Resource efficiency in mining
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Resource efficiency in mining

Lean mining
- cash cost
- opex

Increased recovery of by-products
- resource characterization
- technological breakthroughs
Resource efficiency in mining

Case studies

- *Aitik* – low grade open pit Cu-mine north of arctic circle
- *Kankberg* – complex base metal massive sulphide underground mine
- *Kiirunavaara* – large scale underground Fe-mine north of arctic circle
Aitik 45

45 (38) Mt annually, +20%

Reserve grade 0.22 (0.24)
  • Reserves 1 085 (633) Mt
  • Life of mine 2040 (2030) years
  • Copper life of mine 2 348 (1 471) kt

Capex
  • New crushers with improved reliability
  • Lower stripping, approx. 0.5
  • TMF

<10% costs per ton of ore
  • Economies of scales

Source: Boliden AB webpages
Copper- open pit with mill 2014

Source: Moström 2015
**Key productivity drivers at mine**

Minimizing lead time between work processes faces, stopes and benches

**Aitik - productivity**

<table>
<thead>
<tr>
<th>Open pit Cu mines</th>
<th>Percentile **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head grade</td>
<td>% Cu</td>
</tr>
<tr>
<td><strong>Mine</strong></td>
<td>t ore/hour</td>
</tr>
<tr>
<td><strong>Mill</strong></td>
<td>t ore/hour</td>
</tr>
<tr>
<td><strong>G&amp;A</strong></td>
<td>t ore/hour</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>t ore/hour</td>
</tr>
<tr>
<td>Wage rate</td>
<td>$/hour</td>
</tr>
<tr>
<td>Labour cost</td>
<td>$/t</td>
</tr>
<tr>
<td><em><em>Cash cost, Normal C1</em> - All mines</em>*</td>
<td>c/lb Cu</td>
</tr>
</tbody>
</table>

* Cash cost Normal C1, Wood Mackenzie Q3 2014 estimate for 2014
** All mines in Woodmackenzie model, Q2 2014 estimates for 2014

Source: Moström 2015
Integrated control system drives efficiency

Integrated control system for mine and mill
- Increased efficiency
- Lower costs

Mobile control room
- Enables operators to monitor and adjust in real time

Control system integrated with maintenance system
- Only one original document
- All share same info
- Improved surveillance
- Easier to spot errors
- Diary improves visibility over time

WLan
- Enable status control and operational guidance

Source: Moström 2015
AITIK

- Mo as by-product content 0.0025%
- Recovery 85% to copper conc.
- Annual prod 36 Mt
- Annual prod 544 tonnes Mo/year (9 MUSD/year)
- Additional resources Co in pyrite (reports to tailings)

Source: Wanhainen et al. 2014

By-products

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight ktonne</th>
<th>Grade Cu</th>
<th>[%] Mo</th>
<th>Distribution Cu</th>
<th>[%] Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore feed</td>
<td>36,000</td>
<td>0.25</td>
<td>0.0025</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Cu conc.</td>
<td>324</td>
<td>25</td>
<td>0.2479</td>
<td>90</td>
<td>85</td>
</tr>
<tr>
<td>Mo conc.</td>
<td>0.849</td>
<td>1.6</td>
<td>53</td>
<td>0.02</td>
<td>50</td>
</tr>
<tr>
<td>Cu final conc.</td>
<td>323</td>
<td>25.06</td>
<td>0.1093</td>
<td>89.98</td>
<td>35</td>
</tr>
<tr>
<td>Final tailing</td>
<td>35,676</td>
<td>0.025</td>
<td>0.00027</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>
Kankberg - a "New" Gold Mine
In renewed production since 2012

- Ore reserve 2.9 Mton
- Average Grades
  - Gold 4.1 g/ton
  - Tellurium 186 g/ton
- Average production 320 kton/a
- Gold 1 150 kg
- Tellurium 41 ton

Source: Boliden AB webpages

By-products
Kankberg — Technology breakthrough
leaching of gold and tellurium from gold tellurides, turning a non profit “VMS” into a profitable mine

Conceptual study initiated 2008
A hot leaching process developed
  - Boliden patent
  - Gold recovery 85% (without 45%)
Tellurium leaching process developed
  - Tellurium recovery 65%

Source: Boliden AB webpages

By-products
Kiirunavaara Iron ore
Potential of P and REE in Iron ores

• Apatite Iron ore, mined underground in northern Sweden, >100 km north of the arctic circle
• Production from two large underground mines and one open pit 25.5 Mt 2013
• Iron ores contain 1-5% P in apatite
• P produced as a byproduct during WW I and II, 1952-1953 and 1985-1988
• REE in apatite (av. 0.25%), monazite (c. 70%), allanite (c. 22%) a.o.

• Approx. 30 000 tonnes TREE in tailings
• Approx. 2 000 t/a goes to tailings
• Global annual production c. 110 000 tonnes

Source: Pålsson et al. 2014
Summary

- Cash cost control and lean production leads to economic and sustainable mining of low grade deposits in extreme environments
- Automation, systemic integration, resource characterization key factors
- Technological breakthroughs in especially mineral processing and metallurgy leads to economic extraction of by-products
- Economic extraction of by-products leads to resource efficiency
- Resources efficiency leads to increased economically viable primary extraction