Dealing with Nickel-Cobalt Laterite Deposit Complexity

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OUTLINE

• Processes of laterite development
• Factors controlling the nature of the laterite profile
• Laterite profile classification
• Coping with Complexity
  • Mineral Resource Estimation
  • Mining and Processing
• Conclusions
NICKEL LATERITES

• Regolith, derived from ultramafic rocks, that contains commercially exploitable reserves of nickel (and, commonly, cobalt)

• Formed by weathering, erosion, transport and/or deposition of older material (either the immediate bedrock or material from somewhere else)
• Includes fractured and weathered bedrock, saprolites, soils, alluvium, colluvium
# Chemical Weathering

<table>
<thead>
<tr>
<th>General processes of chemical weathering</th>
<th>Effects in ultramafic rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaching of mobile constituents: alkalis, alkaline earths</td>
<td>Breakdown of olivine, pyroxene, serpentine and leaching of Mg, Ni, Mn, Co</td>
</tr>
<tr>
<td>Formation of stable secondary minerals: Fe and Al oxides, clays</td>
<td>Goethite formation, smectite formation, adsorption of Ni from solution</td>
</tr>
<tr>
<td>Partial leaching of less mobile components: silica, alumina, Ti</td>
<td>Leaching of silica in rainforest and moist savanna climates</td>
</tr>
<tr>
<td>Mobilisation and partial reprecipitation of redox-controlled constituents: Fe, Mn</td>
<td>Precipitation of Mn oxides and adsorption of Ni and Co from solution</td>
</tr>
<tr>
<td>Retention and residual concentration of resistant minerals: zircon, chromite, quartz</td>
<td>Residual chromite concentration</td>
</tr>
</tbody>
</table>
**TROPICAL LATERITE PROFILE**

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>MgO</th>
<th>Ni</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferricrete</td>
<td>&gt;50%</td>
<td>&lt;0.5%</td>
<td>&lt;0.6%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>&quot;Limonite&quot;</td>
<td>40-50%</td>
<td>0.5-5%</td>
<td>0.8-1.5%</td>
<td>0.1-0.2%</td>
</tr>
<tr>
<td>Saprolite</td>
<td>10-25%</td>
<td>15-35%</td>
<td>1.5-3%</td>
<td>0.02-0.1%</td>
</tr>
<tr>
<td>Saprock</td>
<td>5%</td>
<td>35-45%</td>
<td>0.3%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EXAMPLE OF LATERITE PROFILE

Red Laterite

Limonite zone

Saprolite zone

Bedrock pinnacle

Courtesy of PT Inco
Factors controlling the nature of the laterite profile

- Parent rock type
- Climate
- Tectonics/Topography/Drainage
- Structure
CLIMATIC CONTROL
TECTONICS, TOPOGRAPHY and DRAINAGE

New Caledonia

Western Australian craton
VARIATION IN NICKEL LATERITE WITH TOPOGRAPHY – PERIDOTITE

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Hydrous Mg-Ni silicates</th>
<th>Smectite</th>
</tr>
</thead>
</table>

1. Regional water table
2. Free draining
3. Impeded drainage

- Transported overburden
- Lateritic duricrust
- Fe-saprolite (limonite)
- Clay-saprolite
- Saprolite
- Protolith
- Garnierite veins
- Corestones

*after Brand 1997*
INFLUENCE OF WATER TABLE LEVEL

(a) LIMONITIC NICKEL
(b) FRESH ROCK
(c) NICKEL SILICATE
(d) NICKEL IN SOLUTION
(e) GROUND WATER TABLE
STRUCTURAL CONTROL
LATERITE PROFILE CLASSIFICATION

• Oxide laterites
  • Fe hydroxides and oxides in the upper part of the profile, overlying bedrock

• Clay silicate laterites
  • smectitic clays in the upper part of the profile

• Silicate laterites
  • hydrated Mg-Ni silicates (serpentine, garnierite) occurring deeper in the profile
OXIDE LATERITE

Pinares de Mayari, Cuba
CLAY LATERITE

Bulong, Western Australia
SILICATE PROFILE

Thio, New Caledonia
COPING WITH COMPLEXITY

- Mineral Resource Estimation
- Mining and Processing
Mineral Resources – Interpreting lithological boundaries

Courtesy of PT Inco
Mineral Resource estimation – Drilling Density
GPR survey coverage

Courtesy PT Ceria Nugraha Indotama
GPR Cross Section Interpretation

Courtesy PT Ceria Nugraha Indotama
GPR Interpretation – Depth to Bedrock

Courtesy PT Ceria Nugraha Indotama
GPR Interpretation – Thickness of Saprolite

Courtesy PT Ceria Nugraha Indotama
COPING WITH COMPLEXITY

- Mineral Resource Estimation
- Mining and Processing
### Processing Methods for Ni Laterites

<table>
<thead>
<tr>
<th>Schematic Laterite Profile</th>
<th>Common Name</th>
<th>Extraction Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saprolite/Garnierite/Serpentine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yellow Limonite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red Limonite</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acid Leach</td>
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<td></td>
<td></td>
<td>NPI</td>
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<td></td>
<td></td>
<td>Caron Process</td>
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<tr>
<td></td>
<td></td>
<td>Smelting</td>
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</table>
## Ore Control Requirements

<table>
<thead>
<tr>
<th>HPAL</th>
<th>SMELTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni content</td>
<td>Ni content</td>
</tr>
<tr>
<td>Co content</td>
<td>SiO2 : MgO ratio</td>
</tr>
<tr>
<td>MgO content</td>
<td>FeO content of slag</td>
</tr>
<tr>
<td>Al2O3 content</td>
<td></td>
</tr>
</tbody>
</table>
FeNi Smelting Conditions

![Graph showing FeNi smelting conditions with various slag tapping/liquidus temperatures and slag SiO2/MgO ratios.](image-url)

Courtesy M L Steemson
Goro Profile (HPAL)

- Cuirasse
- Fe pisolites
- Red limonite
- Yellow limonite
- Rocky saprolite
- Peridotite

Graphs showing depth (m) vs. Ni%, Co%, Fe%, SiO2%, MgO%.
Goro Test Mine
Ravensthorpe Profile (HPAL/AL)
Thank you