INTERNATIONAL COMMITTEE FOR STUDY OF BAUXITE, ALUMINA AND ALUMINIUM

ICSOBA

NEWSLETTER

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The picture on the front page shows the Alunorte alumina refinery at night.

In case you consider publishing in this forum, please contact the editor before writing your article.

Deadlines for a June issue is 10th of June and for a December issue 10th of December.

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FOREWORD

Dear ICSOBA Members,

We travel across the globe to meet almost every year. Not because we have to, but because we want as it matters. We are fuelled by a common professional passion and a desire to learn from one another. We want to expand our horizons and widen our circle of friends. Our annual event gives us a chance to express ourselves, and provide us with unique exposure to diverse facets of our industry across the world. Although we are active in different fields and work within dissimilar social and economic frameworks, we are united by our common conviction on the strategic role of aluminium in the present stage of world development.

We all know that ICSOBA was founded in 1963 and that over the years various events were held in 12 different counties. Historically speaking, one symposium was already organized in Brazil in Sao Paulo in 1988. The Belem symposium is the second on record on the Brazilian soil and this time ICSOBA came to Brazil to recognize extraordinary progress that this country has made, in the aluminium industry but also in general. Interesting fact, Brazil's economic activity, as captured by the Gross Domestic Product has recently surpassed that of Great Britain.

We came to Belem in great numbers from practically all continents. Over 300 delegates participated and your presence in Belem was the best proof that our industry is doing well. Thank you all for coming and contributing to the symposium! I hope that you built bridges and made new friends. Collaboration is built on trust and friendship. There is no other way to ensure better collaboration than getting people together and sharing experience and work culture. 110 delegates presented their papers in bauxite, alumina and aluminium sessions. We also heard plenty of excellent discussions. All presentations are now published in the TRAVAUX volume that you went home with. It will also be made accessible on our website (www.icsoba.info/travaux). The new documentation provides a wide opportunity that the industry and our respective societies can benefit from. 13 exhibitors took part in our symposium and we believe they all accomplished their objectives. 25 sponsors responded to our invitation and without their generous contributions the organization of this symposium would not have been possible.

Some people put their hearts and tons of work into the preparation and running of the Belem symposium. I want to recognize our contributors and congratulate them on a job well done! Among the symposium and program organizers I would like to thank Michel Reverdy, Arthur Pinto Chaves, David Sugden, Leslie Leibenguth, Wagner Brancalhoni, Marc Dupuis, Andrey Panov, Viktor Buzunov, György Bánvölgyi and Dipa Chaudhuri. I also want to thank our Brazilian partners for their kind support! Two people deserve special recognition. Marja Brouwer and Roelof Den Hond gave countless hours to put everything together and to ensure that this symposium would run smoothly. Thank you for your devotion, initiative and persistence. The symposium was without a doubt a success for the organizers, participants, exhibitors and sponsors. Bravo! Thank you once again to all who mobilized to make this happen.

As ICSOBA gradually concludes its first half century of existence, we are strongly committed to integrity, transparency and mutual trust. Many important decisions have been made at this symposium to ensure the longevity of our society. I thank you all for the opportunity to work with you. With a strong, competent & dedicated board of directors and representative council, we all can look forwards with confidence and believe that a bright future lies ahead. We are determined to focus on the events that will arrive next and we will do our best to make them a success.

We chose our annual symposium venues strategically to provide you with unique exposure to different aspects of our industry across the world. As we begin to focus our operations for next year, the 2013 event will be a joint congress with the Non-Ferrous Metals of Siberia. It will be held in Krasnoyarsk, Russia. This will be a particularity exiting event as ICSOBA will celebrate its 50th anniversary. We urge you all to attend and bring new colleagues with you to fully share this unique experience. We have to reach out to new members, all over the world, so that we can achieve a full representation of our industry.

I wish you all a happy and safe holiday season. May the New Year bring warmth to you and your families.
Best regards
Frank R. Feret
President, ICSOBA

NEWS AND EVENTS

ICSOBA-2012, the 19th International Symposium in Belém, Brazil

The 19th Symposium of ICSOBA, held from October, 29 until December, 2 in Belém, the capital of Pará state in the North of Brazil, attracted more than 300 delegates, about 50% Brazilians and the remainder from 36 countries, including Australia & New Zealand, China, Vietnam, India, the Gulf region, Russia, Europe, Africa, the America's and Caribbean.

The speaker program comprised over 100 lectures in three parallel programs for Bauxite, Alumina and Aluminium and in joint sessions with topics of general interest. Keynote speakers at the joint opening session were Dr. Fernando Simões Henriques, Operations Director of Norsk Hydro Brazil on Hydro's presence in Brazil, Mr. Ayrton Filleti of the Brazilian Aluminum Association on the Brazilian aluminium industry, Prof. Li Wangxing of CHALCO's Zhengzhou Research Institute on the development and future of the bauxite, alumina and aluminium industry in China and Mr. Kelly Driscol of CRU on developments in the global bauxite, alumina and aluminium industry.

The Bauxite program was chaired by Prof Arthur P. Chaves of São Paulo State University and Mr David Sugden, and covered the sessions *Guyana Shield Bauxites*, *Bauxite Mining, Application of Analytical Techniques, Bauxite Beneficiation and Hydraulic Transport of Bauxite*.

The Alumina program, chaired by Mr. Leslie Leibenguth of RTA and Mr. Wagner Brancalhoni of Hatch, focused on *Energy efficiency, Bayer processing, Alumina from non-bauxitic ores, Bauxite residue storage and the Bauxite residue utilization*. In the Aluminium program, Mr. Michel Reverdy of Dubal and Mr Marc Dupuis of STAS, chaired the sessions on *Smelter development, Söderberg technology, Equipment development for smelters, Pot operation and Carbon technology*.

The joint closing session on *Alumina Supply Developments* provided some answers on the issue raised in the opening keynotes of the expected gap between alumina demand and alumina production. The session was chaired by Mr. Roelof Den Hond and had four presentations on future alumina supply, one of Dubal on the Prospects and challenges for developing greenfield alumina refineries outside China, two about greenfield projects in the North of Brazil by Votorantim and Hydro and one about the Development of Vietnam's bauxite, alumina and aluminium industry.

During the breaks one could visit the exhibition tables in the central area of 13 technology suppliers, and during the joint meals there was ample time to meet old and new colleagues or enjoy the Brazilian Samba show in the tropical evening.

The symposium provided opportunities to visit Paragominas mine, Alunorte, the World largest alumina refinery, Albras smelter, and CAP project site.

The list of delegates, the speaker Program, and pictures taken by the photographer are still shown on the ICSOBA website.

Many sponsors contributed to the realization of the event: Hydro as host, Diemme Filtration, Hatch, Jingjin Filter press, Nalco and Outotec as gold, Aker Solutions, Albras, Andritz, Bokela, Boskalis, Bruker, Cargotec, Cytec, Feluwa, FLSmidth, Newtime, Orbite, PANalytical, Pimenta de Ávila Consultoria, Progen, Rio Tinto Alcan, SNF Floerger, Votorantim Metais, Weir as silver sponsor.

ICSOBA-2013, the 31st Conference in Krasnoyarsk, Russia

The International Committee for Study of Bauxite, Alumina & Aluminium (ICSOBA) has great honour to announce the 31st International Conference and Exhibition of ICSOBA. The event will be held in the Siberia hotel of Krasnoyarsk in Russia (Siberia) from 3 to 6 September, 2012 in cooperation with UC RUSAL and Non-Ferrous Metals (NFM), in conjunction with the V International Congress & Exhibition "NON-FERROUS METALS – 2013.

Objectives of the Conference are:

- to review the status of bauxite, alumina and aluminium industries in the world with emphasis on Russia;
- to discuss promising research developments aimed at production, productivity and cost improvements;
- to highlight proposed Greenfield and Brownfield activities in the aluminium industry;
- to discuss developments in the field of environment and safety;
- to update market aspects of bauxite, alumina and aluminium and their products;
- to provide an excellent opportunity to interact with international experts, scientists, engineers, technology suppliers, equipment manufacturers and representatives of aluminium industries the world over.

There will be technical excursions hosted by UC RUSAL to the Krasnoyarsk Aluminium Smelter and Hydro dam or Krasnoyarsk Non-Ferrous Metals Plant included in the program and optionally also to the Achinsk Alumina Refinery and the Khakass Aluminium Smelter in the Krasnoyarsk region.

We look forward to seeing you in September 2013 at the ICSOBA-2013.

Dr. Frank Feret, President ICSOBA

Peter Polyakov, president NFM

For more information please, visit the ICSOBA website.

Media partnership with Metal Bulletin

ICSOBA is pleased to announce that it has media partnered with Metal Bulletin and Industrial Minerals on their [19th Bauxite & Alumina Conference](), taking place on the 13-15th of March, at the Conrad Hilton Hotel in Miami.

As part of our agreement we have negotiated a 15% discount* for our members and readers.

Reasons to attend:

Network with the decision makers from the length of the bauxite and alumina supply chain - over 200 delegates expected

Review demand for refractory grade bauxite across the globe

Hear about new project developments and the way they will influence global supply/demand balance

Analyse China's domestic production and predicted demand for the next 5 years

To take advantage of this offer please quote ICSOBA when registering either when you call UK +44 (0) 20 7779 7222 or when emailing: marketing@indmin.com.

*The discount can be used in conjunction with the early-bird rate (saving a further $300) but this rate will expire on the 18th of January

TECHNICAL PAPERS

Bauxite Exploration Data Analysis and Interpretation – Part II

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Abstract

This paper is the second on the subject of analysing and interpreting exploration data. While the first paper focussed on exploratory data analysis (EDA) [1], the topics covered herein provide an overview of the statistical, mathematical and geological methods applied in the preliminary phase of resource modelling, including spatial distributions, domaining, contact analysis, compositing, cutoff grade sensitivity analysis, verification of domain continuity and grade stationarity. The review of exploration data analysis and interpretation will be concluded in future releases of the ICSOBA Newsletter with an in-depth coverage of variography and implications of exploration data characteristics on modelling.

Keywords: Spatial analysis, grade profile, contact analysis, domaining, compositing, cutoff grade sensitivity analysis, window statistics.

Introduction

The initial characterisation of bauxite is assumed completed following the application of exploratory data analysis (EDA) on litho-facies and main geological units, with a view to establish their grade characteristics, population distributions and relationships [1]. Main geological units are defined as higher order profile units, i.e. assemblages of consistent litho-facies, supporting the definition of model domains the purpose of which is mapping commercial grade bauxite(s) as well as overburden, basal clays and internal waste.

After an introduction on the influence of geomorphologic and geologic settings on the nature of bauxite, this paper reviews the subsequent phases of data analysis and interpretation with the evaluation of the spatial distribution of grades and main geological units by means of maps, sections and profiles, with a view to identify individual layers, boundaries as well as trends, local variations and segregations. Based on the above, model domains are formed in conformity with main geological units to provide the framework for modelling. Contact analyses are conducted to quantify the chemical contrasts between adjacent domains. The nature of such contrasts - ranging from poor to moderate or strong - may impact on the modelling approach and/or require redefining domains. EDA is conducted on model domains, including normality tests. Joint cumulative distributions – i.e. distributions of several grades in function of a specific grade - are produced to evaluate cutoff grade options. The process of compositing is reviewed and a quantitative cutoff grade sensitivity analysis conducted to select the optimum criteria for the definition of model domains. Sections and maps are finally produced to evaluate the spatial continuity of model domains and deviations from grade stationarity.

The above investigation sequence is essentially driven by the following objectives:

- Understand a given bauxite occurrence in its Geomorphologic and Geologic Setting.
- Evaluate the spatial distribution of exploration data and relevant characteristics in three dimensions.
- Synthetize, display and explain exploration results.
- Explore options for optimising a resource in function of specific objectives.
- Define the model domains.

Geomorphologic and Geologic Setting

Bauxite develops from a variety of basic to intermediate source rocks in very diverse geomorphologic and geologic settings, ranging from high peneplanation surfaces to coastal low lands, from plateaux to rolling hills, from cratonic environments to metamorphic mobile belts and sedimentary basins.

Fig. 1 shows a few examples of landforms associated with specific source rocks, from top to bottom:

- Flat topped high plateaux at +900m MSL, supported by dolerite sills and sub horizontal sediments. Separated by 100-200m deep valleys and flanked by steep slopes as well as occasional scarps, the plateaux are highly dissected and eroded. Bauxite is confined to the extent of plateaux. The weathering profile, thick (up to 40m and more) and mature, is capped by a duricrust and underlain by kaolinic clays. Bauxite develops a variety of litho-facies. The upper level of the profile often shows evidences of vertical and lateral movements mainly in the form of intra-formational breccia (collapse structures) and debris flows, less frequently in the form of more distal sedimentary facies (e.g. conglomerate). Bauxite may include intercalations of clayey and ferruginous layers of various extent and thickness, denoting complex and largely polycyclic evolutions. Also, prolonged leaching generates an extreme separation of stable and more mobile phases, with in particular a thorough desilication of bauxite and the formation of an iron rich horizon at the base of bauxite (a useful marker). The above processes promote the segregation of well-developed main geological units.
- Rolling hills culminating at about 500m MSL, supported by N-S trending metamorphic rocks consisting of charnockites with norite and anorthosite inclusions. Bauxite develops as from 200m MSL all the way up, depending essentially on the nature of the source rocks, the drainage conditions and slope gradient. Litho-facies are diverse, the most characteristic being those with relict structures of source rocks. As compared to the previous example, bauxitic profiles are thinner (typically 4-7m) and less mature, hardcap are less developed and the base of bauxite consists of clays and/or source rocks, also main geological units are more irregular.
- Low lying hills and isolated peaks in swampy lowlands developed on intermediate to basic igneous rocks, locally overlain by sediments. Bauxite develops from about 30m to 100m MSL (range shown by contour lines). Litho-facies depend on source rocks; relict structures are frequent as well as fresh rock boulders. Bauxite profiles are thin (1-6m) with their lateral extent limited by swamps and high hills (+100m MSL). The silica and alumina phases are reasonably separated at a small scale but coexist within the bauxite layer. Main geologic units are relatively continuous with however local variations of the bauxite thickness and proportion of the clayey matrix.

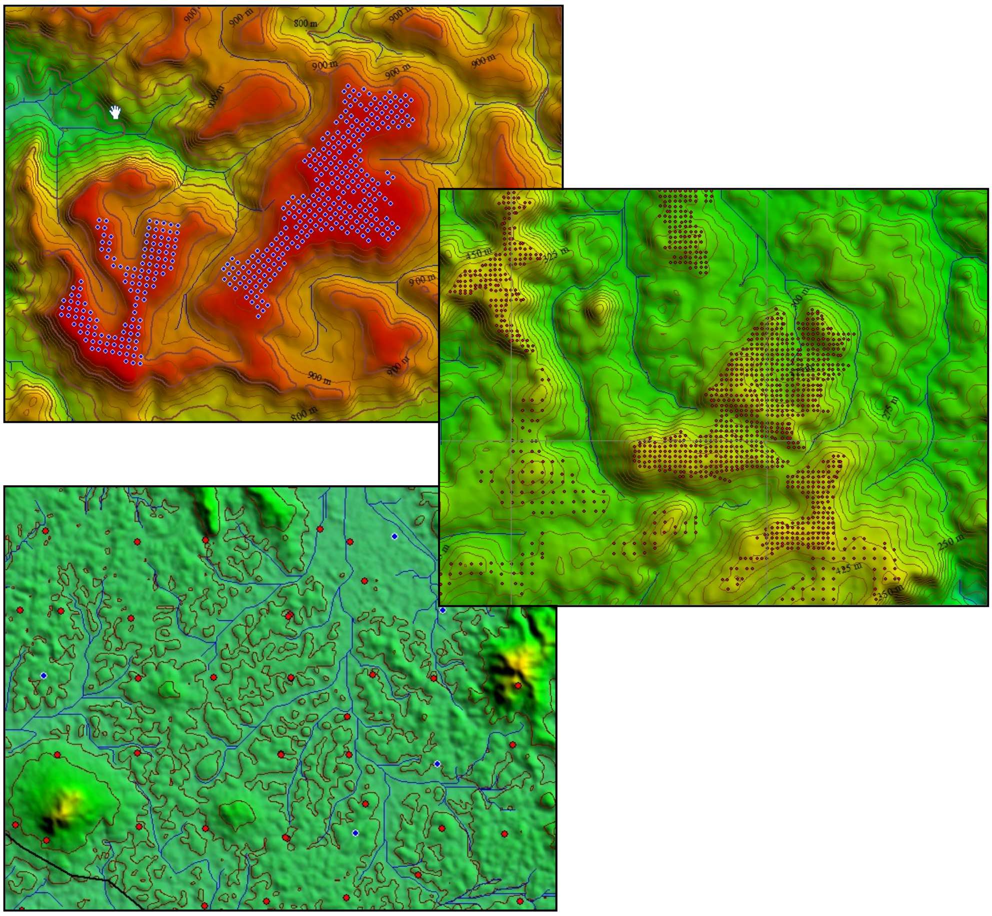

Fig. 1 A few Examples of Typical Geomorphologic and Geologic Settings
Borehole and pit locations are shown with red and blue dots

Geomorphologic and geologic settings clearly have a major impact on the development of the main geological units in general and bauxite in particular. Each deposit or group of deposits occurs in a specific geologic context that must be factored in the interpretation and modelling of exploration data.

Spatial Distribution of Main Geological Units and Grades

The evaluation of the vertical and lateral distribution of main geological units and associated grades is best achieved by generating series of X-sections along and across a mineralisation. Not surprisingly, X-sections are mandatory for reporting resources in compliance with most recognized guidelines. The main reasons are that X-sections provide a three-dimensional view of raw data allowing unbiased checks on the model concept and modelling assumptions, particularly in respect of the following:

- Variations of the weathering profile with depth and location.
- Extent, thickness, continuity and three dimensional development /distribution of main geological units.
- Dependence between main geological units and grades.

Grade breaks, nature of bauxite, overburden and floor, lateral/vertical trends and boundaries between domains.

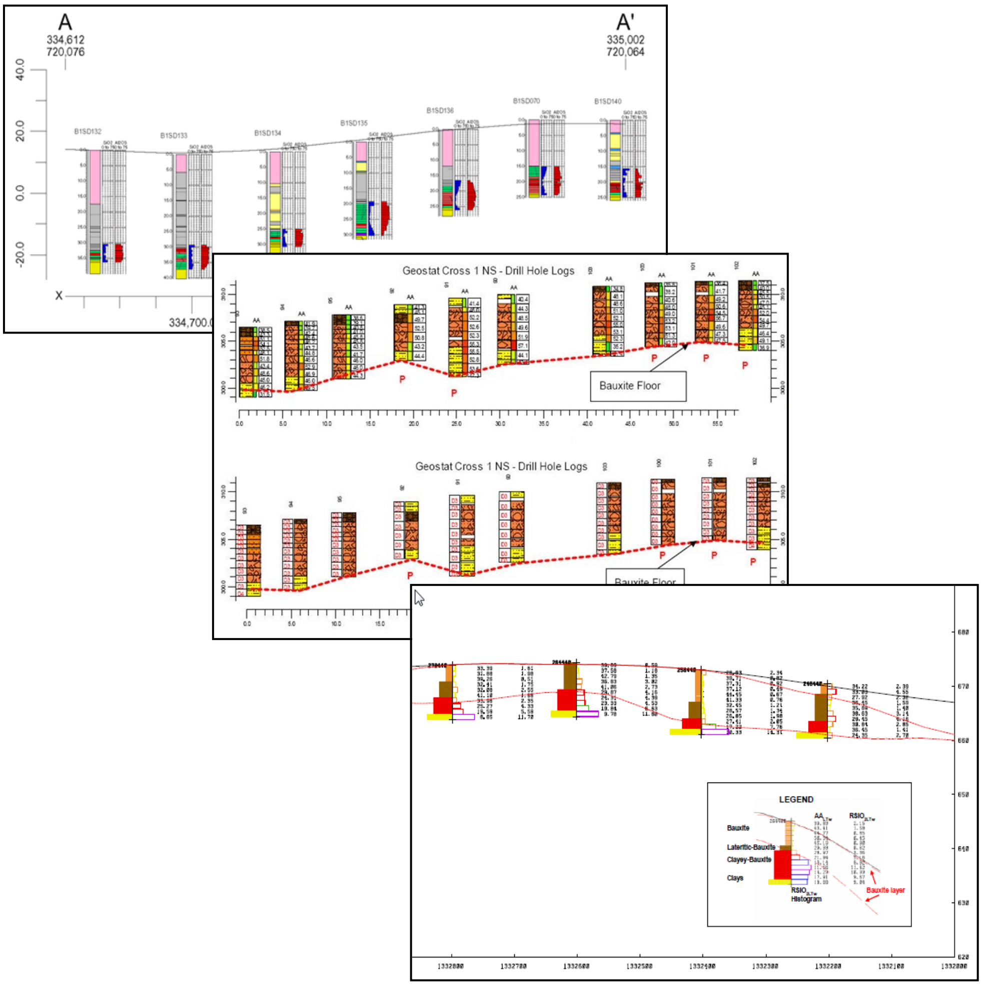

Fig. 2 Sections through Bauxitic Occurrences Showing Main Geological Units and associated Grades

The characterisation of a vertical grade profile is described in Figs. 3 and 4, using the example of low grade bauxite containing relatively high Fe_2O_3 along with moderate AA_{LT} and $RSiO_{2\ LT}$. The natural bauxite boundaries correspond to a ratio $AA/RSiO_2$ (ARSI) of about 10, which delimits an overburden rich in Fe_2O_3 and to a lesser extent in monohydrate (Mono) and silica, and a floor with high concentrations of Fe_2O_3 and silica.

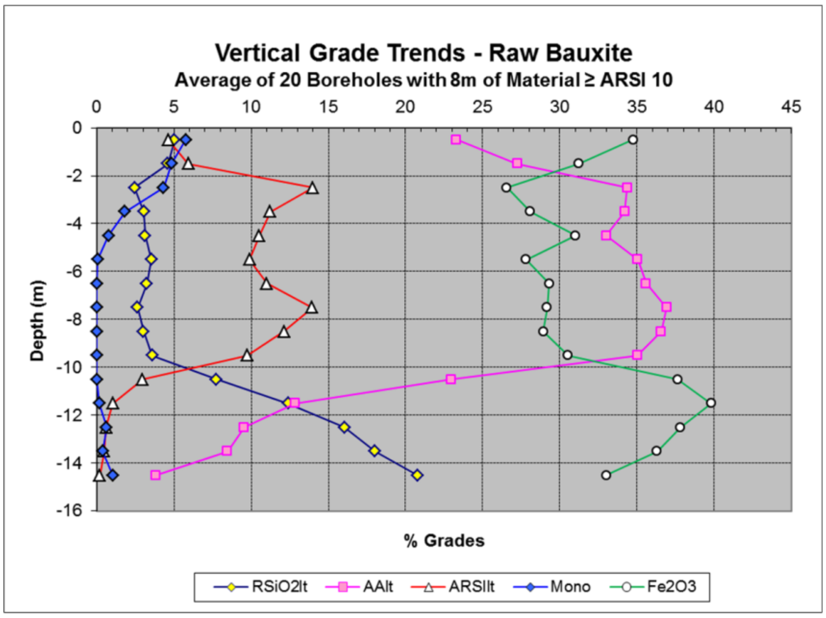

Fig. 3 Vertical Grade Profiles of Bauxite

In response to the marginal ARSI ratio of raw bauxite, below 15 (Fig. 3) as compared to a benchmark of ≥20, upgrading options are evaluated and positive results obtained by crushing and attrition followed by wet screening (Fig. 4).

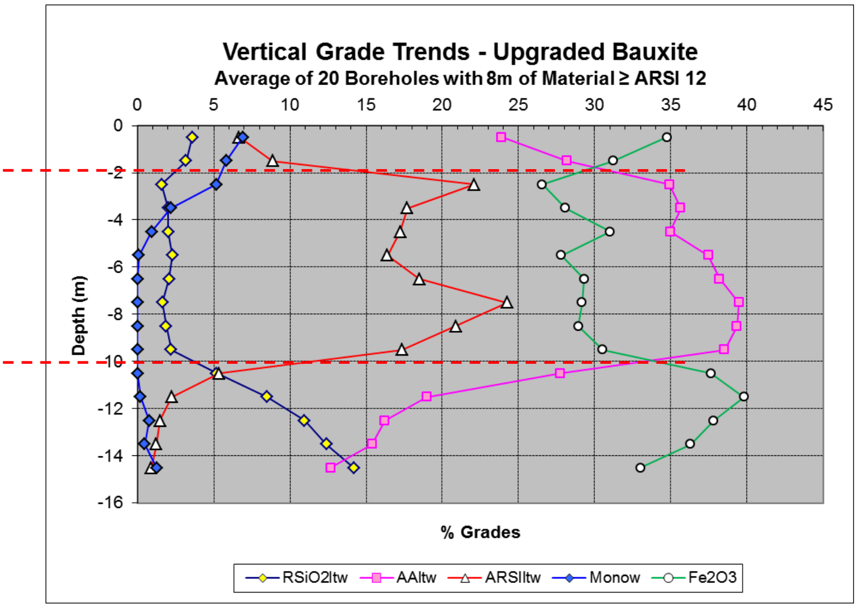

Fig. 4 Vertical Grade Profiles of Upgraded

In spite of a relatively modest response for AA_{LT} (+5%) and statu quo for Fe_2O_3, a significant reduction (-33%) is obtained for $RSiO_2$ with a recovery of 76% at +2mm. The upgrading option substantially improves the grade profile shown in Fig. 3 and brings the ARSI ratio much closer to the optimum level of 20. This option is further evaluated hereafter by means of joint cumulative distributions**.**

Constance of Grade Profiles

Bauxite grade profiles display strong vertical trends, which typically remain similar irrespective of the bauxite thickness. The profile is thus compressed for thin bauxite layers and extended for thick layers, while keeping a similar shape, as shown in Figs. 5 and 6 for bauxite thicknesses of 5, 6 and 9m (SiO_2-I, SiO_2-II and SiO_2-III in Fig. 5).

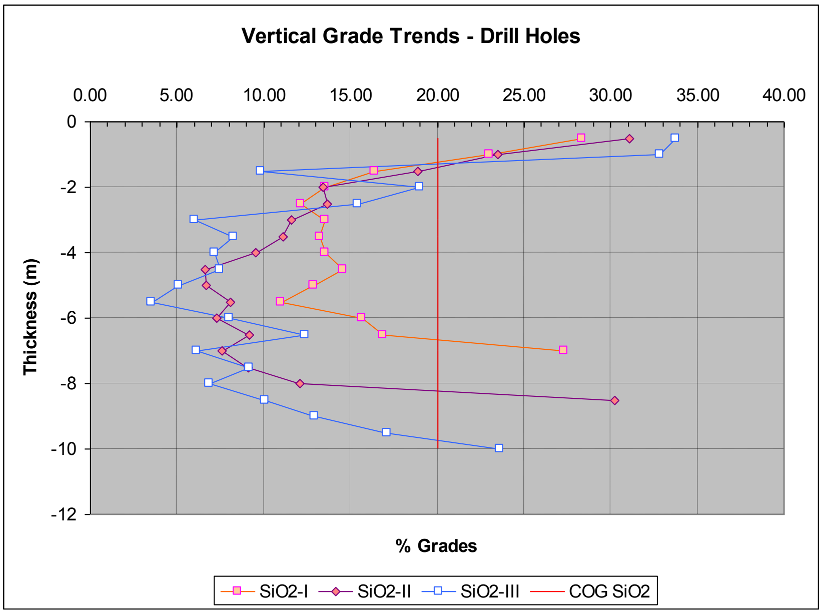

Fig. 5 Silica Profile in Sedimentary Bauxite

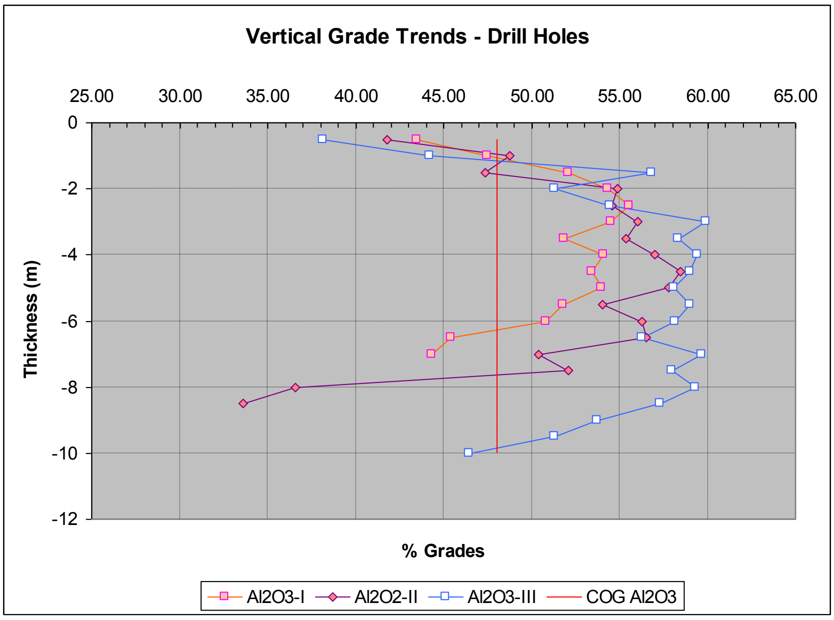

Fig. 6 Alumina Profile in Sedimentary Bauxite

Red vertical lines correspond to selected COGs, i.e. 20% SiO_2 and 48% Al_2O_3.

The grade profile displayed in Figs. 5 and 6 starts with clays and bauxitic clays characterized by high silica values. After a short transition zone, the main part of the bauxite layer follows with silica levels below 5%, until reaching the transition to basal clays with silica values quickly rising to 10-15%. Basal clays are then reached with values of 20% SiO_2 and above. The interface of bauxite with the transition zone stands at ≈5% SiO_2, while that of the transition zone to upper and basal clays is at 17-20% SiO_2.

Domaining

Graphical representations of vertical trends help identifying natural breaks in grade profiles and, with due consideration to target grade specifications, support the selection of domain boundaries and applicable cutoff grades (COGs) for modelling.

The following figure (Fig. 7), based on the same data as Fig. 3, illustrates the average profile of 20 holes with 8m of bauxite and 2m of overburden. The position of the average bauxite layer is shown by red dotted lines. The transition from lateritic hardcap (Domain 1) to bauxite (Domain 2) is indicated by a noticeable fall of Fe_2O_3 and SiO_2 combined with an increase of Al_2O_3 while the transition to basal clayey laterite (Domain 3) is highlighted by a strong increase of SiO_2 and Fe_2O_3, and a fall of Al_2O_3. These are sharp and visible contacts, i.e. natural grade breaks, corresponding to an $ARSI_{LT}$ cutoff of about 10.

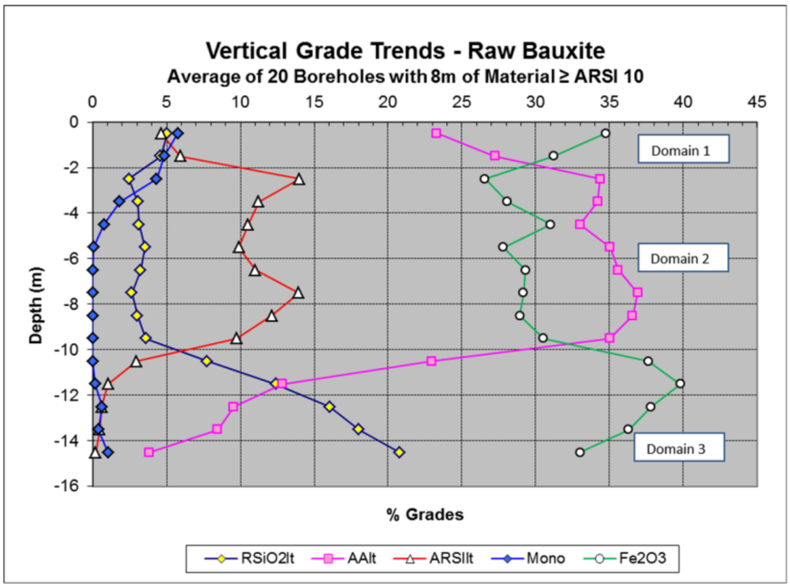

Fig. 7 Domain Definition (Example from Fig. 3)

Main geological units, e.g. clayey or lateritic overburden, bauxite, basal clays in the simplest case, and model domains should be consistent [1]. This harmonization is generally iterative, in the sense that it may take several attempts to identify the applicable physical and chemical boundaries. Although overriding log descriptions based on grades is usually involved, given that sample logging is merely qualitative, the method allows for a detailed mapping of geology into the resource model. Nonetheless, since bauxite is a commercial product with tight specifications, model domains largely rely on quantitative assays and technical/economic considerations.

Contact Analysis

The following figure shows the grade transitions between high silica bauxite and basal clays. While Fe_2O_3 shows a modest variation from bauxite to clays, Al_2O_3 decreases from 57% down to 45% and SiO_2 increases from 11-12% to 30%, all within a distance of 1m. The contact is abrupt and marked by very strong grade contrast.

The purpose of contact analysis is evaluating the nature of the domain boundaries and how should they be treated in modelling, i.e. as “soft” or “hard” boundaries with respectively the interpolation search range extending beyond the boundaries or not. For bauxite modelling, one usually uses “hard” boundaries to preserve the vertical grade profile. These modelling technics will be examined in future releases of the ICSOBA Newsletter.

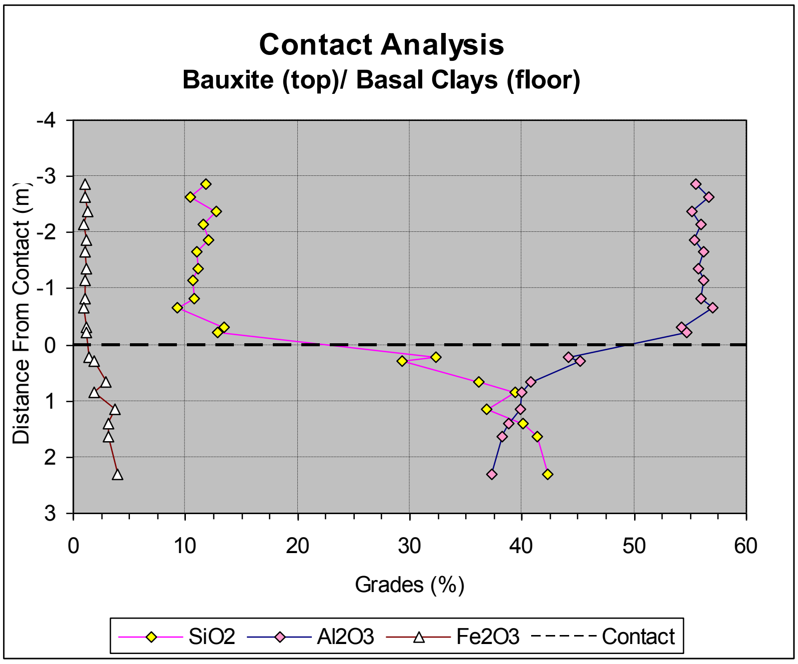

Fig. 8 Contact Analysis - Contact shown by blue dashed Line

EDA of Domains

It is not important if grades of litho-facies or main geological units follow or do not follow any particular mathematically defined distributions [1]. For model domains, the situation is different, particularly for kriging. Although strict adherence to normality is not required, significant deviations from normality due to excessive skewness may prejudice variography and kriging results [2]. It follows that there is a need to test normality compliance of model domains and possibly consider data transformation. Irregularly distributed or highly skewed data can be transformed to a normal distribution and back transformed after modelling [3][4].

Ideally, domains should be free from outliers and display well-behaved distributions. This may prove unachievable when technical/economic considerations impose the inclusion of overburden and/or internal waste into bauxite. In most instances however, model domains consist of reasonably homogeneous data populations amenable to standard modelling methods, as shown in Fig. 9.

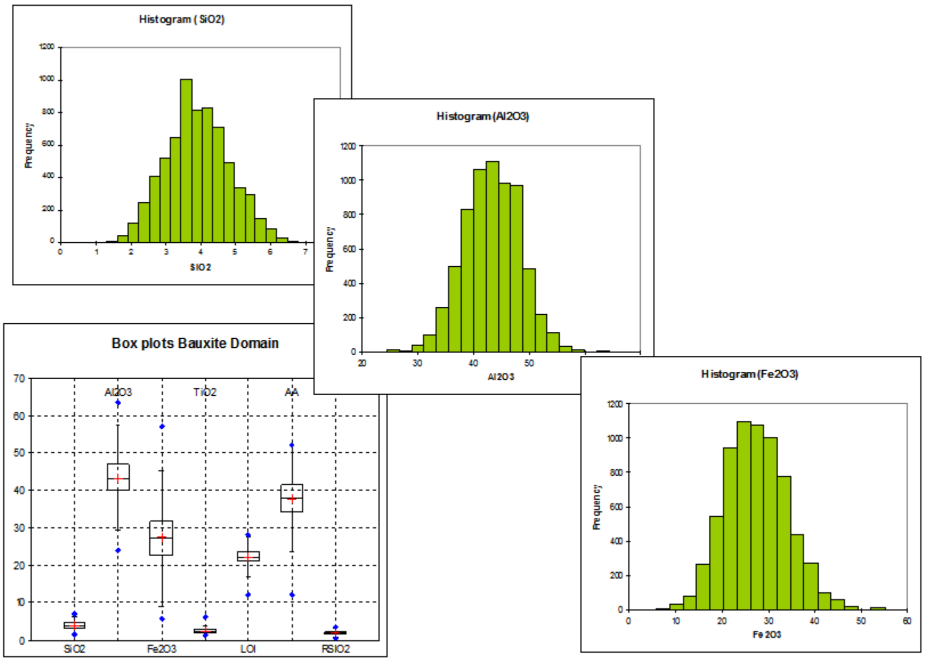

Fig. 9 EDA of Domains – Upgraded Bauxite (Example from Fig. 4)
Bauxite domain characterized by well-behaved distributions with few outliers (blue dots on the box plot).

Joint Cumulative Distributions

Preliminary cutoff grade sensitivities are based on grades of individual samples weighted by the sample length, the area of influence of boreholes (or grid size) and density estimate(s). In the simplest cases, weighing factors are constant and thus ignored.

The objective is evaluating the effects of escalating/decreasing cutoff grade constraints on a sample population. Joint cumulative distributions are typically used to this effect. The method consists in selecting a conditional variable (the cutoff) to sort sample grades in a convenient order, e.g. descending for Al_2O_3 and ascending for SiO_2. The cumulative frequency and cumulated averages of all relevant grades are then computed for selected classes of the conditional variable.

The limitation of the method is a lack of control on the spatial distribution of samples; hence, while it is a good indicator of the dependences between grades, it only provides preliminary estimates of the potential grades and size of a given mineralisation. Tonnage estimates for each class of the conditional variable (as in Table 1) may be useful for the purpose of comparing/ranking cutoff options, e.g. ARSI vs. AA. However, since each sample counts irrespective of its spatial position, tonnage figures are far from representative of the resources.

The ARSI ratio is an effective tool to develop scenarios and identify optimum cut points, but it is tolerant to extreme values and a minimum boundary limit is generally required on AA.

In the examples provided hereafter (Fig. 10, Tables 1 and 2), the purpose is evaluating the potential grades and tonnage achievable for an average ARSI of ≈20 considered as a benchmark. The following tables and figure show the cumulative distribution of $RSiO_2$ and AA, together with the potential tonnage forecast, all in function of ARSI (the conditional variable).

Fig. 10 demonstrates that the ARSI cutoff of 13 could yield average grades of 1.9 $RSiO_{2\ LT}$ and 39.3 AA, corresponding to an average ARSI of 20.

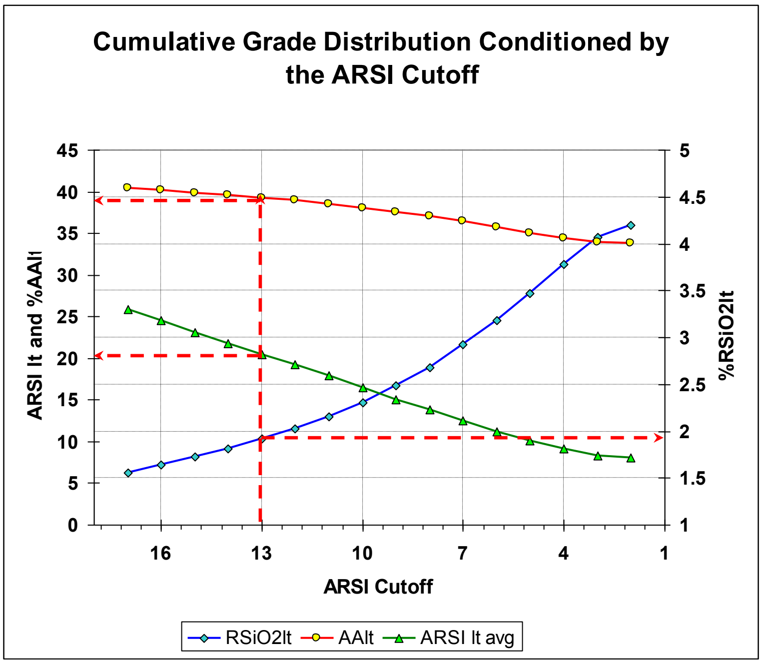

Fig. 10 Cumulative Grade Distribution Conditioned by the ARSI Cutoff

While the ARSI cutoff of 13 achieves the grade objective, it heavily reduces the resource size as shown in Table 1, indicating the need for relaxing the cutoff as low as ARSI 10 to preserve the continuity of the mineralisation.

The cumulative frequency of raw samples with potentially acceptable grades is relatively small, with only 16% and 23% for an average ARSI of 20 and 17 respectively (Table 1). This could result from significant over-drilling typical of initial exploration but also from severe cutoff constraints, an effect less pronounced in the case of upgraded bauxite with 32-35% of the samples close to an average ARSI of 20 (Table 2), and 42% of the samples above ARSI 17.

Table 1. Joint Cumulative Distribution Conditioned by ARSI

Cumulative	ARSI	Cumulated Average Grades			Tonnage Projection
Frequency	Cutoff	$\%RSiO_2$	%AA	ARSI	Mt
10%	17	1.6	40.4	25.9	210
11%	16	1.6	40.2	24.5	230
12%	15	1.7	39.9	23.1	260
14%	14	1.8	39.6	21.8	290
16%	**13**	**1.9**	**39.3**	**20.5**	**330**
17%	12	2.0	38.9	19.2	370
20%	11	2.2	38.5	17.9	420
23%	**10**	**2.3**	**38.1**	**16.5**	**490**
26%	9	2.5	37.6	15.1	570
29%	8	2.7	37.0	13.8	650
34%	7	2.9	36.4	12.5	760
39%	6	3.2	35.7	11.2	880
44%	5	3.5	35.0	10.1	1010
48%	4	3.8	34.4	9.1	1130
51%	3	4.1	33.9	8.3	1210
52%	2	4.2	33.8	8.0	1240

Table 2. Joint Cumulative Distribution Conditioned by ARSI, Upgraded Bauxite

Cumulative	ARSI	Cumulated Average Grades			Tonnage Projection
Frequency	**Cutoff**	**%RSiO$_2$**	**%AA**	**ARSI**	**Mt**
14%	22	1.2	41.2	35.5	230
15%	21	1.2	40.9	34.2	250
16%	20	1.2	40.7	32.7	270
18%	19	1.3	40.5	31.3	290
19%	18	1.3	40.3	29.9	310
21%	17	1.4	40.1	28.4	340
23%	16	1.5	39.8	26.8	370
25%	15	1.6	39.5	25.3	410
27%	14	1.6	39.1	23.9	450
29%	13	1.7	38.8	22.6	490
32%	**12**	**1.8**	**38.4**	**21.1**	**540**
35%	**11**	**1.9**	**38.0**	**19.7**	**600**
38%	10	2.1	37.6	18.2	670
42%	9	2.2	37.2	17.1	730
45%	8	2.3	36.7	15.9	800
49%	7	2.5	36.2	14.7	870

In the face of the above results, bauxite beneficiation stands as an option deserving further evaluation, which in turn could justify detailed studies regarding technical, economic and environmental issues.

Compositing

The process of averaging grades within specific cutoffs over continuous sampling intervals is fundamental for the definition of model domains. More generally, the concept is applicable to the process of assembling continuous intervals with similar physical/chemical properties. In practice, the bauxite layer(s) is/are first defined by applying grade/physical constraints; this in turn defines overburden, internal waste and floor material, all of which may qualify as model domains. Subsequent steps may involve the definition of sub-layers, i.e. sub-domains, such as export and local grade bauxites, and various types of overburden e.g. soft/hard clays and hardcap.

This process involves dedicated algorithms and in some cases several steps of compositing. For small datasets or simple cases, compositing using a spreadsheet or interactive digitizing is applicable. Relatively large multi- domains models are mappable using a spreadsheet with the support of multiple composites. Output of the domaining process should include both the tagging of domain samples and the coordinates of domain interfaces.

The 3D coordinates of domain interfaces are used to develop surfaces (e.g. Triangulated Irregular Networks (TIN) and/or grids), which in turn define domain envelopes, flag samples belonging to specific domains and provide the framework of gridded models as well as 3D models.

Domains are homogeneous volumes systematically drilled, logged and/or sampled and/or tested for physical/chemical properties, with sufficient spatial extent to support modelling. If for technical/economic reasons specific categories of intercepts or discontinuous intercepts are not allocable to domains consistent with their physical/chemical properties, then such intercepts are attributed to adjacent or enclosing domains. This case is typical of 2D models when overburden and/or internal waste not selectively removable are included in the bauxite domain.

Both the minimum and maximum thickness of overburden and internal waste must be considered as mining constraints. This may result in no, partial or full removal of waste material or in bauxite sterilization when bauxite becomes waste by off grade inclusion or when waste exceeds allowable stripping. Obviously, off grade inclusions impact on the bauxite domain homogeneity and may generate grade outliers. The resulting dilution is part of the bauxite domain and therefore included in the resources; as opposed to mining dilution added at the time of transferring resources to reserves.

A constraint on the minimum mineable thickness, although occasionally built in the compositing process, should not apply to the definition of domains, but to the delimitation of the resources, based on the principle that bauxite deemed unmineable considering current or projected technical/economic conditions does not qualify as a resource.

Cutoff Grade Sensitivity Analysis

A quantitative approach to cutoff grade (COG) sensitivity analysis consists in building a series of simple models providing reliable global estimates, such as 2D ISD block models or even polygonal models, using composites based on various cutoff grades. In this process, boundaries are required to clip polygonal models or constrain block models. It is also imperative to control the continuity of the mineralisation, particularly for extreme cutoffs. This is achieved either by applying COG specific boundary limits in the simplest cases or using dedicated software ensuring the continuity of models. Additional constraints are usually taken into account, including the minimum mineable thickness as well as the maximum overburden and stripping ratio. Modelling results, summarized in the form of tables and/or grade tonnage curves, provide for the selection of optimum COG parameters.

Fig. 11 displays an example of cutoff sensitivity analysis for refinery grade bauxite with low reactive silica and low available alumina. The benchmark average ARSI of 20 is obtained for the AA cutoff of 30%, with grades of 38.4% AA and 1.9% $RSiO_2$ corresponding to a tonnage of some 330 Mt. In this example, $RSiO_2$ is almost indifferent to the cutoff while the tonnage is exceedingly sensitive between AA COGs of 25% to 35%, indicating that the benchmark ARSI stands in a critical zone and cuts deeply into the potential resource. Such consideration could support a reduction of the COG criteria in the interest of the continuity of mineralisation and potential resource size.

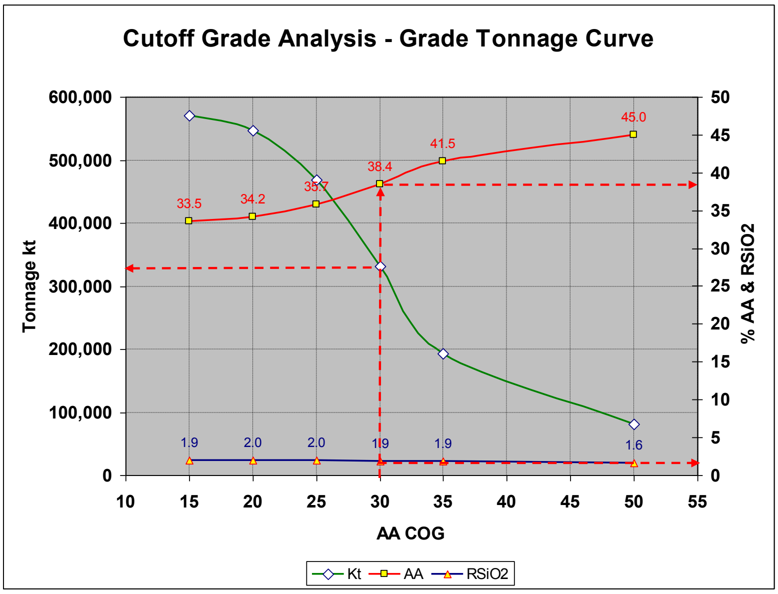

Fig. 11. Cutoff Grade Sensitivity Analysis using 2D Block Models

Cutoff grade sensitivity analysis is a powerful tool to quickly and efficiently evaluate multiple options ahead of variography and resource modelling that entail more elaborate and time consuming investigations.

Spatial Analysis of Domains

The main objectives of spatial analysis are to verify the continuity of domains, the distribution of domain attributes and, for 3D models, the relationships between domains.

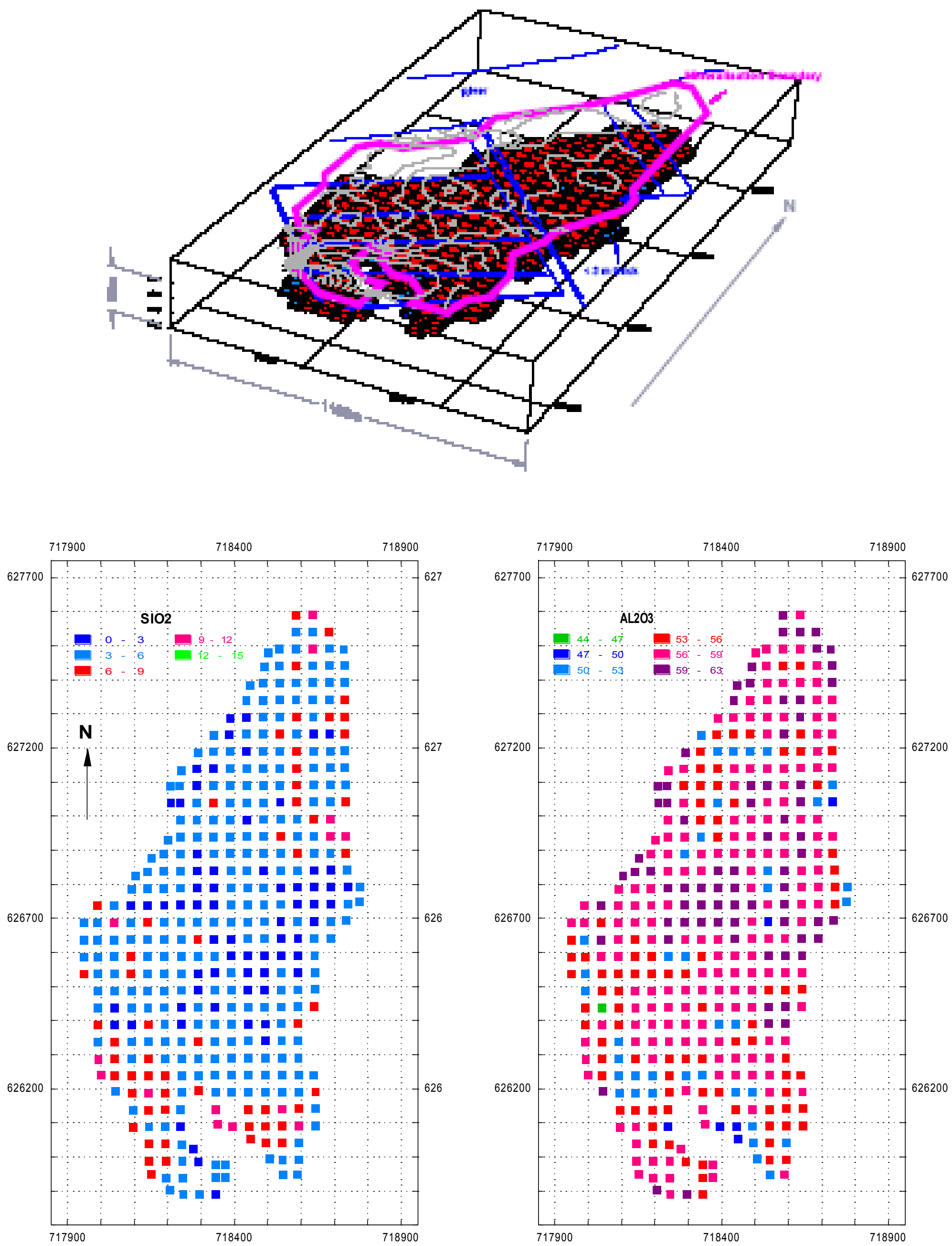

Fig. 12 Continuity of Bauxite Domain Thickness (Top), SiO_2 and Al_2O_3 Grades

Fig. 12 displays the case of a bauxite domain with consistent thickness, a favourable case in terms of mining, with occasional thinning particularly on the edges of the mineralisation, which in this region generally terminates abruptly. There are no obvious grade trends, although the mid and northern sectors contain somewhat better grades, which could impact on the potential mining sequence.

The second case submitted in Fig. 13 is that of a 3D model showing a continuous bauxite domain, with however pinches and swells of thickness that could require specific mining methods to ensure high recovery and selective ore lifting.

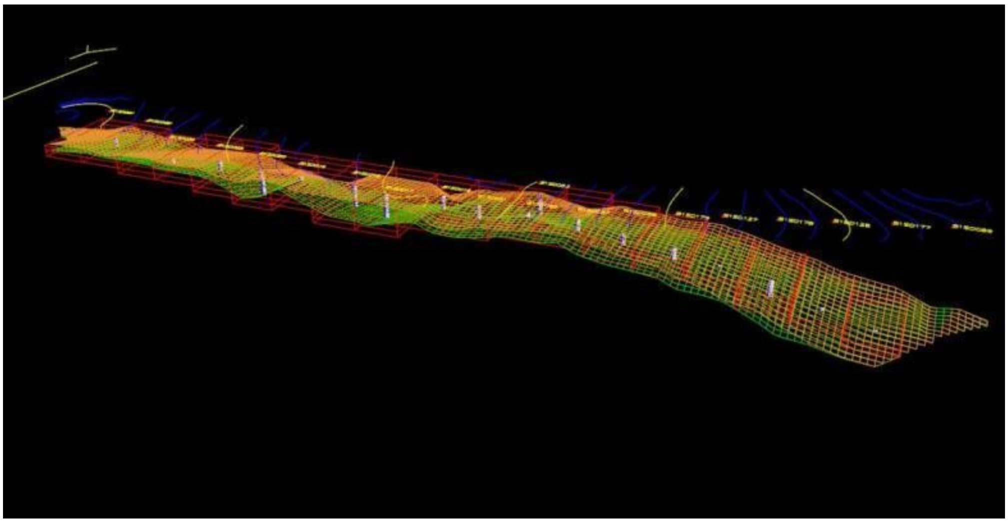

Fig. 13 3D Cross Section - Block Model and Development of the Top and Floor of Bauxite Domain

Window Statistics

Spatial analysis also includes "window" statistics, which consist in mapping local means and variances of grade attributes within search windows of certain shapes (generally squared) and dimensions. The purpose of window statistics is getting a feel for the stationarity of grade attributes, which is fundamental to kriging, and verifying the presence of proportional effects, i.e. the proportionality of variance with grades. The decision of using a given variogram for grade modelling within a specific domain is based on the assumption of stationarity of the grade variance as defined by the sill of the variogram. However, variance tends to increase with grades for positively skewed distributions and the opposite for negatively skewed distributions, which may corrupt the variogram. The search window must include subsets of the data population statistically significant in terms of size and spatial spread. Its dimensions could be based on the search range used for modelling or a multiple thereof, the range of the variogram or other considerations relevant to the area under study.

Variation of local means is a natural feature of most bauxite occurrences; it is not an issue for ordinary kriging (OK), but it is for simple kriging (SK) which assumes a constant mean and therefore has limited usefulness. Local variations of stationarity may result from segregated subsets or fractions of a global population, from organized structures or patterns, or the presence of separate domains. Window statistics therefore contribute to the definition of domains.

How to Reduce / Eliminate the Proportional Effect

Relative variograms (general relative or pairwise relative variograms) rescale the variance to the local mean, therefore suppress the proportional effect. They provide a clearer description of spatial continuity revealing ranges and anisotropy. Variogram rescaling does not change interpolation weights hence kriging estimates and methods to adjust the relative kriging variances have been developed [5].

Transforming data to a normal distribution by lognormal transform (for data lognormally distributed) or normal score transformation effectively removes the proportional effect.

Bauxite modelling requires a variogram common to all or to most grades in order to maintain the linear relationships and the underlying mineralogy. This restricts/complicates the application of the above methods. Therefore delimiting specific domains of grade stationarity usually offers a reasonable alternative.

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Upstream Stacking for Bauxite Residue at Alumar

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Abstract

This paper describes the alternative methodology developed at ALUMAR for bauxite residue disposal. The alternative methodology, called simply "Upstream Stacking", presents significant advantages when compared to the conventional wet disposal technique, used so far at ALUMAR, considering the environmental impact, long-term groundwater contamination risk and residue disposal cost. The alternative method optimizes the use of residue areas, allowing for the disposal of up to 30-40% more residue than the capacity for which such areas were originally designed and constructed. It makes use of the residue surface of a disposal area which capacity has been otherwise exhausted. Therefore, construction and its environmental impacts and costs are minimized, as well as the residue storage footprint and its associated risks and liabilities

Keywords: bauxite residue; upstream stacking; RSA; wet disposal technology; environment.

Introduction

Bauxite Residue Areas (RSA's) at ALUMAR are formed by earthen embankments, with a single composite liner on the bottom and inner slopes, which is composed by a compacted clay layer and a PVC geomembrane, and a base drainage layer. The residue is pumped from the refinery to the residue disposal areas as slurry, with up to 15% solids. The disposal method is called "Wet Disposal" due to the large amount of water with which the residue is transported and disposed of as opposed to the "Dry" method, in which the residue is pumped at much higher solids contents.

When using the wet disposal technique, the Residue Disposal Area is filled with solids up to 1 meter below the dike crest, allowing for a minimum free-board.

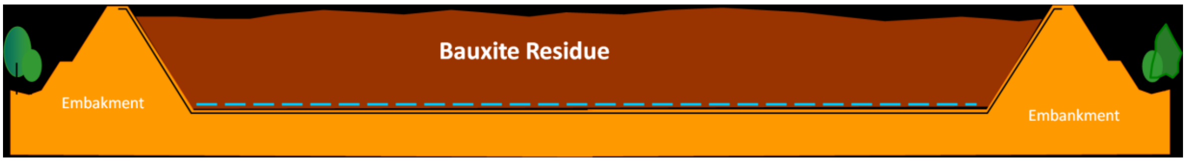


Fig.1 – Typical cross-section of the final configuration of one RDA filled by the conventional wet disposal method

Large volumes of earthen material have to be excavated, transported and compacted for each RSA construction, requiring borrow areas for the different types of soil, local soil for the embankments, clay for the low permeability barrier, sand for the drainage layer, and lateritic soil for roads, slopes and dike crest protection. Extensive areas have to be cleared of vegetation to be used as borrow areas. Besides, due to the geological conditions at ALUMAR, the clay and sand deposits are often found at a certain depth, requiring the removal of significant volumes of overburden. All the borrow areas have to be re-contoured to acceptable topographical conditions and re-vegetated, incurring in elevated costs.

The Upstream Stacking Concept:

The first Upstream Stacking trial was performed on the large and flat surface area of the residue stored in RSA2 (32 ha). The idea was to contain the wet residue within low perimeter dams, while allowing the residue to dewater and the excess water to overflow to the neighbour RSA3. A small scale trial area was built around one of the RSA2 center drops. The results of the trial were a success and encouraged to go ahead.

A full scale trial was then set up and the first perimeter dam was built with an average height of one meter. The dam was permeable and erosion proof, retaining the solids and allowing the excess water to permeate and overflow. Up to 10% of the bauxite residue generated at ALUMAR may be classified as sand. The segregation of the sandy fraction occurs as the residue is dropped and the flow takes the fine particles along leaving the larger and heavier sand particles behind.

Pictures 1&2: View of the first perimeter dam constructed on RSA 2 surface with refractory bricks (another residue from the plant)

The dike construction job, despite its relatively small volume, took more than three months and had to be done during the dry season. Another important difficulty was the transportation of bricks from the plant to the RSA´s. It was expensive and the access was not good. It was a lesson learned that, for the next time, a new material would have to be tested.

Then, the idea of building even lower containment dikes and simultaneously operate the area, going around the perimeter continuously, like a spiral, started to grow. In order to put that in practice, two important aspects would have to be taken care of:

– The excess water would have to be drained;

– The number of residue drops would have to be increased from the existing 12, in order to promote an even distribution of the segregated sandy residue along the perimeter to allow the formation of a continuous and uniform path of workable surface on the fresh residue – valves were installed in the twelve existing drops and four additional drops with valves were installed. Each 8 inch diameter drop was then split into four 4 inch diameter drops, all made with HDPE pipe, adding flexibility as to the exact location where the 72 drops would discharge residue, making it possible to move them around in the vicinity. The operation of the system does not require special equipments or sophisticated methods, what makes it a lot easy and cheap.

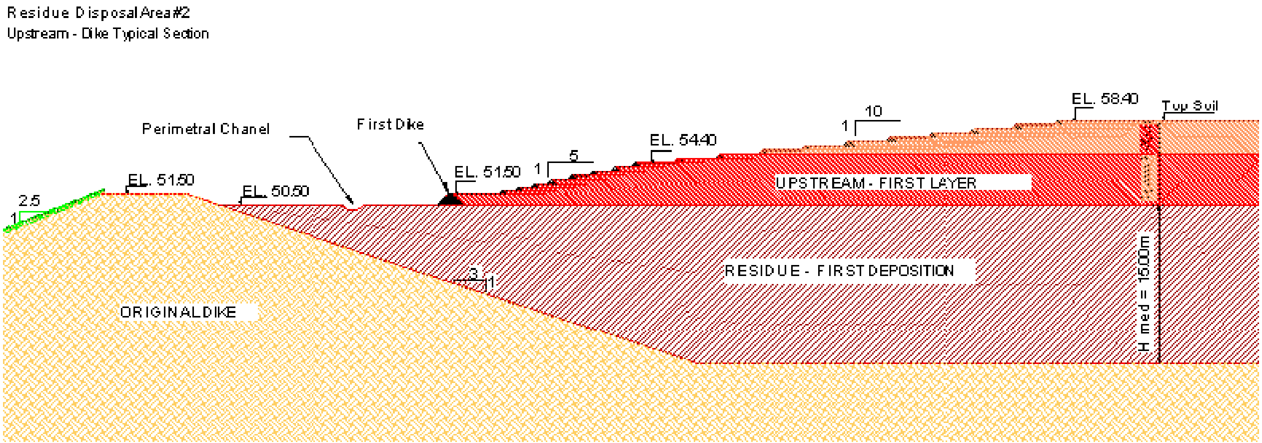


Fig. 2- View of the concept of Upstream Stacking with a base dike of about 1m height and successive lower dikes on top

Also all requirements in the ALCOA Bauxite Residue Management Standards and Guidelines regarding safety would have to be fully met.

One significant advantage of this system is that it would not require any changes to the existing pumping facilities and equipment.

Implementation and Construction Materials

A thorough geotechnical investigation was then planned and carried out with the help of a major Brazilian university (PUC-RJ). Several field and lab tests were performed. Also hydrological studies were carried out to establish the minimum requirements regarding the safety of the operation under low frequency heavy storm events.

The data acquired during the geotechnical investigations was then used for the slope stability analysis. The results of such analysis led to the adoption of the following principles in the design of the Upstream Stacking:

- Maximum pile height of 6m;
- Average external slope 5H:1V;
- Use of low height (max.0.40m) embankments, with a smaller volume, thus enabling an easier and faster construction;
- Preferably use waste material from ALUMAR as construction material;
- Keep a minimum distance of 25m between the original embankment crest and the 1^{st} step-in dike;
- The final contouring of the residue pile favourable to its future rehabilitation;
- Overflow the excess water into the contiguous RSA;

For construction of the dikes the following materials have been employed:

- **Base dike**: 1.0m high in average, built with 3,000 cubic meters of waste refractory material wrapped with geotextil. All of the waste refractory from the ALUMAR Smelter carbon baking furnaces was used in such application, eliminating the waste stockpile and clearing the way to rehabilitate the area.

  Further, after the experience with the refractory bricks, the base dike, from RSA 3 on, is being constructed with nylon bags filled with bauxite residue.

- **Subsequent containment dikes**: about 0.50 m height, built with sewn geotextile 1.5 m long and 0.25 m diameter tubes, filled with waste plastic from ALUMAR.

Picture 3- View of the geotextile bags filled with plastic residue forming the low height successive dike

Sometimes, the volume of waste plastic generated is not enough to supply the construction, so the dikes are made of nylon bags filled with bauxite residue itself.

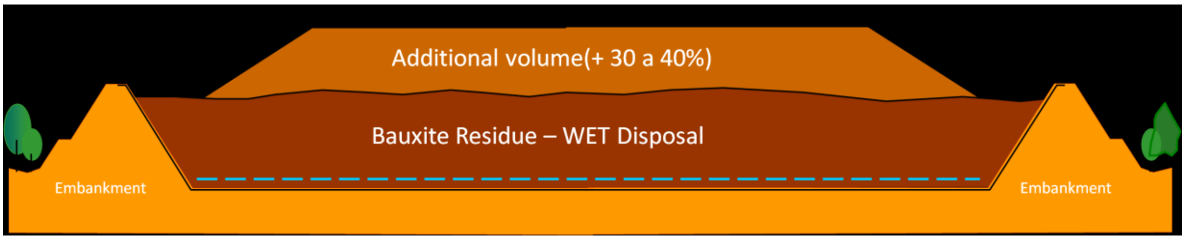


Fig. 3 – Typical cross-section of the final configuration of one RDA with the pile of additional residue on the surface

Operation

The Upstream Operation is quite simple. It does not require any special equipment and no changes must be applied in the Refinery plant. Pinch valves and HDPE piping were installed in order to better distribute the residue all over the area.

Pictures 4&5: View of the pinch valves and of the HDPE piping installed to operate Upstream

A group of 8 people work in the operation and for the successive dikes construction about 13 people. No specialized manpower is required.

Results achieved

The adoption of the upstream stacking technique has a high positive environmental impact since it promotes the reduction of the bauxite residue footprint by 30%, as well as it cuts also by 30% the need of natural soils for the residue disposal areas construction at ALUMAR. The residue surface to be rehabilitated in the future will also be smaller.

The alternative technique of Upstream Stacking proved to be highly successful. In particular, the reuse of waste materials from the plant itself enabled simultaneous cost savings and solution for other environmental problems.

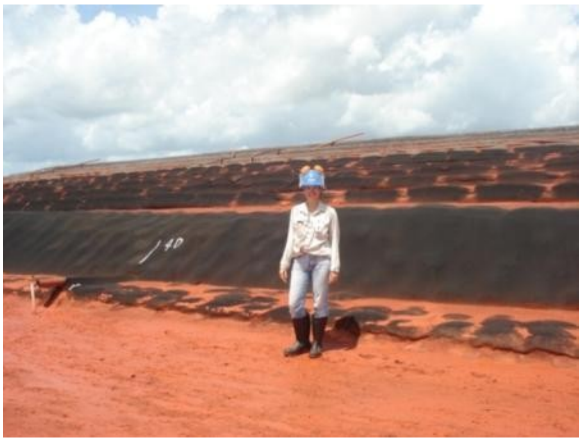
With the adoption of the upstream stacking technique the deposition cost became 70% lower than the traditional method. See below a table with the numbers of Upstream Stacking related to storage capacity extra volume.

	RSA 1	RSA 2	RSA 3	RSA 4	RSA 5
Construction	1983	1990	1996	2004	2008/2009
Start Operation	1984	1990	1997	2005	2010
Residue Surface (m^2)	210.000	320.000	360.000	390.000	609.500
Nominal Capacity (m^3)	2.400.000	4.000.000	4.800.000	5.400.000	10.400.000
Capacity WITH Upstream	-	**5.138.000**	**6.107.000**	**7.800.000**	**13.520.000**
Current Situation	Reabilitated	Reabilitated	Reabilitated	Preparing for Upstream	Wet Disposal

The table below summarizes the results obtained with the Upstream Stacking, applying it until RSA 5.

Original Storage Capacity (m^3)	Final Capacity WITH Upstream (m^3)	Difference
27.000.000	**32.565.000**	**5.565.000 (*)**

(*) This volume is equivalent to an RSA of the same size of RSA4




Pictures 5 and 6: View of the resultant additional pile of residue formed by the Upstream Stacking project

With RSA´s 2 and 3 Upstream Stacking, the following results have been obtained:

- Approximately 100 ha of land will not be cleared of vegetation;
- A volume of about 1,500,000m³ of compacted soil dikes will not have to be built;
- About 30 ha of residue footprint will be saved;
- Other solid waste materials from ALUMAR were used for dike construction, therefore reducing the requirement for landfills.

Other environmental aspects to be considered:

- The elimination of each new area to be constructed (i.e. the residue storage foot print) will reduce the groundwater contamination risk;
- The final sloped surface of the residue pile enables a significant reduction in soil required for rehabilitation, with consequent reduction in new borrow areas;
- Reduced quantities of natural materials for RDA construction reduces markedly the environmental impact of new borrow area exploration as well as their rehabilitation;
- All the rain water that falls in the Upstream overflows to the contiguous RSA that is equipped with supernatant pumps, what permits the pumping of the water back to the Refinery, recovering soda.

Behavior of the Residue Pile:

Monitoring of the stack during the operation is done by:

a) Settlement plates in the central part of the stack, placed on top of the old residue;
b) Vertical and horizontal displacement measuring points on the starting dikes;
c) Measurements of the residue density, shear strength and pore-pressures at several depths both in the old and the new residue to check design assumptions and evaluate changes in behavior twice during the operation period;

The overall behavior of the stack is very satisfactory, with no records of local instabilities or indications of overall movements of slopes, reduced horizontal displacements (generally inward) of the initial dikes and limited overflow occurrences with no consequence to the external slopes.

The use of small dikes heightening of the stack enable a successful continuous operation of the stacking system since the construction of dikes could be done simultaneously with residue discharge, in opposite sides.

Other initiatives to protect the environment

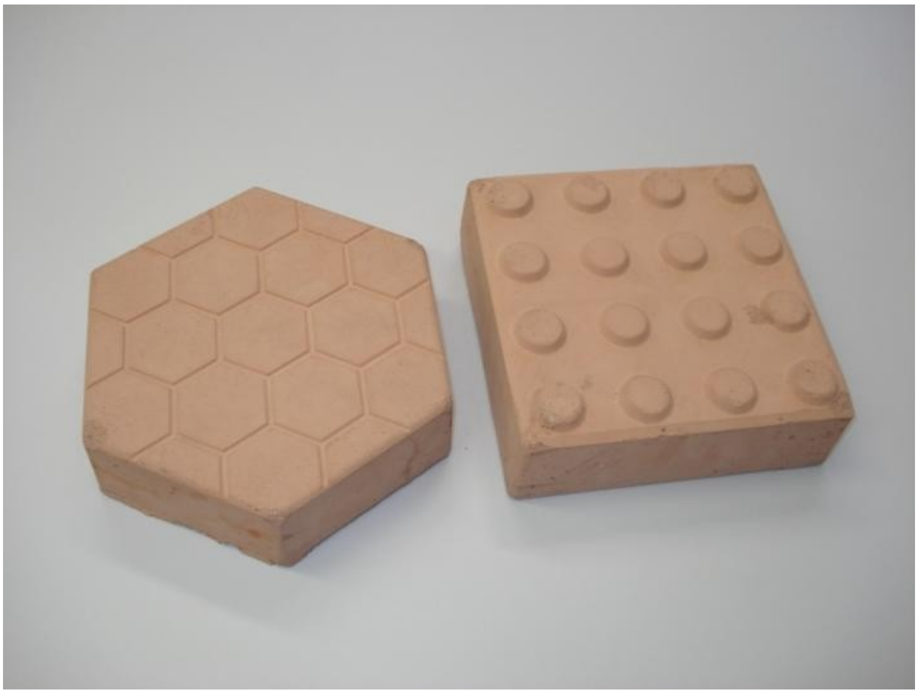
Tests have been made in Alumar to produce paving blocks with residue concrete, show some results obtained, bearing in mind the future use of this material in social projects. The test consists of the replacement of small aggregates (sand) of the concrete formula for the fine aggregate of the bauxite residue (partial replacement) to produce paving blocks.

The paving with concrete blocks has a cozy visual and is perfect for all kinds of uses. Besides, the blocks are very durable (more than asphalt, for example) if well executed. It can play an important social role if used in public roads and squares. The project must take into account the kind and frequency of vehicles in order to define the sub-base materials as well as the floor thickness that can be 6, 8 or 10 cm. It is also very safe for ramps or curve areas, especially if they are wet. Present a great power of sunlight and artificial light diffusion, lower surface temperature during the day and great visibility during the night.

Leaching and solubility tests have been carried out and the results are under analysis. Meanwhile, the results are similar to normal concrete in resistance as well as in leaching and solubility.

More analysis are planned and are necessary to make this alternative feasible and ready to all used as the traditional blocks.

See below some pictures of the blocks and also of some areas where these blocks are being tested in Refinery.



Picture 7- Concrete blocks produced with the replacement of 20% of the sand by bauxite residue

Pictures 8 and 9- Concrete blocks paving test areas in Refinery

Documentation

If necessary, complementary information may be made available like the Geotechnical Investigation, Design and Construction Reports, as well as many photographs of the construction and operation periods.

The "Carbon Footprint" from Primary Aluminium Production

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Introduction

The term "carbon footprint" is a relatively new expression. It was introduced only about fifteen years ago. Since then it has become very popular and it is now in widespread use. "Carbon footprint" can generically be defined as the total amount of carbon-containing greenhouse gases produced, directly and indirectly, to support human activities. The expression may at first glance seem a little strange, because all of the industrial carbon pollution of the atmosphere is in the form of gases, mainly CO_2. And can *gases* really make a *footprint* (like we do when we walk barefoot on a sandy beach)?

CO_2 emissions from the industrial Hall – Héroult process

World-wide aluminium production is responsible for more than 1% of the global human-induced greenhouse gas (GHG) emissions. From the primary aluminium production these emissions are in the form of carbon dioxide from the electrolysis of alumina and perfluorocarbon gases (mainly CF_4 and C_2F_6) from anode effects in the electrolysis cells. None of these gases are collected by the dry scrubbing process in the gas treatment centre of aluminium plants and they are emitted directly into the atmosphere.

Introduction of a CO_2 tax threatens to raise the price of aluminium, reduce its competitiveness as a material, and may put some aluminium producers out of business. In Australia carbon pricing began on July 1, 2012 and in the first year the carbon price is decided to be $A23 per metric ton of CO_2.

With the general trend towards introduction of carbon taxes and the aluminium industry's attempts to reduce its "carbon footprint", there needs to be a clear spelling out also of the "carbon footprint" of the production of the electrical energy used. For example, the emissions of CO_2 from coal-fired power production are 3-4 times higher than from the aluminium electrolysis process itself! Growth areas such as India and China are being dominated by coal-fired power generation, which has a very high "carbon footprint". Coal-fired power produces over 1 kg of CO_2 per kWh of electric power and it is remembered that a smelter consumes in average 14 kWh per kg of aluminium produced. Thus, emissions of CO_2 from electric power generation from fossil fuels exceed the emissions from the aluminium production process.

In average there are 10 kg CO_2 emitted per kg of primary aluminium produced. The annual world production in 2010 was 41 million ton and this corresponded to emissions of about 410 million ton of CO_2 per year for primary aluminium. In comparison the annual production of 21 million ton of recycled aluminium in 2010 gave only an emission of about 1 million metric ton of CO_2 [1].

In order to include the effect of other greenhouse gases than CO_2, like the perfluorocarbons emitted during anode effects, the expression "carbon dioxide equivalency" is used. It is commonly expressed in *equivalent metric tons of carbon dioxide*. It is written CO_2eq and is calculated as parts per million by volume (ppmv). For a given mixture and amount of greenhouse gases, this is the equivalent amount of CO_2 that would have the same global warming potential (GWP). GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question, to the amount of heat trapped by a similar mass of carbon dioxide. The GWP is calculated over a specific time interval, generally 100 years.

Typical ranges of greenhouse gas emissions from primary aluminium production are:

- Indirect CO_2eq emissions from electric power production: 0 – 14 t/t Al.

- Direct CO_2eq emissions from aluminium electrolysis cells: 3.8 – 4.0 t/t Al.

- Emissions from alumina production: 1 – 2 t/t Al.

- Emissions from anode carbon production: 2 – 3 t/t Al (Anode carbon production gives CO_2 from anode production plus from the excess anode consumption (air burn) in the cells).

- Emissions from perfluorocarbon (PFC) gas generation during anode effects: 0.1 – 3 t/t Al.

- Emissions from aluminium fabrication: 0.6 – 1.3 t/t Al.

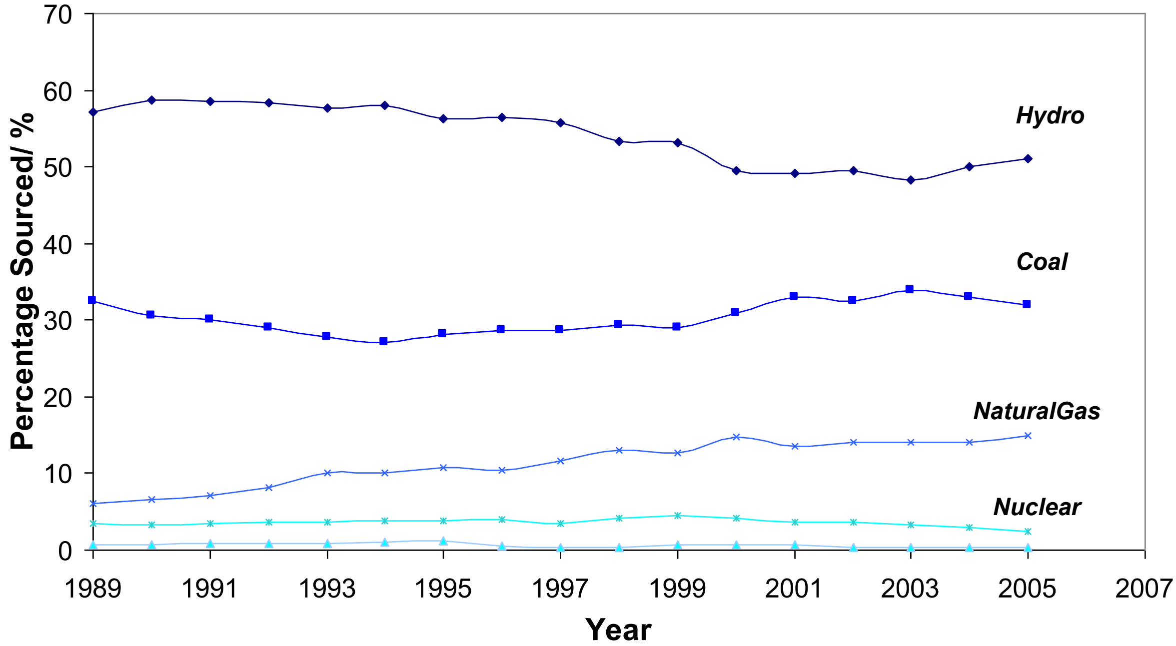

Figure 1. Sources of electrical power used for aluminium production [2].

Fig. 1 shows that in 2005 about 50% of the world's production of aluminium was made on the basis of hydro-electric power. From an environmental point of view this is very positive, because no CO_2 is then formed. About 30% came from coal-fired power plants, while the amount of aluminium produced in plants with gas-fired power was about 15%. Two trends are obvious from the curves in Figure 1. While the contribution from hydro-electric power has been reduced from 60% to 50% from 1989 to 2005, it is seen that the fraction from gas-fired power plants has doubled in this period. It should be added here that there are significant differences in fuel shares between regions. Coal, with the highest CO_2 intensity, provides 20% of the total needs in Europe, but 77% in Oceania.

The target is of course to reduce both the electric energy consumption and the direct carbon dioxide emissions - which we have called "carbon footprint" - in primary aluminium production. However, there are not many possibilities to reduce the greenhouse gas emissions from the aluminium electrolysis process itself. The obvious choice is to try to reduce the *net* anode consumption. This may be achieved by technological and operational improvements, for example by optimised process control, improved current efficiency, better anode quality and good anode cover. Reduced anode effect frequency and duration will reduce the PFC emissions, and all aluminium smelters have indeed achieved great progress here in recent years. These emissions are now significantly lower that the direct CO_2 emissions, while it was opposite twenty years ago.

Can we capture the CO_2 gas from the electrolysis cells? Unfortunately, today large amounts of air are used to ensure under-pressure inside the cell superstructure, mainly to avoid fluoride emissions to enter into the potroom. With a typical value of 100 t air/t Al there will be only about 1% CO_2 in the flue gas and this is a too low concentration for CO_2 capture with the present available technology. We need to concentrate the flue gas, because dilute gases are difficult and uneconomic to work with.

To conclude, aluminium may become an even greener metal than today. Theoretically, and perhaps also technically, the primary aluminium smelters can be close to zero climate gas producers but there is still a long way to go to achieve that. The two main requirements are:

1. The first and most important step will be CO_2 gas cleaning related to the electric power generation from fossil fuels.
2. Then capturing and cleaning CO_2 from the electrolysis process itself may be a technically possible future scenario.

An alternative process - Carbothermic aluminium production

Do we then need an alternative aluminium production process to solve the "carbon footprint" problem from the primary aluminium industry? The non-electrolytic carbothermic alumina reduction is an old process. Aluminium - copper alloys were made carbothermically already from 1886. The first attempts to make pure aluminium were done more than fifty years ago but all attempts in the twentieth century failed for technical and/or economical reasons [3]. However, since 2000 the knowledge about the process has been continuously improved through physical and computer modelling as well as by experimentation at various scales [4]. So maybe this process has a potential for lower "carbon footprint" than the present industrial process?

Let us therefore now take a brief look at the carbothermic process. As the name says, the purpose of the carbothermic method is to use *carbon* and *heat* to reduce alumina to aluminium, according to the overall reaction:

$$\frac{1}{2}\,Al_2O_3(s) + 3/2\,C(s) + \text{heat} = Al(l) + 3/2\,CO(g) \qquad (1)$$

However, this overall equation is very simple and does not give a correct description of the reactions that will actually occur in the system $Al_2O_3 - C$ at high temperatures and ambient pressure. The three main steps in this process are:

1. Production of a molten slag, which contains alumina and aluminium carbide

- Stage 1 (T > 1900 °C):

$$2Al_2O_3\,(s) + 9\,C\,(s) \Rightarrow (Al_4C_3 + Al_2O_3)\,(\text{slag}) + 6CO\,(g) \qquad (2)$$

2. Production of an aluminium-carbon-(carbide)-alloy

- Stage 2 (T > 2000 °C):

$$(Al_4C_3 + Al_2O_3)\,(\text{slag}) \Rightarrow (6Al + Al_4C_3)\,(\text{metal alloy}) + 3CO\,(g) \qquad (3)$$

The molten aluminium phase will always contain some dissolved carbon, and therefore it can be considered chemically as an Al - C alloy.

3. Production of pure aluminium (refining) from the carbon-(carbide)-containing alloy

The carbon content in this alloy must be removed to produce an aluminium quality comparable to that obtained by the present industrial process.

The two most difficult steps here are steps 2 and 3; the production of the Al – C alloy and the subsequent refining of the alloy to commercial grade aluminium. In addition a gas scrubber is needed for collection of the substantial amount of aluminium-containing gases that evaporate from the furnace. This is a large technological challenge.

The "carbon footprint" from aluminium production

Let us therefore go back to the Hall-Héroult process where the overall aluminium-producing reaction is:

$$½\ Al_2O_3(s) + 3/4C(s) = Al(l) + 3/4CO_2(g) \qquad (4)$$

In this reaction 0.75 moles of CO_2 are produced, which corresponds to 1.22 kg of CO_2 per kg of aluminium. However, in addition we have the unavoidable extra consumption of the carbon anodes due to:

- The current efficiency of the process is never 100%.
- There will always be some air burn of the exposed top surface of the anodes.
- The anode can react with CO_2 in the exposed burn area at the working surface of the anode (carboxy attack).

Together these three processes increase the CO_2 emissions by about 0.3 kg, so the real emission from the Hall-Héroult process is close to 1.5 kg of CO_2 per kg of aluminium.

The total carbothermic reaction produces CO as the primary gas and the gaseous by-product is therefore different from the present industrial process. Equation (1) shows that theoretically 1.5 moles of CO are formed per mol of aluminium, which on a mass basis means 1.56 kg of CO per kg of aluminium produced.

Data from IPCC shows that carbon monoxide has a global-warming potential (GWP) of 3 times that of carbon dioxide [5]. The GWP of CO results only from its effects on atmospheric chemistry. CO generally has a lifetime of several months before it converts to CO_2 by natural atmospheric processes.

It is obvious from health and environmental reasons that poisonous CO gas cannot be emitted directly into the atmosphere from the carbothermic aluminium production. The gas will have to be burnt to CO_2 and this reaction can be written:

$$3/2CO\ (g) + 3/4O_2\ (g) = 3/2CO_2\ (g) \qquad (5)$$

This means that 1.56 kg of CO will form 2.44 kg CO_2 per kg Al. This value does not include any CO_2 resulting from electrode consumption during carbothermic reduction but that value is expected to be small, or negligible. Thus, the theoretical production of CO_2 is then increased by about 60% in the carbothermic process.

In practice this means that the CO produced has to be captured. In a closed furnace the fuel value of CO may be utilized for auxiliary heating or for electric power generation. In a recent paper by White, Mikkelsen and Roha [4] it is reported that the CO generated from the process is more than 90% pure and it can then potentially be collected and used as a chemical. The CO gas can be used industrially as raw material for several different chemical products. According to these authors [4] this includes use as a reductant for removing Fe_2O_3 from bauxite or as a reductant in direct reduced iron (DRI) processes. If CO is used as fuel one would produce CO_2, which then has to be stored by carbon capture and sequestration (CCS).

"Carbon footprint" from the electricity production for the carbothermic process

Let us then look at the electrical energy consumption for carbothermic aluminium production. Thermodynamically we know that it can never be below 7.9 kWh/kg Al at these temperatures. But what will it be in practice?

The minimum overall energy consumption for the process has been calculated to be 8.40 kWh/kg Al [4]. This value is very close to the theoretical energy consumption (it means a very high energy efficiency for the process of 94%) and it is of course based on several assumptions. The authors wrote that the energy consumption for an actual commercial process will to a large degree depend on how much of the chemical and sensible energy in the off-gas can be recovered. If the potential from CO (g) combustion is not included in the energy balance, it is expected that the energy demand for carbothermic aluminium production will be 10 - 11 kWh/kg [4]. This is still significantly lower than the best results from Hall – Héroult cells, where a value of 13.0 kWh/kg Al has for many years now been considered as the best available technology (BAT). However, with the recent strong focus on reduction of energy consumption in the Hall – Héroult process, values close to 12.0 kWh/kg Al have recently been reported in the open literature [7].

A reduction in energy consumption from 13 to 11 kWh/kg Al would then mean 18% lower CO_2 emissions from electricity production based on fossil fuels. For non-fossil fuels like hydro, nuclear, wind, and solar this electricity reduction would not make much difference with respect to greenhouse gas emissions. However, with coal-fired power the electricity production presently gives about 13 t CO_2eq per t Al. A reduction in energy consumption by 18% would then reduce this value by 2 t CO_2eq per t Al. This is more than the difference between the present process and carbothermic aluminium of 0.9 t CO_2eq per t Al calculated earlier in this paper. Thus, carbothermic production can indeed reduce the carbon footprint of aluminium production, if the power is coal-fired and if the energy consumption can be reduced from 13 to 11 kWh/kg Al.

Finally, this has been studied in more detail by Myklebust and Runde [6]. They calculated the greenhouse gas emissions for three different scenarios, with existing mix of resources and existing or expected future distribution of smelters. Their conclusion was that regardless of the principle for calculating emissions from power production, the reduction in emitted greenhouse gases for the carbothermic process compared to the Hall-Hèroult process would be at least 30 %.

Conclusions

- The present industrial process for production of aluminium, from bauxite to cast aluminium, emits between 3.8 and 4.0 kg of CO_2eq. In addition we have the emissions from electric power production from fossil fuels, which means an additional 13 kg of CO_2eq if the aluminium is made from coal-fired power.
- A carbothermic process for production of aluminium will theoretically increase the specific CO_2 formation by about 60% compared with the present industrial electrolysis process, if all CO produced is burnt to CO_2.
- Depending on the energy consumption the overall CO_2 footprint may be about 5% less from carbothermic aluminium production compared to the Hall-Héroult process, when utilising coal as fuel for the electricity production.
- Credits from utilizing the CO (g) for energy production will further decrease the overall energy consumption for producing aluminium by the carbothermic route [4].

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[4] C. V. White, Ø. Mikkelsen and D. Roha, "Status of the Alcoa Carbothermic Aluminum Project", International Smelting Technology Symposium (Incorporating the 6th Advances in Sulfide Smelting Symposium), Edited by: J. P. Downey, T. P. Battle, and J. F. White, TMS (The Minerals, Metals & Materials Society), 2012, pp. 81-88.

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ICSOBA MATTERS

Highlights of the year 2012

- ICSOBA site has been moved from Nagpur, India to Montreal, Canada. ICSOBA has been legally incorporated with the Canadian federal government and with the Quebec provincial government.
- ICSOBA's new bank account was opened in the province of Quebec. The money remaining in India at the end of 2011 was successfully transferred to Canada. ICSOBA PayPal account was also established.
- A new ICSOBA website was built (http://www.icsoba.info/)..
- Two NEWSLETTERS were issued and distributed to members.
- ICSOBA proceedings, the TRAVAUX volumes, from past conferences and symposia were electronically scanned and are available for members as searchable pdf files.
- ICSOBA bylaws were revised to the needs of Canadian legislature, adopted by the Annual Members' meeting, and are now submitted to Corporations Canada for approval.
- Three communications highlighting ICSOBA and its mission were published in international journals (Brazil, China and Russia).
- A working contact has been established with the Non-Ferrous Metals of Siberia regarding organisation of joint conference in Krasnoyarsk in 2013. Conditions for this joint event were established and a dedicated letter of intent was signed.
- Secretarial services have been assured contractually.
- A chartered accountant was identified in Quebec and assigned to the task of verification of ICSOBA accounting and preparation of legal documents required by law.
- ICSOBA council was renewed and complemented with new members.
- A very successful symposium was held in Belem, Pará state, Brazil with over 300 delegates and over 10 presentations. Three field trips took place (Paragominas bauxite mine, Alunorte alumina plant and Albras smelter).
- A media partnership has been established with Metal Bulletin and Industrial Minerals. The events of the organizations will be mutually promoted.

Board of Directors and Council

As you all know by now Roelof Den Hond decided to step down as ICSOBA president in the beginning of this year. During four years he guided ICSOBA and set its directions. In connection with the Belem symposium Roelof helped us immensely as chief program organizer. If we had excellent program in Belem we owe it much to him. Roelof decided to leave ICSOBA and pursue other interest. We will all miss him a lot.

The past term Presidency has given way to the Board of directors as a result of ICSOBA incorporation in Canada and consequential formal implications.

The symposium in Belem provided opportunity to validate, refresh and complement both the Board of directors and the council. In the Annual Meeting on 31 October 2012 the ICSOBA members have approved its leadership and future directions.

Four founding members of ICSOBA in Canada: Marja Brouwer, Frank Feret, Andrey Panov and Jeannette See form the Board of directors. They bear moral and ethical responsibility to assure continuity of ICSOBA. The executive body called board of officers is composed of five individuals with responsibilities as follows:

Dr Frank Feret	president
Dr Li Wangxing	vice president
Dr Andrey Panov	vice president
Dr Jeannette See	secretary general
Ms Marja Brouwer	treasurer

The mandate of this group will expire at the end of present term of two years.

Although ICSOBA official seat is now in Canada, Dipa Chaudhuri continues to work for ICSOBA in India and is ICSOBA's contact person to the outside world (Dipa@icsoba.org).

Earlier in 2012 György (George) Bánvölgyi accepted the role of editor for ICSOBA's Newsletter.

Several new council members arrived in 2012 assuring better vocational and geographical representation. The role of the council is to advice the board and help mainly with organization of program for future events. Present composition of the council approved by the Annual Meeting is given in the table below.

ICSOBA Past Presidents

As a preparation for the 50th anniversary of the establishment of ICSOBA, the list of the past presidents and the years of their presidentcy was put together:

1. Jean Papastamatiou 1964 - 1969
2. György Dobos 1969 - 1973
3. Jean Nicolas 1973 - 1978
4. S.S. Augustitis 1978 - 1983
5. Ivan Jurkovic 1983 - 1988
6. Adolfo J. Melfi 1988 - 1993
7. György Komlóssy 1993-1998
8. Peter Paschen 1998-2003
9. Dimitris Contarudas 2003 - 2008

10 Roelof den Hond 2008 - 2011

Council Members:

Region	Bauxite	Alumina	Aluminium	General
Africa			Stef Sep	
N-America	Jeannette See Jeffrey Best	Leslie Leibenguth André Pelland	François R Crevier	Frank Feret
Brazil	Arthur Chaves Fabio Mendes	Wagner Brancalhoni		
S-America, excl Brazil	Paris Lyew Ayee	Rita Vaseur		
China	Wanchao Liu		Yang Jiankong	Li Wangxing
India	Bhagyadhar Bhoi	S. Sankaranarayanan		Chitta Ranjan Mishra
M-East		Ashish Jog	Michel Reverdy	
CIS (Russia)		Andrey Panov	Victor Buzunov	
Europe, excl CIS	Dominique Butty	Marja Brouwer George Banvolgyi Yanis Pontikes		Bernard Allais
Australia	Michael Emond Susany Rocha de Souza	Peter Smith	James Metson	

Internal organisation

The International Committee for Study of Bauxite, Alumina & Aluminium is an independent association that unites industry professionals representing major bauxite, alumina and aluminium producing companies, technology suppliers, researchers and consultants from around the world.

ICSOBA belongs to its members and since the members elect the Board of directors in the Annual Meeting during an ICSOBA Event, members determine the policy of ICSOBA. ICSOBA currently has 238 members.

Membership

ICSOBA provides members with a platform to exchange technical information with each other. Upon their request individual members who are consultants or advisors to the aluminium industry, will be enlisted on the designated Consultants page on the website.

Companies can support ICSOBA by becoming Corporate member. Corporate members are shown in every Newsletter and listed on ICSOBA’s web site. Corporate members can nominate two employees who have the same rights as individual members, such as reduced event delegate registration fee, Newsletters and voting rights. Digital proceedings can be made available to all employees at the company’s intranet, and corporate members can sponsor ICSOBA events at the reduced sponsor fee.

	INDIVIDUAL MEMBERS	CORPORATE MEMBERS
Reduced Sponsor rates at ICSOBA Events		Yes
Reduced delegate registration fee for ICSOBA Events	Yes	Yes for 2 nominated employees
Name listed in ICSOBA's website	In Consultants page upon request	In Corporate Members page with link to web site
Right to vote on ICSOBA matters and eligibility for Presidency and Council	Yes	Yes for 2 employees
Receive a digital copy of a full paper or full proceedings of a past ICSOBA Event	Upon request	Upon request
Biannual Newsletter with articles from members, news and statistics	Yes	Yes to 2 employees. Company mentioned in Newsletters
Annual fee (from July to July)	C$ 100	C$ 500

You can find an application form for individual membership and corporate membership on ICSOBA’s website. You can also renew or apply for individual membership together with your registration for an ICSOBA event.

Public relations and Communication

Website

Printed proceedings of past ICSOBA events, the so-called Travaux volumes, have been scanned to separate searchable pdf files. There are a few exceptions, these are being searched and scanned as soon as possible. The Tables of Contents of the scanned Travaux volumes have been made public on the website http://www.icsoba.info/downloads/proceedings-of-past-events. ICSOBA members can obtain digital versions up to 20 papers each year at no cost by sending an email request to Dipa icsoba@icsoba.info. Additional papers are charged for $ 20 each.

Your feedback to make the website more attractive is welcome.

ICSOBA's executive office

Not only requests for past proceedings, but all inquiries sent to ICSOBA, whether by email to icsoba@icsoba.info or by phone to + 91 982 328 98 17, are addressed by Ms. Sudipta (Dipa) Chaudhuri in Nagpur, India.

Also mailings and the underlying database of ICSOBA's contacts are taken care of by Ms Dipa Chaudhuri in the executive office.

Corporate members

Currently ICSOBA has the following Corporate Members. For more details including links to the company's website, please refer to the member section of the website: http://www.icsoba.info/about-us/corporate-members

AMBER DEVELOPMENT	www.amber-development.com
BOKELA GmbH	www.bokela.com
COLT International BV	www.coltsmelters.com
DUBAL Aluminium Co Ltd.	www.dubal.ae
Hangzhou New Time Valve Co Ltd	www.hzntfm.com
HATCH Associates	www.hatch.ca
HINDALCO Innovation Centre	www.hindalco.com
NALCO India Limited,	www.nalco.com
OUTOTEC Pty Ltd	www.outotec.com
RIO TINTO ALCAN	www.riotintoalcan.com
Shandong Jingjin Filter Press	www.dmxs-com@263.net
STC Engineering GmbH	www.stc-engineering.de
WesTech Process Equipment India P.Ltd	www.westech-inc.com