INTRODUCTION TO NICKEL LATERITE HEAP LEACHING

Presented by: Mark E. Smith
What is a Laterite?

- A “laterite” is a surface formation in tropical (or formerly tropical) areas which is enriched in iron and aluminum.

- Laterites develop by intensive and long lasting weathering of the underlying parent rock (“residual” soil or saprolite).

- Percolating rain water causes dissolution of primary minerals and decrease of easily soluble elements (e.g., sodium, potassium, calcium, magnesium). This gives rise to a residual concentration of more insoluble elements: iron, aluminum, and occasionally nickel & cobalt.
Types of Ni-Co Laterite Profiles

**immature profile**
more consistent rain leads to
more complete dissolution and rapid laterite formation

**Indonesia**
- Limonite
- Goethite?
- Smectite transition
- Saprolite
- Basement

**mature profile**
less consistent rain leads to
periods of re-precipitation, laterite formation less rapid

**New Cal.**
- Ferricate
- Limonite
- Smectite transition
- Saprolite
- Basement

**super-mature profile**
more seasonal rain to arid conditions
common re-precipitation, laterite modified rather than ‘formed’

**Australia**
- Ferricate
- Pure limonite can be absent
- Limonite
- Smectite transition
- Saprolite
- Basement

**Super-mature smectite-rich profile**
abundant evidence of re-precipitation, poor water flow

**Western Australia**
- Ferricate
- Limonite
- Smectite transition
- Saprolite
- Basement

**From Parianos Aug 2006**

Hematite?
Çaldağ, Western Turkey
Gag Island, Indonesia
Brolga, Australia – Smectite Rich
Why Heap Leach Laterite Nickel Ores?

- Nickel demand has been escalating faster than other metals
- Abundant, principally undeveloped nickel sources
- Allows processing of entire laterite profile
- Heap leaching has been successful on every other mineral attempted
- Low Capital, Low Operating, Low Risk
Global Nickel Resources

- Laterite: 73%
- Sulphide: 27%
Formation controlled by Climate, Parent Material, Organic Matter, Relief and Time

From Parfános Aug 2006, Butt & Elias 1998
Nickel Demand: Outpaces other Metals

Metal Growth

- Stainless Steel
- Mild Steel
- Aluminium
- Zinc
- Copper
- Lead

Growth %pa

0 1 2 3 4 5 6
Primary Nickel Supply: Committed Projects

Graph showing the primary nickel supply over the years from 2006 to 2020. The graph includes:
- Current Installed Capability
- Nickel Pig Iron Supply (adjusted)
- Average Demand (industry analysts)
- Com’ Brownfield Cap’
- Com’ Greenfield Cap’

The graph includes the following projects:
- Ravensthorpe
- Goro
- Onca Puma
- Caldag
- Avebury
- Voisey’s Bay
- Koniambo

The supply percentages for each year are indicated:
- 2006: 1,400 kt
- 2016: 1,600 kt
- 2017: 1,800 kt
- 2018: 2,000 kt
- 2020: 2,600 kt

The graph shows a projection of the supply increase with percentages for each year:
- 2018: 4.3%
- 2019: 5.6%
- 2020: 2.8%
5 Year Nickel

Sep 25, 2001 to Sep 25, 2006 / 13.7076 ▲ +11.5053

(Change calculation is from the start of this chart)

www.kitco.com
## Comparison of Nickel Production Technologies

<table>
<thead>
<tr>
<th>Process Technology</th>
<th>Typical Capacity tpa of Ni</th>
<th>CapEx US $/pound-Ni capacity</th>
<th>OpEx US $/pound-Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelting</td>
<td>18,000 to 60,000</td>
<td>23 to 38</td>
<td>2.20 to 4.00</td>
</tr>
<tr>
<td>HPAL / AL</td>
<td>10,000 to 100,000</td>
<td>19 to 36</td>
<td>2.70 to 5.00</td>
</tr>
<tr>
<td>Heap Leach</td>
<td>10,000 to 80,000</td>
<td>10 to 15</td>
<td>2.20 to 3.00</td>
</tr>
</tbody>
</table>
## Tropical Laterite Profile

<table>
<thead>
<tr>
<th>SCHEMATIC LATERITE PROFILE</th>
<th>COMMON NAME</th>
<th>APPROXIMATE ANALYSIS (%)</th>
<th>EXTRATION PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ni</td>
<td>Co</td>
</tr>
<tr>
<td></td>
<td>RED LIMONITE</td>
<td>&lt;0.8</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>YELLOW LIMONITE</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.8</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>SAPROLITE/GARNIERITE/SERPENTINE</td>
<td>0.3</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>FRESH ROCK</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Heap leaching is now of interest because:

- Success in gold, silver, copper, nitrates, iodine
- Success in laboratory, bench & pilot testing
- Success in heap leaching low permeability ores
- Abundant deposits of Ni laterites that are unsuitable for smelting, HPAL or AL
- Flexible metallurgy (process wider range of ores)
- Far less complex process than HPAL, AL, etc
- Fraction of the CapEx, lower OpEx v. HPAL
- Ni (and Co) recoveries of ~70% common
New Technology – R&D started ~15 years ago, but not yet commercialized

Only started dealing with material handling & containment issues in last 2 years
Several pilot projects are now underway
- Murrin Murrin, Australia (100,000 tonne pilot, on-going)
- Nornico/Metallica, Australia (on-going)
- Cerro Matoso, Colombia (15,000 t pilot, on-going)
- Çaldağ, Turkey (15,000 t pilot, on-going)
- Zambales, Philippines (10,000 t pilot, 2009)
- Piauí, Brazil (2009-2010)
Large Quantity of Geomembranes
Raincoats, Rain Shields, Floating Covers
Interlift Liners & Drainage
Stabilizing Leached Lifts
Wastes: Ripios, Plant Residue (tailings)
High Temperature Leaching
Concentrated Acid
Large Quantity of Geosynthetics

- Ni Heap Leaching will require, per project:
  - Base liners of 500,000 to 2,500,000 s.m. for heap
  - Base liners for tailings can equal heap
  - Interlift liners of 500,000 to 1,000,000 s.m. annually
  - Raincoats for Heap of 500,000 to 1,000,000 initially plus partial replacement annually
  - Raincoats for wastes can exceed heap demand
  - Lift Stabilization of 500,000 to 1,000,000 s.m. per year
  - Closure Caps of 1,000,000 to 3,000,000 s.m.
  - Floating Covers on process ponds (in some cases)
Tropical Heap Leaching

- Most Nickel projects are in high rainfall locations
- Rainfall:
  - Dilutes process solution
  - Increases reagent consumption & interferes with Ni recovery
  - Creates surplus water inventory for treat-and-discharge
  - Damages surface agglomerates, creating impermeable crust
Other Benefits of Raincoats?
Technology pioneered by oxide copper leaching – to reduce acid consumption
In Ni HL, required for acid control & low permeability ores
Each lift of a conventional or “multi-stack” heap is finished by
- Stabilizing the top of the leached lift
- Installing a thin interlift liner & perforated drain pipes – usually concurrently with ore stacking
Multi-stacking of Ni laterites: before stacking the next lift, the prior lift requires stabilization
- Leached laterites are very wet, highly degraded
- 25% of solids dissolved in leaching
- CBR of <<10 common
- Cannot support stacking equipment without either:
  - Drying time
  - Mechanical or chemical stabilization
- Stabilization techniques
  - Compact with fly ash or cement (if climate allows)
  - Reinforcing grid + Waste rock
Geosynthetic Issues in Ni HL

- Large Quantity of Geomembranes
- Raincoats & Rain Shields
- Interlift Liners & Drainage
- Stabilizing Leached Lifts
- Wastes: Ripios & Plant Residue (Tailings)
- High Temperature Leaching
- Concentrated Acid
Nickel Plant Residues

- ~0.4 to 1.1 tonne tailings per tonne leached ore
- Chemical precipitates, not traditional “tailings”
- pH = 2 to 4
- Soluble elements:
  - heavy metals: Mg, Mn, Al, Hg, others
  - sulfates
  - salts
- Physical stability: erosion, slope stability, liquefaction, very difficult to reclaim & stabilize
High Temperature Leaching

- Ambient temperatures 40 to 50°C
- Exothermic reaction (acid leaching)
- Internal temperatures of 50 to 75°C expected
- Affects pipes, geomembrane, reinforcing grid
Temperature Affects
1.5mm LLDPE at 120 m ore depth
ambient (l) & 60° c (r)
# Pipe Deflection vs Temperature

<table>
<thead>
<tr>
<th>Heap Height (m)</th>
<th>Deflection @ 23°C (%)</th>
<th>Deflection @ 50°C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td>60</td>
<td>11.6</td>
<td>17.6</td>
</tr>
<tr>
<td>100</td>
<td>16.8</td>
<td>24.9</td>
</tr>
<tr>
<td>140</td>
<td>21.4</td>
<td>31.0</td>
</tr>
</tbody>
</table>
Concentrated Acid

- 2 decades of experience in Copper HL
  - Pre-cure ore with +/-5 to 20 kg acid per tonne ore
  - Leach with 10 to 20 g/l H2SO4
  - Operating temp = ambient to ~45°C

- Nickel Heap Leaching
  - Pre-cure with 50 to 150 kg per tonne
  - Leach with +/- 50 to 100 g/l
  - Operating temp = ambient to ~75°C
The Final Product: MHP
QUESTIONS?
¿PERGUNTAS?
¿PREGUNTAS?

THANK YOU!
MIL DE GRACIAS!
MUITO OBRIGADO!

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Nickel Laterite Heap Leaching

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