Mineralogical, lithological, and alteration sources of geophysical anomalies

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Workshop 8: "Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting"

Hard rock petrophysics

• Induced magnetism (susceptibility)	IN SITU, BOREHOLE, LAB
• Seismic velocity (P-, S-wave)	IN SITU, BOREHOLE, LAB
• Remanent magnetism	LAB, BOREHOLE (?)
• Electrical conductivity	IN SITU, BOREHOLE, LAB
• Electrical polarisation	LAB, BOREHOLE
• Density	FIELD, BOREHOLE, LAB
• (Dielectric properties)	
• (Radioelement concentrations)	FIELD, BOREHOLE, LAB

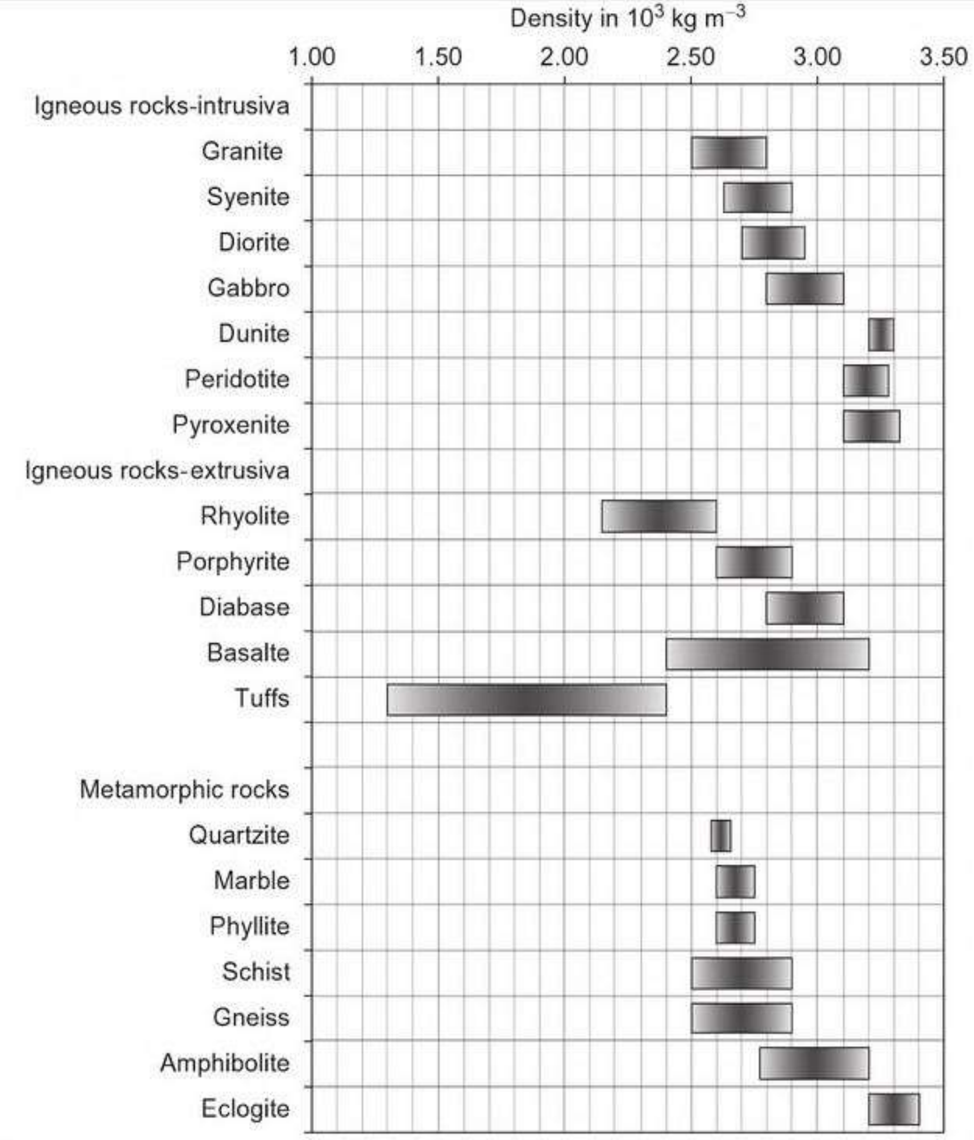
Issue:
STILL NOT ENOUGH BOREHOLE DATA BEING COLLECTED !!!!!!!!!!

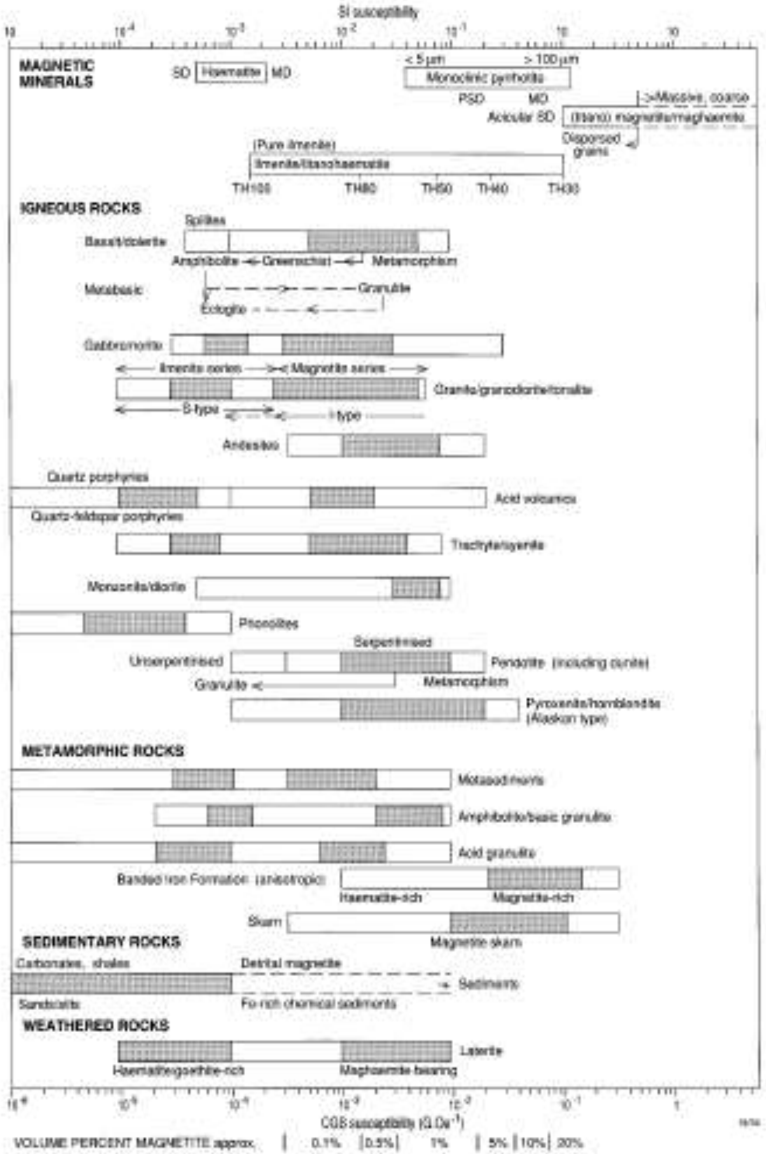
GEOLOGICAL CONTROLS ON PETROPHYSICAL PROPERTIES

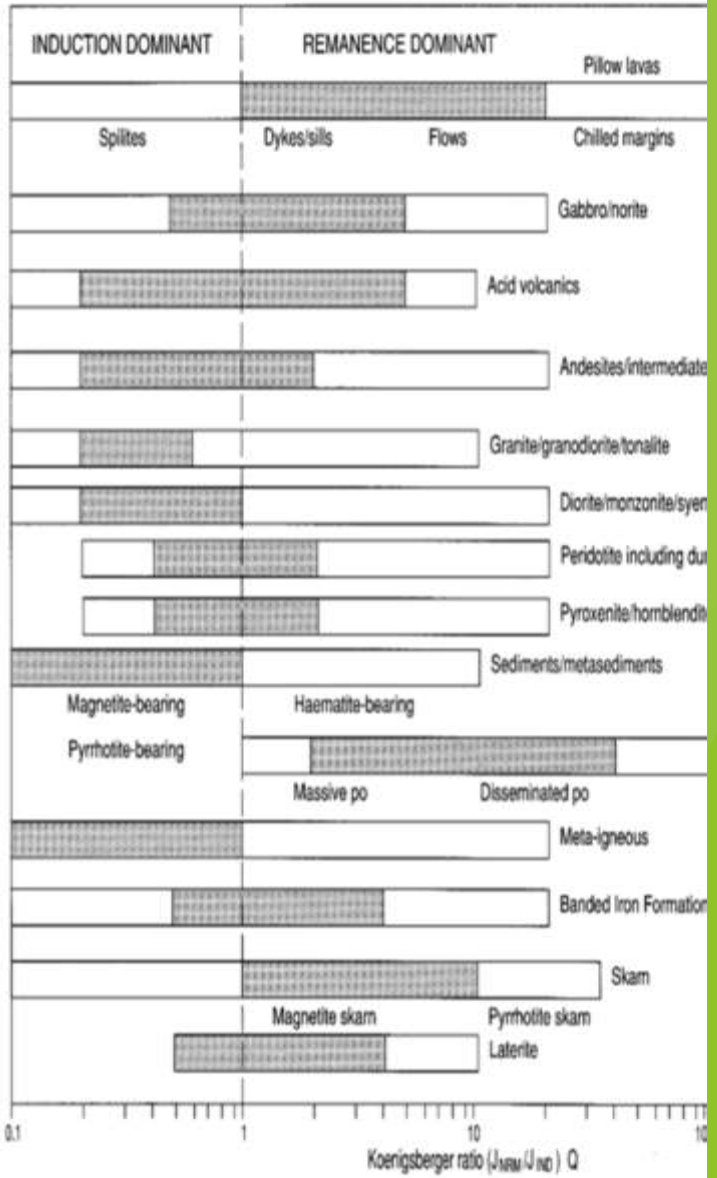
LITHOLOGICAL / STRATIGRAPHIC CHANGES
SPATIAL / ZONATION CHANGES LAYERED INTRUSIONS
METAMORPHISM (REGIONAL)
WEATHERING (SURFICIAL)
ALTERATION MINERALISATION

PETROLOGICAL OUTCOME AND PETROPHYSICAL RESULTS
LOCATE FRACTURE BASED SYSTEMS, YES
PORPHYRY COPPER, SEE TALK BY CLARK
OTHER MINERAL DEPOSIT SYSTEMS??

OXIDATION… MAGNETITE TO HEMATITE TO GOETHITE.
REDUCTION.. FORMATION OF PYRITE, PYRRHOTITE.
SERPENTINISATION.. FORMATION OF CHLORITE, MAGNETITE

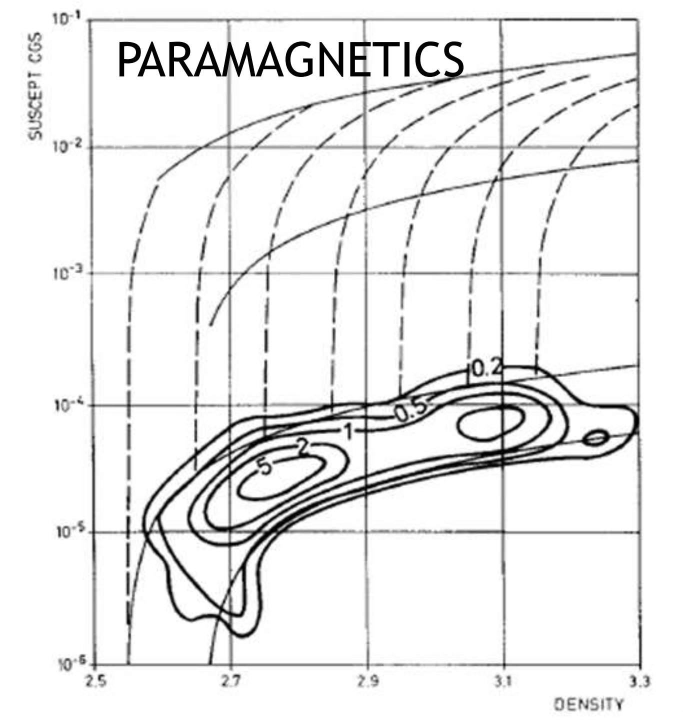


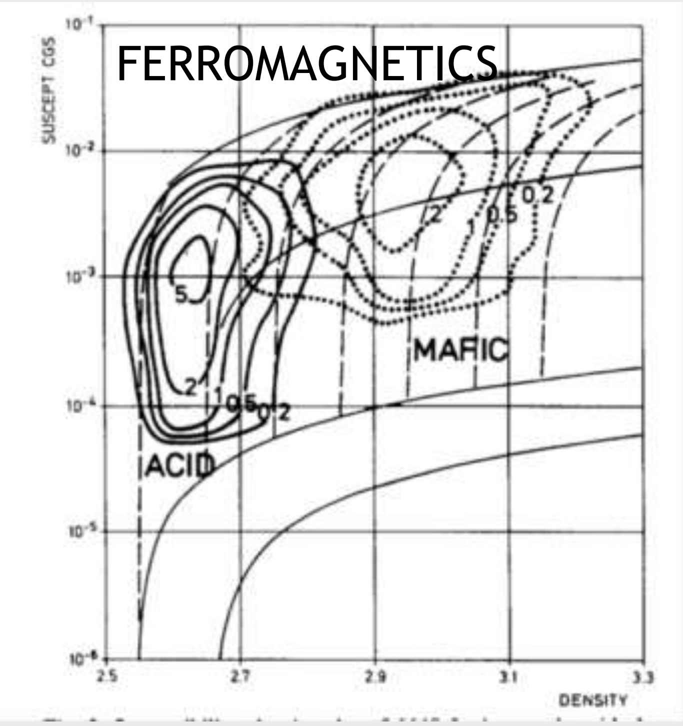


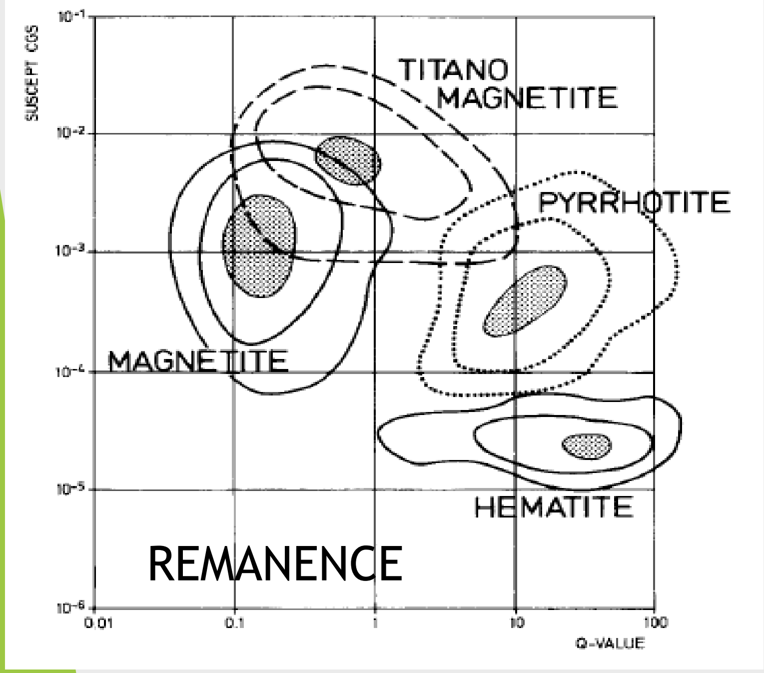


DATABASES… GSC, Mira…. But CALIBRATION !!!!!!

LOCALLY APPLICABLE ?????

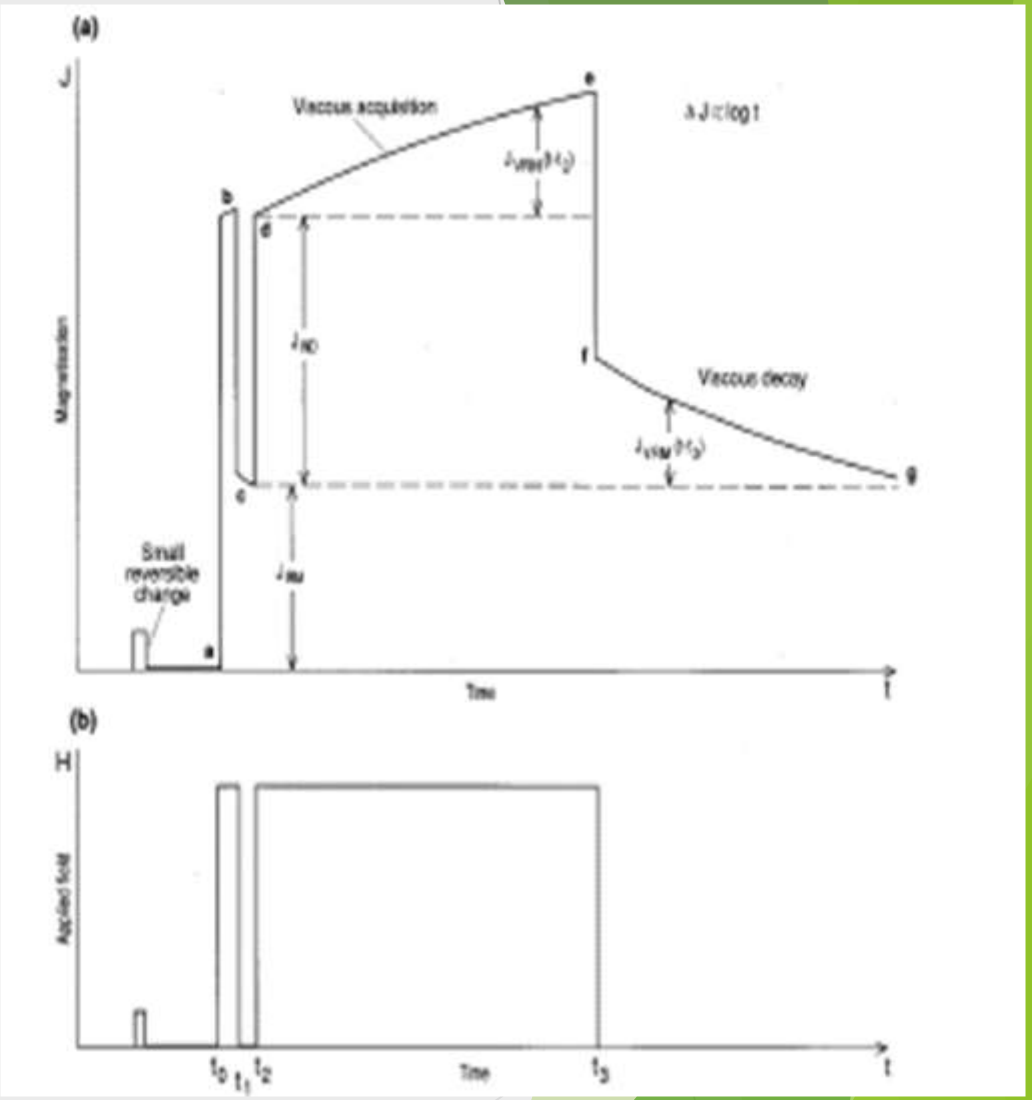






HENKEL,1994
STANDARD DIAGARAMS

Reference plots for discriminating between minerals, lithology, on basis of density, susceptibility and remanence



CLARK, 1997
Induced, Viscous, and Remanent magnetisations

ATIKOKAN, ONTARIO ALTERATION

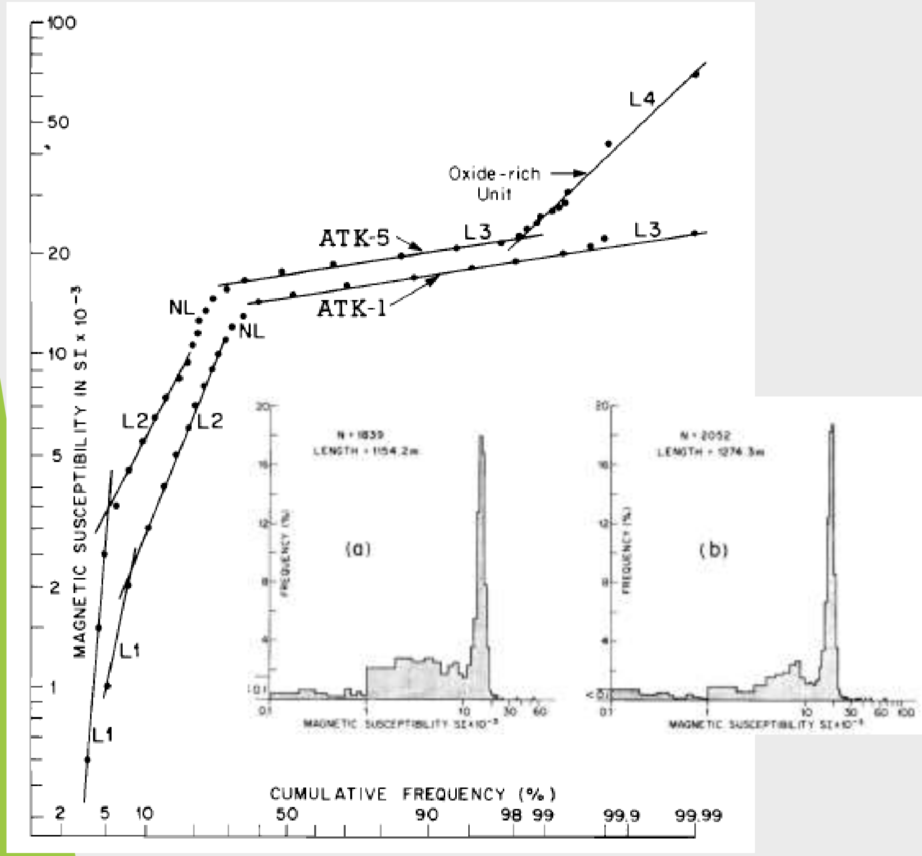
RADWASTE PROJECT to LOCATE FRACTURES

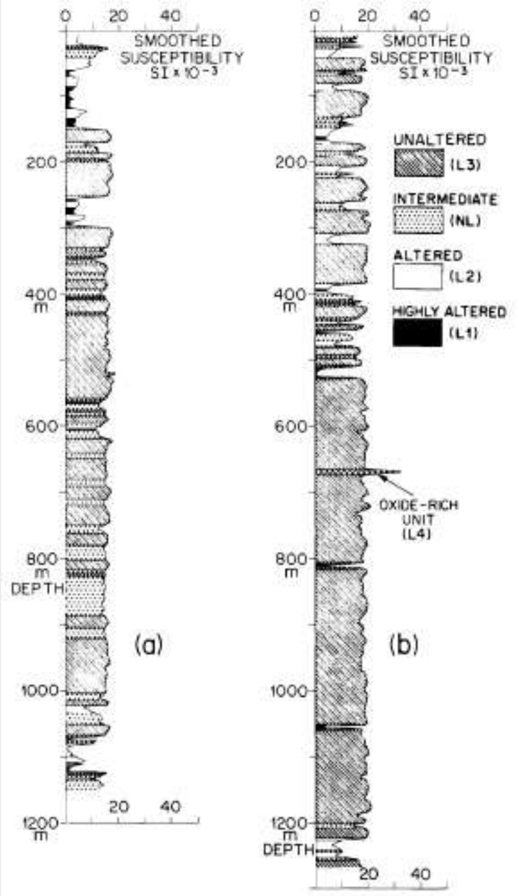
COERCIVITY ANALYSIS SHOWS OXIDATION OF MAGNETITE TO HEMATITE

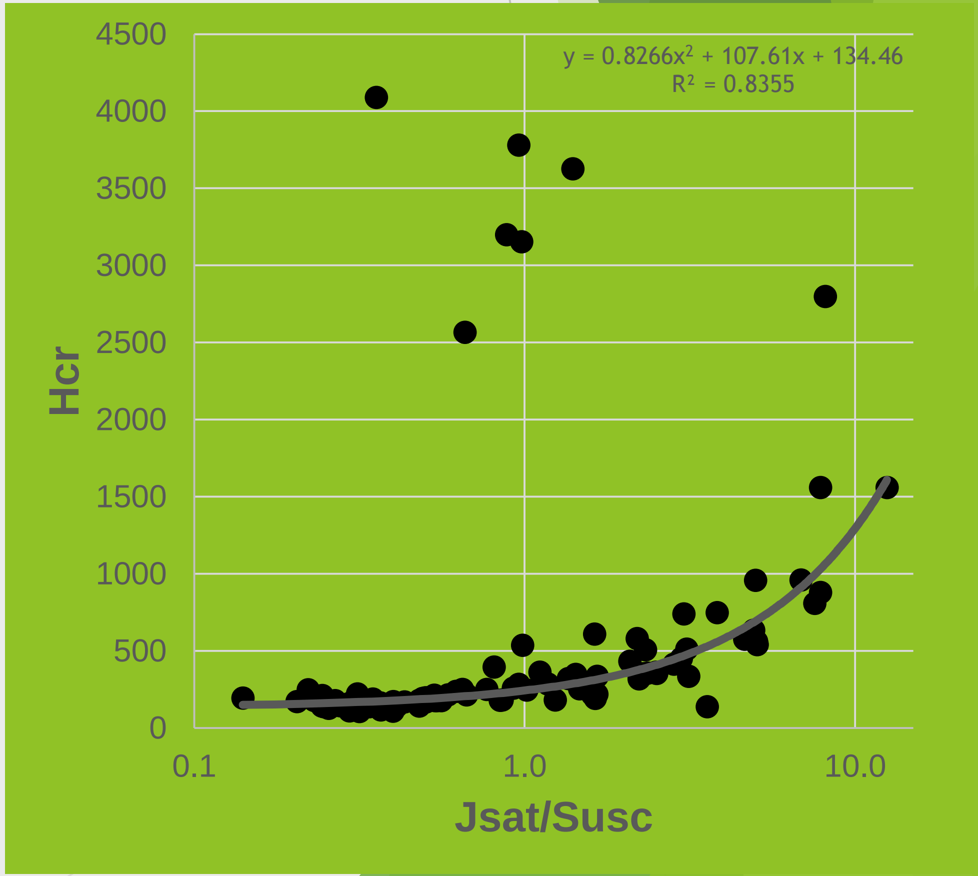
Lapointe et al., 1984, 1986

Geological unit[a] and infilling material[a]	Characteristic magnetic susceptibility level (SI × 10⁻⁶)	Susceptibility-derived Line segment (SI × 10⁻⁶)	Susceptibility-derived alteration level
Diorite[a]	22 000 – 35 000	L4 (22 000 – 50 000)	—
Unaltered granite [a]	17 000 – 18 000	L3 (14 000 – 22 000)	Nonaltered
Epidote group[b]	10 000 – 11 000	NL (9 500 – 14 000)	Intermediate
Chloride group[b]	3 400 – 5 400	L2 (3 500 – 9 000)	Altered
Clay, carbonate, iron hydroxides[b]	<3 500	L1 (<3 350)	Highly altered

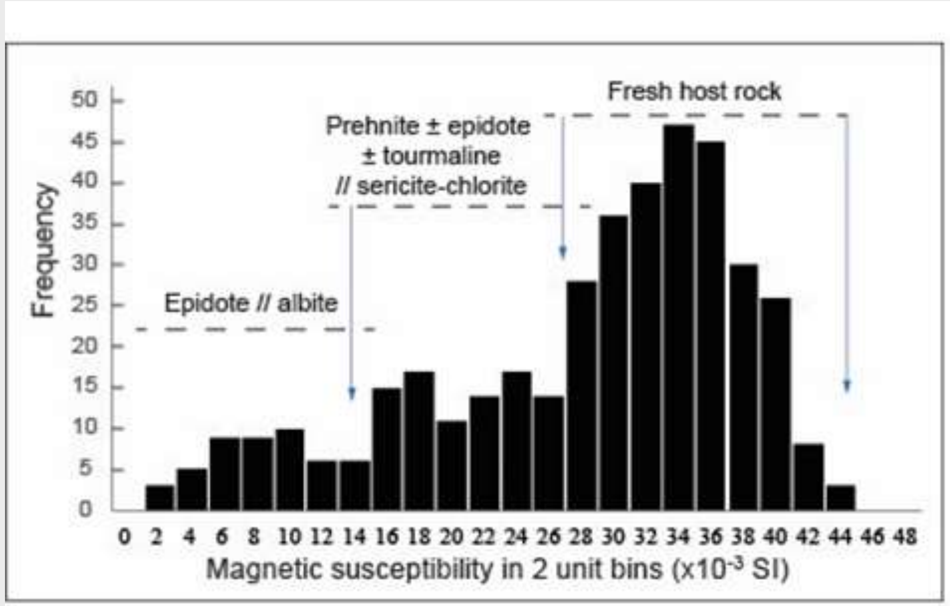
NOTES: The levels of susceptibilities associated with the different groups (epidote, chlorite, clays) are an average of a core sample of at least 160 cm³. Hence, the susceptibilities measured represent a rock average and not a mineral average.

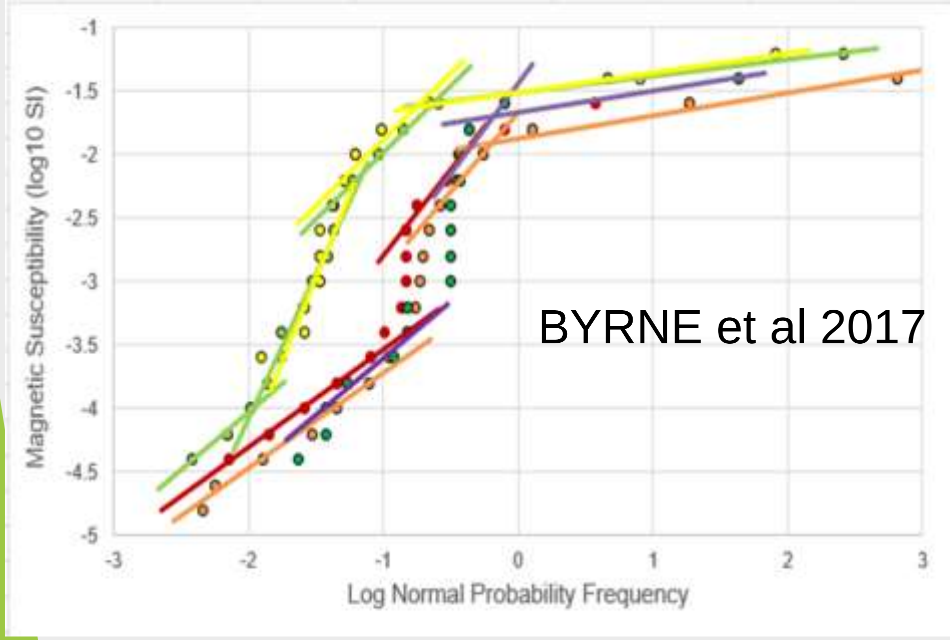




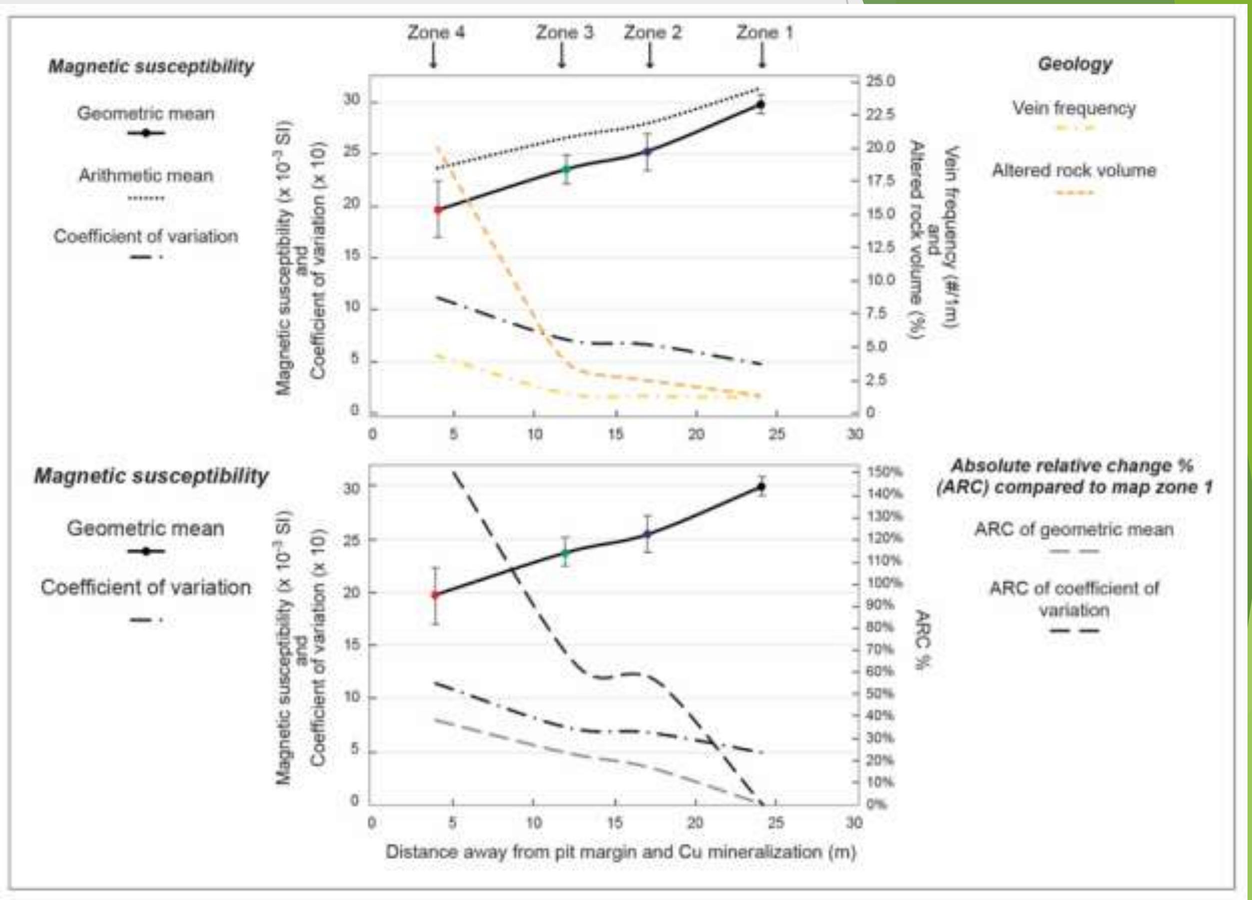


IN SITU SUSCEPTIBILITY MEASUREMENTS .. ALTERATION





BYRNE et al 2017

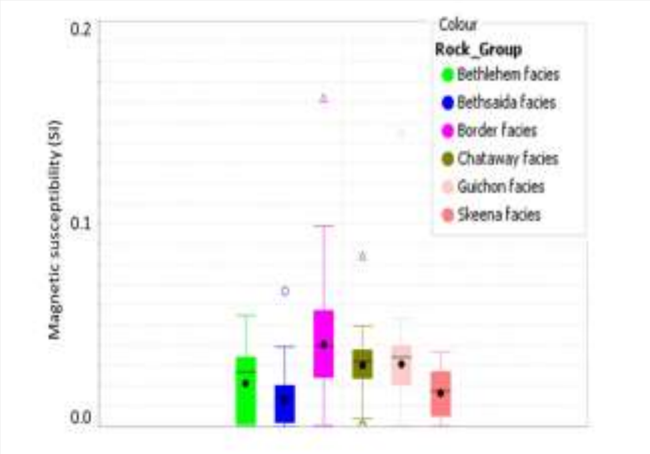


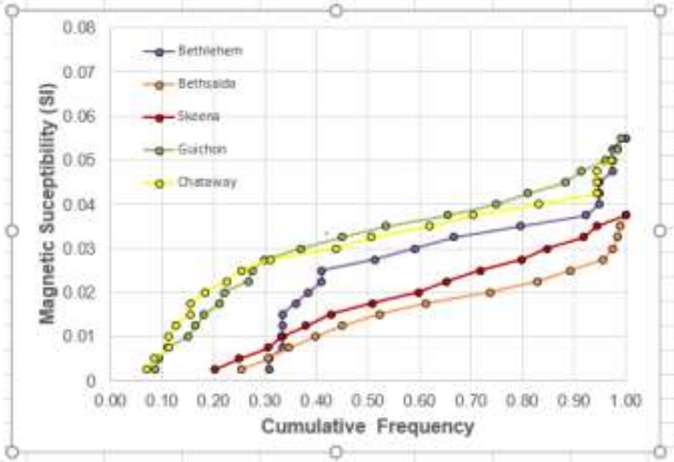
Ten measurement sets of ten measurements each were completed in each of the four zones, resulting in a total of 400 magnetic susceptibility measurements

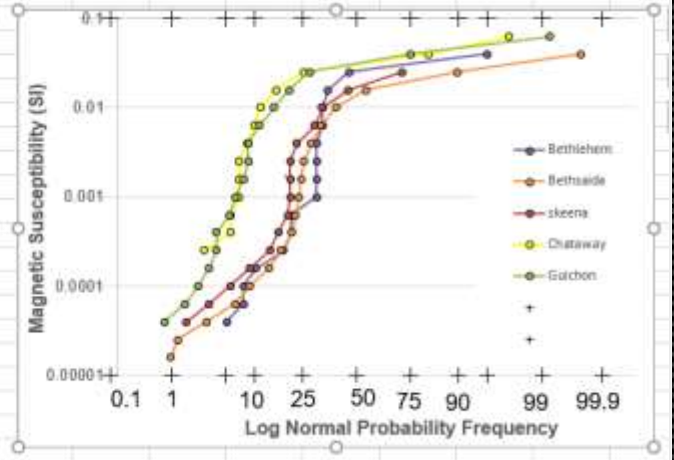
Internal consistency of measurement provides ability to determine degree of alteration

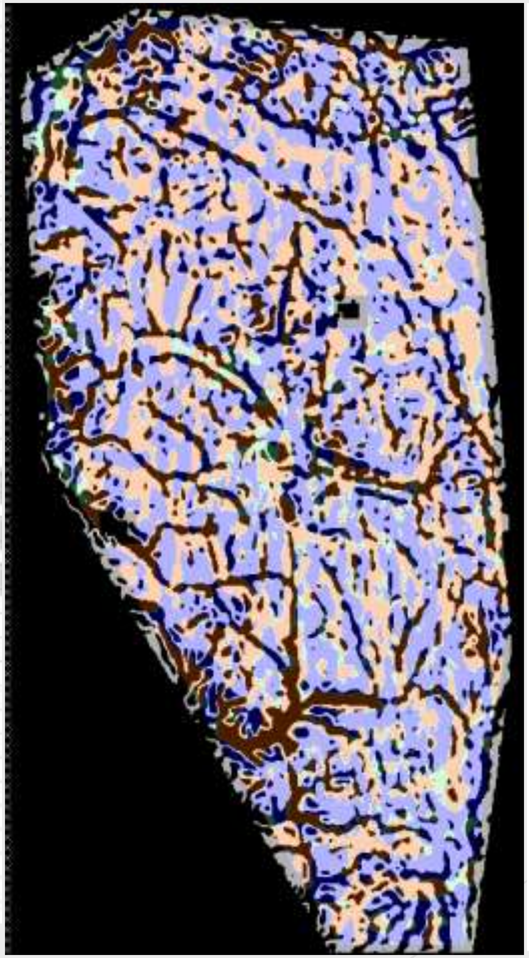
LITHOLOGY AND FRACTURE MAPPING

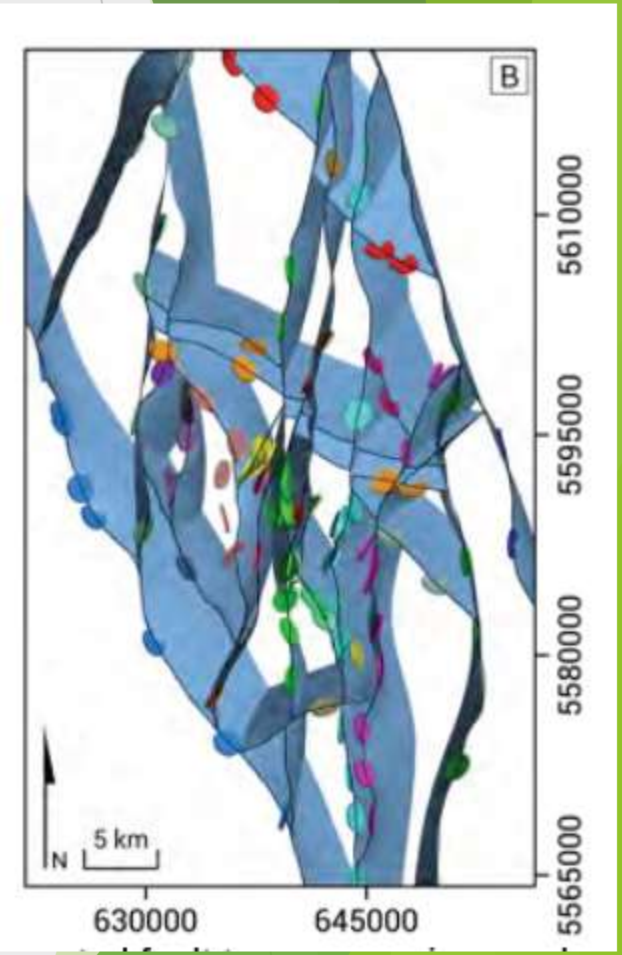
Highland Valley Copper Deposit









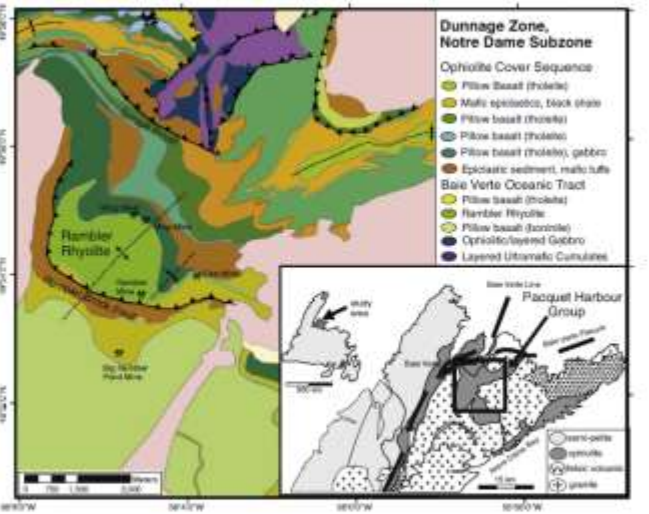


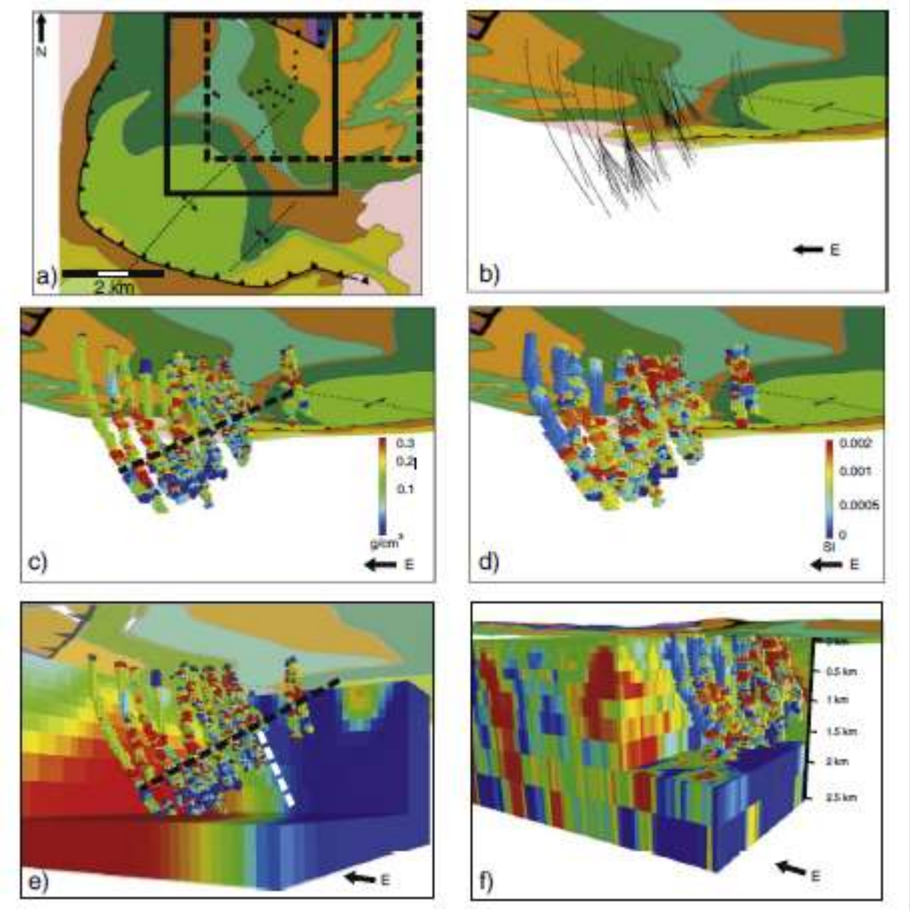
LESAGE et al 2017

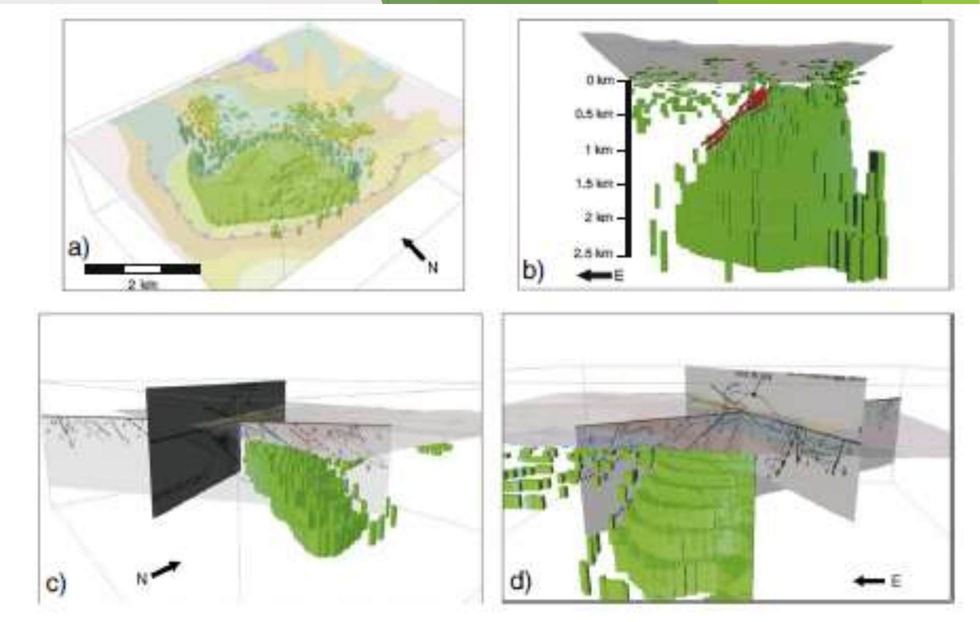
BAIE VERTE, NEWFOUNDLAND

SPICER, et al., 2011

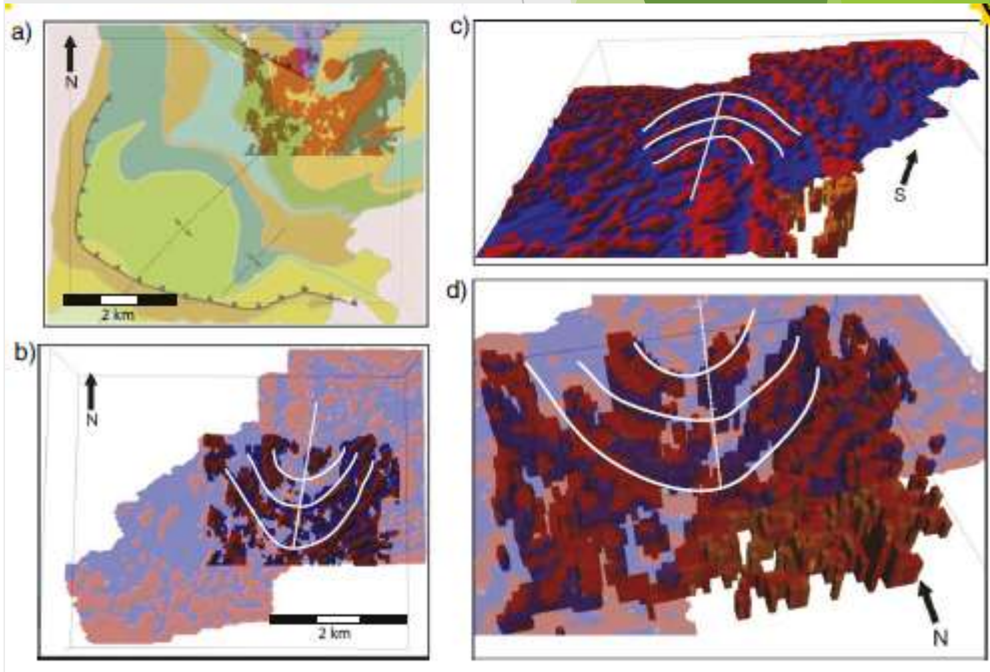
Code	Description	Average density (g/cm³)	Standard deviation	n	Average susceptibility (S.I.)	Standard deviation	n
B	Mafic volcanic rocks	2.88	0.09	310	0.0002	0.0004	730
F	Felsic volcanic rocks	2.82	0.11	95	0.0002	0.0006	494
Mgb	Gabbro-diorite dykes	2.93	0.09	209	0.002	0.003	609
S	Sedimentary rocks	2.79	0.06	12	0.0005	0.001	32
Vms	Sulfide (stringer)	3.32	0.26	5	0.001	0.002	41







GRAVITY



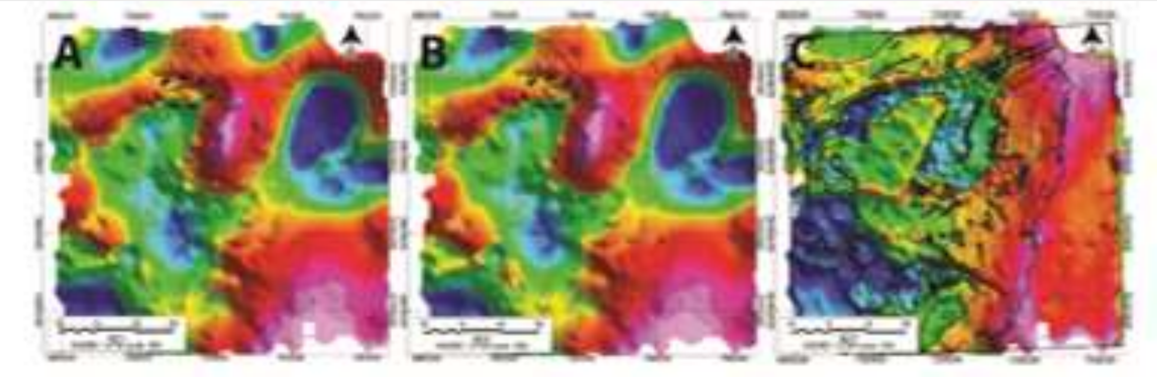
MAGNETICS

Constrained inversion

LITHOLOGY

BATHURST, NEW BRUSWICK LITHOLOGY

GRAVITY GRADIOMETRY VARIABLE DENSITY TERRAIN CORRECTION



Ground gravity, a) 2.67, b) variable, c) difference

MAJOR STRATIGRAPHIC UNITS HAVE DIFFERING AVERAGE DENSITY

2.67 gm/cc produces topographic artefacts

Use variable density as defined by covariance (Nettleton)

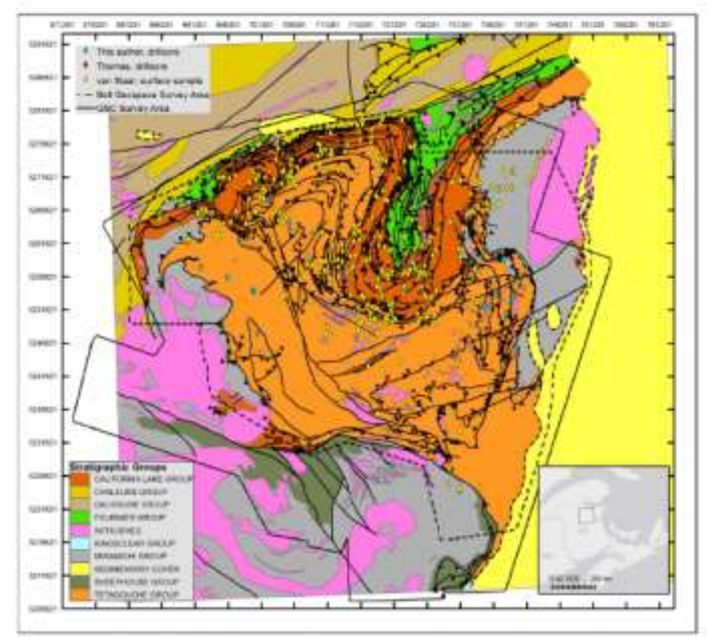
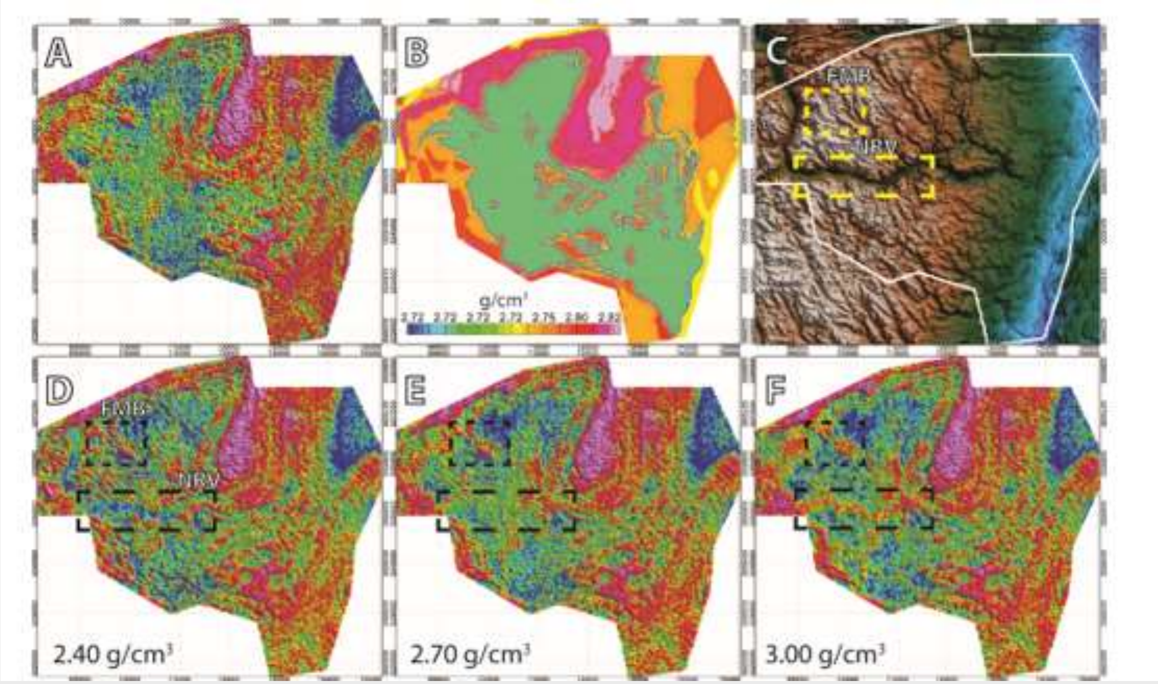
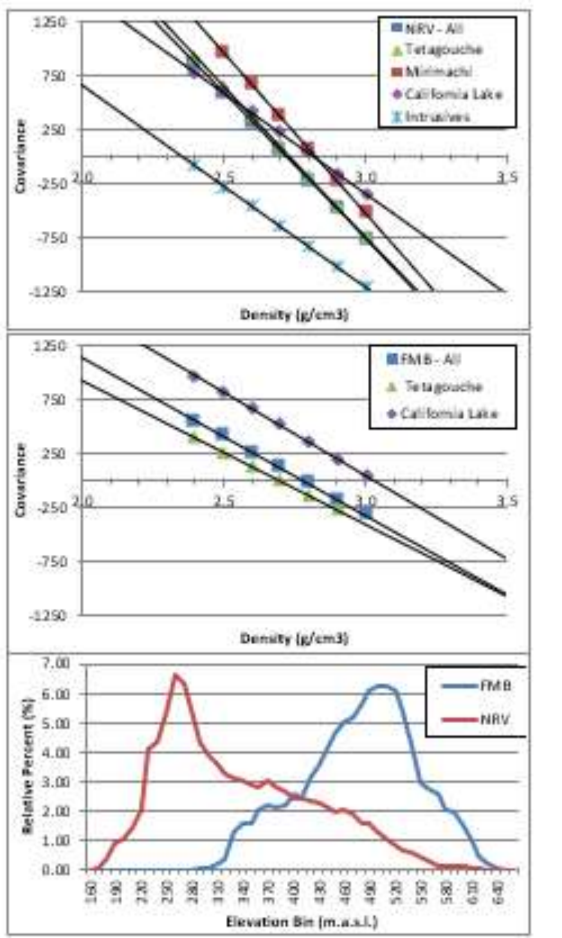


Figure 1: Generalized geologic map of major stratigraphic units throughout the Bathurst mining camp. Locations of drill-core sampled by Thomas (2003) and this author (2011) as well surface samples measured by van Staal (1986, 1987)



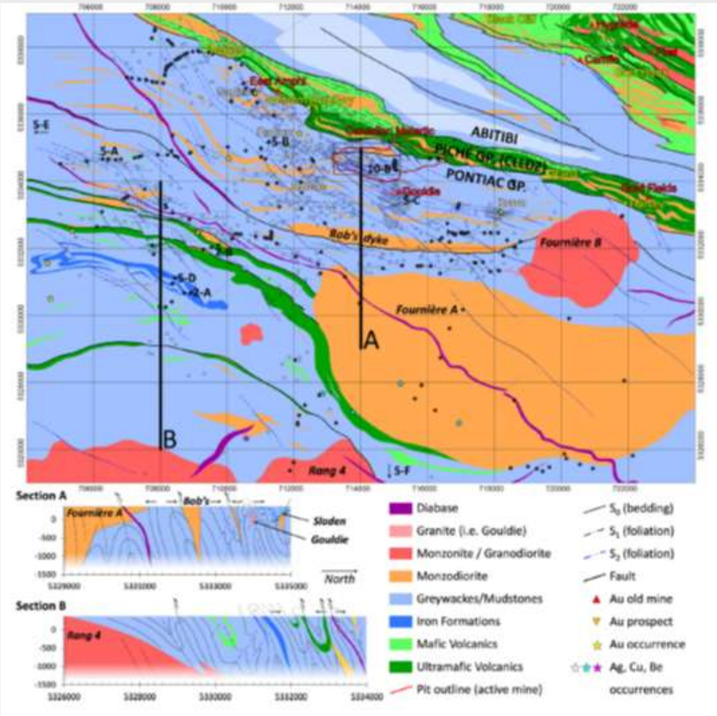


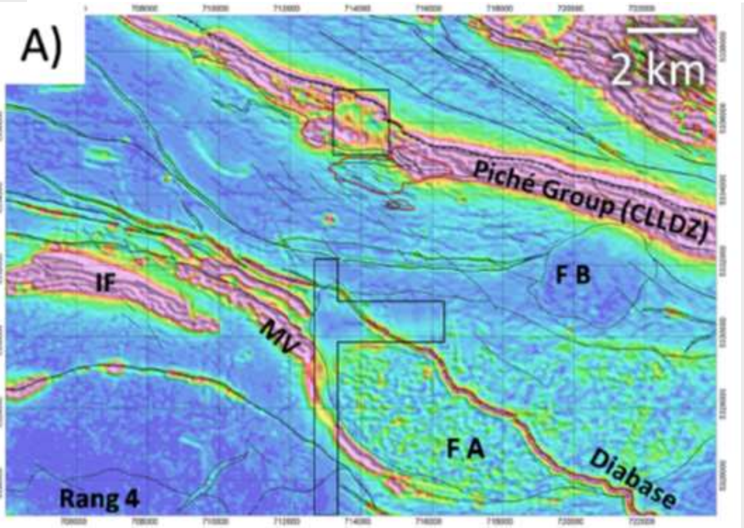
Tschirhart. P., 2011

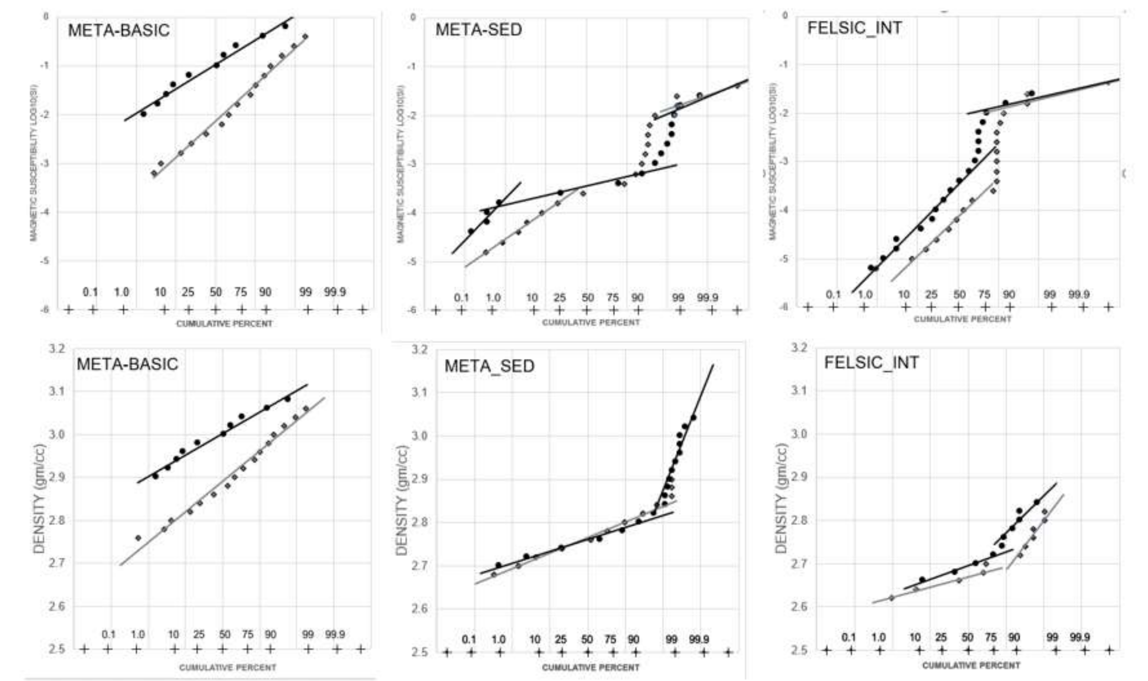
Gravity Gradiometry Gzz, a) variable density terrain,
b) Terrain correction grid, c) CDED,
d,e,f) uniform terrain corrections using values on graphs

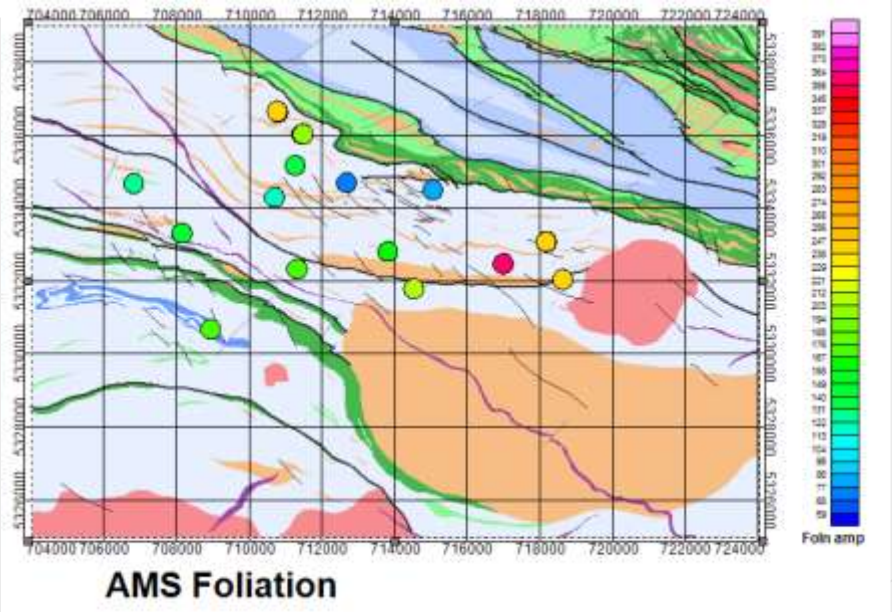
MINERALISATION AND ANOMALY DETECTION

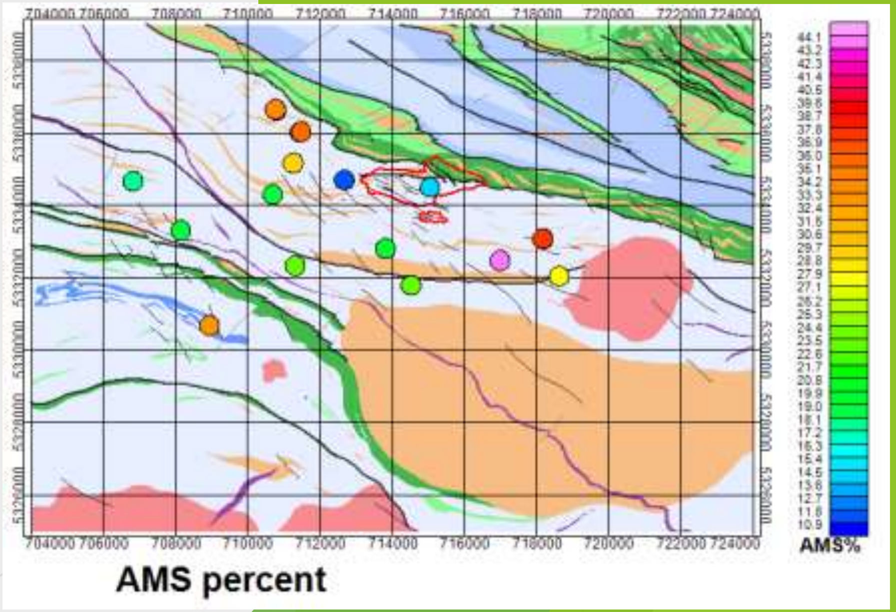
Malartic Gold Deposit





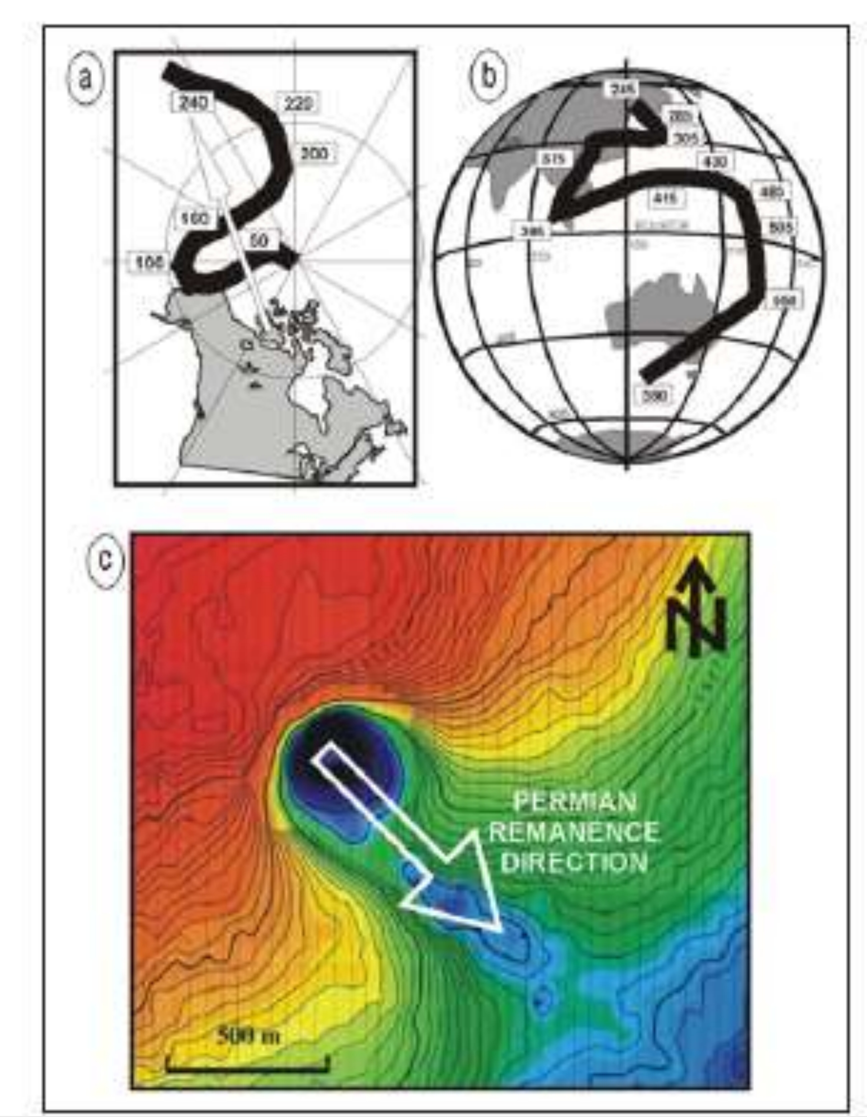






- Alteration produces big change in meta-basic dykes, but volumetrically too small for detectable anomaly
- Change in meta-sediments is significant but hidden by large anomaly
- Magnetic fabrics, provide clear and obvious evidence of localised alteration associated with mineralisation

INDUCED, VISCOUS, REMANENT MAGNETISATIONS And Magnetic Anomalies



Remanence direction used in inversion modelling CANNOT have a random orientation

It must be consistent with age of rock, or its alteration, the degree and sense of deformation and the appropriate polar wander path

Morris et al., 2007

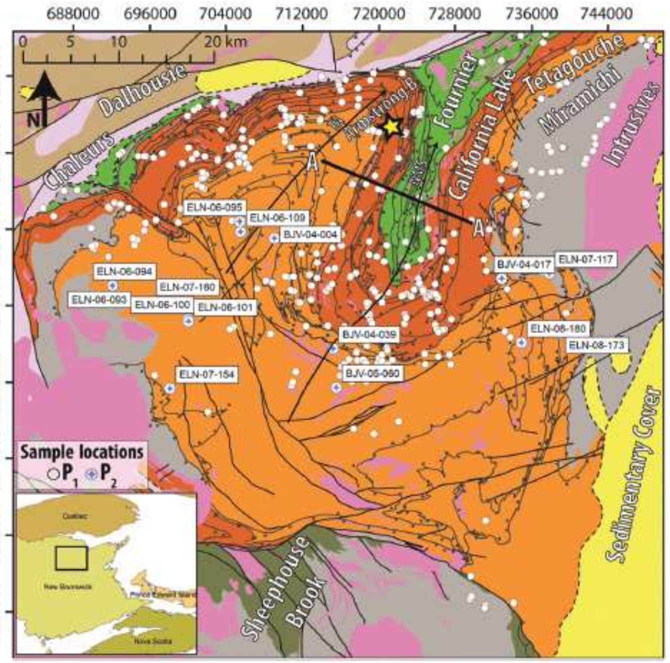
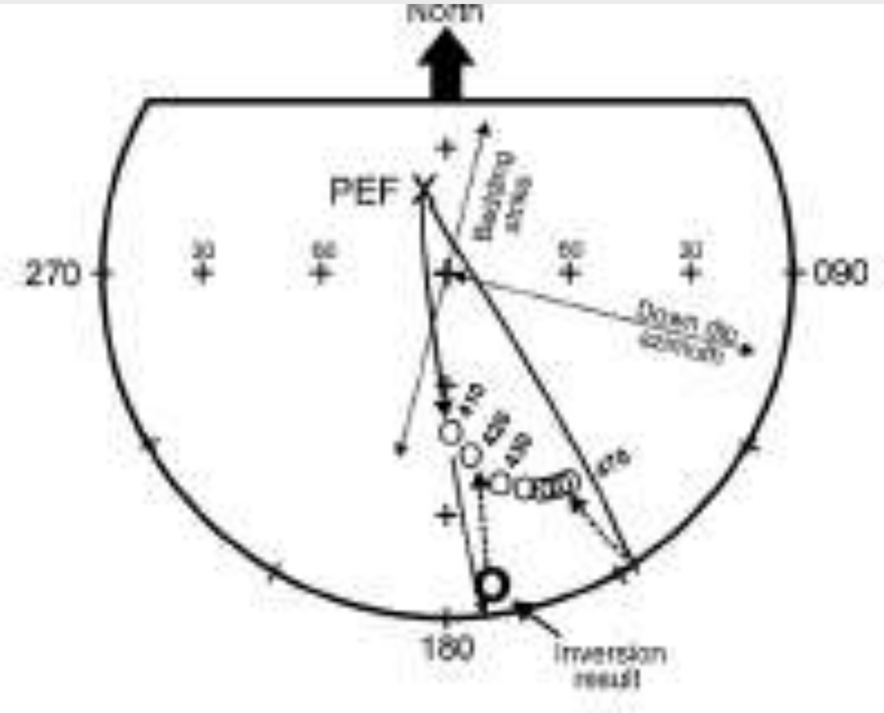


Figure 1. Simplified tectonic map of the BMC outlining the geologic groups, modified from Van Staal et al., 2003. Locations of rock property samples and geophysical models identified. TA = Tetagouche Antiform, NMS = Nine Mile Synform.



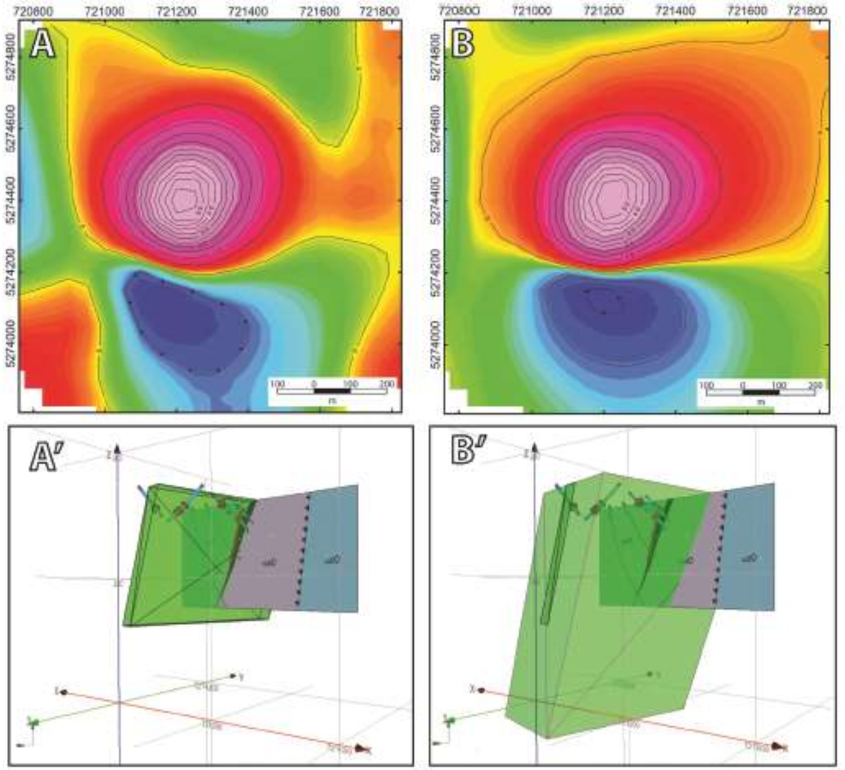


Figure 12. Magnetic anomaly model inversion results for the Armstrong B Deposit. (A) Observed magnetic anomaly pattern. (A′) Input (starting) geophysical model with input constraints provided by borehole logs. (B) Magnetic anomaly pattern of best-fit inversion model. (B′) Optimized geologic model. Note computer derived increased width of ore zone which is probably an artifact of data sampling.

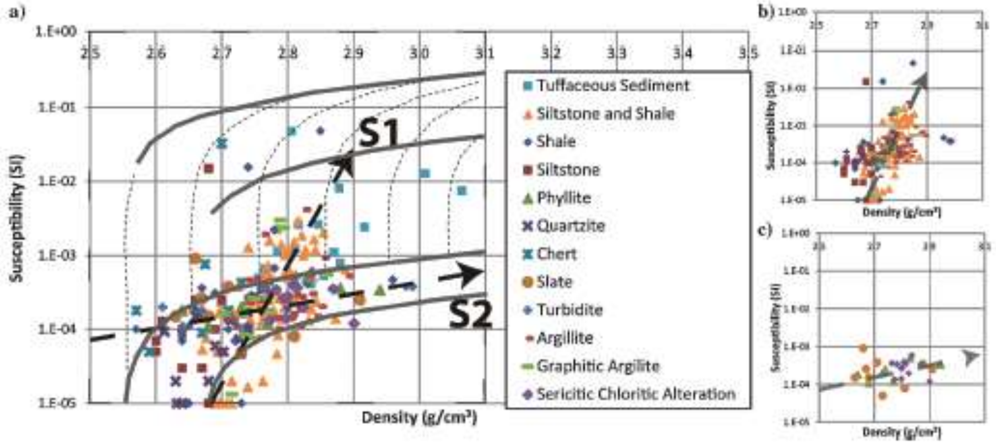
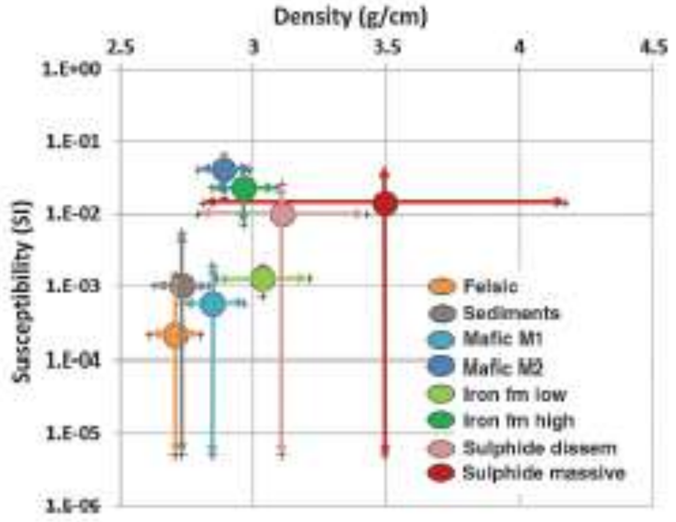


Figure 3. Bivariate MS-density plot for sedimentary rocks. (a) Comparison of all lithologies for sedimentary rocks excluding iron formations. (b) Nonmetamophosed or altered sedimentary rock types. (c) Metamorphosed or altered lithologies.



BATHURST, NEW BRUNSWICK

REMANENCE POST FOLDING
PEF / VISCOUS OVERPRINT

Tschirhart, P., et al 2014

MINERAL SYSTEMS

Various mineral system classifications:

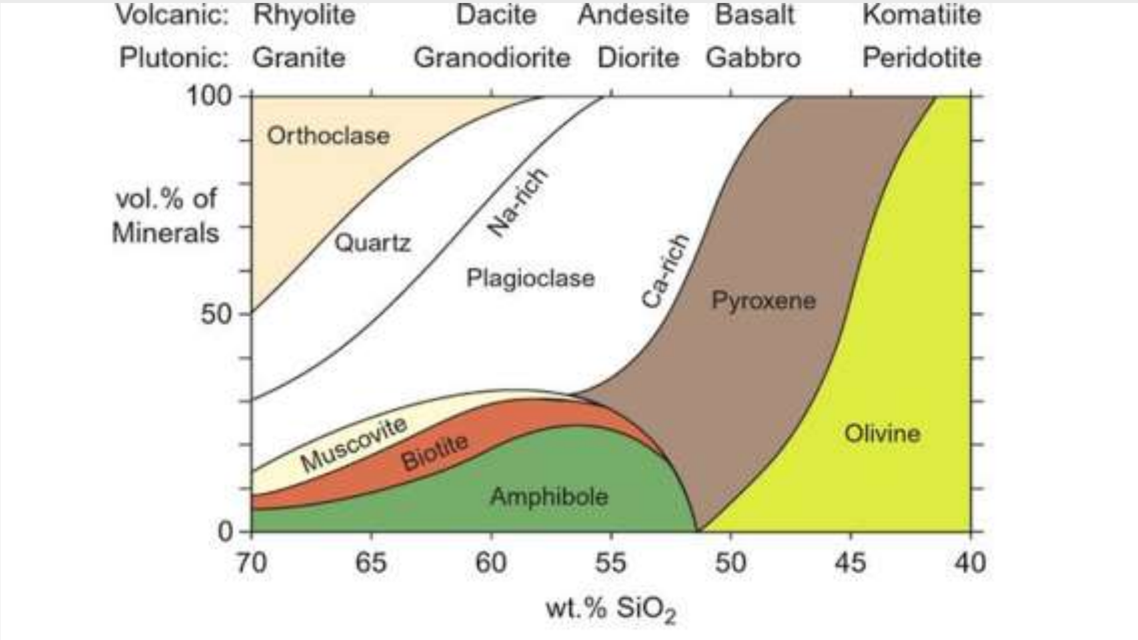
- Porphyry-epithermal (porphyry Cu-Au-Mo, low sulfidation epithermal, high sulfidation epithermal, skarn)
- Granite-related (intrusion-related gold, intrusion-related Sn-W, porphyry Mo, pegmatite rare metal, Rossing-type U?)
- Iron-oxide copper-gold (Olympic Dam-type IOCG, Andean-type IOCG, Cloncurry-type IOCG; Tennant-type IOCG)
- Mafic-ultramafic orthomagmatic (komatiite-associated Ni-Cu, mafic-ultramafic intrusion-hosted Ni-Cu, PGE and Fe-V-Ti)
- Alkaline intrusion-related (diamonds, REE deposits, peralkaline granite-related U-Th-REE)
- Subaqueous volcanic-related (volcanic-hosted massive sulfide, Broken Hill-type Zn-Pb-Ag)
- Basin-hosted (Mt Isa-type Zn-Pb-Ag, Mississippi Valley-type Zn-Pb, sediment-hosted Cu-Co-Ag, unconformity-related U, sandstone-hosted U, calcrete-hosted U, iron ore, phosphate, graphite)

Source: http://www.ga.gov.au/data-pubs/data-and-publications-search/publications/critical-commodities-for-a-high-tech-world/mineral-systems-framework

WHAT MINERAL SYSTEMS AND ALTERATION PROCESSES DO WE NEED TO DOCUMENT TO OBTAIN A BETTER UNDERSTANDING OF SIGNIFICANCE OF PETROPHYSICAL RESPONSES ?

HOW MANY DO WE KNOW?

Oxidation
Porphyry Copper
Serpentinization?



- Recognising geophysical response from mineral system components needs a new approach to petrophysics
  - Move beyond a lithology-only geological context
  - The need for better integration with mineralogy/petrology data
  - Develop a process-based understanding and a predictive capability

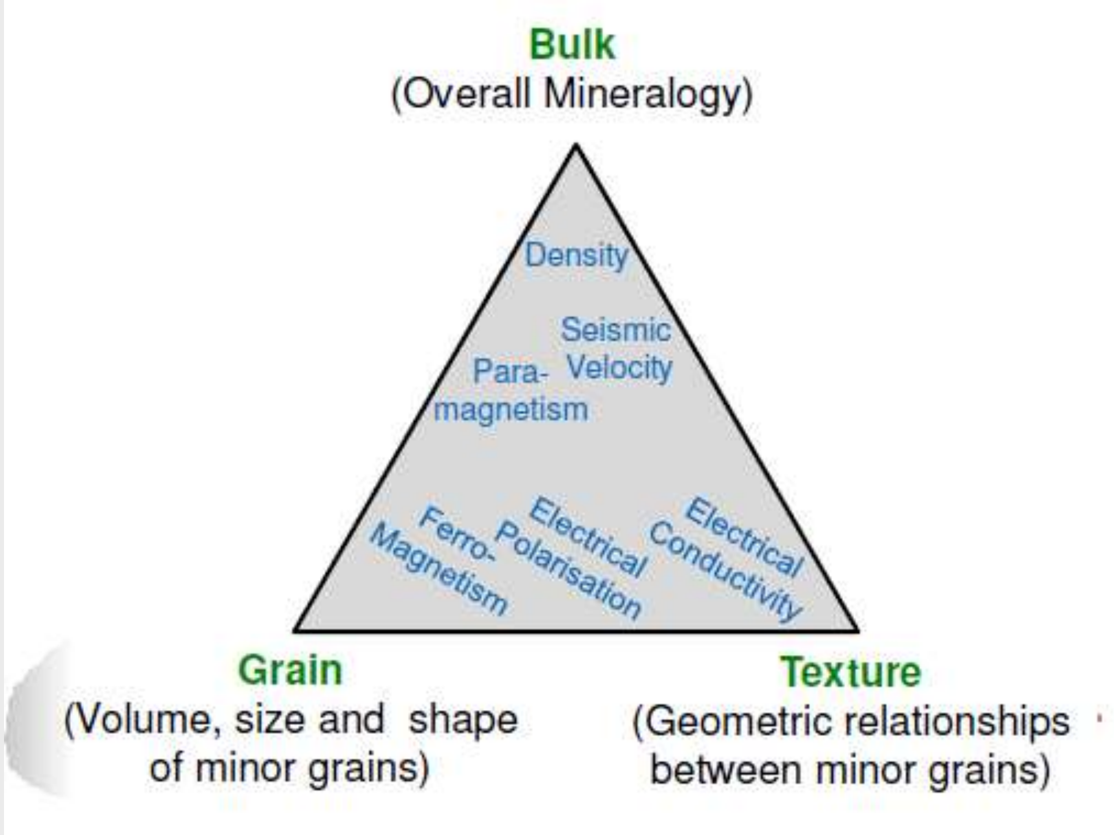


Image processing of thin sections and polished sections to obtain estimates of mineral content, grain size, and pore geometry

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BULK

AVERAGE OF PROPERTIES OF ALL MINERALS.

PROPERTIES OF INDIVIDUAL MINERALS AND THEIR RELATIVE ABUNDANCE
PREDICT USING SIMPLE MIXING MODEL FROM CHEMICAL, OR MINERALOGY

DENSITY, SEISMIC VELOCITY, PARAMAGNETISM

GRAIN PROPERTIES

CONTROLLED BY PRESENCE / ABUNDANCE OF MINOR MINERAL PHASES

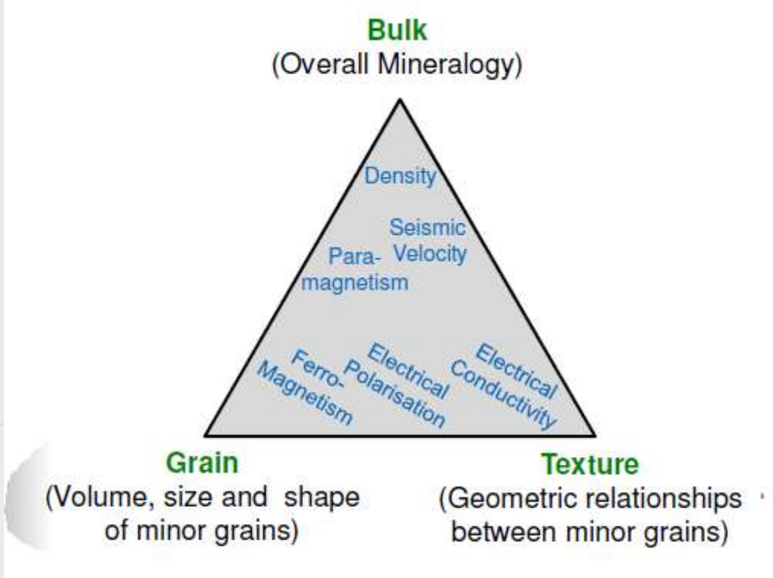
SIZE, SHAPE OF MINERALS

FERROMAGNETISM (INDUCED AND REMANENT MAGNETISATION)
ELECTRICAL POLARISATION

TEXTURE

CONTROLLED BY PRESENCE / ABUNDANCE OF MINOR
MINERAL PHASES, SHAPE, CONNECTIVITY

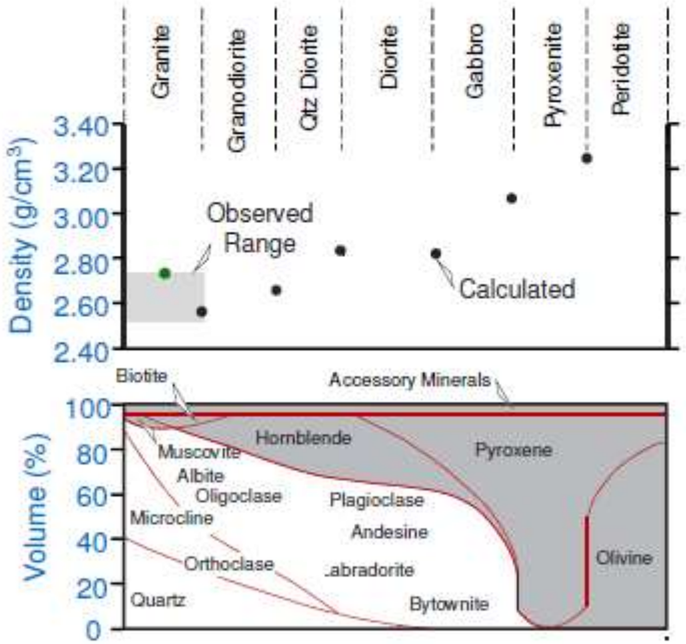
ELECTRICAL CONDUCTIVITY, POLARISATION

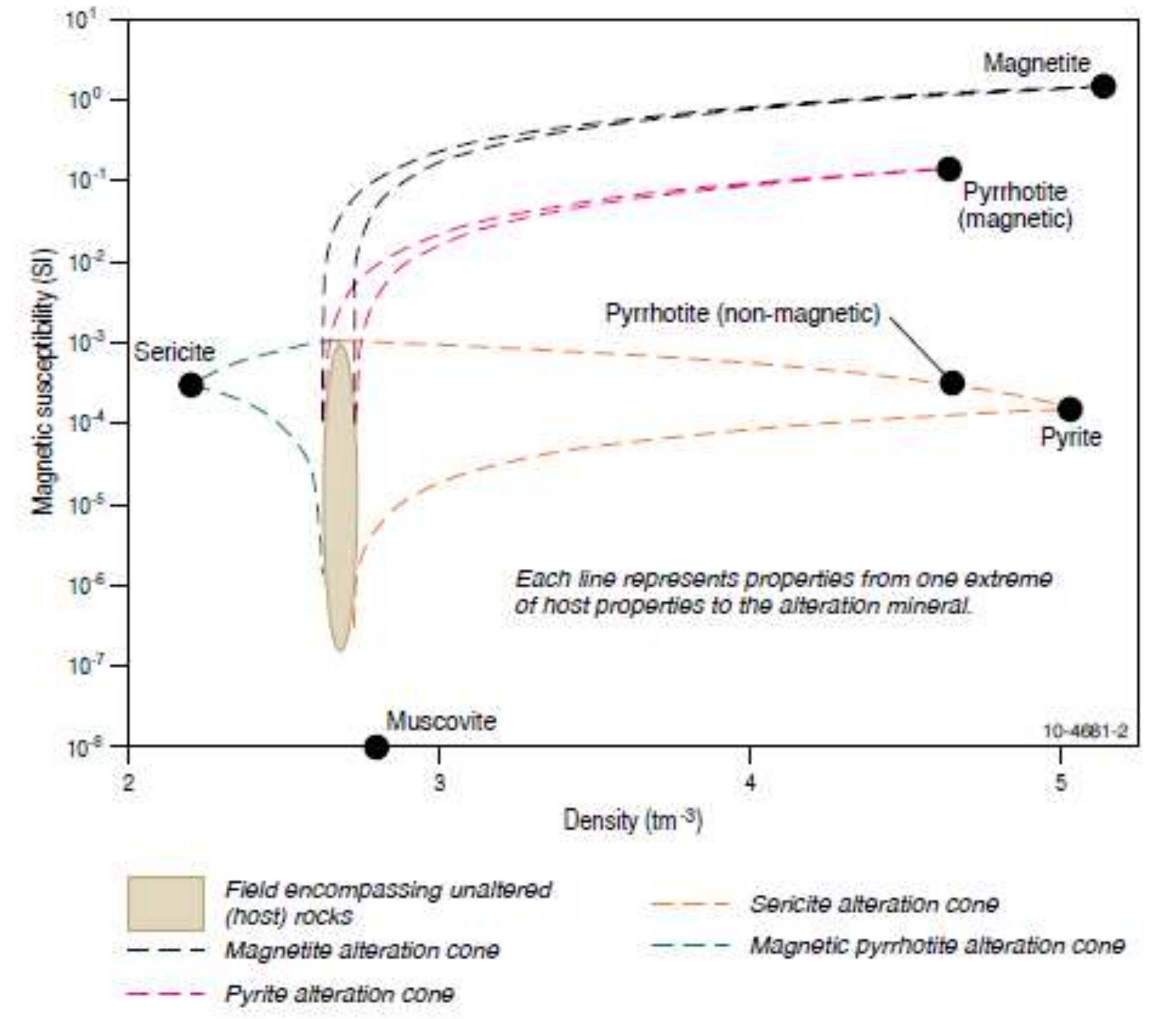


PHYSICAL PROPERTY MODELLING

Relationship with mineralogy: Calculating the density of a granite:

Quartz	50%, ρ = 2.65 g/cm³	0.5*2.65 +
Plag' Fsp	20%, ρ = 2.61 g/cm³	0.2*2.61 +
Alkali Fsp	20%, ρ = 2.56 g/cm³	0.2*2.56 +
Biotite,	5%, ρ = 2.80 g/cm³	0.05*2.80 +
Opaques	5%, ρ = 5.00 g/cm³	0.05*5.00 = 2.75 g/cm³





IMPORTANT TO LINK PHYSICAL PROPERTY VARIATIONS TO MINERALOGICAL AND GEOCHEMICAL DATA
MUST TAKE ADVANTAGE OF NEW pXRF, and HYPERSPECTRAL MINERAL MAPPING TOOLS

MINERALMAPPER3D
WILLIAMS and CHOPPING
VAN DER WEILEN and CHOPPING

CONCLUSIONS

- PHYSICAL ROCK PROPERTIES GENUINELY REPRESENT THE LINK BETWEEN GEOLOGY AND GEOPHYSICAL RESPONSE, BUT NOT JUST LITHOLOGY
- INSTRUMENT CALIBRATION IS A CRITICAL ISSUE
- PHYSICAL ROCK PROPERTIES ARE ESSENTIAL CONTROL WHEN ATTEMPTING ANY TYPE OF INVERSION OF GEOPHYSICAL DATA
- REMANENCE……. INTEGRATE WITH APWP CONSTRAINT…
- NEED TO DEVELOP A BETTER UNDERSTANDING OF CHANGES IN PHYSICAL ROCK PROPERTIES ASSOCIATED WITH GEOLOGICAL PROCESSES
- NEED TO TAKE ADVANTAGE OF NEW GENERATION OF PORTABLE MINERAL MAPPING AND GEOCHEMICAL TOOLS.
- NEED TO DEVELOP METHODS FOR RAPIDLY CHARACTERISING MAGNETIC MINERAL CARRIER, COERCIVITY ANALYSIS, VARIABLE FREQUENCY / FIELD SUSCEPTIBILITY
- NEED TO DEVELOP AND USE NEW DATA INTEROGATION TECHNIQUES FOR USE WITH PHYSICAL PROPERTY DATA.

Thanks, Questions?

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