GEOMETALLURGY – NEW IDEAS FOR MINING AND MINERAL PROCESSING AT LKAB

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LKAB, SWEDEN
• Owned by the Swedish Government
• About 4,220 employees (including temporaries)
• World-leading in pelletization for more than 50 years
• Production in 2016:
  • 24.0 Mt pellets (DR-pellets and blast furnace pellets)
  • 2.9 Mt fines and special products

IRON ORE OPERATIONS OF LKAB
GEOMETALLURGY

Geometallurgy, in its basics, combines geological and metallurgical information to create a spatially-based predictive model for mineral processing plant to be used in production management.

(Lamberg, 2011)
GEOMETALLURGY

The area of geometallurgy is in its context not entirely new but:

– Development of automated mineralogy technologies.
– New mines and more complex geology.
– Increased competition and environmental demands.

has made it even more feasible today.

From rock to finished product
FOCUS ON GEOMETALLURGY

• The area of geometallurgy is not a new area at LKAB, but it has become more important today – because:
  ➢ More complex geology and mineralogy of iron ore deposits in Kiruna and Malmberget.
  ➢ Increased production at Kiruna mine: 22.3 Mt (in 2000) to 26.9 Mt (in 2016).
  ➢ Exploiting new iron ore deposits.
  ➢ Increased environmental demands - and competition.
Ornstein and Fagerberg (1962) had an idea to create a rough, preliminary forecast for the product outcome of beneficiation of the iron ore from the Leveäniemi deposit with help of the systematic macroscopic examination of drill cores.
Bergström and Anttila (1973) made an attempt to compare the experimental results of grinding in the laboratory- and pilot-scale with the large scale operation to determine the energy efficiency of the mills, the energy consumption and to develop conversion factors.
THE PROJECT ‘SILICA IN THE MINE’

- In 2007 fluctuations and increase of SiO₂ grade in the crude ore in Kiruna.
- Problematic specially in the case of DR-pellets (LKAB DR Oxide Pellets).
- Develop a simplified method at the laboratory scale for predicting the physical properties of the ore at the mineral processing.
- Make a reliable prognosis for the SiO₂ grade in the crude ore and processing parameters for future mining.

Oulu Mining Summit
07.09.2017
SYSTEMATIC MINERAL PROCESSING TESTS AT LKAB’S LABORATORY

- CRUSHING GRINDING
- SCREEN ANALYSIS
  - DAVIS MAGNETIC TUBE
  - CHEMICAL ASSAYS
  - SPECIFIC SURFACE
  - DENSITY
  - LASER GRANULOMETER
- SIMULATION OF PARAMETERS

Logging of drill cores
Sampling

~ 3000 SAMPLES
~ 1815 ANALYSED

DATABASE
SIMULATION OF PARAMETERS

\[ Y = X + 0.187 \cdot \% \text{SiO}_2 \text{ in DT-conc. (lab)} \pm 0.04 \% \text{SiO}_2 \]

\( X \) = the percentage of \( \text{SiO}_2 \) in the Davis magnetic tube concentrate in the laboratory by \( P(80) = 45 \mu\text{m} \).

0.187 = the difference between the mean of \( \text{SiO}_2 \) grade in the laboratory scale and at the concentration plant.

0.04 = characterizes empirical inaccuracy limit.

\[ E = A + T \cdot B \pm 0.47 \text{ kWh/t} \]

\( A = 5 \text{ kWh/t} \) (constant).

\( T \) = the retention time of the material in the laboratory ball mill.

\( B = 0.65 \text{ kWh/t/minute} \) (constant).

0.47 kWh/t = characterizes empirical inaccuracy limit.
## Simulation of SiO$_2$-Grade in the Magnetite Concentrate

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ore type</th>
<th>Crude ore</th>
<th>DT concentrate</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Fe %</td>
<td>SiO$_2$ %</td>
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<tr>
<td>6252</td>
<td>B2</td>
<td>64.47</td>
<td>3.72</td>
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<tr>
<td>6351</td>
<td>B2</td>
<td>63.04</td>
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<td>B2</td>
<td>64.54</td>
<td>5.76</td>
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<td>B2</td>
<td>67.63</td>
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<td>6370</td>
<td>B2</td>
<td>58.41</td>
<td>5.89</td>
</tr>
<tr>
<td>6387</td>
<td>B2</td>
<td>65.20</td>
<td>4.27</td>
</tr>
</tbody>
</table>

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SILICATES IN THE ORE TYPE B2

Actinolite
\[ \text{Ca}_2(\text{Mg,Fe})_5\text{SiO}_8\text{O}_{22}(\text{OH,F,Cl})_2 \]

Phlogopite
\[ \text{KMg}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{F,OH})_2 \]

Quartz
\[ \text{SiO}_2 \]

Titanite (Sphene)
\[ \text{CaTiSiO}_5 \]

Albite
\[ \text{Na(AlSi}_3\text{O}_8) \]
NEW 3D GEOLOGICAL AND BLOCK MODEL

MINERALOGY
B2-a, B2-b

GEOLOGY
ORE TYPES

MINERAL PROCESSING PARAMETERS

TONNAGE GRADE
(Fe, P, SiO₂, ...)

ORE TYPES

MINERALOGY
B2-a, B2-b

GEOLOGY
ORE TYPES

MINERAL PROCESSING PARAMETERS

TONNAGE GRADE
(Fe, P, SiO₂, ...)

PERFORMANCE IN IRONMAKING
IRON ORE DEPOSIT IN MALMBERGET

• ~ 20 separate ore bodies, of which 13 are currently mined.
• 95% magnetite och 5% hematite.
• Variations in Fe and P grades 49% - 63% Fe; 0.1 – 1.2 % P
• ViRi → magnetite, high V and Ti, low P
• Printzsköld → magnetite, low V and Ti, high P
GEOLOGICAL AND MINERALOGICAL DATA FOR GEOMETALLURGICAL MODELLING

Logging DDH
Lithology, mineralogy, mineral textures

Ore types
Preliminary

Mineralogical study
Sampling ore types
Mineral chemistry
EMC recipe
Textural archetypes

Metallurgical tests
Ore variability tests
Particle Tracking

Plant Survey
Full scale operation
Several mineral circuits

Geometallurgical ore types

Geometallurgical block model
Geo database

Process model
Breakage model
Grinding model

Production model
Simulate and forecast the production

(Lund 2013)
# Classification for a Geological Model

**Classified ore body** | **Ore type** | **Sub-type** | **GEM-type** | **Texture**
--- | --- | --- | --- | ---
**FABIAN**
Semi-massive | Feldspar rich | Fsp | | Schistose
Massive | Amphibole rich | Amph-(Ap-Bt) | Granoblastic, porphyroblastic, exsolution, lamellas
 | Apatite rich | Ap-(Amph) | Granoblastic, porphyroblastic, exsolution, lamellas

**PRINTZSKÖLD**
Semi-massive | Feldspar rich | Fsp | | Schistose
Massive | Biotite rich | Bt-(Amph-Ap) | Schistose, granoblastic, porphyroblastic
 | Apatite rich | Ap-(Amph) | Granoblastic, porphyroblastic, exsolution, lamellas

(Lund 2013)
LEVEÄNIEMI DEPOSIT

- The Leveäniemi open pit was operated between 1964 and 1981 and was reopened in 2015.
- Exploration drilling program carried out.
- No geometallurgical information available until 2015.
- Chemical assays, some rock mechanical data, some information about the mineralogy.
- PREP-project, co-operation with LTU
GEOMETALLURGICAL PROJECT / LEVEÄNIEMI

Geological data  Sampling  Test work  Process model  Simulation  Geomet. model

(PREP / LTU; Lishchuk / Koch)

PERFORMANCE IN IRONMAKING
A COURSE IN GEOMETALLURGY AT LKAB

- To create a common ‘geometallurgical’ language within LKAB.
- Lectures, exercises and practical laboratory work in collaboration with Technical University of Luleå (Sweden) following LKAB’s processes.
- Participants from different departments of LKAB.
- From ‘mine to mill’ and from ‘mill to finished product’.
A REAL CHALLENGE – DIFFERENT Fe-ORE TYPES
SUMMARY

• The area of geometallurgy is not something entirely new at LKAB and we have worked according to the ideas ‘from mine to mill’ and ‘minerals to products’ for several years.

• The idea of geometallurgy at LKAB covers a broad area from the internal education to the instrumental side at the R&D Department.

• The projects of a great importance for new geometallurgical thinking at LKAB were the project ‘Silica in the Mine’ and the mineralogical, chemical and textural characterization of the Malmberget iron ore deposit for a geometallurgical models.

• There are many new and interesting challenges for the experts and skilled personnel at LKAB to race with respect to the field of geometallurgy.
THANK YOUR FOR LISTENING!

The “geometallurgical” Team of LKAB