



# Representative Sampling for Elaboration of the Alumina Manufacturing Process (Theory and Practice)

George Komlóssy\*

Managing Director, GeoKom Geological Exploration Ltd, Vercse u. 23 H-1124 Budapest Hungary.

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## Abstract

Sampling of any geological formation needs comprehensive knowledge of the rock genesis, through the di- and epigenetic processes (secondary alterations) up to the physical properties and the chemical and mineralogical composition of the rock. Well established theoretical knowledge should be complemented by practical experience. Besides the geological exploration of a raw material, its representative sampling is the most responsible task of the expert. Elaboration of the technology of the mineral processing i.e. the operating cost of the plant highly depends on reliable sampling which is essential for an optimal utilisation of the deposit. Nowadays, when green-field plants below 1 Mt/a capacity are rarely set up, proper sampling is even more important than before. Several million USD/annum can be saved in operating cost with a well-established sampling procedure which, according to the experience of the author, is often neglected by the investors or project management. In this paper the author clarifies the terminology of the characteristic and representative samples and introduces several typical cases both for karst and laterite bauxites. Distinction is made between technologically homogenous and heterogeneous type deposits. Examples are taken from Iranian, Indian, Vietnamese, West African, and South American deposits. Proposals are given for sampling procedures in different stages of the exploration, when the first samples are to be taken for technological tests. The question is investigated whether the bauxite is necessary for an already operating plant (when the bauxite should be fitted to the plant) or when a green-field refinery technology is to be fitted to the deposit(s). In conclusion, it is established that no reasonable economy may exist for mining and alumina processing separately. The economy of the mine and the plant is to be regarded as a single economic unit. For achieving this purpose reliable representative samples are necessary.

**Keywords:** Bauxite, Sampling, Alumina manufacturing, Refinery.

## 1. Introduction

All kinds of geological sampling for analyses need comprehensive geological knowledge about the rock (geological formation) to be sampled. The purpose of the sampling determines its method. Establishing the actual sampling method belongs to one of the most important responsibilities of the geologist; first of all if it relates to a mineral resource, that is, a possible financial investment. For elaboration of the technology of processing of the mineral the geologist must be aware of the detailed information on the quantitative and qualitative characteristics of the ore deposit(s) such as:

(1) Size: extension and thickness, along with the shape of the ore body (as quantitative parameters which determine the number of the sampling sites).

(2) Chemical and mineralogical make up of the ore body and their variance both in horizontal and vertical terms. In this aspect the geochemistry, the genesis and the possible secondary alterations must be understood, as well. These qualitative parameters, beside the

number of the sampling points, determine the location of the sampling sites.

This information is based on the knowledge of the general geological features of the deposit derived from the exploration data, individual laboratory assays and data of the reserve/resource estimates of the ore deposit. For satisfying the demand of representation a composite sample must be collected which is fitted, not only to the results of the reserve's inventory, but to the grade of the run-off mine ore planned to be extracted in a long term. In the following the most important geochemical and mineralogical characteristics of bauxites are summarised and a guide-line is given for sampling.

It is emphasized that no universal prescription can be written, as the bauxite deposits are so different in their nature that the sampling methods must be fitted to the deposit(s) and to local conditions.

***Some aspects to the question: what is a representative bauxite sample to be collected for technological tests?***

From the geomathematical point of view, Bárdossy [1] distinguished six sampling systems such as: (a) random, (b) pattern, (c) traverses, (d) cluster, (e) random stratified grid and (f) regular grid samplings. Representative sampling for technological purposes

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\*Corresponding author.

E-mail address (es): komgeo@hotmail.com

represents partly a combination of (b) and (e): as the sampling points are spaced in such a manner that they are fitted to the shape of the deposit (b) and as they involve the series of individual samples (e) and partly (f) (see Section 5.3.).

**Representative sample**, as the term used in this study, is a special case of geological sampling. It serves a definite purpose, that is, clarification of the technological properties of the alumina ore. Several hundred kg of bauxite has to involve the most possible relevant information about the million or hundred million tons of an anisotropic mass. The data for determination of the most viable processing methods must be in harmony with the qualitative characteristics (chemical and mineralogical make up) of the available source(s). The capacity of the refinery is based on the demand of the market and the optimum production rate. Accordingly, the companies select among the possible resources. Most of the operating and several investment costs are also deduced from the results of the tests. Representative bulk sample is composed of:  
 -individual samples representing one meter interval and  
 -subsamples representing one section (average of a bore hole, pit, or channel of mine face composed from individual samples).

From the *chemical point of view* the bauxite sample can be regarded as a representative one provided the difference between the expected run-off mine ore (diluted quality) and the sample is in the following ranges:

-Al<sub>2</sub>O<sub>3</sub> (av.) % < +/- 1.5 abs.% if the Al<sub>2</sub>O<sub>3</sub> (t) content is >45% and 1.0 abs.% if it is < 45%,

-SiO<sub>2</sub>(r): +/- 0.5 – 0.8 abs.%, if the SiO<sub>2</sub> (r) content is > 5.0 % and 0.5 abs.% if it is < 5%.

**At any rate, the conditions must be clarified with the responsible process engineers before the sample is composed.**

In the case of laterite bauxites the difference for Fe<sub>2</sub>O<sub>3</sub> is not so important because there is a very close negative correlation between the Al<sub>2</sub>O<sub>3</sub>(t)% and Fe<sub>2</sub>O<sub>3</sub>%. The correlation coefficient (R) is around 0.90 – 0.95. As a consequence, if the bauxite is representative for alumina it must also be representative in its iron oxide content within an acceptable range (+/-1-2%). On the contrary, in the case of karst bauxites the correlation between the alumina and iron, is a positive one and it is not so tight. The representative sample should be taken in such a way that the difference in iron be less than 2 abs. %.

The other contaminants like C<sup>org</sup>, ΣSO<sub>3</sub>, ΣCO<sub>2</sub>, MnO<sub>2</sub>, etc. are related typically to the epigenetic (secondary) processes. Their variances are extremely high both vertically and horizontally. These elements are not involved in the routine analyses of the exploration but in most cases there are data, for the deposit average. Based on geostatistical calculation

extreme and most frequent values may also be known. Process engineers must be informed about these data and it is also necessary to take these into account when the bulk sample is being composed (see details in Section 6.1).

Based on the exploration data the representative sample must be taken within the real variance of each element. It means that the representative bulk sample has to involve individual samples of extreme concentrations of each main element. However, it must be emphasized that how far the sample will be really representative in practice, i.e. how far the chemical composition of the sample and mine product are uniform, depends highly on how far the exploration and reserve calculations are reliable, and how far the mining method is fitted to the deposit characteristics.

**The representative sample comprises all of the errors of the exploration method, techniques, sampling, analyses and reserve calculation.**

As far as the *mineralogical representation* is concerned the question is more complex. It can be stated, with the exception of some deposits, that the mineralogical tests are neglected during the exploration, so that, when sampling points are marked out the geologist has not always adequate data. This inadequacy does not play a significant role provided:

(a) the routine analyses comprise the determination of the available alumina and reactive silica contents measured regularly under one digestion temperature (such as Fria – Guinea, Saddleback – Australia, etc.), or under different temperatures (e.g. Sangaredi) and the sampling points can be marked on the basis of these data

(b) the bauxite is expected to be “homogenous” from the mineralogical point of view: the mineralogical make up can be deduced from the chemical composition (see details in Section 4)

(c) the bauxite is “heterogeneous” but the mineral alterations are restricted only to the vertical direction.

When the mineralogical make up is suspected to change horizontally and no sufficient information is available on the mineralogical make up of the bauxite (which is the usual case), it is recommended that the subsamples be investigated before blending them for representative bulk sample (Section 6.2)

**The total quantity of the representative (bulk) sample advised by the process engineer(s) varies between 50kg and 200kg for a preliminary lab test and 1-2 tons for refinery design.**

## 2. Heterogeneity of the ore body: vertical and horizontal changes in the mineral composition

The mineralogical constitution depends on the Eh-pH conditions [2, 3, 4, 5 and 6].

The Eh-pH conditions are controlled by the paleorelief, i.e. determined by the position of the area of bauxite forming/accumulation which varies as a function of the oscillating karst or ground water table. In case of the laterite bauxites the parent rock is also an important factor in the bauxite chemistry and mineralogy.

As these conditions vary within even one deposit (ore body) the chemical and mineralogical compositions of bauxite deposits also change both vertically and horizontally. There are data on the distribution of the main elementary components, sometimes semi-variograms and iso-concentration maps are also available; if not, they can be computed and constructed by using different programs. Such documents help in the location of the representative sampling sites.

As far as the mineralogy is concerned, from the processing view point, the changes of the gibbsite: boehmite, boehmite: diaspore, goethite: hematite, kaolinite: quartz, kaolinite: chamosite ratios and  $Al_2O_3$  molar % ratio in the iron minerals are the most important data.

In several cases, secondary (accessory) minerals like pyrite, alunite, calcite, siderite, etc. may also occur in high variance within short distances. Distributions of these accessories are known, if at all, only vertically. It is impossible to take into account their horizontal distribution when the sampling points are decided. The process engineers must be informed about their expected extreme values in the mine product.

**Horizontal changes** in mineralogy are typical mainly in karst bauxites. It is an important phenomenon because it plays a role in the number and location of sampling points; however, these data are sporadic.

For example, in the Iszkaszentgyörgy (Hungary) deposits, the gibbsite/boehmite ratio drops from 2.0:1.0 to 1:10 and the goethite/hematite ratio increases from 4:1 to 3:1 towards the N and NE directions [4]. In the Jajarm (Elborz – Iran) deposit, the chamosite/diaspore ratio increases dipward (from the south to the north); Chamosite concentration changes from about 1-5% (southern outcrops of the Golbini and Zoo sectors) up to 15 – 18% in the north. A similar phenomenon is known at the Severouralsk bauxite deposit (Russia) where chamosite and carbonate minerals increase from the west to the east (dipward).

There are not known available data for horizontal mineralogical changes in laterite bauxites with the exception of the Az Zabirah (Saudi Arabia) where the decrease in gibbsite: boehmite ratio was revealed along the strike line from NW – SE [7]. Some examples for horizontal changes in mineralogy are shown in Fig. 1, 2 and 3.

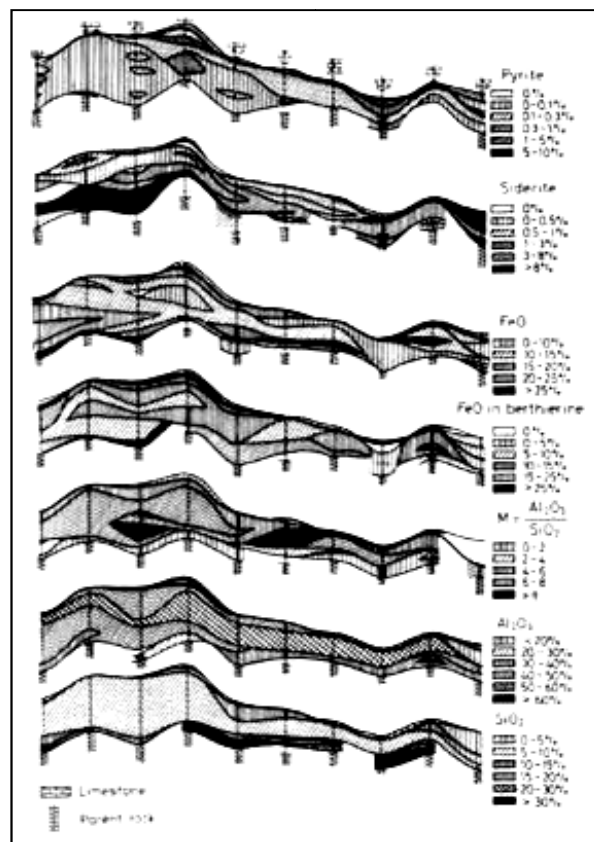


Fig.1. Mineralogical and chemical cross-section of the Belgorod (Russia) Bauxite deposit (Nikitina, 1985) in [8].

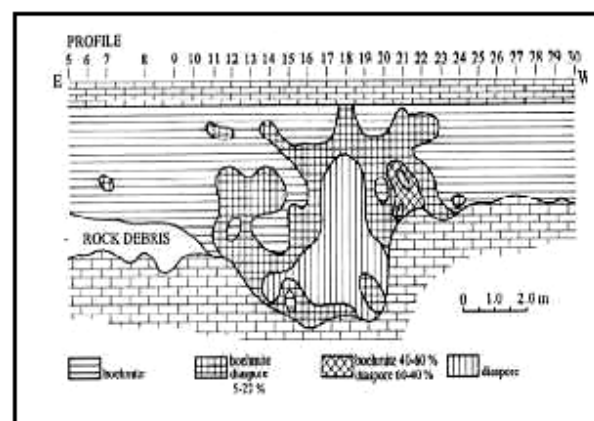


Fig.2. Distribution of alumina hydrate modifications at the southern edge of the Kethro deposit (Greece) [5].

There are much more data on the vertical changes of the mineralogical make up both in the karst and in the laterite type bauxites. Typical vertical mineralogical profiles are shown in Figs. 5–7.

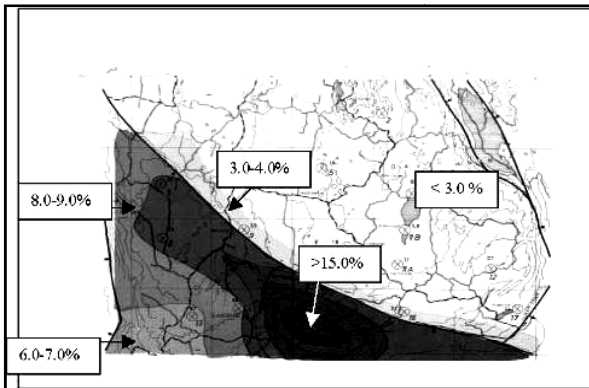


Fig.3. Manchester Plateau South – (Jamaica); Distribution of boehmite concentration: ALUTERV -FKI – Javemex Report [9].

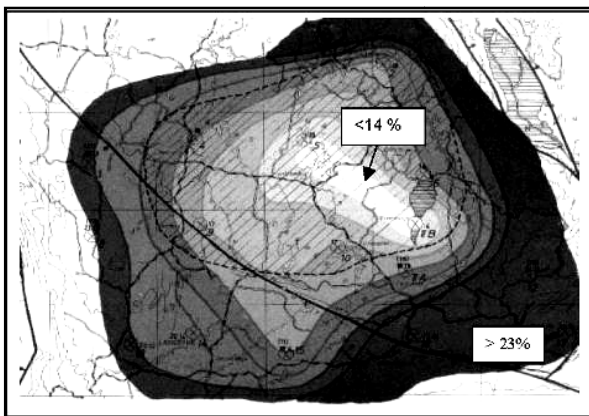


Fig.4. South Manchester Plateau (Jamaica): AIOOH substitution in goethite (mol%). Isolines are in 1 % interval [9].

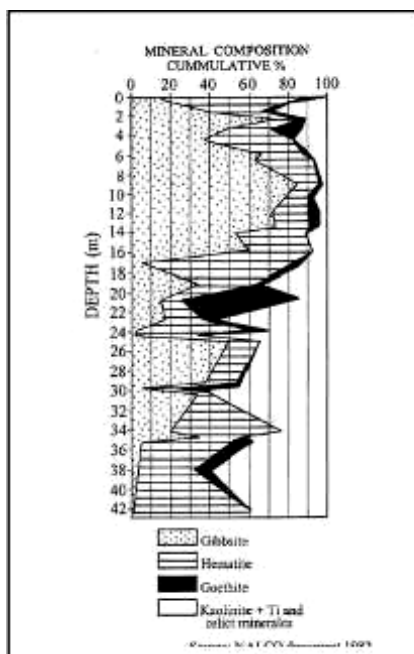


Fig.5. Mineral composition of the Panchpatmali Plateau (Orissa-India) BALCO document [10].

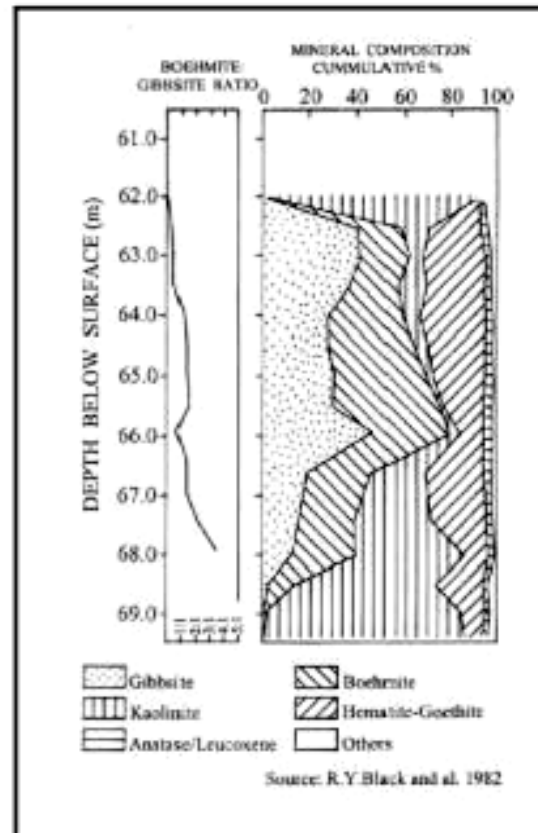


Fig.6. Mineral composition of the Az Zabirah deposit (Saudi Arabia) [7].

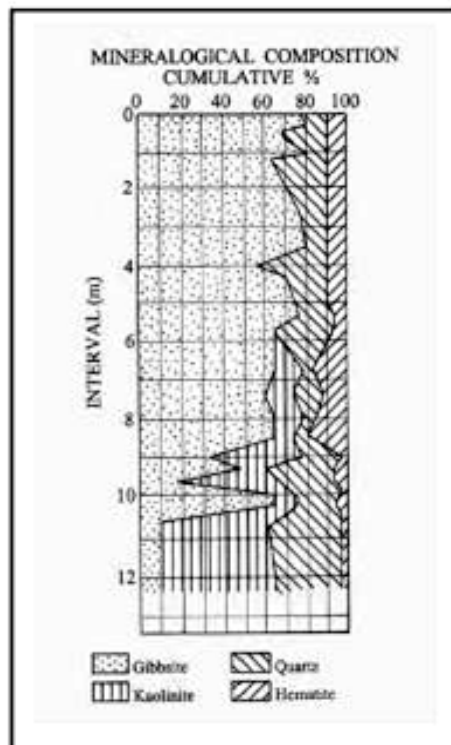


Fig.7. Mineral composition of the Los Pijiguaos deposit (Venezuela) [11].

### 3. Classification of the bauxites by their mineralogical composition

Based on the fundamental processing properties of the bauxites they are classified into the following main types:

- (a) Gibbsite bauxite: at least 95% of its free  $\text{Al}_2\text{O}_3$  content must be in gibbsite<sup>1</sup> form.
- (b) Gibbsite/boehmitic and gibbsite / boehmitic+diasporic bauxite: at least 90% of the free  $\text{Al}_2\text{O}_3$  content must be in the gibbsite<sup>2</sup> form.
- (c) Boehmitic bauxite: > 10% boehmite, at least 95% boehmite+gibbsite.
- (d) Boehmitic/diasporic bauxite 5%-10%; free alumina content is in boehmite and/or diasporic form.
- (e) Diasporic bauxite: more than 10% of its free  $\text{Al}_2\text{O}_3$  content is in diasporic form
- (f) Chamositic/diasporic bauxite: chamosite content is more than 5 %.

The reason for the virtually asymmetrical classification is that a bauxite with more than 10 % of the less digestible mineralogical form of free  $\text{Al}_2\text{O}_3$  requires such digestion conditions which correspond to this mineral. Bauxite with 5% to 10% of the less digestible mineral requires digestion tests at both sets of conditions, because on the basis of the test results detailed economic calculations will decide which digestion conditions will be selected for their processing. In the case of chamositic bauxite, such a process parameter should be selected which ensures that the balance of the digestion of the diasporic and chamosite be optimal, i.e. the maximum amount of diasporic and minimum amount of chamosite be dissolved.

In order to find the common understanding between the geologists and process engineers, it is recommended for the economic geologists to follow the classification of the bauxites, described above because it determines the most important technological properties of the feedstock and it is in harmony with the value of the ore, as well.

### 4. Grouping of bauxite deposits based on their processing properties and the number of representative samples

#### Homogenous bauxite deposits

The total amount of the ore can be processed by either low (140-170°C), medium (240-260°C) or high (260-300°C) temperature ranges of digestion.

<sup>1</sup> It is also qualified as "low mono content" ore (Sangaredi – Guinea)

<sup>2</sup> It is also qualified as "high mono content" ore (Sangaredi – Guinea)

1. Based on the aluminium bearing minerals the whole deposit can be ranked into one of the groups from (a) to (f) as described in Section 3 and the trihydrate / monohydrate ratio is constant.

2. Silica minerals are either fully in kaolinite or the kaolinite/quartz ratio is relatively constant.

3. Iron minerals are mainly in hematite or in goethite or the hematite/goethite ratio is relatively constant.

4. Other contaminants like carbonates, C<sup>org</sup>, sulphur, etc. can be constantly kept at an acceptable level during the mining operation.

In such a case it is satisfactory to take 1 representative sample.

#### Heterogeneous bauxite deposits:

##### Laterite bauxites:

Based on the aluminium bearing minerals different types of ores may occur in one deposit: the so called *low mono content* type (a) and *high mono content* type (b, d); most frequently in laterite bauxites type (a) and (b) are present i.e. the gibbsite / boehmite ratio changes horizontally and/or vertically. There are two possibilities:

(1) High mono content type of ore cannot be extracted separately – the total amount of the ore is digested under medium- or high-temperature conditions. In this case the fluctuation in gibbsite / boehmite and in kaolinite / quartz ratios do not play a significant role in the selection of technology. One representative sample may be enough + 2 separate subsamples, representing 1-10% of the bulk sample in weight are recommended to be collected from the extreme parts of the deposit.

(2) High mono content bauxite can be separately extracted. The run-off mine ore is stocked and supplied separately to different plants. Two representative samples are needed for two different plants.

Based on the iron concentration some deposits can be divided into an iron rich ( $\text{Fe}_2\text{O}_3$  typically > 24 – 26 %) and an iron poor ( $\text{Fe}_2\text{O}_3$  typically: 12-15%) part due to the different parent rocks (e.g. Saddleback – Worsley mine, Australia or Sinthiourou, Boké, Guinea, etc.). In such cases process engineers are satisfied with three samples; one main bulk sample which represents the average values and two (smaller) subsamples representing the two extremes.

##### Karst bauxites

Karst bauxite mining usually proceeds from the surface toward the depth. It may occur that the bauxite grade and mineralogy gradually change with depth (Section 2). No average bauxite can be shipped to the plant but only a continuously changing ore. In this case either the plant homogenises the quality from different sources or pays different prices for the bauxite or both. In such a situation one representative sample should be

composed on the average values and two subsamples should be taken from the extremes.

In some karst deposits, ore bodies are significantly different in their mineralogical constitution. The example of the Manchester Plateau (Jamaica) shows how far the goethite concentrations are different in two parts separated by a fault zone (Fig. 3) or how far the rate of the Al-substitution in goethite disperses horizontally (Fig. 4). This is also the case when three samples are recommended to be collected.

## 5. Compilation of a sampling plan

### 5.1. Data required:

- (1) Capacity of the refinery, that is, bauxite demand (quality and quantity).
- (2) Concept of mine planning for the next 10 – 30 years, i.e. location of the ore reserves planned to be extracted
- (3) Minimum thickness of ore planned to be extracted
- (4) Run-off mine ore reserves (tonnage and grade by mining units; ore bodies)
- (5) Chemical and mineralogical analyses of the bauxite, accessory (contaminant) elements.
- (6) Quantity of the sample.

Overview of the geochemical, hydrological (drainage conditions) and geo-morphological features which are determinant in deposit geology: establishing the variance of each main element and mineral both vertically and horizontally.

### 5.2. Marking of the sampling sites on map:

The number of the sampling points depends on:

- (1) Tonnage of the reserves taken into account.
- (2) Number of the ore bodies taking also into account their size and shape.
- (3) Heterogeneity of the reserve (details in Section 5.)

### Notes:

(1) As a general rule, provided the deposit represents >100 million tons of bauxite, the number of sampling points should be 1 whole section ( bore hole, pit, channel sampling from mine face) for every 5 - 6 million tons of bauxite. In case of a smaller deposit (ore body) relatively more sampling points are recommended to be marked e.g. in case of a deposit of about 10 million tons one sampling point should represent 2.5 – 3 million tons.

2) When a deposit consists of more ore bodies all of them are recommended to be sampled, provided its reserve reaches the tonnage of minimum annual production of the mine. Each ore body is to be sampled in proportion to its tonnage.

(3) If the bauxite to be sampled is heterogeneous (see Section 5) it is not always necessary to mark more

sampling sites, but in their location its heterogeneity is to be taken into account and composition of three sample(s) are advised such as: one big bulk sample which represents the average values and two smaller subsamples for the extremes. In such a case three tests are advised to be made: a complete test and two partial ones especially for those properties which may influence the choice of technology.

### 5.3. Location of sampling sites on laterite deposits

Sampling points (bore holes, pits), having been marked on a map, must be checked on the sites to clarify the access possibilities.

In the case of surface (laterite) bauxite the shape and the morphology of the ore body gives the guideline for locating the sampling points. Based on the morphology there are three main types of deposits. In all of the three types, the points must be located in such a way that the possible horizontal variation of mineralogy be taken into account.

(1) The deposit consists of number of ore bodies developed on an undulating surface and the commercial grade ore is restricted to the positive morphological forms (single or complex heaps (e.g. Fria – Guinea, Mulanje (Malawi), Bao Lok (Vietnam, etc). The points are to be located at the weight point(s), close to the centre and also at the slopes at different topographic levels Fig. 8.

(2) The bauxite deposits are developed on elongated, amoeba like quasi-flat plateaux such as the bauxites developed on Deccan basalt, or khondalite in India. Sampling points are proposed to be located at the “reference points” of the deposit (pattern sampling, Section 1) as shown in Fig. 9.

(3) Huge, slightly undulating plateaux, representing bauxite in order of 100 million tons such as: Bidikum, Sinthiourou in Guinea, etc. a regular grid sampling is recommended to be carried out (Section 1)

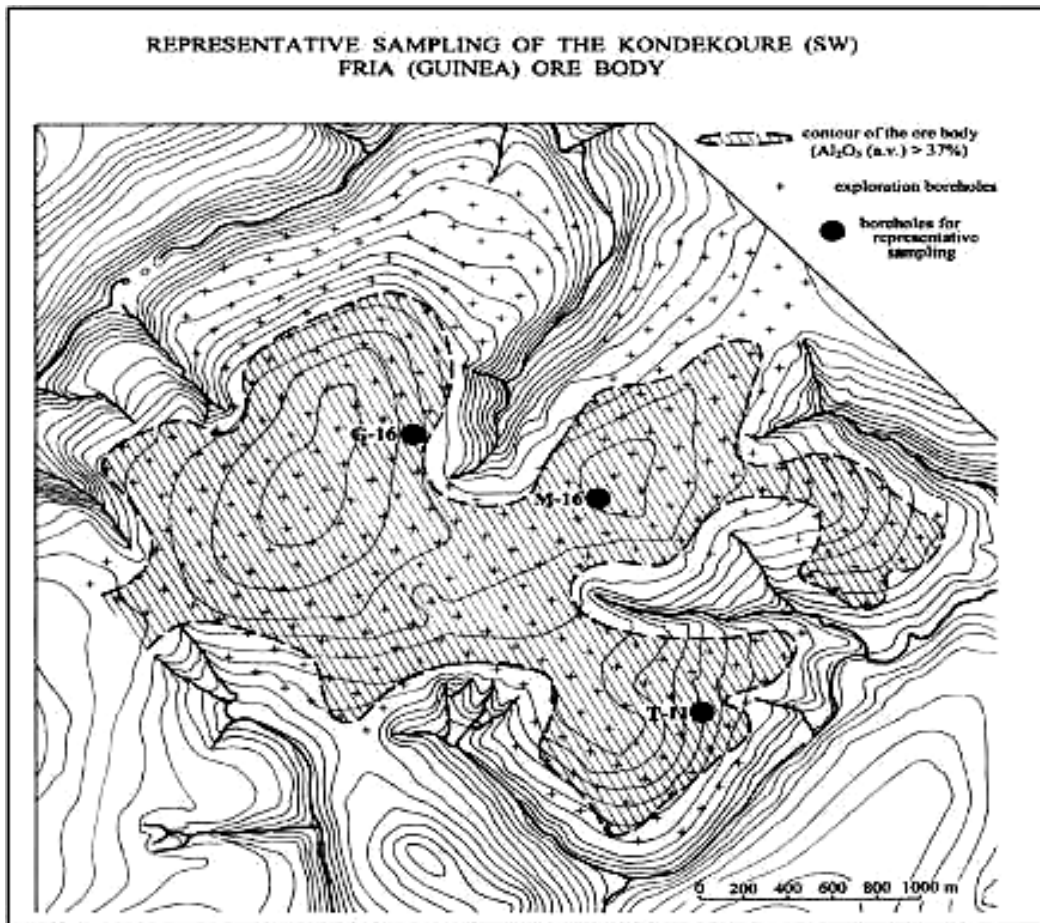


Fig.8. Representative sampling of the Kondekoure (SW) ore body Fria (Guinea) [12].

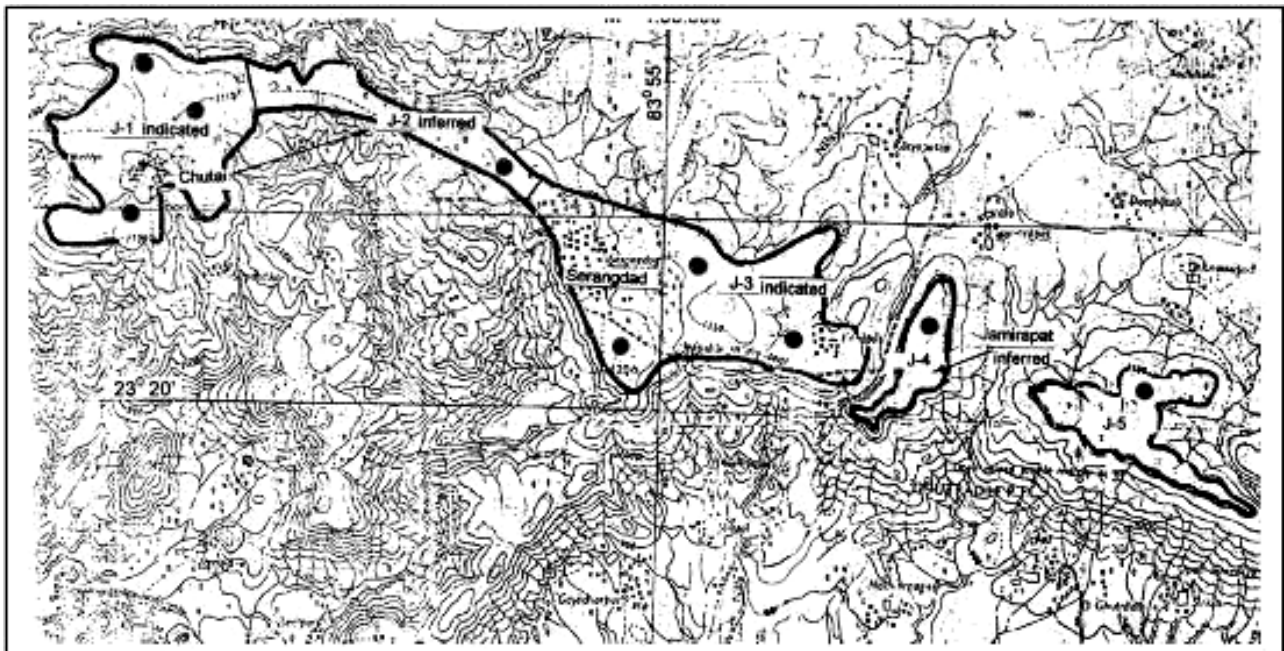


Fig. 9. The Jamirapat Plateau (Chattisgarh State – India) showing reference points on a Deccan bauxite deposit proposed to drill for sampling [10].



## 6. Sampling method and analyses

### 6.1. Sample taking and preparation for analyses:

- Sampling can be made from bore holes, from pits or mining face (channeling).

- Samples must not be taken from old pits (along the wall of old pits the bauxite quality has considerably changed (kaolinite is washed out, iron precipitated, even within a half meter width even in a very short time).

- As demonstrated in Figs 5, 6 and 7, the whole extractable section must be sampled in order to represent the vertical changes in mineralogy.

- Samples are advised to be taken at one meter intervals and analysed for  $\text{Al}_2\text{O}_3(\text{t})$ ,  $\text{SiO}_2(\text{t})$  and  $\text{Fe}_2\text{O}_3$ . It is very useful if the following additional measures are taken:

(a)  $\text{Al}_2\text{O}_3(\text{av})$  and  $\text{SiO}_2(\text{r})$  are also determined, if not in every interval, at least in a composite sample of one section,

(b) the accessory contaminants ( $\text{C}^{\text{org}}$ ,  $\Sigma\text{SO}_3$ ,  $\Sigma\text{CO}_2$ ,  $\text{MnO}_2$ , etc.) are also advised to be analysed in each section in order to learn how far the expected average values of these elements fit to the reserve averages.

- Mineralogical tests of every sampled section are highly recommended to be made before the sample compilation.

- It is advantageous if the analyses are made at the existing plant (if any) which utilises the bauxite or at the mine's lab with the same procedure as was done during the exploration. When the analytical methods are different the correspondence between the methods should be clarified.

- Depending on the required total weight of the representative sample from one sampling interval, one wet sample (1–10kg) is needed + two additional spare bulk samples representing about 2 x 20% of the total representative sample. One spare sample may be needed for upgrading and another one for downgrading purposes (see Section 7.2.).

- For preparation of bauxite for analyses it must be ground to:

In case of 1 kg sample: grain size < 4.5 mm

In case of 10 kg sample: grain size < 14mm (Richards-Cherchette's formula)

### 6.2. Sample compilation

- Weighted average chemical composition of the individual samples is to be calculated.

These results must be compared with that of the run-off mine ore planned to be extracted. The difference will be greater than accepted for a representative sample (see details in Section 1) either for one or more components.

Such a calculated (theoretical) blending is to be made

which satisfies the demand by adding proportional quantities from the individual samples. It is a mathematical iteration and the result is still a theoretical composition.

- In case of heterogeneous bauxites subsamples are also recommended to be composed (from each section) for making analyses for accessory elements (contaminants) and mineralogy. In this case the representative sample should be combined on the basis of the average values of the subsamples.

- The well-blended bulk sample must be sampled by forming a cylinder which is not higher than 20 cm in case of 100 kg sample and 50 cm in case of a one ton sample. At least three channel samplings are to be made by mixing the bauxite prior to each sampling. Sample taken out in this way must be reduced by quartering and prepared for analyses. The analytical results may be still different from the required composition.

- The desired composition can be reached by proportional addition of the spare samples (up-grader or down-grader).

If we follow the procedure correctly we will have a bulk and reliable sample which is hopefully representative or at least very close to it.

### 6.3. Case history about a representative sampling carried out at a bauxite deposit in Guinea [12]

#### Initial data:

- Required bauxite for an alumina plant: 80 Mt in a period of 20 years.

- Average quality based on the reserve calculation:  $\text{Al}_2\text{O}_3(\text{av})$ : 41.72%,  $\text{SiO}_2(\text{r})$ : 0.77%, cut-off grade is given at > 37 % ( $\text{Al}_2\text{O}_3(\text{av.})$  at 107 °C)

- No mining loss and dilution were taken into account in the reserve calculation (unfortunately),

- Number of ore bodies: 7.

- Sampling -14 bore holes were drilled + 2 additional samples taken: one from mining face (channel sample) and one from the stock yard.

- One section represents 5 Mt of bauxite.

- Altogether 117 individual samples were collected.

- Analyses and preparation -Each individual sample was weighed and analysed in the plant lab.

- Calculation of the weighted average composition. - Reducing the weights and excluding several intervals in order to achieve the average values of the desired grade. The third calculated (theoretical) variant satisfied the demand. 76 individual samples (from the 117 ones) were selected for blending as follows:

- Mixing of the individual samples.

- Channel sample was taken from the homogenized bulk sample

- Checking the grade of the bulk sample in the plant lab.



-The bulk sample was reanalysed in a European lab where one of the series of the technological tests were made.

Based on the above data it can be established that the grade of the representative sample determined at the plant's lab compared to that of the mine product expected to be extracted in the next ten years satisfies the demand of the concept of representation as detailed in Section 1.

The original 117 individual samples gave a lower concentration for alumina as it had been expected on the basis of the exploration bore holes. For upgrading the weighted average values of bauxite exclusion of 41 samples was necessary. The reason is that the data of the bore holes drilled for sampling purposes have not confirmed the results of the exploration bore holes in every case.

In order to avoid such a discrepancy between the average grade calculated on the basis of the exploration bore holes and the averages of the representative sampling bore holes it would have been better if *upgrader* and *downgrader* spare samples were collected (see Section 6.1) because it is better to add rather than to omit from the collected sample.

## 7. Economic considerations

The basic concept of the present author is that the geology, mining, transport and alumina manufacturing is one single economic unit where the maximum profit should be achieved. In this respect there are three determinant items:

- (1) Operating cost of the plant
- (2) Operating cost of the mine (including transport cost)
- (3) Lifetime (both the mine and plant).

Representative samples are usually taken when the deposit has been explored and reserve calculation made: quality and quantity accepted (several times by authorities). The representative sampling is fitted to a

previously decided source in which the concept of the cut-off grade ore was not justified economically. Unfortunately, the established cut-off values which determine the tonnage and grade of the bauxite – were not always clarified by technological tests and economical calculations. During the exploration and reserve calculation the geologist is not aware of the grade which makes the highest profit in the bauxite - alumina industry.

Let us investigate this question based on a rough estimation for a Deccan bauxite. Modification of the bauxite and caustic soda price at an alumina plant of 800,000 t/a capacity, as a function of different cut-off values, are shown in the Fig. 10. The tonnage drops by 35% and the value of the deposit increases by 151 M USD when the two extreme variants are compared as summarised in Table 2.

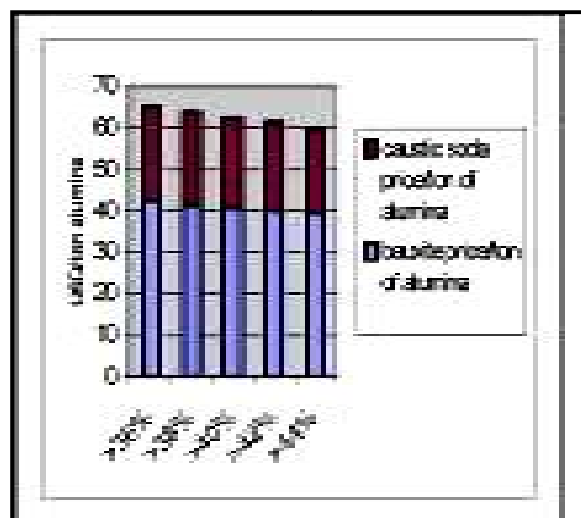


Fig. 10. Bauxite and caustic soda price at different cut-off values for  $\text{Al}_2\text{O}_3$ .

Table 1. Comparison of chemical data obtained at different stages of investigation and by different labs

Bauxite	$\text{Al}_2\text{O}_3$ (av.) % 107° C	$\text{Al}_2\text{O}_3$ (t) %	$\text{SiO}_2$ (r) %	$\text{SiO}_2$ (t) %
Average of bauxite in the Company's inventory, status 01.04.	41.72	na	0.77	na
Average quality of the mine product between 2004 – 2013	40.20	na	1.05	na
Calculated weighted average of 117 individual samples	37.80	na	1.10	na
Calculated weighted average of 76 individual samples	42.36	na	0.89	na
Composition of representative sample Analysed at Company's lab(111.3 kg /107°C)	40.30	42.80	0.94	2.17
Composition of representative sample Analysed in the European lab (30kg 155°C)	39.60	44.09	0.75	2.27

The above example suggests that the representative sampling for technological test ought to be taken after the correctness (economical viability) of the cut-off value is established. For that reason it is highly recommended that before the representative bulk sample is composed the economic parameters be clarified and if necessary the recalculation of the reserves made. Representative bulk sample is to be collected and composed for technological purpose accordingly.

## 8. Sample for beneficiation tests

When the exploration was being carried out in such a way that the samples were beneficiated continuously as a routine procedure of the exploration program (i.e. Trombetas – Brazil, North and South Vietnam) the recovery was another factor which determined the location of representative sampling points. In this case it was very important to be aware of the fact that both the quantity and quality of the recovered fractions depend on the beneficiation method. It is a general rule that when the quantity is less, better quality can be gained. If different beneficiation processes were applied in the course of the exploration as planned to apply on the industrial scale, the geologist must have data which show how the results of the two methods relate to each other.

If the reserves in tonnage and grade were calculated on the basis of the exploration beneficiation process and the alumina refinery will be fed by the beneficiation plant's product. In such a case a new reserve calculation is necessary which is based on the results of the commercial scale beneficiation test. In this case the representative sampling must be based on the results of the recalculated reserves.

The present author took "representative" sample from the Bao Lok deposits (S. Vietnam) in 1989 for ALCAN, based on the exploration data. ALCAN made beneficiation tests from the "raw bauxite" and technological tests from its own beneficiated ore. The sample which was taken was not "representative" for the explored deposit; moreover, it could hardly be called as a similar one. This is the point when the recalculation of the reserves would have been necessary before taking a representative sample. This problem was perfectly solved at Trombetas (Brazil).

## 9. Sampling for grinding purposes.

For grinding purposes a separate representative sample must be taken. Bauxite pieces 5–10cm in size are needed. It may be stated that the hardness depends mainly on the bauxite structure. The sample is to be taken so that all of the texture types are represented proportionally. If there is no access to an open wall for sampling an extra pit should be dug out or core drilling

deepened to take samples in a place where the whole section is presumed to be developed. It is important to mention that bauxite pieces collected from the surface of a laterite plateau are not representative for the deposits (because they are harder than the average).

Table 2. Annual extra profit calculated for different cut-off grades of  $Al_2O_3$ .

Cut off $Al_2O_3$	Extra profit on quality M USD*	Lifetime of the mine
>36	0	40.1
>38	46.6	39.4
>40	56.6	37.6
>42	106.4	35.0
>44	151.2	31.0

\*Cumulative discounted annual "extra profit" was calculated with a discount factor of 1.10

## 10. Conclusions and summary

- All of the deposits and ore bodies of bauxite are different in nature which needs a very careful approach when taking samples for technological tests.
- Unfortunately, according to the general experiences, sufficient data are not always available for taking representative samples (mineralogical tests, iso-concentration maps, semi-variograms, etc.).
- Economic considerations, in many cases, are neglected in the reserve calculation. As a consequence, the responsible geologist has to fit his sampling procedure to such a grade which does not ensure the maximum profit.
- There is no universal standard for sampling, but there are several aspects which are worth following. First and foremost, the sampling sites must be correctly marked which needs not much subjective judgement when adequate data are available.
- Industrial grade section of the bauxite profile must be sampled from its top to the bottom.
- Adequate number of sections must be sampled which may vary between one section per 2–6 Mt of bauxite depending on the size of the deposit and its heterogeneity.
- Subsamples are recommended to be composed so as to represent one section and others for upgrading or downgrading purposes.
- Reliability of the representative sample depends on the reliability of the exploration data and reserve calculation, the applied chemical and mineralogical tests which is the basis of locating the sampling sites.
- There is no point in saving money on the analyses

which are necessary to be made prior to the compilation of the bulk sample.

- A responsible geologist must be present at the time of sampling and sample composition and preparation for analyses from the beginning to the end.

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