



# Bauxite

## Technical Note

### What is bauxite?

Bauxite is a rock formed by the weathering of aluminium rich rocks that have been severely leached of silica and other soluble materials in a wet tropical or subtropical climate.

Hence, the major deposits are generally close to the surface. Bauxite is a mixture of aluminium minerals, clay minerals, and insoluble materials. Three aluminium minerals can occur in bauxite: gibbsite, boehmite and diaspore.

#### Physical forms of bauxite



*Pisolitic*



*Pisolitic*



*Earthy*



*Hard rock*

Bauxite is the world's principal source of aluminium and can vary from a very soft earth to a very hard rock. It can occur as red-yellow compacted earth (both friable and re-cemented), small red round pebbles (pisolites), or large pale (pink, white, buff) hard stones (see below left).

Bauxite is usually classified according to its intended commercial application: abrasive, cement, chemical, metallurgical and refractory. Approximately 85% of the world's bauxite production is metallurgical bauxite and the alumina is extracted from the bauxite in a refinery using a wet chemical caustic soda leach process known as the Bayer process. The alumina is then converted to aluminium metal via electrolysis in a smelter using the energy-intensive Hall-Heroult process.

### Bauxite formation

Bauxite forms from the breakdown of clays when large amounts of rainfall leach away the more mobile elements in the host rock leaving the relatively immobile aluminium with some silicon, iron and titanium. Because climatic conditions play an important role in the formation of the deposits, they can be very extensive and are found on almost every continent. The largest known economic resources occur in Guinea and Australia, followed by Brazil, Vietnam and Jamaica. Indonesia, India, Guyana, China and Greece make up the remainder of the top 10 countries.

There are two types of bauxite deposits. Both are a result of chemical weathering:

## 1. Lateritic

These are the silicate bauxites formed in situ from weathering of various aluminous silicate rocks such as granite, gneiss, basalt, syenite, and shale. They are found mostly in tropical and temperate regions and occur primarily on plateau surfaces and hill slopes. Most are residual accumulations from which most other constituents of the parent rock, other than alumina, have been leached. Lateritic bauxites consist mostly of gibbsite or a mixture of gibbsite and boehmite. About 90% of bauxite is of lateritic origin.

## 2. Karstic

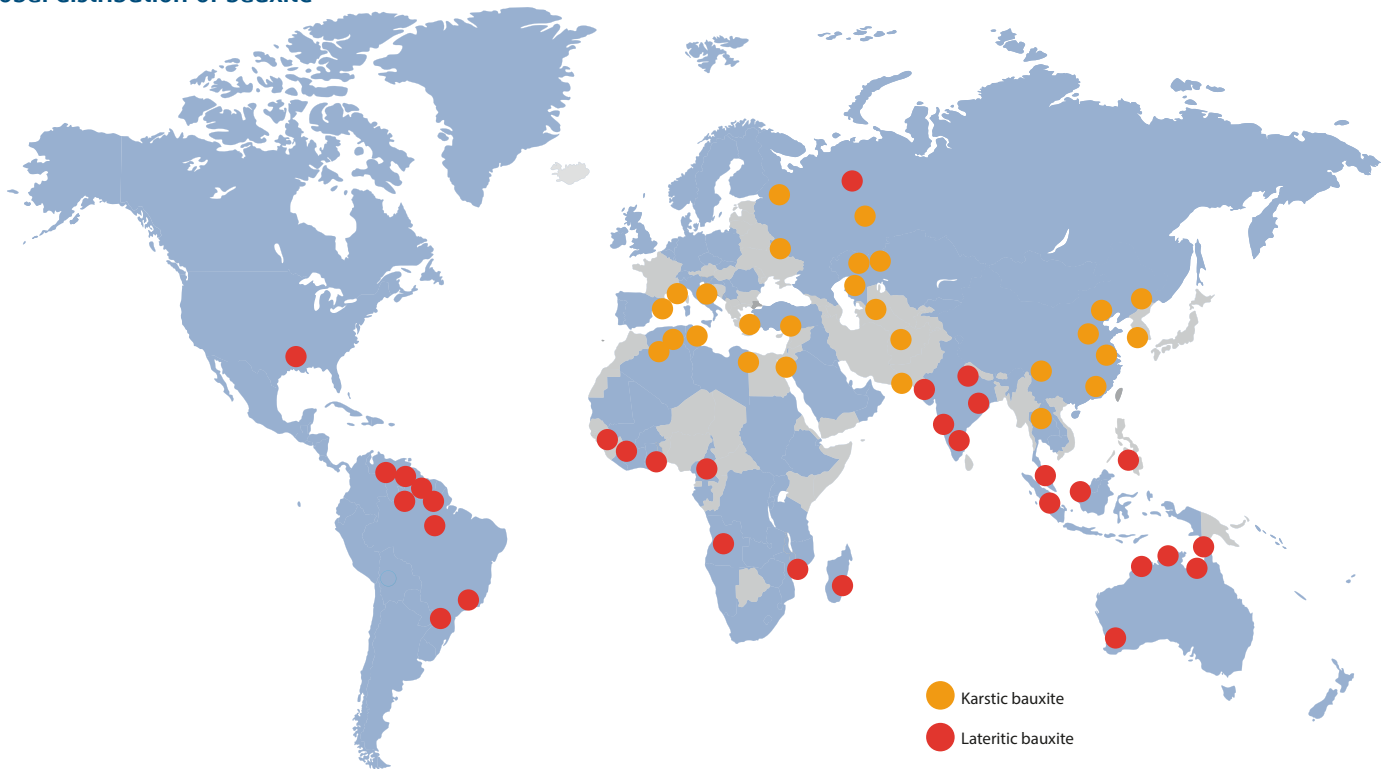
These are the carbonate bauxites that occur above carbonate rocks (limestone and dolomite). They form when dispersed clay layers in the limestone are concentrated as the enclosing limestones gradually dissolved during chemical weathering. The clays are

transformed to bauxite through lateritic weathering. Often the partially or fully transformed clays (bauxite) were washed into and accumulated in eroded limestone cavities where further transformation occurred. Karstic bauxites are usually diaspore deposits and occur predominantly in Europe, the Middle East, China and Jamaica.

They are generally smaller, poorer quality and have more complex mineralogy (high processing costs) than lateritic deposits.

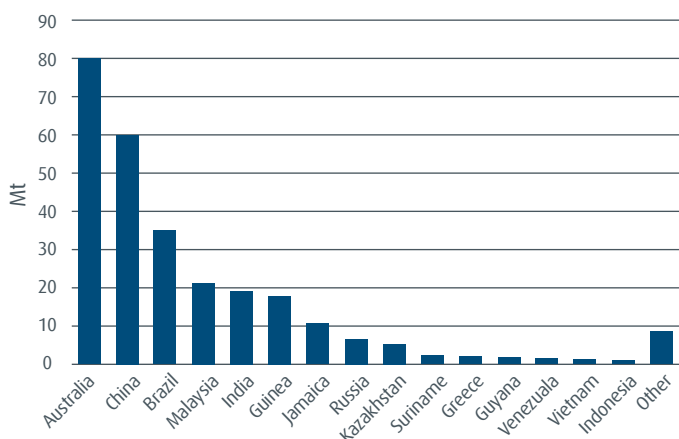
Most bauxite mines produce Direct Shipping Ore (DSO) bauxite as they require no processing before being sent to a refinery. However, some bauxites require some form of screening (either wet or dry) to remove the fine grained material to improve the grade and/or handleability. These deposits usually have a beneficiation plant that washes the bauxite and sends the high silica fines (kaolinite and/or quartz) to a tailings dam prior to ship loading the bauxite.

## Global distribution of bauxite



## Annual mine production

Worldwide bauxite mine production for 2015, by major producing countries



## Principal mineral components of bauxite

The three main aluminium minerals are:

- Gibbsite
- Boehmite
- Diaspore

The other minerals are impurities and include:

- Kaolinite (clay)
- Quartz
- Haematite and Goethite (iron oxides)
- Anatase and Rutile (titanium dioxide).

## Bauxite mineralogy

The mineralogy is very important as it dictates the refining conditions that must be used and has a large bearing on the economics of processing bauxite. Alumina refineries are usually classified as either high temperature (>240°C) or low temperature (~143°C - 150°C).

Pure gibbsite or mixed gibbsite and boehmite deposits with a low boehmite content are usually sent to low temperature refineries. However, once the deposit has more than about 6% boehmite, then it must be sent to a high temperature refinery due to economics.



## The aluminium minerals

### Gibbsite - $\text{Al}(\text{OH})_3$ or $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$

Commonly referred to as tri-hydrate due to the three lots of water. The three OH bonds are relatively weak and require the lowest refining temperature to break them, typically 143°C - 150°C.

### Boehmite - $\text{AlO}(\text{OH})$ or $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$

Commonly referred to as monohydrate due to the single water. The single OH bond is much stronger than the three bonds in gibbsite and requires a higher refining temperature to break it, typically 240-260°C

### Diaspore - $\text{AlO}(\text{OH})$ or $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$

Has the same composition as boehmite but is denser and harder due to a different crystal form.

Diaspore requires the highest refining temperatures to process, typically +260°C.

## Metallurgical extraction – The Alumina Refinery

Bauxite is converted to alumina in a refinery through a continuous four stage Bayer process involving:

### 1. Digestion – dissolving the bauxite's alumina content

Finely ground bauxite is mixed with recycled hot caustic soda solution under pressure. This dissolves the alumina content of the bauxite and the solution is then cooled in a series of flash tanks.

### 2. Clarification – settling out and separating undissolved impurities

The undissolved impurities are allowed to settle as a fine mud in thickening tanks. The caustic soda is recovered by washing this bauxite residue (red mud) through several stages before the pumping the red mud to waste storage dams. The solution of alumina in caustic soda (the liquor) is further clarified by filtration with the aid of lime.

### 3. Precipitation – forming alumina crystals

The liquor is further cooled to allow the alumina to be deposited in solid form as alumina hydrate crystals. Crystal growth is assisted by seeding the liquor with previously precipitated fine grained alumina crystals. The finished mix of crystals is settled from the liquor stream and separated. The spent liquor is returned to Digestion where it is re-heated, fresh caustic soda added and then used to dissolve more bauxite as it starts another circuit on its continuous journey around the plant.

### 4. Calcination – high temperature drying of alumina

The hydrate crystals are washed and calcined at temperatures exceeding 1000°C. This forms the dry white aluminium oxide powder, alumina, which is cooled and conveyed to storage sheds.

(Source: Queensland Alumina Limited pamphlet)

## The impurities

The impurities are often more important to consider than the alumina grade because of their detrimental effect. Silica is the most commercially important impurity in bauxite as generally the more silica in the bauxite, the higher the amount of caustic soda consumed in the refining process and the higher the loss of alumina to the red mud tailings in the desilication product (DSP).

The two main sources of silica in bauxite are kaolinite and quartz.

### Kaolinite

- Kaolin -  $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$  or  $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
- 100% reacts (dissolves) in both low and high temperature refineries

### Quartz

- Silicon dioxide -  $\text{SiO}_2$
- Reacts (dissolves) at temperatures above 200°C
- 0% reacts in low temperature refineries and a portion reacts in high temperature refineries. The percentage depends on refinery conditions.

The iron oxides essentially pass through the refinery process unchanged. They either remain insoluble or react and reprecipitate and end up in the red mud. However, very low levels of iron in

bauxite often result in a high concentration of iron in the liquor and consequently leads to a high iron content in the precipitated alumina as there is insufficient seed to enable the reprecipitation of the iron. The two main iron oxides are haematite and goethite.

### Haematite

- Iron oxide -  $\text{Fe}_2\text{O}_3$

### Goethite

- Iron hydroxy-oxide -  $\text{FeO}(\text{OH})$
- Can contain some  $\text{Al}_2\text{O}_3$
- When fine grained, it can be associated with slow or poor settling of red muds.

### Anatase and Rutile - $\text{TiO}_2$

- Associated with scaling inside refining equipment which reduces plant efficiency and increases maintenance costs.
- Can increase caustic usage in high temperature plants
- Essentially, they remain insoluble and end up in the red mud.

### Organic Carbon

- Organic matter is broken down as part of the Bayer process and forms sodium oxalate.
- Increases operating costs by reducing plant efficiency and lowers alumina purity. Alternatively increases capital cost by adding an organic removal facility, e.g. oxalate plant.

## Drilling and sampling of bauxite deposits

As bauxite deposits are usually extensive, relatively thin (most average <10m thick) and close to the surface, drilling is usually a series of shallow vertical holes set out on a regular grid. It would be rare for drill holes to exceed 50m depth with drilling at most deposits being much shallower than this. Consequently, sample intervals are small with sub metre sampling being common. Sample sizes are also small meaning that little or no sample preparation is required at the drill site other than splitting of the larger intervals down to the appropriate subsample size, usually a couple of kilograms to be sent to the laboratory for analysis.



## Sample preparation and analytical methods at the laboratory

Once at the laboratory, sample preparation for DSO bauxites is usually limited to drying, weighing, crushing, sub-sampling and grinding the sample to less than 75 microns. For bauxites that are subject to beneficiation, the laboratory preparation will include a screening step as well as additional drying and weighing steps and the calculation of a percentage yield.

Although bauxite comprises a mixture of minerals, the industry-standard analytical method for reporting the composition is by elemental analysis, expressed as metal oxides. This analysis is usually determined by X-Ray Fluorescence Spectrometry (XRF). In addition, Loss on Ignition (LOI) is also measured by Thermogravimetric Analyzer (TGA). This determines the loss of mass due to volatiles that are driven off when the sample is heated from 105°C to 1000°C (i.e. after the removal of free moisture).

The sum of the major oxides ( $Al_2O_3$ ,  $SiO_2$ ,  $Fe_2O_3$  and  $TiO_2$ ) and LOI usually sum to greater than 99% for bauxites. Trace elements make up the remaining percentage.

**Bauxite =  $Al_2O_3$  +  $SiO_2$  +  $Fe_2O_3$  +  $TiO_2$  + LOI + trace elements**

The major oxides reported are usually referred to as Total  $Al_2O_3$ , Total  $SiO_2$ , etc. However, this information by itself can be misleading as several minerals can contribute to each oxide value. For example:

Total  $Al_2O_3$  - gibbsite, boehmite, diasporite + clay minerals (kaolinite)

Total  $SiO_2$  - clay minerals (kaolinite), quartz

Not all of the  $Al_2O_3$  (alumina) is available for making aluminium as some is in the clays and is lost in the Bayer process to the DSP

(aluminium-silica compounds or  $3[Na_2O \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O]Na_2X$ ).

The total amount of alumina that is extractable in solution from bauxite in the Bayer process is called the Total Available Alumina (TAA). It is made up of two parts:

- **THA – Trihydrate Alumina.** This is the alumina that is extracted in a low temperature refinery.
- **MHA – Monohydrate Alumina.** This is the extra alumina that will be extracted in a high temperature plant.

The relationship can be simply expressed as  $TAA = THA + MHA$

Similarly, not all of the  $SiO_2$  (silica) present in the bauxite causes caustic soda loss in the Bayer process. The part of total silica which reacts with caustic soda and forms sodalite complex through sodium silicate route is termed as Reactive Silica. Thus, the non-reacting component of total silica with caustic soda is also known as Non-Reactive Silica.

In a low temperature refinery, reactive silica = kaolinite. In a high temperature refinery, reactive silica = kaolinite + partial quartz.

In addition to XRF and TGA LOI analysis, ALS also offers additional characterisation methods such as organic carbon, reactive silica and available alumina analysis (see the table below). However, when requesting an available alumina and/or reactive silica from the laboratory, it is important to understand if the bauxite being tested will be going to a high or low temperature refinery as the digestion temperature for the analysis needs to be specified.

ALS can also provide TGA loss of mass at multiple temperatures to assist in confirmation of various mineral phases.

Multi-screen sizing to determine the optimum screen size for recovery and subsequent wet beneficiation are also available.

ANALYTES & RANGES (%)						DESCRIPTION	CODE
$Al_2O_3$	0.01-100	MgO	0.01-40	SrO	0.01-1.5	Fused disc XRF	ME-XRF13n (normalised)  ME-XRF13u (un-normalised)
BaO	0.01-10	MnO	0.01-31	$TiO_2$	0.01-30		
CaO	0.01-40	$Na_2O$	0.01-503	$V_2O_5$	0.01-8		
$Cr_2O_3$	0.01-10	$P_xO_5$	0.01-23	Zn	0.01-106		
$Fe_2O_3$	0.01-100	$SiO_2$	0.05-100	$ZrO_2$	0.01-1.5		
$K_2O$	0.001-6.3	$SO_3$	0.01-12.5	Total	0.01-110		
Loss on Ignition						Furnace or Thermogravimetric Analyser (TGA)	OA-GRA05x ME-GRA05
Total Organic Carbon (Non Carbonate Carbon)						TOC by Combustion Furnace	C-IR17
Reactive Silica and Available Alumina						Microwave digestion, chemical separation/ICP-AES analysis <sup>#</sup>	ME-LICP01 ME-LICP02

<sup>#</sup> Digestion temperature, caustic strength and sample/caustic weight ratio to be specified by client