A Geological Model for the Thompson Ni-Co Sulfide Ore Deposits, Manitoba, Canada

Peter C Lightfoot, Rob Stewart, Graeme Gribbin, Steve Kirby
Vale Base Metals
Thompson Nickel Belt
Geology and Stratigraphy

FROM LIGHTFOOT ET AL. (2012)

THOMPSON DEPOSIT

AFER BLEEKER AND MAEC (1990)
1951: Belt covered by one of the earliest airborne electromagnetic surveys flown @ 1200’ line spacing

1950’s: Ground Geophysical Surveys: magnetic and vertical loop electromagnetic survey with 200/400’ line spacing

Second priority target: strong conductor but moderate magnetic response; drilled in 1956

1961: commercial production
SNOWBALL EXPRESS  A system of tractor trains worked night and day during the winter of 1956-57 to move more than 30,000 tons of material and equipment from the rail head at Thicket Portage to the mine site. The 70-mile round trip took 14 hours.
Take-away messages

- Thompson Deposit: hosted by P2 member of the Pipe Formation in the Thompson Dome Structure
- Primary ultramafic rock association
- Sulfide saturation triggered by addition of crustal sulfur
- Dense magmatic sulfides segregated and concentrated at the base of intrusions (chonoliths?)
- Four main phases of deformation have remobilized the primary sulfide ores
- Systematic variations in ore mineralogy spatially controlled by deformation & metamorphism – sulfide kinesis
- Process models: emphasis on post-magmatic rather than primary magmatic events
- Ongoing exploration success; mineral potential remains enormous in this world-class belt
Outline of talk

Geology of the TNB

Geology of the Thompson Dome

Chemistry of the Thompson sulfides

Exploration implications

Process of deformation and modification of sulfides
TNB Geology: Stratigraphy

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Sulphide occurrence</th>
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<tbody>
<tr>
<td>Bah Lake Formation</td>
<td>B1-3</td>
<td></td>
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<tr>
<td>Setting Formation</td>
<td>S1</td>
<td></td>
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<tr>
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<td>P3</td>
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<td>T3</td>
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<tr>
<td>Manasan Formation</td>
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<td></td>
<td>M1</td>
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</tr>
<tr>
<td>Archean</td>
<td>A</td>
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- Mafic Molson Dykes
- Ultramafic
- Ni Sulphide Ore
- Metavolcanics
- Quartzite / Schist
- Pelitic Schist
- Iron Formation
- Calcareous Metasediment
- Semi-pelitic Schist
- Quartzite
- Basement Gneiss

Manasan Formation (M2)

Thompson Formation

Archean

Basal Quartzite (M1)
Massive Sulphide

Ultramafic
Ni Sulphide Ore
Quartzite / Schist
Pelitic Schist
Iron Formation
Calcareous Metasediment
Semi-pelitic Schist
Quartzite
Basement Gneiss

Mafic Molson Dykes

TNB Geology: Stratigraphy

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P3 Iron Formation

Massive Sulphide

0 10 cm
## Sulfide-Controlling Structures

- Low strain pressure shadows (boudin necks) between competent ultramafic bodies. *e.g.* Birchtree 83
- Dilatant zones along lithological contacts
- Brittle fracture / brecciation

- Zones of dilatency developed proximal to fold hinges. *e.g.* Thompson 1D
- Plunge of ore shoots typically parallel to fold axis (defined by lineation)
- Step over structures

- Late stage brittle offset
  - Birchtree 609 Fault
- Associated drag folds of mineral zone proximal to fault offset (*E.g.*
  - Birchtree 109 and 108 zones
Fold Interference in Ospwagan Formation at Thompson Mine – 1D Deposit

Plan based on drill core data
3500L, Thompson 1D Mine

Outcrop Scale – Thompson Open Pit

Mushroom style fold interference

- Nickel sulfide mineralisation
- Ultramafic rock
- Setting Formation
- P2 Formation schist
- Thompson Formation
- Archean gneiss
Outline of talk

Geology of the TNB

Geology of the Thompson Dome

Chemistry of the Thompson sulfides

Exploration implications

Process of deformation and modification of sulfides
Thompson Mine: plan and long section

TNB historic production: 2500kt Ni

2014 reserves: 21.75 mmt@ 1.76% Ni (Thompson and Birchtree)
Thompson Mine, 1D ore body
Cross and Long Section

Looking West

37000 North Section Viewed towards South

Lightfoot et al. (2012)
Thompson Mine; 1D Ore Body - massive and semi-massive sulphide (45% of contained Ni)

- Pyrrhotite – Pentlandite +/- Chalcopyrite +/- Pyrite assemblage.
- Thickened zones of massive sulphide proximal to fold hinges.
- Grading to less continuous massive bands/pods with increasing intensity of deformation.
Thompson Mine, 1D ore body:
Inclusion-bearing sulphide (30% of contained Ni)

- Angular to well-rounded inclusions of foliated P2 schist, pegmatised schist and ultramafic bodies
- Late syn-deformation remobilisation evidenced from folded, highly deformed pelitic fragments incorporated within sulphide
- Distal from primary ultramafic source
Thompson Mine, 1D ore body: Mineralised schist (15% of contained Ni)

- Concordant with stratigraphy.
- Typically within highly deformed P2 schist.
- Attenuated lenses parallel to foliation.
- Developed along both fold limbs and hinge zones.
Thompson Mine, 1D ore body: Mineralised ultramafic bodies (10% of contained Ni)

- Thompson ultramafic bodies are boundins heavily brecciated by sulphide
- Very minor fresh dunite and peridotite preserved with primary sulphide textures
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Process of deformation and modification of sulfides
Terminology: Ni tenor; i.e. $[\text{Ni}]_{100}$

Definition of Ni tenor: The measure of the Ni concentration in 100% sulfide (different to nickel grade of the rock)

Calculation in simplest form:

$[\text{Ni}]_{100} = \text{Ni} \times 38 / \text{S wt\%}$ [for S>1 and Ni>0.25]

Limitations and caution:

- Reliable Ni and S assays (S proxy: estimated sulfide content)
- Established based on Po-Pn-(Cpy) ore types; sensitivity to pyrite, arsenide minerals, etc.
- Ultramafic host rocks contain silicate nickel – correction is not straightforward
Thompson Mine: Grouped frequency distribution of [Ni]_{100} (wt%) from assay database – variations in massive sulphide and semi-massive sulphide
Thompson Mine: data density plot showing different $[\text{Ni}]_{100}$ trends in sulphide ores – principal control is Pn content.

More Pn

More Po

S wt %

Ni wt %

Ni 100 = 13

Ni 100 = 11

Ni 100 = 8

Ni 100 = 4

Ni 100 = 1
Thompson Mine: 1D Deposit. Compositional diversity in Pentlandite (LA-ICPMS)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pentlandite Texture</th>
<th>n</th>
<th>Ni wt%</th>
<th>Co ppm</th>
<th>Pd ppm</th>
<th>Pd %</th>
<th>Pd %RSD</th>
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<td>Fine grain veinlet</td>
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<td>31.22</td>
<td>4476</td>
<td>1.67</td>
<td>0.8</td>
<td>48%</td>
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Thompson Mine, 1D ore body: Ni tenor sized to S (5ft composites)
0-1, >1-7wt%[Ni]_{100}
Thompson Mine, 1D ore body: Ni tenor sized to S (5ft composites) >13wt%[Ni]$_{100}$
Thompson Mine, 1D ore body:
Ni tenor sized to S (5ft composites)
detail of F3 structure
Thompson Mine, 1D ore body: Ni tenor sized to S (5ft composites) detail of western flank of F2 fold

Symbols sized to sulfur content and colored by Ni100 with +/- 40ft clipping to geology section
Leapfrog model showing Ni grade distribution in the 1D orebody, Thompson Mine

37000 North Section

Model prepared by Steve Kirby

Model prepared by Lisa Gibson

Legend:
- Blue: Isosurface Ni>2wt%
- Green: Isosurface Ni>3.5wt%
- Orange: Isosurface Ni>5wt%
- Black dotted: F3 Fold - Setting Formation
- Red dotted: F3 Folds - mineral zone
Leapfrog tenor shell model for Nickel in the 1D orebody, Thompson Mine
Cross Section

Geology

Nickel tenor of sulfide

Model prepared by Lisa Gibson

Nickel tenor of 100% sulfide
- $\text{Ni}_{100} > 13\text{wt}\%$
- $10 < \text{Ni}_{100} \leq 13\text{wt}\%$
- $7 < \text{Ni}_{100} \leq 10\text{wt}\%$
- $5 < \text{Ni}_{100} \leq 7\text{wt}\%$
- $0 > \text{Ni}_{100} \leq 5\text{wt}\%$

Legend:
- Fold axis
- Direction of younging
- Trend of bedding
- Nickel Sulphide
- Serpentinitised ultramafic rock
- Setting Formation
- Pipe Formation
- Thompson Formation
- Manasan Formation
- Archean granitoid rocks
Southern Closure (nose), Thompson Mine

PLAN VIEW

M1 Impure Quartzite

M2 pelitic schist and T1-T2 quartzite with calc-silicate

Looking SE
Nose structure ore bodies, Thompson Mine (estimated Ni100 based on historic estimated visual sulphide content)

Symbols are sized to visual estimate of sulphide content:
- Red: Estimated Ni tenor >13wt%
- Green: Estimated Ni tenor >7-9wt%
- Yellow: Estimated Ni tenor >1-7wt%

Legend:
- Base of Setting Formation (shaded by sun-angle)
- Larger serpentinised ultramafic boudins
- Position of level plans in Figures 17A-C
Thompson Mine Nose: estimated Ni tenor sized to sulphide content (not composited)

Symbols sized to estimated sulphide content and colored by estimated Ni\textsubscript{100} with +/-70m clipping to the geology section.

- **Serpentinised ultramafic rock**
- **Setting Formation**
- **Manason, Thompson and Pipe Formations**
- **Archean granitoid rocks**

- **Ni\textsubscript{100} <= 1 wt%**
- **1 <= Ni\textsubscript{100} <= 6 wt%**
- **6 <= Ni\textsubscript{100} <= 8 wt%**
- **8 <= Ni\textsubscript{100} <= 10 wt%**
- **10 <= Ni\textsubscript{100} <= 13 wt%**
- **Ni\textsubscript{100} > 13 wt%**
Outline of talk

Geology of the TNB

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Chemistry of the Thompson sulfides

Exploration implications (Steve Kirby)

Process of deformation and modification of sulfides
Structural controls: Thompson Extensions Zone

BH 1301450 4.75% Ni, 1.28 g/t TPM / 31.0m true thickness
Structural controls: Thompson Extensions Zone

Composite Section
360N - 380N

Looking South

BH 1140690 2.04% Ni, 0.505 g/t TPM / 17.1m true width
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Geology of the TNB

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Process of deformation and modification of sulfides
Thompson Nickel Belt Evolution
Primary structural controls
Phase 1 of 3

Primary komatiite magmatism in rift

Chonolith intrusions

Thompson

Birchtree

Primary site of sulphide accumulation

Kisseynew terrain
- Nickel sulfide and barren sulfide
- Ultramafic rock
- Bah Lake volcanic rocks
- Setting Formation
- Manasan, Thompson and Pipe Formations
- Archean gneiss
Thompson Nickel Belt Evolution
D1-D2 events; sulfide kinesis
Phase 2 of 3

Thrusting and sulfide kinesis

Diagram showing lateral sulfide kinesis during deformation.
Thompson Nickel Belt Evolution
D3 event
Phase 3 of 3

Folding

Removed by erosion

Surface

Thompson

Birchtree

Pipe

Kisseynew terrain
Nickel sulfide and barren sulfide
Ultramafic rock
Bah Lake volcanic rocks
Setting Formation
Manasan, Thompson and Pipe Formations
Archean gneiss
The infiltration of soft sulphides into the various rock types is represented, and the arrest and initial incorporation of rock inclusions.

Note that the initial inclusion shape is controlled by the infiltration pattern.

Inclusions in the high flux show extensive wearing.

(Monteiro, 2006)
Sulfide kinesis: P-T controls
Process Models for Thompson

• Komatiitic magma emplaced into a rifted continental margin sequence (possibly chonoliths in D0 structures)
• Assimilation of sedimentary sulphide from Pipe Formation, sulphur saturation and density segregation to form magmatic massive and disseminated Ni-Co sulphide
• D1-D2 event: high grade metamorphism (750°C, 6.5 kbars; Bleeker, 1991) accompanied thrusting and folding
• D3 event: localized the sulfides into structures on the flank of the Thompson Dome
• D4 event: further remobilization along flanks of Thompson Dome
• Sulfide kinesis responsible for diversity in sulfide ore types
• Detachment from primary ultramafic intrusion
• Localization in pressure shadows in Pipe Formation
• Process of sulfide kinesis also segregated Pn from Po and mixed barren with nickeliferous sulfides
SUMMARY: Continuum of Deposits (Schematic)

(modified after Gribbin 2011)
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