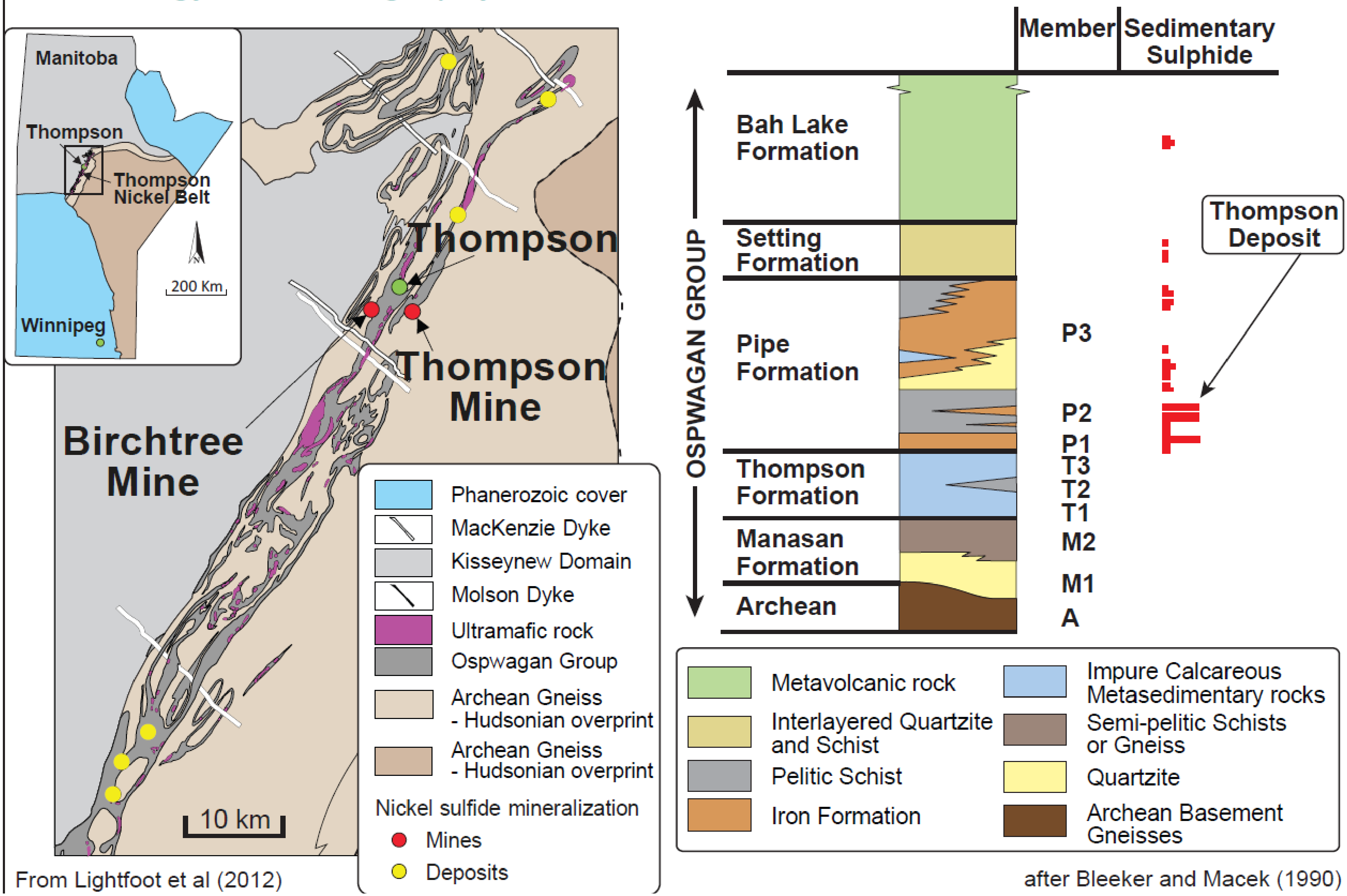
A Geological Model for the Thompson Ni-Co Sulfide Ore Deposits, Manitoba, Canada

Peter C Lightfoot, Rob Stewart, Graeme Gribbin, Steve Kirby
Vale Base Metals

Thompson Nickel Belt

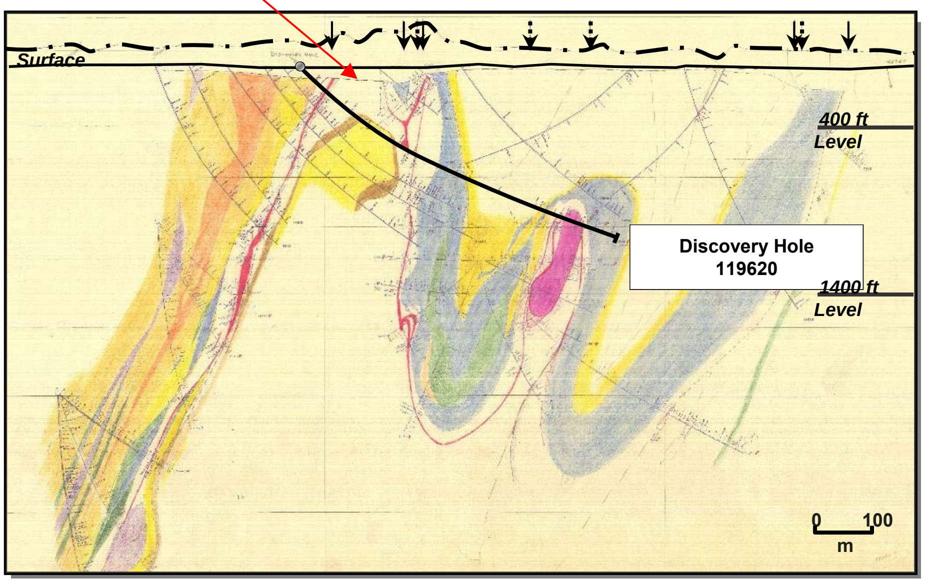
Geology and Stratigraphy



From Lightfoot et al (2012)

after Bleeker and Macek (1990)

Thompson Discovery Hole - 1956



- •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

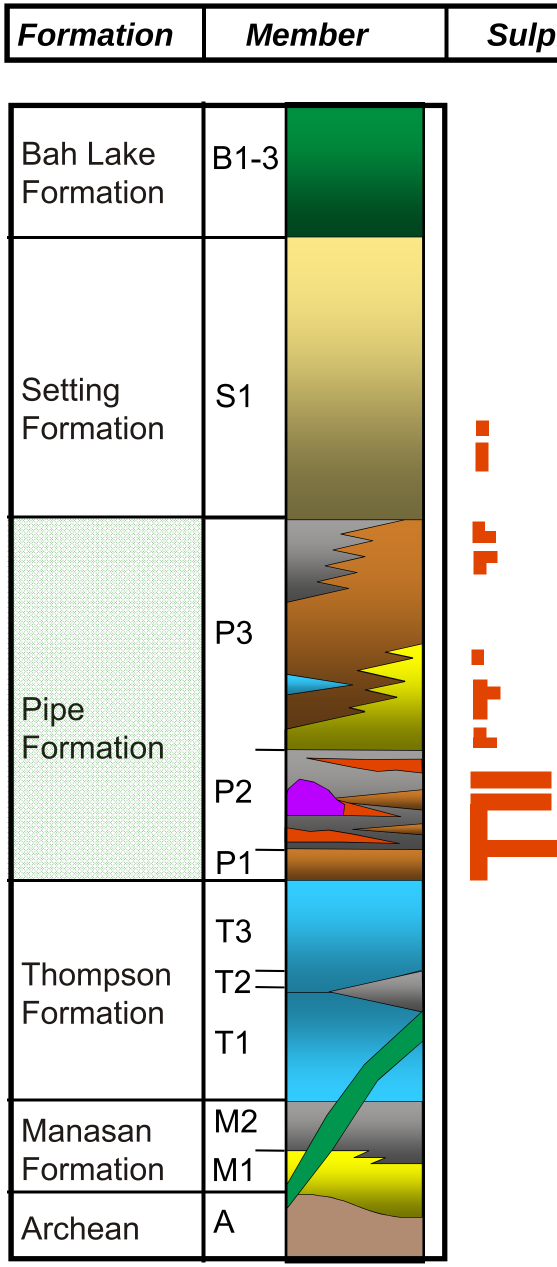
Geology of the Thompson Dome

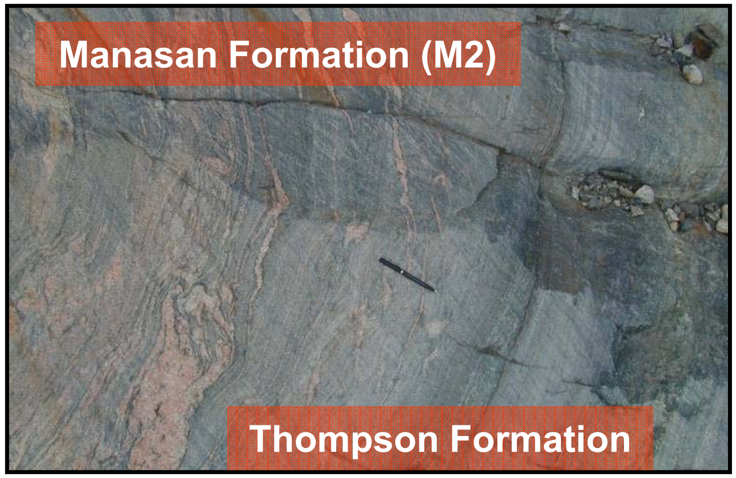
Chemistry of the Thompson sulfides

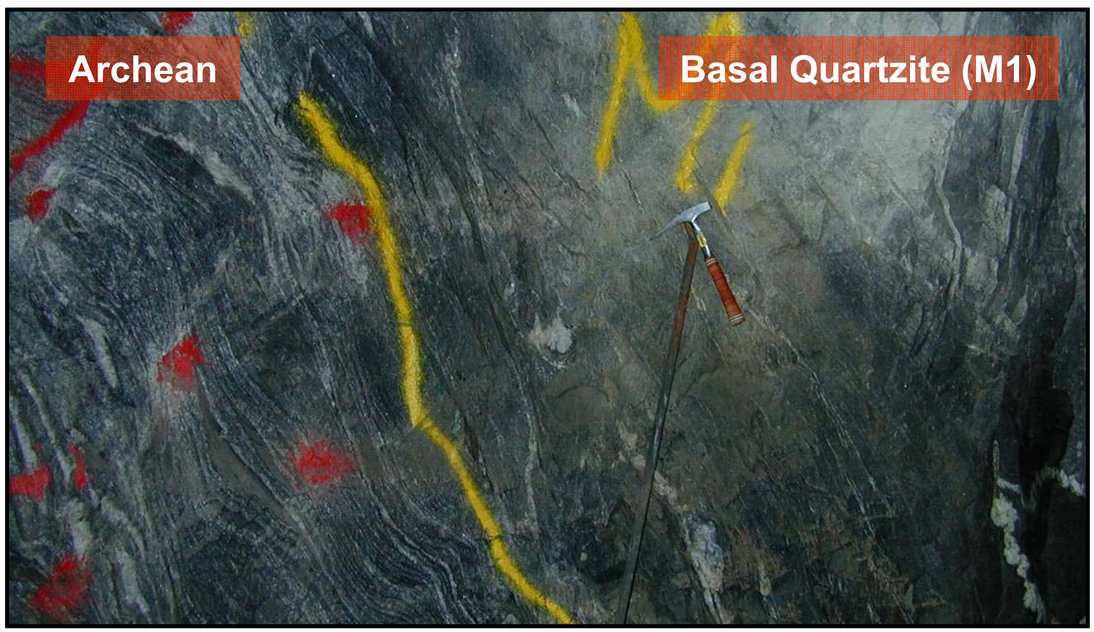
Exploration implications

Process of deformation and modification of sulfides

TNB Geology: Stratigraphy

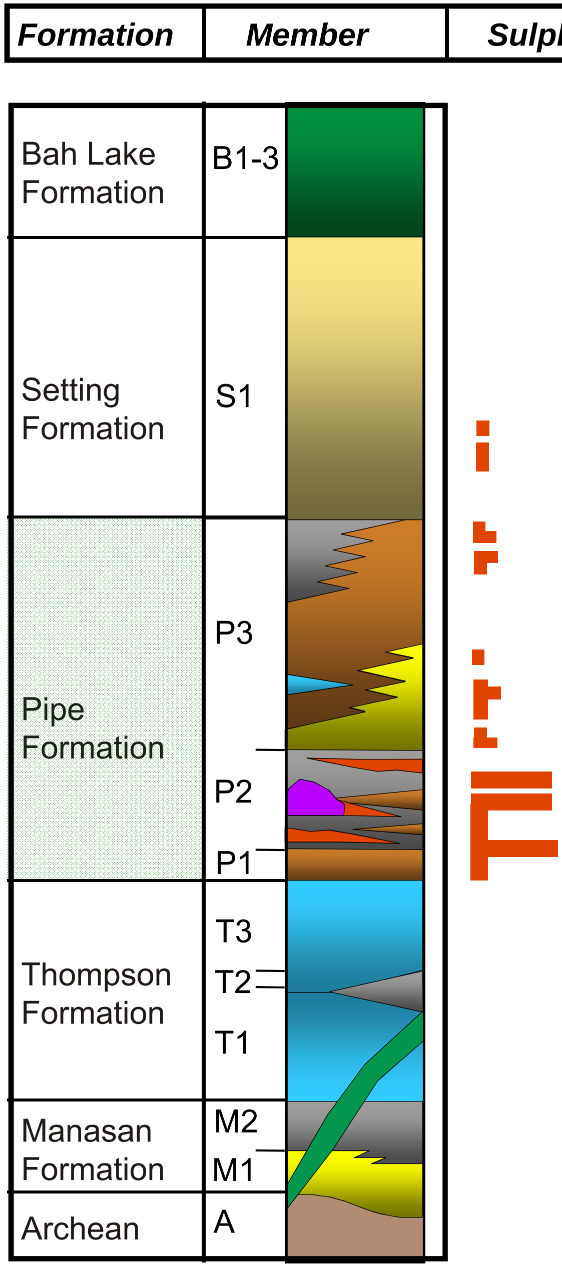


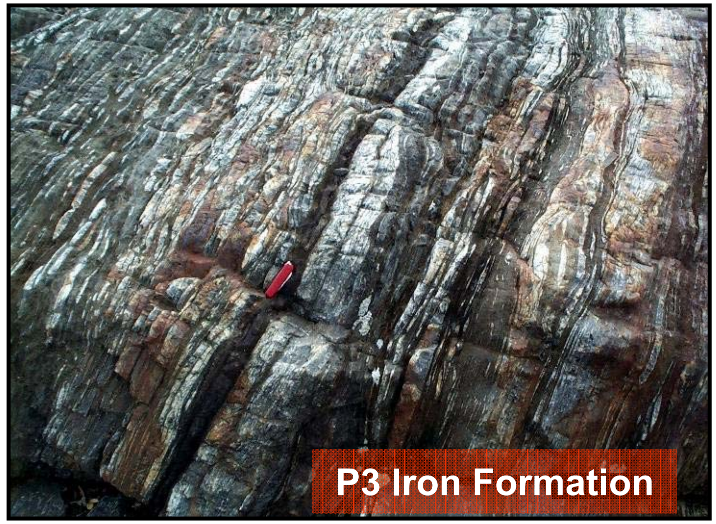


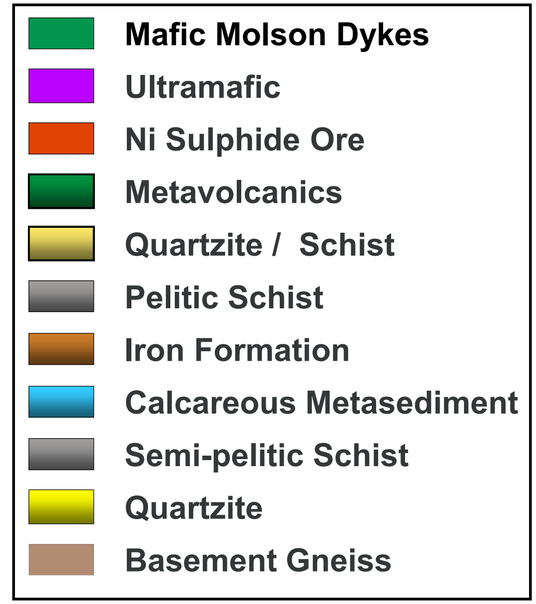


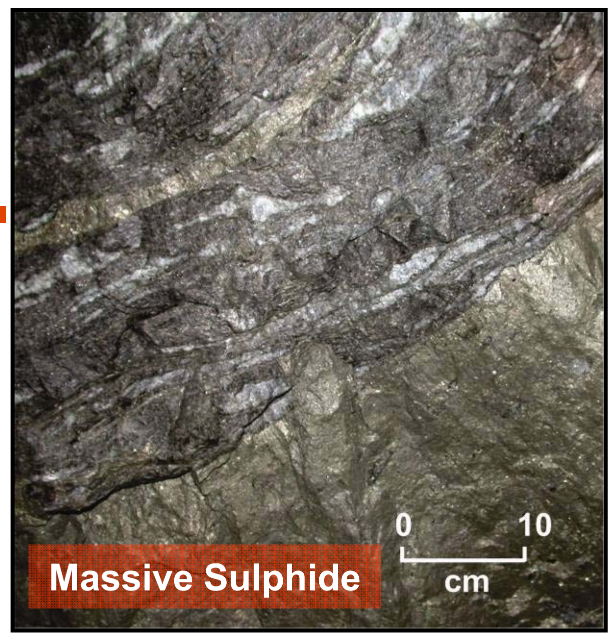
- Mafic Molson Dykes
- Ultramafic
- Ni Sulphide Ore
- Metavolcanics
- Quartzite / Schist
- Pelitic Schist
- Iron Formation
- Calcareous Metasediment
- Semi-pelitic Schist
- Quartzite
- Basement Gneiss

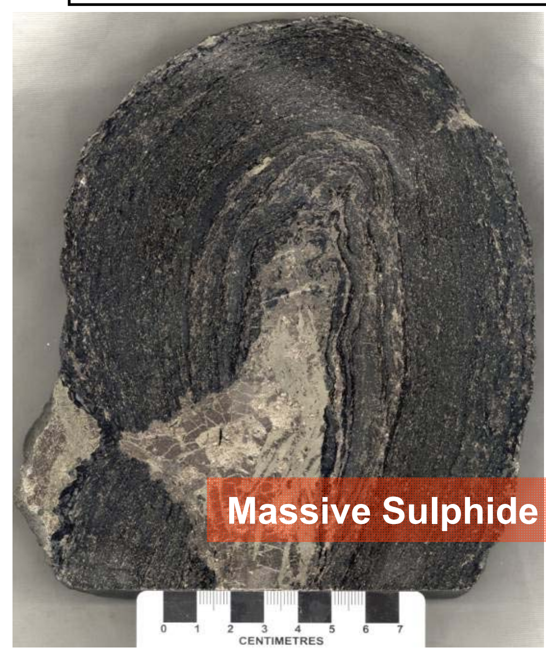
TNB Geology: Stratigraphy





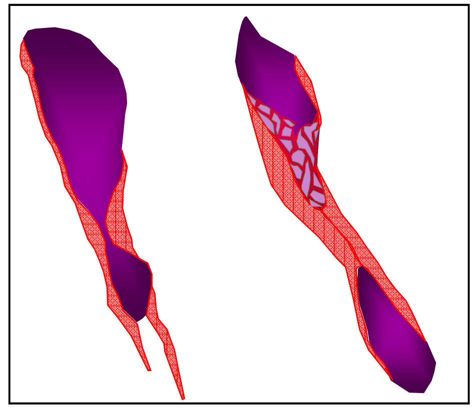


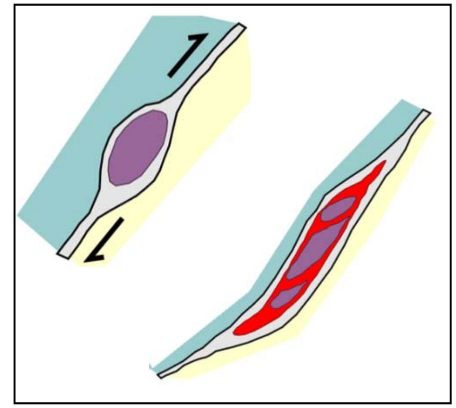




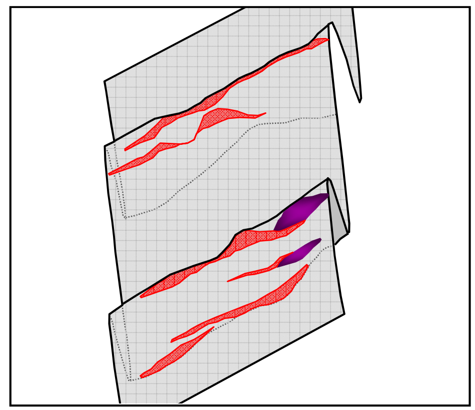
Sulfide-Controlling Structures

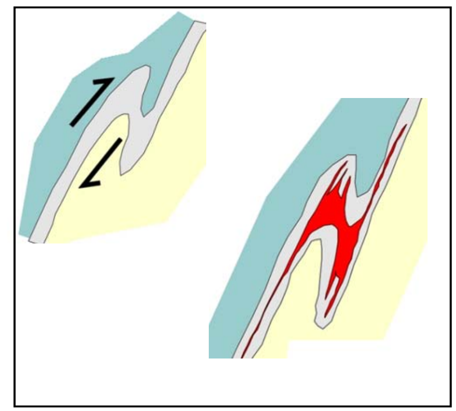
- Low strain pressure shadows (boudin necks) between competent ultramafic bodies. e.g. Birchtree 83
- Dilatant zones along lithological contacts
- Brittle fracture / brecciation



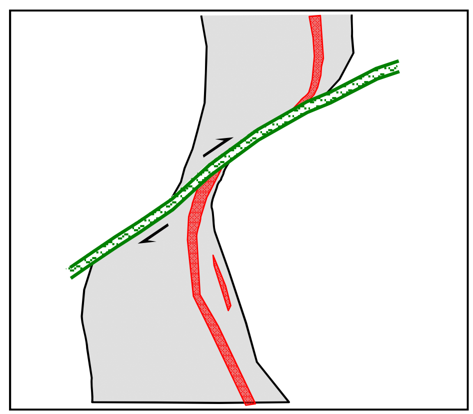


- Zones of dilatency developed proximal to fold hinges. e.g. Thompson 1D
- Plunge of ore shoots typically parallel to fold axis (defined by lineation)
- Step over structures





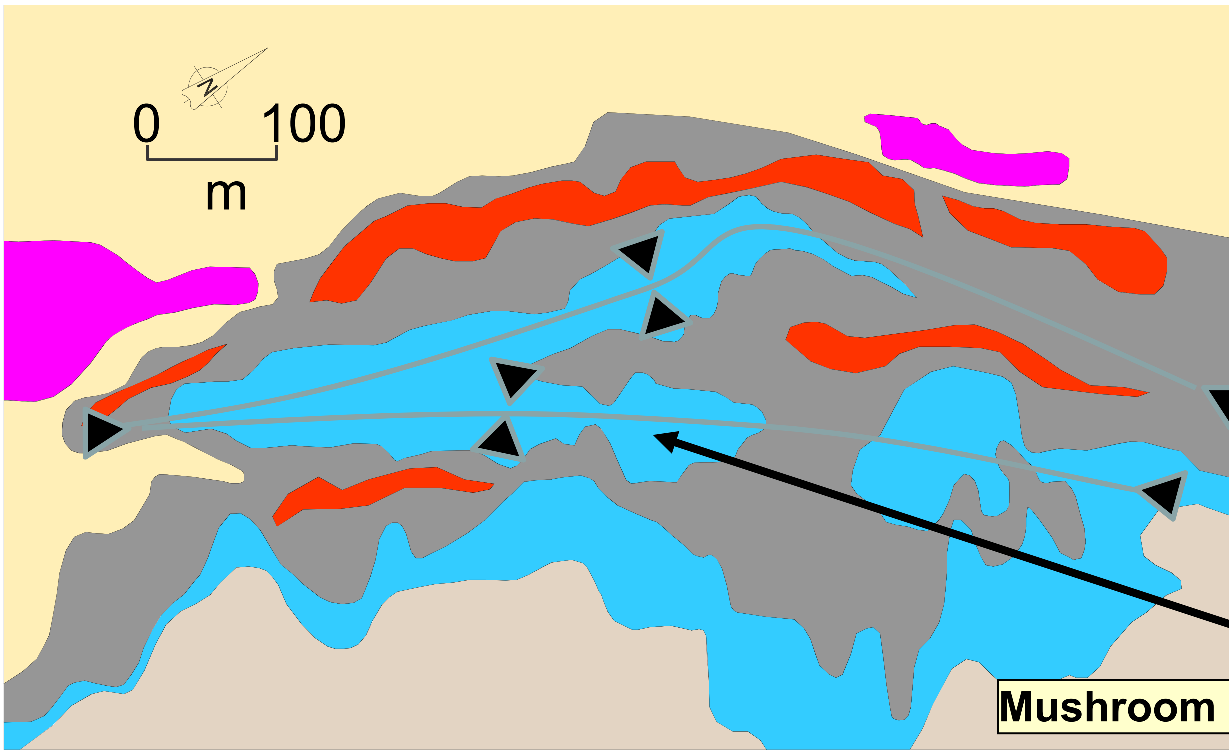
- Late stage brittle offset
  - Birchtree 609 Fault
- Associated drag folds of mineral zone proximal to fault offset (E.g.
  - Birchtree 109 and 108 zones



Fold Interference in Ospwagan Formation at Thompson Mine – 1D Deposit

Plan based on drill core data

3500L, Thompson 1D Mine



Nickel sulfide mineralisation

Ultramafic rock

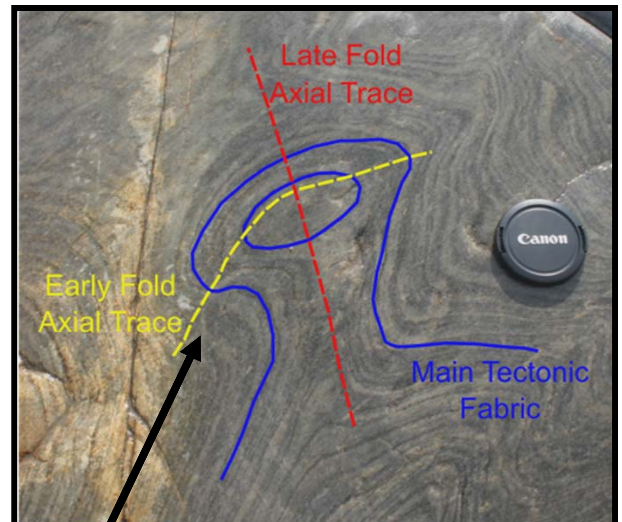
Setting Formation

P2 Formation schist

Thompson Formation

Archean gneiss

Outcrop Scale – Thompson Open Pit



Mushroom style fold interference

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Chemistry of the Thompson sulfides

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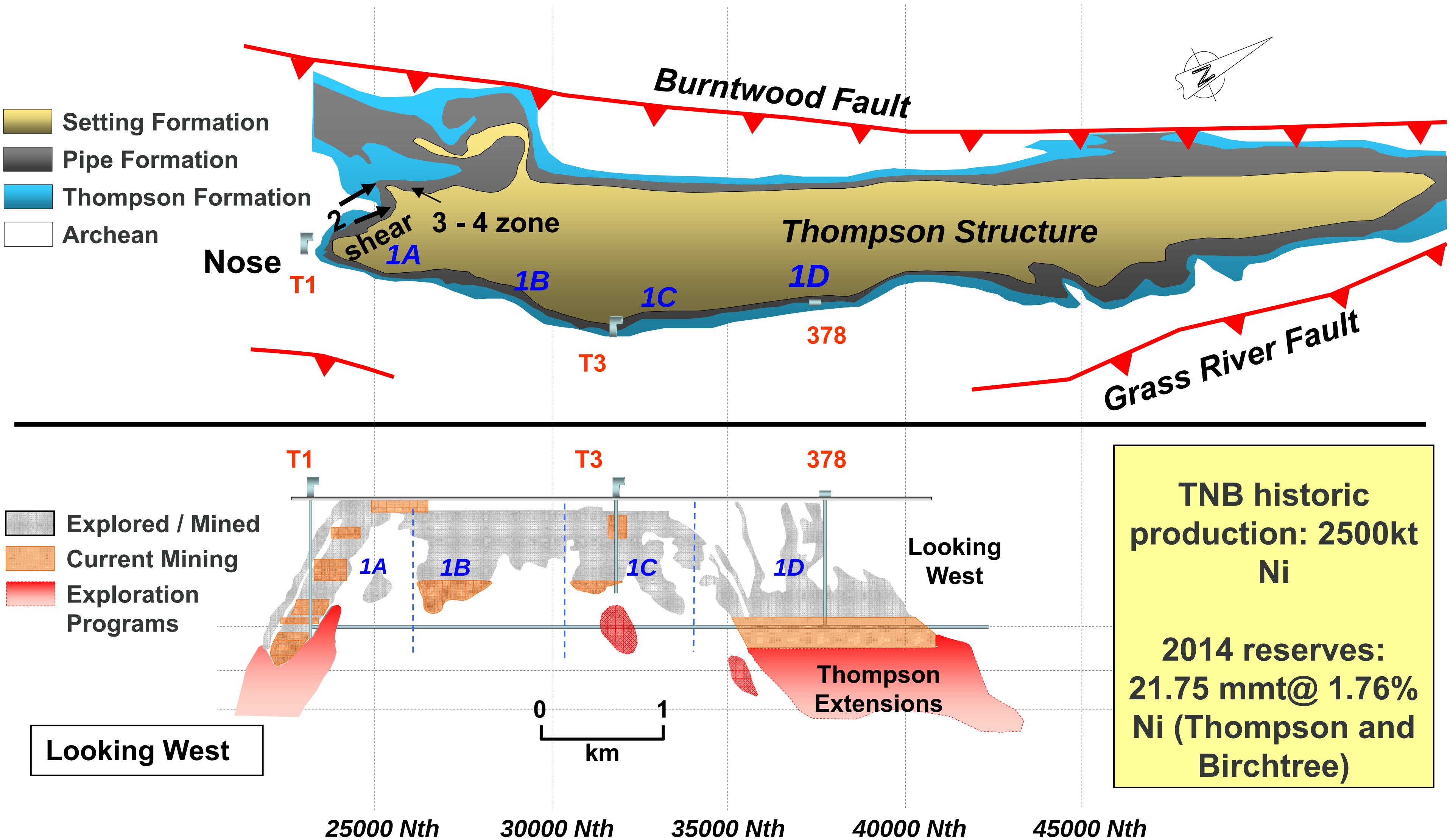
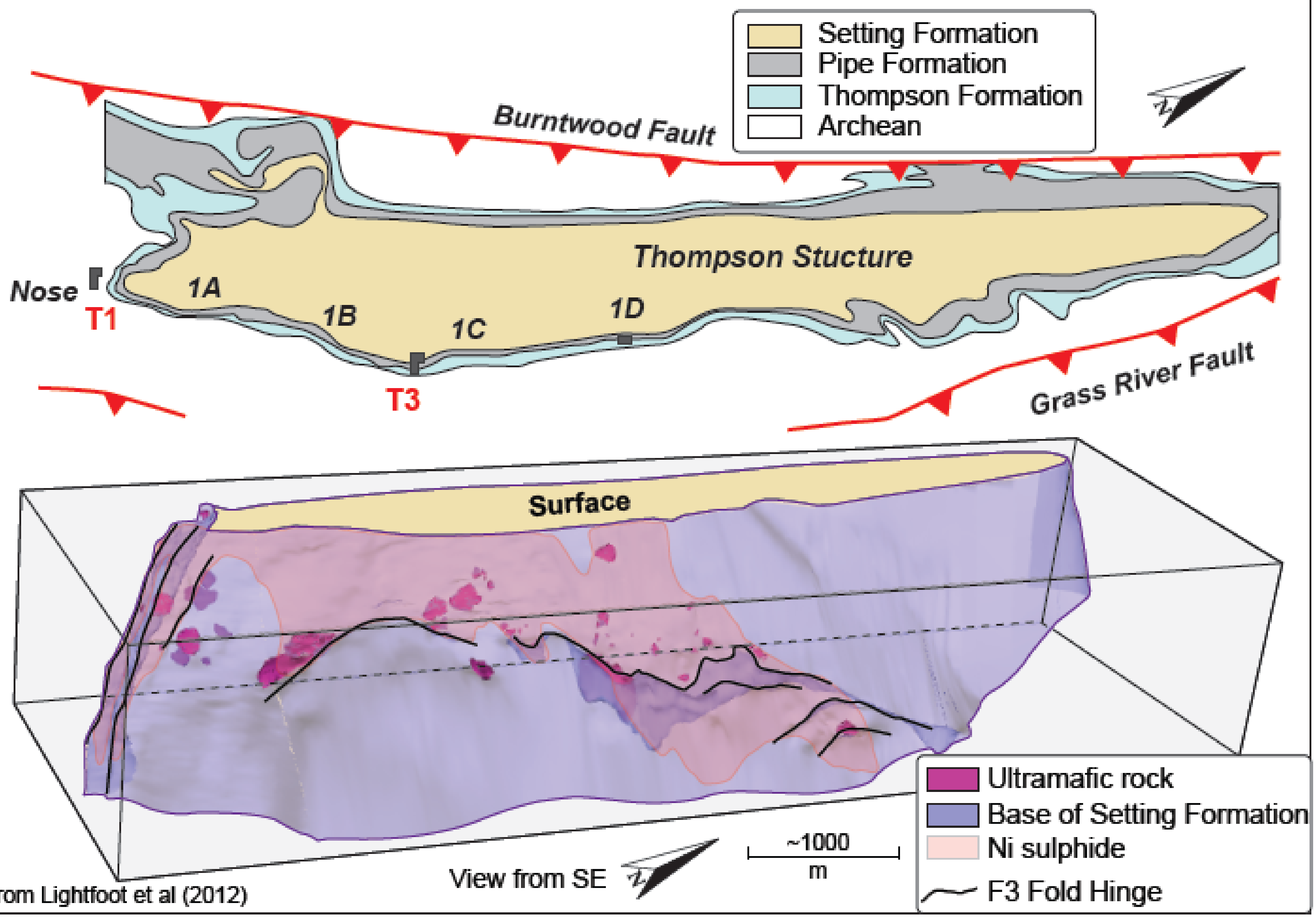
Thompson Mine: plan and long section



TNB historic production: 2500kt Ni

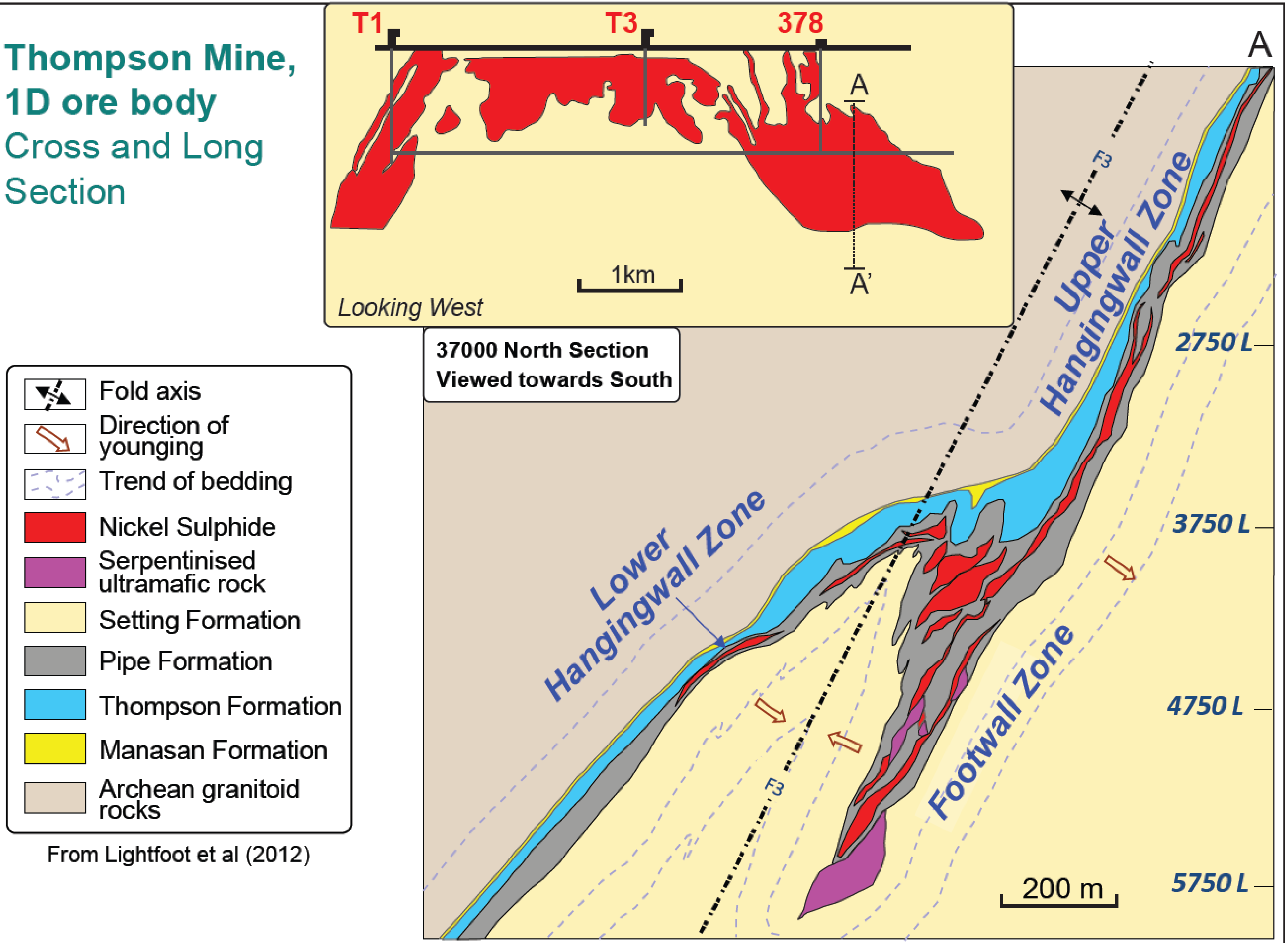
2014 reserves: 21.75 mmt@ 1.76% Ni (Thompson and Birchtree)

Plan and 3D View of the Thompson Dome



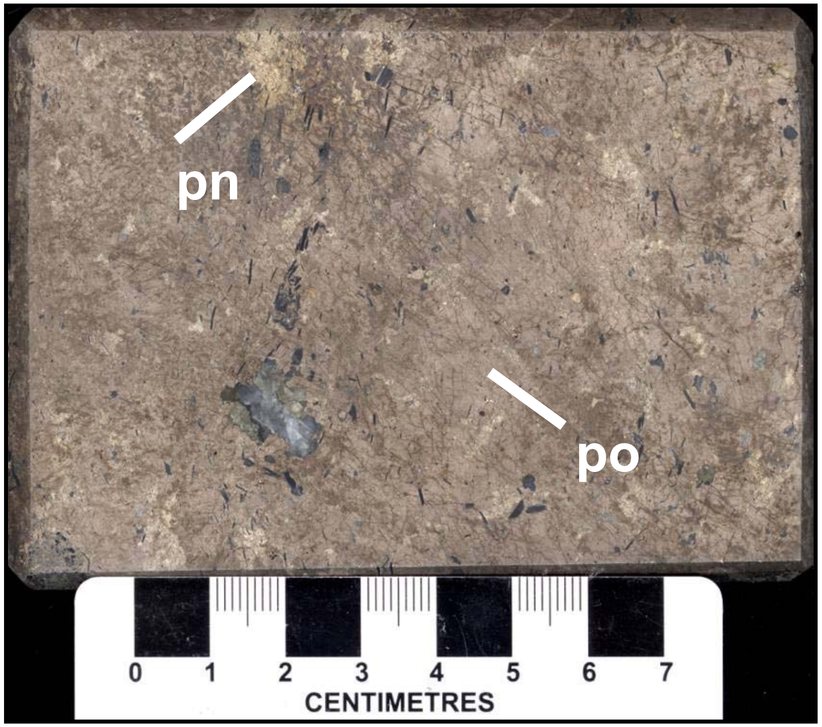
From Lightfoot et al (2012)

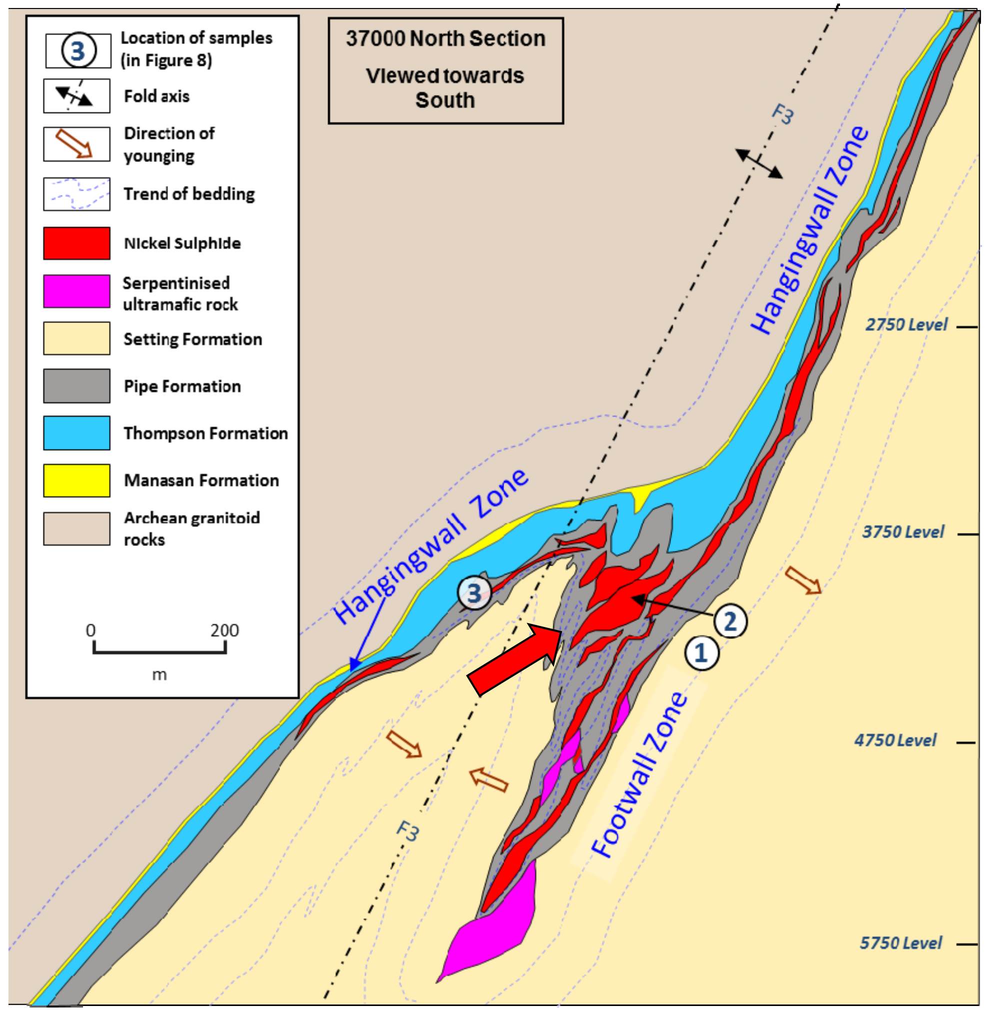
Thompson Mine, 1D ore body
Cross and Long Section



Lightfoot et al. (2012)

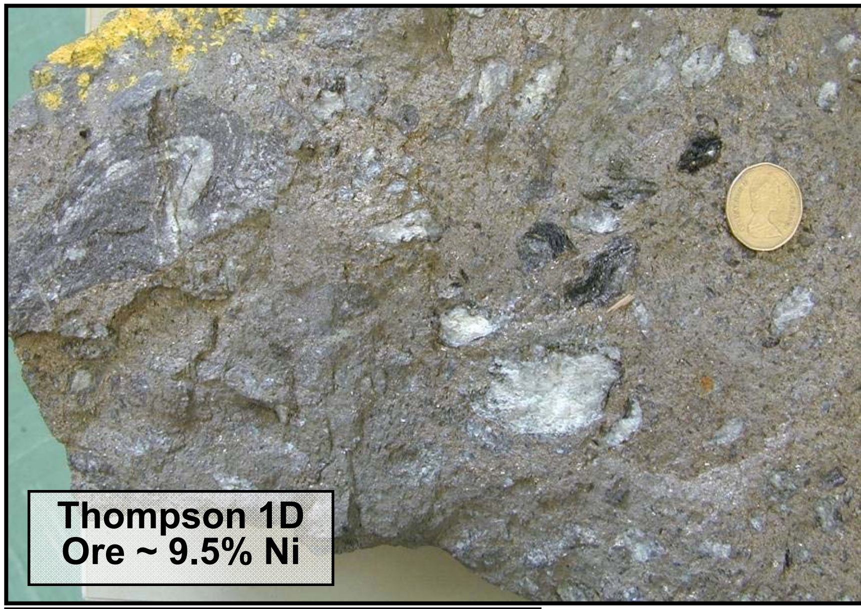
Thompson Mine; 1D Ore Body - massive and semi-massive sulphide (45% of contained Ni)

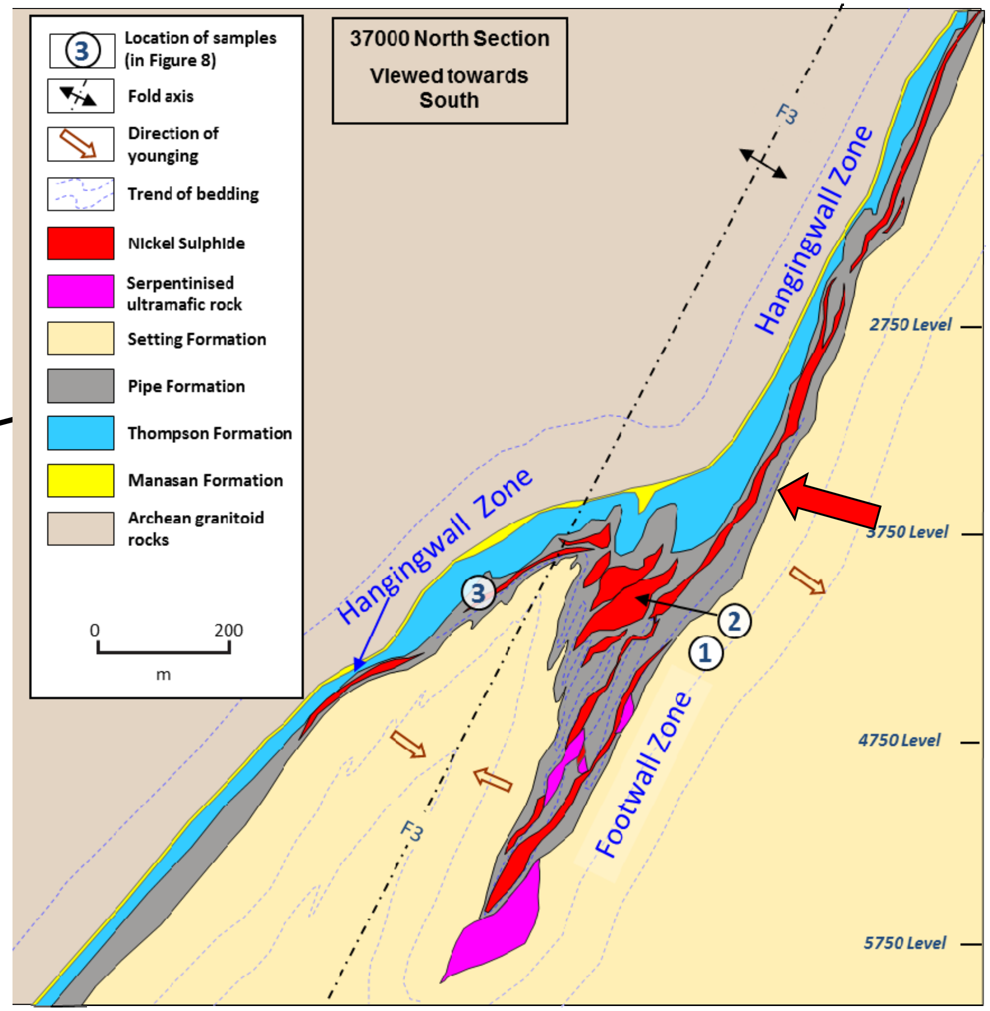




- Pyrrhotite – Pentlandite +/- Chalcopyrite +/- Pyrite assemblage.
- Thickened zones of massive sulphide proximal to fold hinges.
- Grading to less continuous massive bands/pods with increasing intensity of deformation.

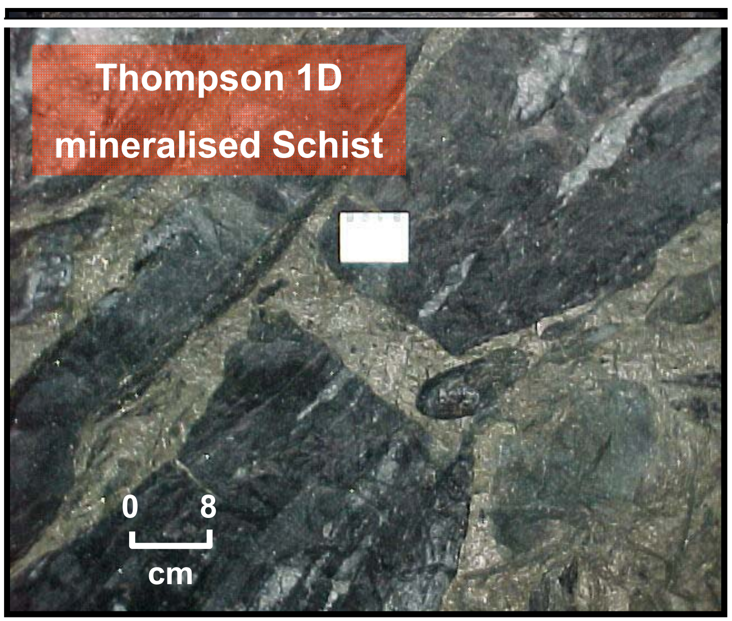
Thompson Mine, 1D ore body: Inclusion-bearing sulphide (30% of contained Ni)

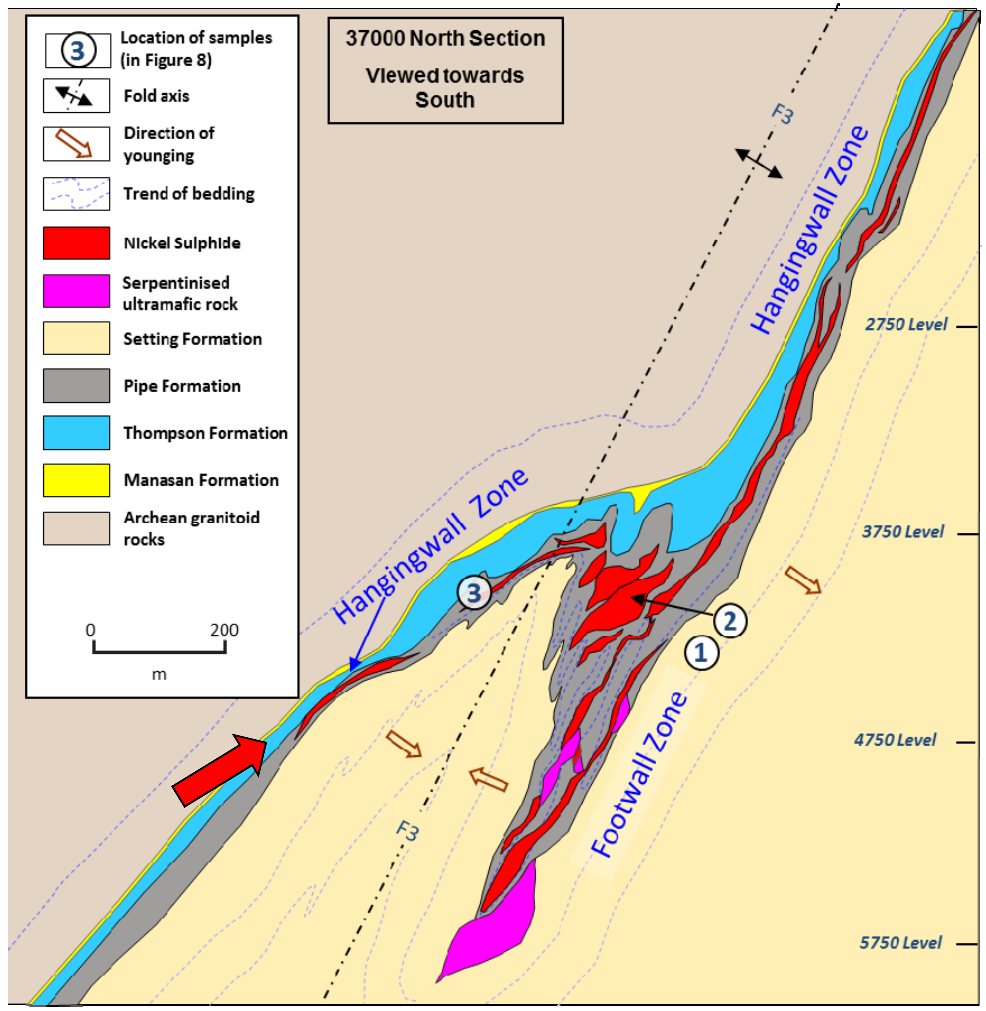




- Angular to well-rounded inclusions of foliated P2 schist, pegmatised schist and ultramafic bodies
- Late syn-deformation remobilisation evidenced from folded, highly deformed pelitic fragments incorporated within sulphide
- Distal from primary ultramafic source

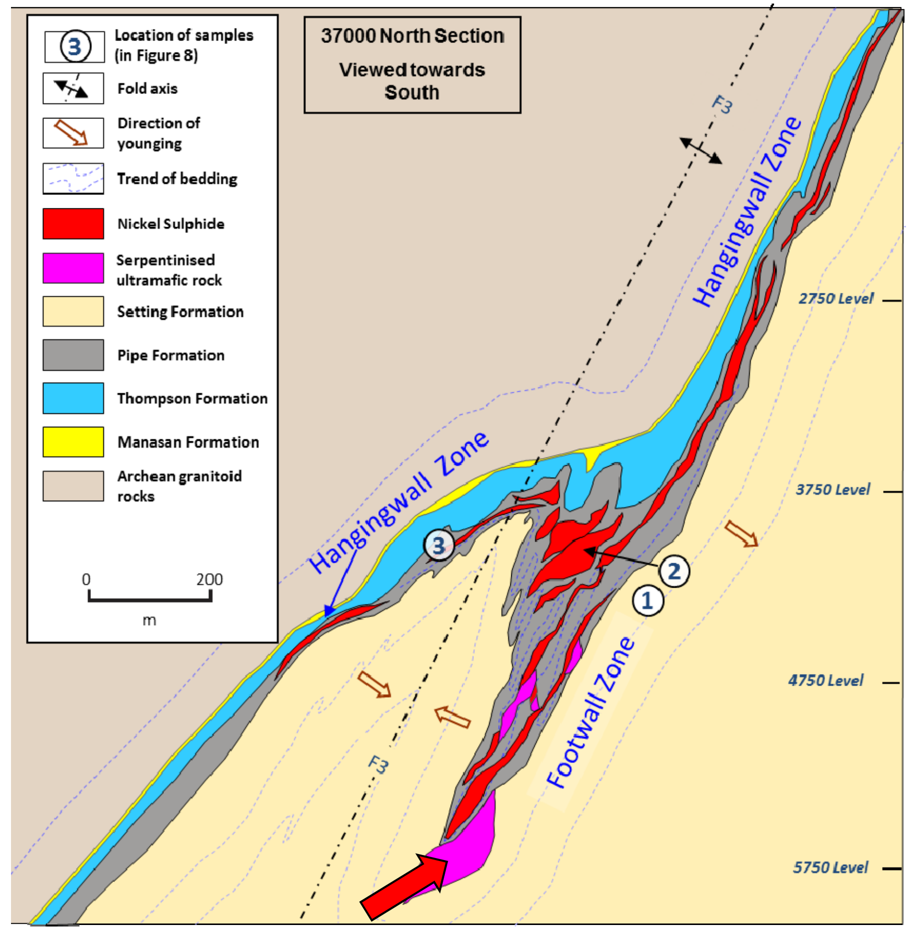
Thompson Mine, 1D ore body: Mineralised schist (15% of contained Ni)





- 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

Outline of talk

Geology of the TNB

Geology of the Thompson Dome

Chemistry of the Thompson sulfides

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Terminology: Ni tenor; i.e. $[Ni]_{100}$

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

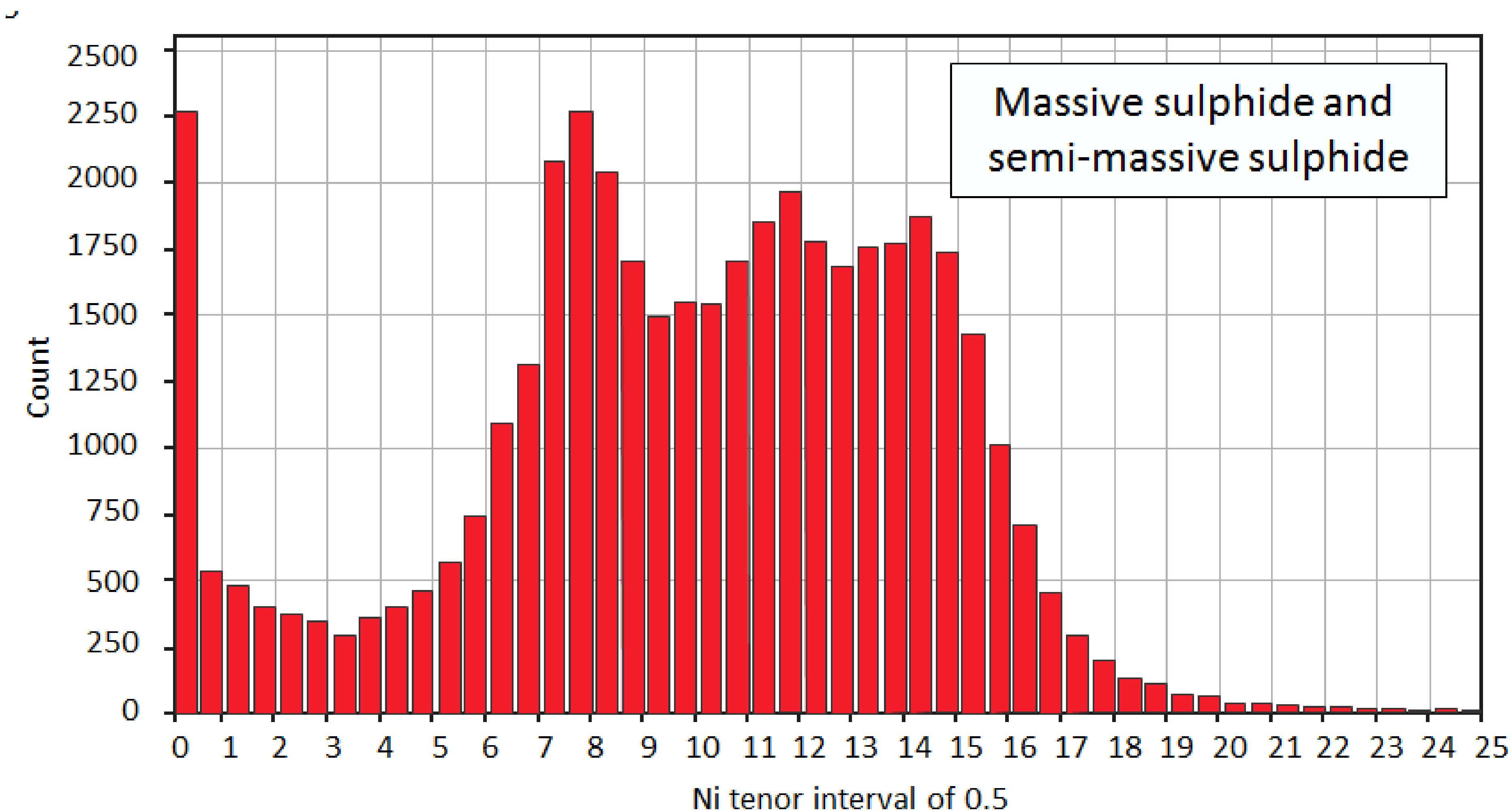
Calculation in simplest form:

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

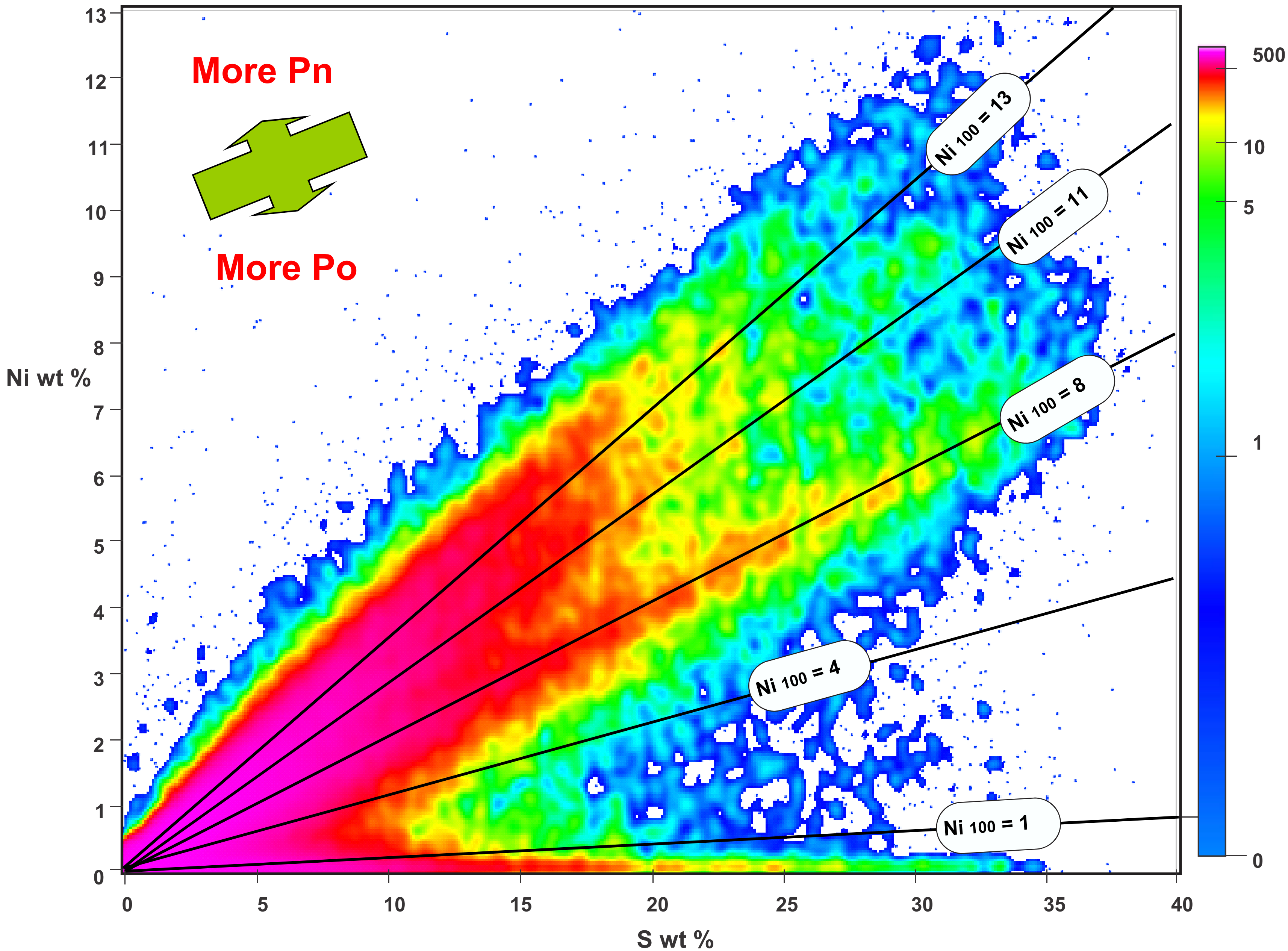
Limitations and caution:

- 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 $[Ni]_{100}$ trends in sulphide ores – principal control is Pn content

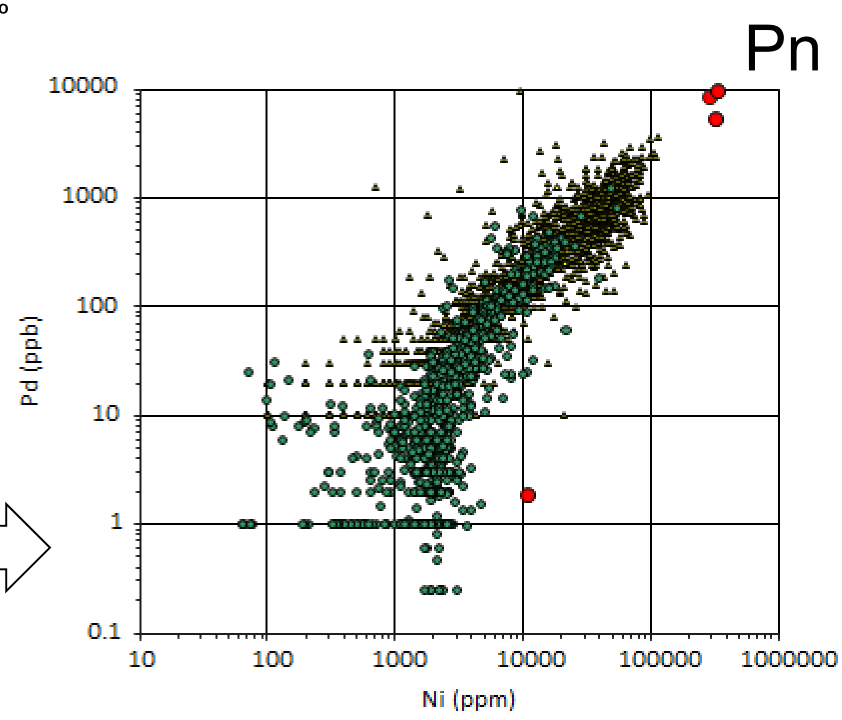


Thompson Mine: 1D Deposit. Compositional diversity in Pentlandite (LA-ICPMS)

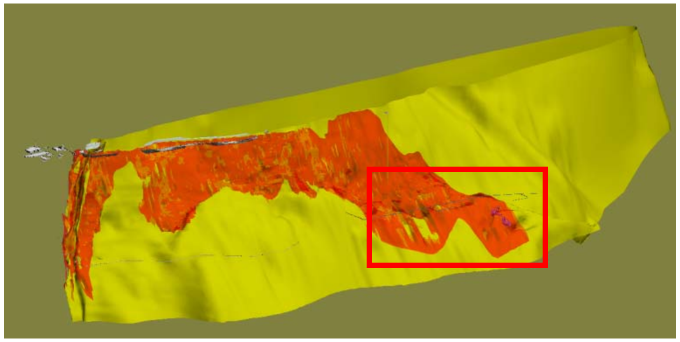
Table 2:

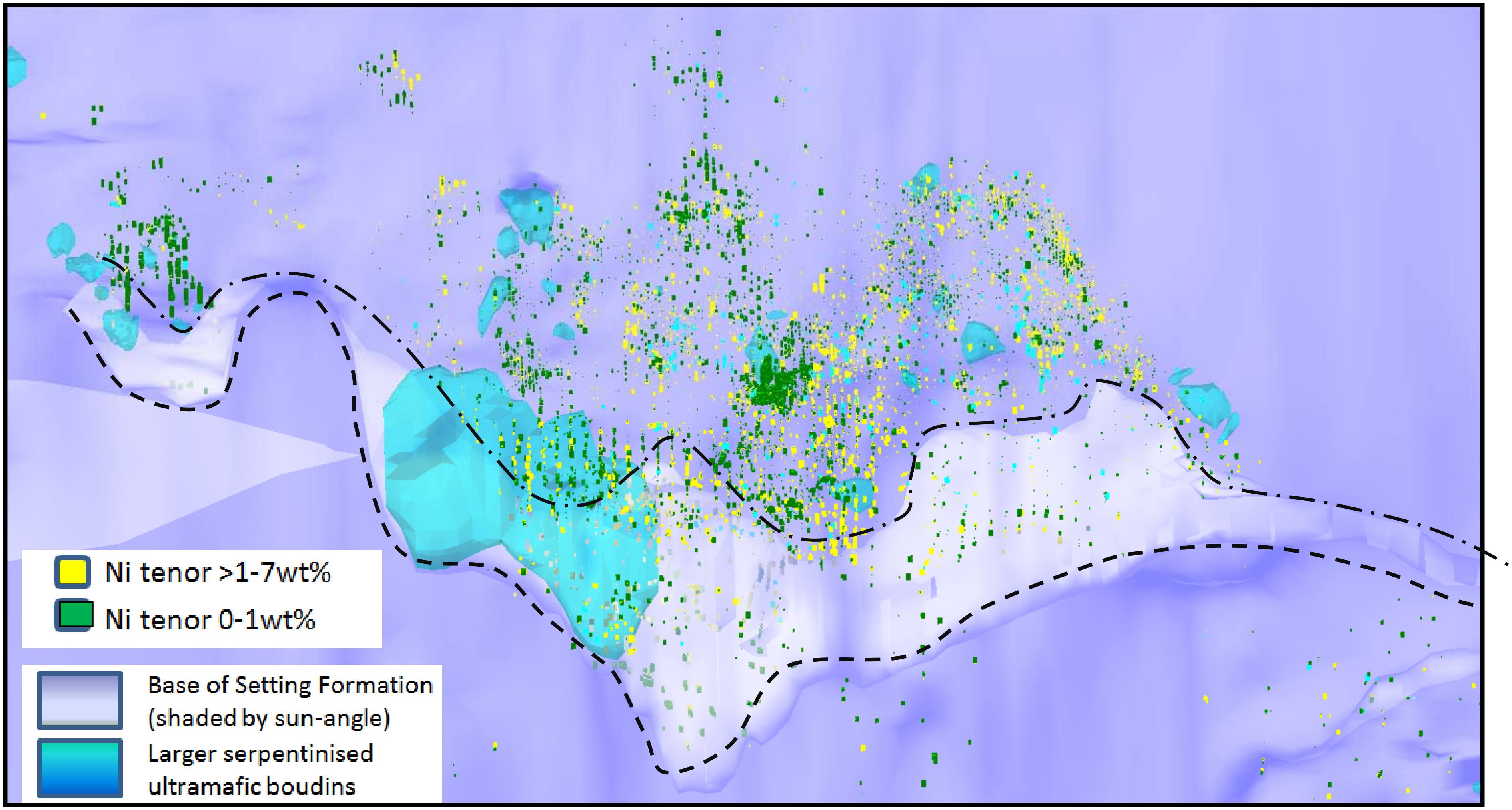
Sample	Pentlandite Texture	n	Ni wt%	Co ppm	Pd ppm	Pd s	Pd %RSD
1226610	Coarse-granular (Core)	4	30.58	5413	12.55	2.3	19%
	Coarse-granular (Rim)	3	29.1	4788	7.91	1.6	21%
	Medium granular	1	29.2	4144	5.55		-
	Fine grain veinlet	2	30.95	3407	0.91	0.2	24%
	Average		29.63	4782	8.67		-
1226600	Coarse-granular (Core)	6	33.95	7402	12.41	0.5	4%
	Coarse-granular (Rim)	5	33.24	6989	7.23	1	13%
	Medium granular	2	32.95	6411	3.91	0	1%
	Fine grain veinlet	3	31.4	5188	2.18	0.5	24
	Average		33.6	7196	9.82		-
1226630	Medium granular	6	32.4	6354	5.44	2.1	38
Averages							
	Coarse-granular (Core)	10	32.6	6606	12.47	1.4	11
	Coarse-granular (Rim)	8	31.69	6164	7.48	1.19	16
	Medium granular	9	32.17	6121	5.11	1.79	35
	Fine grain veinlet	5	31.22	4476	1.67	0.8	48

Assay database: 1D

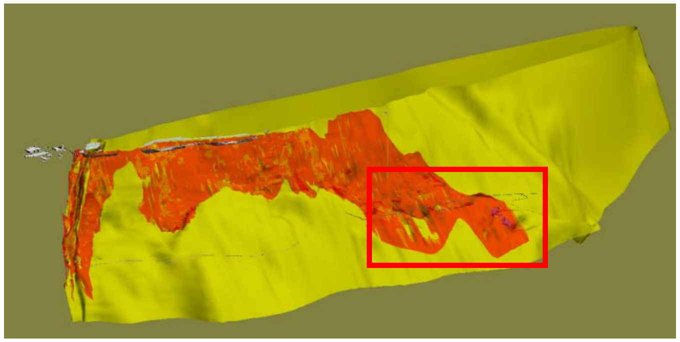


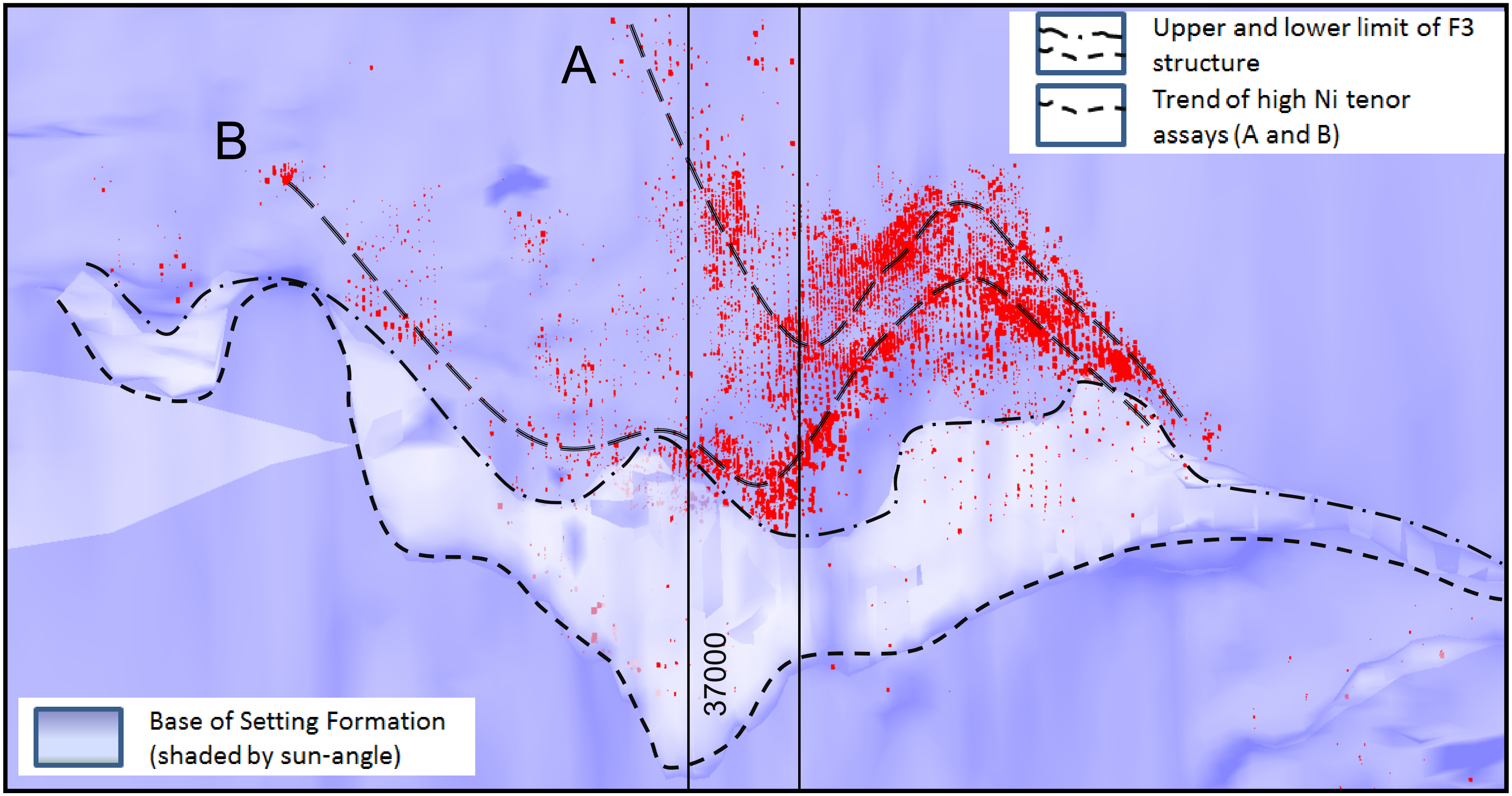
Thompson Mine,1D ore body: Ni tenor sized to S (5ft composites) 0-1, >1-7wt%$[Ni]_{100}$

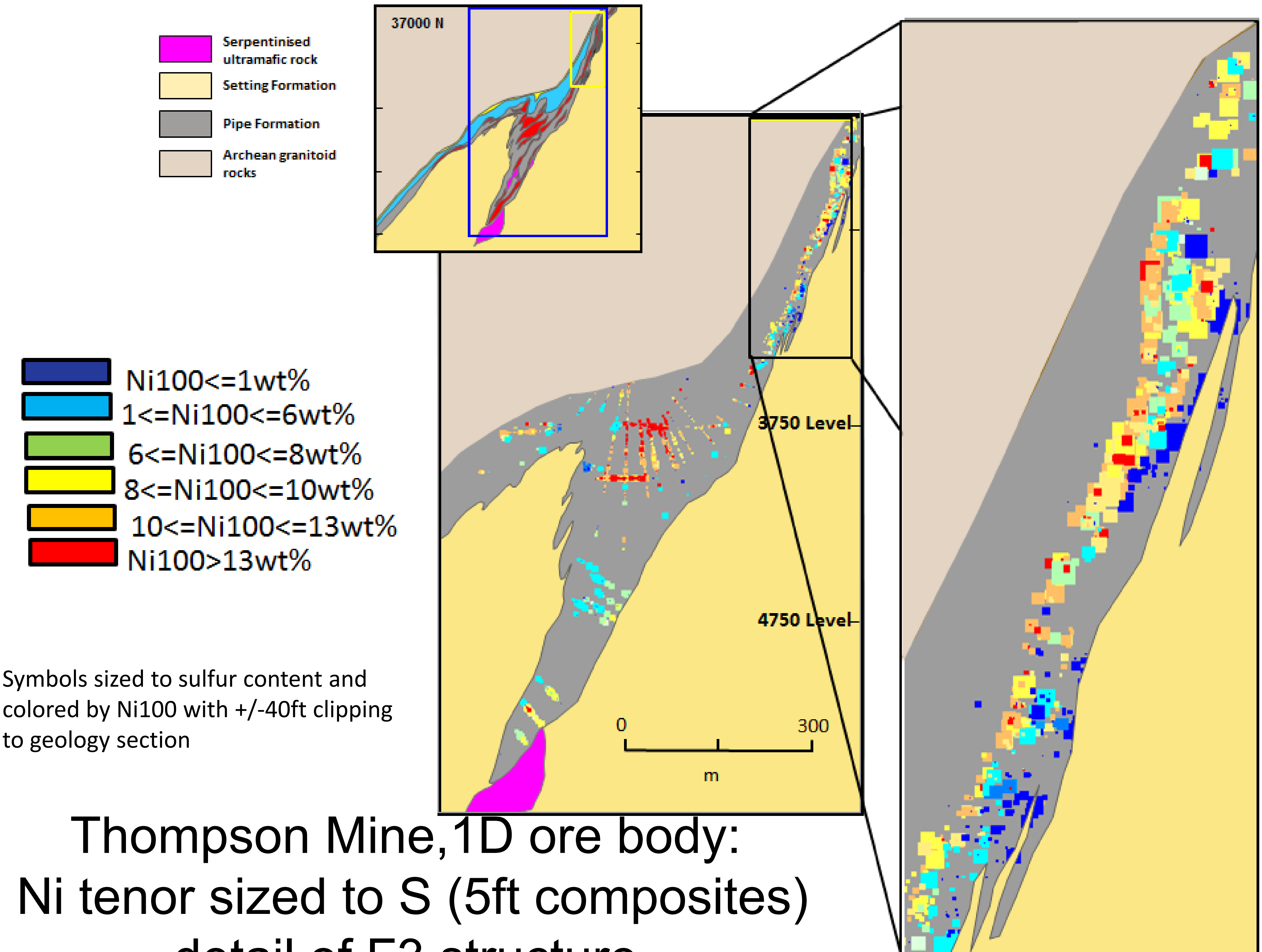




Thompson Mine, 1D ore body: Ni tenor sized to S (5ft composites) >13wt%$[Ni]_{100}$



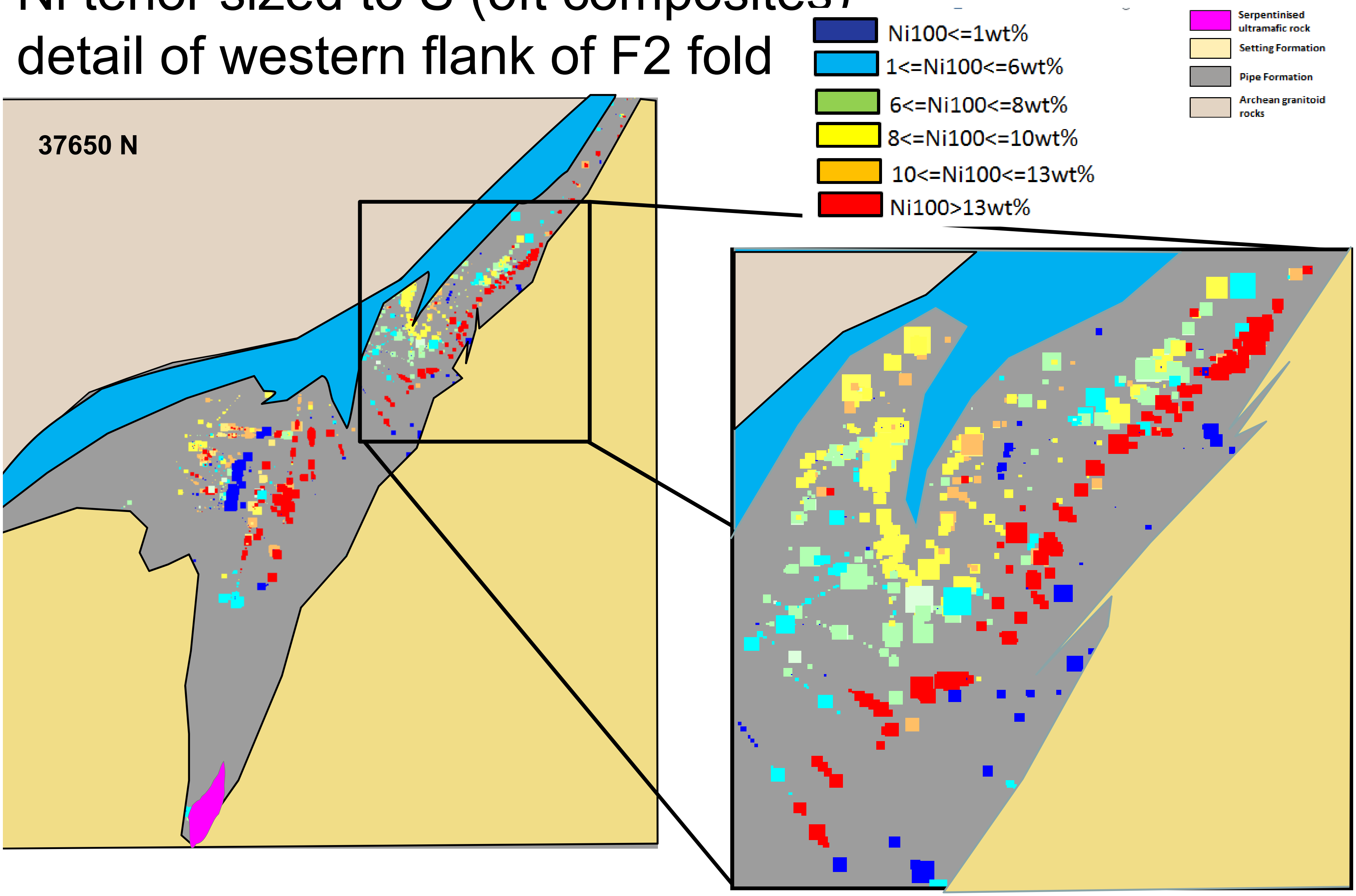




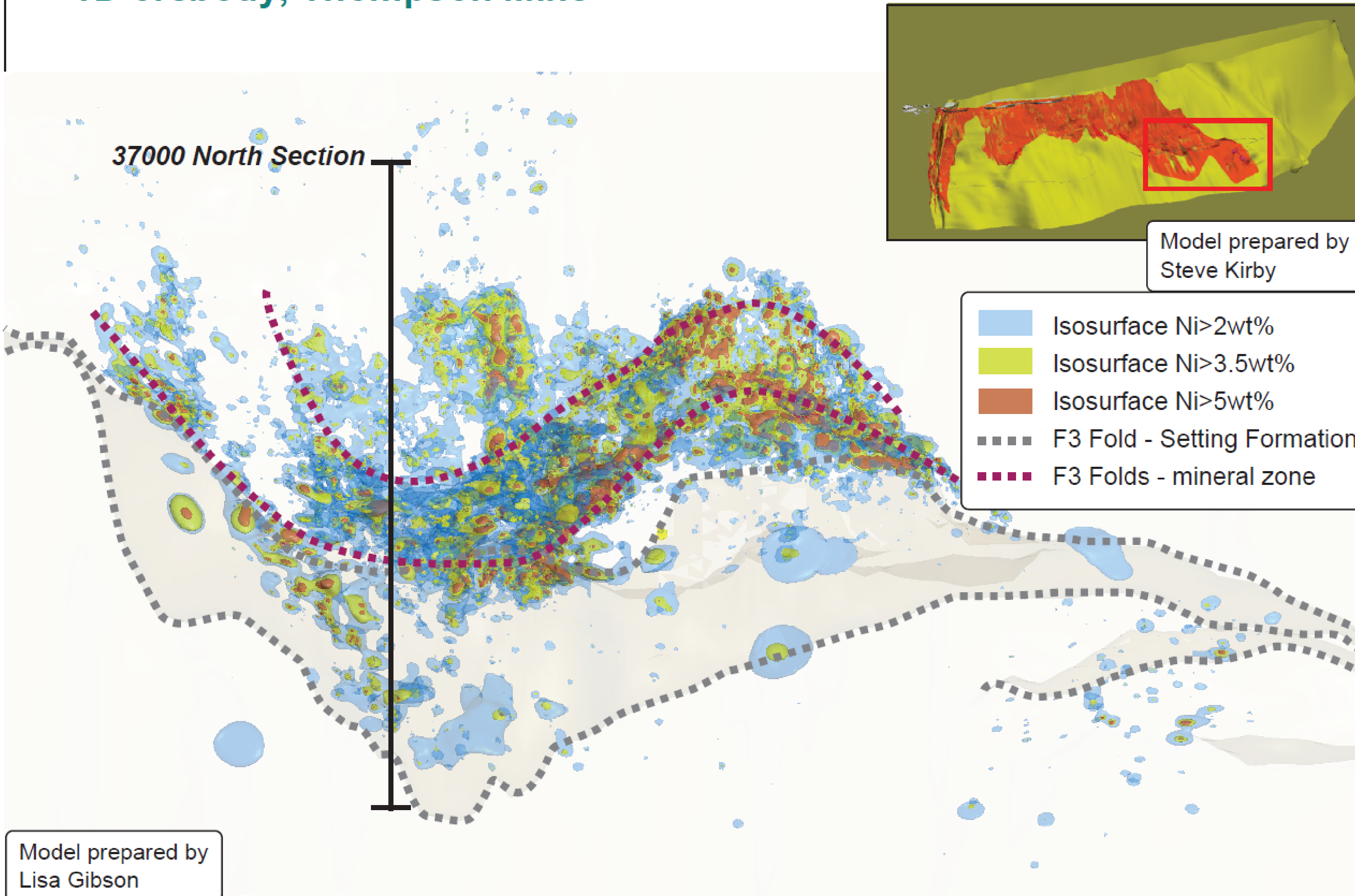
Thompson Mine, 1D ore body: Ni tenor sized to S (5ft composites) detail of F3 structure

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

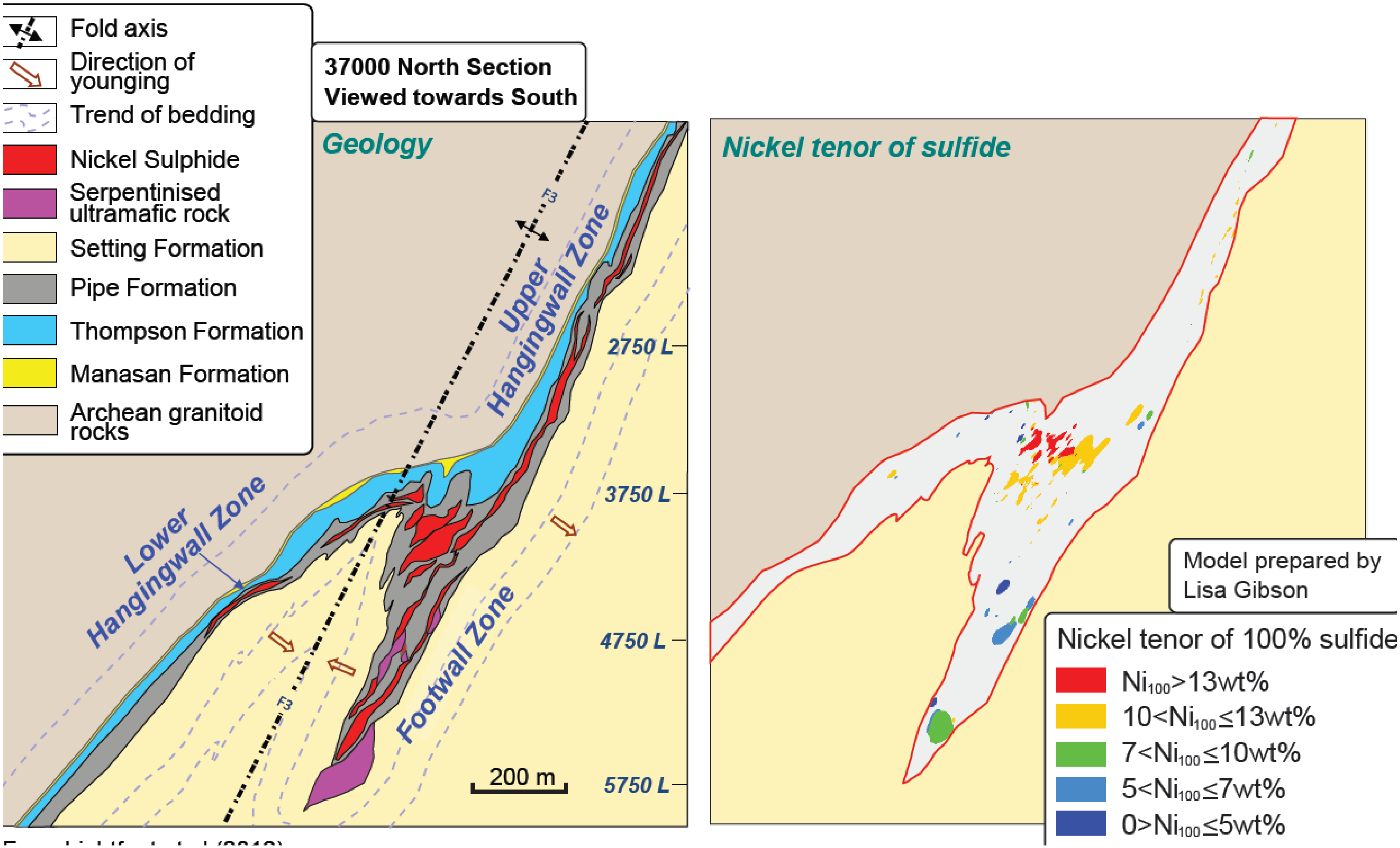


Leapfrog model showing Ni grade distribution in the 1D orebody, Thompson Mine

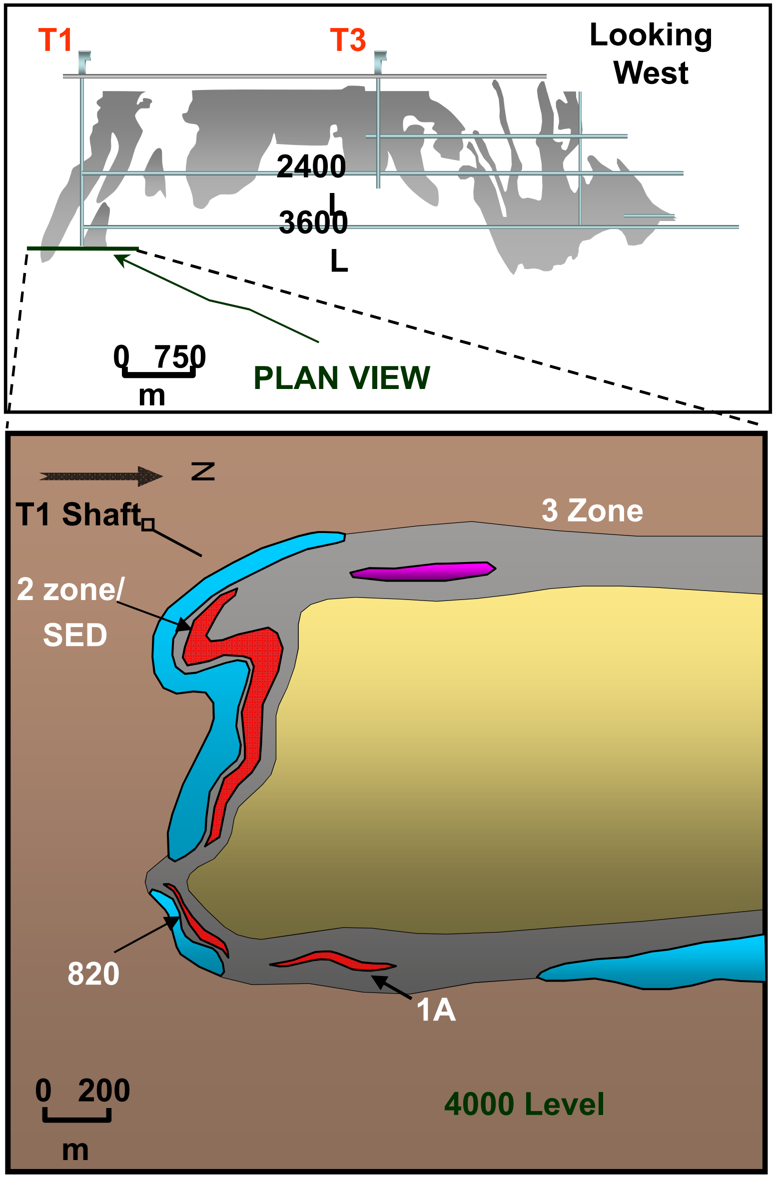


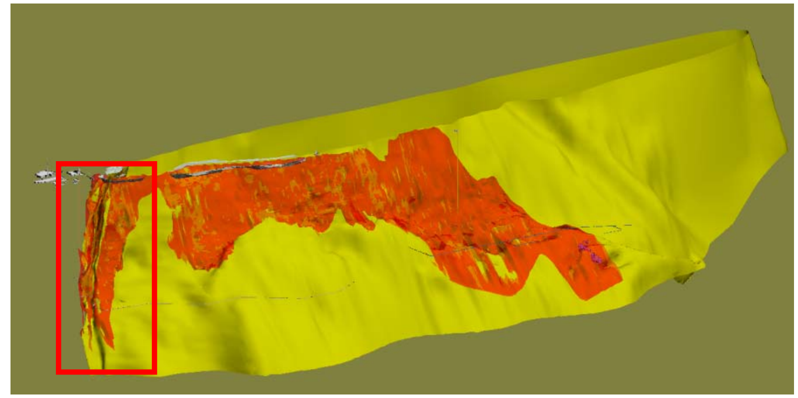
Leapfrog tenor shell model for Nickel in the 1D orebody, Thompson Mine

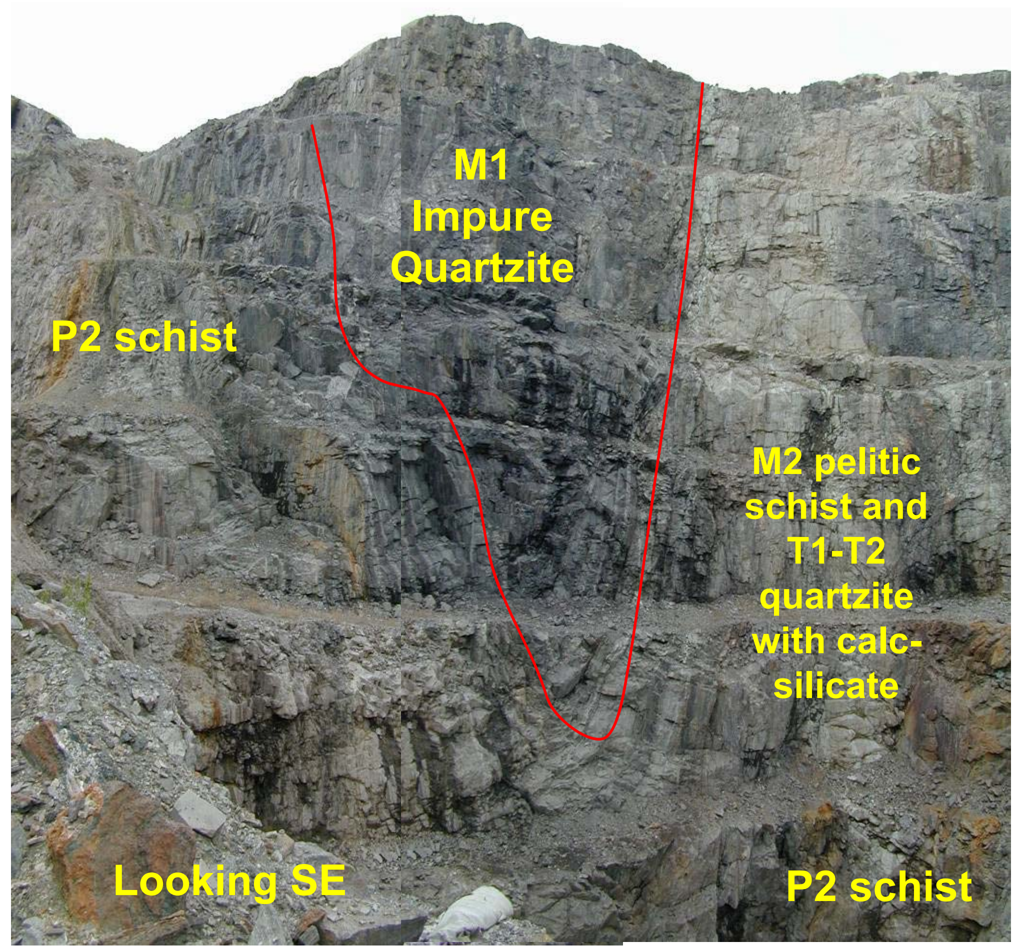
Cross Section



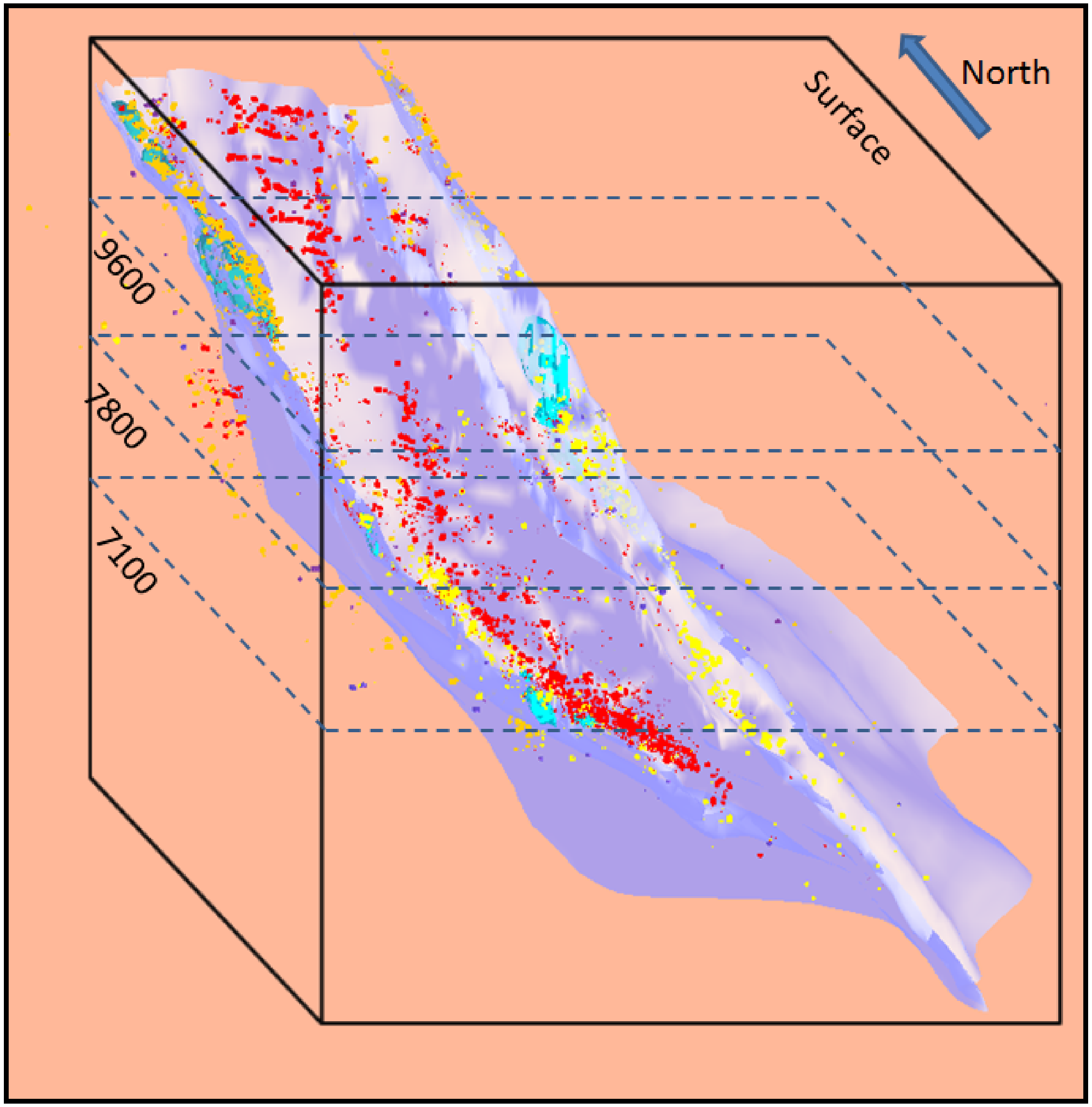
Southern Closure (nose), Thompson Mine

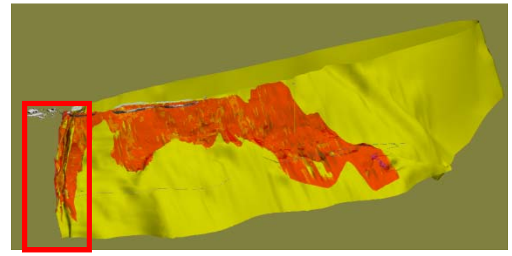






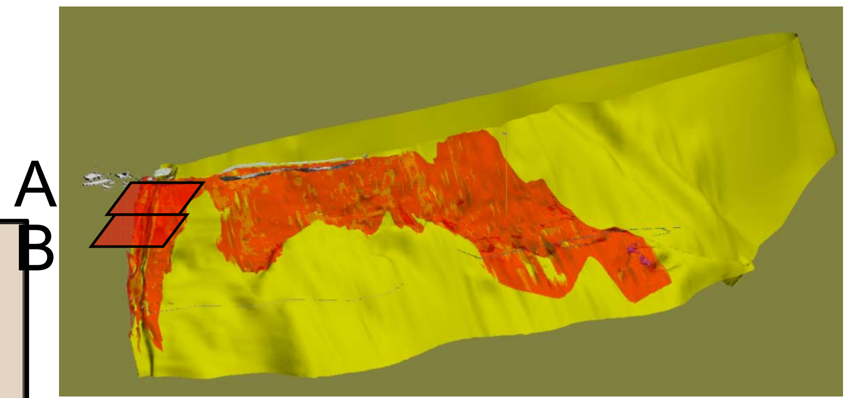
Nose structure ore bodies, Thompson Mine (estimated Ni100 based on historic estimated visual sulphide content)

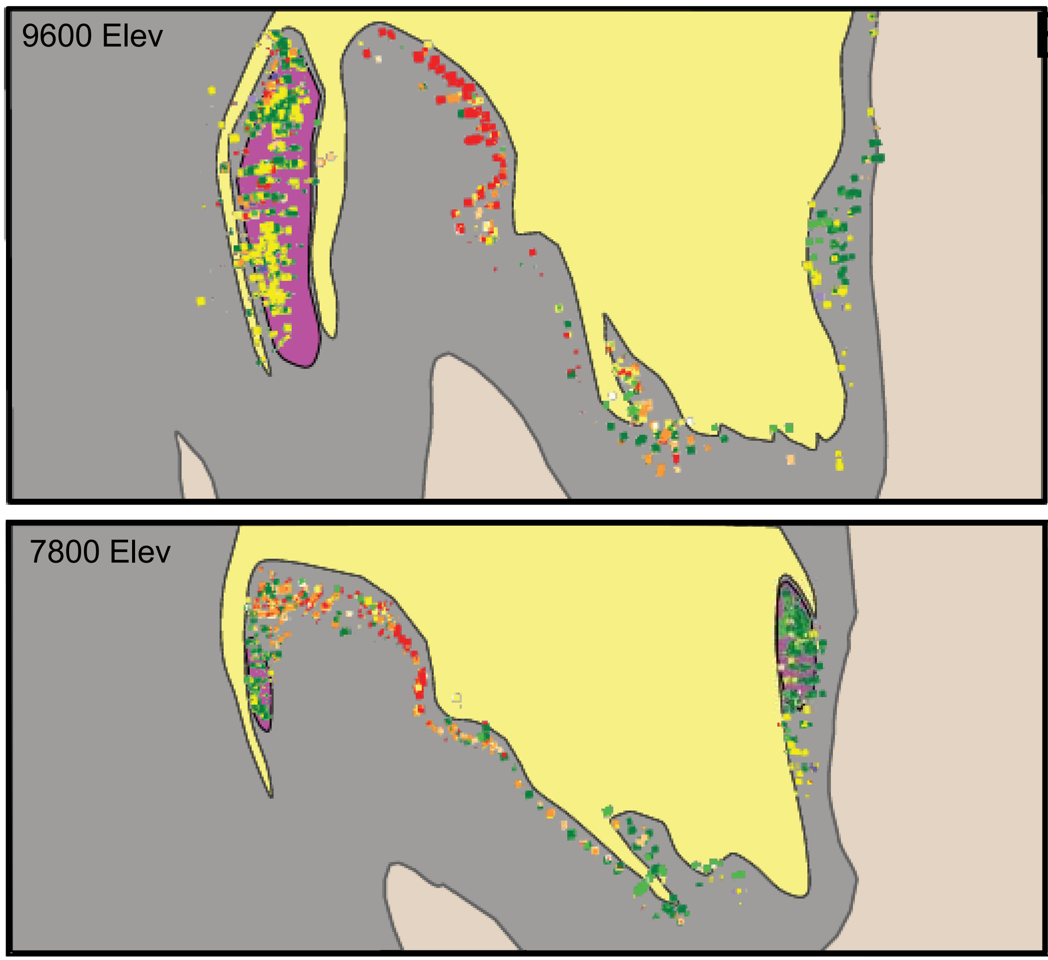




Thompson Mine Nose: estimated Ni tenor sized to sulphide content (not composited)

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





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

- Ni_{100}<=1 wt%
- 1<=Ni_{100}<=6 wt%
- 6<=Ni_{100}<=8 wt%
- 8<=Ni_{100}<=10 wt%
- 10<=Ni_{100}<=13 wt%
- Ni_{100}>13 wt%

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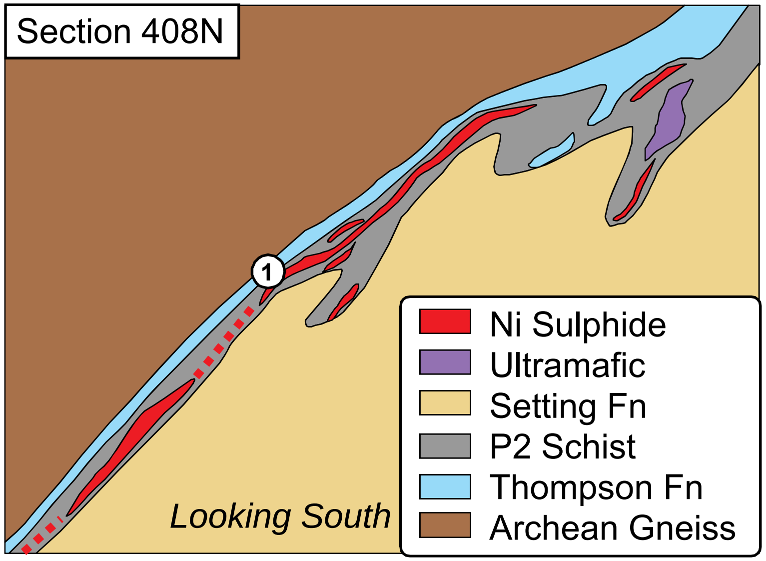
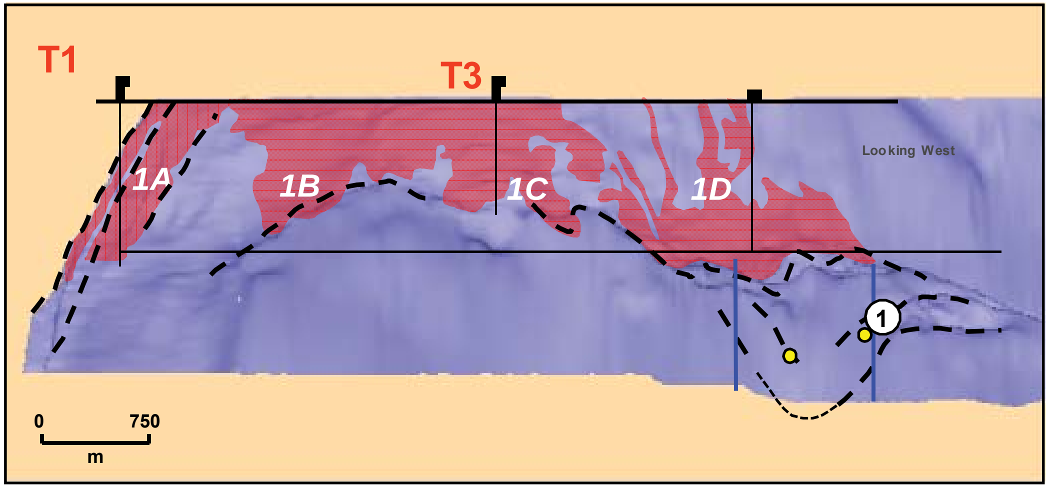
Chemistry of the Thompson sulfides

Exploration implications (Steve Kirby)

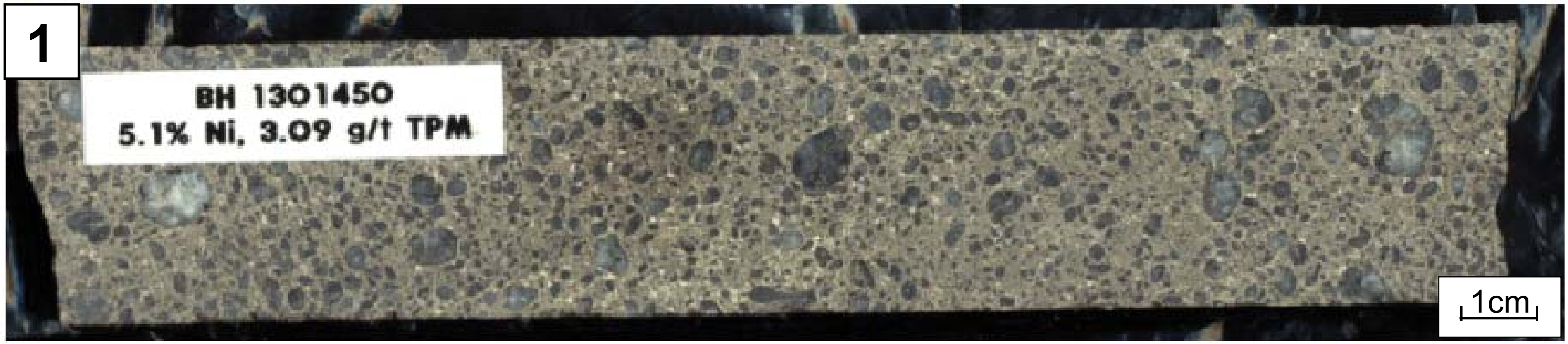
Process of deformation and modification of sulfides

Structural controls: Thompson Extensions Zone

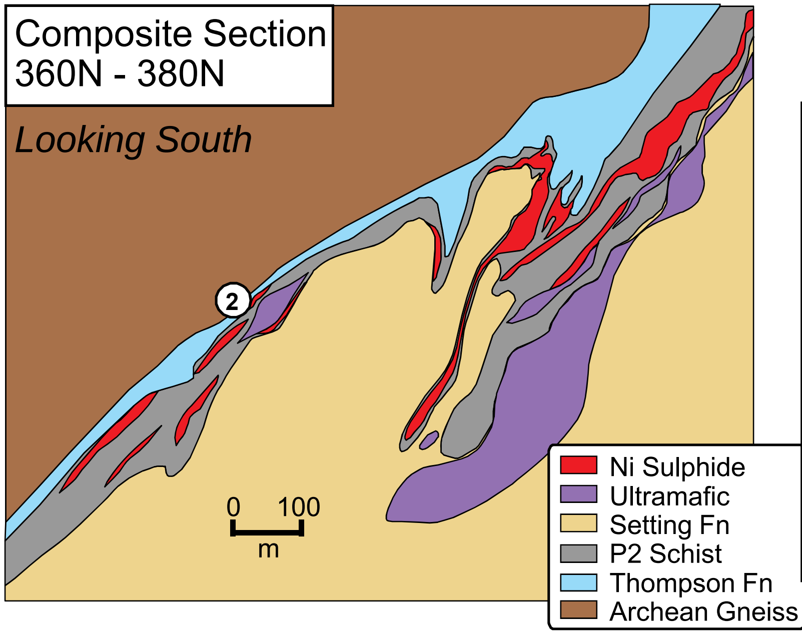


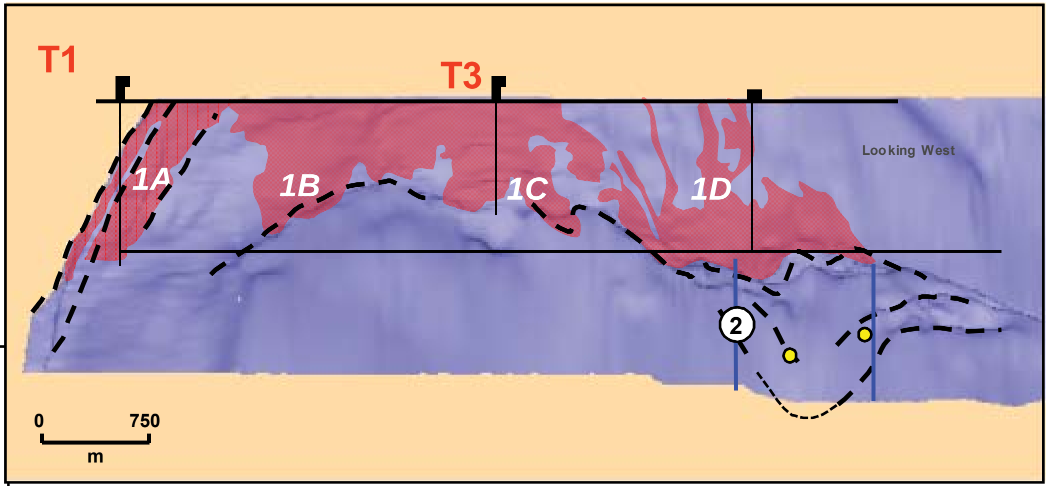


BH 1301450 4.75% Ni, 1.28 g/t TPM / 31.0m true thickness

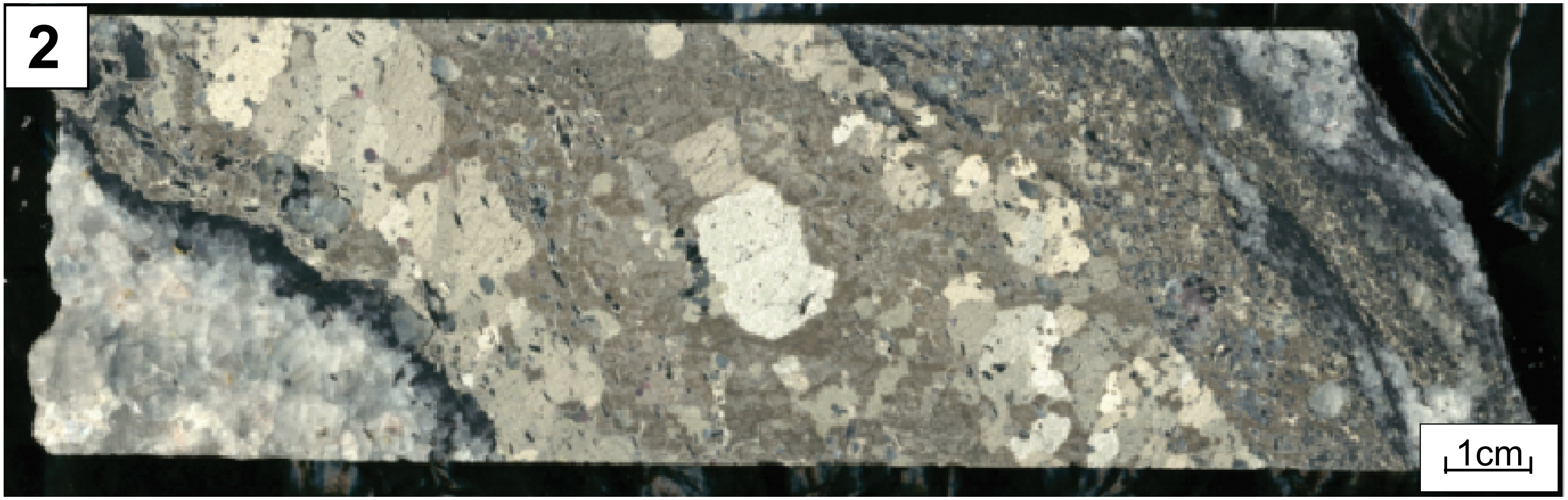


Structural controls: Thompson Extensions Zone





BH 1140690 2.04% Ni, 0.505 g/t TPM / 17.1m true width



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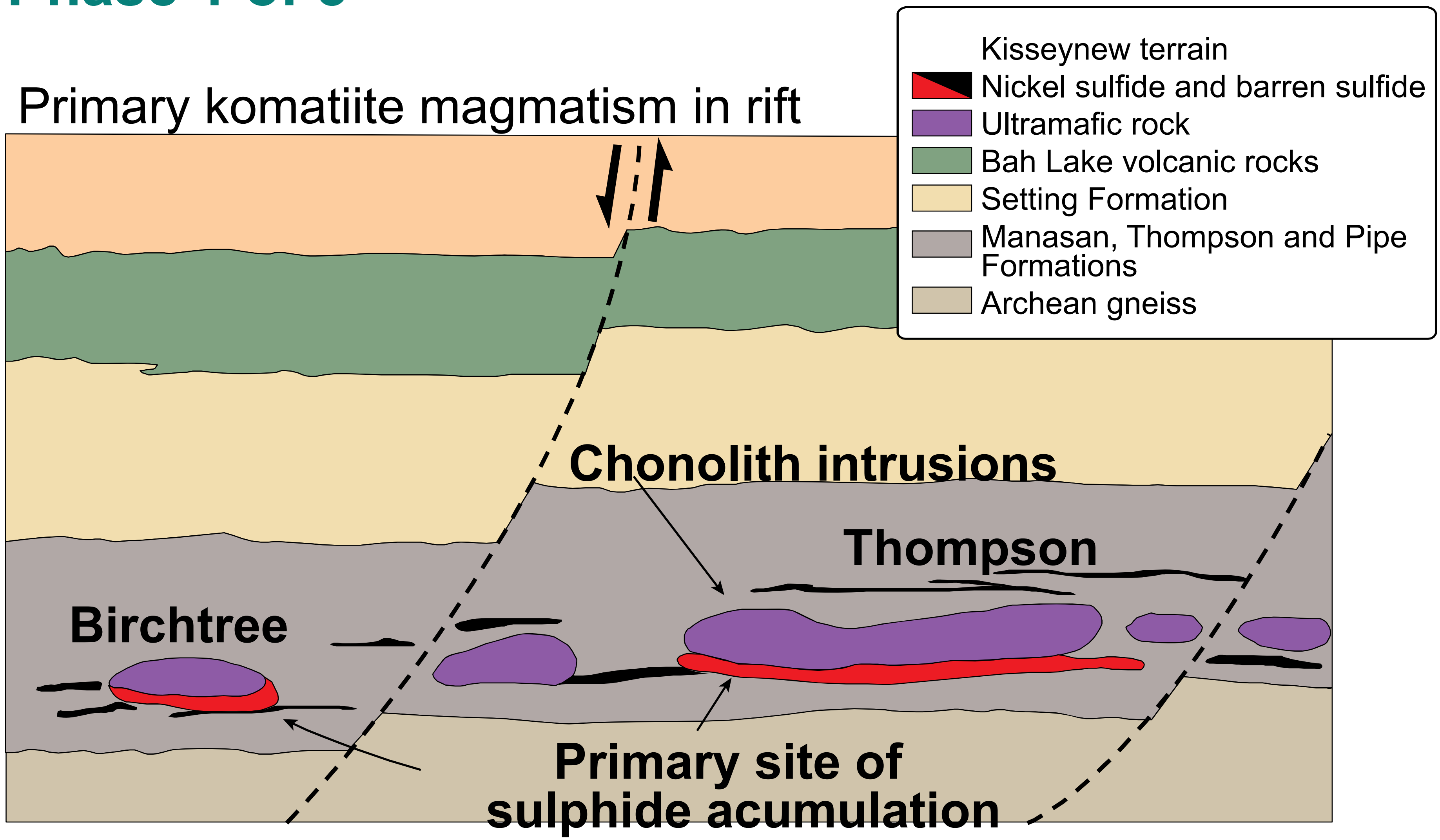
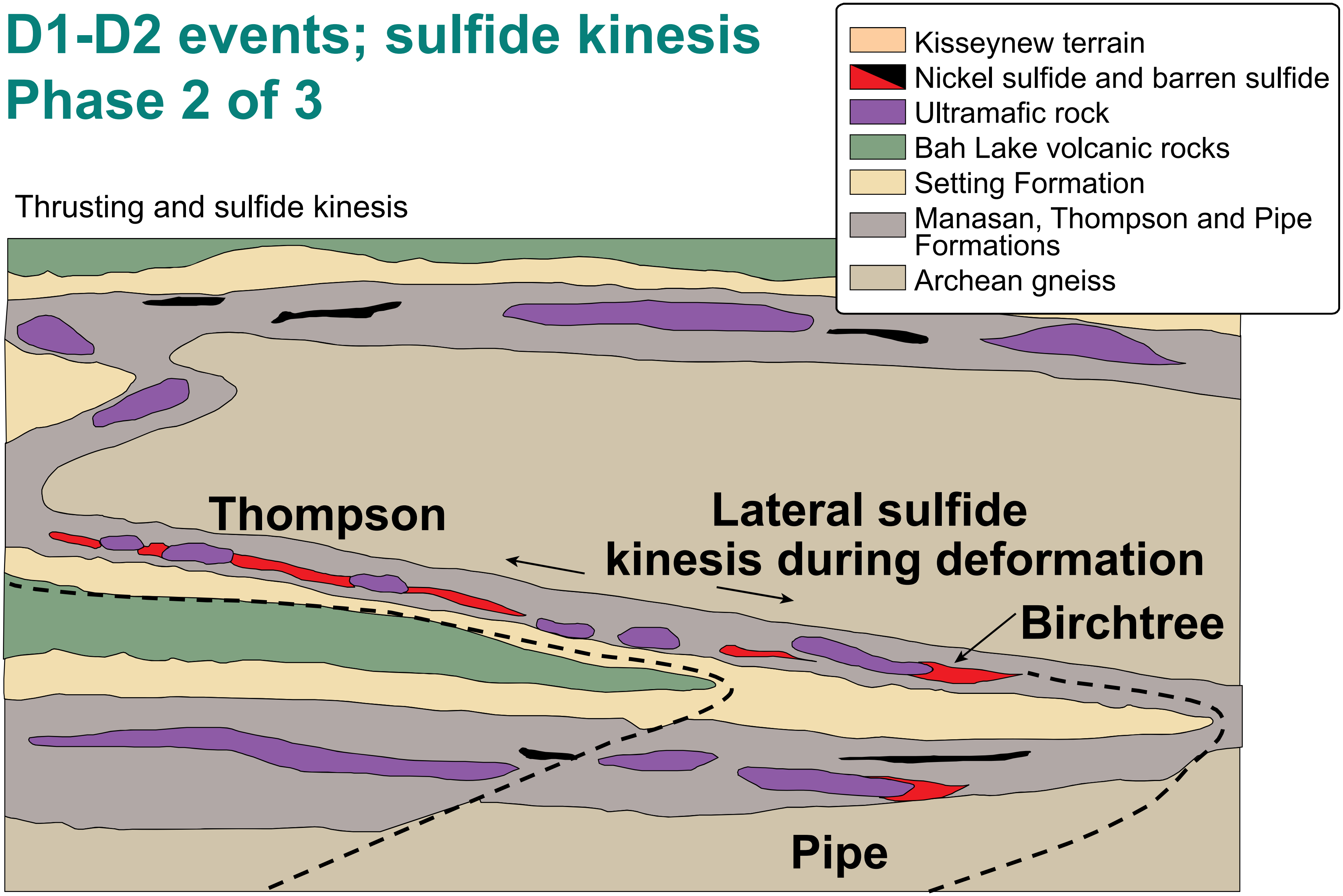
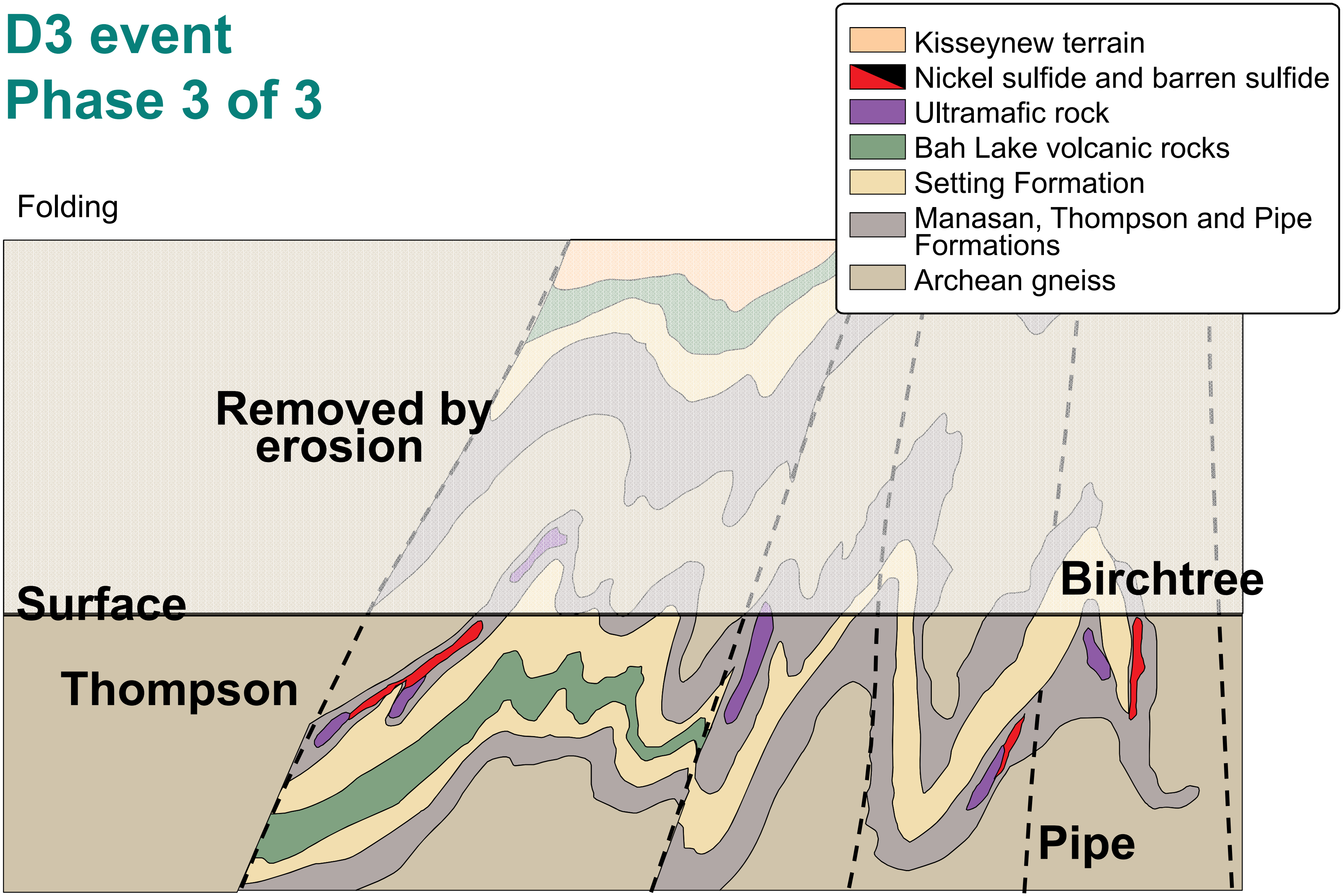
Thompson Nickel Belt Evolution
Primary structural controls
Phase 1 of 3



Thompson Nickel Belt Evolution
D1-D2 events; sulfide kinesis
Phase 2 of 3



Thompson Nickel Belt Evolution
D3 event
Phase 3 of 3



Cartoon showing the various aspects of mechanical erosion and sulfide remobilisation

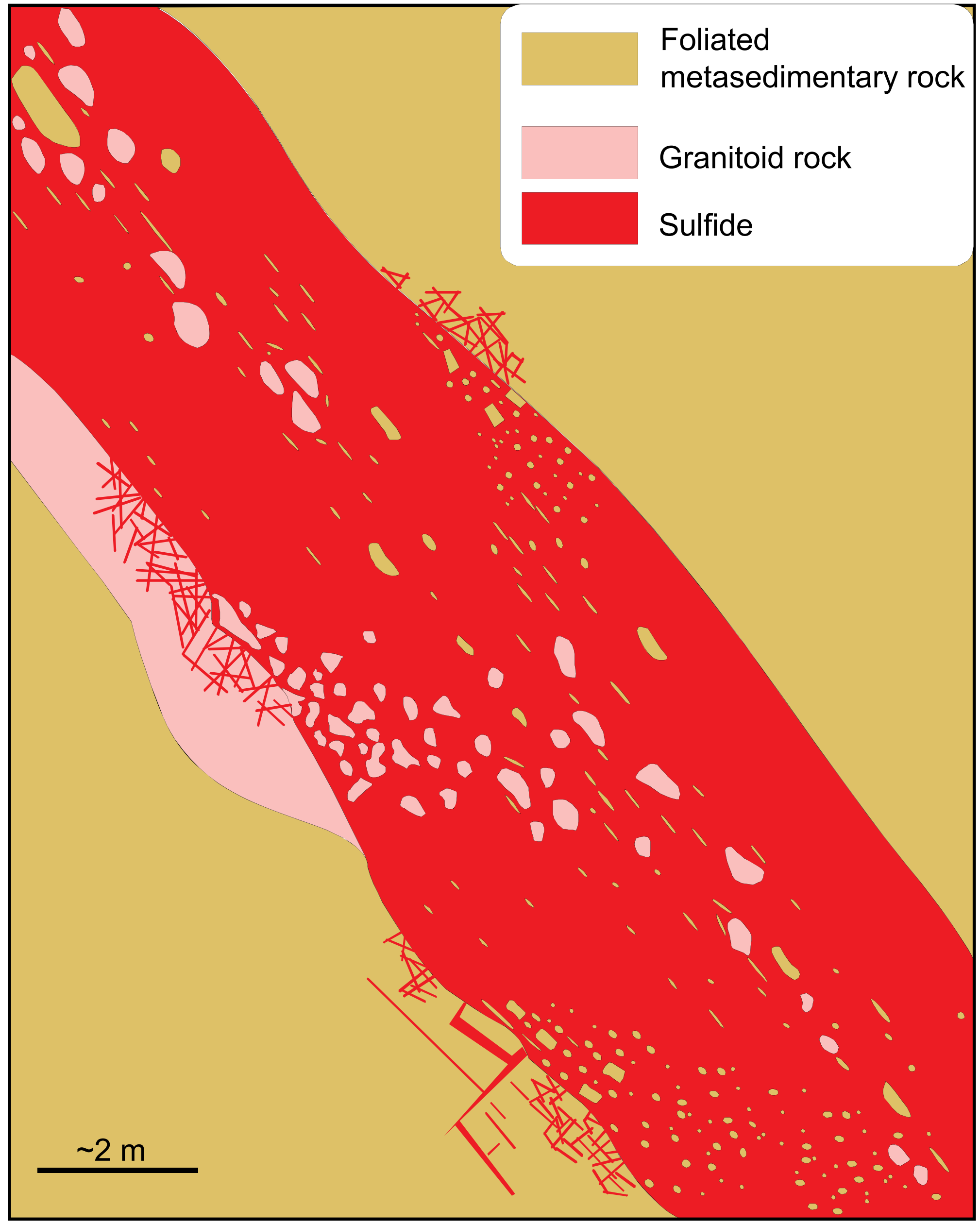
Sulfide kinesis

The infiltration of soft sulphides into the various rock types is represented, and the arrest and initial incorporation of rock inclusions.

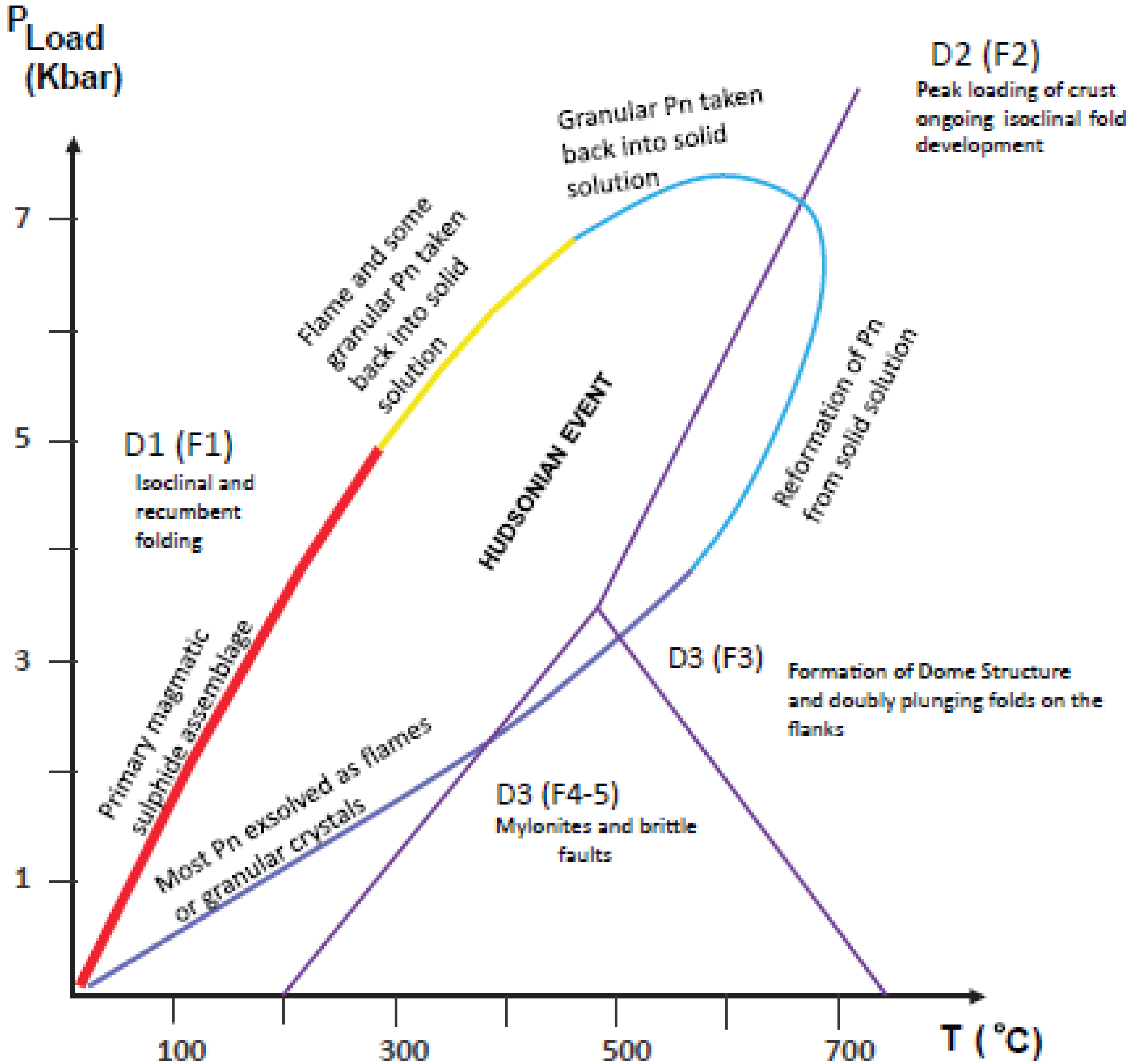
Note that the initial inclusion shape is controlled by the infiltration pattern.

Inclusions in the high flux show extensive wearing.

(Monteiro, 2006)



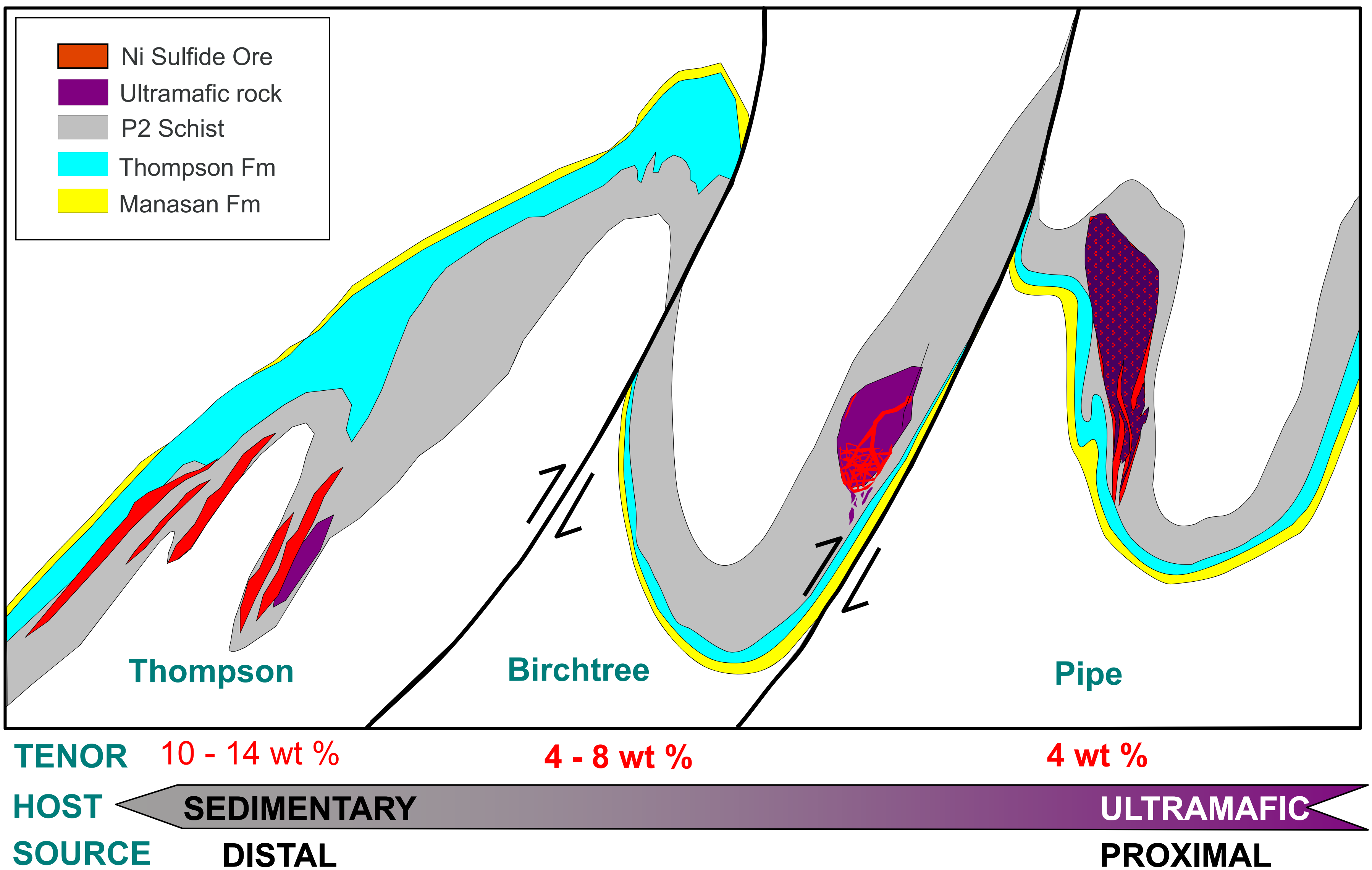
Sulfide kinesis: P-T controls



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^{o}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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