The History of Nickel Exploration in the Yilgarn Craton of Western Australia

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MEGWA 15 August 2007
• This presentation is based on the Hronsky & Schodde (2006) paper published in SEG Special Publication 13

• Richard Schodde is acknowledged for his major contribution to the analysis reported in this presentation

• Much of the paper drew on the excellent summary by Marston (1984)

• David Burt, Jeff Gresham and Jim Ross are thanked for their input
Special Publication Number 13

Nickel Deposits of the Yilgarn Craton:
Geology, Geochemistry, and Geophysics
Applied to Exploration

Stephen J. Barnes, Editor

SOCIETY OF ECONOMIC GEOLOGISTS, INC.
Why should we care?

- Provides an important context to understanding of current Ni exploration potential of the Yilgarn Craton

- A very well constrained case-study of province-scale exploration (clearly defined in space and time) that provides general learnings regarding the mineral exploration process
How it all began
– A long gestation

- 1939 – Prospector George Cowcill digs green-stained gossan from pits near the abandoned Red Hill gold mine, near the abandoned gold mining town of Kambalda
- 1953 – INCO discovers first nickel deposit in WA, the Wingellina Ni laterite deposit
- 1954 – Samples of this gossan submitted for analysis to the Kalgoorlie School of Mines on the suspicion they contained uranium. Bill Cleverly, geology lecturer, reports no uranium but anomalous nickel
- 1964 – John Morgan, a friend of Cowcill, submits more gossan samples from Red Hill area to Roy Woodall from Western Mining Corporation
- 1964-65 – Follow up exploration by WMC defines extensive gossanous outcrops in Red Hill area
- 1966 – KD1 intersects 2.75m @ 8.3% Ni (in what would become Lunnion Shoot) on January 28
George Cowcill with a lump of Lunnon Gossan (Gresham, 1991)
Roy Woodall with student John McKay at the Kambalda field camp 1964-65 (Gresham, 1991)
The Silver Lake Shaft in 1966 (Gresham, 1991)
Shaft sinking began in July 1966, less than 6 months after KD1. First concentrate was produced in early June 1967
Why did it take so long?

- An intriguing aspect of the discovery of Nickel in WA is that outcropping deposits remained undiscovered for more than 70 years in the heart of a major mining region – Why?

- Maybe because:
  - Nickel was a relatively unknown commodity in WA (the first Ni explorers were the North American companies, Newmont and INCO)
  - Prior to the 1960s the Ni price was very stable so there were no price booms to drive interest
  - Geological thinking was dominated by the Sudbury model (large mafic intrusions)
  - The obscuring effect of the regolith in obscuring sulphide deposits and even their ultramafic hosts
A Play in Four Acts

• Four major phases can be recognised in the history of nickel exploration in the Yilgarn

• The Nickel Boom (1966-1971)

• The Long Hiatus (1972-1987)

• The Sulphide Revival (1988- Present)

• The Laterite Boom (1996-2001)

- **Expenditures**
  - **Sulphide**
  - **Laterite**

- **Nickel Boom**

- **Sources:** ABS, Mackenzie and WMC

- **H1 2004 Ni price**
The Nickel Boom (1966-1971)

- 1966 – WMC announces Kambalda discovery on April 4
- 1967 – First discoveries outside Kambalda region (Widgiemooltha area) and by other groups by WMC
- 1968 – Discovery of Scotia and Nepean
- 1969 – Discovery of Mt Keith (largest deposit in Province and first discovery in the Agnew-Wiluna belt); Discovery of Mt Windarra by Poseidon on September 24
- 1970 – Poseidon peaks in early February at intraday high of $280 marking end of speculative boom; Discovery of Yakabindie; Peak year of exploration spend and peak year of Nickel Boom era nickel price
- 1971 – Discovery of Perseverance and Forrestania Camp
- 1972 – Nickel exploration spend falls to < 50% of 1971 level
The Poseidon Adventure

Picture from Sykes (1978) – Poseidon would eventually go into receivership and be subject to government enquiry.
Expenditures (2004 A$ Million) vs Nickel Price (2004 A$/lb)

- **The Long Hiatus**

Sources: ABS, Mackenzie and WMC
The Long Hiatus (1972-1987)

- Declining real nickel price through this period
- Effectively no junior exploration
- Most exploration focused around existing camps
- Gradual closure of mines
- In 1986 WMC became only remaining nickel producer (and stayed so until 1992 when Outokumpu developed Forrestania)
- In mid-1980s even WMC brownfields in Kambalda region fell below sustainable level
- From mid-1980s nickel overshadowed by major gold exploration boom in Yilgarn
Expenditures (2004 A$ Million)

Nickel Price (2004 A$/lb)

Sources: ABS, Mackenzie and WMC
The Sulphide Revival (1988-Now)

- 1988 – Major (although short-lived) spike in nickel price
- 1988 – Purchase of Leinster Operations by WMC; rapid development of Rocky’s Reward – renewed focus on Agnew-Wiluna belt
- Early 1990s- WMC revives Kambalda brownfields effort and is rewarded with success (Mariners, Miitell, Coronet)
- Early 1990s- Technological advances make low-grade deposits potentially economic; ACM leads with Mt Keith development
- 1995 – Silver Swan discovery by MPI; first junior discovery in >20 years
- 1997 – More junior discoveries; Cosmos (Jubilee) and Emily Ann (Forrestania Gold)
- 2000 – WMC begins Kambalda divestment process leading to several new junior nickel producers
Expenditures (2004 A$ Million) vs Nickel Price (2004 A$/lb)

Sources: ABS, Mackenzie and WMC
The Laterite Boom

- Most nickel laterite deposits first drilled during nickel boom but not considered economically significant
  - Marston (1984) describes the Central Bore deposit as “…the possible presence of a large deposit of nickeliferous clay in lateritic profile…the nickel content of the clay averages between 0.8 and 1.5% and a tonnage approaching 100 MT could be present.”
  - This area would later be developed by Anaconda as the Murrin Murrin deposit
- In the mid-1990s the potential of the Pressure acid Leach (PAL) process to treat these ores was recognised, leading to a boom in nickel laterite exploration
- This drove Yilgarn nickel exploration spending to levels comparable with the nickel boom; laterite spending exceeded sulphide spending in 1997 and in 1999-2001, although much of this was resource delineation
- Three mines were developed in the late 1990s; Bulong (by Resolute), Cawse (by Centaur) and Murrin Murrin (by Anaconda);
How were the deposits found? A tale of two halves

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>Direct Surface Expression</th>
<th>Surface Geochemical Anomaly</th>
<th>Discrete Geophysical Target</th>
<th>Recon. Drilling</th>
<th>Follow Up to known mineralization</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966-71 (Nickel Boom)</td>
<td>24</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>42</td>
</tr>
<tr>
<td>1971-2003 (Post Boom)</td>
<td>6</td>
<td>-</td>
<td>1</td>
<td>6</td>
<td>22</td>
<td>35</td>
</tr>
</tbody>
</table>

Nickel boom era exploration was highly effective at locating outcropping NiS deposits

Subsequent success has been driven by follow up to known mineralization
The Nickel Boom
Discovery Technology Package

- Geological understanding that deposits were associated with the basal contact of ultramafic horizons, where these were locally of an anomalously magnesian nature

- The capability to map ultramafic rocks through obscuring regolith – in particular the application of magnetics

- The capability to discriminate Ni-bearing gossans from other ironstones (based on relict textures and geochemistry)

- The understanding that Cu analysis was required to supplement Ni in surface geochemistry because of the high Ni background in the host ultramafics
Which geological concepts made a difference?

• The “trough-flank” model first developed at Kambalda (Ross & Hopkins 1975) and then ultimately expanded in modified form to all sulphide deposits

• The recognition that high MgO komatiites can form in both prospective channellized facies and barren sheet flow facies (Hill et al, 1990)

• The understanding of laterite profiles over High-MgO ultramafic rocks (eg Elias et al, 1981) – important in understanding laterite deposits and exploring for sulphide deposits

• The recognition that in more highly strained environments, massive sulphide orebodies can occur dislocated (up to a 100m) from their host ultramafic unit
Exploration spend has been closely related to commodity price but this is *not* the complete story.

In both the early and late 1980s, a large price rise resulted in only small increases in expenditure.

The Laterite boom began against a background of low and falling prices.

The other critical factor is the opening up of a new *exploration search space*.

The Nickel Boom was the “Perfect Storm” of a major price rise coinciding with the opening of a large, completely-virgin search space.
How did it vary between Near-Mine and Grassroots?

Expenditures (2004 A$ Million)

Sources: WMC estimates

NiLat Grassroots + Adv
NiLat Minesite
NiS Grassroots + Adv
NiS Minesite

When was exploration most successful?

- For sulphide deposits, this question has a simple answer – right at the beginning!
- The first 6 years of Ni exploration in the Yilgarn resulted in the discovery of the overwhelming majority of the metal, all of the giant deposits, and most of the major deposits.
- This is a very good example of the benefits of moving early into a new exploration search space
- For laterites, this is a difficult question to answer meaningfully as most were already known before they were “discovered”
Sulphide Discovery History
(Post-discovery growth is attributed back to the discovery date)

Ni Discovered (mt)

Total = 12.78mt

excluding 0.07mt in deposits with no published discovery date

Excludes Prospects

Source: WMC
Expenditure vs Discovery Rate: Sulphide Deposits

Ni Discovered (mt) vs Expenditures (2004 A$ Million)

- NiS Discoveries
- NiS Exploration Expenditures
Cost per Discovery (2004 A$m)

- $1,562.40
- $1,249.92
- $937.44
- $624.96
- $312.48
- $0

Cost per Pound (2004 A$ Cents/lb Ni)

Average Discovery Cost: Sulphide Deposits

Based on 3-Year Rolling Average
Expenditure vs Discovery Rate: Laterite Deposits

Ni Discovered (mt)

Expenditures (2004 A$ Million)

- Exploration Expenditures
- NiLat Discoveries

Discovery Year

### Summary of Exploration Performance

#### 1966 - 2003

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>Total Spend</th>
<th>Ni Metal discovered</th>
<th>Av. Cost per pound Ni</th>
<th>Av. Cost per discovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphide</td>
<td>$1,485 M</td>
<td>12.78 mt</td>
<td>5.2</td>
<td>$17.7 M</td>
</tr>
<tr>
<td>Laterite</td>
<td>$280 M</td>
<td>19.5 mt</td>
<td>0.6</td>
<td>$6.5 M</td>
</tr>
</tbody>
</table>

**Notes:**
1. All currency amounts in 2004 AUD
2. Minimum deposit size 5kt Ni
Summary and Conclusions

• The Ni exploration history of the Yilgarn Craton is a great success story!

• In a period of less than 40 years, the known endowment of the craton has grown from zero to 14% of the global inventory of Ni resources (and 18% of global Ni sulphide resources)

• The most successful period of exploration was at the beginning when a major new search space was opened

• Exploration expenditure was driven by a combination of metal price and new search space

• Future exploration success will depend on continuing to develop the new technologies and concepts that
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