with other alkaline rocks connected with ultrabasic, basic, and acid magma. According to the opinion of some scientists (Shaneman, 1959), alkaline rocks are formed under conditions of relative tectonic immobility. For this reason the most probable areas of development of alkaline rock are platforms and areas of complete folding. Alkaline rocks, connected with ultrabasic and basic complexes, are developed on the platforms.

Nepheline rocks are represented chiefly by a group of iolite-urtites. In areas of complete folding nepheline-syenite intrusions are developed and are connected with alkaline granitoids. Under these conditions the massives of these rocks are enormous but the rocks contain less nepheline and more feldspars. Nepheline is a mineral which is easily destroyed during the processes of autometamorphism, hydrothermal and surface changes which remove aluminium and alkalies from the rock.

79. During secondary alterations a canoritization and zeolitization of rock takes place. These changes decrease the quality of the rock, reduce the content of useful components (aluminium and alkalies) and make the technological process more difficult. The spreading of nepheline rock in the lithosphere is small and considerably less than that of bauxites. The area occupied by these rocks in the Union of Soviet Socialist Republics is only about one per cent of the whole area of eruptive rocks. Nepheline rocks are found in Finland, Canada, North Korea*, United Arab Republic, Brazil and some other countries. In very few places have they been studied as a raw material for aluminium production.

80. The content of feldspars, such as albite and plagioclases, increases with the decrease of the above-mentioned nepheline content in alkaline quartzless rocks. The content of silica relatively increases, makes the process more difficult, and increases the quantity of rock to be processed. Some difficulties arise in the sintering technology itself, the causes of which have not yet been studied. In the case of using essentially feldspathic and, naturally, monofeldspathic rocks the content of alkalies decreases to a large extent, which leads to a decrease in use and economic profit.

81. Investigations of feldspathic rocks have been carried out in some countries on a semi-industrial scale. In the United States of America anorthosites were investigated as they occupy an area of about 4,600 sq. km., and their reserves are estimated as several milliard tons with a content of 25 to 30 per cent of Al_2O_3 and 2.5 to 6 per cent of alkalies.

82. In Norway during the Second World War a small plant was built for the extraction of alumina from labradorites as large massives of anorthosite are known to exist. In Italy there are leucite-containing rocks, the reserves of which are estimated as 100 milliard tons with a content of 17 to 18 per cent of Al_2O_3 and 7 to 12 per cent of K_2O.

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* Designations employed in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers.

During the Second World War a small quantity of alumina and potash were extracted from these ores. The reserve of leucite rock in the United States of America (Wyoming) is estimated as two milliard tons.

Kaolinite raw material

83. As stated above, an increase content of aluminium is observed in minerals of the clay group: kaolinite, halloysite, as well as in the anhydrous alumosilicate, dusthen groups. These minerals are of great economic interest as raw material for the production of alumosilicon alloys. The output from kaolinite concentrates is carried out on an industrial scale in the Union of Soviet Socialist Republics. The advantage of such raw material consists in an aluminium-to-silicon ratio near to that necessary for the alloys, so that alumina should be added only in small quantities. In the case of concentrates of disthen (sillimanite, andalusite) there is no need for any addition of alumina. Investigations on obtaining aluminium from sillimanite concentrates by means of an electrothermic method were carried out on a semi-industrial scale in the Union of Soviet Socialist Republics.

84. The most important way to utilize alkali-free alumosilicates is based on the possibility of their beneficiation. Severe requirements are placed upon raw materials used for the production of alumosilicon alloys. The content of certain oxides, first of all ferric ones, must not exceed 0.5 per cent; alkalies not more than 0.5 per cent; and CaO+MgO, not more than 0.6 per cent. The difficulty of receiving such concentrates is determined in many cases by the fact that the harmful oxides stated above are in the composition of the proper minerals and thus exclude the possibility of using mechanical beneficiation. An important advantage in using alumosilicates is their wide-spread existence on the earth compared to bauxites.

85. Kaolinite clays are known in various climatic zones and countries. Moreover they are found in countries, where up till now there are not known and probably will not be found any bauxites. Clay is encountered in two types of deposits: eluvial and sedimentary or primary and secondary. The first occurring directly on weathering alumosilicate rocks, is characterised by a lower quality, i.e. by a lower content of Al_2O_3 and higher content of SiO_2, than the second one. The content of kaolinite, depending on the composition of the mother rock and the intensity of chemical weathering, does not exceed 17 to 20 per cent in eluvial primary clays, and it may reach 25 per cent in sedimentary redeposits. Clay deposits in which processes of gibbsitisation are apparent are of particular interest. They can increase considerably the total content of Al_2O_3. Kaolinite argillites containing up to 36 per cent of Al_2O_3 are also of great interest. However, it is necessary to use beneficiation of all types of clay to obtain a concentrate with a content of Al_2O_3 not less than

35%, SiO_2 - not more than 47%, Fe_2O_3 - not more than 0.5%, TiO - not more than 0.3%, CaO + MgO - not more than 0.6%, Na_2O + K_2O - not more than 0.5%. Beneficiation may be carried out by means of the wet or dry process.

86. In the Union of Soviet Socialist Republics investigations of kaolinite raw material follow the trends given below:

(a) Obtaining alumosilicon alloys and silumine from the kaolinite concentrate with an addition of alumina by means of the electrothermic method;

(b) Obtaining alumina by means of sintering together with limestone; and

(c) Obtaining alumina by means of acid (chiefly by a sulphuric acid-method).

Disthen (sillimanite, andalusite) raw material

87. The anhydrous alumosilicates of the disthen group are spread in a considerably smaller degree than kaoline clays. Disthen-containing rocks (sillimanite, andalusite) usually compose ancient metamorphic complexes, which form the basements of platforms. Disthen-containing schists are largely developed in the North of Europe, in the United States of America, South Africa and many other regions of the world.

88. The use of disthen-containing rocks (andalusite and sillimanite) is possible only under the condition of receiving a concentrate of these minerals. On the strength of long-term investigations and economic calculations in the Union of Soviet Socialist Republics it has been determined that the concentrate must contain: Al_2O_3 - not less than 57%; SiO_2 - not more than 37%; Fe_2O_3 - not more than 0.5%; TiO_2 not more than 0.6%; Na_2O + K_2O - not more than 0.4%; CaO + MgO - not more than 0.6%. Such a concentrate can be obtained practically only where there is an absence of the abovementioned impurities in the composition of the useful mineral. Beneficiation is carried out by gravitation, magnetic separation, or floatation. The results received when using the second method are usually higher than in case of the other two methods. Both the reserves of rock and of the proper useful minerals are enormous. They can be estimated at many hundred million tons. For some countries such as South Africa they are the only local raw material.

Alunite raw material

89. Alunite may also be used as a raw material for the production of alumina. This mineral, as well as nepheline, was used for industrial purposes in the Union of Soviet Socialist Republics in 1966 for the first time in the world. It is reported that an alumina plant processing alunite ore has been put into operation in Mexico. Judging by the quantity of raw material being used (80 thousand tons of ore annually) the capacity of the plant is not high. In Japan the attempts of using alunite as a raw material for alumina production were not successful.

90. The economic value of alunite as a raw material for alumina production is considerably lower than that of the rocks mentioned above because of its relatively small distribution; however, knowledge in this respect is far from complete. Accumulations of alunite are found under various geological conditions: in volcanic regions; in zones of "secondary quartzites", connected with post-volcanic hydrothermal processes; in zones of oxidation of sulphide ores; in zones of surface sulphuric-acid weathering and coal-bearing strata. The deposits formed in zones of young volcanism are of the utmost interest.

91. As the formation of alunites is connected with the influence of sulphuric gases and solutions on the bearing rocks, veined and layered deposits of alunites are known, depending on their penetration. Deposits formed during the process of surface sulphuric-acid weathering, represent accumulations of alunite nodules in clay. These deposits often form on the ancient karst relief.

92. Alunite is a complex raw material from which, besides alumina, potash and sulphuric acid can be produced. Since ancient times mankind has received alum from alunites. For the first time the industrial use of alunite was started on a large scale in the United States of America, in the state of Utah in the Merriswell region. Potash was extracted from it. A pilot plant for processing alunite to alumina has been built in Salt Lake City, Utah.

93. Alunite deposits of different genetic types are known in many parts of the world. The largest deposits are said to be found in south-eastern China in Phan-Shan and Taihu. Reserves are estimated to be 210 to 280 million tons. The deposits here are represented by alunitized rhyolites and their tuffs. The lodes have a layered nature and a considerable thickness. In the Union of Soviet Socialist Republics large alunite deposits are found in the South Caucasus and are connected with tuffaceous and volcaneous rocks. These deposits have large dimensions. There are relatively small deposits in the United States of America not exceeding 10 million tons each but having a rather high content of alunite. In the above-mentioned Merriswell deposit it constitutes on the average 54 per cent. Deposits in the state of Wyoming representing alunitized clay schists contain 60 to 90 per cent alunite and are of great interest because of their dimensions and the extent of alunitisation.

94. It is stated that in Puerto Rico in the region of Porro la Tisa there are large deposits of alunite, probably of a secondary quarzite type; according to an estimation the reserves exceed 280 million tons. However, the type of the deposit does not seem to have value for industrial significance. There are interesting deposits of alunites in Australia where they are exploited as raw material for the production of potassium salts and alum. However, the deposits of alunite known at present have

been discovered, unfortunately, chiefly in countries where large bauxite deposits are known - China and Australia. The economic ability of alunite ores to compete with bauxites under equal conditions is not yet known.

V. OUTLOOK FOR DISCOVERY OF NEW RESOURCES OF ALUMINIUM RAW MATERIAL

Present deposits

95. Bauxite formation took place during the time of the total geological history of our planet. The most ancient outcrop of bauxites which can be attributed to the Sinian period exists only in the Union of Soviet Socialist Republics and is in Eastern Siberia at the frontier with Mongolia. However, there are no reasons to think bauxites are unique for that epoch. Analysis of geological conditions attribute to the Upper Proterozoic period a wide development of bauxite accumulations. There are also bauxite outcroppings related to the Cambrian period, although they have no practical significance.

96. It is known that in Siberia, India and other regions the deposits of the Cambrian period were favourable for bauxite formation. In the Union of Soviet Socialist Republics deposits providing the aluminium industry with raw materials at present are connected with the Devonian period. Besides the Union of Soviet Socialist Republics, no Devonian bauxite-bearing rocks have been discovered in other parts of the world, although the Devonian is known in Western Europe, North America, China and Western Australia. Bauxites are detected in a greater extent in the deposits of the Permian-Carbonic age. Bauxites are known in the Union of Soviet Socialist Republics (Middle Asia, north-eastern, central regions of the European part of Russia), China, the United States of America, England and France.

97. During the Triassic period bauxites were probably formed on the Indo-Chinese peninsula. Bauxites of the Cretaceous and Tertiary periods are particularly well known. Deposits belonging to this age are known to be in Europe, Asia, Australia, China, North America, India and Central America. At present the main part of bauxites being processed by the aluminium industry is provided by these deposits. Quarternary as well as the present bauxites and bauxite-like rocks are spread chiefly on the territory of Equatorial Africa, South America, Australia, on the Indo-Chinese and Hindustani peninsulas and Indonesia.

Discovering new deposits and increasing existing reserves

98. Assumption of the fact of existence of a deposit within a certain geological period cannot serve as a basis for a general discovery of bauxites. For discovery of bauxites it is necessary to determine many geological factors, such as: location of the climatic zones in different geological epochs, as bauxites were formed in

tropical and subtropical regions; tectonic conditions and paleogeomorphological conditions of specific regions; and spreading of eruptive and other alumosilicate rocks, which can be mother-bauxite.

99. The geological history of our planet has been studied on the whole only in a general way and merely from the point of view connected with determination of useful minerals. Therefore, a sufficiently optimistic estimation of the possibility of discovering new bauxite-bearing regions is reasonable. The success reached in present technology has decreased the requirements for bauxite ores. Proceeding from these two conditions we may consider the estimation of world resources of 10 to 15 milliard tons, made by different experts, as far from being an optimum. The greatest increase of bauxite reserves may be expected on the African continent, where about 50 per cent of all reserves discovered at present are concentrated. We may expect that reserves of this part of the world may be doubled. A reliable prediction can be made with respect to the discovery of bauxites in Asia. The islands of Indonesia, the territory of China, countries of the Indo-Chinese peninsula and India have practically not been investigated. The part of the reserves of these countries is estimated as 10 per cent of world reserves. In the future we expect here not a doubling of reserves, but a far greater increase of them.

100. The possibilities of an increase of bauxite reserves in Europe are more limited. Geological knowledge does not allow for a discovery of large deposits. However, it is quite possible to expect not less than a double increase of European resources. The increase of the reserves in Europe will probably take place at the expense of ores in old bauxite-bearing regions, which are o nsidered to be low-grade according to present technological requirements. But the possibility of discovering large deposits of high-grade bauxites in Yugoslavia, Greece, Turkey, both in the "European" - Low Cretaceous bauxite horizon and in more ancient ones, e.g. in France in the Carbonic, cannot be excluded. Summarising, it is necessary to say that the bauxites on the earth, especially those, connected with the ancient cycles of bauxite formation, have been studied in most countries to quite an insufficient extent. The great number of these cycles and the large deposits, connected with them in separate bauxite regions, allow discoveries of new deposits in other regions where similar geological conditions exist.

101. Achievements reached in technology allow for the extraction of alumina buaxite ores with a considerably worse composition than that of ores being processed at present, but with the same technical-economic indices. These conditions permit an estimate of the possible world reserves of bauxites at not less than 25 milliard tons.

102. The total reserves of alumosilicate alkaline (nepheline rocks) and alumosilicate alkaline-free (feldspathic and kaoline rocks) raw materials undoubtedly constitute many scores of milliard tons. It is impossible to show how they are spread quantitatively among continents and countries because this question has not been studied sufficiently. Nepheline-containing rocks are certainly the most perspective ones for the next 20 to 30 years. Up to now large reserves of this raw material have been discovered only in the Union of Soviet Socialist Republics, the United States of America and Canada. Nepheline rocks are especially economical for countries which cannot count upon discovering bauxites because of their geological structure such as Canada and the Scandinavian countries.

103. Alumosilicates of the disthen type are of common interest to all countries, especially those with a high consumption of aluminium. In the use of these minerals there is a possibility for rational producing of alloys and simumine omiting the separate stage of obtaining alumina and metallic silicon. The processing of such rocks would keep bauxite for the production of pure aluminium. Reserves of disthen rocks have been discovered only in a few countries such as the United States of America, the Union of Soviet Socialist Republics and South Africa but the potential possibilities of their discovery are very great.

[redacted]

74. 10.10