INTERNATIONAL COMMITTEE FOR STUDY OF BAUXITE, ALUMINA AND ALUMINIUM
ICSOBA

NEWSLETTER

Bauxite Residue Seminar field trip to Belgaum's rehabilitated storage area

A biannual publication

Volume 6 – 15 December 2011

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FOREWORD

Dear ICSOBA Members!

While opening this Newsletter you must have certainly noticed its new graphical form: a fresh format which includes a picture on the front page that is representative of current events. The picture on this issue shares a moment from the field trip to the Belgaum re-vegetated bauxite residue storage area, following the latest ICSOBA Symposium in Goa, India (October 17th-19th, 2011). In fact, a good part of this Newsletter is dedicated to the highly successful Bauxite Residue Seminar in Goa. Altogether some 130 participants from all over the world took part. The seminar was set up with much effort from various international organisers, hosted by our Indian colleagues and was very much appreciated by all participants. Let me extend thanks to all authors, speakers, session chairmen, delegates and all others who contributed to the success of the seminar.

Following the Hungarian Ajka accident involving the bauxite residue storage area, all topics relating to bauxite residue had a chance to be addressed. In this Newsletter you will find a report on the seminar and the outcome of the Round Table discussion: the Summary and Conclusions. The articles obtained before the Seminar were published in Travaux volume and distributed among the participants. Members can obtain a free electronic copy of the proceedings (Travaux) from the Secretariat.

There are two technical presentations in this Newsletter. The article “Bauxite Exploration Data Analysis and Interpretation – Part I” was submitted by D.L. Butty of Switzerland and constitutes a fundamental review on the subject. Further articles from the same author will follow. The second article is by Tran Minh Huan on bauxite, alumina and aluminium developments in Vietnam.

Should you wish to publish your article in one of the future issues of the ICSOBA Newsletter please do not hesitate to contact us. Should you be interested in sharing your comments or perhaps impressions from the past Goa Symposium and field trip, please feel welcome. In future issues we would also like to include articles dealing with equipment used in various areas of bauxite / alumina / aluminium industry, their technical specifications, operating parameters and feedback from their users. We welcome contributions from our readers and members in this regard. We need technical contributions as well as information on various activities in mines and plants.

Also in this issue you will find the latest changes to the ICSOBA Council and Presidency. Dr Ashok Nandi as well as Dr T.R. Ramachandran have resigned following the Goa Symposium and are no longer on the Council. We want to thank them for years of contributions and collaboration and wish them well in their future challenges.

Our next goal on the horizon is the ICSOBA Symposium in Belem, Brazil. It will be staged in cooperation with two Brazilian organisations, Associação Brasileira de Metalurgia, Materiais e Mineração (AMB) and Associação Brasileira de Alumínio (ABAL). Please expect to hear from us, dear Members, early next year, inviting you to submit technical presentations in the areas of bauxite & alumina and carbon & reduction. Again, your support and help will be eagerly welcomed. The next issue of the Newsletter, due in June 2012, will include abstracts of papers scheduled for presentation at the Belem Symposium.

We would like to reemphasize what we have already stated in the past. We need to enrol as many members as possible in order to sustain our activities, including new participants that historically have been underrepresented at ICSOBA events.. Application form for membership can be found in the ICSOBA website.

Thank you for the opportunity to work with you throughout the year. We would like to wish you a joyous and memorable holiday season, with the hopes that the coming New Year continues to bring you and your family health and happiness. Let’s also hope for peaceful and wonderful New Year!

Frank R. Feret
ICSOBA Executive Director

NEWS AND EVENTS

17-19 October 2011 - Bauxite Residue Seminar in Goa, India

Notwithstanding its limited scope, bauxite residue only, 130 delegates, representing producers, researchers, technology suppliers and service companies from 26 countries, participated actively in the seminar during two long days of presentations. The river cruise with dinner and traditional Indian dance show on the evening of the first day did make up for all the serious work.

After the keynote presentations of Dr Mukesh Kumar, President Vedanta and Ron Knapp, Secretary General, International Aluminium Institute, followed three sessions:

- Bauxite Residue Characterization
- Bauxite Residue Processing, Storage and Storage Area Rehabilitation
- Bauxite Residue as Feedstock

The Round Table Discussion at the end of the second day resulted in the Summary and Conclusions document. The final text of this document is included just after below pictures and summarizes the contents of the presentations. The full papers are printed as ICSOBA Travaux volume 40, and the electronic version, including the presentations, is available for members and can be obtained from the Secretariat (info@icsoba.org).

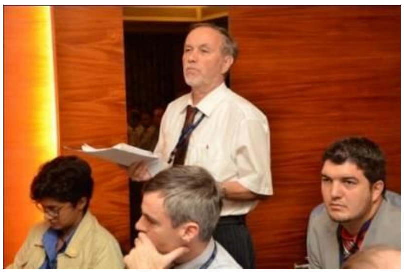
On the third day two busses with delegate undertook the journey to the Belgaum refinery for seeing with their own eyes the successfully re-vegetated bauxite residue storage area (depicted on the cover page).

Enclosed are some pictures of the Seminar, more pictures can be found on the web site.
















Bauxite Residue Seminar Round Table Discussion 'Summary and Conclusions'

I. Bauxite residue facts

Depending on bauxite quality and process parameters, some 1 to 3 tonnes of residue is produced per tonne alumina at a disposal cost of some 2-10 US$/t dry residue. Mining of lower grade bauxites will increase the residue factor. Global annual dry residue production is about 120 Million tonnes, increasing at a rate of about 10% per year.

Only a few per cent of the annual residue production is currently being used, mainly in cement & ceramics, in agriculture, as land fill covering or road and embankment construction. The remainder is largely stored (wet or dry) on land and added to the 2.7 billion tonnes of residue that is already stored. The economic feasible distance of residue transportation from refinery to potential users is proportional to the cost of storage and the realised value of the residue.

Residue has a fine particle size (typically 90% < 75 µm, 50% < 10 µm) and hence substantial leaching potential. However, investigations have shown that the residue solids from the Ajka refinery incident in October 2010 don't present a respiratory threat.

Untreated fresh bauxite residue slurry is highly alkaline, typical pH 12.5 to 13. Due to chemical reactions the pH bounces back after initial neutralisation, although weathering over decades reduces the pH to ≈ 10. A method was presented to rapidly predict long-term residual alkalinity or acid neutralising capacity using a buffer system.

In addition to compounds, such as desilication product (DSP) and tricalcium aluminate (TCA) that are formed during the Bayer process, the residue contains oxides and minerals that were present in the original bauxite. Due to the extraction of alumina from bauxite, the concentration of many compounds in the residue has roughly doubled. The potential toxicity and usefulness of the compounds depend on their concentration and their mineralogy.

Key residue issues are:

- Potential failure of residue retaining dams, groundwater contamination (older storage areas are normally not lined), dusting at storage areas and sustainability of closed storage areas.
- The large volume of residue that has to be stored leads to the search for large scale utilisation of residue as a feed stock with the ultimate goal of achieving a zero waste solution.

II. Actions for dealing with residue topics – Refineries

Each refinery operates in a unique context, resulting in specific risks, needs and opportunities. Below list presents actions for dealing with bauxite residue.

1) Reduce pH. Where possible, reduce the pH before storage or at the residue storage area by mud farming, the latter enabling atmospheric carbonation. The pH of the residue stored in a deposit should preferably be below 11.5; whilst this is technically feasible, significant costs are normally involved. Neutralisation technologies can include: flue gas desulphurisation, CO_2 capture (injection in residue slurry and/or through mud farming), addition of acid or gypsum, or mixing with sea water or brine.

2) Apply Dry Storage. The Best Available Technology for new residue storage is Dry Storage (hence this is not applicalbe for legacy and existing storage areas). Dry Storage involves an initial slurry dewatering step, also reducing soluble soda losses with the disposed residue.

Dewatering technologies are:

a) Modern flocculants in combination with up-to-date deep thickeners producing underflow slurry with 45-55 wt% moisture.
b) Vacuum drum filters producing a filter cake with a moisture content of 35-50 wt%.
c) Filter presses and Hi Bar filters producing a dry filter cake with a moisture content of 24-30 wt%.

Dry Storage technologies are:

a) Dry Stacking:
High density residue slurry (see a. and b. above) is pumped to the storage area and deposited in thin layers. A layer is allowed to consolidate and dry by natural evaporation before successive layers are deposited to form a stack. The smooth surface slope and the angle of deposition allow rainwater to run off. The storage area is under-drained to improve residue consolidation and to avoid water leakage to the underground. Water reclaimed from the storage area is pumped back to the plant or treated and discharged to the environment.

b) Dry Disposal:
Dry filter cake (see c. above) is transported by truck or conveyor belt to the storage area for spreading by earth moving equipment. The storage area is under-drained to avoid water leakage to the underground. Water reclaimed from the storage area is pumped back to the plant or neutralised and discharged to the environment.

Dry Stacking and Dry Disposal on an under-drained storage area result in stable residue deposits with a final moisture content of about 25 wt%.

3) Rehabilitate full Dry Storage areas and treat water before discharge. In the absence of top soil, the addition of gypsum, compost, manure, sewage sludge and fly ash have shown to lower pH and electrical conductivity and to effectively promote vegetation with locally suitable species. Water discharges are collected for further processing as required.

4) Develop methods for utilisation of residue as valuable feed stock, leading to a zero waste solution.

A. There are opportunities to extract valuable components from the residue

Examples are: residual Gibbsite and caustic soda, trace elements such as Sc, Y, etc. These opportunities do not substantially reduce the amount of residue.

B. Make products that incorporate bauxite residue as input material

Pre-treatment, such as dewatering and neutralisation, is needed for certain applications.

Technically possible applications include the use of bauxite residue:

- In agriculture for retention of water and nutrients (possibly pre-treated with for example sea water/brine, gypsum, etc).
- In civil construction such as storage embankment (possibly mixed with other compounds such as fly ash) and road foundations or in landfill site covering.
- In iron and steel metallurgy as component of the agglomerate charge or as a bentonite substitute in pelletizing for iron smelting feed.
- As raw meal input for Portland cement clinker production (3 - 5 wt% bauxite residue).
- As an almost impermeable seal for storage of industrial waste.
- In ceramic applications for roofing tile, pavement tiles and brick production (30-40 wt% bauxite residue) depending on additional materials (firing required).
- After de-watering (and possibly calcination) as pozzolanic material in cement (up to 30 wt% bauxite residue) for concrete applications and end-products (tiles, building blocks etc).
- As a geopolymer for building materials or immobilisation/stabilisation of problematic waste. Adding other materials, such as fly-ash, may be needed as Si- and Al- inputs. (process at room temperature)
- As a component in natural fibre reinforced polymer composites for the fabrication of building products (such as doors, tiles, partition walls etc).
- As a catalyst for iron/iron oxide catalyzed reactions e.g. hydrocarbon cracking and production of carbon nanotubes.
- As a sorbent and coagulant for treatment of waste streams such as acidic waste, mining waste communal waste, CO_2 sequestration, etc.

Some of the above technologies are industrially mature, whilst others are emerging technologies.

III. Recommendations

1) The aluminium industry should be more active in informing the outside world about the positive qualities and opportunities of bauxite residue, such as its long lasting acid neutralising capacity, its pozzolanic and agricultural features and the occurrence of valuable trace elements.

2) The aluminium industry should be more pro-active in clarifying recurring issues that create a negative image of bauxite residue by promoting related scientific research. Whilst untreated highly caustic bauxite residue slurry is harmful, there is no evidence that dry bauxite residue is hazardous although its non-hazardous nature must be scientifically proven on a case by case basis. Potential exposure to bauxite residue differs from site to site and realistic studies of population exposure should be carried out, compared with reference conditions to which the population is normally exposed and the results should be made public.

3) The aluminium industry should involve potential users, technology suppliers, relevant R&D institutions and government agencies to seek opportunities to work together in the further development of specific applications for (large scale) utilisation of bauxite residue. This applies both to new technologies as well as technologies that are currently being developed. Representatives of producers can join forces to develop pre-competitive projects.

4) The round table session did not reach a shared conclusion regarding the role of government regulation to solve the issues related to bauxite residue. Positions ranged from "the industry is in the best position to address bauxite residue issues" to "without more stringent legislation progress will be insignificant".

Bauxite Residue Seminar - List of Delegates

Delegates of the Bauxite Residue Seminar 2011 Goa, India

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6 – 9 November 2012 - 19th International Symposium in Belem, Brazil

In a meeting with the Brazilian Aluminium Association (ABAL) and the Brazilian Metallurgy, Materials and Mining Association (ABM) we reached agreement on venue, budget, speaker sessions, and distribution of tasks for the joint ICSOBA-2012 Event. The Symposium will be held in Belém, in the north of Brazil. After a plenary session with key note speakers there will be parallel sessions for Bauxite, Alumina and Aluminium (including Carbon and Cast house) on November 6 and 7. The plenary session and formal closure at the end of November 7 will be followed by an ICSOBA General Assembly meeting in which new ICSOBA Presidency and Council members will be elected and Statutes related to the legal registration in Canada adopted.

November 8 will provide opportunity for delegates to visit the world's largest alumina refinery Alunorte and / or the nearby Albras smelter. In case of sufficient interest a field trip on November 8 - 9 will be organized to the Paragominas bauxite mine, with its 250 km long bauxite pipeline ending at Alunorte's drying station.

The selection of Brazil follows ICSOBA's practice of rotating the venue of International Meetings to countries that are important for the global aluminium industry. Presently Brazil accounts for 14% of world's bauxite, 10% of world's alumina and 4% of world's aluminium production. Brazil's untapped bauxite resources are massive and will serve as basis for future industry developments. Especially the recently developed Paragominas and Juruti mines readily serve future alumina refining developments. The large Trombetas bauxite mine, with a capacity of 18 Mt/y, is famous for its successful mine rehabilitation program.

Brazil's current alumina refining production is 11.3 Mt. The Alunorte refinery - producing 6.3 Mt/y, the nearby CAP project that envisages the construction of a similar alumina producing giant, and Votorantim's project for a mine and refinery at Rondon do Pará will further develop Pará state into one of the world's major bauxite & alumina production centres. Other important refining operations include Poços de Caldas, CBA and the recently expanded Alumar refinery, with its two huge digestion units for a total alumina production of 3.5 Mt/y.

Brazil's aluminium capacity stands at 1.6 Mt/y. The 8,400 MW Tucuruí hydroelectric power plant is the world's fourth largest facility, feeding the Albras and Alumar aluminium smelters. Other smelting operations include CBA, Alcoa in Poços de Caldas and Novelis in Ouro Preto.

September 2013 - 20th International Symposium in Krasnoyarsk, Russia

ICSOBA will celebrate its 50th anniversary during the 20th International Symposium on Bauxite, Alumina and Aluminium, which will be organized jointly with VAMI-RUSAL and the Non-Ferrous Metals Congress and Exhibition in Krasnoyarsk, Siberia, Russia. ICSOBA's President Roelof den Hond and Vice President Andrey Panov participated in the 2011 Non-Ferrous Metals Event and made preliminary arrangements for 2013.

The III International Congress and Exhibition: Non-Ferrous Metals 2011 held in Krasnoyarsk, Russia September 7 – 9 2011.

TECHNICAL PAPERS

Bauxite Exploration Data Analysis and Interpretation – Part I

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Abstract

The present paper is the first on the subject of analysing and interpreting exploration data. After a brief introduction on the logic, principles and sequence of the process, the use and application of exploratory data analysis (EDA) are examined in some details, including univariate, bivariate and multivariate statistics, respectively dealing with single, paired and multiple data attributes. The role of EDA is establishing the statistical characteristics of the relevant datasets and understanding such characteristics in their geologic context, e.g. root causes of high negative skewness, bimodality, relationships and grade dependences. The implications for modelling are evaluated after completing the process of data analysis and interpretation, with all elements in hand to develop the most appropriate approach. This topic will be covered in the next ICSOBA newsletter.

Keywords: Exploratory data analysis (EDA), univariate statistics, bivariate statistics, multivariate statistics, outliers, data population.

Introduction

Analysing and interpreting exploration data requires an exhaustive and reliable database consistent with the stage and objectives of the project and providing a detailed account of the bauxite occurrence in terms of geology, geotechnics, mining, beneficiation as well as processing.

The purpose of this series of papers, on analysing and interpreting exploration data, is characterizing a bauxite occurrence and its interfaces with off-grade material above, within and below.

Bauxite and off-grade material are usually categorized in various facies resulting from a variety of genetically related physical, chemical and mineralogical characteristics. Facies elements, usually characterized by short range continuity, are the smallest geological units observable at the scale of outcrops and/or drill samples. Facies systems include facies elements sharing a common set of distinctive characteristics and show continuity at the scale of a bauxite occurrence or part thereof. At a higher order, facies complexes include a series of facies systems characterizing the geological setting of specific types of bauxite deposit, such as lateritic plateau, sedimentary and buried bauxite deposits to name a few.

To use field terminology, the terms facies elements and facies systems are hereafter referred to as litho-facies and main geological units respectively.

As indicated earlier, litho-facies seldom have sufficient spatial continuity to support modelling. Main geological units therefore provide a broader framework representing the geology of a bauxite occurrence and associated material. In turn, the main geological units support the definition of model domains, the purpose of which is mapping commercial grade bauxite(s) as well as overburden, basal clays and internal waste. While the main geological units focus on the representation of geology, model domains are concerned with overburden stripping and bauxite mining, which may involve the selective extraction of specific ore types. One can think of these two complementary representations, as the geological model on the one hand and the resource model on the other, which usually includes a sub-set of the former.

Table 1. Example of Litho-Facies – Obtained from Coring

Description	**Proportion**	**SiO_2 %**	**Fe_2O_3 %**	**Al_2O_3 %**	**TiO_2 %**	**$RSiO_{2LT}$ %**	**AA_{LT} %**	**LOI %**
Lateritic Hardpan	7.1%	2.5	25.2	45.8	1.7	0.9	43.1	23.8
Bauxitic Hardpan	7.7%	2.6	15.6	52.7	1.2	1.2	49.5	26.8
Jointed Blocky Bauxite	56.2%	4.7	16.9	50.3	1.7	3.1	45.2	25.5
Clayey Bauxite	10.5%	12.6	10.5	51.4	1.0	11.1	38.2	23.5
Pelitomorphic Bauxite	18.2%	15.4	14.0	47.1	1.3	13.1	32.0	21.2
Floor Material	0.3%	16.8	11.0	48.5	1.5	14.7	31.1	21.2

$RSiO_{2\,LT}$ and AA_{LT} refer to reactive silica and available alumina at low temperature digest.

The above table shows that floor material is poorly sampled. This raises the issue of completeness of drilling, which must always be questioned. Is the mineralisation fully sampled by drilling? Why holes stop in bauxite, hard rock, water, breakdown or error? In the above case, hard rock is the main reason.

The use of destructive drilling for exploration precludes or limits logging of litho-facies, in which case logging must at least support the definition of main geological units, as shown in Table 2. Frequently, litho-facies are known only from a few pits/trenches or core drill holes, and logging of main geological units constitutes the bulk of the sample descriptions.

Table 2. Example of Main Geological Units – Obtained from Auger Drilling

Description	**Proportion**	**SiO_2 %**	**Fe_2O_3 %**	**Al_2O_3 %**	**TiO_2 %**	**LOI %**
Bauxite	42.1%	2.1	25.2	44.9	2.5	24.6
Lateritic Bauxite	27.5%	2.7	32.0	39.9	2.3	22.3
Laterite	25.2%	4.6	37.3	35.1	2.0	19.9
Basal Clay	2.3%	23.7	25.5	32.1	1.9	14.6

Litho-facies as well as main geological units are derived from sample logging, i.e. essentially the visual observations and estimates of basic physical characteristics such as colour, structure, texture, moisture, consistency and strength. Logging is qualitative, not quantitative, and it depends on the quality of the samples and the experience of logging personnel. By contrast, model domains are mainly based on quantitative assay determinations. Given that bauxite is a commercial product with tight specifications, chemical and physical characteristics relevant for the definition of ore grades must be considered when forming model domains.

In spite of these important differences, main geological units and model domains should be consistent. This harmonisation process is generally iterative and easier to perform when forming main geological units from litho-facies. Although overriding litho-facies descriptions based on grades is involved, e.g. including as ore grades material logged as bauxitic clays on the evidence of low silica, the method allows for a detailed mapping of the geology into the resource model. Less geologic details will be mapped into the resource model when forming model domains from main geological units based on destructive drilling. The process essentially involves developing envelopes within the main geological units to map bauxite and off-grade materials.

Work Flow

Initially, the characterisation of a bauxite resource involves exploratory data analysis (EDA) of litho-facies and/or geological units, with a view to establish their grade characteristics, distributions and relationships. The spatial distribution of grades and facies is then examined by means of profiles, sections and maps, to identify specific layers and boundaries as well as trends, variations or segregations in specific areas and/or strata. Based on the above, main geological units are formed as well as tentative model domains. EDA is conducted on model domains, including normality tests. Sections are produced to evaluate spatial continuity and contact analyses are conducted to quantify the chemical and/or physical contrasts between adjacent domains. The nature of such contrasts - ranging from poor, moderate or strong - may impact on the modelling approach and/or require redefining domains. Joint distributions – i.e. distributions of several grades in function of a specific grade - are produced to evaluate cutoff grade options. Cutoff grade sensitivities are also run to select a set of optimum parameters and firm up the definition of model domains. Variography is applied at this stage and/or earlier for the preliminary definition of model domains. Variograms are produced for each domain to characterise spatial variability in the vertical and horizontal directions. If unfolding is deemed necessary for modelling, then variography must be conducted in a flat space.

The present paper, the first on the subject of analysing and interpreting exploration data, will cover Exploratory Data Analysis.

Exploratory Data Analysis (EDA)

EDA is applicable to a wide range of chemical or physical data attributes. However, exploration data mainly consist of sample grades which therefore are our focus. EDA includes univariate, bivariate and multivariate statistics, respectively dealing with single, paired and multiple data attributes.

The role of EDA is establishing the statistical characteristics of the relevant datasets and understanding such characteristics in their geologic context, e.g. root causes of high negative skewness, bimodality, relationships and grade dependences. The implications for modelling are evaluated after completion of data analysis and interpretation, with all elements in hand to develop the most appropriate approach.

EDA is more meaningful when applied to litho-facies, rather than coarser data categories. For this reason, detailed logging is quite helpful to get an in-depth understanding of exploration data.

Univariate Statistics

Descriptive satistics include a series of tests establishing the characteristics of datasets, as follows:

Measures of Location

- Range, the minimum and maximum data values are indicative of the spread of the population.
- Quartiles are the three points Q_1 (lower quartile), Q_2 or Median and Q_3 (upper quartile) dividing a dataset into four equal parts.
- Median or Q_2, the point dividing a dataset in two equal parts.
- Mean (the first moment), the arithmetic average of all data values, which equates to the median for normal distributions. Both the mean and median provide a measure of the central tendency of the frequency distribution curve. The mean is very sensitive to erratic highs or lows, while the median is not concerned by the values of data but by their proportions.
- Standard error of the mean, the square root of the ratio of the variance s $(n-1)^2$ to the sum of weights Sw.

$\perp$

$$s_{\mu} = \sqrt{\frac{s(n-1)^2}{Sw}}$$

- The upper/lower bound on the mean at a given confidence interval (CI), generally 95%.
- The geometric mean of a set of positive values is always less than or equal to the arithmetic mean. It tends to reduce the effect of outliers in highly skewed datasets.

$$\mu_G = \exp\left(\frac{1}{Sw}\sum_{i=1}^{n} w_i Ln\left(x_i\right)\right)$$

- Mode, the observation with greatest frequency.
- Modal Class, the class interval with greatest frequency.

Measures of Spread

- Variance $s\ (n-1)^2$ (or the second moment), the sum of the squared differences between individual data values xi and their mean μ, divided by the number of data values n minus one (n-1). Exploration usually generates data populations rather than sample datasets, and this calls for the use of the (n-1) denominator which takes into account an approximation associated with sampling (1 also equates to the degree of freedom). Conversely, the variance $s\ (n)^2$ is a biased estimate which assumes that the sample provides a reliable representation of the total population. The variance is a measure of the spread of data values about their mean:

$$s\left(n-1\right)^2 = \frac{\sum_{i=1}^{n} w_i\left(x_i-\mu\right)^2}{Sw - Sw/n}$$

where Sw is the sum of weights, equal to the number of data values n in absence of weighing by length and/or density. Likewise the mean, the variance is very sensitive to outliers. Data weighing should be used in statistical computation, when dealing with samples of irregular lengths and/or litho-facies with high density contrast. Or at least, the impact of not using weights should be evaluated.

- Standard variation, the square root of the variance.
- $Q_3 - Q_1$ stands for the inter-quartile range IQR, which is a measure of dispersion. In presence erratic highs or lows, IQR is preferred to the standard deviation which depends on the mean. Any data outside the Lower Fence (Q_1 – 1.5 IQR) and Upper Fence (Q_3 + 1.5 IQR) are considered outliers.

Measures of Shape

- Coefficient of variation, the ratio of the standard deviation to the mean. It measures the dispersion of a sample relative to its mean and is used for comparing the dispersion of samples with different scales or means.
- Skewness (the third moment), the degree of asymmetry of a distribution. It is negative if the distribution is concentrated on the left of the mean, and positive in the opposite case. A symmetrical distribution has zero skewness. Minor oxides tend to be positively skewed and the opposite for major oxides. There are various formulae for computing skewness, including that defined with respect to the third moment about the mean:

$$\gamma_1 = \frac{\sum(X-\mu)^3}{n\sigma^3}$$

and that of proposed by Fisher, which is not biased on the assumption of data normality.

$$g_1 = \frac{n\sum z^3}{(n-1)(n-2)}$$

Skewness is very sensitive to erratic highs and lows.

- Kurtosis (the fourth moment), an indication of the shape of the distribution. It is negative if the peak of the sample distribution is more flattened out than that of a normal distribution and positive in the opposite case. β_2 is often referred to as "Pearson's kurtosis and $\gamma_2 = \beta_2 - 3$ as "kurtosis excess", also referred to as the Pearson kurtosis.

$$\beta_2 = \frac{\sum (X - \mu)^4}{n\sigma^4}$$

Flat-topped distributions ($\gamma_2 < 0$) are referred to as "platykurtic," less flat-topped distributions ($\gamma_2 > 0$) as "leptokurtic," and equally flat-topped distributions as "mesokurtic" ($\gamma_2 \approx 0$) [1].

Fisher unbiased estimator for γ_2, not assuming data normality, stands as:

$$g_2 = \frac{n(n+1)\sum Z^4}{(n-1)(n-2)(n-3)} - \frac{3(n-1)^2}{(n-2)(n-3)}.$$

Table 3. Descriptive Statistics–Litho-Facies Jointed Blocky Bauxite

Facies Jointed Blocky Bauxite (From Table 1)	SiO_2 %	Fe_2O_3%	Al_2O_3%	TiO_2%	$RSIO_{2LT}$%	AA_{LT}%	LOI%
No. of observations	642	642	642	642	642	642	642
Minimum	0.19	0.31	18.01	0.03	0.01	7.61	9.32
Maximum	36.48	65.12	62.27	3.66	33.39	58.25	31.32
1st Quartile	1.9	8.78	45.27	1.15	0.77	40.51	23.04
Median	3.12	15.14	51.04	1.73	1.48	46.65	26.01
3rd Quartile	4.88	24.08	56.09	2.15	2.64	51.68	28.31
IQR	2.98	15.30	10.82	1.00	1.87	11.17	5.27
Mean	4.67	16.89	50.34	1.67	3.12	45.18	25.46
Geometric mean	3.23	13.35	49.79	1.47	1.49	43.96	25.16
Variance (n-1)	28.56	103.16	50.19	0.49	25.84	79.89	13.66
Standard deviation (n-1)	5.34	10.16	7.08	0.70	5.08	8.94	3.70
Variation coefficient	1.14	0.60	0.14	0.42	1.63	0.20	0.15
Skewness (Pearson)	3.35	0.72	-0.58	-0.01	3.44	-1.27	-0.86
Skewness (Fisher)	3.36	0.72	-0.58	-0.01	3.45	-1.27	-0.86
Kurtosis (Pearson)	12.94	0.48	0.09	-0.42	12.97	2.26	0.75
Kurtosis (Fisher)	13.05	0.49	0.10	-0.42	13.08	2.29	0.76
Standard error of the mean	0.21	0.40	0.28	0.03	0.20	0.35	0.15
Lower bound on mean (95%)	4.26	16.10	49.79	1.61	2.73	44.49	25.17
Upper bound on mean (95%)	5.09	17.68	50.89	1.72	3.52	45.88	25.75

The minimum, maximum values as well as the spread of the quartiles and IQR are indicative of wide ranging grades. High coefficient of variations, significant gaps between the mean and median as well as a high degree of skewness and kurtosis reflect the presence of grade outliers for SiO_2 and $RSiO_2$, as confirmed by Fig.1.

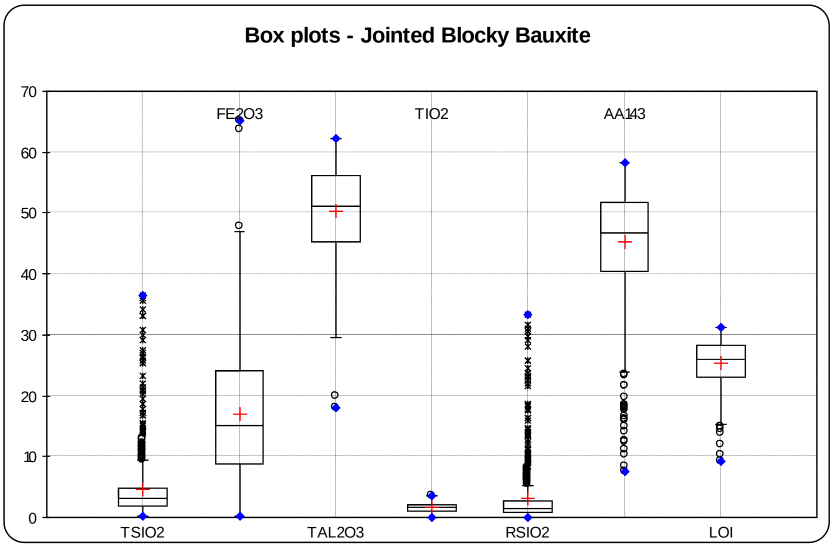

Fig. 1. Box Plot of Jointed Blocky Bauxite (Litho-Facies Table 1).

Box plot is a powerful tool providing graphical support to descriptive statistics. In this case, it fully characterises in a single graph the litho-facies Jointed Blocky Bauxite (Table 3).

Box Plot Conventions

- The lower edge of the box represents the first quartile Q_1.
- A black line represents the median.
- A cross represents the average.
- The upper edge of the box represents the third quartile Q_3.
- Lower limit or Lower Fence: $Q_1 - 1.5\ (Q_3 - Q_1)$.
- Upper limit or Upper Fence: $Q_3 + 1.5\ (Q_3 - Q_1)$.
- Values outside the range Q_1 - 3 $(Q_3 - Q_1)$ and $Q_3 + 3\ (Q_3 - Q_1)$ are displayed with the ⨯ symbol.
- Values within Q_1 - 3 $(Q_3 - Q_1)$ and $Q_1 - 1.5\ (Q_3 - Q_1)$ or within $Q_3 + 1.5\ (Q_3 - Q_1)$ and $Q_3 + 3\ (Q_3 - Q_1)$ are displayed as circles. Maximum and minimum values as shown as filled circles.

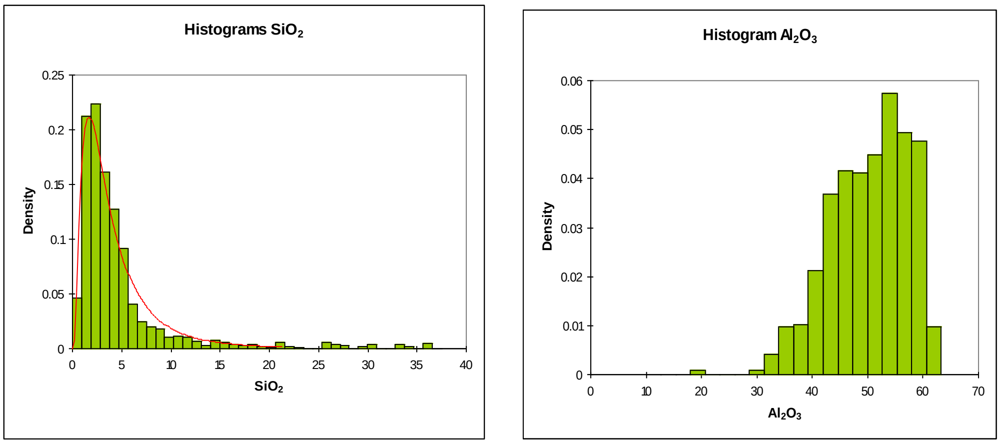

Fig. 2. Histograms of SiO_2 and Al_2O_3, Jointed Blocky Bauxite.

Histograms are most appropriate to visualize grade distributions and detect the presence of various mineralogical phases. It is evident from Fig. 2 that the Jointed Blocky Bauxite includes a minor proportion of high silica material, essentially aluminous clays – assumption based on the minor gap between SiO_2 and $RSiO_2$ **-** in the form of interstitial matrix, lenses or transitions to adjoining litho-facies. For this reason, silica almost follows a lognormal distribution (shown by a curve) due to a long tail of high values.

Descriptive statistics (Table 3) show that Jointed Blocky Bauxite mainly consists of good quality bauxite. Clearly, it stands as the backbone of this bauxite occurrence and will form the main component of the bauxite domain, which will be delimited in due time using profiles, sections and contact analysis.

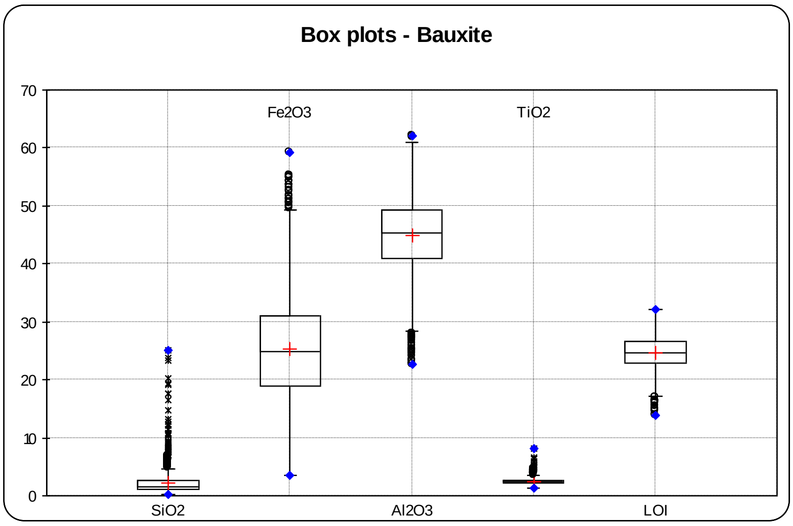

Fig. 3. Box Plot of Bauxite (Main Geological Unit - Table 2).

The above Bauxite main geological unit is based on the logging of samples produced by destructive drilling (auger samples). This geological unit contains in reality a variety of litho-facies that have been recorded in a few pits and core samples. Hence, auger sample logs offer a low resolution image the bauxite bearing layer. In this case however, the situation is relatively simple and clear with the bulk of the population with grades above 40% Al_2O_3 and below 5% SiO_2. Grade profiles, sections, joint grade distributions and contact analysis will help designing the envelopes of the model domains, a process that will be largely driven by target grade specifications.

Testing Populations

Geological data tend to deviate from a normal distribution given their multiple constituents with varying chemical properties. In fact, geological data seldom fit a specific distribution; highly skewed datasets tend to deviate from a lognormal distribution while the most symmetrical datasets can fail strict compliance with normality.

Grade distributions reflect the nature of litho-facies and/or main geological units, and therefore must be evaluated and understood. It is not really important if grades of litho-facies or main geological units follow or do not follow any particular mathematically defined distributions.

For model domains, the situation is somewhat different. Kriging, the interpolation method of reference, does not require data normally distributed; normality is however necessary for some simulation methods (e.g. Sequential Gaussian) and probability maps produced with ordinary, simple and universal 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].

Of the various methods available, the normal score (NST) and natural log transformations are often applied. NST is designed to fit a dataset to a normal distribution, by ranking the data values from lowest to highest and matching these ranks to equivalent ranks generated from a normal distribution [5]. The process uses either the frequency distribution or the cumulative frequency distribution of the dataset.

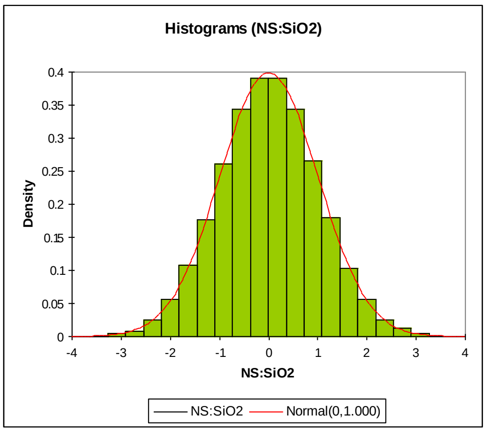

Fig. 4. Histogram of NST Transformed SiO_2 from Fig. 2.

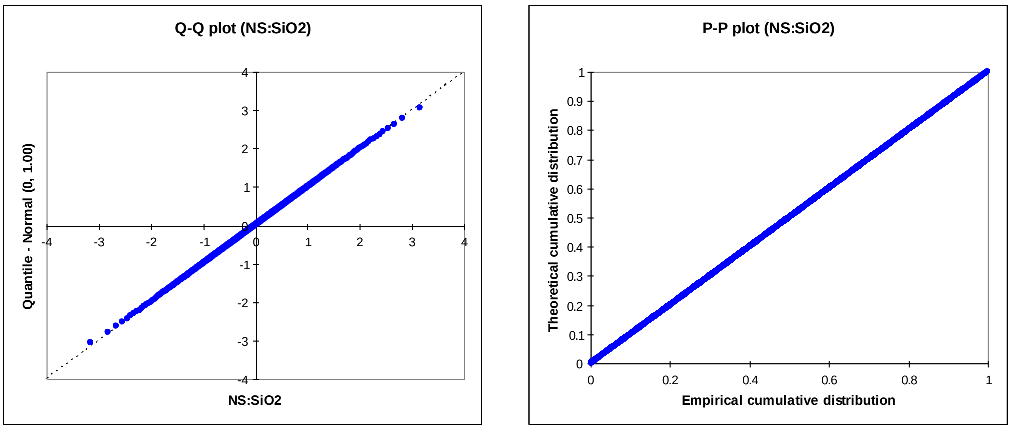

Fig. 5. Q-Q and P-P Plots of NST Transformed SiO_2 from Fig. 2.

A variety of statistical tests are available to verify normality, e.g. Shapiro-Wilk, Anderson-Darling, Lilliefors, Jarque-Bera, or fitting distribution [6]. As shown in Fig. 5, Q-Q and P-P plots provide a visual evidence of compliance with normality.

- Probability-Probability plots (P-P) compare the empirical distribution function of a sample with that of a sample distributed according to a normal distribution of the same mean and variance. If the sample follows a normal distribution, the points will lie along the first bisector of the plan.
- Quantile-Quantile plots (Q-Q) compare the quantiles of a sample distribution with those of a sample distributed according to a normal distribution of the same mean and variance. If the sample follows a normal distribution, the points will lie along the first bisector of the plan.

Dealing with Outliers

Outliers result from a variety of causes, including sampling/analytical errors and natural heterogeneity. In the case of data almost normally distributed but including spurious data, Winsorisation [7] provides robust estimates of the mean and variance. The method consists essentially in assigning values [8] within selected limits to outliers, thus reducing the spread of the dataset while preserving the number of data elements. This method is an alternative to trimming outliers, which often is a questionable approach. With exploration datasets, outliers are generally supported by a significant number of measurements and carry valuable information. It is therefore important to understand the reasons for outliers and evaluate implications.

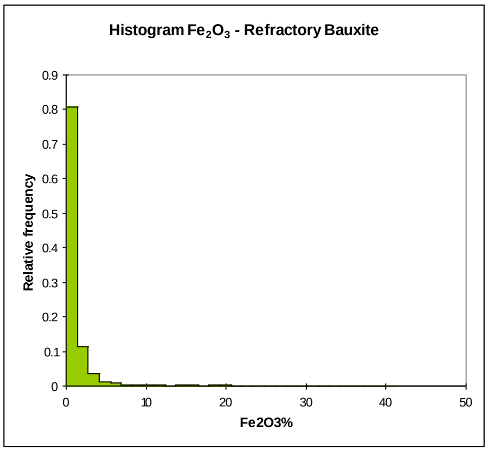

Fig. 6. Fe_2O_3 Histogram of Massive Bauxite.

Fig. 6 displays the distribution of Fe_2O_3 within massive bauxite showing evidence of extensive Fe_2O_3 leaching. Outliers of high Fe_2O_3 values indicate the presence local zones or pockets of incomplete leaching or more likely of local concentrations resulting from variations of Eh and/or pH and the attendant formation of iron oxides/hydrates, pyrite, marcassite or siderite.

Iron contamination could cause quality control issues for this refractory grade bauxite; hence the need to map local concentrations in profiles, sections and maps, and to evaluate implications for selective mining.

Bivariate Statistics

There are strong bivariate and multivariate dependences between grades, which reflect the mineralogical composition of bauxite.

Bivariate statistics focus on the relationships between paired grades such as their degree of correlation (matrix, Table 4), relationships between groups of grades (dendrogram, Fig. 7) or compatibility between two datasets, e.g. between two generations of assays data on the same material or from the same locations (Fig. 8).

Table 4. Correlation Matrix (Pearson) – Jointed Blocky Bauxite (from Table 3)

Variables	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**TiO_2**	**$RSiO_{2\ LT}$**	**AA_{LT}**	**LOI**
SiO_2	**1**	**-0.243**	**-0.131**	**-0.243**	**0.984**	**-0.661**	**-0.470**
Fe_2O_3	**-0.243**	**1**	**-0.924**	**0.441**	**-0.289**	**-0.558**	**-0.728**
Al_2O_3	**-0.131**	**-0.924**	**1**	**-0.417**	-0.074	**0.821**	**0.908**
TiO_2	**-0.243**	**0.441**	**-0.417**	**1**	**-0.246**	**-0.186**	**-0.260**
$RSiO_{2\ LT}$	**0.984**	**-0.289**	**-0.074**	**-0.246**	**1**	**-0.626**	**-0.431**
AA_{LT}	**-0.661**	**-0.558**	**0.821**	**-0.186**	**-0.626**	**1**	**0.958**
LOI	**-0.470**	**-0.728**	**0.908**	**-0.260**	**-0.431**	**0.958**	**1**

Values in bold are different from 0 with a significance level alpha = 0.05

The Pearson correlation, the classical linear correlation coefficient, is well suited for continuous data and measures the degree of linear correlation between two variables [6]. The Spearman correlation coefficient, based on the ranks of observations and not their values, is applicable to ordinal data.

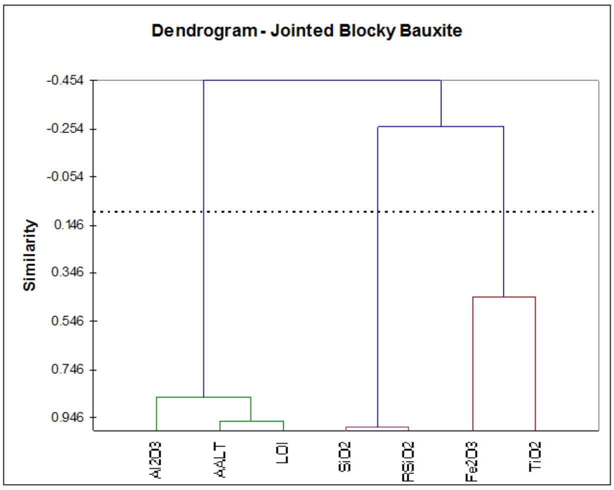

Fig. 7. Dendrogram of Variables in Table 4.

The above dendrogram provides graphic support to Table 4 and highlights the privileged correlations within the gibbsite, kaolinite and FeTi groups. In the latter group anatase is likely derived from the weathering of the FeMg minerals; also Ti and Fe tend to share similar geochemical behaviors in the weathering processes, hence their relationship.

Compatibility of assays belongs to quality control (QC), but is mentioned under EDA because this important issue is easily overlooked. Fig. 8 shows the Kolmogorov-Smirnov distribution fitting test (a non parametric test), which compares the empirical distributions of Fe_2O_3 and SiO_2 from two datasets (1 & 2) originating from separate exploration drilling at the same locations (twin holes). The test results confirm that SiO_2 1 & 2 follow the same distribution while Fe_2O_3 1 & 2 are not. Q-Q plots (as well as P-P plots) are also used to compare the distributions of variables from two datasets. If the two distributions are similar, the points in the Q-Q plot will approximately lie on the line $y = x$ (see Fig. 5). If the distributions are linearly related, but not similar, the points will approximately lie on a line, but not on that of $y = x$.

Other parametric tests (i.e. assuming a mathematically defined distribution) are available to evaluate the distributions of separate variables based on the comparison of variances (Fisher's F test, Levene's test, Bartlett's homogeneity of variances test) [6].

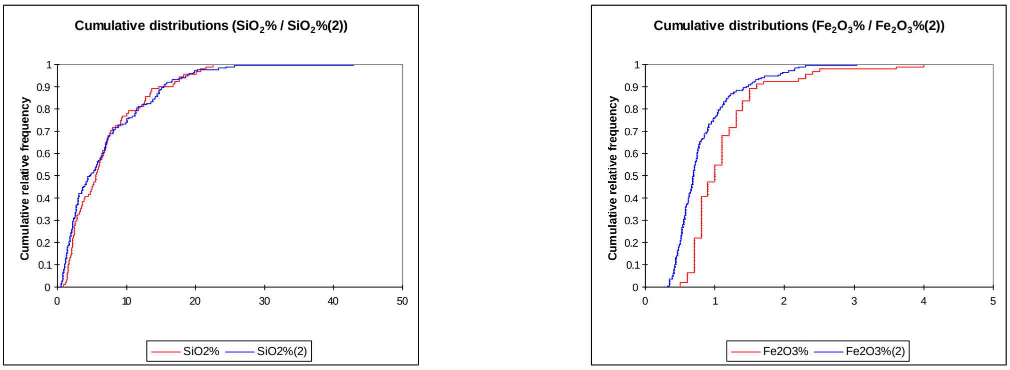

Fig. 8. Cumulative Distribution of SiO_2 and Fe_2O_3 (drill samples from two separate exploration campaigns at the same locations).

Multivariate Statistics

Multivariate statistics deal with relationships between one and several grades (Fig. 9) and the proportions between multiple grades (ternary plots, Fig. 10). The distribution of several grades in function of a single grade (joint distribution), is also dealing with several variables and is based on the dependence between these variables. Joint distributions will be examined when evaluating the effects of cutoff grades.

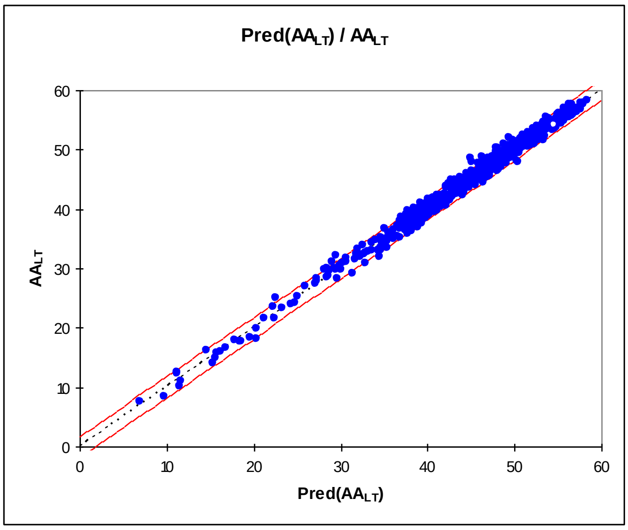

Fig. 9. Multilinear Correlation – AA_{LT} vs. Major Oxides and LOI.

Table 5. Goodness of Fit Statistics

DF	636	Degrees of freedom
R^2	0.990	The determination coefficient for the model.
Adjusted R^2	0.990	Correction to the R^2 taking into account the number of variables used in the model.
MSE	0.810	Mean squared error, equates to the variance for an unbiased estimator.
RMSE	0.900	The root mean squared error, the RMSE is the square root of the variance, i.e. the standard deviation.
MAPE	1.763	Mean Absolute Percentage Error.
DW	1.315	Durbin-Watson coefficient used to check that the residuals of the model are not auto correlated, given that the independence of residuals is one of the basic hypotheses of linear regression. Table of Durbin-Watson statistics are available to check if the independence hypothesis for the residuals is acceptable.
F	15950	F statistic.
$F_{(0.1,4,636)}$	3.4	Critical value for alpha 0.1, from table.
P	< 0.0001	p-value corresponding to the F test.

The value of DW lies between 0 and 4; if it is substantially less than 2, there is evidence of positive correlation between successive error terms. This does not impact on the estimate of the regression coefficients, but may lead to the overestimation of the level of statistical significance. With a DW of 1.3, the above multi linear correlation shows evidence of positive correlation, at the same time the level of significance of the F-tests on the model (Table 5) and each quantitative variable indicate a robust correlation. If DW is less than 1.0, then there may be cause for concern. If DW >2 successive error terms are negatively correlated, which can result in the underestimation of the level of statistical significance [9].

The following ternary plots display the relative proportions of Fe_2O_3, SiO_2 and Al_2O_3 in the litho-facies Massive Bauxite (also shown in Fig. 6) and Clayey Bauxite. Both facies are heavily depleted in iron, but contain a varying proportion of clays. Ternary plots are ideal graphic tools to characterize litho-facies in a single graph, based on the relative proportions of silicon, iron and aluminium oxides.

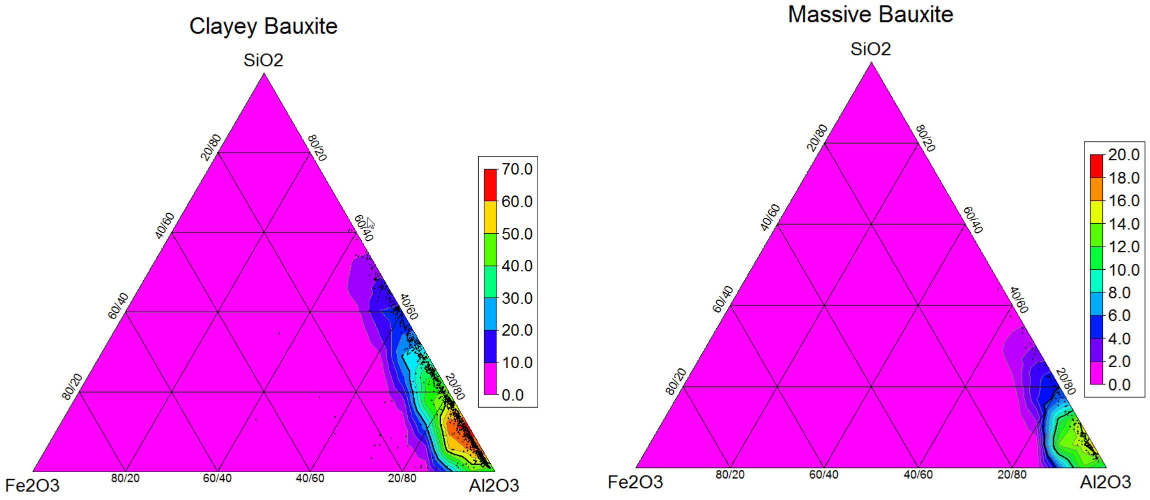

Fig. 10. Ternary Plots – Refractory Grade Bauxite, Clayey and Massive Bauxite.

The foregoing considerations on analysing and interpreting exploration data will be followed by a review of the statistical, mathematical and geological methods applied in the preliminary phase of resource modelling - including spatial distributions, cutoff grade analysis, domaining, contact analysis and variography - which will be published in the next release of the ICSOBA newsletter.

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Development of the bauxite-alumina-aluminium industry of Vietnam

Dr. Tran Minh Huan, Fr. Director General, Vietnam's Ministry of Industry

Abstract

Bauxite has been found in Vietnam in karstic and also in lateritic genetic forms. The karstic bauxite is concentrated in the northern regions with the total resource of diasporic bauxite of nearly 200 million tons. The bauxite located in the southern regions originated by lateritic weathering of neogene/quaternary basalts with total resources of this type of bauxite of 6,750 million tons.

Total demonstrated reserves of bauxite in Vietnam were explored and estimated to be of around 2,772 million tons (Mt), of which bauxite ores of lateritic type are about 2,358 Mt. The total resources are forecasted to be 6,740 – 7,600 Mt. If these amounts are reliable, Vietnam is considered to be a bauxite-rich nation.

In early 1970's, Vietnam tried to exploit bauxite deposits in the Lang Son Region (Tam Lung, Ma Meo and other deposits) in the North to produce alumina and abrasive materials. In the late 1970's and in the 1980's, Viet Nam used to cooperate with former socialist countries (Soviet Union and Hungary) to develop bauxite projects in the Central Highlands. Over the last years, Vietnam has been developing two 650,000 t/a alumina refineries in the Highlands.

Needless to say, in order to successfully develop a desired bauxite-alumina-aluminium industry, the Government and concerned organizations should work out down-to-earth policies and decisions, which are in line with both the domestic and international conditions; otherwise, "Miss Vietnamese Bauxite" will continue to sleep in the forest for good.

Keyword: Bauxite resource, development way, challenging infrastructure.

1. The bauxite resources of Vietnam

Bauxites in Vietnam have been found in karstic and also in lateritic genetic forms. The karstic, diasporic bauxite is concentrated in the northern regions (with the total resource of diasporic bauxite of nearly 200 million tons (equal to 91 million tons of bauxite concentrates, of which 84 million tons (Mt) are in $B+C_1+C_2$ categories (as per the reserve calculation system used in the former COMECON terminology) and 7 Mt in the P (prognostic) category.

The lateritic (gibbsitic) bauxite formed in the weathering profile of neogene/quaternary basalts is concentrated mainly in the Central Highlands with the total resources of 5,400 Mt (equivalent to 2,300 Mt of bauxite concentrates, of which 2890 Mt is $A+B+C_1$ level of knowledge, 1,620 Mt of C_2 level and 386 Mt of P_1 level) .

Total demonstrated reserves of bauxite in Vietnam were investigated and estimated to be 2,772 Mt, of which bauxite ores of lateritic type are 2,358 Mt. The total resources could be forecasted to be of 6,740 – 7,600 Mt. If these amounts are reliable, Vietnam's bauxite reserve is likely to rank 4th in the world (after Australia, Guinea and Brazil). If a country was endowed with such a big natural resource, it should develop strong bauxite - alumina industry and, obviously, first thing to do is to work out a proper strategy for this important resource.

Karstic bauxite

The chemical composition of this type of bauxite Al_2O_3 = 42-57%, SiO_2 = 4-15%, Fe_2O_3 = 20-29%, TiO_2 = 2-4%; L.O.I = 11-13 %; mineral composition: diaspore, boehmite, chlorite, kaolinite, haematite.

In terms of their location, except for some scattered deposits of bauxite ores in Son La, Lai Chau provinces, bauxite is concentrated in clusters in Ha Giang, Cao Bang, Lang Son provinces, Lo Son-Hai Duong province and Qui Hop - Quy Chau, Nghe An province.

a / Ha Giang province has 27 deposits. The chemical composition of the (un-beneficiated = un-washed) bauxite found here is: Al_2O_3 = 30-45% (highest 59.56%) SiO_2 = 10-15%, Fe_2O_3 = 19-25% (highest 34.1%, the lowest 9%); TiO_2 = 1.3-5.5%, CaO = 0.01-1.83%, S = 0.002-0.55%, Alumina/silica ratio is usually around 4-10. Reserves here were estimated at about 60 Mt.

b / Cao Bang province has 35 deposits. The chemical composition of the (crude) bauxite: Al_2O_3 = 30-65% (average> 43%), SiO_2 = 4.5-15% (the lowest is 1.2%, the highest is 31.8%), Fe_2O_3 = 19-25% (the lowest is 2.5%, the highest is 40.16%), TiO_2 = 2-4%, CaO = 0.1-0.8%, the harmful impurities (TiO_2, CaO, S) are within the permissible range of fields of use. The reserves were estimated to be of about 240 Mt in the $B+C_1+C_2$ categories.

c / Lang Son province has 36 deposits. The chemical composition of the crude bauxite: Al_2O_3 = 44.65-58.84%, SiO_2 = 6.4-19.2%, Fe_2O_3 = 21.32-27.35%, TiO_2 = 1.2-3.26%; CaO = 0.18-0.42%, S <0.02%, P_20_5 = 0.01-0.03%; mineral compositions are mainly diaspore (60-70%), boehmite (20-30%), a little gibbsite. The Ma Meo and Tam Lung bauxite deposits have the chemical composition as follows: Al_2O_3 = 47.71-50.07%, SiO_2 = 8.81-19.97%, Fe_2O_3 = 21.76-25.0%, TiO_2 = 2.57-3.35%, CaO = 0.8%, S = 0.02%, P_2O_5 = 0.02%. Reserves of the above deposits were estimated to be of 33 Mt for the $B+C_1+C_2$ level, of which from Tam Lung and Ma Meo have 21.4 Mt. The resources of the whole group was estimated to be of about 50 Mt.

d / The Lo Son and Kim Mon bauxite mines, Hai Duong province have been exploited since 1937, provided raw materials for the abrasive materials and grinding wheel factory at Hai Duong. Bauxite resources here have been almost exhausted.

e / Quy Chau, Quy Hop deposits in Nghe An province: have metamorphosed bauxite, of no value, except Ban Ngoc deposits has small ore body with a reserve of about 01 Mt.

Lateritic bauxite in the profile of the weathered basaltic rocks in the South

The total areas of Quaternary/Neogene basalts are scattered in more than 20,000 km^2. Basalt plateaux have areas with tens of thousands of km^2 and are distributed on existing terrain at altitudes from a few tens of meters to 1,200 meters. The lateritic bauxite occurrences with economic value are concentrated in three altitudes 2,500-2,950 m, 1,000-1,100 m and 600-900 m. The thickness of weathering profile of basalt can reach 60 m, in which lateritic zones the thickness of the bauxite vary from 1 to 15 m.

The chemical composition of the crude (un-washed) lateritic bauxite ore: Al_2O_3 = 36-39%, SiO_2 = 0.5-10%, Fe_2O_3 = 25-29%, TiO_2 = 4-5%; LOI = 21-23%. The concentrate, after the washing of the bauxite of a particle size larger than 1 mm, have the following chemical composition: Al_2O_3 = 42-53%, SiO_2 = 1.6 to 5%, Fe_2O_3 = 17-22%, TiO_2 = 2-3%; L.O.I = 22-23%. A number of mineral bauxite deposits were investigated, surveyed and explored at different levels, have great potential and are distributed in the following areas

a / Dak Nong-Phuoc Long: The areas containing lateritic bauxite and most promising ones are located in three main deposits in Dak Nong, one in Dong Nai and one in Binh Phuoc. Only "1st of May" was explored in detail (200x200 m grid), others are being under exploration.

"1st of May" is located at elevations from 800 to 1,000 m in Dak Nong district, Dak Nong province. The chemical composition of the concentrate of the bauxite ore: Al_2O_3 = 48-50.1%, SiO_2 = 2.08-3.48%, Fe_2O_3 = 17.10-21.82%; mineral compositions: gibbsite = 59.7-79.9%, kaolinite = 1-3.4%, quartz = 0.3%, alumogoetite = 7.7-29%, ilmenite = 0.2-0.8%. The calculated reserve of "1st of May" (in $B+C_1+C_2$ categories) is 97 Mt for the grain size > 1 mm.

b / Lam Dong province has three main deposits, of which only the Tan Rai has been meticulously explored (with 200x200 m grid); The resource of the Bao Loc deposit was only estimated, the reserves of the Tan Rai deposit were calculated.

In the Tan Rai deposit the ore bodies were found at an altitude of 800-1,080 m. The chemical composition of the concentrate (washed bauxite) bauxite: Al_2O_3 = 44.69%, SiO_2 = 2.61%, Fe_2O_3 = 23.35%, TiO_2 = 3.52%; L.O.I = 24.30%. The mineral composition: gibbsite = 59.2 % kaolinite = 8.8%, goethite = 17.4%, hematite = 8.6%, ilmenite = 3.0%, anatase = 1.4%. Ore reserves (with 46.4 % of washing recovery) of Tan Rai is 57 Mt for grain size> 1 mm in the C_1 category, and 120 Mt the C_2.

Crude ore reserves of Bao Loc is about 378 Mt for the $C_1 + C_2$ level, of which the C_1 level showed 209 Mt with an average Al_2O_3 = 36.3%, SiO_2 = 6.3%, Fe_2O_3 = 29.7%. The chemical composition of the ore concentrate for a grain size > 3 mm: Al_2O_3 = 44.7%, SiO_2 = 2.2%, Fe_2O_3 = 23.4% , LOI = 24.3%.

c / Kon Plong-An Khe areas have two main deposits in Kon Tum province. Mang Den, explored in the area is 90 km^2, found 156 Mt of crude bauxite reserves with the average chemical composition: Al_2O_3 = 38.61%, SiO_2 = 12.93%, Al_2O_3/SiO_2 ratio = 3 for the C_2 category. The average chemical composition of the ore concentrate for a grain size > 1 mm: Al_2O_3 = 44. 21%, SiO_2 = 5.9%, Al_2O_3/SiO_2 ratio = 7.5, recovery after beneficiation = 55.8%. Kon H'Nung's reserve is 210.5 Mt for the C_2 category with an average chemical composition: Al_2O_3 = 39.64%, SiO_2 = 12.71%, Al_2O_3/SiO_2 ratio = 3.1. The average composition of the ore concentrate for the grain size > 1 mm: Al_2O_3 = 53.23%, SiO_2 = 3.81, Al_2O_3/SiO_2 ratio = 13.9, recovery after beneficiation = 35.02%. There should also be noted here: Kon H'Nung is located in the catchment area, so the exploitation of bauxite here will affect the environment and the watershed downstream.

d / An Hoa area of Phu Yen province has 2 main deposits. The chemical composition of the crude ore reserves are: Al_2O_3 = 39-43%, SiO_2 = 5-11%. Their crude ore reserves in $C_1 + C_2$ categories are about 24.3 Mt.

e / Quang Ngai province has some small-size deposits, The chemical composition of crude bauxite is: Al_2O_3 = 41-42%, SiO_2 = 10-12%. Crude bauxite reserves of Thien Than and Thien An are about more than 1 Mt.(1), (2)

No	Region	Concentrate (thousand tons)				Crude ore (thousand tons)			
		A+B+C1	C_2	(P_1)	Total	A+B+C_1	C_2	(P_1)	Total
I.	South Vietnam	289.404	1.616.479	385.997	2.291.380	817.051	3.612.168	1.003.204	5.432.424
II.	North Vietnam	30.200	51.221	7.091	88.512				
III.	Total	319.604	1.667.700	393.088	2.380.392	817.051	3.612.168	1.003.204	5.432.424

Table 1: Bauxite reserves of Vietnam(6)

2. The way of the bauxite industry development in Vietnam

The issue arises whether Vietnam should form an industry in bauxite mining, alumina production, aluminium smelting? In terms of exploitation, difficulty will not encounter in Vietnam because of all bauxite deposits are near the surface; difficulties here are likely the financial resources, environmental protection and the transport of the bauxite-alumina out of the Central Highlands.

In early 1970's, Vietnam made a plan to use diasporic bauxite in Ma Meo deposits (Lang Son province) to produce alumina. Firstly, thanks to the assistance rendered by the former Soviet Union, based on Ma Meo's bauxite, Vietnam made a feasibility study for constructing a plant with the capacity of 100,000 tons/year of abrasive brown corundum grains and abrasive grinding wheels in Chi Linh district, Hai Duong province. Subsequent to a Vietnamese-Hungarian geological expedition activity in the Lang Son – Tam Lung area (Tam Lung, Ma Meo and other deposits) a Feasibility Study was completed for an alumina plant of 200.000 ton/year capacity in 1977. Due to the war conditions and lack of financial resources, none of these projects could be implemented.

From 1975 to present, big bauxite deposits in the Highlands of the southern Vietnam have been drawing due attention and interests of many foreign companies, e.g., some from the former Socialist Economic Block (COMECON or SEV), Daewoo, Alcoa, Pechiney, Chalco, NFC and Yunnan Non-ferrous Metal Company, BHP-Billiton, Rusal, Mitsui, Marubeni and others.

In the late 1970's and in the 1980's, Vietnam used to cooperate with the former socialist countries to develop bauxite projects in Dak Nong and Lam Dong provinces in the Highlands, especially "1st of May " and Tan Rai projects respectively.

But indeed, responsible persons of the Vietnam Bauxite Project Team of COMECON, the Soviet experts, might have attempted to deviate Vietnam from the utilization of the bauxite reserves in Vietnam by arguing that such an exploitation and refining may cause the risk of serious ecological damages. The Soviet experts considered these reserves as a potential to fulfil the needs of the COMECON (first of all the Soviet Union), they invested time and money in the exploration especially the deposits of "1st May", and they also considered these reserves as "theirs". But they did not have the resources to implement a refinery, but had sufficient power to block the development. (Hungarians were involved in the prospecting of the Tan Rai deposit.)

There were three giant foreign companies, which were waiting for the assessment and approval of their joint venture projects. One is the Dac Nong bauxite-alumina project (planned joint venture with Chalco) with the production capacity of up to 1.5 to 2 Mt of alumina per annum and mining projects in 02 deposits "1st of May" and "Quang Son" (Dac Nong). The second project was proposed by BHP Billiton to explore deposits in North Gia Nghia, Tuy Duc, Dac Song. Alcoa wanted to explore deposits Nhan Co and Gia Nghia.(3), (4), (5)

On November 1st, 2007, Vietnam's Prime Minister signed the Decision on approval of the Master Plan on Exploration, Exploitation, Processing and Refining, and Use of Bauxite Ores in the 2007-2015 period, with the 2025 vision taken into consideration.

This Master Plan launched the following objectives:

a) Bauxite exploration: speed up the exploration, ensuring reliable reserves for the sustainable development of nationwide mining and processing industry.

b) Mining and processing: Exploit bauxite and alumina production of appropriate quality for electrolysis.

Expected output of alumina in 2010: 0.7 – 1.0 Mt/year; in 2015: 6.0 – 8.5 Mt/year; in 2025: 13-18 Mt/year. The period prior to 2015, alumina products are expected to be for export; the period after 2015, the alumina output is provided for domestic aluminium electrolysis and export;

- Manufacturing of aluminium hydroxide in order to satisfy the domestic and export demands. The expected output in 2010 was about 0.65 Mt;

- Manufacturing of primary aluminium of international standard. The expected output of period prior to 2015 was about 0.2 – 0.4 Mt, after 2015 increase the output according to the market demand and balance the use of electricity;

- Producing bauxite ore concentrates after beneficiation stage with the contents of $Al_2O_3 \geq 48\%$ (for bauxite mines with limited reserves in the northern parts of Vietnam and the coastal areas).

Vietnam National Coal Mineral Industries Group (Vinacomin, state-owned company) plays the leading role in the exploration of all bauxite mines in Tay Nguyen region (except for the bauxite mines permitted by the Prime Minister and have been mined by other enterprises) in order to evaluate reserves for carrying out investment in bauxite – alumina-aluminium projects.

Vinacomin and enterprises that belong to all economic sectors and are qualified and experienced in exploring bauxite deposits, in Ha Giang, Cao Bang, Lang Son provinces and the central coastal regions (except for the bauxite mines have been permitted by the Prime Minister).(6)

Based on these objectives and guidelines, over the last years, Vinacomin has been developing two 0.650 Mt/a alumina refineries at Tan Rai and Nhan Co in Lam Dong and Dak Nong provinces respectively. The Tan Rai refinery, mining and beneficiation plant with the total investment costs of about US$ 630 million is now under construction and will be put in operation by the end of this year. The construction of the Nhan Co alumina refinery started on 28/2/2010, the total investment capital for this complex is estimated to be of US$ 655 million (US$ 500 million for the refinery and the rest for the mining and beneficiation). Vinacomin plans to double the capacity both of these refineries after 2015. Both refineries are being built by China Aluminium International Engineering Company (Chalieco), the engineering arm of the Aluminium Corporation of China Ltd (Chalco).

The Government permitted Vietnam Fertilizer and Chemical Group (Vinachem) and Japan's Sojitz to set up a 0.500 Mt of aluminium hydroxide/year joint venture in Bao Loc, Lam Dong province. Vinachem is conducting the bauxite exploration of Bao Loc deposit for this JV project.

Beside these, An Vien Group, a private company, completed the exploration of its bauxite deposits Tap Na in Cao Bang province. Due to the difficult transportation and the small reserves, An Vien may ask the Government to export the bauxite ore instead of establishment of a planned 0.300 Mt of alumina/year refinery there. It is also said that An Vien will get a permission to explore bauxite deposits in Binh Phuoc province for its planned 1.4 Mt/a alumina refinery project.

Hanoi Trading and Technology Company completed an exploration of bauxite deposit Kon H'Nung in Gia Lai province for its planned 1.4 Mt alumina refinery project.

However, this Master Plan was considered as "too hot" or "aggressive" or "unrealistic" in terms of the domestic and international demands, financing, management, operation and environment.

Some scientists, former governmental officials, social activists, war veterans, ethnologists, environmentalists raised concerns over the national security and social and environmental impacts of the mining and refining activities in the Highlands.

The Highlands constitute a strategic position (so called "Roof of the Indochina house") for the entire south of Indochina. Opponents say that who is the master of the Central Highlands is the master of southern Indochina. Therefore, they think that foreign mining companies from few countries, which intended once to dominate Vietnam, would not be welcomed in this region.

This region produces 80 per cents of the coffee output of Vietnam and is also a key area for commodities such as pepper, rubber, cocoa and cotton. Coffee is not grown on soil containing bauxite ore.

Opponents raise concerns that the environmental and social damages would far outweigh any economic benefit, have especially concerns over the open pit mining (eroding the land and causing floods downstream), especially on the red mud disposal posing hazards in the underground water and the reliability of transfer of the modern technology.

In May 2009, Prime Minister has assigned the Ministry of Industry and Trade to amend this Master Plan. The amendment is expected to be submitted for approval by the end of this year. (3), (4), (5)

3. Challenging infrastructure

In order to gradually match with the technology, financing and infrastructure, during the period from 2010 to 2025, Vietnam will likely focus on mining of the bauxite of some important deposits in Lam Dong and Dak Nong provinces and processing bauxite to alumina for export. The infrastructure is one of the many difficult issues such as mobilization of financing, global markets and environment. The Government requests investors to set up refineries and smelters nearby the bauxite mines whilst all important mines are in the heart of the plateaus of the Central Highlands or on the high hills, and permits foreigners only to buy stakes in the refinery projects of Vinacomin. Since large-size bauxite-alumina projects require billions of USD of investment capital, foreign investors often prefer to sign an off-take contract, provide suitable technologies and make up the majority capital contribution to the project. By doing so, the investors can ensure their return on capital.

Therefore, the development of an export-oriented aluminium industry gives rise for the need of construction of a railway and seaport system to serve the industry. Currently, there are no conditions of the infrastructure of an alumina export port in Vietnam. The lack of infrastructure and the long distance to the coast are serious negative factors.

Alumina should not be only produced in modern refineries by an optimum process technology but also be transported by an optimum transportation system at the lowest transportation costs and exported from a seaport that has the best location.

Moreover as the seaport is the terminal of the alumina transportation system, the selection of the location of the seaport is extremely important as only a minor change in the location will lead to changes of the whole railway system.

In general, transport by railway will bring economic efficiency, social development and contribute to the socio-economic stability and development of the Highlands in the long run, but will not have immediate economic effects if it transports only the alumina and alumina production-related materials.

In the world, such railway and seaport systems are jointly invested, owned and operated by governments. When investing in a railway and seaport system, the Government wants the system not only to serve the alumina industry development but also the socio-economic development of the Highlands.

Some sites belonging to Ba Ria – Vung Tau province have been recommended for the construction of an alumina export seaport, however, though some seaports are in operation at these sites, expansion of these existing seaports to accommodate the alumina export would be impossible.

Passengers and commodities are now transported from/to the Highlands mainly by road. It can be seen that the route Highlands – Hochiminh City is the main transportation flow from/to the Central Highland not only at present but also in the future. Hochiminh City is the biggest southern economic hub of the country. We can compare Hochiminh City with a hub and imagine that bottlenecks hinder the transportation flows from Hochiminh City to other provinces and vice versa. A railway line connecting the Highlands with Hochiminh City therefore should be built soon or later to meet the transportation requirements.

Along with the development of the bauxite deposits, a feasibility study on the construction of a railway line to transport alumina through route Dac Nong-Lam Dong-seaport in Binh Thuan to serve for the Dac Nong alumina and other projects has been completed by the Transport Engineering and Development Inc.(TEDI) of Ministry of Transportation. This project contains a 1,435 mm double track railway line of 260-280 km including many stations, tunnels, bridges of various sizes, inter-cuts, sharp turning and big slope. Its transportation capacity was calculated for 10 Mt (2015) and 25 Mt (2025), similar to the amount of alumina to be exported (6 - 8 Mt). Total investment capital for this project was estimated to be of US$ 3-4 billion.

Ke Ga of Binh Thuan was selected for the development of a seaport specializing in the alumina export. The commodity transportation flow of the planned alumina industry will be from Dak Nong via Tan Rai and finally terminated at Ke Ga.

The future seaport at Ke Ga will occupy 315 ha, have a wave breaking dam, a 165 ha general port with 11 berths and total quay length of 3,050 m, a 150 ha bulk port with 14 berths and total quay length of 2,830 m, cargo handling capacity: 12-15 Mt/a in the first stage and accommodate 50,000-80,000 DWT vessels.

From the above analysis, it can be seen that the two transportation flows have absolute different directions. It is really a big challenge to the idea of using a unique transport system to meet both transport and export requirements of the alumina industry and the economic development of the Highland.

However, Binh Thuan is not an economic hub, its economic international transactions and export revenues are still very low in comparison with other regions. Therefore, concerns have been raised whether the planned construction of a railway and a seaport for alumina export could be justified in terms of the economic efficiency and the reality of striving to become an alumina exporting nation.(3), (4), (5)

Given the above situation, the risk of failure in finding an appropriate site for the construction of an alumina export seaport and projecting a proper railway route is very high.

Conclusion

The geological reports show that Vietnam is well endowed with considerable bauxite resource, which is among the largest reserves in the world. Over the decade, Vietnam has been attempting to develop an alumina complex in the Lam Dong and Dak Nong provinces. Vietnam should address the challenges of the arrangement of investment capital and the lack of experience in alumina refining. However, needless to say, in order to successfully develop a desired bauxite-alumina-aluminium industry, the Government and concerned organizations should work out down-to-earth policies and decisions, which are in line with both the domestic and international conditions, while not draining out the country's natural resources; otherwise, "Miss Vietnamese Bauxite" will continue to sleep in the forest for good.

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ICSOBA MATTERS

Presidency and Council

Professor Olga Lahodny-Sarc who has been for many years a very important contributor to ICSOBA, is unfortunately no longer in a position to actively perform the duties of General Secretary and the Presidency is happy to announce, with Olga’s full support, that Dr Jeanette See who already was a Council member, has accepted this important post which includes chairing the Council meetings.

The transfer of ICSOBA’s seat to India in 2008 has turned out to be not the anticipated success and Dr Ashok Nandi and Dr T.R. Ramachandran have resigned following the Goa Symposium. Dr. Frank Feret and Ms Marja Brouwer have accepted the request from the Presidency to replace them ad interim. The procedure for registration of ICSOBA as a legal entity in Canada has been initiated. During the ICSOBA 2012 symposium in Brazil, there will be a General Assembly meeting of all ICSOBA members present during which new by-laws can be adopted and elections for Council and Presidency members will be held.

The following persons now constitute the Presidency:

Mr. Roelof Den Hond	President
Dr. Li Wangxing,	Vice-President
Dr. Andrey Panov	Vice President
Mr. Dimitri Contaroudas	Past President
Dr. Jeanette See	Secretary General
Dr. Frank Feret	Executive Director
Ms Marja Brouwer	Executive Treasurer

Although ICSOBA’s official seat is now in Canada, Dipa Chaudhuri in India will continue to work for ICSOBA and be ICSOBA’s contact person to the outside world (dipa.chaudhuri@icsoba.org).

Membership

ICSOBA is an association of members with voting rights. In order to avoid the dilemma on the number of votes of a corporate member, the term corporate member will be replaced in 2012 by the more appropriate term Corporate Supporter. Delegates at the recent Seminar in Goa have in principle all become individual members. The delegate fee for those who were not yet a member or an employee of a corporate member combined the membership fee of $100 plus the reduced members’ delegate fee. It will be the new policy that ICSOBA has individual members only and all of them have voting rights in our association. In addition to voting rights, members receive the biannual Newsletter, receive upon their request an electronic copy op past proceedings. Payment of your 2012 membership fee will extend your membership until July 2013.

In case you have PayPal account, payments can be made to: pay@icsoba.org

In case of a bank transfer:
Beneficiary: **ICSOBA** -- Address: Clinckenburgh 10, 2343JH Oegstgeest, Netherlands
ING bank -- Address: POB 94780, 1090 GT Amsterdam, Netherlands
BIC or SWIFT code of ING bank: **INGBNL2A**
ICSOBA’s Account number: 5250356;
For international transfers use the International Bank Account Number or IBAN: **NL26INGB0005250356**

Corporate supporters

Currently ICSOBA has the following Corporate Members, and we trust that they will become Corporate Supporters in 2012. Please refer to the member section of the website (icsoba.org), where more details are available and clicking on a particular company will display a full company presentation.

BOKELA GmbH	Tullastrasse 64,76131 Karlsruhe, Germany
HINDALCO Industries Ltd.	Air India Building, 15th Floor, Nariman Point, Mumbai 400021, India
DUBAL Aluminium Co Ltd.	P.O Box 3627, Dubai UAE
RIO TINTO ALCAN	1188 Sherbrooke Street West,Montreal, Quebec H3A 3G2, Canada
Rio Tinto Alcan Exploration	1 Research Avenue, Bundoora Melbourne, Australia 3083
HATCH	5 Place Ville-Marie, Suite 200, Montreal, Quebec, Canada H3B2G2
STC Engineering GmbH	Altenburger Straße 63, 08396 Waldenburg, Germany www.stc-engineering.de
MBE Coal & Mineral Technology India Pvt Ltd	Ecospace 11F/12, New Town Rajarhat, North 24 Parganas, Kolkata – 700156, India
ANRAK Aluminium Ltd	8-2-268/A/2/S Road No 3 Banjara Hills Hyderabad, Andhara Pradesh, India
National Aluminium Company Ltd (NALCO)	Corporate Office, NALCO Bhavan, Nayapalli, Bhubaneshwar Orissa 751013, India www.nalcoindia.com
ALUCHEM INC	One Landy Lane, Reading Ohio USA BK Tarabaigarden Road, Pleasant Homes, BS 5-6, Tarabai Park Kolhapur, 416003,Maharashtra India
BAUXITE RESOURCES LTD	Level 2, Building E, 355 Scarborough Beach Rd, Osborne Park WA 6017 , PO Box 1800, Osborne Park, DC WA 6916 www.bauxiteresources.com.au
AMBER DEVELOPMENT	846 Chemin saint pancrace 84800 isle sur la sorgue, France www.amber-development.com
WesTech Process Equipment India P.Ltd,	E 155, Classic Apartment, Plot No. 11, Sector 22, Dwarka, New Delhi 110075, INDIA, www.westech-inc.com
OUTOTEC (Australasia) Pty Ltd	1/25 Frenchs Forest Road Frenchs Forest NSW 2086, Australia,
Vedanta Aluminium Ltd	Po Lanjigarh, Via: Biswanathpur, Dist: Kalahandi, Orissa-766027 India
PT. Antam Tbk	Head Office Gedung Aneka Tambang, Jl. Letjen. TB. Simatupang No. 1, Lingkar Selatan, Tanjung Barat, Jakarta 12530, Indonesia
Shandong Jingjin Environmental Protection Equipment Co., Ltd.	Mr. LU YI, Vice General Manager Email: dmxs-com@263.net
Nalco India Limited,	20A Park Street, Kolkata 700 016, India, Mr Partha Kar, District Manager (Alumina), pkar@nalco.com
Hangzhou New Time Valve Co Ltd	Linglong Industrial Zone, Lin'an, Zhejiang Province, China http://newtime.en.alibaba.com www.hzntfm.com