GEOPHYSICAL POTENTIAL FIELD DATA APPLIED TO BETTER UNDERSTAND CRUSTAL SCALE CONTROLS ON METAL ENDOWMENT

Esmaeil Eshaghi

Research Associate, Metal Earth

MERC short course program

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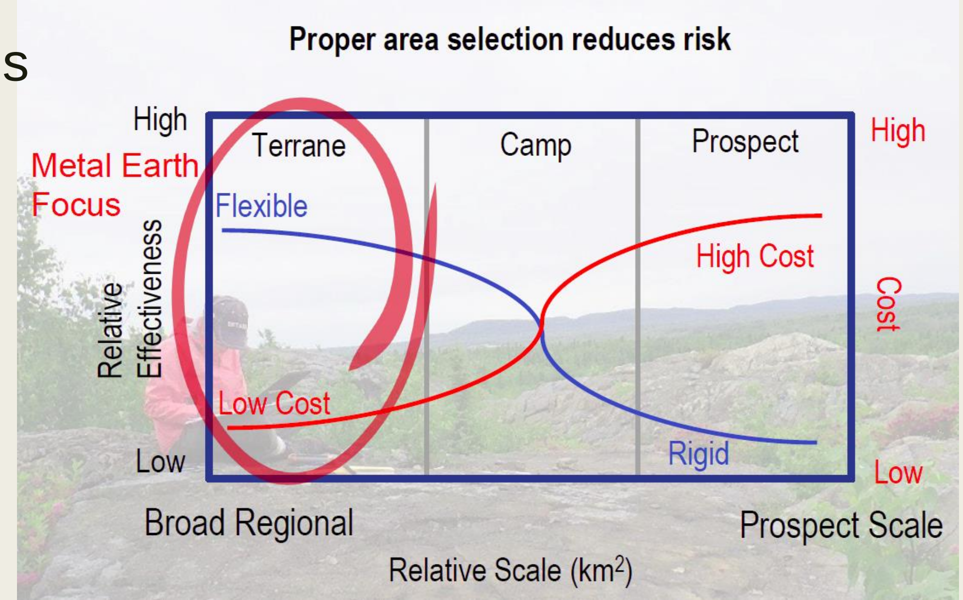
- Integration of multidisciplinary geological and geophysical data (surface geology, stratigraphic sections, seismic data, petrophysical measurements, and potential field data etc.).
  - *Integrated **Modelling**.*

Metal Earth strategy

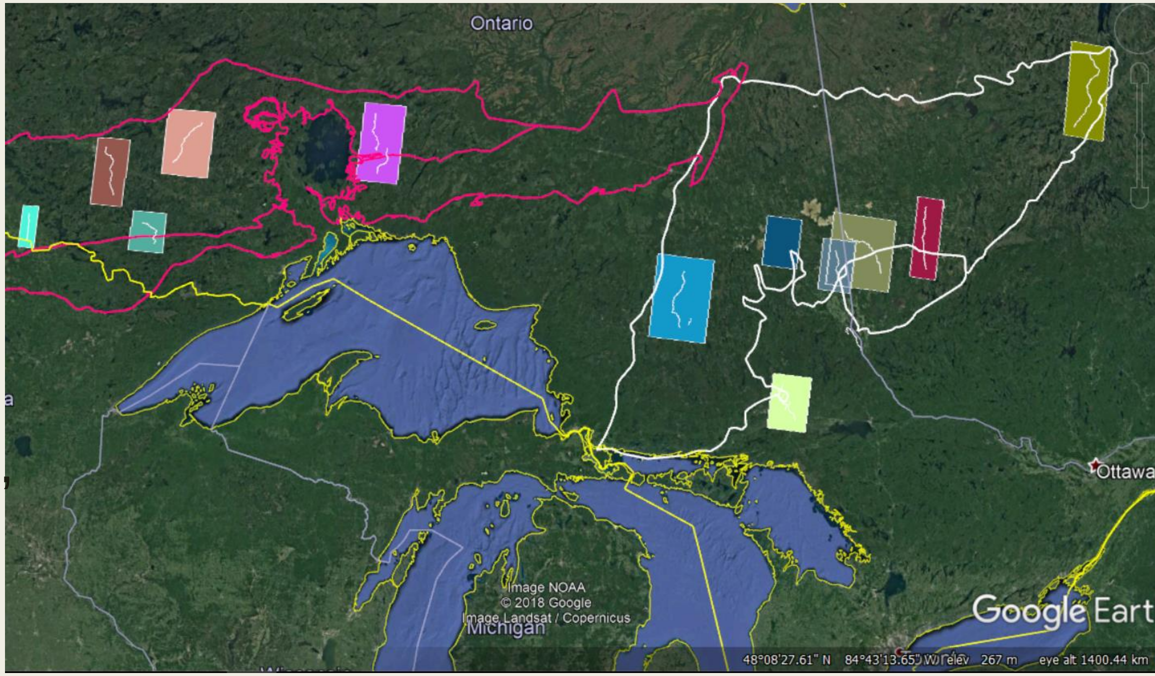
- Mineral Exploration Research Centre (MERC) is a collaborative centre for mineral exploration research and education supported by industry, government and Laurentian University.
- Metal Earth is a MERC led collaborative research project, fully-funded seven-year $104M, focused on metal endowment on Archean greenstone belt to improve understandings of key mechanisms responsible for the genesis of base and precious metal deposits.
- Image ore and non-ore systems

  at full crust-mantle scale.



Metal Earth transects

- 13 transects within Superior Craton across Abitibi and Wabigoon Subprovinces.
- In Summer 2018, ~50 field crews of professors, mentors, supervisors, RAs, students and field assistants in the field, collecting geological, geophysical and petrophysical data.



Application of potential field data for mineral exploration

- Potential field methods (i.e. magnetic and gravity data) can be used for mineral exploration either for:
  - *Direct exploration of minerals:*

    Magnetic methods

    - *some iron ore deposits (magnetite or banded iron formation)*

    Gravity

    - *deposits of high-density: chromite, hematite, and barite*
    - *deposits of low-density halite, weathered kimberlite, and diatomaceous*
  - *Indirect exploration such as identification of:*

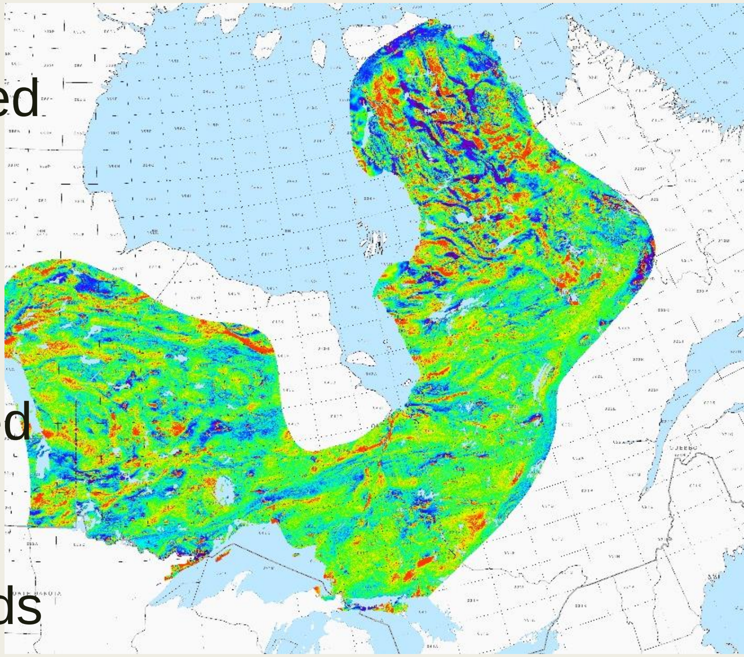
    Geological features (intrusions, alterations, metamorphisms and halos)

    Geological mapping

    Geological boundaries (e.g. faults and folds)

Magnetic data compilation and processing

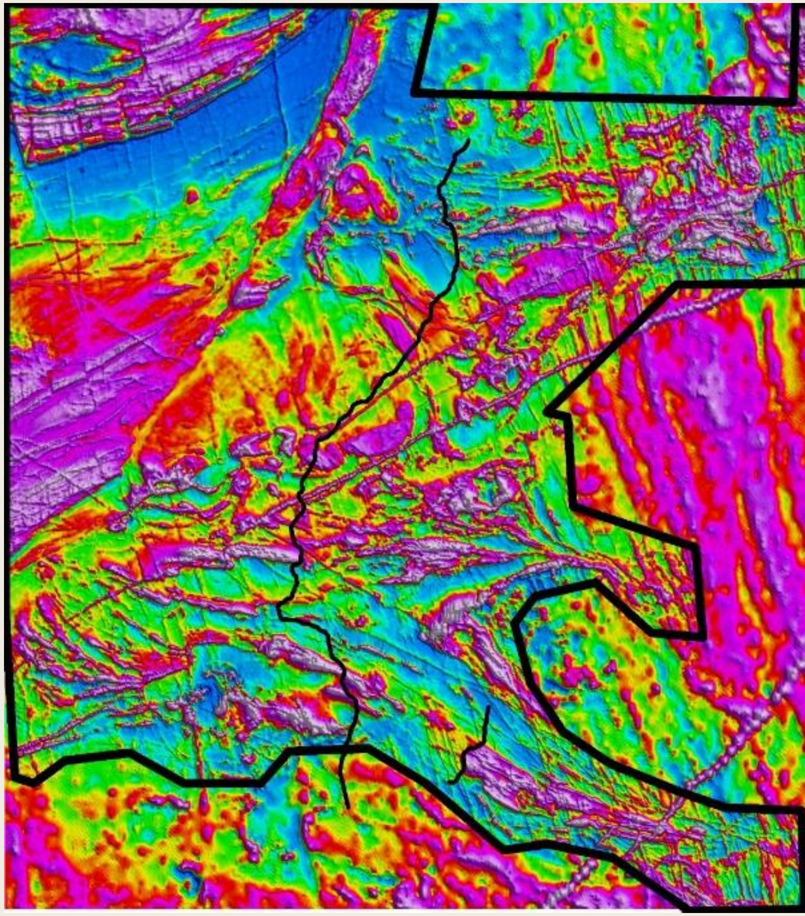
- Magnetic data associated with different resolutions, elevations and acquisition equipment have been compiled (e.g. GSC, OGS, MERN, ME partnerships, ME drone surveys).
- The highest resolution data were selected and combined to obtain a consistent coverage along transects.
- Compiled magnetic grids were processed and products (e.g. RTP, 1VD, 2VD, Tilt, etc.) are delivered in both formats of grids and maps (geotiff).



Superior scale magnetic grid (Montsion et al, 2018)

Example: SW transect

- Most of the area is covered by OGS, Geophysical DataSet-1037 (40mCS, 70mLevel).
- S and E of the area is blank and Ontario Master Grid (250mCS, 305mLevel) was used to fill the AOI.
- Ontario Master Grid was re-levelled and stitched to the high resolution grid for a consistent coverage.



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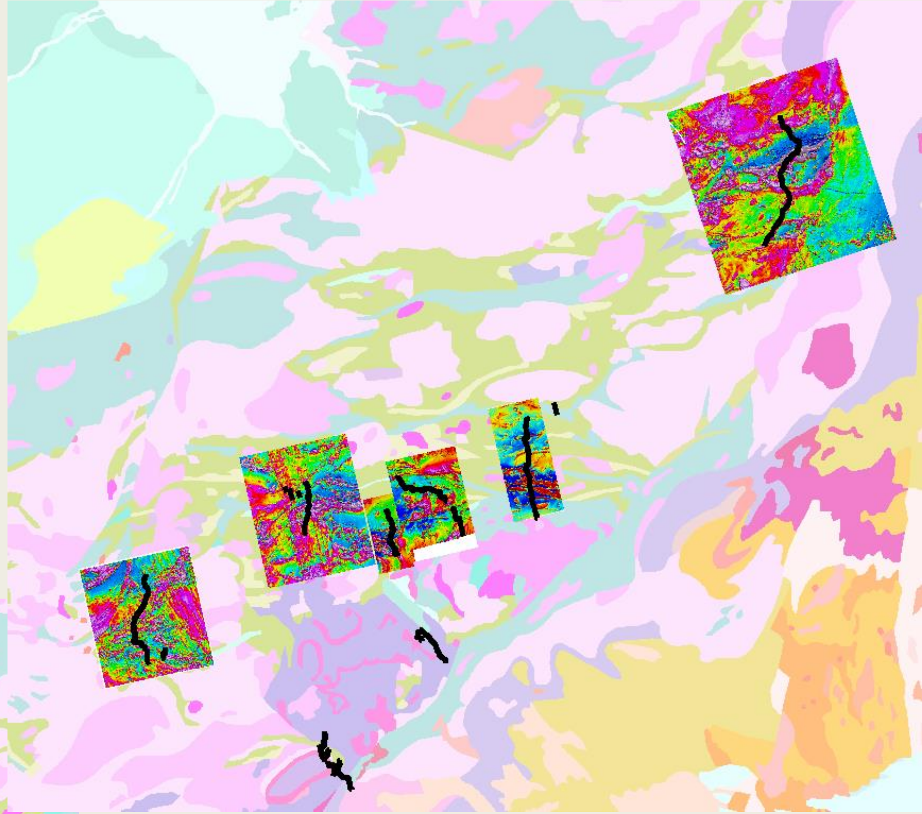
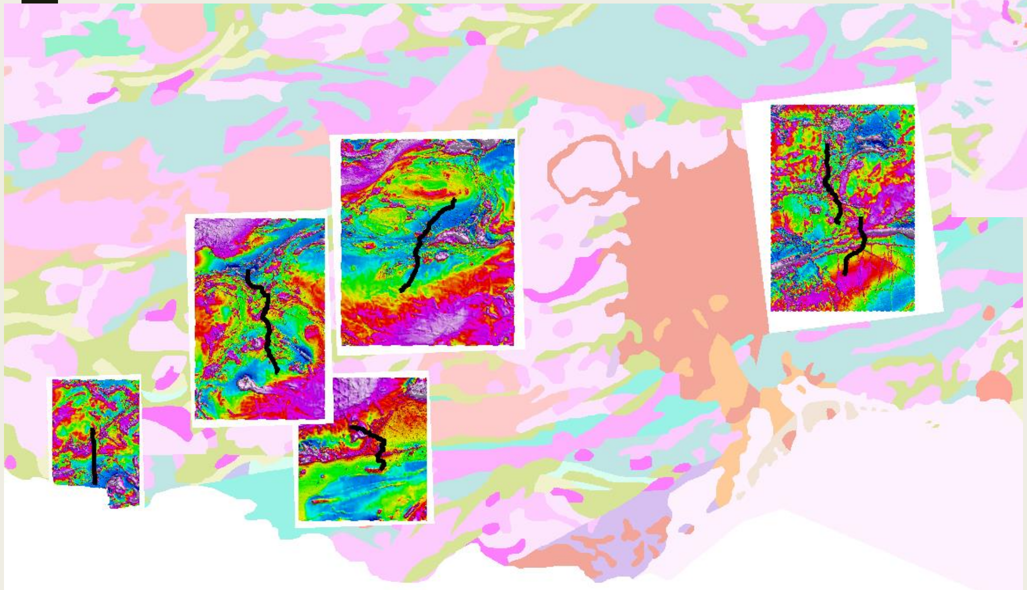
Magnetic Products



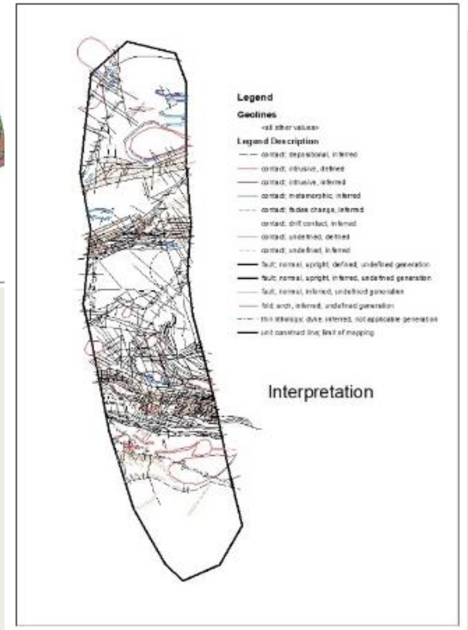
Grids across Abitibi

Grids across Wabigoon



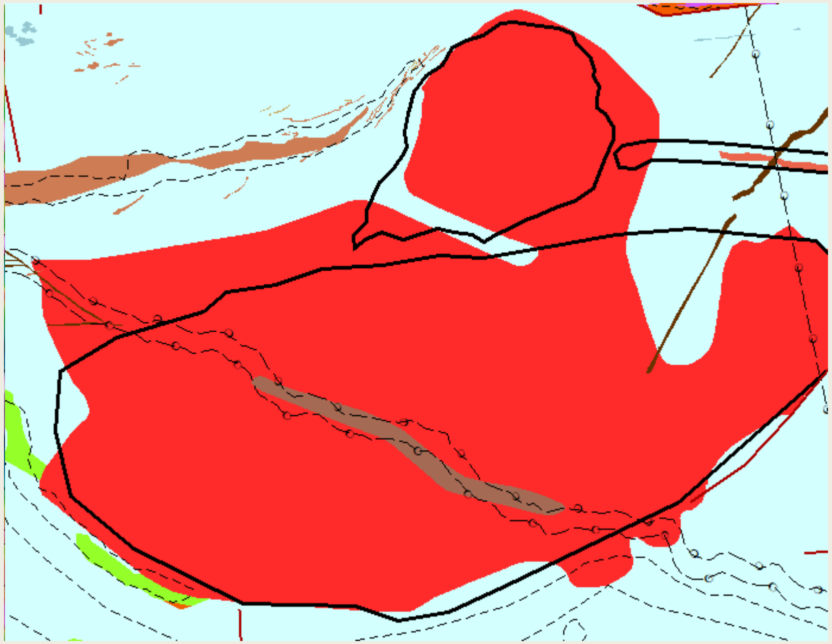
Geological interpretation of magnetic data

- A buffer zone of 7-10 km surrounding transects are interpreted using magnetic grids to assist geologists.
- Magnetic features (e.g. lineaments, high magnetic responses, dykes, intrusions, etc.) were delineated.

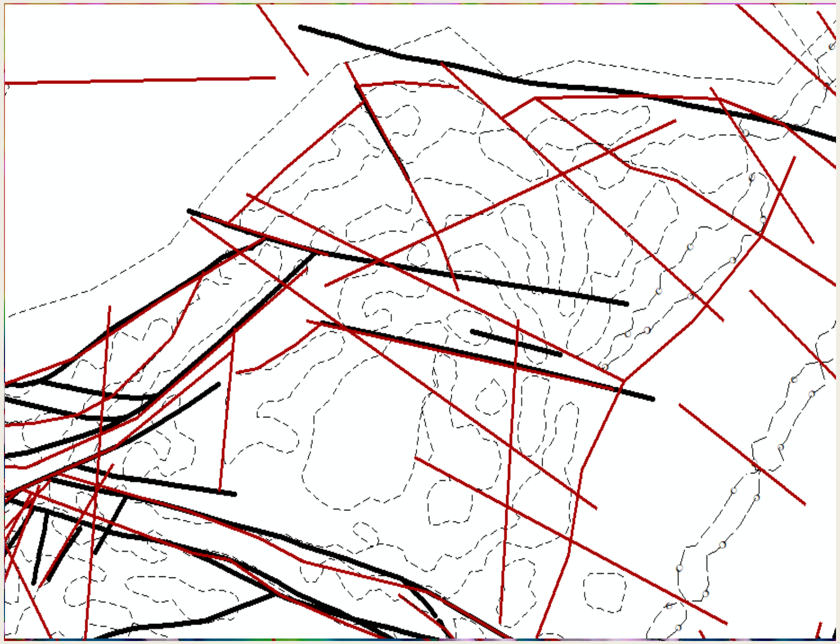


Magnetic interpretation of AM transect

Magnetic Interpretations (Examples)



Magnetic interpretation of an intrusion, south of Malartic (AM transect).



Magnetic interpretation of fault network, north of Malartic (AM transect).

Gravity data collection and processing

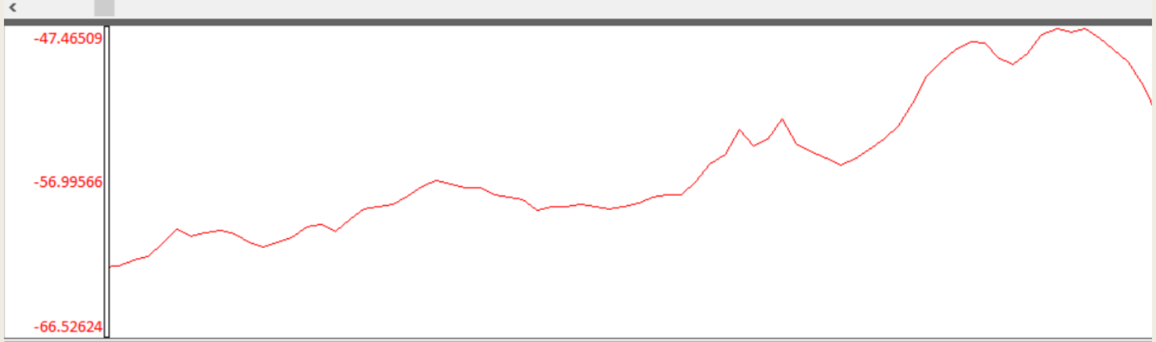
- Geophysical field crews have been collecting gravity data along seismic transects.
- Gravity data from GSC were collated for each AOI.
- Gravity data collected by ME were processed and Free Air anomaly, Terrain correction, and **Complete Bouguer Anomaly** were calculated.
- A combined grid was created for each transect consisting of both ME and GSC data.

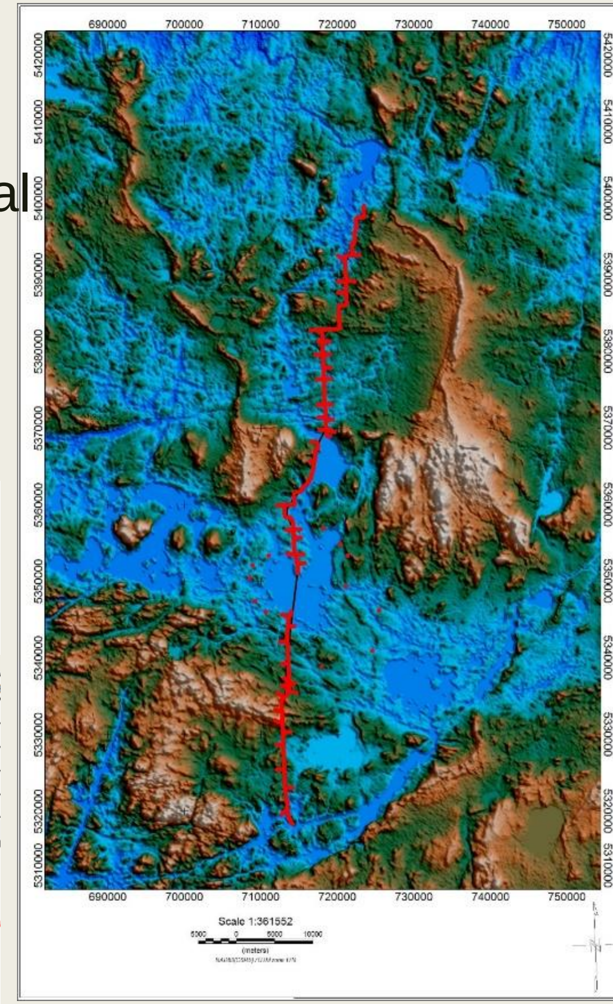
Gravity data collection and processing

- So far, ME geophysicists have acquired a total of 2974 gravity readings along approximately 822 line- kilometres (1066 gravity readings along 309 line-kilometres in 2017, and 1908 gravity readings along 523 line-kilometres in 2018).

RN_BL_GSC_Gravity_Observations_Processed.gdb
RN_BL_GSC_Gravity_Observations_Processed_HighErrorsRemoved.gdb
RN_Gravity_Observations_combined_ME_GSC.gdb
RN_ME_Gravity_Observations_Processed.gdb

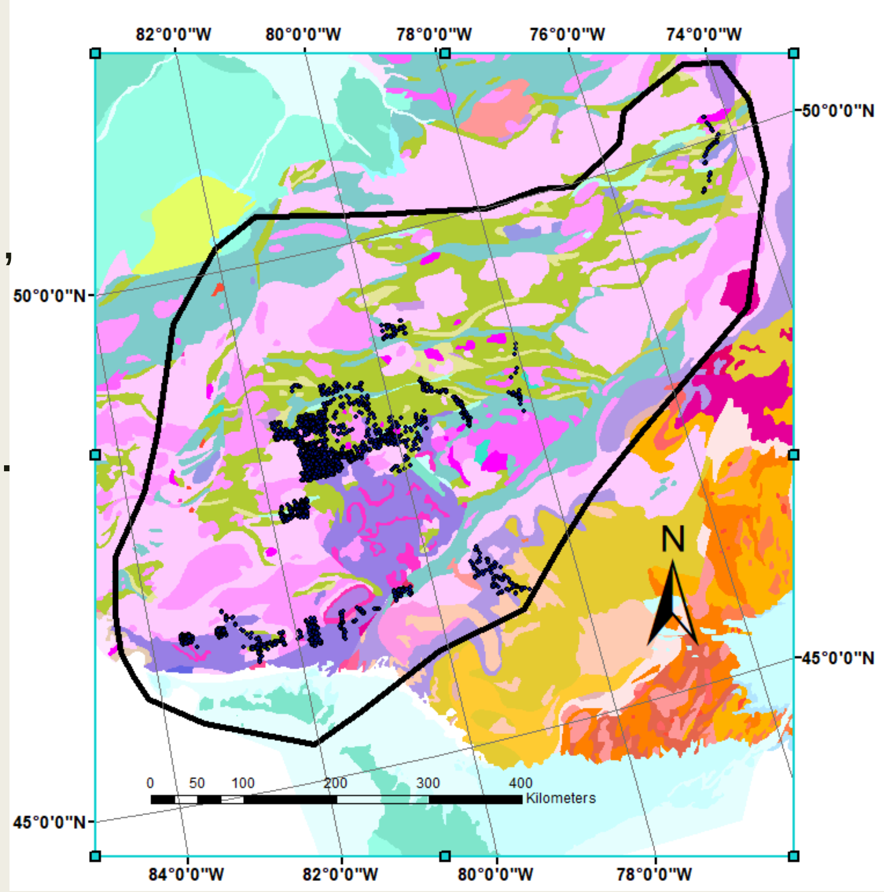
LSouth	Longitude	Elevation	Date	Observe_gravity	Terrain	Free_Air	Bouguer_Anomaly	Complete_Bouguer_Anomaly
11.0	-78.14	298.75	20170809	980767.6899	0.1332	-31.17448	-65.0100	-64.87678
12.0	-78.14	299.83	20170809	980768.3115	0.0702	-30.43424	-64.3916	-64.32146
13.0	-78.14	299.62	20170809	980768.8540	0.0584	-30.20908	-64.1426	-64.08423
14.0	-78.14	306.09	20170809	980768.1244	0.0504	-29.17661	-63.8425	-63.79213
15.0	-78.14	308.60	20170809	980768.4773	0.0284	-28.31455	-63.2641	-63.23569





Petrophysical characterisation

- Magnetic susceptibility and density data (> 36000 mag sus and > 43000 density) were compiled from various sources (e.g. GSC, OGS, Minnesota, ME, Footprint).
- Two sets of datasets are compiled (Abitibi and Wabigoon).
- Across Abitibi, >12800 mag sus and > 14300 density measurements were compiled, assessed and combined.
- Petrophysical data are systematically characterised.



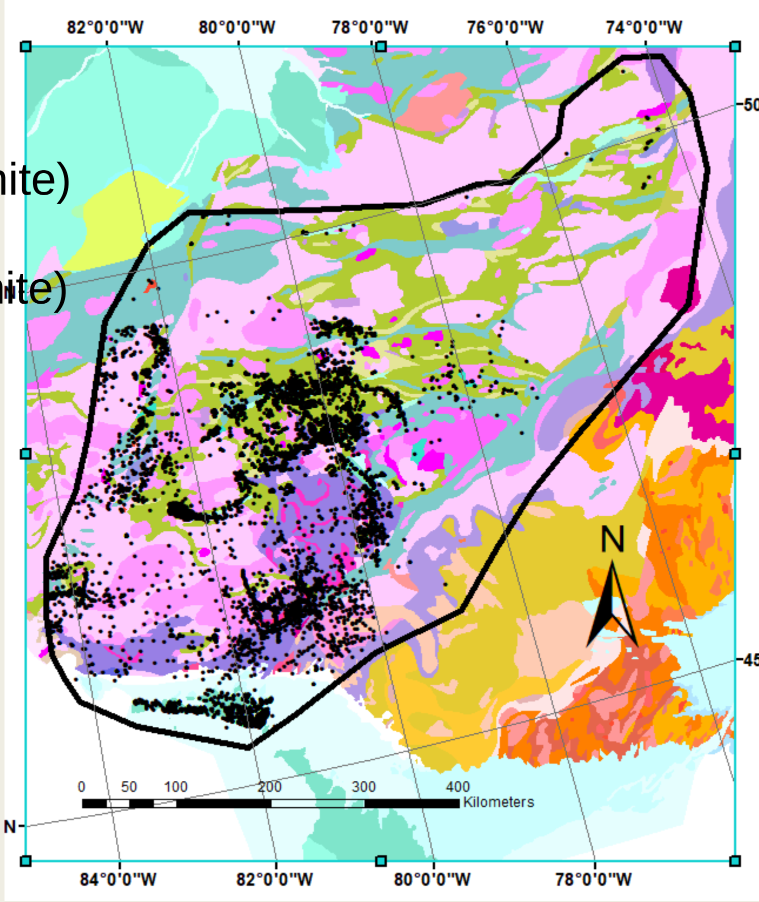
Distribution of mag sus measurements within Abitibi greenstone belt.

Lithological hierarchy

Igneous rocks

- **Plutonic**
  - **Felsic** (e.g.Granite, tonalite,Trondhjemite)
  - **Intermediate** (e.g. Dirotie, Monzonite, Syenite)
  - **Mafic** (e.g. Anorthosite, Gabbro, Norite)
  - **Ultramafic** (e.g. Dunite, Peridotite, Pyroxenite)
- **Volcanic**
  - **Felsic** (e.g. Dacite, Rhyolite)
  - **Intermediate** (e.g. Trachyte)
  - **Mafic** (e.g. Andesite, basalt)
  - **Ultramafic** (e.g. Komatiite)

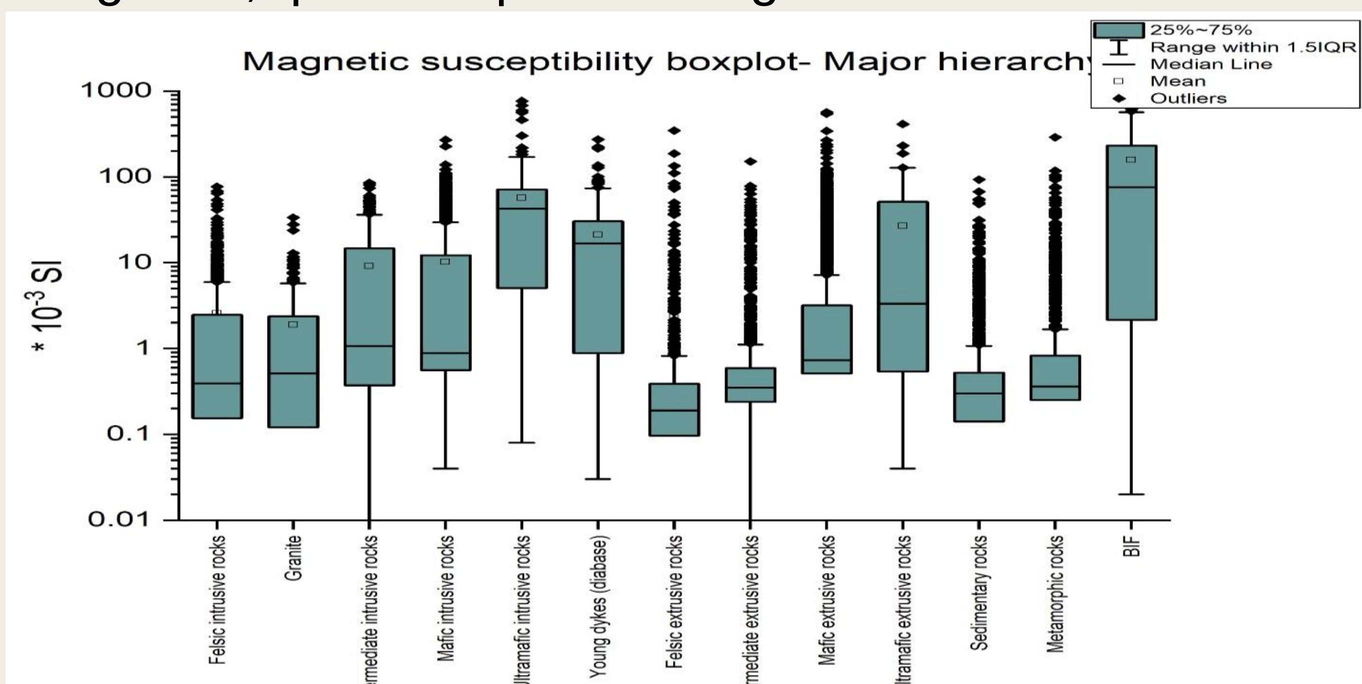
Metamorphic
Sedimentary
Young Dykes (Diabase)
Fault rocks (e.g. Mylonite, Pseudotachylite)



Distribution of density measurements within Abitibi greenstone belt.

Petrophysical characterisation

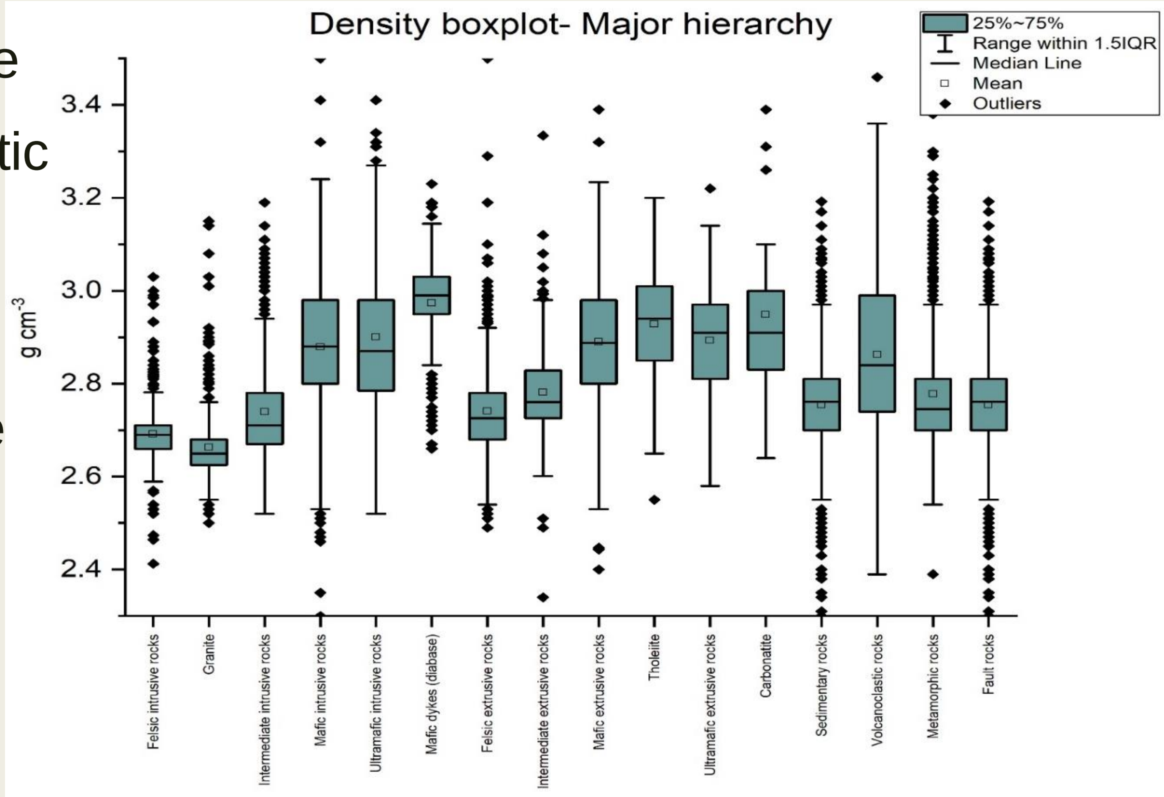
- Magnetic susceptibility and density datasets can define the average and range of properties to provide model constraints.
- Therefore, petrophysical properties are divided based on the lithology and histograms, quantile-quantile diagrams and boxplots are plotted.



Boxplot of magnetic susceptibility of major lithological units.

Petrophysical characterisation

- Felsic igneous rocks represent relative low magnetic susceptibility and density properties, while UM and diabase return high mag sus and densities.
- Sedimentary rocks are generally non-magnetic with a wide range of densities.
- BIFs highlight a range of mag sus from low-mag to highly magnetized.



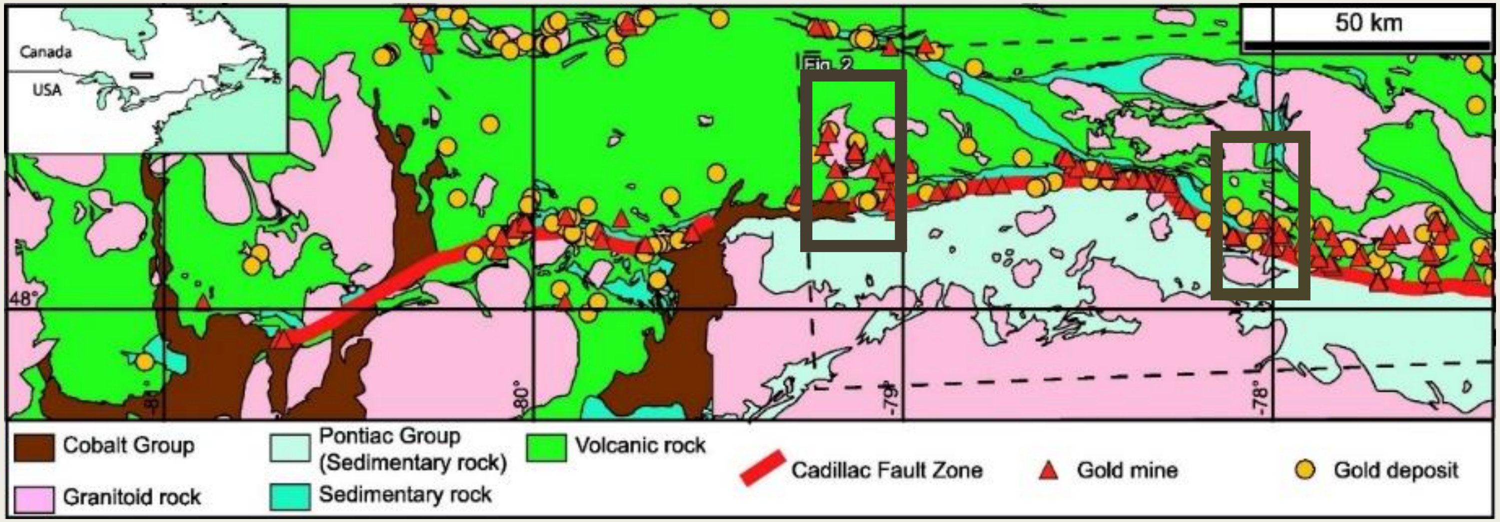
Boxplot of density of major lithological units

Characterised properties

Unit	Subgroup	Sub-group 2	Density (g cm^{-3})		Magnetic susceptibility($\times 10^{-3}$ SI)	
			Value	Range	Value	SD
Felsic intrusive			2.69	2.63—2.75	1.76	6.21
	Granodiorite		2.69	2.63—2.75	2.82	5.53
		Unit-1			0.28	0.21
		Unit-2			5.79	7.06
	Trondhjemite		2.66	2.62—2.70		
	Tonalite				1.44	2.62
	Granite		2.65	2.61—2.69	1.45	3.52
	Felsic to intermediate intrusion		2.69	2.62—2.76	2.27	8.87
		Unit-1			0.21	0.32
		Unit-2			14.90	10.70
Intermediate intrusive rocks			2.74	2.63—2.85	9.14	14.39
	Monzonite		2.66*	2.50—2.82		
	Syenite		2.71	2.63—2.79	11.80	12.37
	Diorite		2.83	2.70—2.95	0.45*	12.01
Mafic intrusive rocks			2.88	2.74—3.02	0.88*	19.87
	Norite		2.88	2.74—3.02	1.63*	6.59
		Unit 1			0.60	0.20
		Unit 2			32.79	26.51
	Norite mssve		2.82	2.76—2.88		

Integration of multidisciplinary datasets

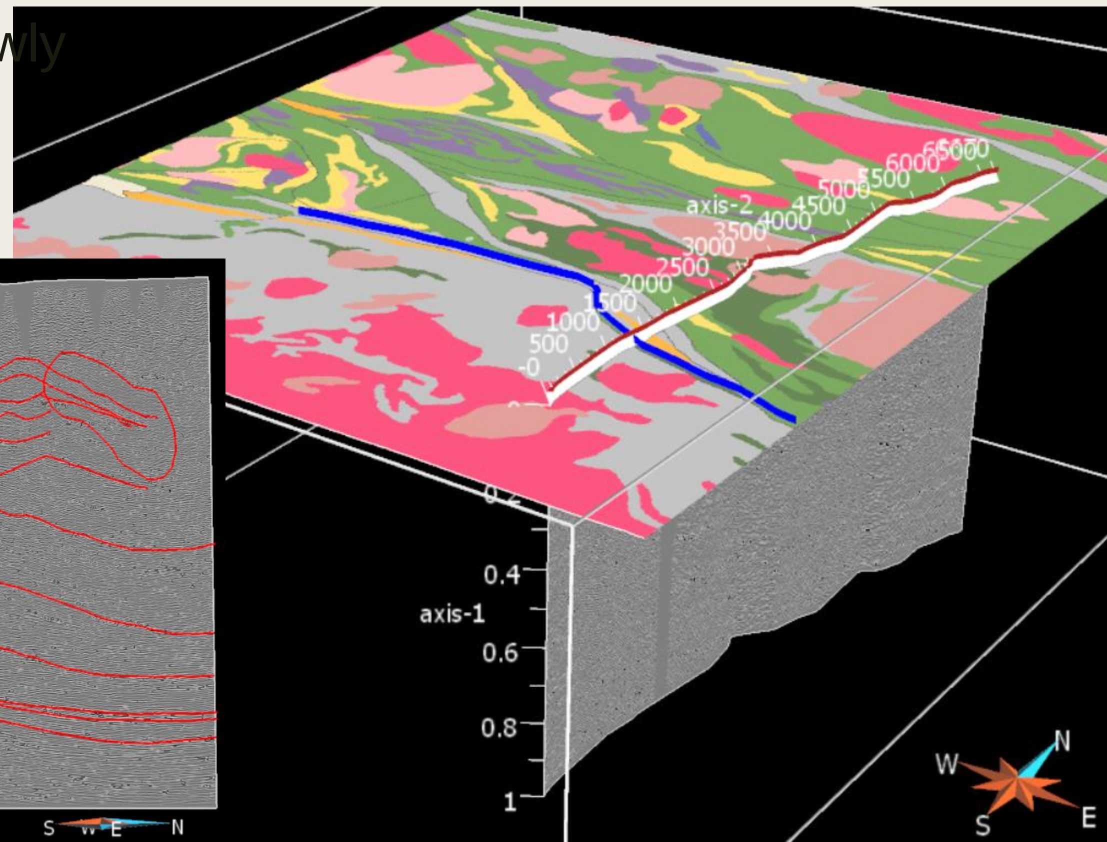
- Cadillac-Larder Lake Fault (CLLF) in south of the Abitibi Greenstone Belt is associated with a high number of Au-mineral occurrences (e.g Canadian Malartic Gold Mine).
- Amos-Malartic (AM) transect intersects this major fault.

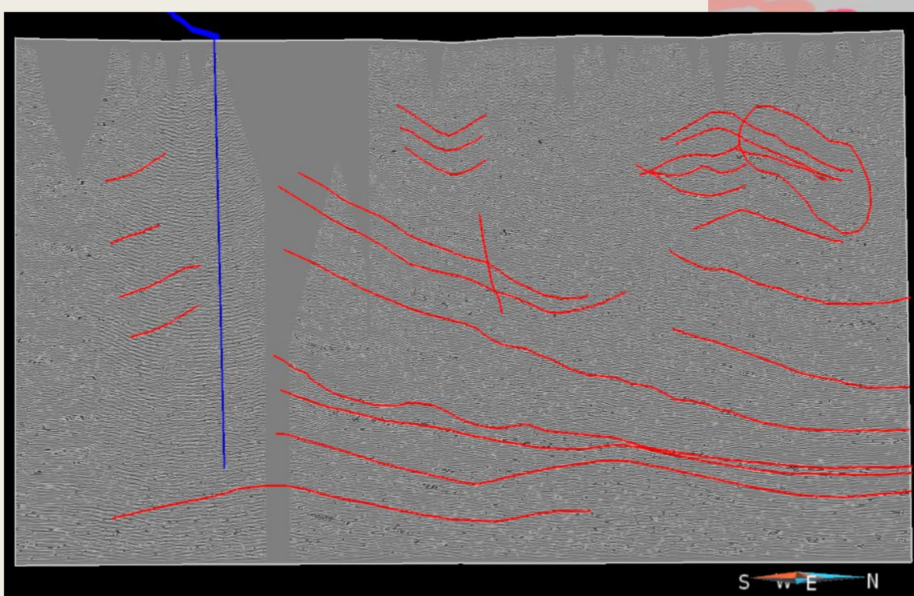


Bedeaux et al. (2017), Ore Geology Reviews, v. 82, pp. 49-69

Seismic data interpretations

- Seismic section across the AM section, shown with the geology map superimposing topography on top, indicates some notch areas where no source points were possible due to lack of access for the vibrators.
- Sub-horizontal and shallowly dipping reflections are extensive in the mid-crust.

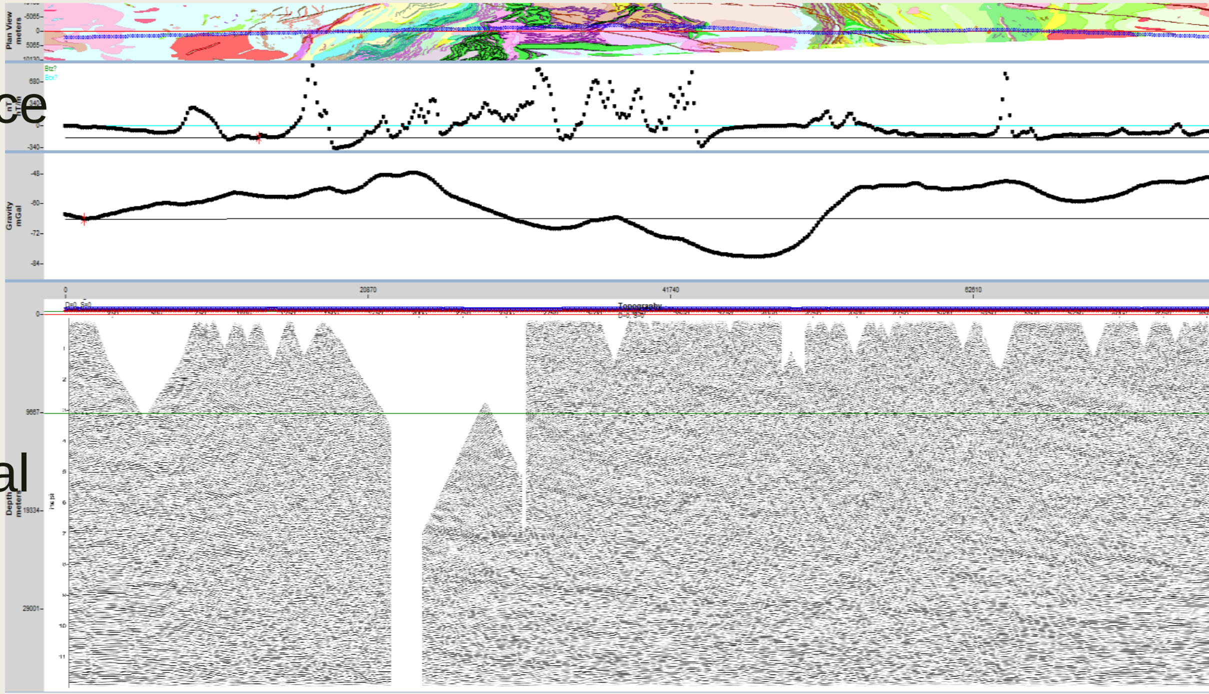




Integrated constrained modelling

- Integration of multidisciplinary data (e.g. surface geology, seismic sections, petrophysical data, potential field geophysical data) for a constrained modelling.

- Construct valid models constrained by geological and geophysical data
- Sections honor surface geology and depth seismic information
- Identify components participating in mineral endowment



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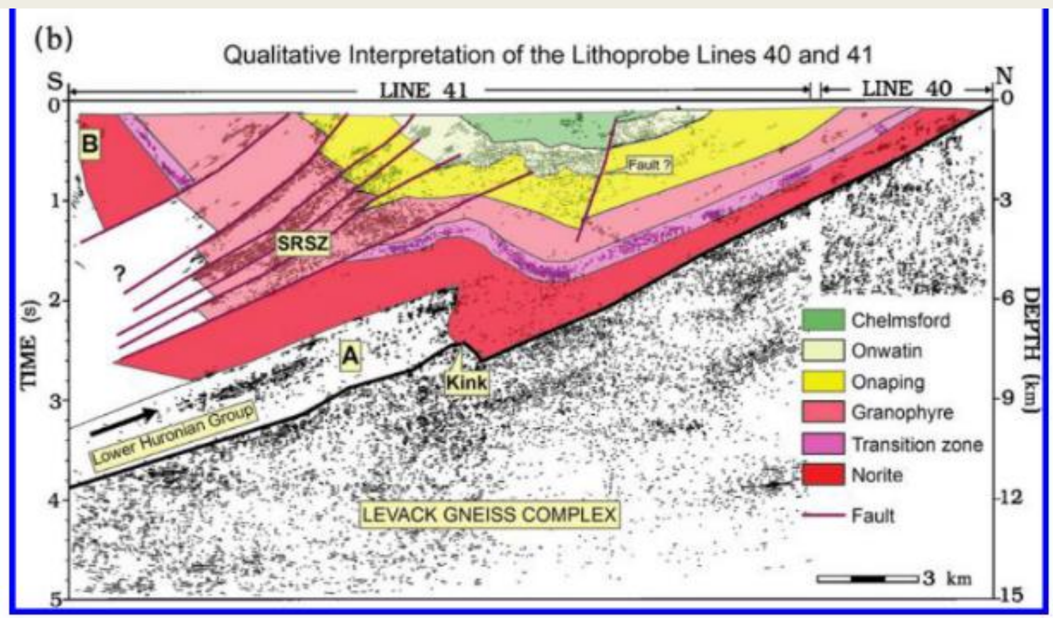
Constrained 2D modelling of potential field data

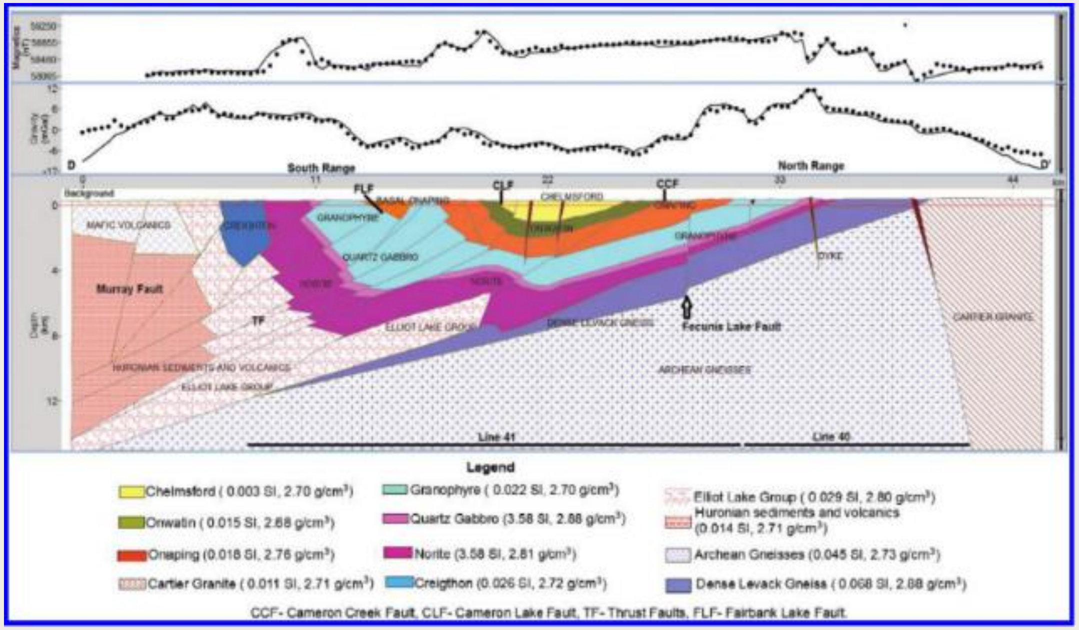
- Surface geology will be used to constrain the model
- Seismic 2D models assists to delineate/interpret deep boundaries and constrain deep features.
- Petrophysical characterisations will be utilized to constrain properties



Geological interpretation of seismic sections in Sudbury area (Olaniyan et al., 2014)

Constrained 2D modelling of potential field data

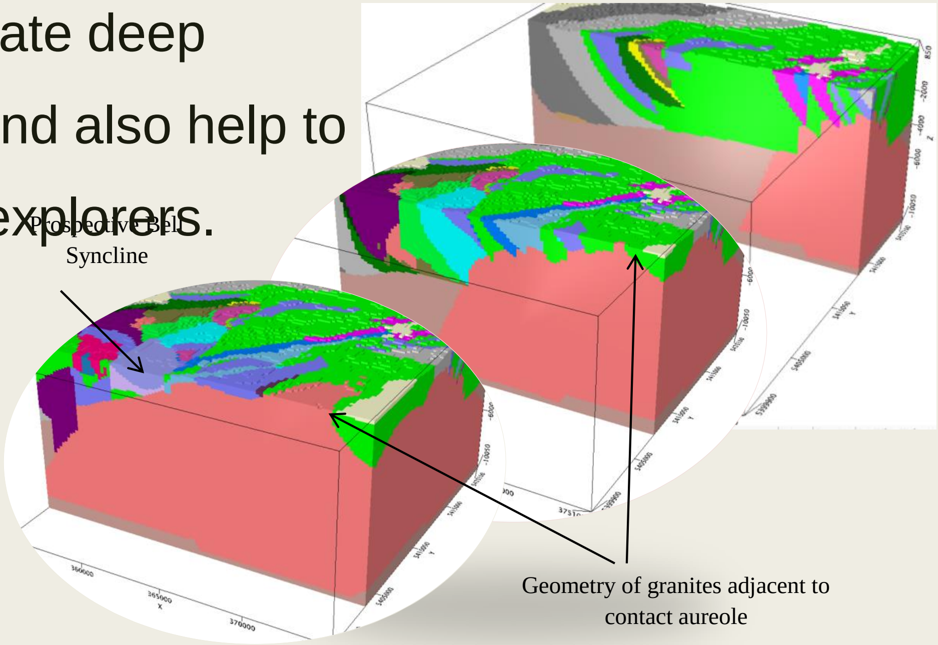
- Forward and inverse modelling of gravity and magnetic data can assist to modify and improve geometry and property of subsurface features based on the petrophysical property contrasts (e.g. felsic plutons and dykes).
- The model can identify sources of mineralisation and pathways.



Constrained 2D modeling of potential field data in Sudbury (Olaniyan et al., 2014)

Integrated advanced 3D modelling

- The initial 3D model will be constructed using available information (e.g. geology maps, seismic sections, geology sections, etc.).
- The model will be refined using 3D inversion of gravity and magnetic methods constrained by petrophysical data.
- The refined model can investigate deep constraints on mineralisation and also help to direct the activities of mineral explorers.

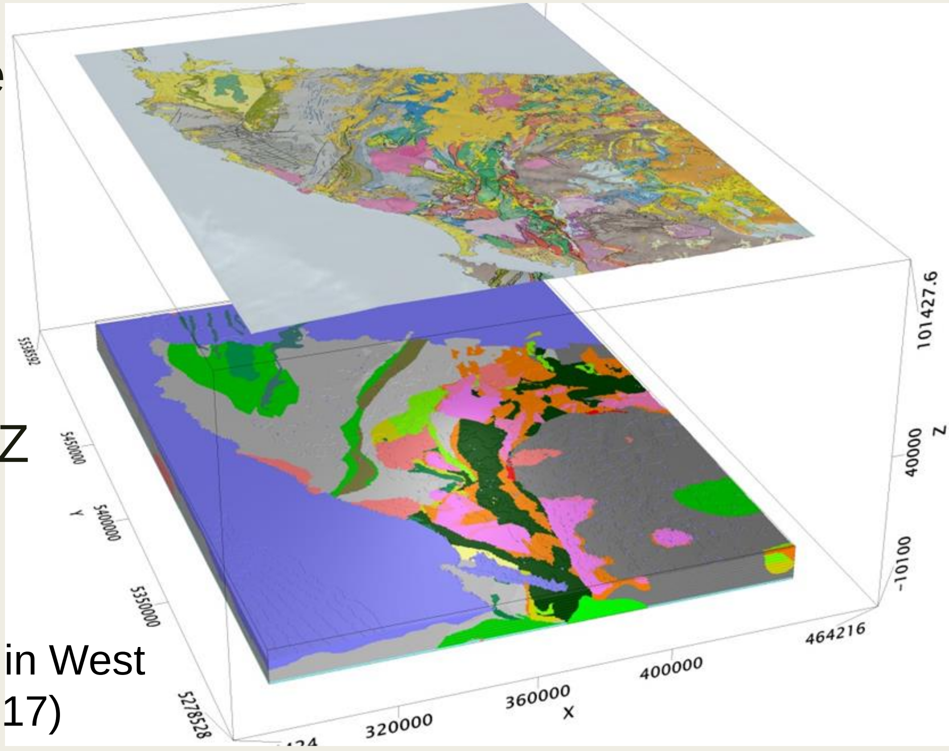


3D model constructed to assist geologists and mineral explorers in Tasmania(Eshaghi, 2017)

Constrained 3D modelling, Example 1

- West Tasmania is very prospective for multiple mineral deposits.
- Basement of this area exhibits rocks from Mesoproterozoic to current eras.
- Three major orogenic events are identified (Wickham, Tyennan and Tabberabberan Orogenies).
- Extent of AOI:

  158km EW, 216km NS, 10km Z

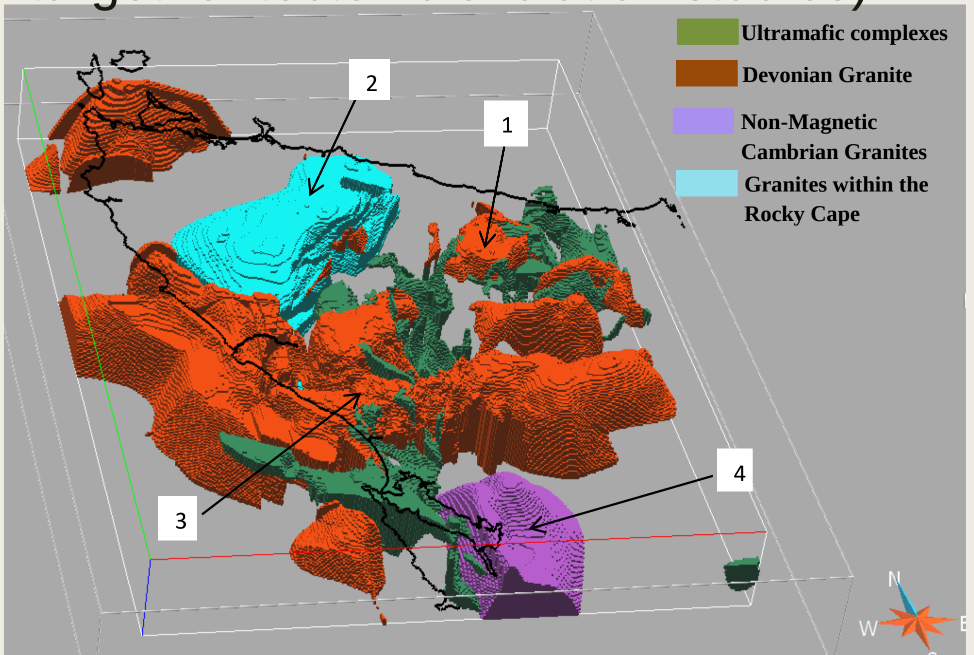


Constructed 3D model in West Tasmania (Eshaghi, 2017)

Constrained 3D modelling, Example 1

- This model identified four regions where exhibit high misfit between forward modelling and geophysical responses.

- Detailed investigation of the four regions suggested the presence of a new granitic intrusion at depth (a target for tectonic evolution studies) and new geometry of Devonian Granites and CMUC (assisting future mineral explorations).

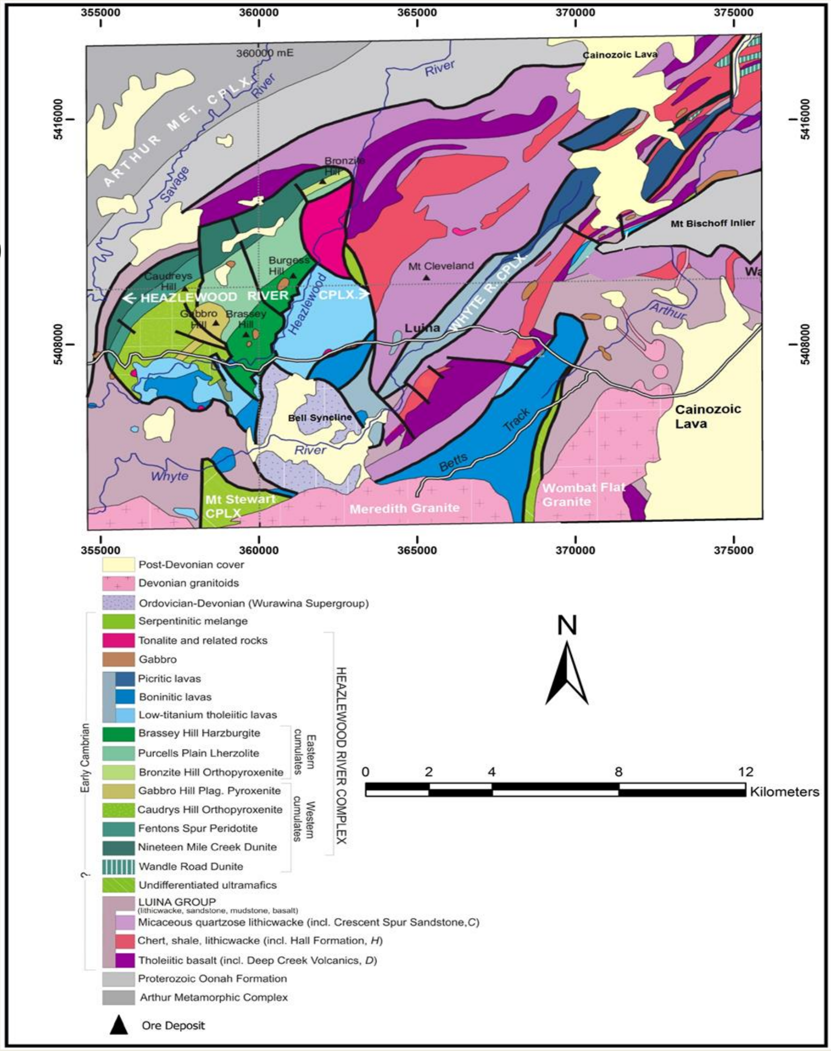


Refined geometry of the major units across the study area (Eshaghi, 2017)

Constrained 3D modelling, Example 2

- HLW region is highly prospective area in NW Tasmania with two group of mineralisation (related to CMUC, or Devonian hydrothermal events).
- The area was very complex and hardly accessible.
- AOI is covered by geology maps with different resolutions.
- Extent of the AOI:

  20 km EW × 20 km NS × 10 km Z



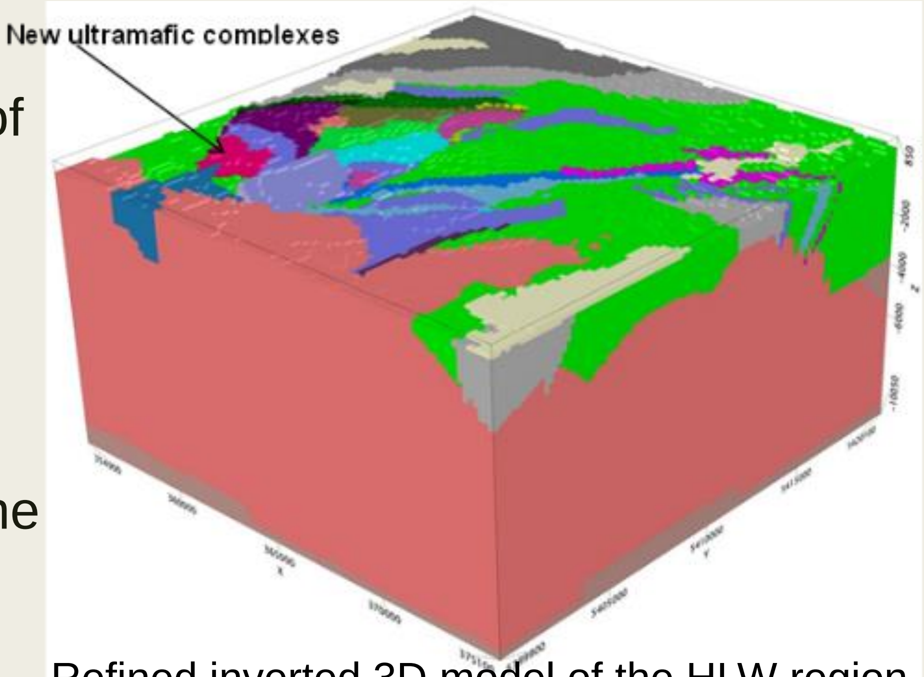
Geology map of HLW region (Cumming et al., 2014)

Constrained 3D modelling, Example 2

- Initial model was constructed using surface geology, and three geological sections.

- Forward modelling of gravity data resulted in a misfit likely due to inaccurate subsurface geometry of granitic units.

- Forward modelling of magnetic data represents areas associated with high misfit. Further investigation of the area led to identifying new CMUC in SW of the AOI.



Refined inverted 3D model of the HLW region (Eshaghi, 2017)

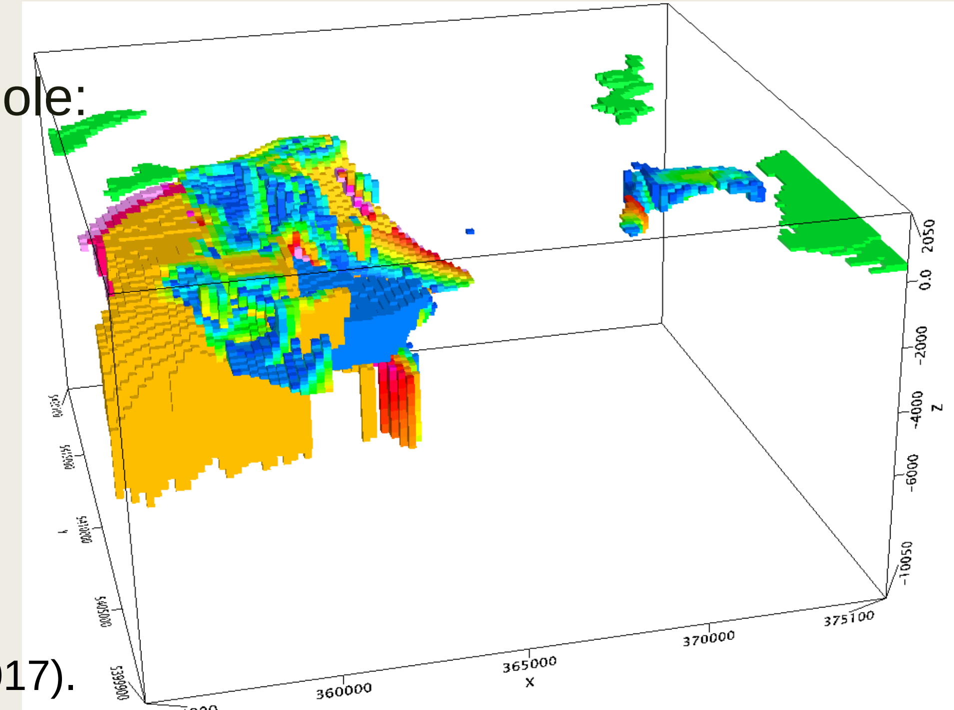
Constrained 3D modelling, Example 2

- The prospect model of HLW aims to highlight trap sites and halos for future exploration:

    1- Recently discovered CMUC

    2- Bell Syncline (contact aureole: Pb-Zn and polymetallic skarn deposits)

    3- NE of the study area



High magnetic susceptibility values across the HLW region (Eshaghi, 2017).

How constrained 2D and 3D modelling can assist to better understand crustal scale controls on metal endowment (ME scopes)

- Modelling will potentially link areas associated with high and low mineral enrichment. This enables us to better compare AOIs and highlight difference and similarities at depth.
- 2D and 3D modelling can also assist to identify new regions for further detailed investigations
- 2D and 3D seismic- and geology constrained modelling of potential field data can assist to identify sources and pathways (e.g. fault networks) contributing to mineralisation (revalidate existing scenarios).
- In addition, this credible model can reveal other factors and variables that might contribute on mineralization (modify exiting ones, develop new scenario).

Other projects (students)

Amir Maleki (MSc)

Acquisition and modelling of gravity data across the Chibougamau Transect, NE Quebec.

Will McNeice (MSc)

Magnetic susceptibility measurements and characterisation, an application for magnetic modelling of deep structures.

Fabiano Della Justino (MSc)

Seismically- and geologically-constraint modelling of gravity and magnetic data across the Sudbury Transect.

Brandon Hume (BSc)

Density measurements and characterization of major stratigraphic units across the Abitibi Greenstone Belt.

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Questions ????