EFFECT OF BAUXITE MICROSTRUCTURE ON BENEFICIATION AND PROCESSING

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Abstract

The microstructure of bauxite determines to a significant extent the opportunities for its beneficiation and optimum processing downstream. Adequate fine grinding commensurate with its microstructure may result in proper mineral liberation and grain size distribution required for effective ore dressing (i.e. H/M or magnetic separation) and digestion respectively. Particle size distribution, mean diameter and amount of ooidal grains as well as degree of dissemination of the impurities in polished sections of raw bauxite, ground bauxite and red mud samples were determined by means of scanning electron-microscope, electron probe micro-analyser and digital image analysis. The results of beneficiation tests (effective removal of liberated limestone but insufficient reduction of finely disseminated reactive silica) and the required digestion parameters of the mainly oolitic Greek diasporic and the Hungarian boehmitic (partly dolomitic) bauxite are discussed. Based on the microstructure, the effectiveness of beneficiation, the degree of grinding (required particle size) and also the necessary digestion parameters of any bauxite can be adequately predicted.

Introduction

The microstructure of the bauxite plays determining role in planning and evaluating the technological experiments and in the development of the optimum process technology. Detailed investigation of microstructure is especially important for the ore grinding, the possibilities of the economical beneficiation (ore dressing), the optimization of the process stages of the Bayer process, and above all for the digestion and separation of red mud. The detailed study of the bauxite microstructure along with the quantitative phase analysis are the basic methods applied for technological development. (1) The determination of the opportunities for bauxite beneficiation and elaboration of the ore dressing technology are mainly based on the adequate study of the bauxite microstructure (2, 3) Furthermore, the evaluation and optimization of the Bayer process stages, especially concerning the digestion and red mud separation requires the knowledge of the phase analysis and microstructure of red mud formed under the investigated varying conditions. (4, 5, 6). Recently J. See and M. Edmond (7) delivered a very interesting paper on comparative liberation analyses of silica in sub-economic lateritic bauxites by means of size fractionation studies, mineral texture analyses and image analysis of scanning electron microscope (SEM) to determine appropriate comminution and optimum ore washing methods.

The Microstructure of Bauxite

The texture of a sedimentary rock – according to the Glossary of Geology – can be defined as "the general physical appearance or character of a rock, including the geometric aspects of, and the mutual relations among component particles e.g. size, shape and arrangement of the constituent elements". It is also very important, that this term is applied to the smaller (microscopic – macroscopic) features within the size-range of tenths of micrometers to centimemers.

The texture of a bauxite – as defines the character of the rock in this scale of investigation – has a direct effect on technological properties of this mineral resource if the critical grain size of the ground material is in the same range as that of the critical texture elements or features. Prior to discussing this relationship, we shall breafly introduce the principal texture elements that could appear in a bauxite.

Bauxite is primarily a fine-grained residual sediment, consisting mainly of Al, Fe and Ti oxides and hydroxides with the predominancy of Al-bearing phases. If the environmental and tectonic conditions remain unchanged during the diagenesis and resedimentation does not take place, this microcrystalline material forms a so-called pelitomorphic matrix. Obviously it can include particles with bigger size as well, which usually are remnants of hard, resistant mineral grains such as anatase, rutile, ilmenite, etc.

Changes in physico-chemical conditions during the diagenesis could lead frequently to ooid formation, which is a common textural feature predominantly of monohydrate bauxites. The ooid formation starts on small cores and develops towards, resulting in alternating iron- and alumina-rich shells. These cores of recrystallization are small grains, grain size of which is at least one order larger than that of the matrix. The kaolinite-content usually decreases from the core towards the outermost crust in an ooid.

During late diagenesis, the bauxite material could suffer deformation by tectonic movements and – depending on burial conditions – it can lead to its ductile or brittle deformation. Ductile deformation can be detected by flattened ooids where axes of flatening have the same orientation (see Figure 1). Brittle deformation results in brecciated texture, where the fissures can be filled by gibbsite, diaspore or goethite or by non-bauxite minerals such as calcite or siderite (see Figure 2).

Ductile-brittle deformation not rarely results in pressure solution. It is characterized by stylolite formation subparallel to bedding plane and by pore- or crack sealing subvertical to that. The cracks and pores are filled by crystalline gibbsite or diaspore as the result of recrystallization of the dissolved material.

In summary, the following main texture elements could be distinguished in bauxites, according to Bárdossy (8):
Matrix: Components with grain size below 5 microns dominate with groundmass. Changes in mineral composition take place gradually. Significant changes cannot be observed at the microscopic level (see e.g. figures 4 and 5); they occur only at the

macroscopic scale. Consequently, this matrix can be considered from technological point of view as a homogeneous material.

Encrusted grains: ooids (up to 1 mm in diameter), **pisoliths** (d>1 mm). Most frequently occur in size, ranging from 0.1 to 1 mm, less frequently as **micro-ooids** (d < 100 microns) or as **pisoliths**. From technological point of view, the most important feature is their composition relative to the embedding matrix as well as the compositional variety and thickness of the individual crusts. If the ooid composition does not differ considerably from the matrix, the bauxite can be considered as homogeneous. Conversely, if one of the shells has distinctive high iron-content (mainly goethite), the encrusted part cannot be liberated during the benefication.

Crack filling: associates with pressure solution or tectonic movements that take place during diagenesis or epigenesis. Cracks can be filled by gibbsite, diaspore or goethite (pressure solution) or carbonates, clay minerals (epigenetic movements). The crack sealing material is characterized by a larger crystal size than the matrix. The thickness of cracks varies from 0.1-1 mm up to a few cm.

Pore filling: Similar to cracks, the pores ar filled also by diaspore, gibbsite, calcite or siderite. They are formed during early diagenesis or epigenesis and characterized by a larger crystal size than the matrix. Both crack- and pore filling can influence on the homogenity of the bauxite ore.

Bauxite clasts: larger fragments with pelitomorphic or oolithic texture, usually iron-rich ones that had been resedimented within the basin. Due to the rising or increased iron concentration these clasts have greater hardness, therefore these can be transported to longer distances. These clasts lower the homogenity of the bauxite in different size-ranges, as it is shown in figures 3 and 4.

Clastic grains: residual grains, usually of hard minerals, which are resistant to erosion. Represented in a few thousands, with size less than 60 microns and disseminated in the matrix or in the shells of ooids (see e.g. figures 5 and 8). Consequently, they cannot be separated from the bauxite.

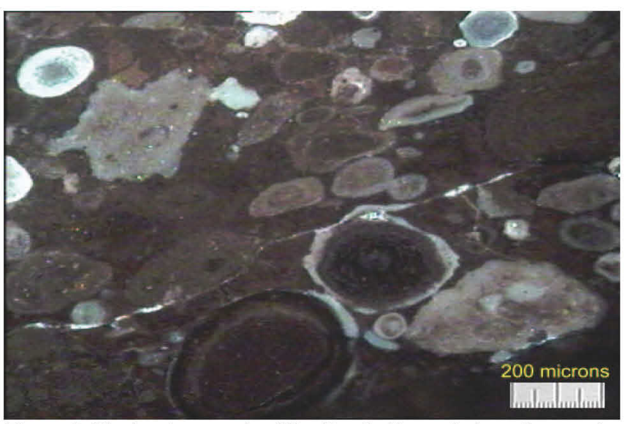

Figure 1. Photomicrograph of the Greek diasporic bauxite sample, Flattened deformed ooids cut by a microfault. Plane polarized light, crossed Nicols.

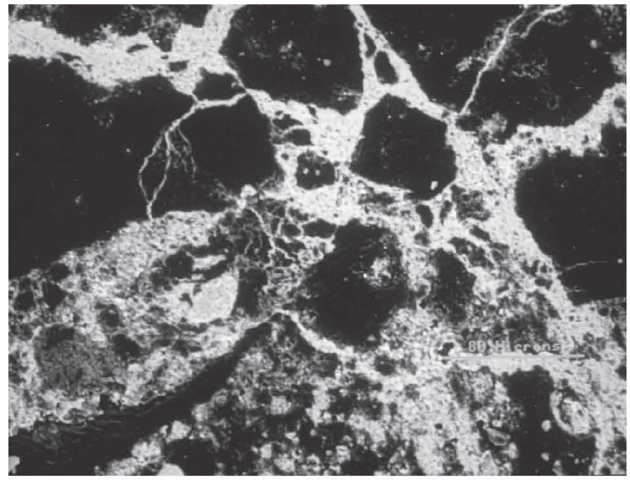

Figure 2. Greek boehmitic bauxite, the pelitomorphic matrix is brecciated, Backscattered SEM image

Figure 1 shows the ooidic, while Figure 2 represents a pelitomorphic microstructure. The phase analyses of few investigated samples can be found in Table 1.

Table 1. Mineralogical composition of the investigated bauxite samples

Component	Greek Boehmitic	Greek Diasporic	Hungarian Halimba
Al_2O_3 % in			
Gibbsite	0	0	7.4
Boehmite	46.7	38.8	37.0
Diaspore	**2.1**	**18.7**	0.2
Kaolinite	4.2	1.6	5.2
Goethite	0	0.1	0.6
Hematite	0.4	0.4	0.5
Total:	**53.4**	**59.6**	**50.9**
SiO_2 % in			
Quartz	0	0	0
Kaolinite	4.7	1.9	6.1
Total:	**4.7**	**1.9**	**6.1**
Fe_2O_3 % in			
Goethite	1.4	2.1	2.8
Hematite	21.5	18.4	19.2
Total:	**22.9**	**20.5**	**22**
TiO_2 % in			
Anatase	1.7	2.0	2.0
Rutile	0.6	0.8	0.7
Total:	**2.3**	**2.8**	**2.7**
CaO % in			
Calcite	0.8	0.4	0.2
Dolomite	0	0	1.5
Total:	**0.8**	**0.4**	**1.7**
MgO % in			
Dolomite	**0**	**0**	**1.2**
L.O.I. %	**13.0**	**12.5**	**14.7**

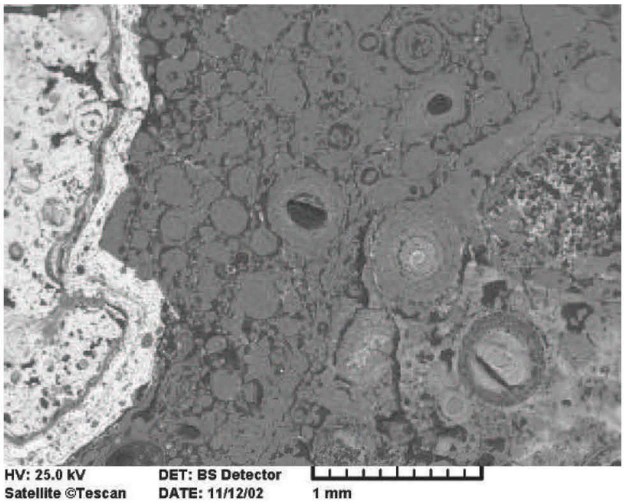

Figure 3. Greek diasporic bauxite. Resedimented, iron-rich fragment is shown on left side. Backscattered SEM image.

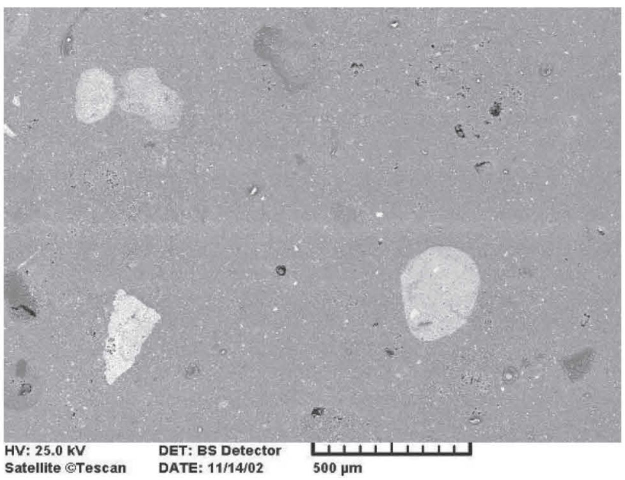

Figure 4. Greek boehmitic bauxite. Resedimented, iron-rich fragments flowing in the pelitomorphic matrix. Backscattered SEM image.

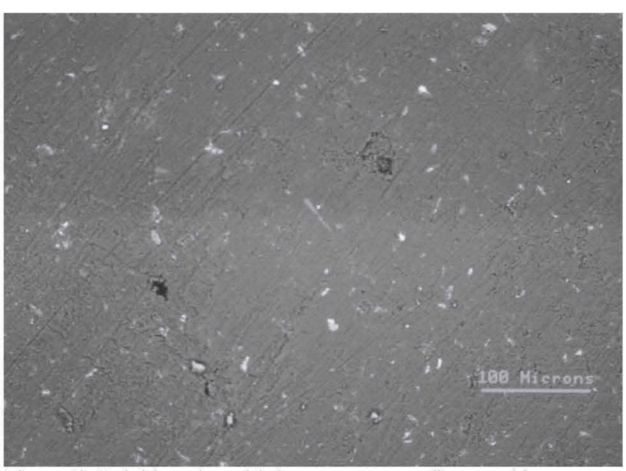

Figure 5. Boké bauxite with homogenous, pelitomorphic stucture. Backscattered SEM image.

From a technological point of view, the texture and the features of individual texture elements play an important role if some of them are in the size-range that is commensurable with the most frequent particle size of the ground bauxite material. Thus it is important to define the critical size range of the critical textural feature that could take effect on the property of the ground bauxite during the processing. This statement will be highlighted further by a few examples.

Microstucture and Beneficiation of Monohydtrate Bauxite

The SEM images and element distribution maps are used very successfully to determine the theoretical possibilities of the beneficiation and also to control the results of the ore dressing procedures (stages), when the investigation of the average samples (fractions) is preferred, therefore many grains (particles) should be embedded in artificial resin.

The monohydrate types of bauxite suitable for beneficiation can be divided into two basic categories:

- The first type (greater part) consists of very finely dispersed hematite-rich cryptocrystalline texture and relatively coarser contaminant minerals embedded into it.
- The second type contains significant amount of relatively harder, mainly hematitic-boehmitic/diasporic ooids with low silica content.

The first stage of the ore dressing process in both cases is the selective dry (or wet) grinding. This is followed by classification, sorting the raw bauxite into high quality concentrate and into middling-type fraction. The latter may be further beneficiated by magnetic separation, heavy media separation (H/M) or table separation.

In some kinds of bauxite, liberated iron minerals (hematite) or Fe- and Al-reach ooids are present which can be removed (concentrated) by magnetic separation. As a consequence, a much higher grade of bauxite with reduced Fe_2O_3 content and iron-rich concentrate can be produced. This ore dressing method should be preferred in case of long-distance and costly transport of the bauxite raw material, when the transportation costs may be significantly reduced.

The Greek bauxite usually contains significant amount of liberated limestone: 2 - 4 % expressed as CaO. (Note: in Table 1. the low CaO values relate to the rich or beneficiated ores.)

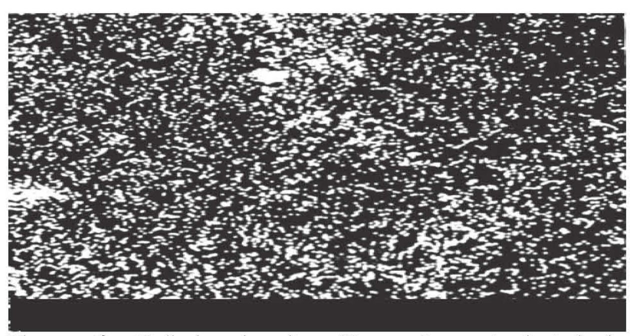

Figure 6. Halimba bauxite (Hungary) contaminated by homogenously distributed dolomite micro-grains. Mg K_α radiation.

The Greek bauxite was examined by means of SEM and WDS element mapping. Individual calcite grains were detected among bauxite clasts as it is shown on the calcium X-ray element map taken by the WDS spectrometer. Figure 7 shows a well developed liberated calcite grain. This type of contaminant can be removed by the H/M (Heavy Media Separation) method with high efficiency as done on an industrial scale practice in Greece. (9)

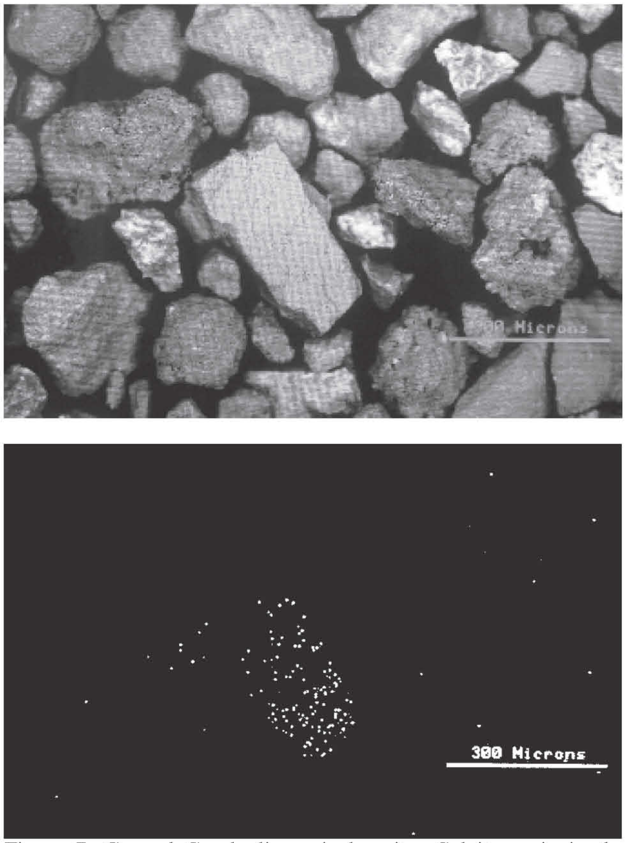

Figure 7. Ground Greek diasporic bauxite: Calcite grain in the middle: Backscattered SEM image (above) and Ca K_α radiation (below).

In contrary, the dolomite content of the Hungarian Halimba bauxite (See the distribution of Mg in Figure 6) cannot be removed
due to its finely dispersed character and homogenous distribution.

Effect of Microstructure on Grinding and Digestion

Most of the different kinds of bauxite have pelitomorphic microstructure with relatively homogenous element distribution and finely dispersed minerals, therefore the grain size distribution of the ground bauxite does not play determining role in the efficiency of digestion and relatively coarse grain size can be accepted after the grinding.

In contrary, different kinds of bauxite with ooidal grains require special (optimum) ore preparation (grinding) and/or very carefully selected digestion parmeters. This consideration is especially valid for the Greek ooidal, hard diasporic bauxite (Table 1). The photomicrograph of this texture type is shown in Figure 8.
Detailed microscopic studies have been performed in order to determine the size distribution of ooids both in original and ground bauxite samples as it is demonstrated in the following figures.

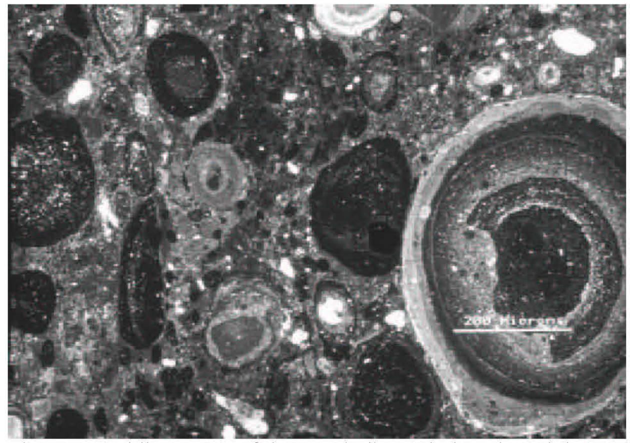

Figure 8. Ooidic texture of the Greek diasporic bauxite. Light gray level indicates Fe-rich parts, while dark gray level refers to Al-rich areas. Backscattered SEM image.

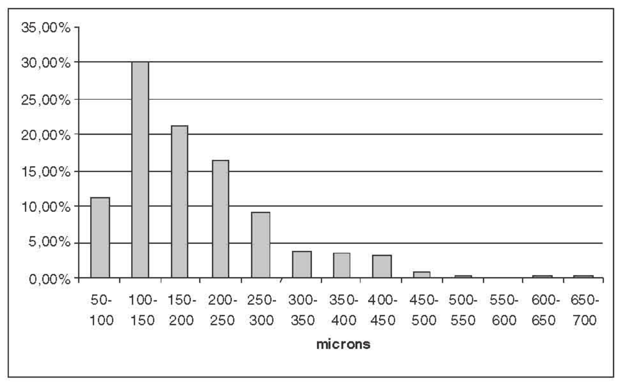

Figure 9. Size distribution of the ooids in the original bauxite sample measured by image analysis of 400 ooids.

In the original sample (see Figure 8), the space between the ooids is filled with cryptocrystalline matrix and small diasporic clasts with sizes between 5 and 30 microns. The average size of ooids is about 200 microns. Their size distribution shows a log norm character as shown in Figure 9.

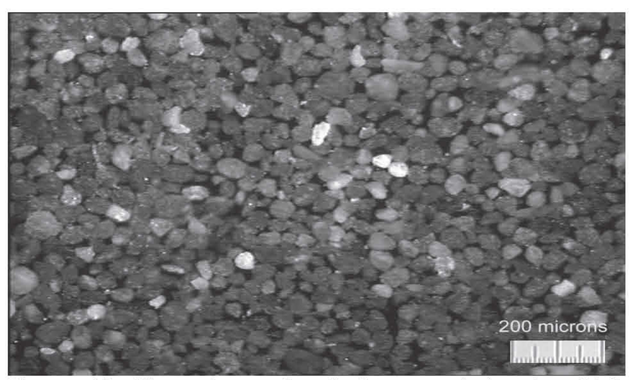

Figure 10. Photomicrograph of the ground bauxite. Light microscopic image.

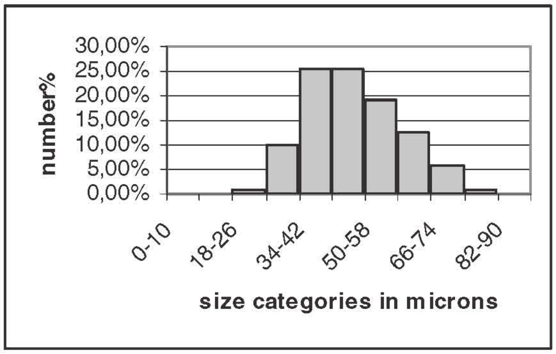

Figure 11. Particle size distribution of the ground bauxite (clay fraction is waived).

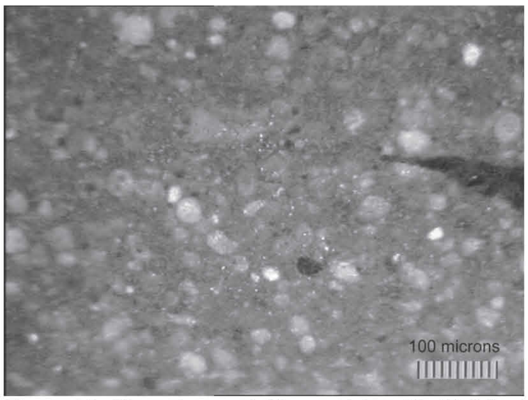

Figure 12. The microcrystalline matrix with 20-30 micron-sized micro-ooids and diasporic clasts. Light microscopic image.

From a grindability aspect, the textural investigation and size distribution show that ooids of d > 100 microns should be well-fractured by grinding. They represent about 40 % of the sample. On the other hand, difficulties can be expected with the liberation of small (10-20 microns) diasporic clasts and micro-ooids, which represent 5-10 % of the sample (see Figure 12). Nevertheless, in the ground material no particles were found with oolitic structure, i.e. all the ooids were fractured (see Figure 10). Rarely fragments of white shells of ooids could be observed, but in general the ground sample predominantly consists of consists of angular particles with size less than 63 microns (see Figure 11). The composition of the particles is rather homogenous, hence the Fe-rich and Al-rich parts were well separated down to individual particles.

The element distribution within the shells of ooids was also studied. Formation of hematite crusts on the ooid surface can lead to difficulties in digestion since this hard crust cannot be easily dissolved. Such crusts can be formed not only as the outermost shell of the ooid but also as an inner shell. This was typically the case for the examined Greek diasporic bauxite. It was compared with the well-known Weipa bauxite.

The chemical composition of the different shells of the ooids were investigated for both bauxite samples. Figures 8 and 13 are backscattered electron images of the Greek and Weipa bauxite respectively. Well-defined oolitic texture characterises both samples, however, the mean size of ooids differ significantly. Table 2 summarizes the microprobe analyses (wt%) of the two samples.

Table 2. Comparative chemical analyses of the ooids of the Greek diasporic and Weipa bauxite samples

Sample investigated	Al_2O_3 wt %	Fe_2O_3 wt %	SiO_2 Wt %	TiO_2 wt %
Greek bauxite, core of the ooid	74.23	19.27	3.43	2.30
Greek bauxite, ooid outer shell	55.61	29.00	7.00	8.39
Greek bauxite, hematitic encrustation	26.84	62.94	5.99	4.23
Weipa, ooid core	77.22	11.58	7.16	4.05
Weipa, ooid shell	81.77	6.17	3.22	8.84
Weipa, ooid outer shell	72.74	19.71	5.11	2.71

Table 2 shows significant differences in different spherical shells of ooids in Greek diasporic bauxite sample, while in Weipa bauxite the chemical composition within the ooids is rather uniform. The high reactivity of the minerals in Weipa bauxite is well-known, the finely dispersed microstructure of the ooids of this bauxite confirms this experience.

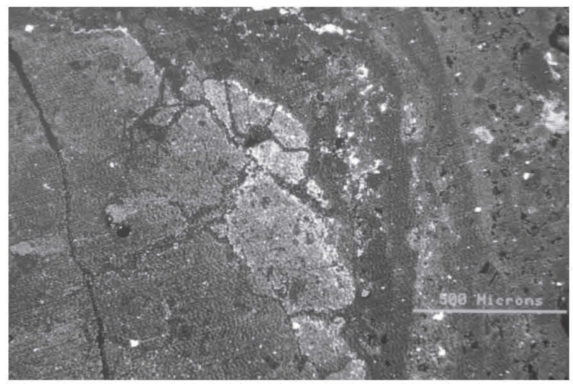

Figure 13. Ooid grain in Weipa bauxite sample. SEM backscattered image.

One major conclusion can be drawn to the effect that the Greek diasporic bauxite should be ground below 100 microns, preferably below 63 microns, otherwise the Al-rich (and Fe-rich) ooids cannot be dissolved completely and some undigested alumina can be expected with at least a few percents reported as losses. The coarser grain size of the ground bauxite more or less can be compensated by the selection of more effective digestion parameters such as: increased digestion temperature and retention time, higher caustic soda concentration, higher dose of burnt lime, and special preparation and feeding of lime at high temperature. (10, 11)

Microstructure of Red Mud

Certain mineralogical phases found in red mud – principally iron minerals as hematite, some titanium minerals and accessory minerals such as calcite and dolomite – have not suffer profound changes during the digestion and form separate grains in the red mud. This is also true for undigested boehmite, diaspore and chamosite grains. In contrast, new phases formed in digestion are finaly dispersed. Electron probe microanalysis is a reliable tool for studies of the red mud structure.

Figure 14 shows the electron probe micrographs of the red mud obtained from the carbonate-rich Hungarian bauxite. The sample was prepared by embedding the red mud in synthetic resin The pictures show the backscattered SEM image and the distribution of Fe and Ca. (Magnification: 200 x)

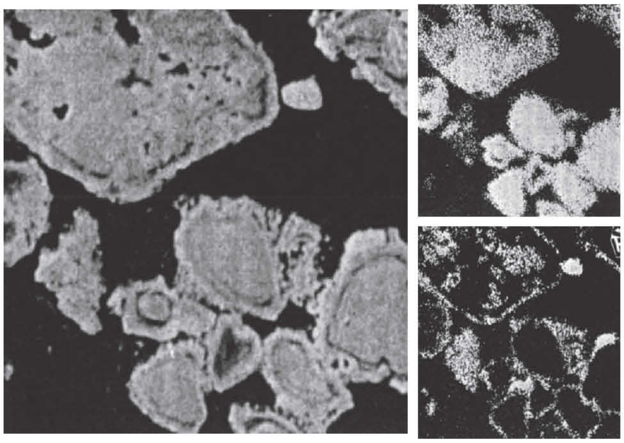

Figure 14. Element distribution in the red mud sample formed from carbonate-rich Hungarian bauxite. SEM backscattered image (left side) and the Ca K_α (upper right) and Fe K_α (lower right) radiation images.

Distribution of Mg was identical with Ca distribution, indicating non-reacted dolomite particles. The distributions of Al, Si, and Ti are identical to the distribution of Fe, indicating that the particles are enclosed by the finely dispersed red mud in which the size of the individual phases are less than 1 micron; therefore, homogeneous mixture of sodium-hydro-silicates and iron minerals has taken place. In other pictures hematite grains, titanium minerals (anatase, rutile) and undigested boehmite and diaspore were identified.

The method is suitable, along with quantitative phase analysis, to control the efficiency of the digestion and to follow the different other process stages such as bauxite grinding and beneficiation, predesilication, red mud separation and washing (including also the potential autoprecipitation).
Figure 15 shows that the Jamaican bauxite sample which is composed of spherical aggregates. The individual crystallites being only 0.01 to 0.2 micron size. This fact explains the high reactivity of this ore and the higher processing difficulties encountered especially at the stage of red mud separation.

Conclusions

The microstructure of bauxite significantly influences its optimum preparation (grinding), the possibilities of beneficiation and the optimization of the process stages of the Bayer process. Special attention should paid to the processing of ooid-type bauxite. The study of the bauxite microstructure by means of scanning electron-microscope, electron probe micro-analyser and digital image analysis is an adequate method for the better understanding of the peculiarities of the bauxite processing and for optimisation of the process stages.

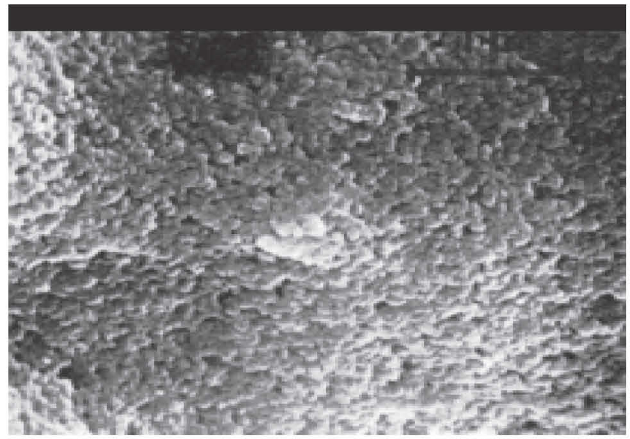

Figure 15. Microphotograph of Jamaican bauxite. SEM secondary image.

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