Case study comparison of airborne EM data over two magmatic nickel deposits

Hannah Peterson

Condor Consulting

May 10th, 2023

The Leading Edge®

A comparison of airborne geophysical data over two magmatic nickel deposits

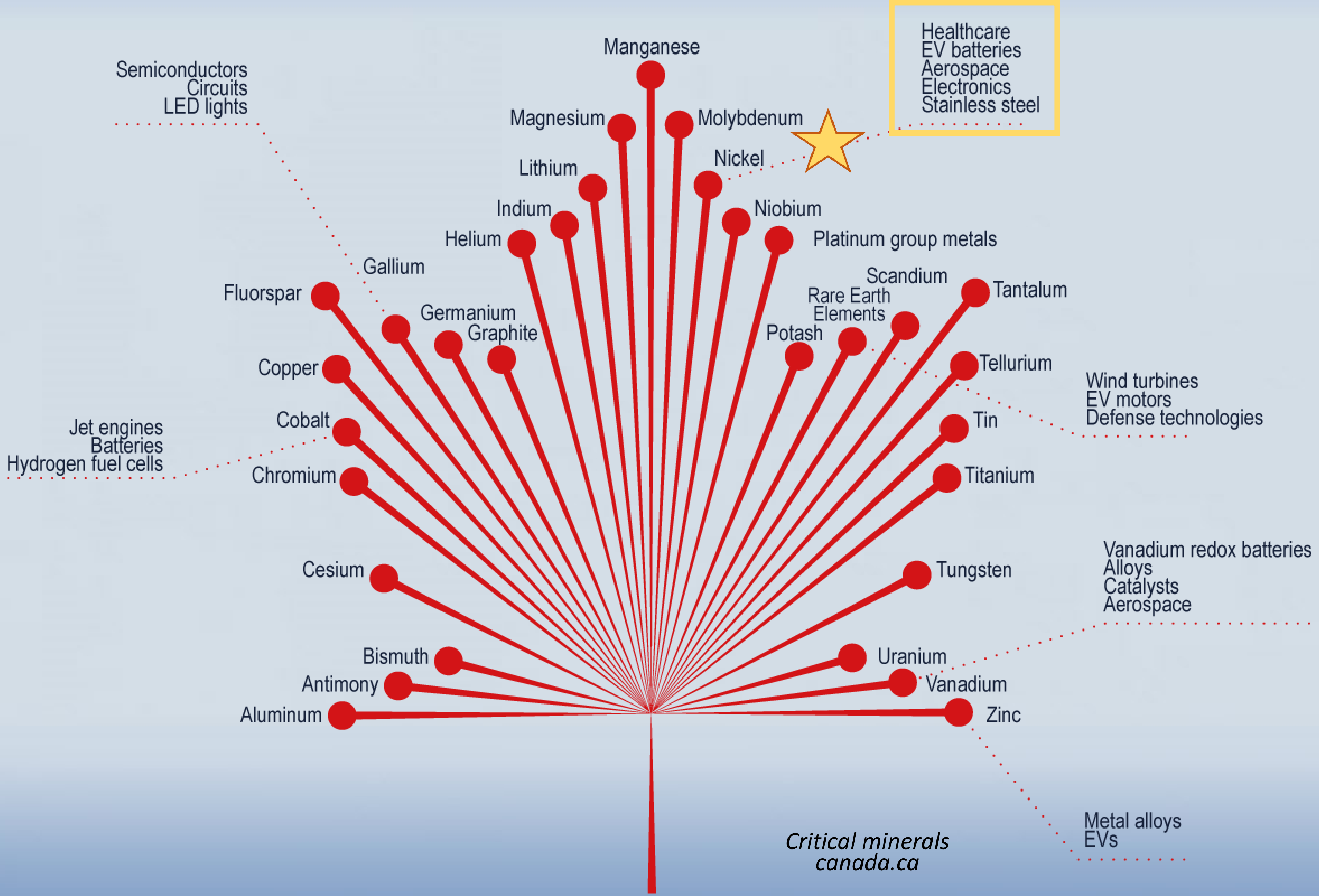
Blake Cross[1] and Hannah Peterson[1]

https://doi.org/10.1190/tle42040237.1

Abstract

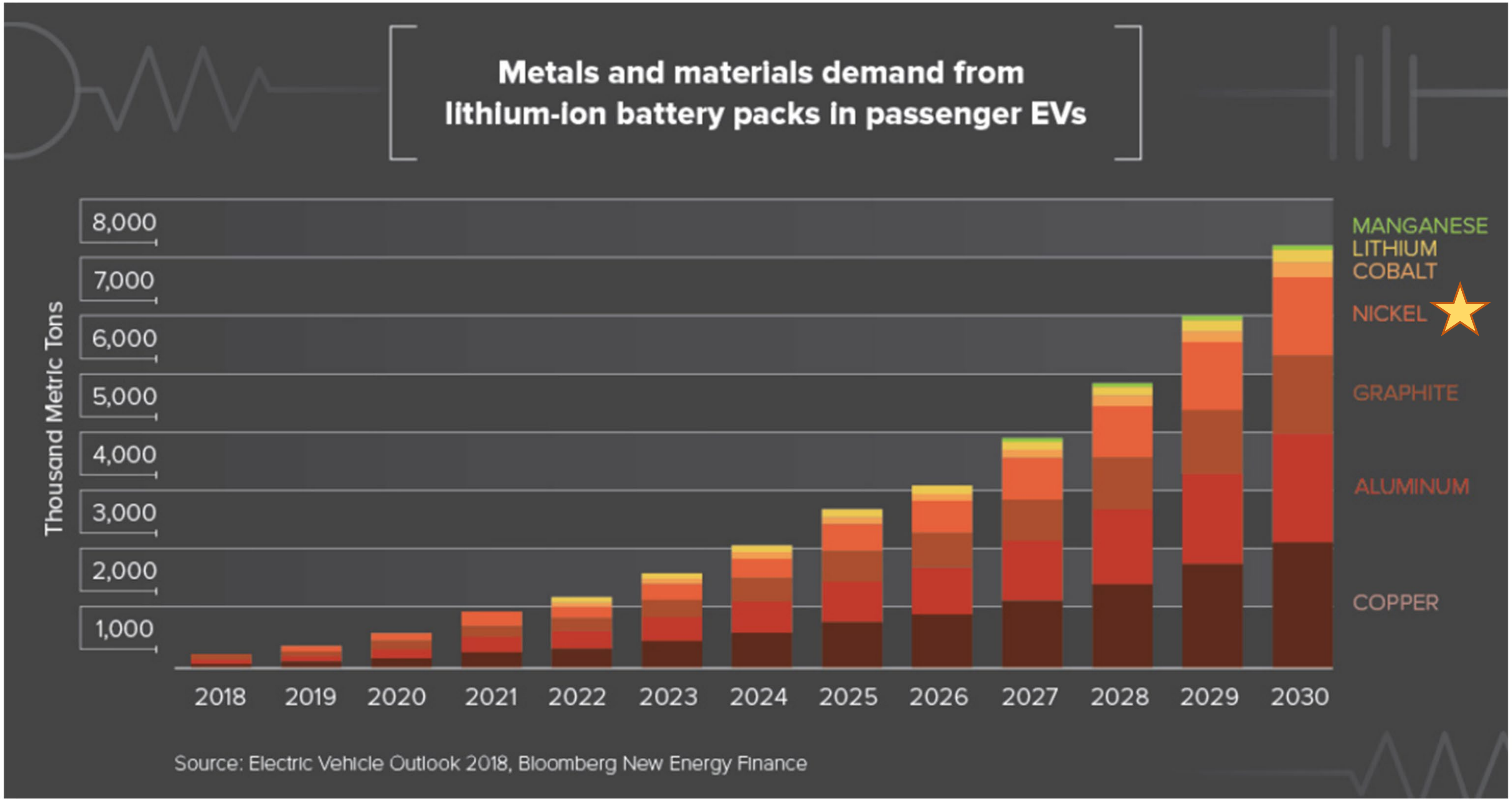
Historical exploration for economic nickel (Ni) mineralization has often targeted magmatic sulfide deposits in extensional settings. However, convergent-margin-hosted Alaskan-type complexes represent a potentially underexplored source of Ni. Case studies of the geophysical responses associated with two magmatic Ni deposits (one is typical, and one is associated with an Alaskan-type complex) are presented, and the results are compared. Data were assessed from historical and newly acquired airborne geophysical surveys that were collected over the Mayville property in southeast Manitoba and the Turnagain property in northern British Columbia. The properties were explored by Mustang Minerals Corporation and Giga Metals Corporation, respectively. Airborne electromagnetic (EM) and magnetic data were utilized to compare the two properties and the mineralized zones. The review showed that the Mayville magmatic sulfide deposit was directly detectible with EM methods, and the passive and active-source methods were complementary to one another. The EM data did not directly detect the Turnagain Alaskan-type deposit, but the magnetics data proved to be successful in defining the geologic framework. Implications for future targeting and exploration for economic Ni mineralization are considered.

Leading Edge Vol. 42, No. 4.



Critical minerals
canada.ca

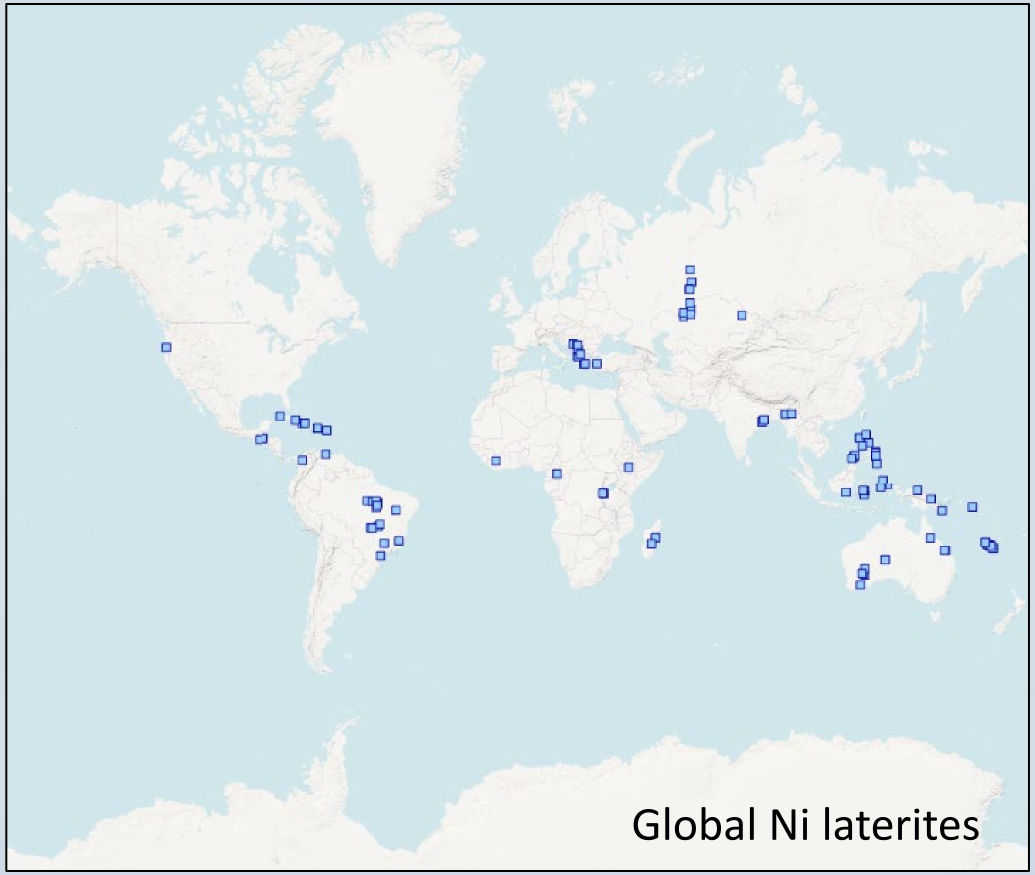
Nickel is considered a critical mineral in the US and Canada and has increased demand due to use in electronics, the aerospace industry and electric car batteries



Metals and materials demand from lithium-ion battery packs in passenger EVs
Thousand Metric Tons
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
MANGANESE
LITHIUM
COBALT
NICKEL
GRAPHITE
ALUMINUM
COPPER
Source: Electric Vehicle Outlook 2018, Bloomberg New Energy Finance

Nickel Exploration

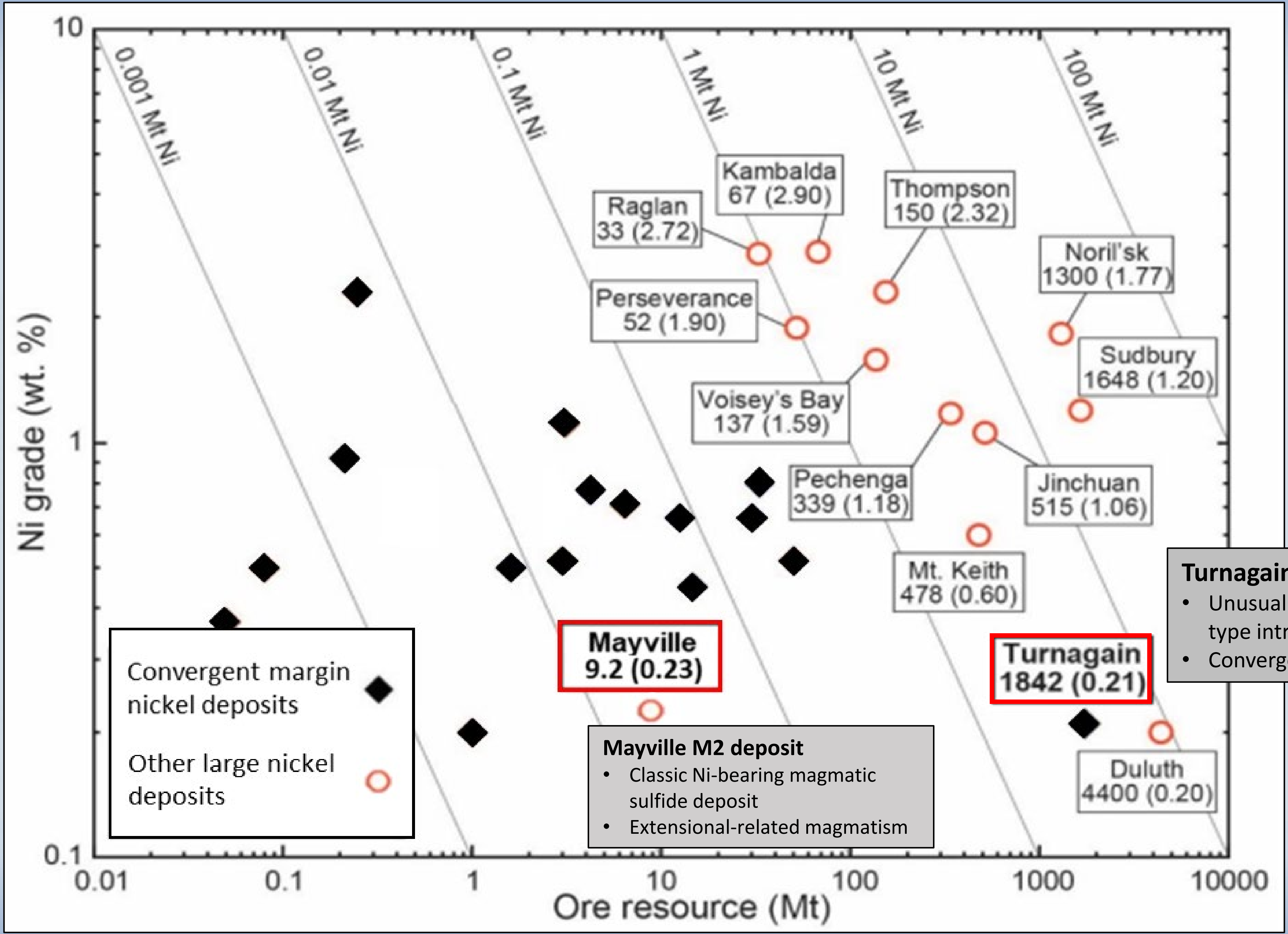
- Majority of modern Ni exploration targets are magmatic sulfide deposits with high sulfide content (>10%)
  - World class examples include Noril'sk and Voisey's Bay
- Magmatic sulfide deposits have historically been good geophysical targets given strong EM responses, but we can expect that most of the "easy" to find deposits have been found
- Ni laterites (another major source of global Ni) are not common in Canada or the US
- Meeting future Ni demand may require readjusting the exploration practices and looking for less common Ni deposit styles as well as lower grade deposits



Study areas

Turnagain deposit (British Columbia)

Mayville M2 deposit (Manitoba)



Turnagain deposit

- Unusual Ni-bearing Alaskan-type intrusive complex
- Convergent margin setting

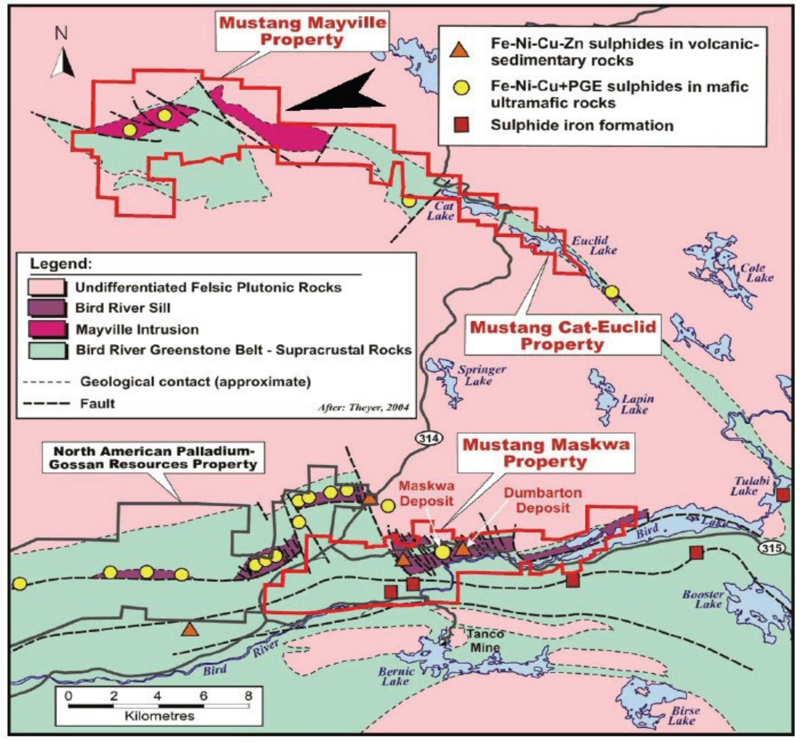
Do convergent margins have further Ni exploration potential?

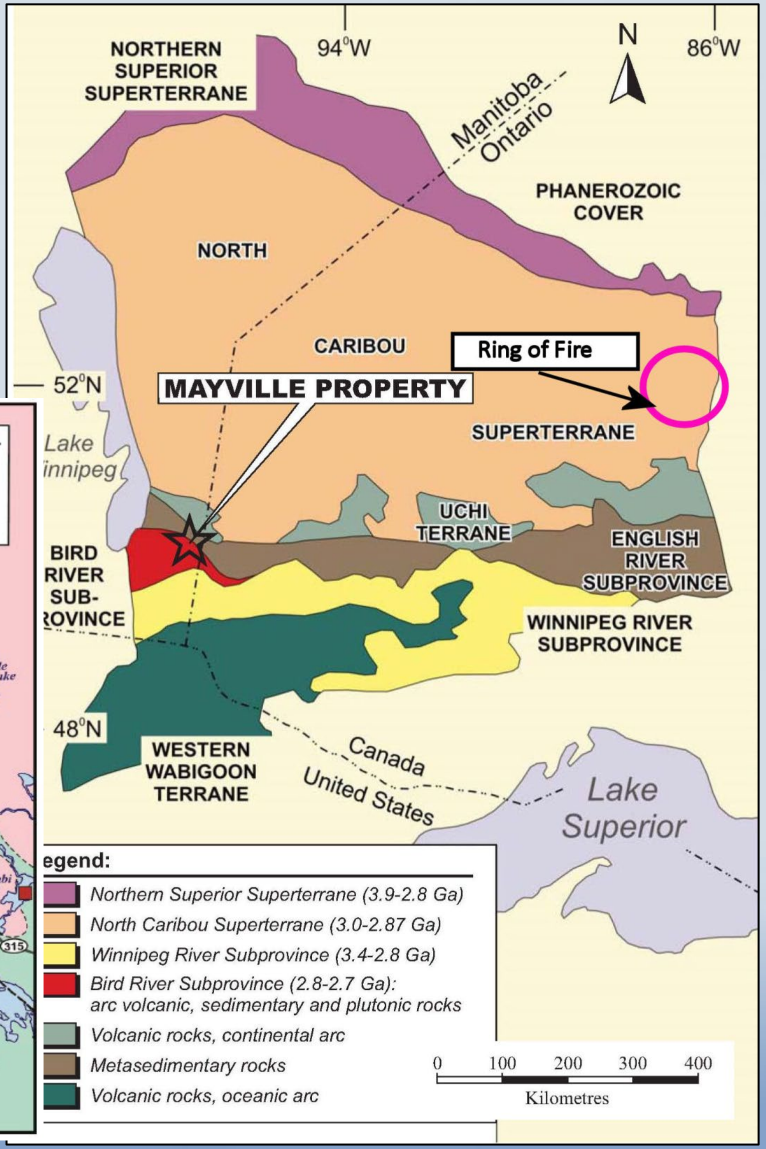
Regional Geology - Mayville

- The Mayville property is in the E-W trending Archean Bird River greenstone belt (BRBG)
  - Consists of bimodal assemblages of metavolcanic rocks and platform-type metasedimentary rocks

- The belt is bounded by granites and gneisses, which form a typical Superior Province assemblage

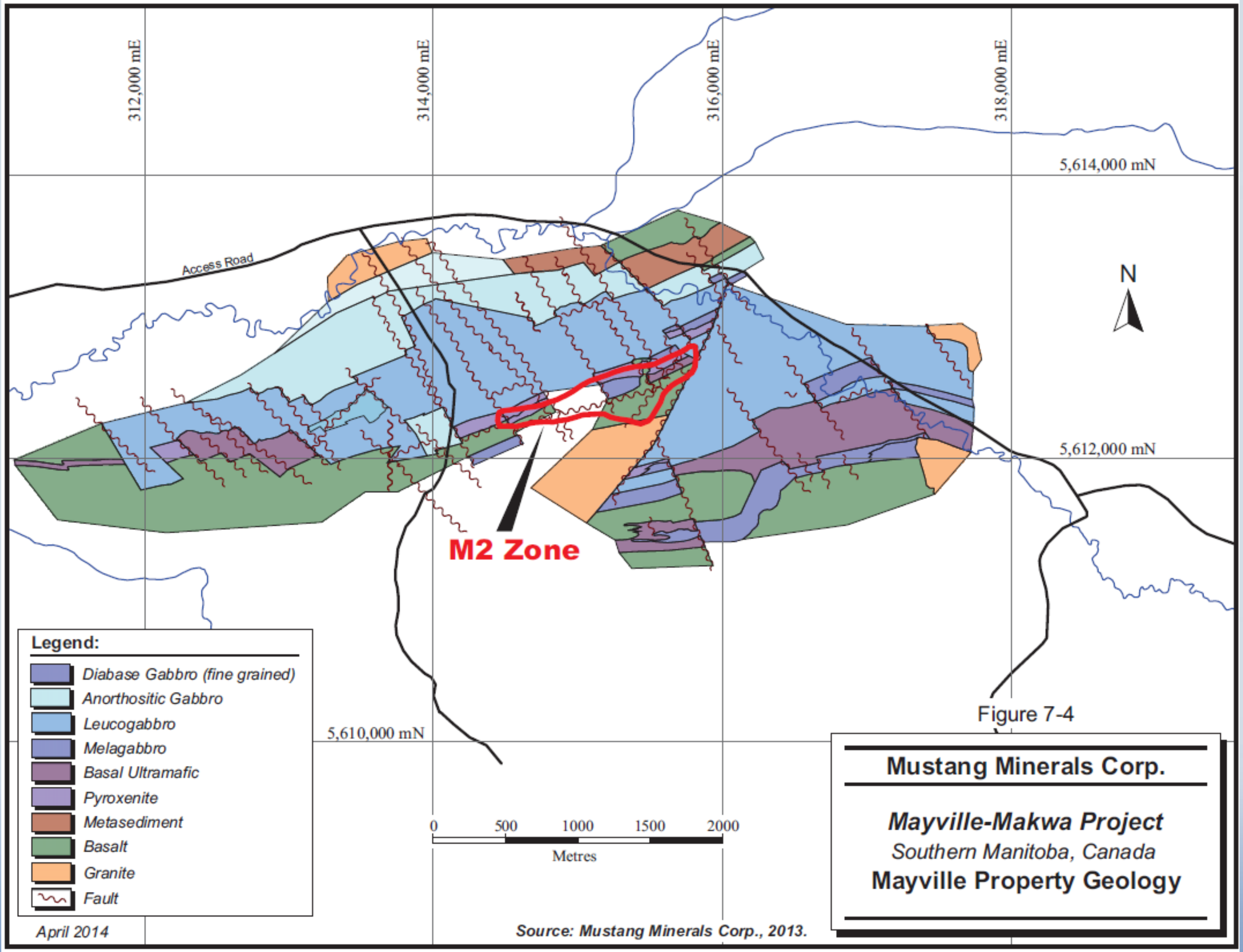
- Magmatic Ni-Cu-PGE and chromite resources have been identified within nine mafic and ultramafic intrusions distributed over the BRBG (75x20 km area)





Property Geology - Mayville

- The northern branch of the BRBG spans ~40 km E-W and 1-4km N-S
- Supracrustal rocks are composed mainly of pillowed and flow-textured volcanic rocks
- It's bounded to the north by felsic to intermediate orthogneiss and to the south by mafic to intermediate metavolcanic rocks of the Lamprey Falls Formation (overturned sequence of mafic volcanic rocks dipping south)
- Syn to late-tectonic felsic intrusions included pegmatitic granites and REE enriched pegmatites
- Faulting is mostly SSE
- The upper and lower contacts of the Mayville Intrusion are not exposed

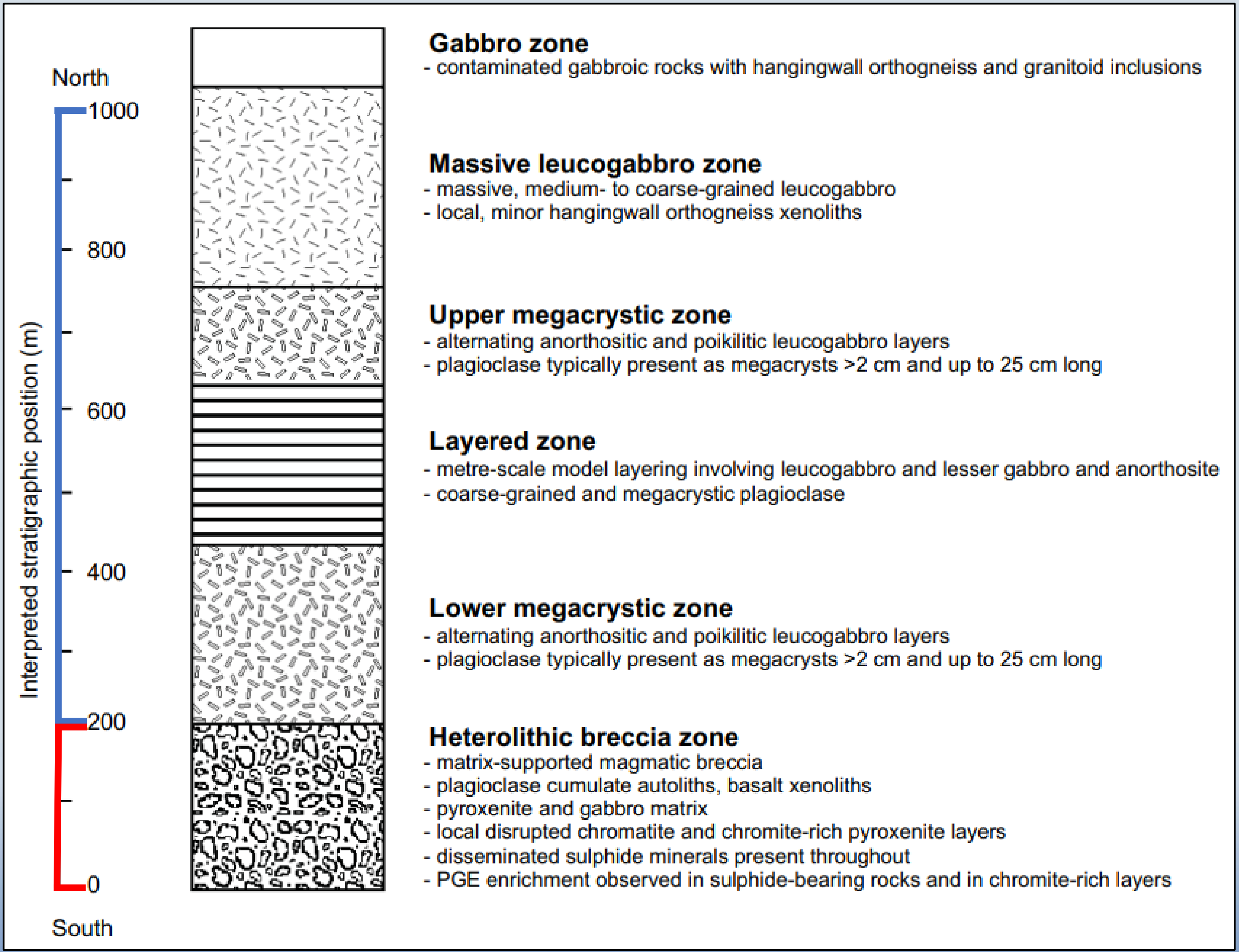


Mayville Intrusion

- The Mayville intrusion has undergone greenschist to amphibolite grade metamorphism
- Original igneous textures are often preserved since deformation is confined to areas proximal to shear zones
- The system is divided into upper and lower zones (or N and S zones)

  - **700m to 800m** upper zone consists of gabbroic and anorthositic rocks with a variety of textures including massive and metacrystic gabbros

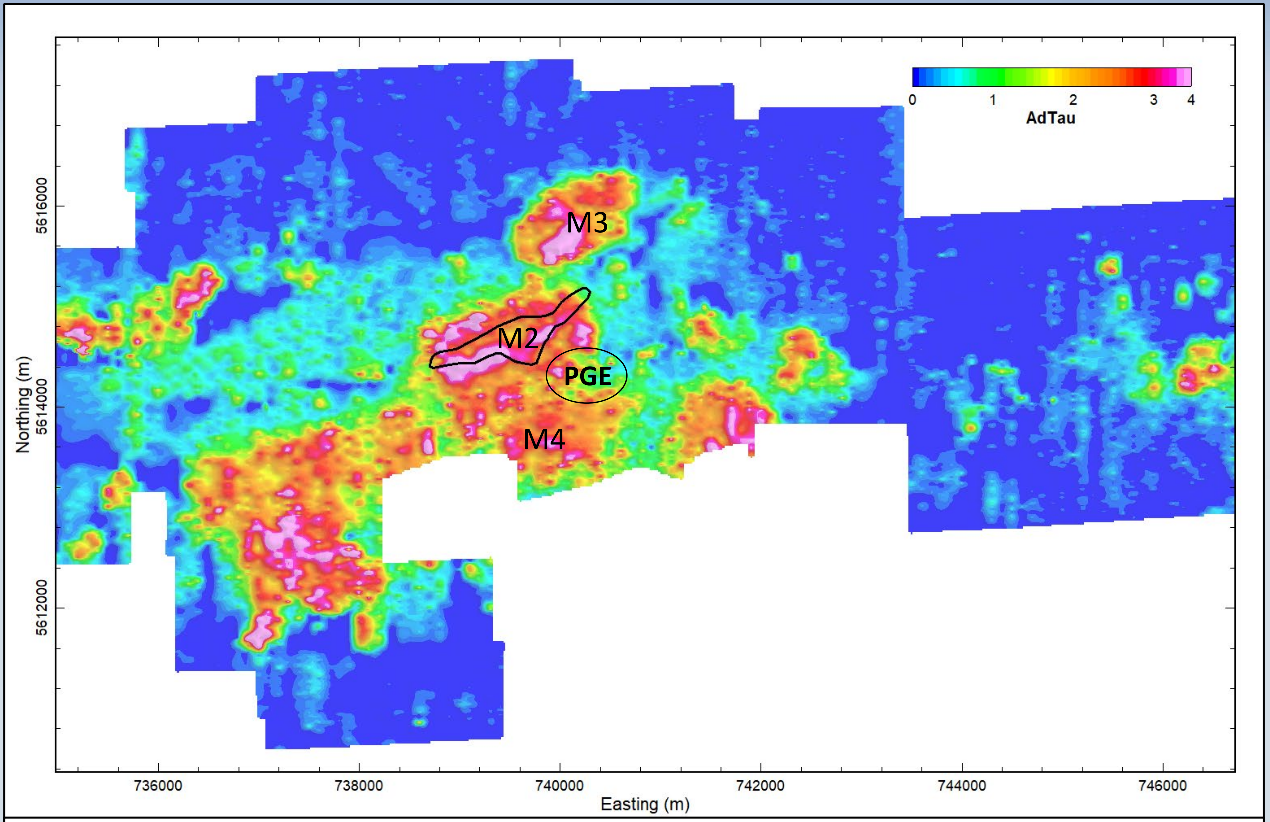
  - **200m to 300m** lower zone consists of heterolithic breccias and hosts the 'M2' Zone mineralized zone as well as the PGE zone

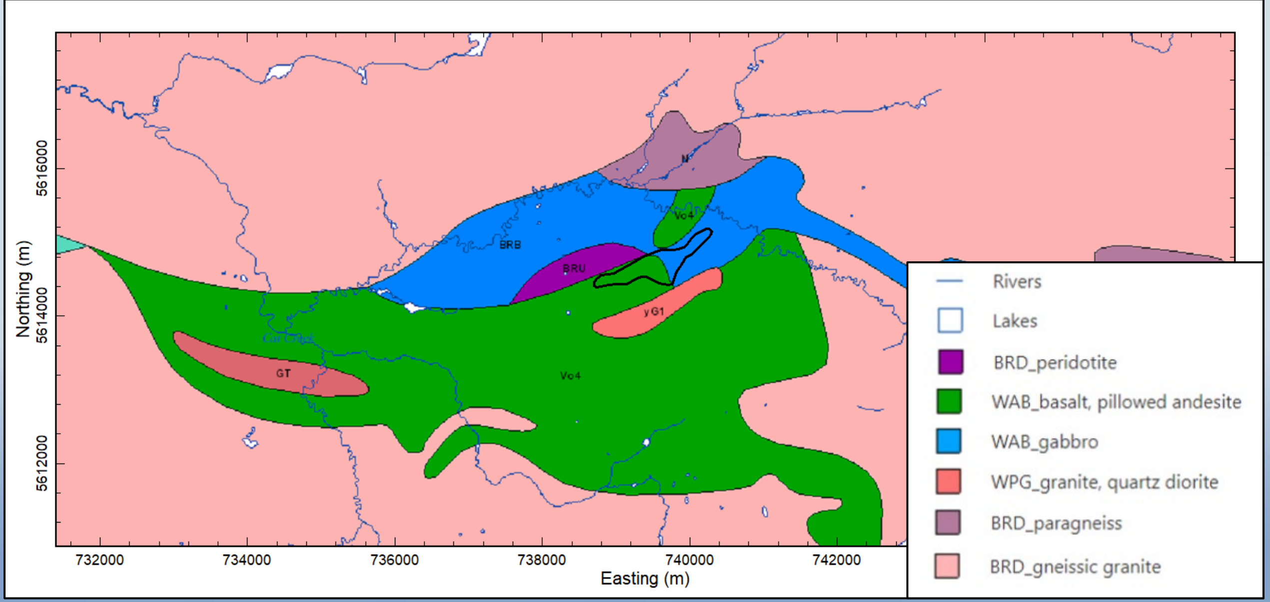


Yang et al., 2011

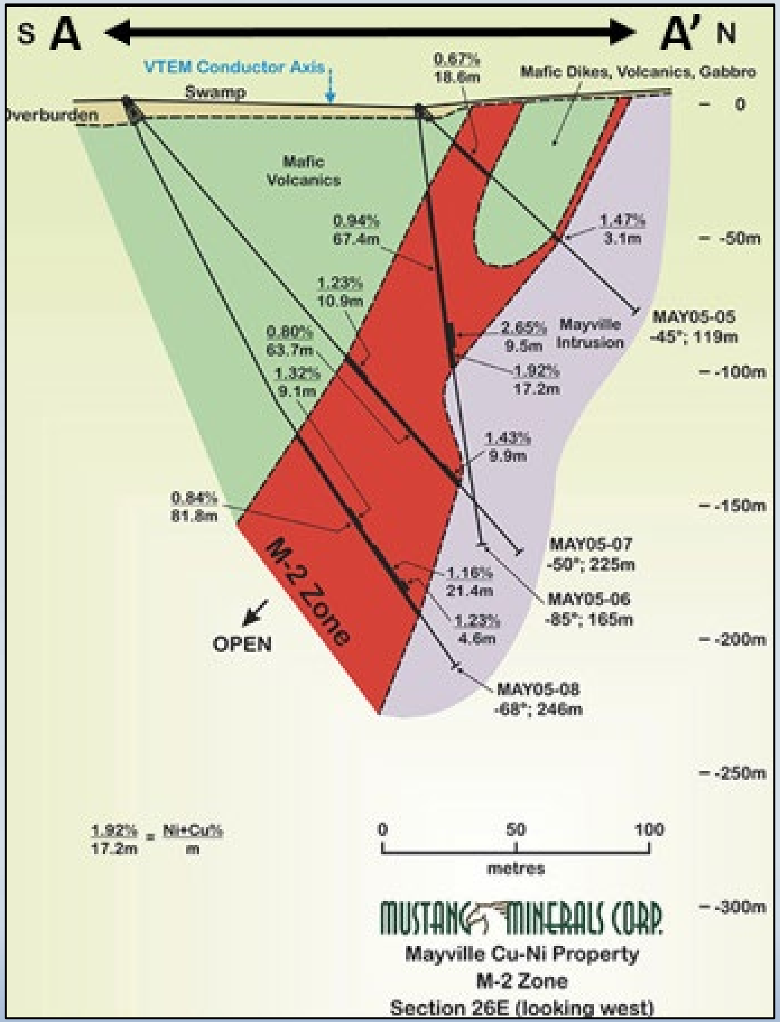
Mineralization – Mayville

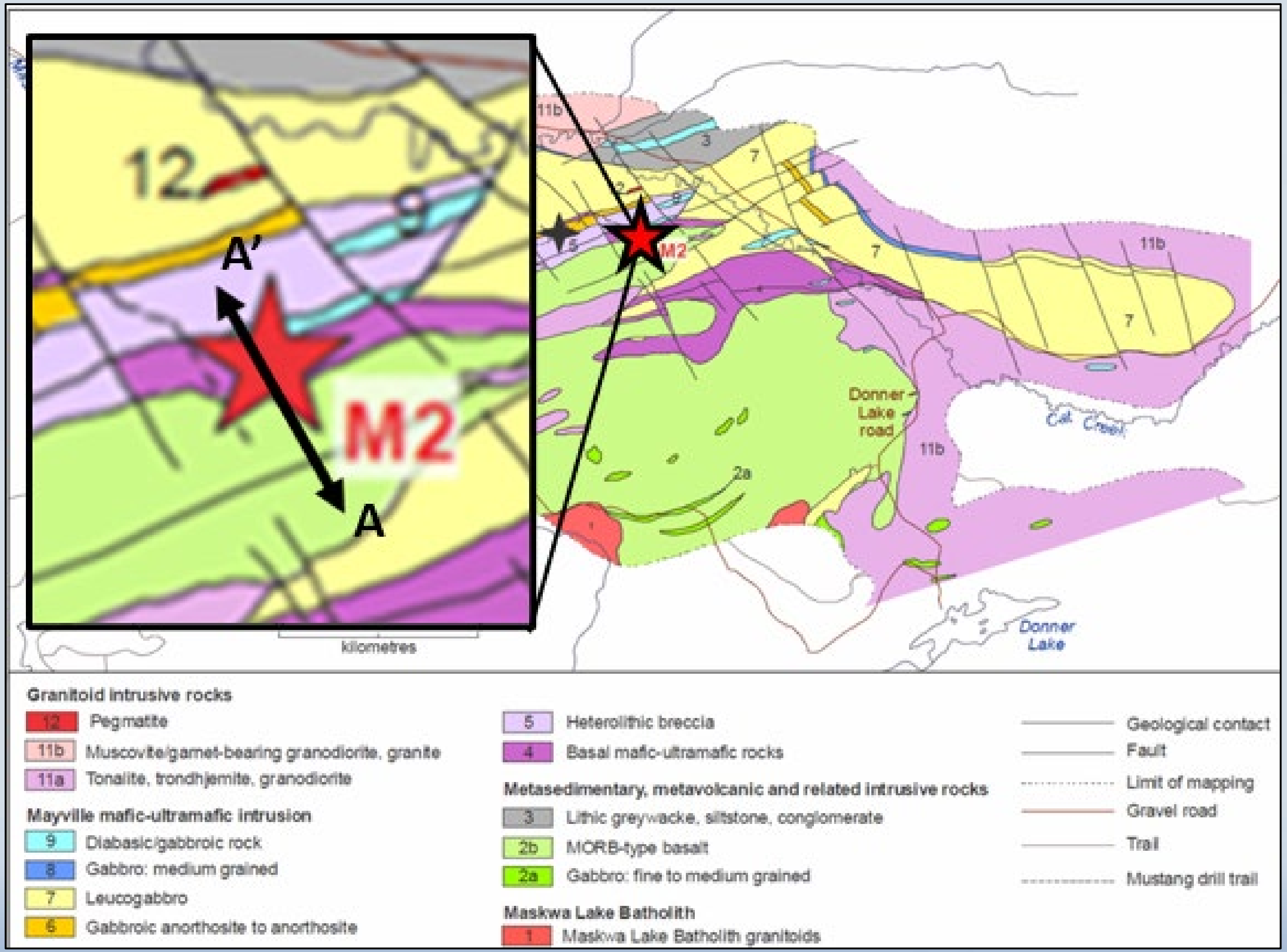
- Ni-Cu sulfide mineralization at Mayville is hosted at the base of the heterolithic breccia zone, just below the structural hanging wall mafic volcanic rocks
- Sulfide mineralization consists of chalcopyrite, pyrrhotite, pentlandite and pyrite in a variety of textures including disseminated, vein, semi-massive and massive
    - Massive sulfides appear to be more Fe and Ni rich, containing pyrrhotite and pentlandite; disseminated sulfides are more Cu rich, containing more chalcopyrite
- M2 mineralized Zone has been intersected by drilling for a strike length of 600 meters and vertical depth of 300 meters; average true thickness ~40 meters
- Platinum group element (PGE) mineralization in on the property just to the southeast of the M2 Zone.





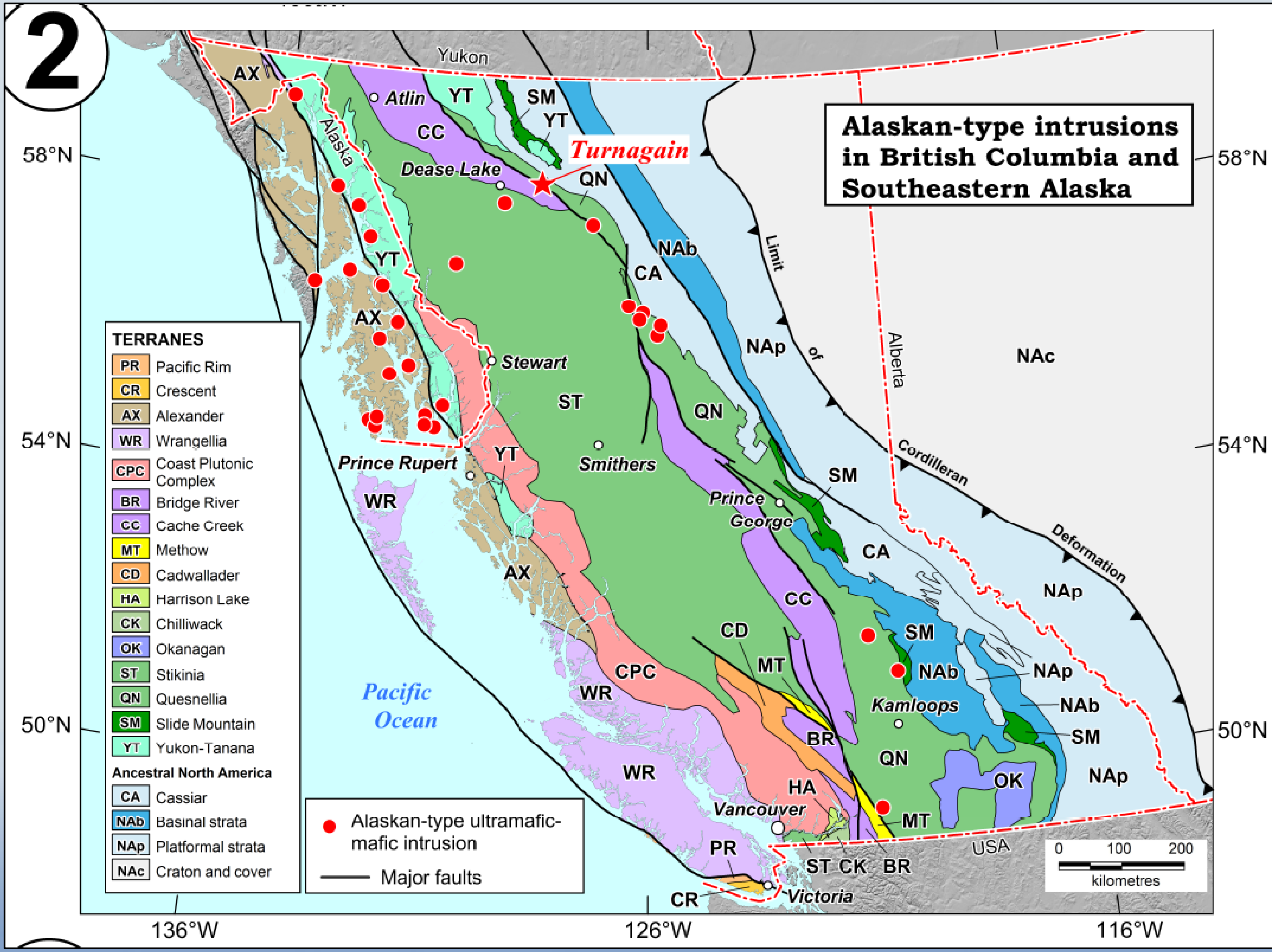
M2 Deposit


S A
A' N
VTEM Conductor Axis
Swamp
Overburden
0.67%
18.6m
Mafic Dikes, Volcanics, Gabbro
Mafic Volcanics
0.94%
67.4m
1.47%
3.1m
1.23%
10.9m
0.80%
63.7m
1.32%
9.1m
2.65%
9.5m
1.92%
17.2m
Mayville Intrusion
MAY05-05
-45°; 119m
1.43%
9.9m
0.84%
81.8m
M-2 Zone
OPEN
1.16%
21.4m
1.23%
4.6m
MAY05-07
-50°; 225m
MAY05-06
-85°; 165m
MAY05-08
-68°; 246m
0
-50m
-100m
-150m
-200m
-250m
-300m
1.92% / 17.2m = Ni+Cu% / m
0 50 100
metres
MUSTANG MINERALS CORP.
Mayville Cu-Ni Property
M-2 Zone
Section 26E (looking west)


12
A'
A
M2
11b
3
7
11b
7
Donner Lake road
11b
2a
Cat Creek
Donner Lake
kilometres
Granitoid intrusive rocks
12 Pegmatite
11b Muscovite/garnet-bearing granodiorite, granite
11a Tonalite, trondhjemite, granodiorite
Mayville mafic-ultramafic intrusion
9 Diabasic/gabbroic rock
8 Gabbro: medium grained
7 Leucogabbro
6 Gabbroic anorthosite to anorthosite
5 Heterolithic breccia
4 Basal mafic-ultramafic rocks
Metasedimentary, metavolcanic and related intrusive rocks
3 Lithic greywacke, siltstone, conglomerate
2b MORB-type basalt
2a Gabbro: fine to medium grained
Maskwa Lake Batholith
1 Maskwa Lake Batholith granitoids
Geological contact
Fault
Limit of mapping
Gravel road
Trail
Mustang drill trail

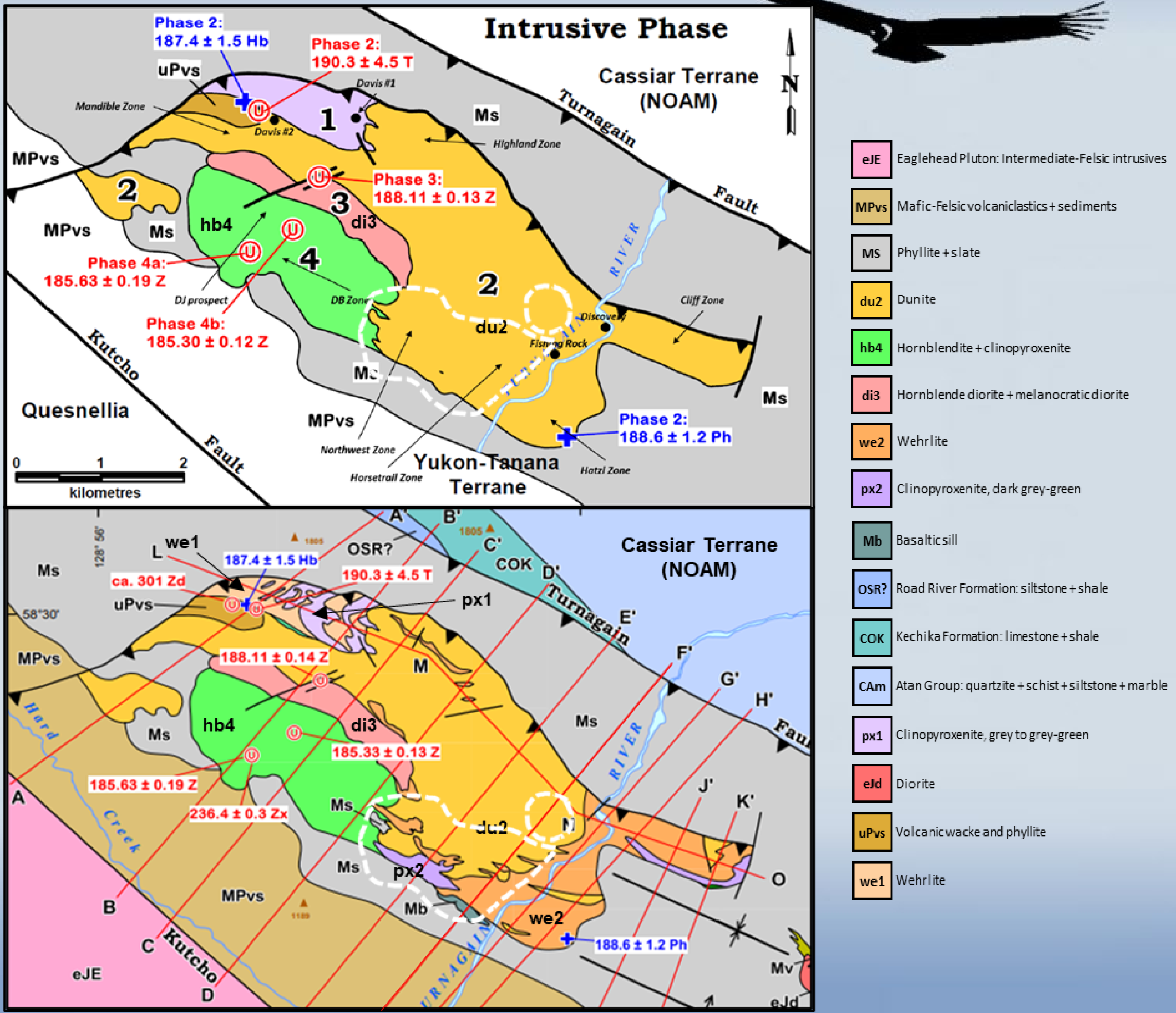
Regional Geologic Setting - Turnagain

- The Turnagain complex lies along the boundary of Quesnellia and the Yukon-Tanana Terranes and adjacent to the Cassiar Terrane
- The Turnagain complex is fault-bounded and lies to the north of the Kutcho and Thibert-Hottah Faults
- Surrounding rocks include:
  - Graphitic phyllite (which is strongly pyritic and graphitic around the Turnagain complex)
  - Possibly volcaniclastic rocks to the south
  - Dioritic to granodioritic rocks crop outcrop south
- Two emplacement theories exist: supra-subduction setting on a cratonic margin & imbricated rocks thrust onto margin of NA craton



Property Geology- Turnagain

- The Turnagain complex exhibits characteristics of typical Alaskan-type intrusions, including a steeply dipping dunite-wehrlite core
- The sulfur saturation necessary to precipitate a Ni deposit was most likely reached when the intrusion interacted with the host carbonaceous phyllite wall rocks
- There were 4 intrusive phases, with Phase 2 hosting the Ni mineralization
- Ore comprised of massive to semi-massive sulfides, disseminations, and rare breccias
- Principal ore minerals include pyrrhotite, pentlandite, and chalcopyrite



Airborne Data Coverage - Mayville

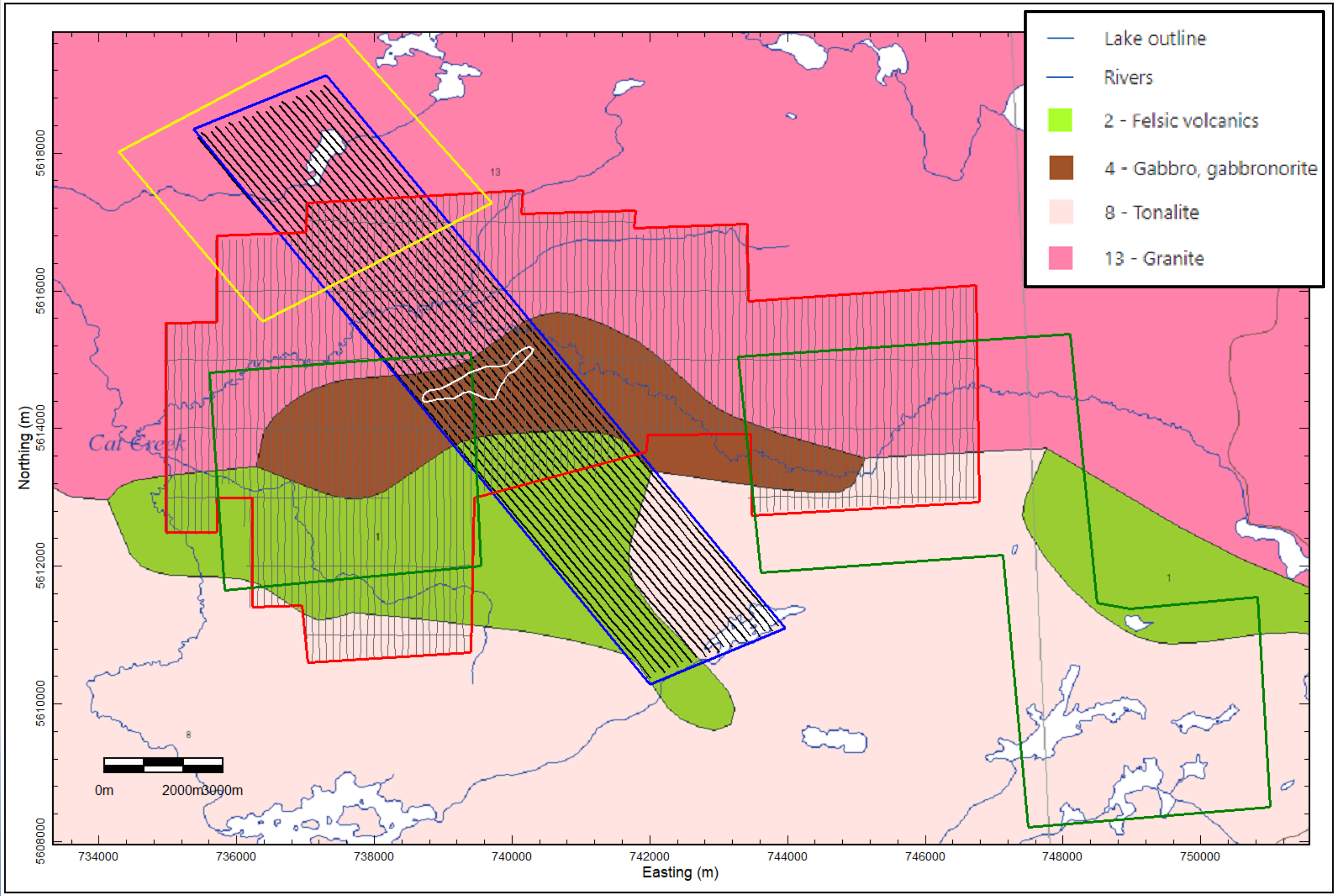
VTEM (2005), 580 line-km, 100m line spacing, E-W flight lines

ZTEM (2010), 218 line-km, 100m line spacing, 140⁰ flight lines

M2 Mineralized Zone

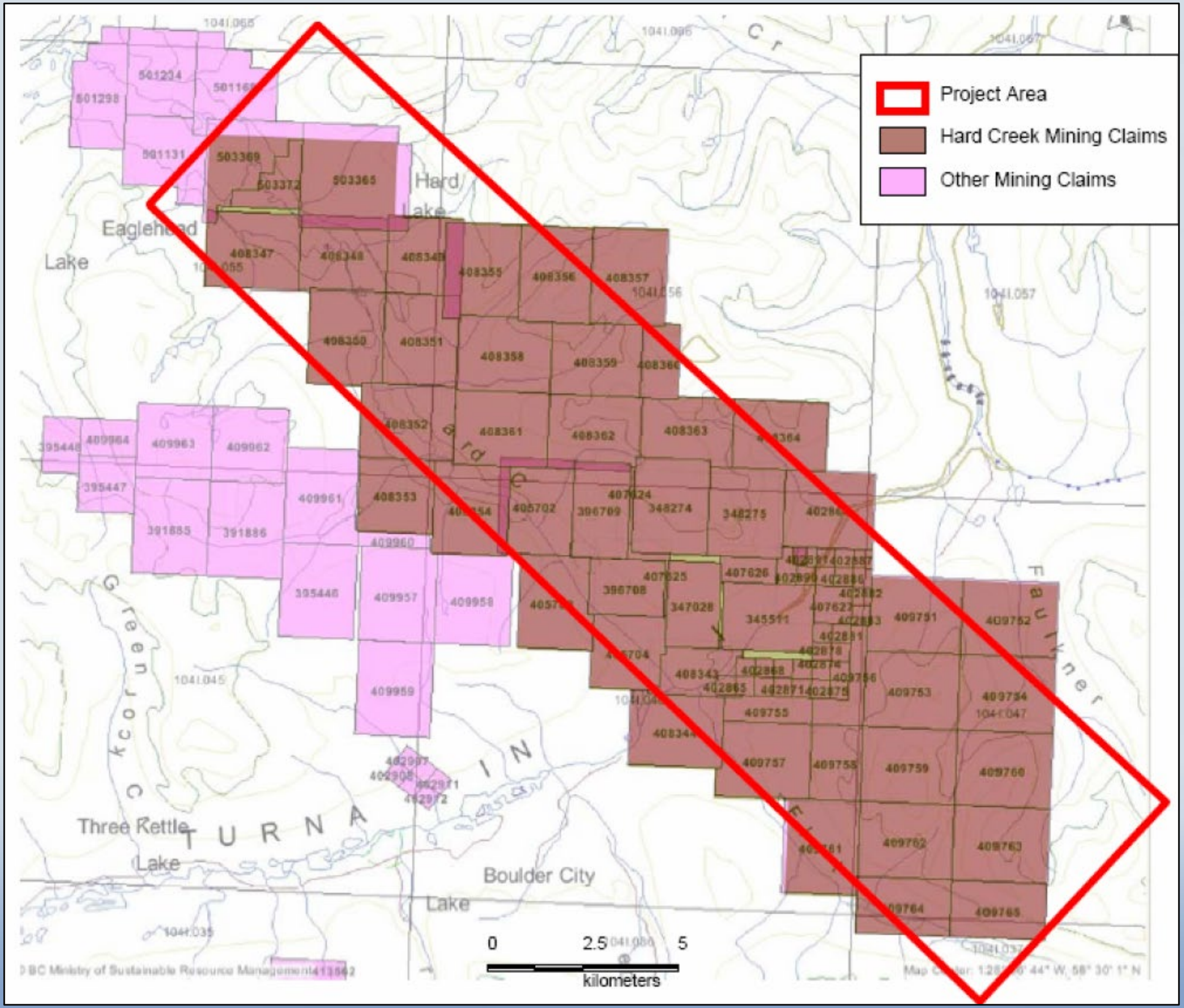
VTEM (2010)

VTEM Max (2013)



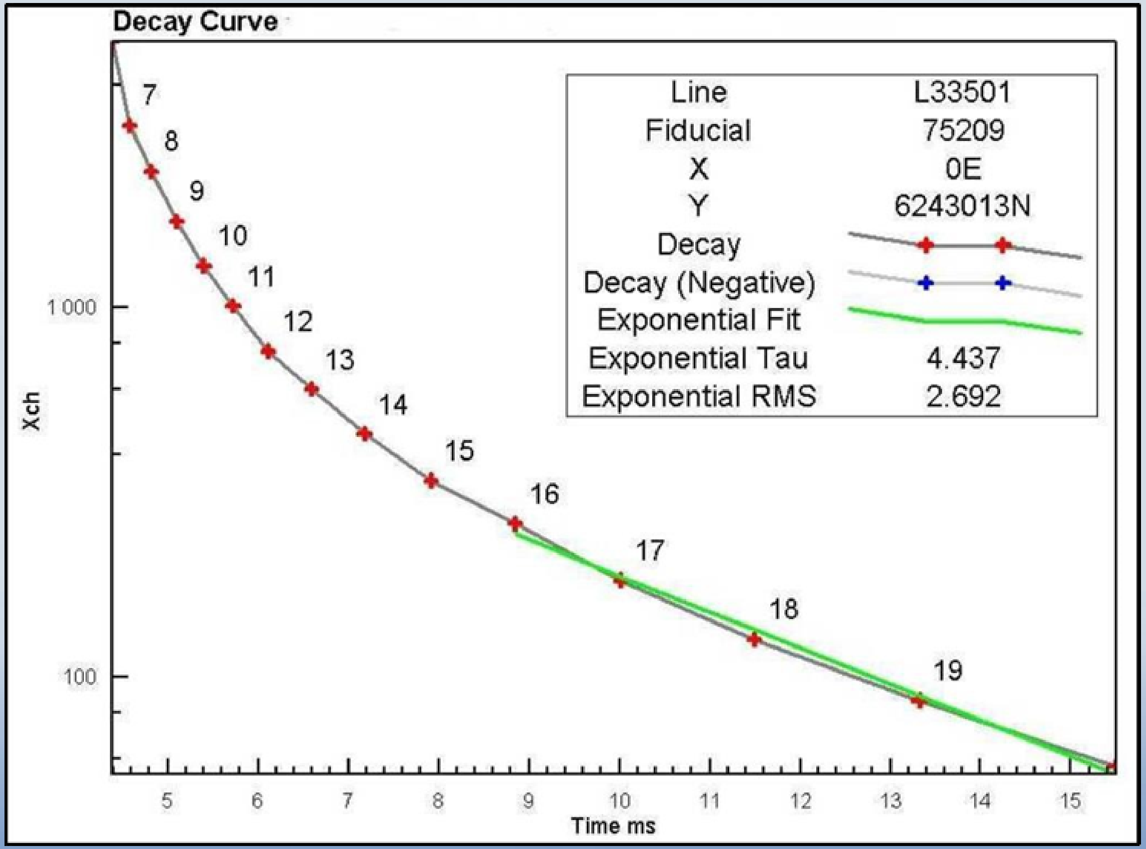
Airborne Data Coverage - Turnagain

- AeroTEM II (2004), 1866 line-km, 100/200m line spacing at 40.5º



Data Processing

- VTEM surveys were flown by Geotech Ltd. in 2005/2010 and a heliborne Z-axis tipper EM (ZTEM) audio-frequency magnetic (AFMAG) survey was flown by Geotech in 2010 over the Mayville Property
- AeroTEM II heliborne EM and magnetic data were acquired over the Turnagain property in 2004.
- Geophysical data processing included:
  - Calculation of an EM time-constant (AdTau)
  - Conductor picking
  - 1D layered earth inversions of the time-domain EM data
  - 2D inversion of ZTEM using a 2D MT algorithm
  - 3D inversion of the ZTEM data using UBC-GIF code MTZTEM
  - Magnetic grid processing
  - 3D magnetic susceptibility modeling using UBC-GIF 3D code



Geophysical Target Model

- Ni-bearing magmatic sulfides often make great geophysical targets because they commonly occur with conductive minerals such as pyrrhotite, chalcopyrite and pentlandite (King, 2007)

- Magmatic sulfides sometimes produce magnetic highs, but direct detection with magnetic methods is rare
  - However, magnetic data can be useful in defining areas of intrusive rocks

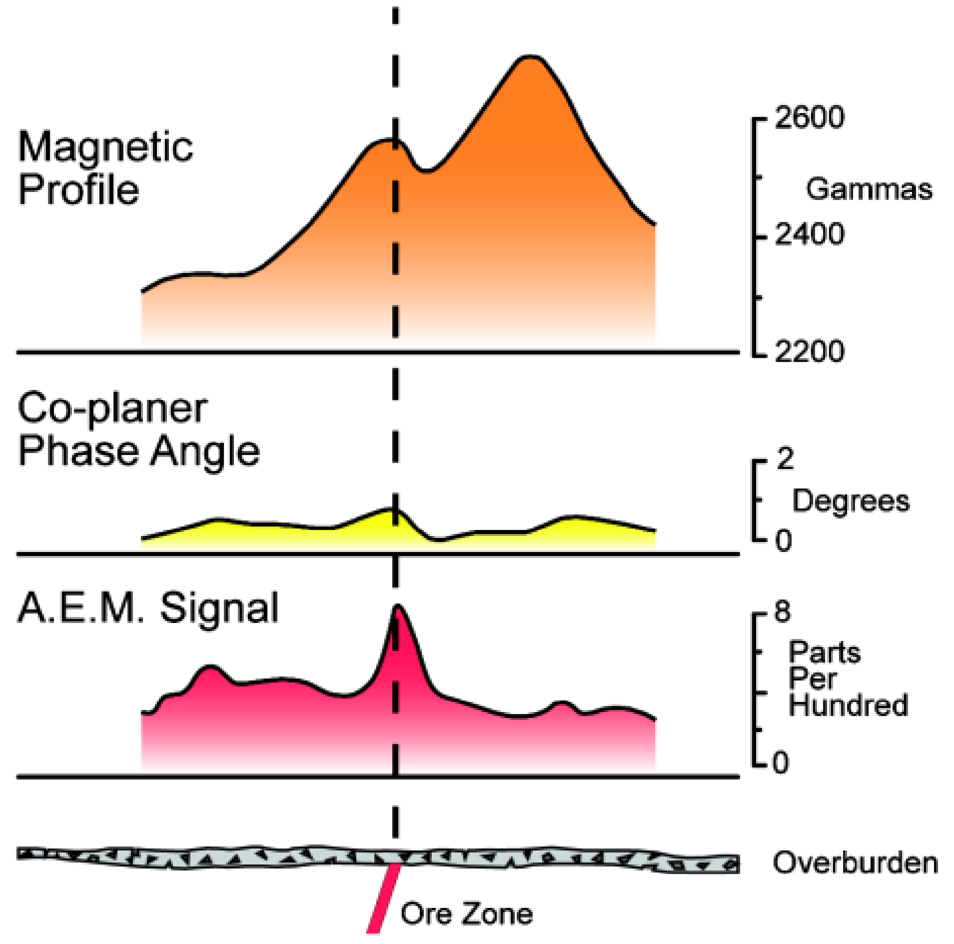
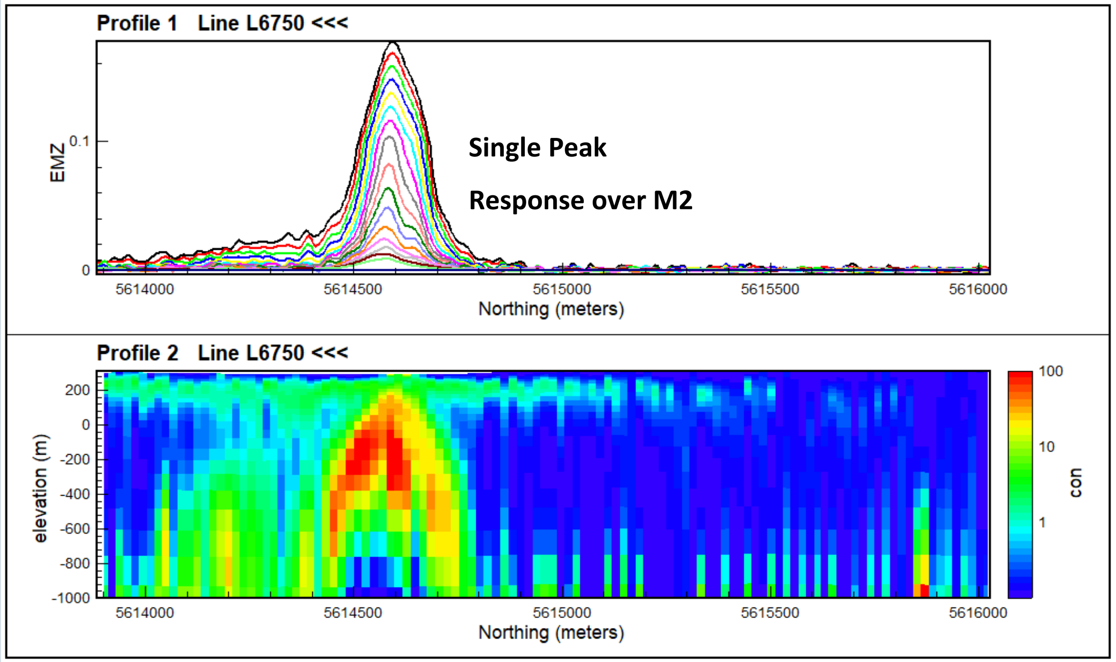
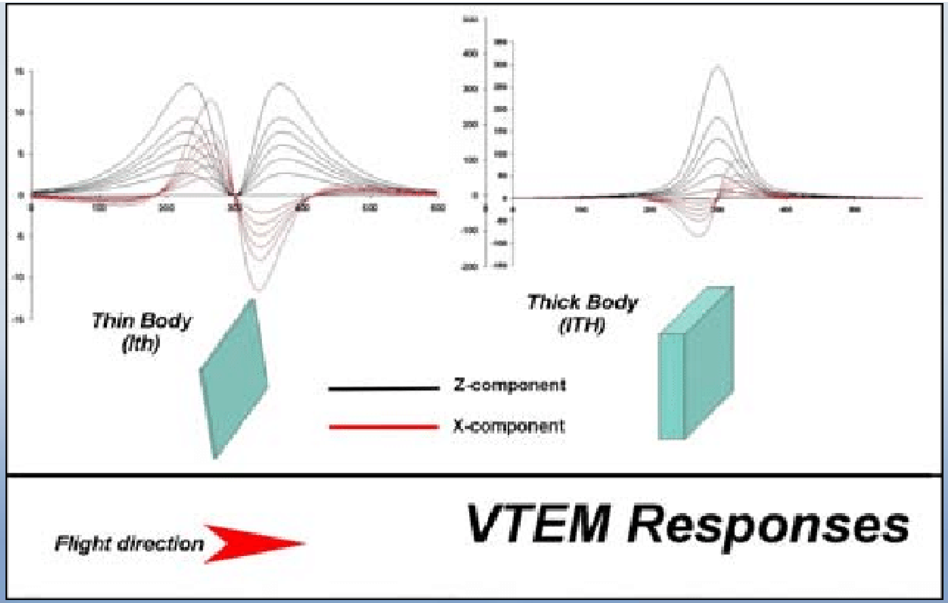


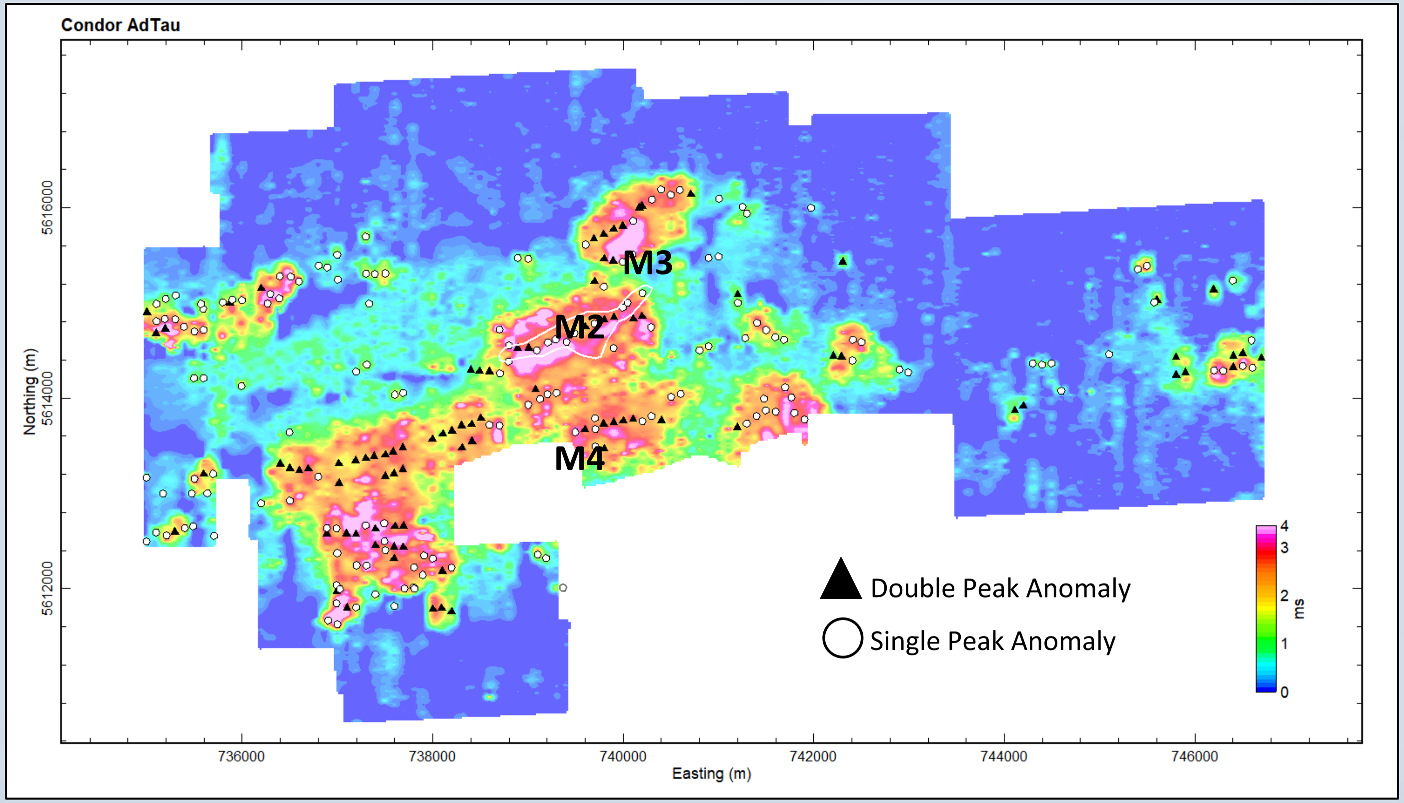
Figure 9: Inco AEM and Magnetics - Thompson Discovery Manitoba.

King, 2007

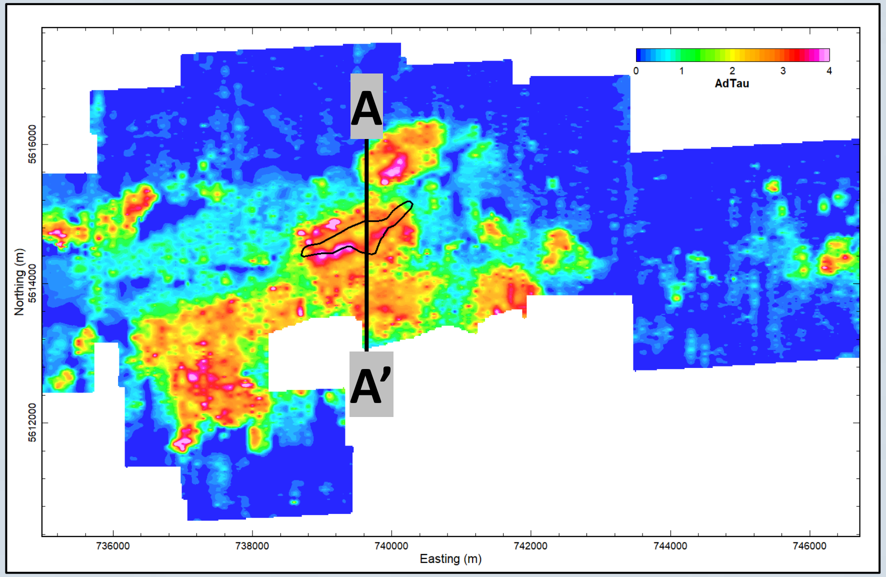
Time-domain EM Anomaly picking

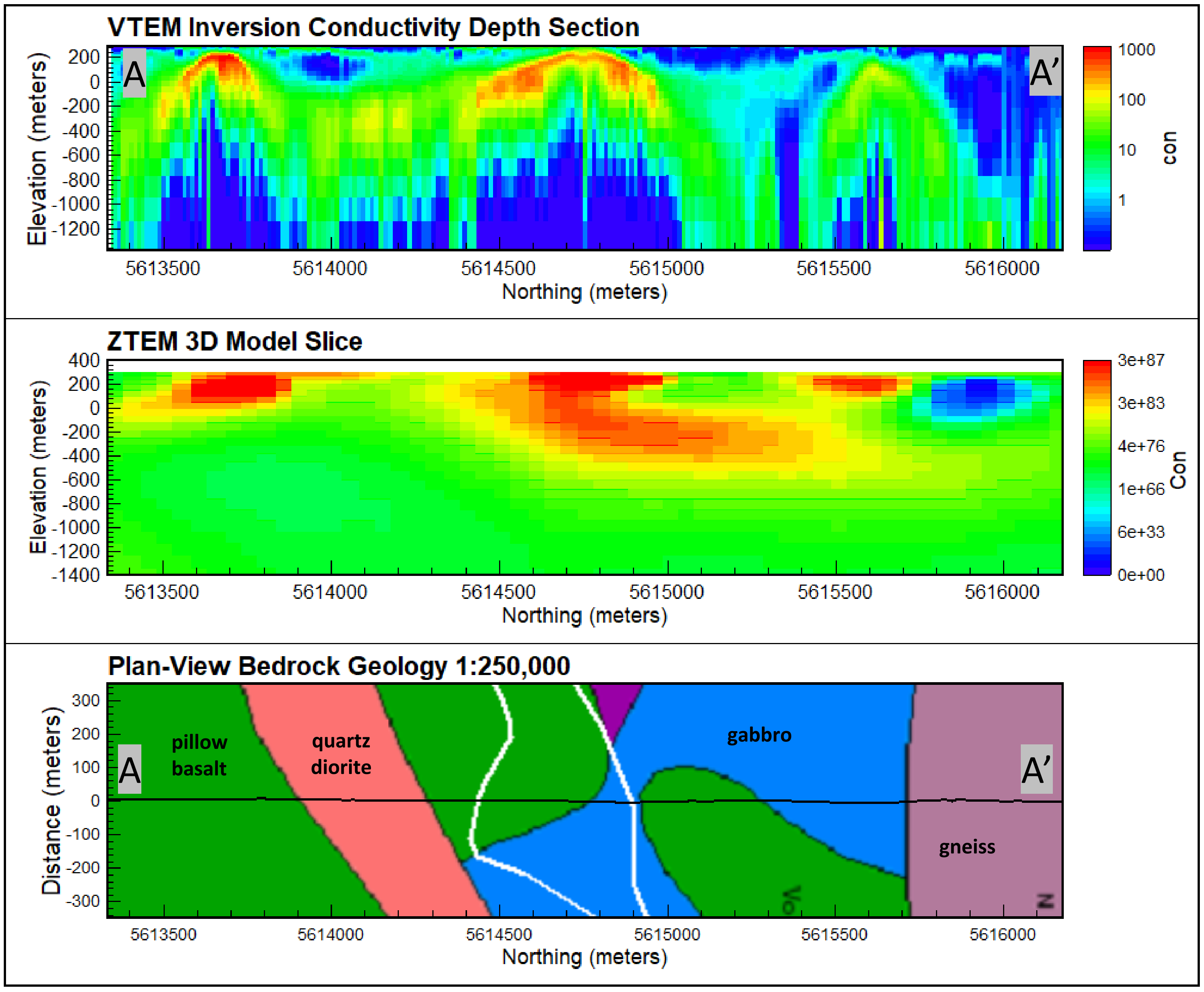




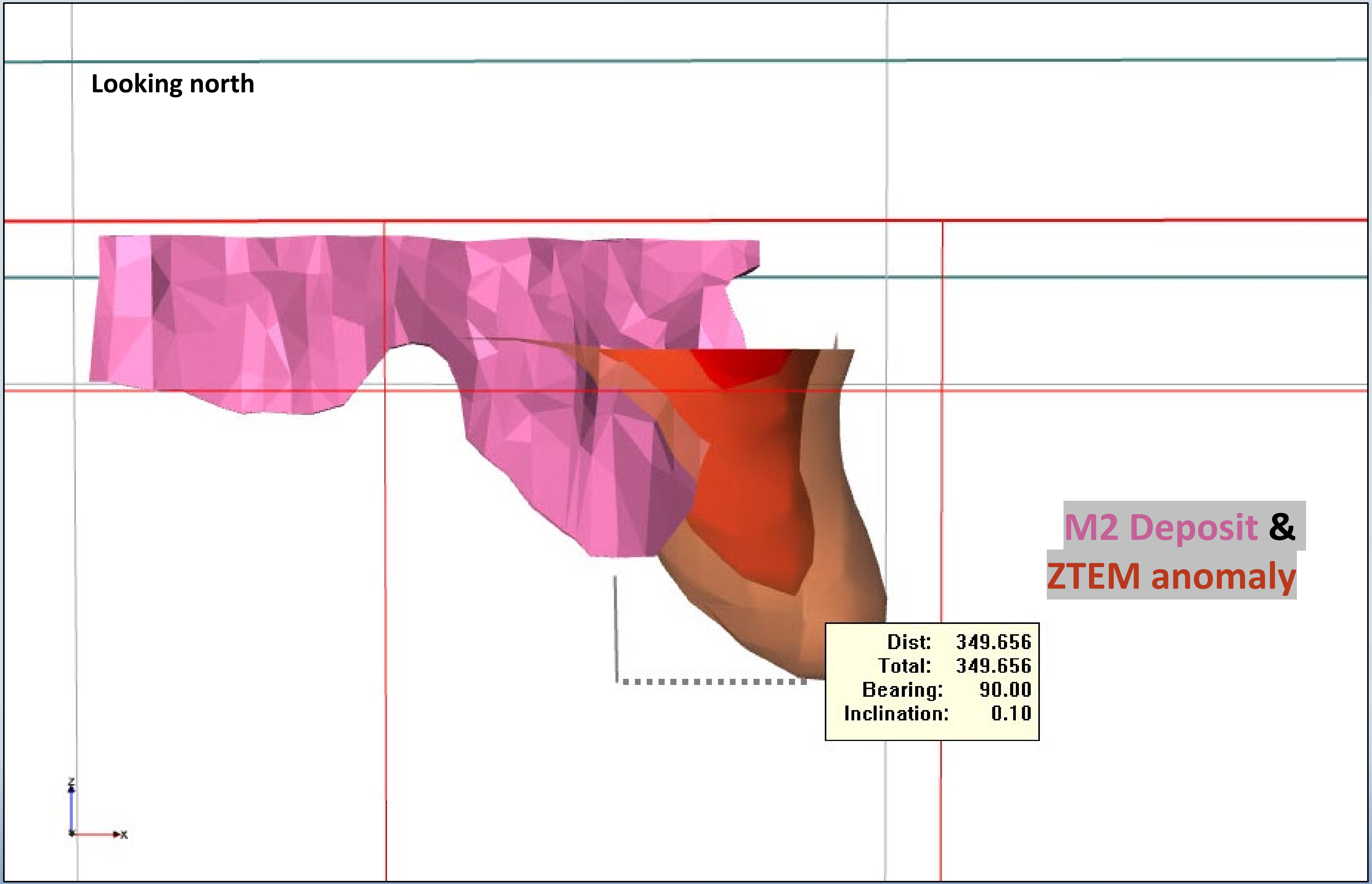


Mayville EM Responses



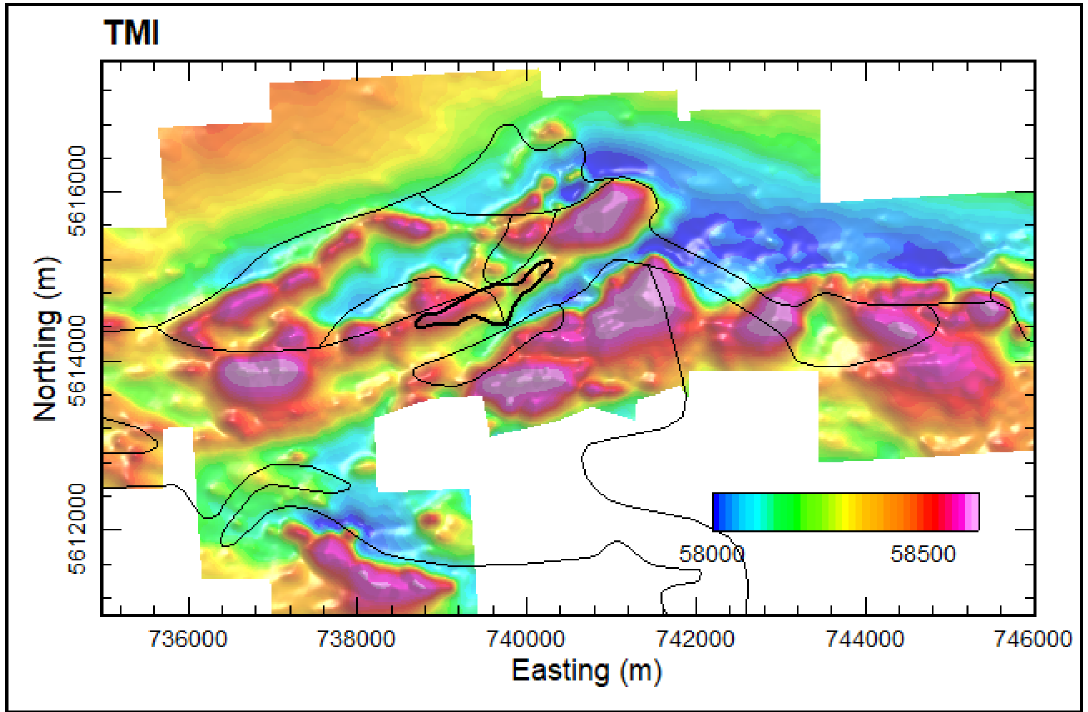


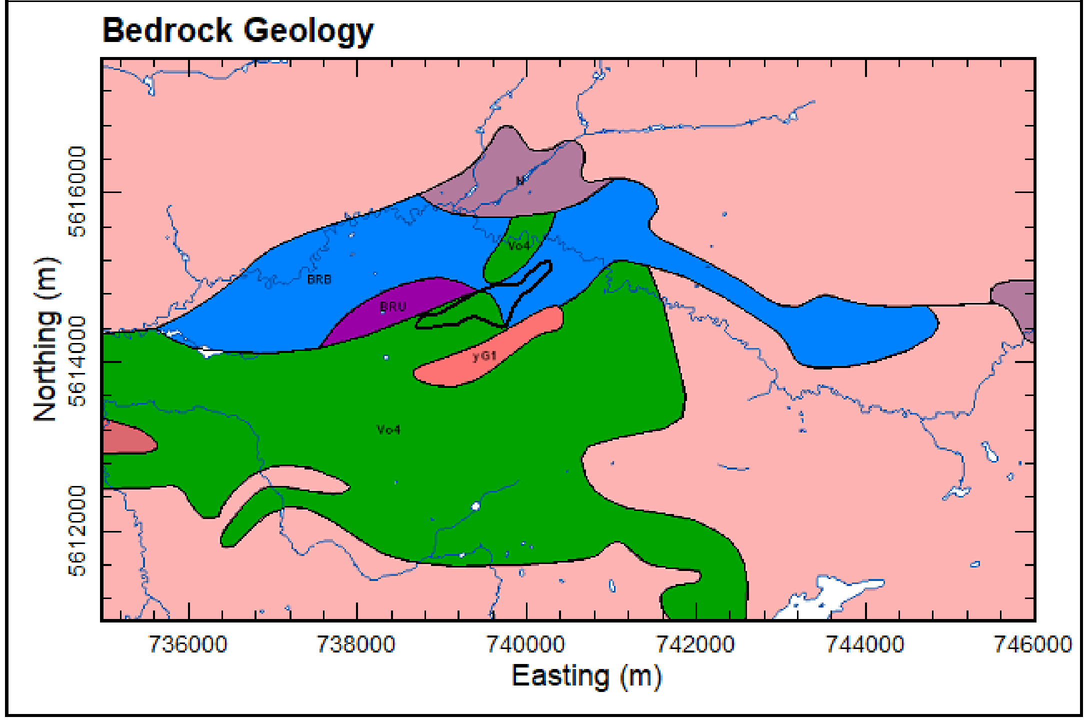
3D ZTEM Model



Magnetics

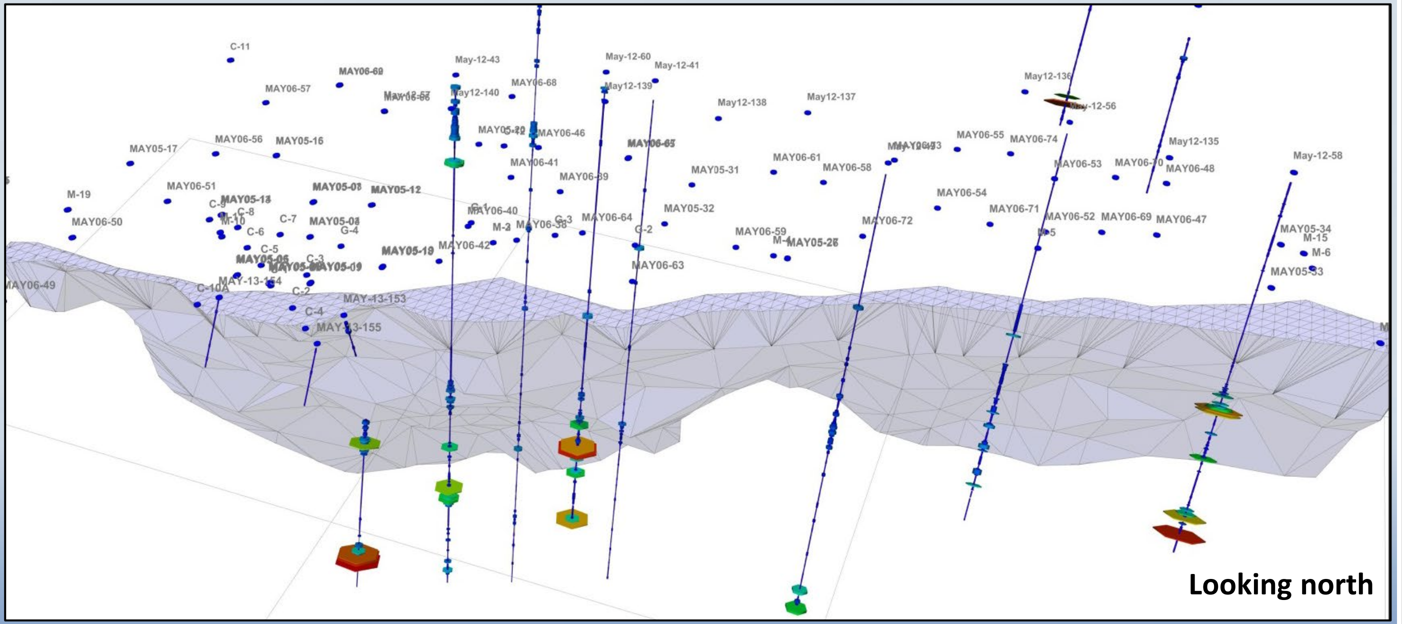
- The magnetic data is in fair agreement with the bedrock geology (thin black outline)
- There are strong magnetic highs are associated with the gabbroic rocks and some of the mineralized area, however the magnetics don’t directly correlate with the deposit or the intrusion as a whole
- The magnetics can be used as a mapping tool; areas of mineralization aren’t directly correlated with magnetic anomalies
- This sets the Mayville apart from many other nickel deposits that have a direct magnetic signature or anomaly related to the intrusion

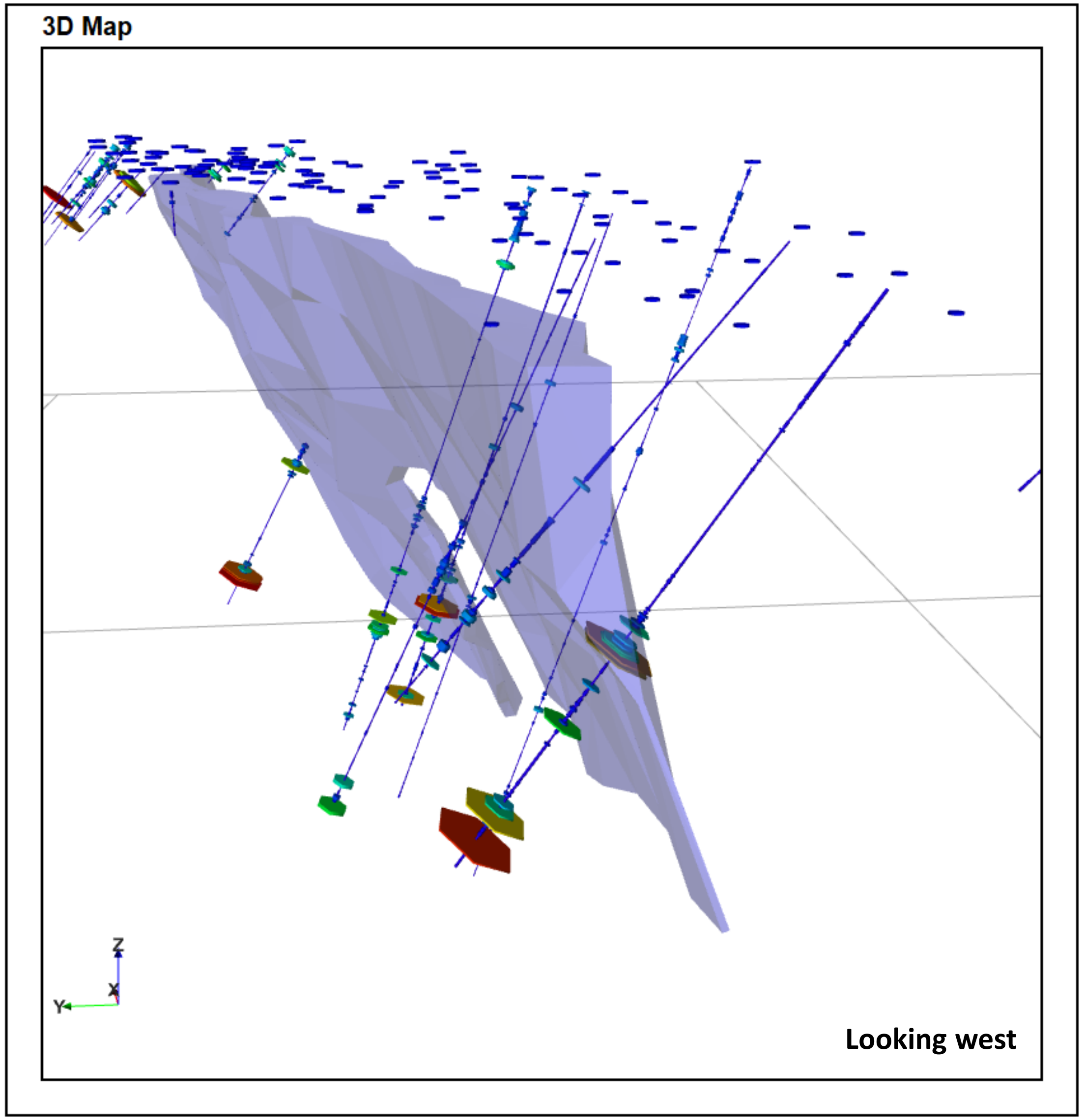


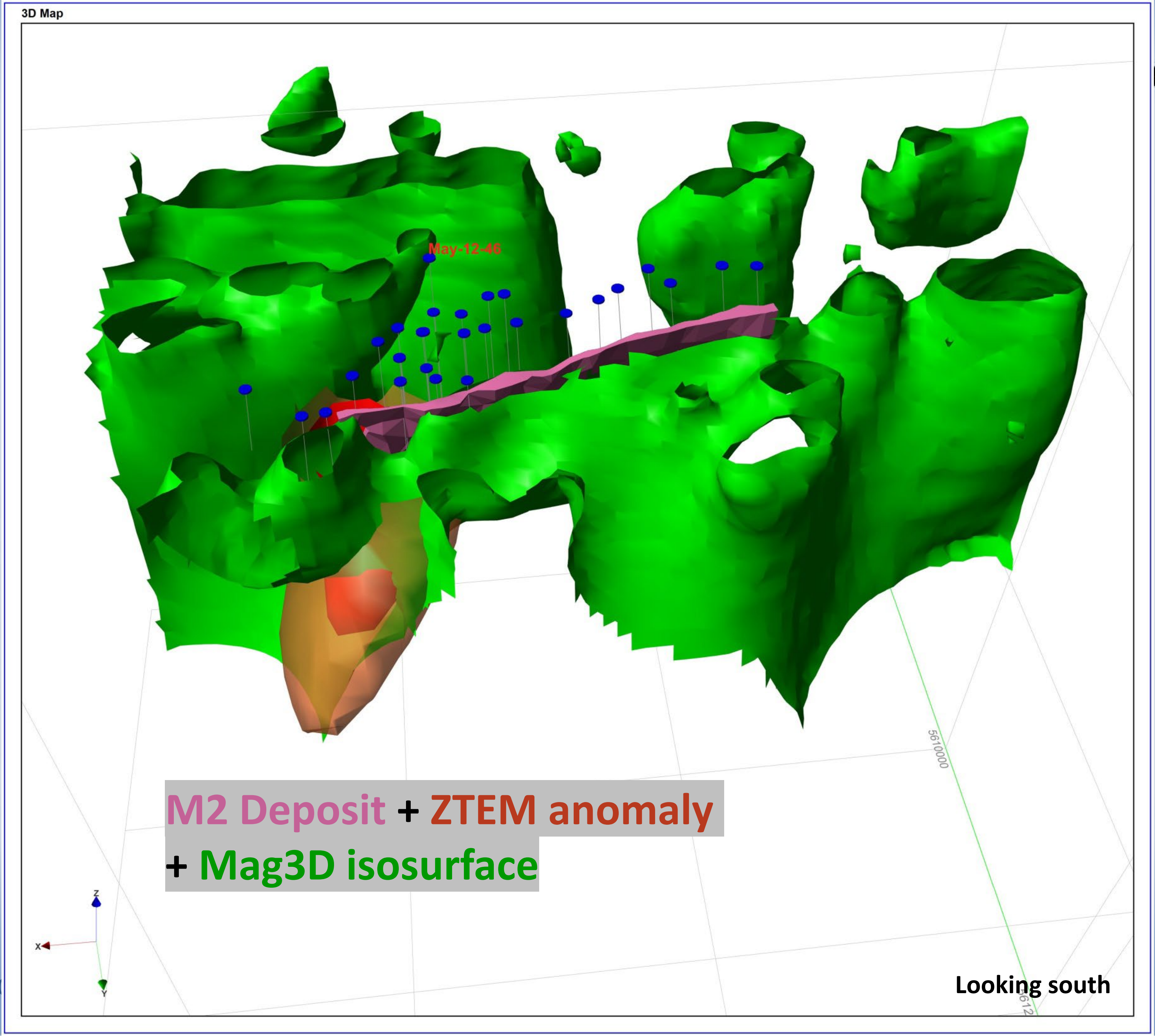


Magnetic Susceptibility

- Downhole magnetic susceptibility work shows that the mineralized zone (blue solid) was non-magnetic, while the footwall rocks were magnetic.
- Geologic evidence shows that the sequence here is overturned, so the hanging wall rocks represent the lower contact of the Mayville intrusion
- Mag3D model is in good agreement with this result.

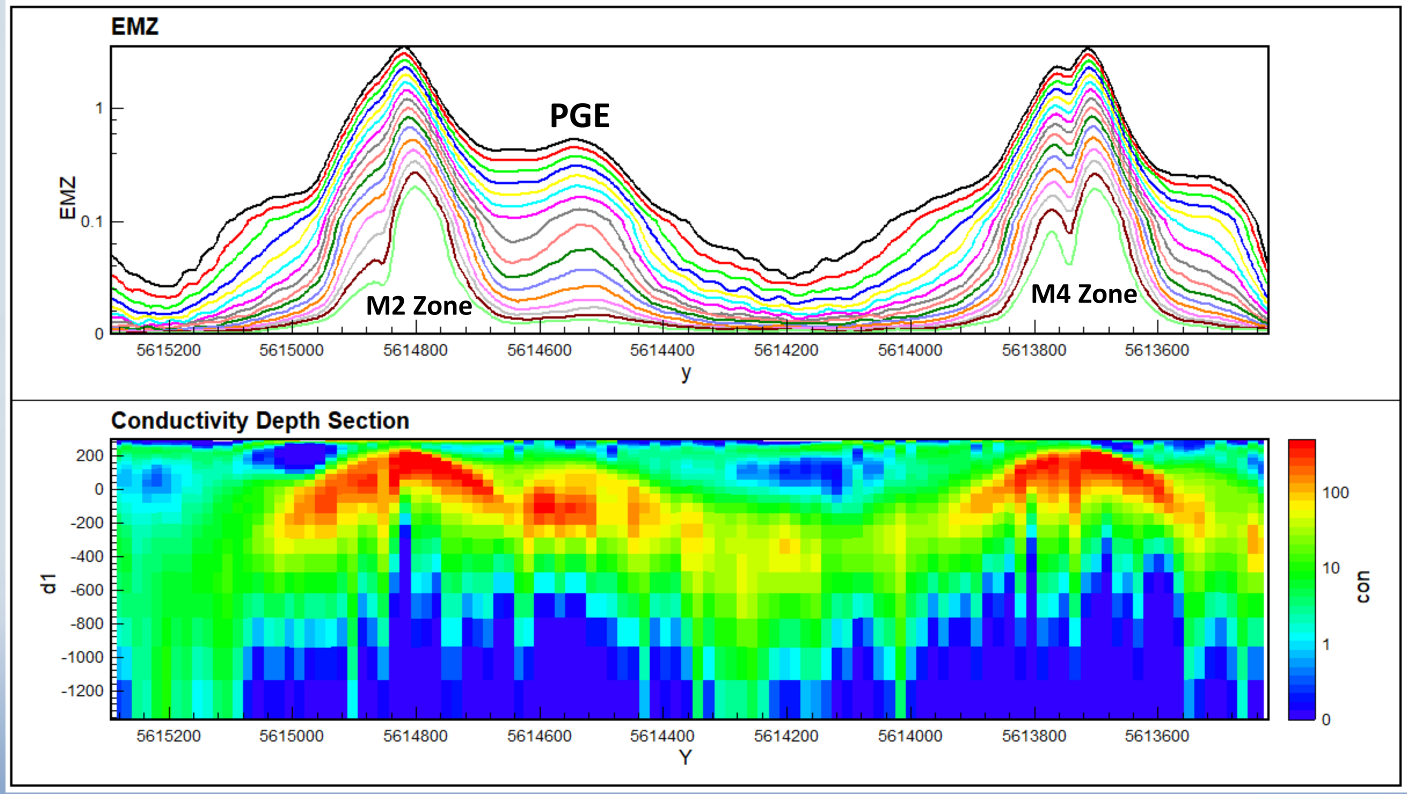


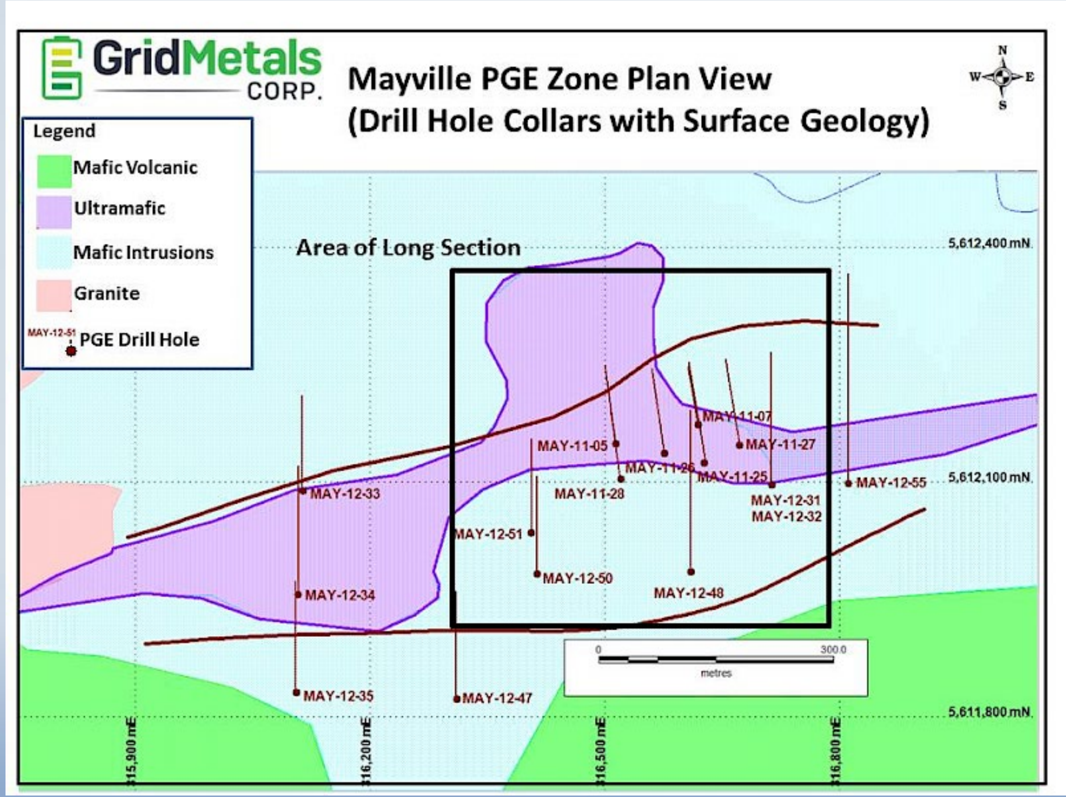



3D Map
May-12-46
5610000
M2 Deposit + ZTEM anomaly
+ Mag3D isosurface
Z
X
Y
Looking south

PGE Zone

- In addition to the Cu-Ni zone on the Mayville property, there is also a known platinum group element (PGE) zone.
- PGE dominant mineralization (palladium – platinum) with low copper nickel values; stratigraphically related to chromite mineralization. The host ultramafic package strikes for about 1km (Grid Metals website).





Summary of Geophysical Responses over the M2 deposit

MAG:

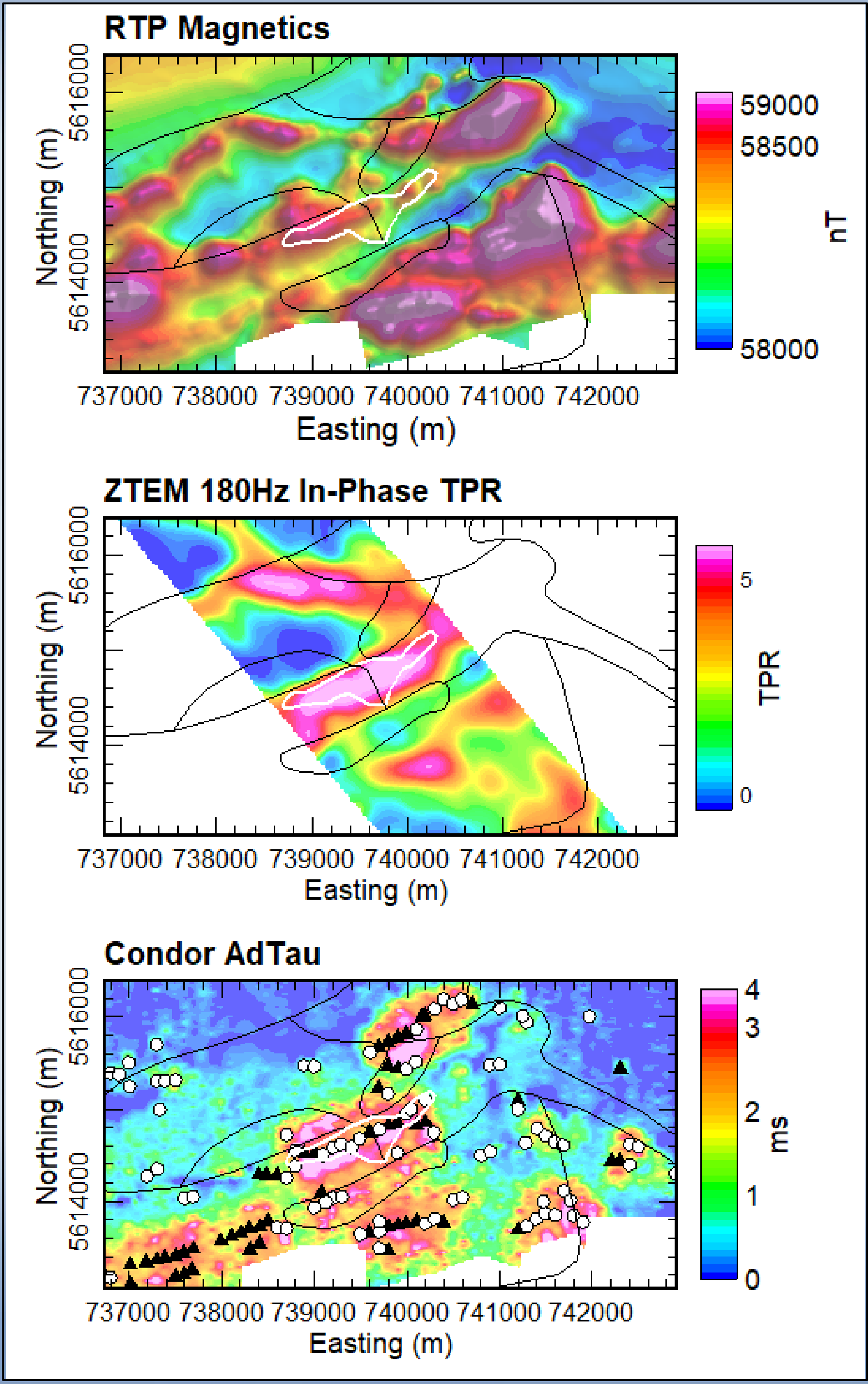
- The magnetic anomaly associated with the M2 zone is more extensive to the SW than the mineralized area.
- Generally, there are strong anomalies associated with, but not limited to areas of known mineralization on the property.

ZTEM:

- There is a distinct ZTEM anomaly that is apparent at high and low frequencies, suggesting that the mineralized zone may be under thin cover and also has a large vertical extent.
- The ZTEM anomaly agrees with the geologic contact between gabbros/pillow basalts and quartz diorites.

VTEM:

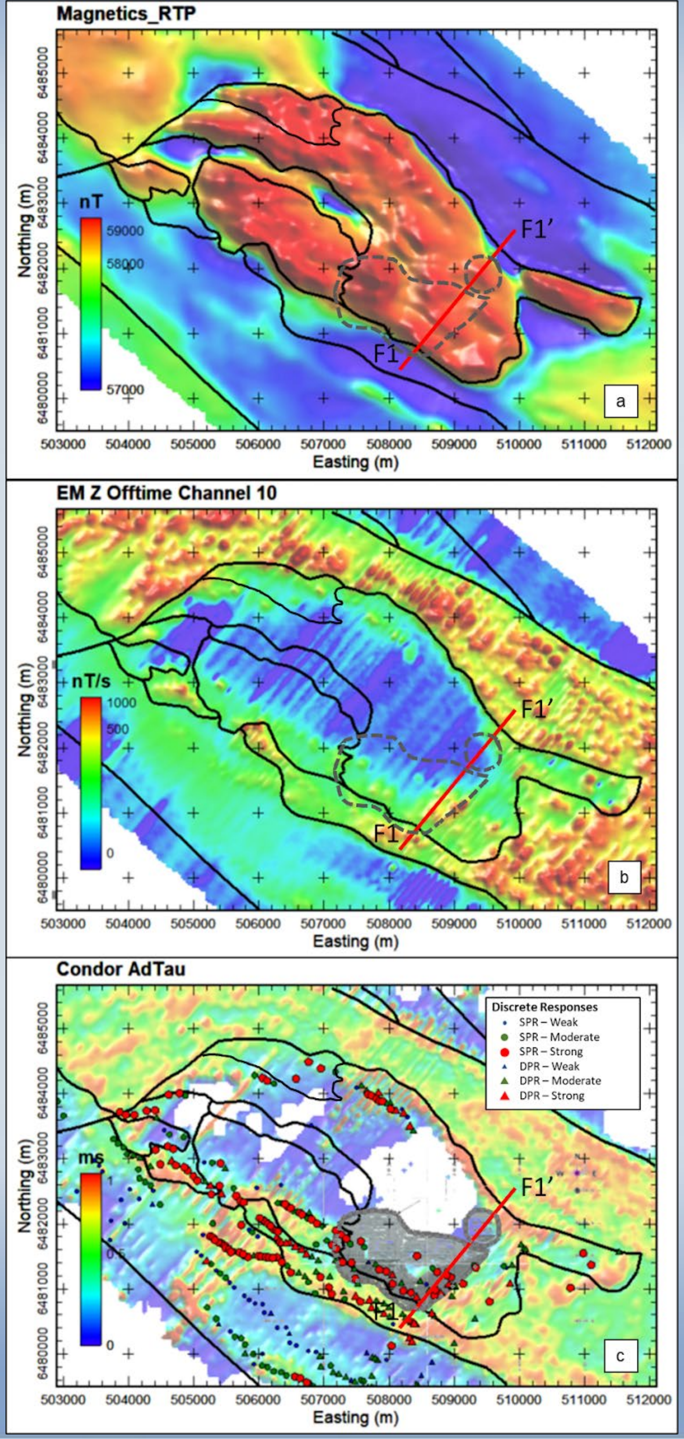
- Very high AdTau response (3-4 ms) around the M2 deposit and other areas of known mineralization.
- The conductive trend contains both single and double peak anomalies across sixteen N-S flight lines.



▲ Double Peak Anomaly
○ Single Peak Anomaly

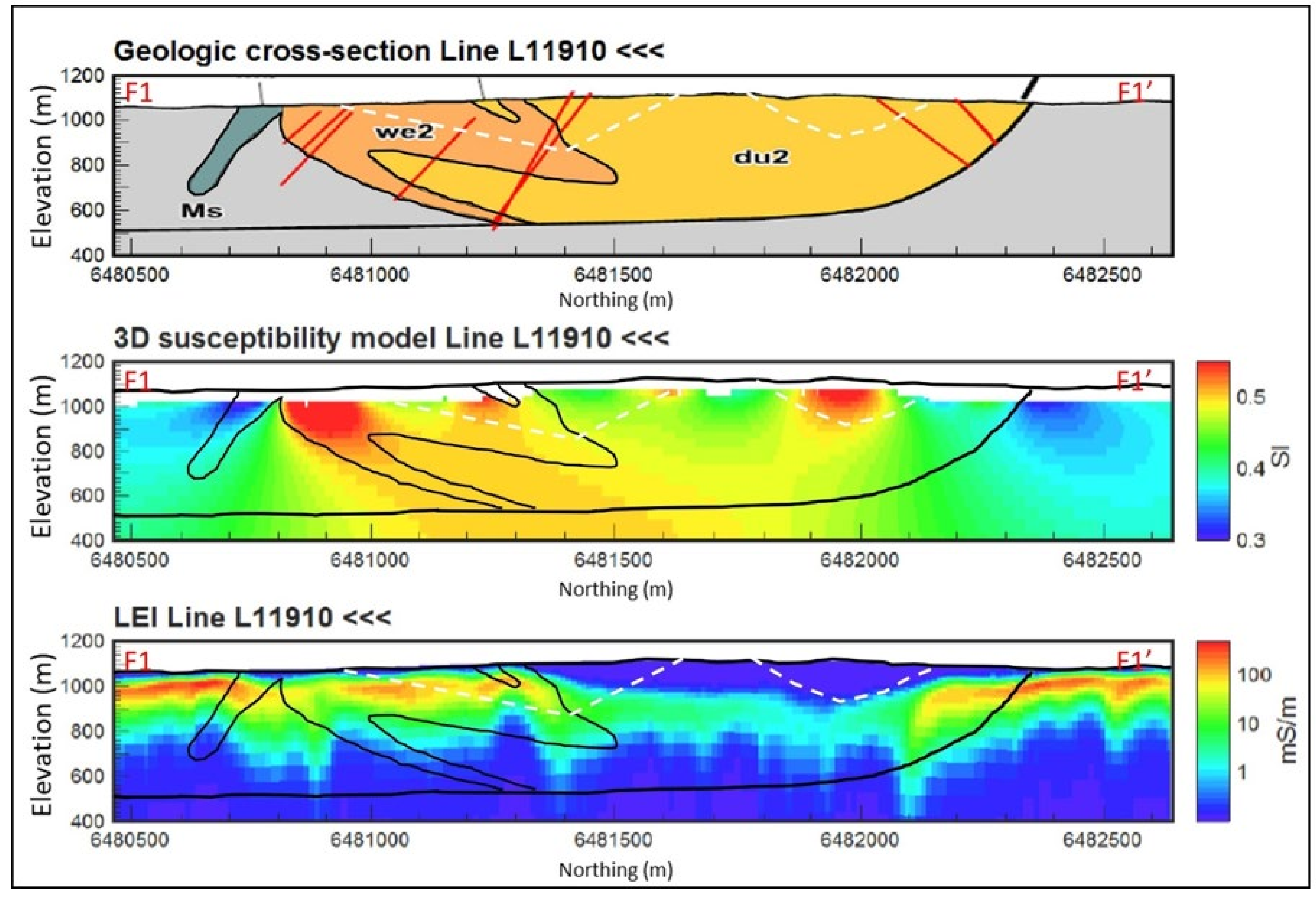
Turnagain Geophysical Responses

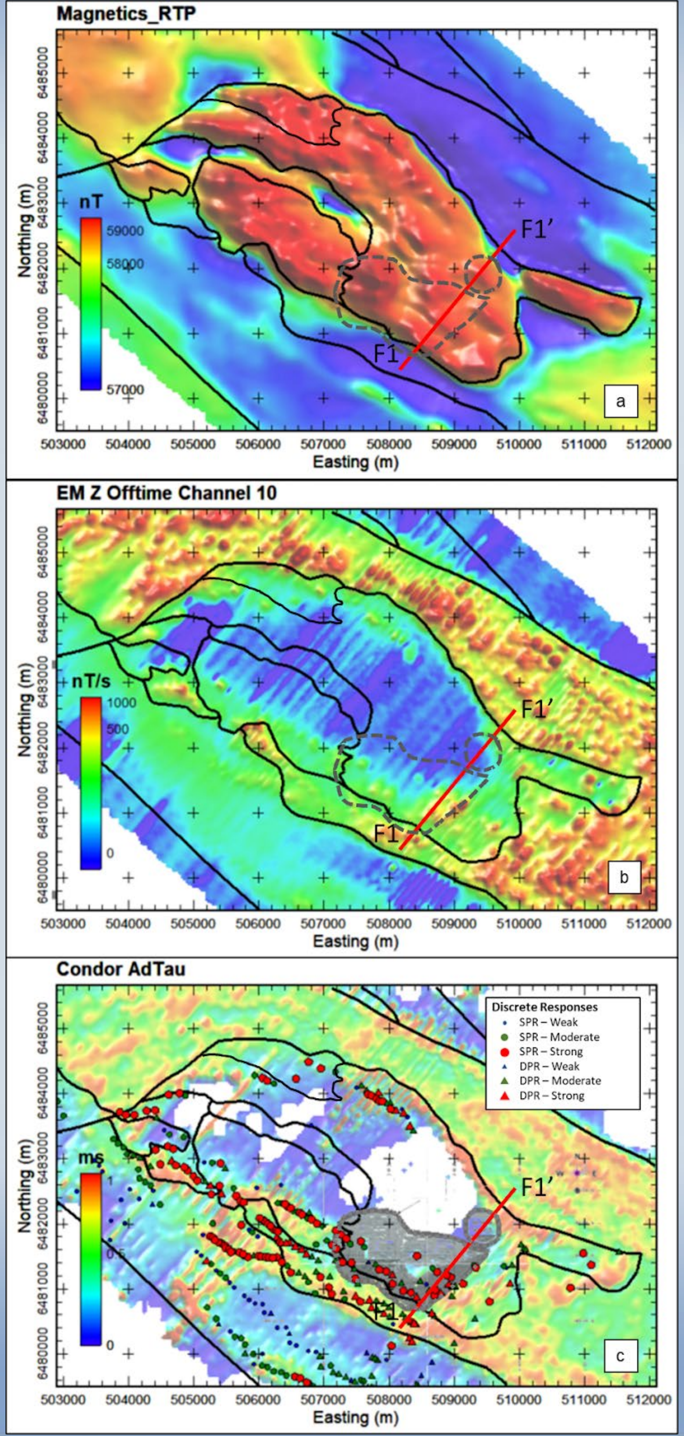
- AeroTEM data coverage over this deposit allows for comparison of EM/mag responses
- Excellent agreement between the deposit and a series of highly conductive discrete EM responses at Mayville; the association is not as clear at Turnagain
    - The intrusion complex at Turnagain is in very good agreement with a magnetic anomaly; in this case the EM does not correlate as well with known mineralization
- Time domain EM data very effectively outline the intrusive complex and regional geologic contacts; near-surface expression of the deposit is well resolved



Most recent planned pit outline

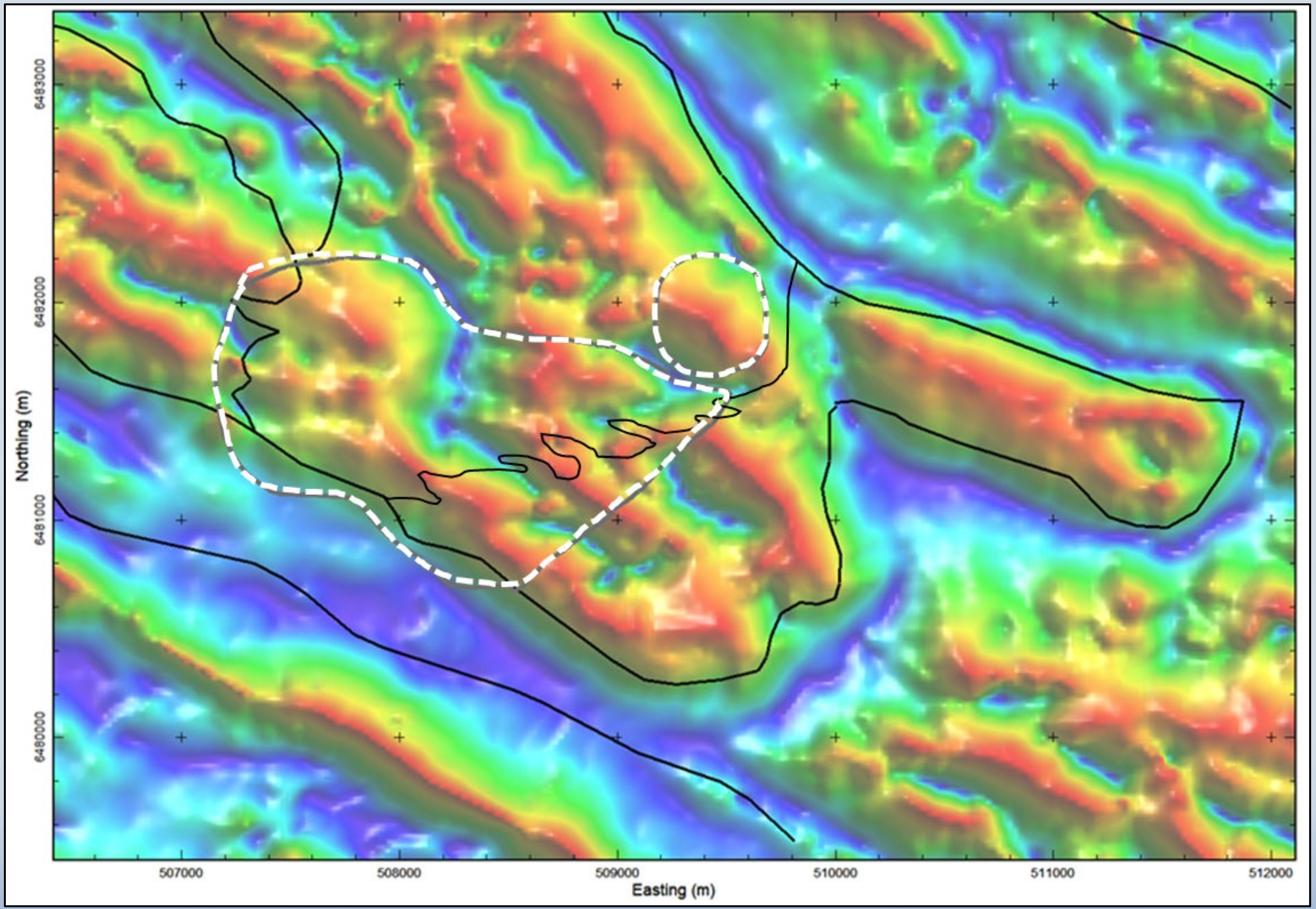
Turnagain Geophysical Responses





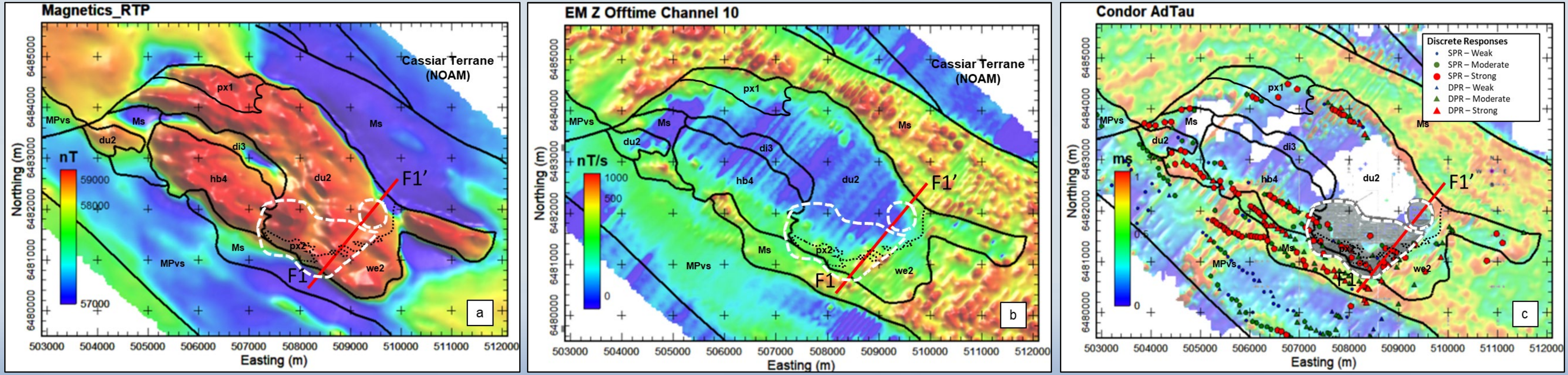
Turnagain Geophysical Responses

- The Tilt generated from the AeroTEM magnetic data reveal character within the zone of elevated magnetic response
- Some associations between intrusion phases and tilt are apparent
- Approaching limitations of survey specs



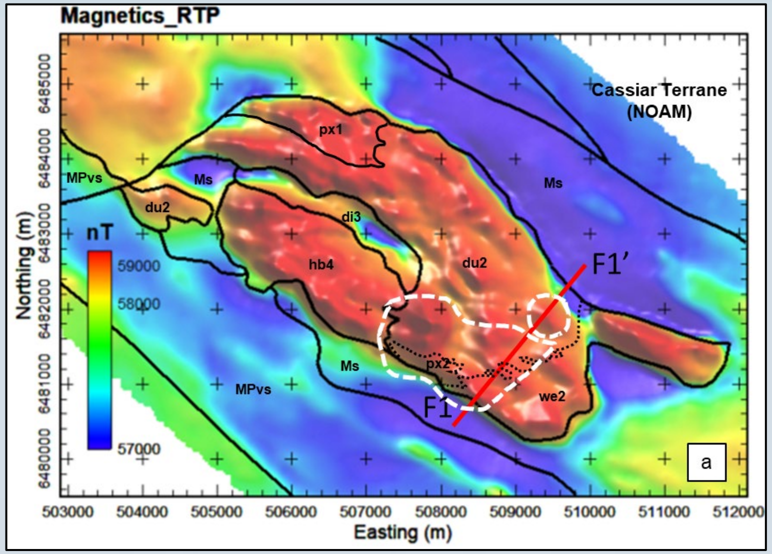
Summary of Turnagain Geophysical Responses

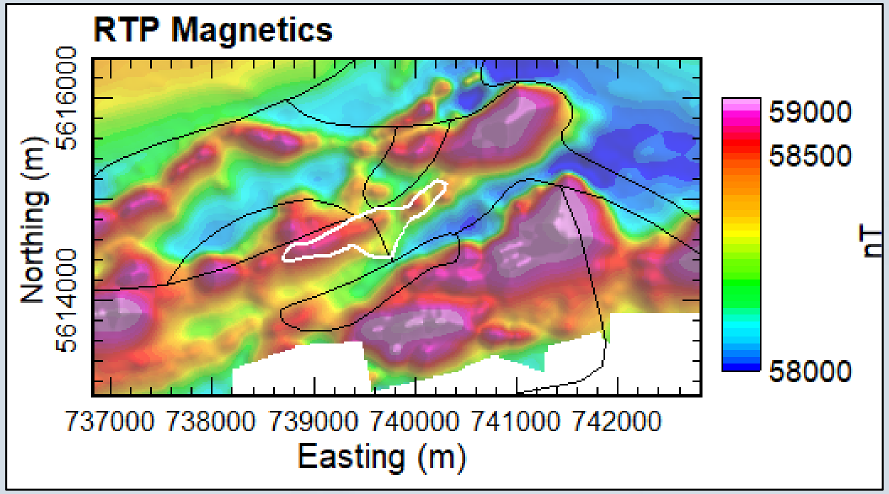
- Turnagain intrusive complex shows up as a distinct geophysical feature in both the magnetic and EM datasets and reflects good agreement with mapped geology
- The deposit area is less distinctly mapped, with some elevated EM and magnetic responses and associated conductor picks of more ambiguous significance

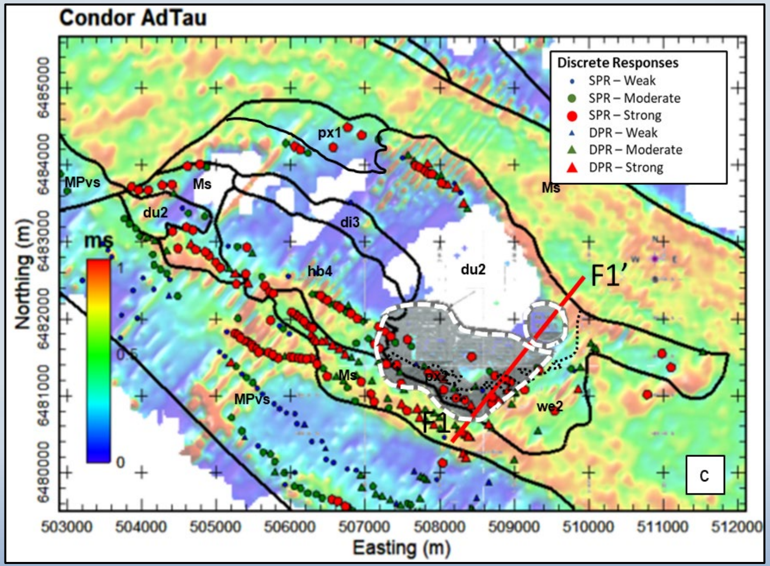


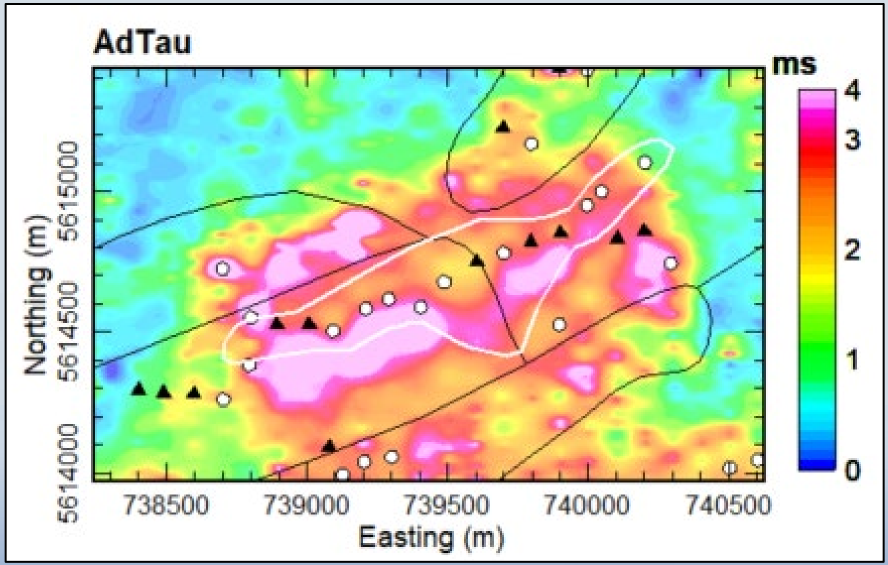
Comparison of Geophysical Responses

- Magnetic data over Turnagain highlights the intrusive complex that is related to mineralization.
- It is less obvious in the Mayville magnetics data
- There is a direct correlation with a conductor and the Mayville deposit; the Turnagain mineralization does not have a clear conductivity anomaly









Double Peak Anomaly
Single Peak Anomaly

Implications for future targeting

- Airborne EM methods remain useful in targeting traditional magmatic sulfide Ni

- AFMAG methods may allow for deeper mapping to identify large mafic/ultramafic intrusions

- Alaskan-type intrusive complexes & convergent margin settings can be prospective for economic Ni mineralization given the right geologic ingredients
  - *A key piece of this may be that the intrusion interacted with sulfur-rich host rocks*

- EM can be an effective tool for identifying these complexes and has potential to highlight mineralized zones…
- …but we cannot, and perhaps should not, expect mineralized zones in these settings to produce an EM response

- Potential follow up methods could include:
  - High resolution mag data over Alaskan-type intrusive complexes may reveal intrusive phase boundaries with implications for prospectivity
  - Use of DCIP surveys may be effective for mapping lower grade-high tonnage Turnagain-like Ni deposits
  - “Boots on the ground” geologic mapping remains an effective supplemental tool to geophysical surveying

Conclusions

- The airborne EM surveys successfully identified conductors associated with the Cu-Ni mineralization on the Mayville property, while on the Turnagain property EM was more successful at mapping the full intrusive complex

- Airborne mag and EM remain good first-pass geophysical tools in Ni exploration (for both traditional magmatic sulfides and other possible Turnagain-like deposits)

- Convergent margins may represent an underexplored region with Ni prospectivity (potentially more lower grade, higher tonnage targets)

- Detecting large mafic/ultramafic intrusions under cover can be a good first step in exploration

- Highlights the importance of studying different deposit types to add value to Ni exploration.

Thanks to

GridMetals CORP.

GIGAMETALS CORPORATION

Blake Cross

Ken Witherly

Condor Consulting, Inc.

Daniel Sattel

EM Solutions, LLC

GEOTECH

SEG SOCIETY OF EXPLORATION GEOPHYSICISTS

MTNet

Questions?

Contact information:

hannah@condorconsult.com
https://www.linkedin.com/in/hannah-peterson-gp/