Beckenanalyse 1:
Economic Deposits in Sedimentary Environments  [M.Geo.136a]
Part 2: Laterite, bauxite, karst-bauxite

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http://www.sediment.uni-goettingen.de/staff/dunkl/

[1] Definitions, Mining economy in brief
[2, 3] Deposits related to weathering / residual sediments
[4] Placer deposits (gold, zircon + rutile + ilmenite + REE, diamond, tin)
[5] Chemical sediments (Fe- and Mn-sediments, Kupferschiefer, phosphate )
[6] Exhalative, infiltration and metasomatic deposits (SEDEX, Kupferschiefer,
   MVT-type deposits, Carlin-type gold deposits, sandstone-type U-ores)
[7 - 9] Combustable materials
   tar sand, shale gas, gas hydrate)
[10] Mineral processing
Weathering

Figure 30. Sketch of formation of weathering mantle in areas that are tectonically inactive (1) Fresh Rock; (2) zone of gruss eluvium, little altered chemically; (3) hydromica-montmorillonite-beidellite zone; (4) kaolinite zone; (5) ocher, Al₂O₃; (6) soil armor, Fe₂O₃ + Al₂O₃. After Strakhov (1967); used by permission of Oliver & Boyd Ltd.

kaolinite!
Weathering

Figure 4.1 Simplified scheme on the basis of ionic potential (ionic charge/ionic radius) showing the relative mobility of selected ions in aqueous solutions in the surficial environment (modified after Leeder, 1999).
Chemistry of weathering

Tab. 15. Chemische Veränderungen von Dolerit im kühlen und im tropischen Klimagebiet.

<table>
<thead>
<tr>
<th></th>
<th>Dolerit Staffordshire, England</th>
<th>überlagernder Ton</th>
<th>Dolerit Bombay, Indien</th>
<th>überlagernder Laterit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gestein</td>
<td></td>
<td>Gestein</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>49,3</td>
<td>47,0</td>
<td>50,4</td>
<td>0,7</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17,4</td>
<td>18,5</td>
<td>22,2</td>
<td>50,5</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2,7</td>
<td>14,6</td>
<td>9,9</td>
<td>23,4</td>
</tr>
<tr>
<td>FeO</td>
<td>8,3</td>
<td></td>
<td>3,6</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>4,7</td>
<td>5,2</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>8,7</td>
<td>1,5</td>
<td>8,4</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>1,8</td>
<td>2,5</td>
<td>1,8</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>4,0</td>
<td>0,3</td>
<td>0,9</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>2,9</td>
<td>7,2</td>
<td>0,9</td>
<td>25,0</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0,4</td>
<td>1,8</td>
<td>0,9</td>
<td>0,4</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0,2</td>
<td>0,7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summe</td>
<td>100,4</td>
<td>99,3</td>
<td>100,5</td>
<td>100,0</td>
</tr>
</tbody>
</table>

\[
\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6 \text{SiO}_2 + \text{CO}_2 + 2 \text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2 \cdot 2 \text{H}_2\text{O} + \text{Na}_2\text{CO}_3 + 4 \text{SiO}_2
\]

albite

kaolinite

[Cissarz]
Weathering

Figure 4.8 The effect of rainfall on clay mineral formation in (a) felsic and (b) mafic rocks (after Barshad, 1966).
Lateritization

Figure 20. Changes in cation exchange capacity (cec) and pH with increased weathering of basalt.
Weathering

Figure 28. Stability relations of phases in the system $\text{K}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2 - \text{H}_2\text{O}$ at 25°C and 1 atmosphere total pressure as functions of $[\text{K}^+]/[\text{H}^+]$ and $[\text{H}_4\text{SiO}_4]$ (after Feth et al. 1964).

Figure 29. Stability relations of phases in the systems $\text{Na}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2 - \text{H}_2\text{O}$ at 25°C and 1 atmosphere total pressure as functions of $[\text{Na}^+]/[\text{H}^+]$ and $[\text{H}_4\text{SiO}_4]$ (after Feth et al. 1964).
Fig. 7.16 Geochemical environments in terms of $E_h$ and pH (after Baas Becking et al. 1960); weathering and depth environments after Sato (1960).
Figure 15. Solubility in relation to pH for some components released by chemical weathering.

[Loughnan]
Lateritization

Figure 17-10. Eh-pH relations with respect to bauxite and laterite formation. 1 = environment of laterite oxide-hydroxide formation; 2 = bauxite field; 3 = podzol soil field; 4 = high-iron laterites. (After Norton, 1973, Fig. 3.)
Bild 2.18. Bodenprofile der Lateritbildung in Abhängigkeit von den Niederschlagsverhältnissen

a) Regenzeit mit starker Wasserzufuhr (humid);
b) Trockenzeit mit überwiegender Verdunstung (arid);
1 Ausgangsgestein; 2 Zone der Auslaugung; 3 Zone der Anreicherung

Die Pfeile geben die Haustrichtung der Bewegung der im Boden gelösten Stoffe an

[Bauman et al.]
Lateritization

[Robb, 2005]
Laterites are products of intense subaerial rock weathering. They consist predominantly of mineral assemblages of goethite, hematite, aluminium hydroxides, kaolinite minerals and quartz. The $\text{SiO}_2 / (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$ ratio of a laterite must be lower than that of the kaolinized parent rocks. [Schellmann, 1982]

Bauxite is a member of the family of lateritic rocks. It is characterized by a particular enrichment of free aluminium hydroxide minerals.
Distribution of laterite on the surface of the Earth

[Gidigasu, 1976]

[Aleva, 1986]
The ferruginous bauxite deposit of Rio Norte, Brazil. The bauxite bed, 6 m thick, is overlain by an 8 - 10 m thick kaolinite bed, which in turn is covered by an Amazonian-type tropical forest.

*Photo: R.R. Anand.*

Lateritic weathering section showing transition of saprolite, on which the boy stands, a mottled zone within the lower part a relict colour pattern of core boulders, followed upward by a weakly indurated brown laterite beneath a thin lateritic soil. Kerala, India.

*Photo: W. Schellmann.*
Figure 17-10. Eh-pH relations with respect to bauxite and laterite formation. 1 = environment of laterite oxide-hydroxide formation; 2 = bauxite field; 3 = podzol soil field; 4 = high-iron laterites. (After Norton, 1973, Fig. 3.)
Lateritic bauxite

Fig. 5–10. Relationship between ground water and type of alteration profile (after Valeton, 1983a). 1. formation of bauxite at various levels above the water-table, without separation of Al and Fe; 2a. low-silica bauxite and 2b. high-silica bauxite; top of the section near the surface of the ground-water level; strong separation of Al and Fe; 3. formation of flintclay below ground-water level by total extraction of Fe.
Fig. 7.13 Gabbin kaolin – geology and assay sections (Line 15800N) (from Walker 1978).

[Edward and Atkinson]
Typical textures of bauxites
## Major bauxite minerals

<table>
<thead>
<tr>
<th></th>
<th>Gibbsite</th>
<th>Böhmite</th>
<th>Diaspore</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td>Al(OH)$_3$</td>
<td>AIO(OH)</td>
<td>AIO(OH)</td>
</tr>
<tr>
<td><strong>Maximum Alumina Content [%]</strong></td>
<td>65.4</td>
<td>85.0</td>
<td>85.0</td>
</tr>
<tr>
<td><strong>Crystal System</strong></td>
<td>Monoclinic</td>
<td>Orthorhombic</td>
<td>Orthorhombic</td>
</tr>
<tr>
<td><strong>Density [gcm$^{-3}$]</strong></td>
<td>2.42</td>
<td>3.01</td>
<td>3.44</td>
</tr>
<tr>
<td><strong>Temp. for Rapid Dehydration [°C]</strong></td>
<td>150</td>
<td>350</td>
<td>450</td>
</tr>
</tbody>
</table>

[International Aluminium Institute]
Major bauxite provinces

Fig. 4—2. Geographic distribution of the bauxite deposits. 1 — lateritic bauxites; 2 — karst bauxites; 3 — Tikhvin-type bauxites; 4 — lateritic-bauxite provinces; 5 — karst-bauxite provinces; 6 — Tikhvin-type provinces.

[Bárdossy and Aleva]
Bauxite deposits

Fig. 7.7 (a) Isopachs of bauxite in the main deposit, Gove, Australia and (b) isoquality map for the main deposit (from Lillehagen 1979).

[Edward and Atkinson]
Los Pijiguaos bauxite deposit – laterite on a dissected Late Cretaceous planation surface

[Robb, 2005]
Bauxite deposits

Fig. 3—12. Schematic section through the Ivory Coast laterite-bauxite-capped hills, with the surface areas and the prevalent textures for duricrust/bauxite horizons of the successive levels (modified after Grandin, 1976).
Lateritic bauxite

Fig. 7.6 (a) Schematic profile of laterite capping on the plateau. (b) Sections through laterite and bauxite, Gove deposit, Australia (from Lillehagen 1979).

[Edward and Atkinson]
Table 5—2. The proportion of parent-rock types in the global tonnage of bauxite

<table>
<thead>
<tr>
<th>Rock types</th>
<th>Number of bauxite districts or groups of deposits</th>
<th>Percentage of tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>10</td>
<td>9.0</td>
</tr>
<tr>
<td>Diorite, granodiorite</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>Monzonite</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Anorthosite</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Leucogabbro</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Gabbro, norite</td>
<td>5</td>
<td>3.0</td>
</tr>
<tr>
<td>Syenite</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Nepheline syenite, foyalite</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Dunite, peridotite</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Dolerite</td>
<td>16</td>
<td>17.1</td>
</tr>
<tr>
<td>Pyroxenite</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Tinguite</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Metasomatized dolostone</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>2</td>
<td>0.1</td>
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<tr>
<td>Trachyte</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Andesite</td>
<td>5</td>
<td>0.9</td>
</tr>
<tr>
<td>Basalt</td>
<td>22</td>
<td>19.0</td>
</tr>
<tr>
<td>Phonolite</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Undifferenciated volcanic rocks</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Metavolcanites (basic)</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Greenstone</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Schist (mainly sericitic)</td>
<td>10</td>
<td>1.2</td>
</tr>
<tr>
<td>Amphibolite</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td>Hornfels</td>
<td>3</td>
<td>0.8</td>
</tr>
<tr>
<td>Gneiss, granite–gneiss</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>Granulite (charnockite, khondalite, etc.)</td>
<td>6</td>
<td>7.7</td>
</tr>
<tr>
<td>Kaolinitic sandy clay</td>
<td>4</td>
<td>10.6</td>
</tr>
<tr>
<td>Shale, slate</td>
<td>10</td>
<td>10.0</td>
</tr>
<tr>
<td>Kaolinitic siltstone, -sandstone</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Arkosie sandstone, -siltstone</td>
<td>10</td>
<td>12.9</td>
</tr>
<tr>
<td>Graywacke</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Plutonic rocks: 15.5%
Hypabyssal rocks: 17.3%
Volcanic rocks: 20.3%
Metamorphic rocks: 12.8%
Sedimentary rocks: 34.1%
Geochemistry of Sardinian bauxite

[Mameli et al., 2007]
Geochemistry of bauxites in N. Iran

[Esmaeily et al., 2010]
Fig. 10 REE chondrite-normalized patterns (Profile 1). Patterns of the basal samples, from 1–1A to 1–3, have high $\Sigma$REE contents and high (La/Yb)$_{ch}$ ratios. Patterns for the upper samples have low $\Sigma$REE and low (La/Yb)$_{ch}$. The distribution of the Eu/Eu* ratio all along the profile shows that this index suffers negligible changes.

[Mameli et al., 2007]
Geochemistry --- Scandium enrichment in a world-class lateritic deposit

[Chassé et al., 2017]
Karst bauxite

Esmaeily et al., 2010
Karst bauxite and paleogeography

[Di Stefano and Mindszenty, 2000]
Karst bauxite deposits

Jenisey, Russia

Haut-Var, Provence, France
SiO2 content of a Transdanubian karst bauxite deposit

[Szantner et al., 1986]
Bauxite horizon in a hyatus in Sardinia

Fig. 2 Geological map and cross section of the mined area of Olmedo. The different types of bauxite deposits are evidenced both in the map and in the cross section.
Geochemistry of Sardinian bauxite

Fig. 4 Tectonic control on different ore deposits typology (modified after Combes et al. 1993). Schematic distribution of both $\text{Al}_2\text{O}_3$ and $\text{SiO}_2$ along the different profiles are showed below.

[Mameli et al., 2007]
Q: lateritic or karst bauxite?

Fig. 5—13. Geologic cross-section of the lateritic-bauxite deposits in the Middle Timan Mts (after Diomina and Iatskievitch, 1982).
1. Quaternary sediments; 2. volcanic tuffs and tuffites — Late Devonian; 3. diabase dikes and sills; 4. terrestrial sandstone and siltstone; 5. bauxite; 6. saprolite (kaolin); 7. slightly weathered parent rock (rotten-rock); 8. limestone and dolostone — Riphean; 9. layers of hydrothermal–metasomatic orthoclase and microcline.

[Bárdossy and Aleva]
Schematic stratigraphy of Transdanubian Central Range

Million years

- Yellow: siliciclastic
- Green: volcanic tuff
- Blue: carbonate
- Red: bauxite

Periods:
- Tertiary
- Cretaceous
- Jurassic
- Triassic
- Permian

Time:
- 0
- 50
- 100
- 150
- 200
- 250
Typology of zircon crystals (Pupin, 1980)

<table>
<thead>
<tr>
<th>P</th>
<th>Y</th>
<th>R</th>
<th>A</th>
<th>M</th>
<th>I</th>
<th>D</th>
<th>E</th>
<th>S</th>
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<tbody>
<tr>
<td>(100)</td>
<td>(100)</td>
<td>(100)</td>
<td>(100)</td>
<td>(100)</td>
<td>(100)</td>
<td>(100)</td>
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<td>100</td>
<td>I</td>
<td>200</td>
<td>N</td>
<td>300</td>
<td>D</td>
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<td>500</td>
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<td>600</td>
<td>E</td>
<td>700</td>
<td>800</td>
<td>T</td>
<td></td>
<td></td>
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</tbody>
</table>

- P: Prismatic
- Y: Yelkoidal
- R: Rutiloid
- A: Ameltophite
- M: Monoclinic
- I: Isometric
- D: Dolomitic
- E: Esthmic
- S: Sphenoid
Zircon typology of Eocene and Oligocene PAL-related magmatites

Monor 1/8

Kápolnásnyék-3
1140 m

Recsk-357 356 m

Dudar DUD-2 and. PPD

Zalatárnok Zt-1/8 and.

Kápolnásnyék-3
1140 m

Tükrösmajor-190

Nagykökényes-1/11
M-168

Tóalmás-4/5
M-172
Rounded and euhedral zircon crystals in the NCA bauxite
Table 7.6 Data provided in a bauxite analysis (Strahl, 1982)

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>P₂O₅</th>
<th>MnO</th>
<th>ZnO</th>
<th>LOI</th>
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</thead>
<tbody>
<tr>
<td>Sw 1</td>
<td>14.14</td>
<td>2.37</td>
<td>0.32</td>
<td>6.19</td>
<td>51.34</td>
<td>0.56</td>
<td>0.56</td>
<td>0.032</td>
<td>24.49</td>
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</table>

**XRS chemical**

**Alumina distribution**

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>TA</th>
<th>TAA Al₂O₃</th>
<th>ReSil</th>
<th>THA Al₂O₃</th>
<th>ReSil</th>
<th>UA</th>
<th>Boehmite Al₂O₃</th>
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</thead>
<tbody>
<tr>
<td>Sw 1</td>
<td>51.34</td>
<td>43.93</td>
<td>6.06</td>
<td>39.45</td>
<td>4.65</td>
<td>1.35</td>
<td>5.89</td>
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</tbody>
</table>

**Iron distribution**

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Haematite (%)</th>
<th>Goethite (%)</th>
<th>(Mole diasp.)</th>
<th>H/G ratio</th>
<th>Settling rate (ft/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw 1</td>
<td>6.97</td>
<td>7.17</td>
<td>23.05</td>
<td>0.7</td>
<td>8</td>
</tr>
</tbody>
</table>

**Key**

- LOI = Loss on ignition (calculated by difference)
- TA = Total Al₂O₃
- TAA = Total available Al₂O₃ (boehmite digestion conditions)*
- THA = Trihydrate available Al₂O₃ (gibbsite digestion conditions)*
- UA = Unextractable Al₂O₃
- ReSil = Reactive silica
- H/G ratio = Intensity of haematite peak × (10/7)/intensity of goethite peak
Table 8—2. Chemical composition of typical bauxite grades before (a) and after (b) calcination

<table>
<thead>
<tr>
<th>Grade</th>
<th>L.O.I.</th>
<th>T.Al₂O₃</th>
<th>R.SiO₂</th>
<th>F.SiO₂</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>30.8</td>
<td>59.2</td>
<td>4.0</td>
<td>0.5</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>b</td>
<td>0.0</td>
<td>85.7</td>
<td>5.7</td>
<td>0.7</td>
<td>4.3</td>
<td>3.6</td>
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<tr>
<td>Metal grade with 30% ABEA</td>
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</tr>
<tr>
<td>a</td>
<td>18.0</td>
<td>47.1</td>
<td>1.1</td>
<td>0.8</td>
<td>29.9</td>
<td>3.1</td>
</tr>
<tr>
<td>b</td>
<td>0.0</td>
<td>57.4</td>
<td>1.3</td>
<td>1.0</td>
<td>36.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Refractory grade</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>31.8</td>
<td>59.9</td>
<td>4.1</td>
<td>1.4</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>0.0</td>
<td>88.0</td>
<td>6.0</td>
<td>2.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Abrasive grade</td>
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<td></td>
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<td></td>
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<td>30.0</td>
<td>57.5</td>
<td>3.0</td>
<td>7.0</td>
<td>2.5</td>
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</tr>
<tr>
<td>b</td>
<td>0.0</td>
<td>82.1</td>
<td>4.3</td>
<td>10.0</td>
<td>3.6</td>
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</tr>
<tr>
<td>Chemical grade</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>31.2</td>
<td>60.4</td>
<td>5.0</td>
<td>1.4</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>0.0</td>
<td>87.8</td>
<td>7.3</td>
<td>2.0</td>
<td>2.9</td>
<td></td>
</tr>
</tbody>
</table>

[Bárdossy and Aleva]
Fig. 8—11. Nomogram for the computation of the theoretical trihydrate bauxite composition. A straight line through points selected on two of the graded vertical lines gives the other components at the intersection of the same line with the other two graded lines.
Bauxite economy

aluminium

production (metric ton)

unit value (1998$/metric ton)

[A (1889) B (1898) C (1945) D (1973)]

production and production trend line

unit value trend line

$0 $10 $20 $30 $40 $50 $60 $70 $80 $90 $100


year

bauxite

production (metric ton)

unit value (1998$/metric ton)

$0 $10 $20 $30 $40 $50 $60 $70 $80 $90 $100


year

History of Aluminium

1808: Sir Humphrey Davy (Britain) discovered the existence of the shiny metal we are so dependent on today and gave it a name - Aluminum.

1821: P. Berthier (France) discovered a hard, reddish, clay-like material containing 52 per cent aluminum oxide near the village of Les Baux in southern France. He called it bauxite - after the village. Today, we recognize bauxite as the most common ore of aluminum.

1845: Wohler determined the specific gravity of aluminum (2.7) which illustrated one of its unique physical properties - it was extremely light in weight compared to most metals known at the time.

1854: Henri Sainte-Claire Deville (France) create the first commercial process for producing aluminum which - at that time - was more valuable than gold.

1855: A bar of aluminum was exhibited alongside the Crown Jewels at the Paris Exhibition.

1886: Two unknown young scientists, Paul Louis Toussaint Heroult (France) and Charles Martin Hall (USA), working separately and unaware of each other's work, simultaneously invented a new electrolytic process (eventually called the Hall-Heroult process) which is the basis for all aluminum production today. They discovered that if they dissolved aluminum oxide (alumina) in a bath of molten cryolite and passed a powerful electric current through it, molten aluminum would be deposited at the bottom.

1889: Freidrich Bayer (Austria), son of the founder of the Bayer chemical company, invented the Bayer Process for the large scale production of alumina from bauxite.
Bayer process

- Figure 17.1. Flowsheet of the Bayer process.
Complete extraction from **diasporic** bauxite requires stronger caustic solutions, in addition to higher temperatures and pressures. In practice this means that for deposits containing the more easily recovered **gibbsite** only, production costs are much lower than when **boehmite** or **diaspore** are present. The control of silica in the conventional Bayer Process is most important and in fact ores having reactive silica greater than 7% cannot be economically processed.

Unlike **quartz**, which is considered virtually non-reactive at **gibbsite** extraction temperatures, some minerals, including **kaolins**, dissolve rapidly and the reaction of the **silica** can give rise to appreciable loss of caustic soda and aluminum.

\[
\text{Na}_2\text{CO}_3 + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + 2\text{NaOH}
\]
**Bayer process**

**Crushing and grinding**

**Digesting:** The slurry is pumped to a digester where a solution of sodium hydroxide (caustic soda) dissolves AlOH minerals (under 30 atm pressure, between 200 and 240 °C). After the extraction stage the liquor (containing the dissolved $\text{Al}_2\text{O}_3$) must be separated from the insoluble red mud.

**Settling:** After washing to recover alumina and caustic soda, the remaining red mud is pumped into large storage ponds where it is dried by evaporation.
**Bayer process**

**Precipitation:** The clear sodium aluminate from the settling and filtering operation is pumped into the precipitators. Fine particles of alumina - called "seed crystals" (alumina hydrate) - are added to start the precipitation of pure alumina particles as the liquor cools. Alumina crystals begin to grow around the seeds, then settle to the bottom of the tank where they are removed to the calcination kilns.

**Calcination:** Calcination is a heating process to remove the chemically combined water from the alumina hydrate. From precipitation, the hydrate is filtered and washed to rinse away impurities and remove moisture. The calcining kiln is brick-lined inside and gas-fired to a temperature of 1,100°C. It slowly rotates and is mounted on a tilted foundation which allows the alumina to move through it to cooling equipment. The result is a white powder like that shown below: pure alumina.
Red mud  (pH=13)

![Red mud](redmud.org)

![Red mud](vietnam.net)

![Red mud](nol.hu)

<table>
<thead>
<tr>
<th>Red mud constituents</th>
<th>Average measured for testing (% wt.)</th>
<th>Red mud constituents</th>
<th>Average measured for testing (% wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>21.10</td>
<td>ZrO</td>
<td>0.065</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>33.60</td>
<td>Cr</td>
<td>0.11</td>
</tr>
<tr>
<td>SiO₂</td>
<td>10.25</td>
<td>Co</td>
<td>2 ppm</td>
</tr>
<tr>
<td>MgO</td>
<td>0.05</td>
<td>Cd</td>
<td>0.4 ppm</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.12</td>
<td>Zn</td>
<td>249 ppm</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.06</td>
<td>Ni</td>
<td>24 ppm</td>
</tr>
<tr>
<td>CaO</td>
<td>3.10</td>
<td>Cu</td>
<td>19 ppm</td>
</tr>
<tr>
<td>S total</td>
<td>2.20</td>
<td>Pb</td>
<td>47 ppm</td>
</tr>
<tr>
<td>TiO₂</td>
<td>3.47</td>
<td>As</td>
<td>31 ppm</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>0.10</td>
<td>Ga₂O₃</td>
<td>90 ppm</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.08</td>
<td>Sc₂O₃</td>
<td>12 ppm</td>
</tr>
<tr>
<td>MnO</td>
<td>0.015</td>
<td>Re₂O₃</td>
<td>66 ppm</td>
</tr>
<tr>
<td>LOI (inc. water)</td>
<td>20.63</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Material and energy consumption of the Bayer process

BAUXITE AS ALUMINIUM ORE
4—5 t bauxite

11 GJ steam
1.5 GJ electric power
8 GJ fuel

BAYER PROCESS

1.95 t ALUMINA

17 GJ petroleum
500 kg cokes-pitch
56 GJ electric power

HALL—HEROULT PROCESS

30—40 kg cryolite or Al-fluoride

93.5 GJ
1 t ALUMINIUM

BTU = British Thermal Unit

1 BTU = 1055.1 Joule
1 Cal = 4.2 Joule
1 Wh = 3.6 kJ

1 JOULE = 9.5 × 10⁻⁴ BTU
= 0.24 cal
= 2.78 × 10⁻⁴ Wh

Fig. 8—2. Chart summarizing the bauxite, chemicals, other ingredients and energy requirements of the Bayer and the Hall–HÉroult Processes for a medium- to high-grade bauxite of mainly gibbsitic composition. All quantities in SI units; G stands for giga = 10⁹.

[Bárdossy and Aleva]