Integrated geological and geophysical 3D modelling:
Value added to exploration and mining projects

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SRK Consulting (Canada) Inc.

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- The approach: integrating geology & geophysics
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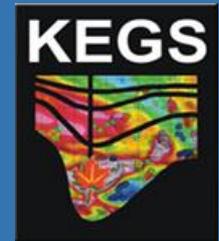
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Motivation

- As consultants, we have seen the need for integrated and collaborative work
  - Geophysics →Geology
    - Meaningful models that can provide actual geological data, instead of our usual geophysical jargon ("low-passed version of the horizontal derivative of the field")
    - Help interpretation geologists extract the most out of their data
  - Geology → Geophysics
    - Refine the number of possible geological scenarios on a geophysical interpretation
  - In general, it is about asking the right questions and developing a common language
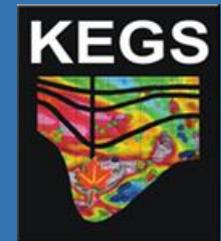
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# Methodology:
2D modelling

- A simple model can provide good information on physical properties and a sense for geometry

- However, we must keep in mind that models are non-unique

- …here comes the geological input
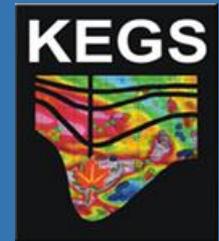
Back to basics:
2D modelling
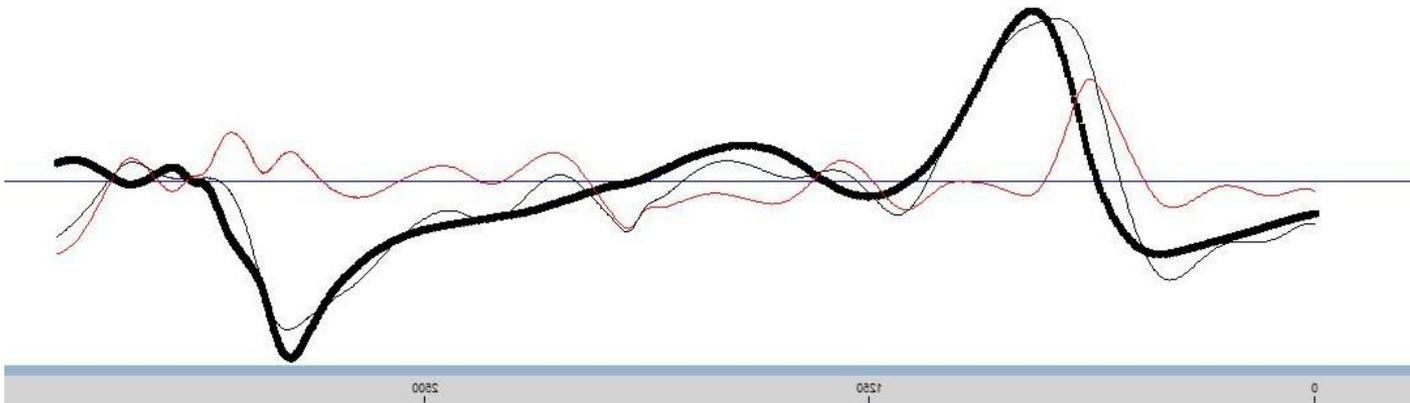
Simple case:
- Mag data
- Inclination: 80 deg; Declination: 24.1
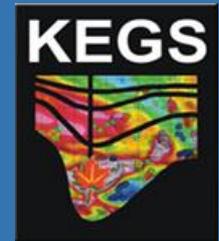
Back to basics:
2D modelling
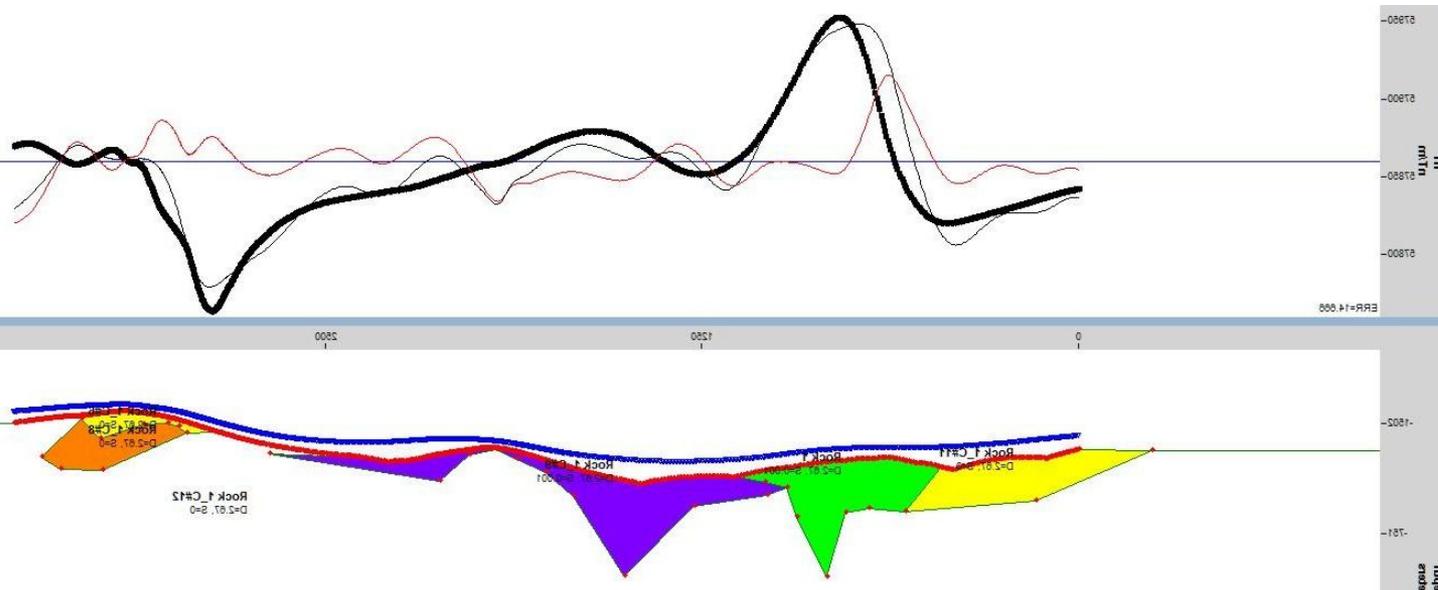
Model 1:

- 5 bodies with "awkward" geometries and susceptibilities on 0-0.0008 cgs

Back to basics:
2D modelling
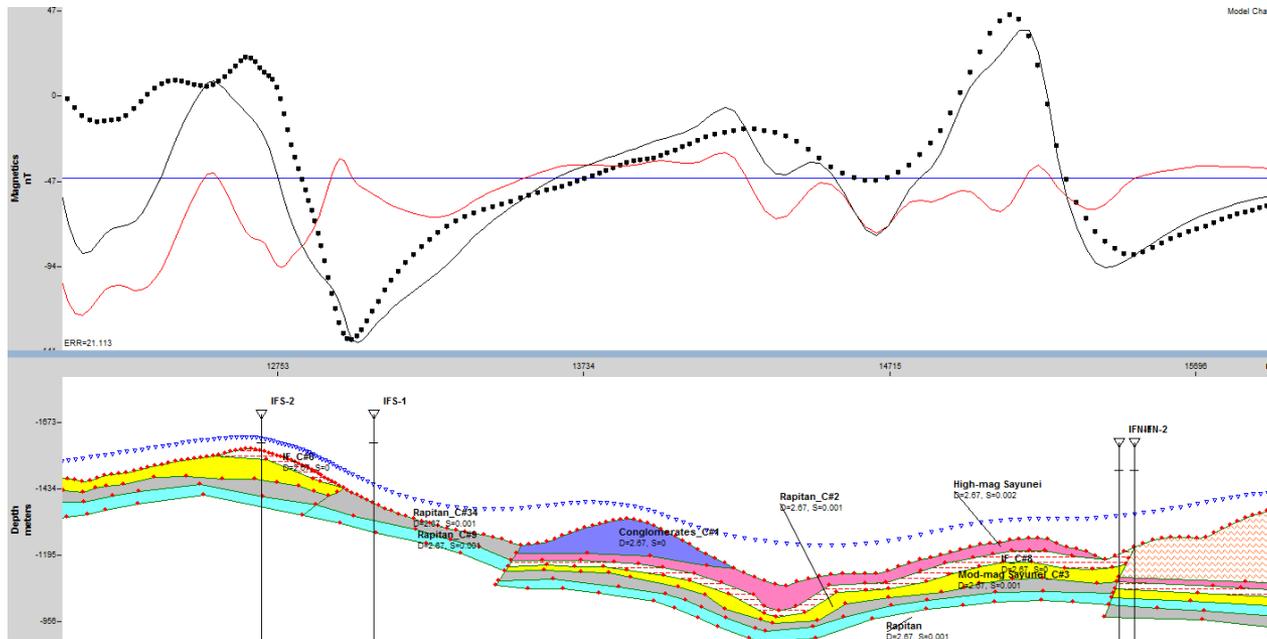
Model 2:
- A series of sub-horizontal bodies
- Folds and faults
- *However: this requires a priori knowledge of the structure/geology*
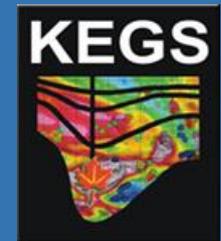
Geological input

- What do we need:
  - Structure (strike/dip: layers, faults, folds)
  - Lithology (rock type, and more than that, physical properties)
- Normally we have a isolated strike/dip points and no susceptibility measurements
- We must obtain these constraints from somewhere else…
- Or work with the structural geologist(s) in charge of the project
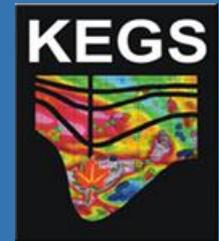
Case 1: Thinking out of the box regarding processing

- We start with a "typical" exploration program where magnetics is used to map structure and lithology under cover

Case 1: Regional Geology

Greenstone belt composed of Archean mafic to felsic volcanic rocks, bound by a Plutonic complex and Gneiss Belt.

The key is to trace gold bearing structures in an area of "faded" magnetic response (sedimentary rocks)

Legend

BedrockGeo

1 Mafic volcanics	3 Greywacke	9 Migmatitic gneiss
11 Greywacke, arkose	4 Gabbro, gabbronorite	Orr Limestone, dolomite
12 Granodiorite, gneiss	5 Amphibolite	Orrch Chert dolomite
13 Granite	6 Metasedimentary gneiss	Ow Sandstone
2 Felsic volcanics	8 Tonalite	
	8a Tonalite gneiss	

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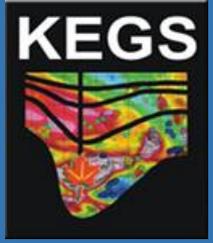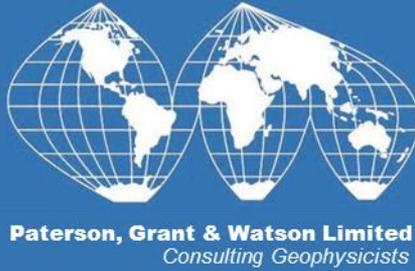
Case 1:
Regional Geology & Mag
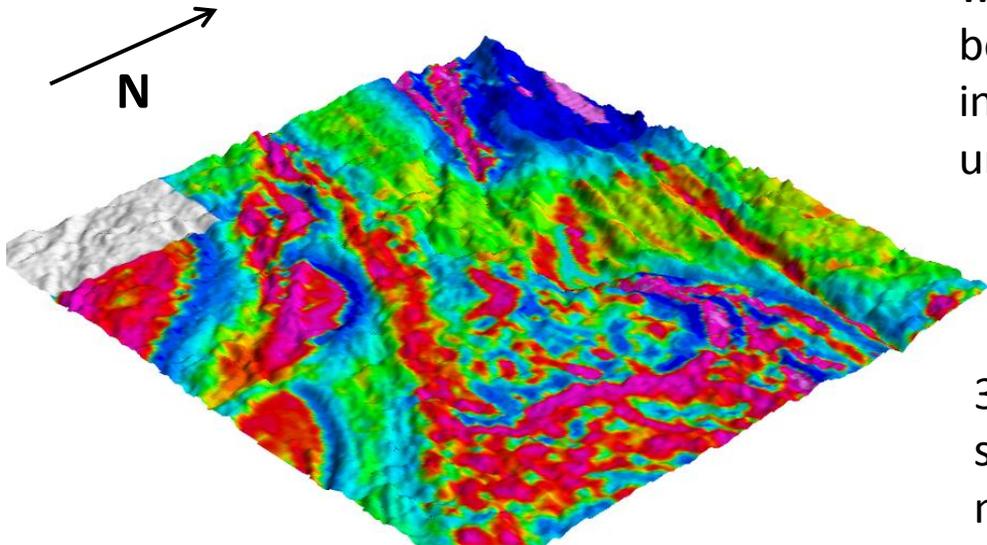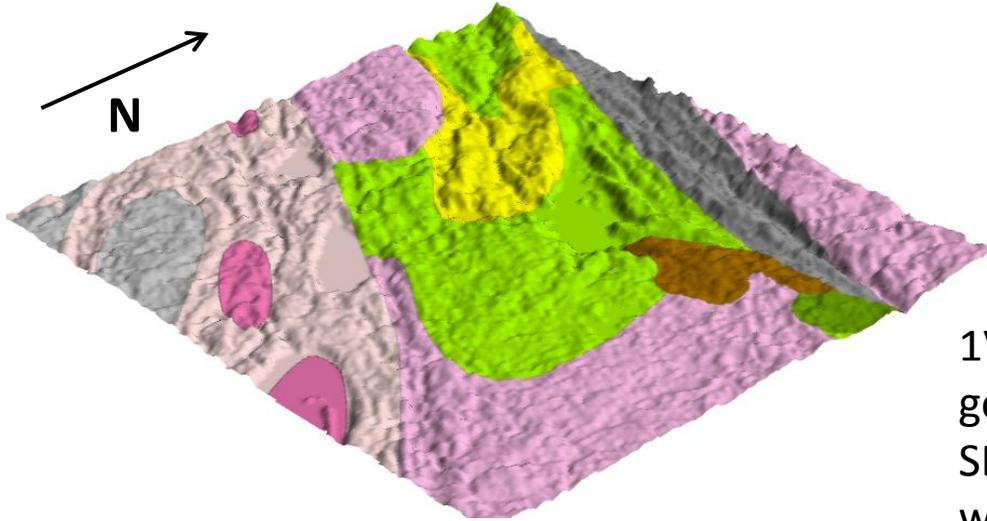
1VD Mag shows good definition of SE-NW structures as well as main contacts between volcanic, intrusive and gneissic units.

300 m line spacing survey; 150m nominal flying height

Case 1:
Regional Geology & Mag
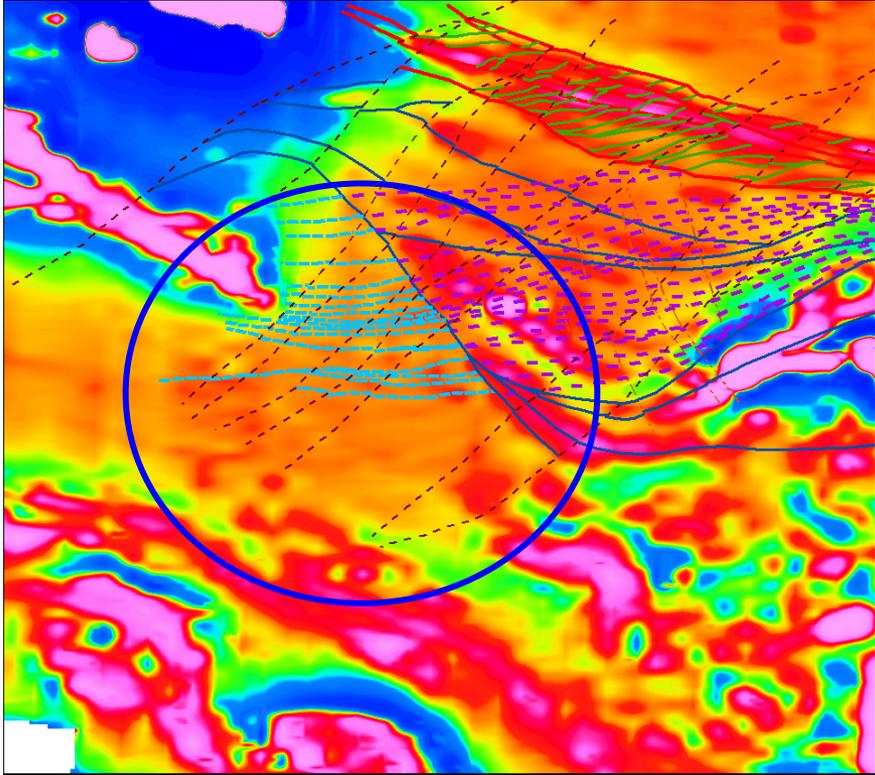
First pass of interpretation has identified multiple generations of shear zones.

The goal is to trace SW-NE structures under the thick sedimentary sequence.

Legend

| Structures		Mag1VD
ft_order	----- 5	**nT/m**
	-·-·- 5b	High : 63.5717
—— 1	- - - sz	
—— 2	-·-·- sz-int	Low : -8.76923
—— 3		

Kilometres
0 0.5 1 2 3 4
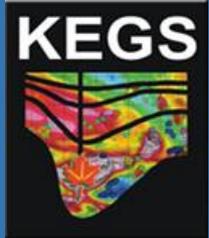
Case 1:
Additional Processing
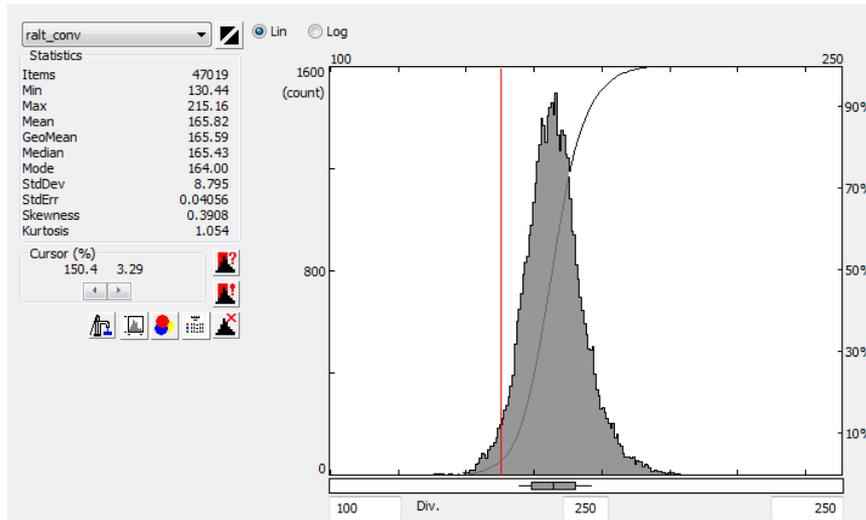
Nominal height was 150-160m. Red line is @ 150m, thus most of the data is above that.

We applied a Taylor expansion algorithm over profiles to normalize the amplitudes of the measured mag data.
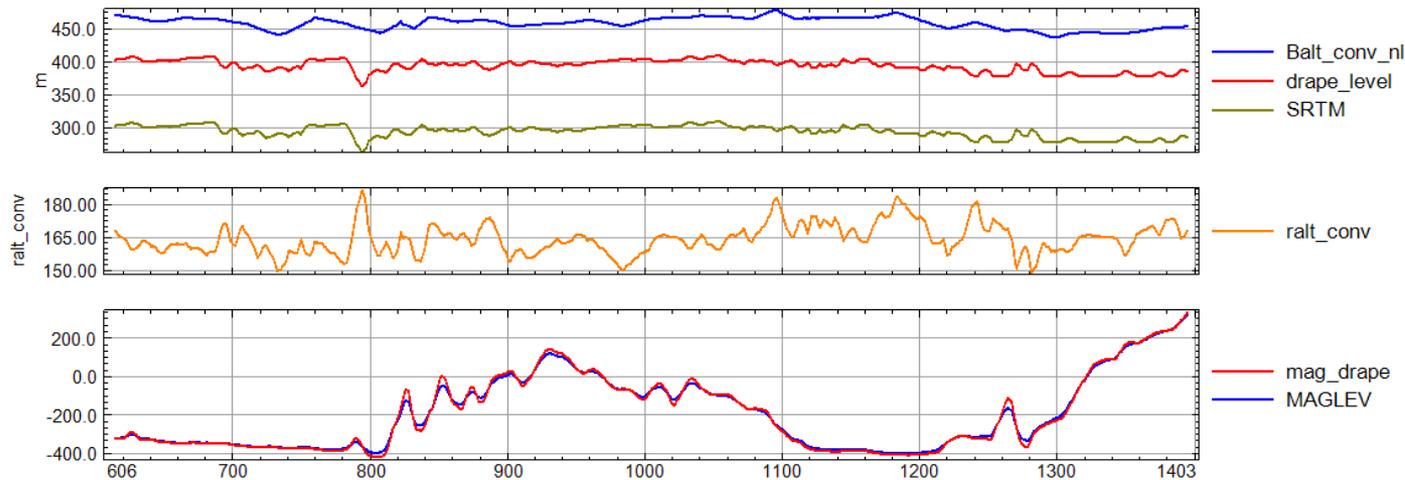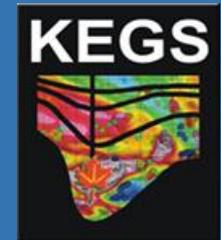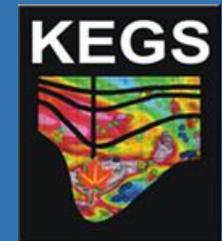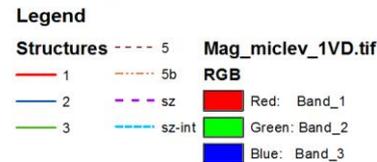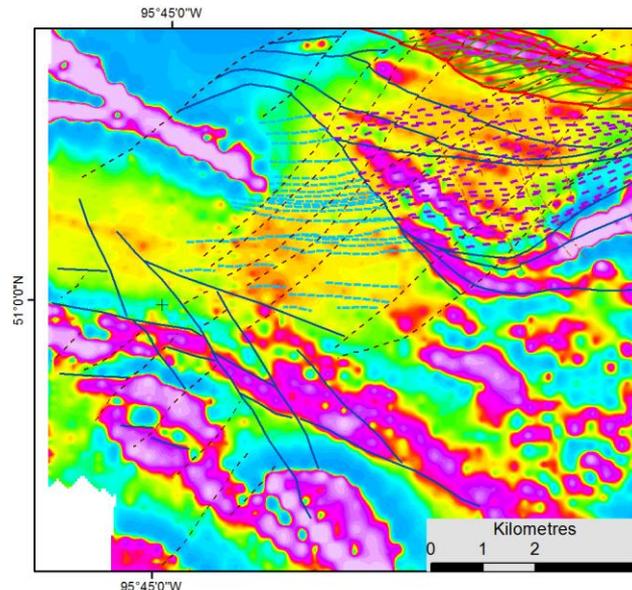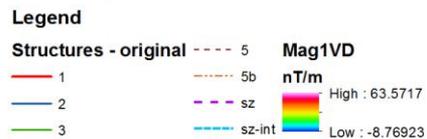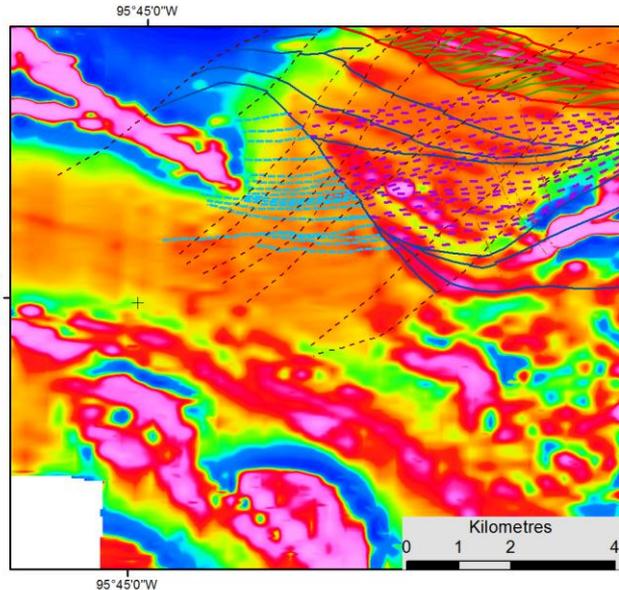
Case 1: Results


1) The Taylor expansion on profiles, although subtle, allowed to recover more signal on the sedimentary covered areas;
2) The addition of contours to the image helps on the definition of subtle structures.

Case 1: Results
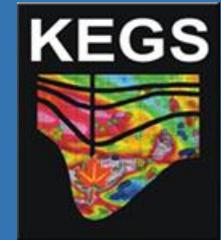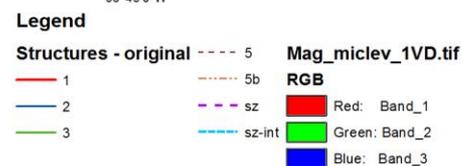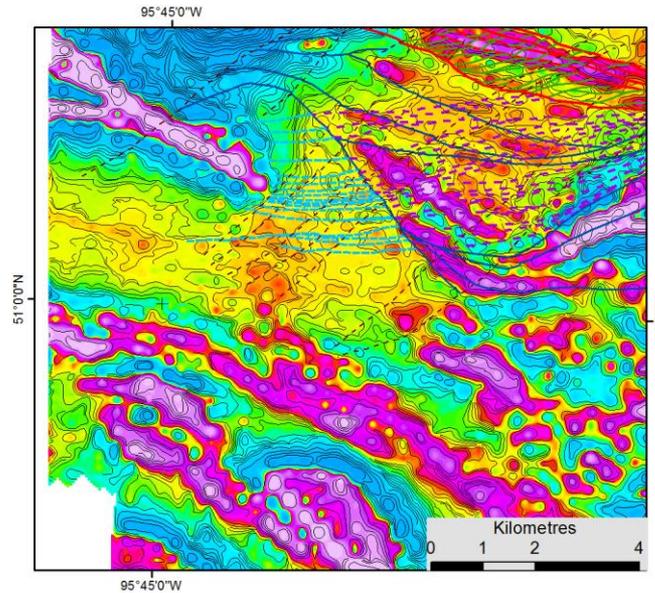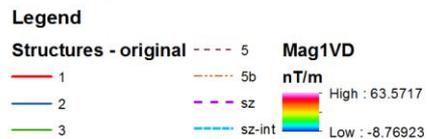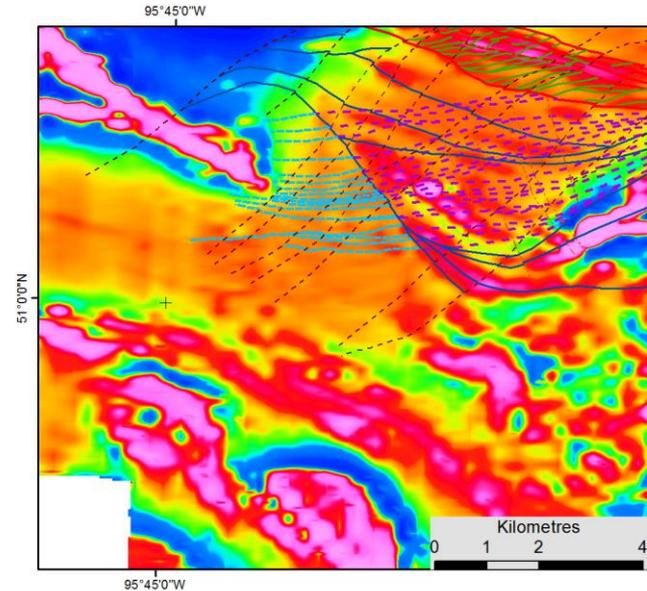
1) The Taylor expansion on profiles, although subtle, allowed to recover more signal on the sedimentary areas;
2) The addition of contours to the image helps on the definition of subtle structures.

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Case 1:
Results - detail

Before
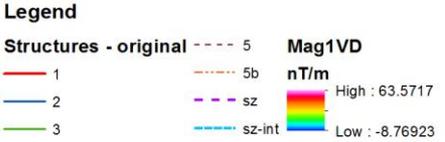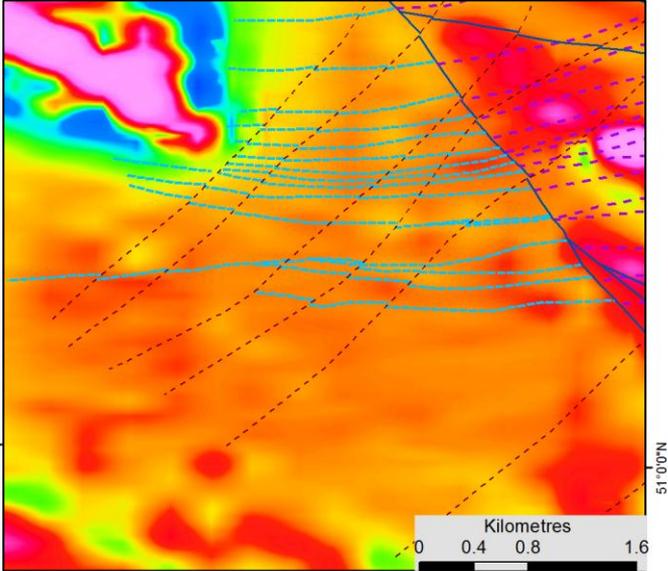
After
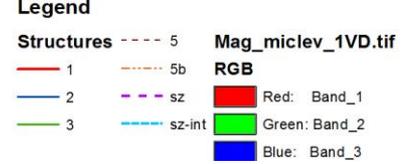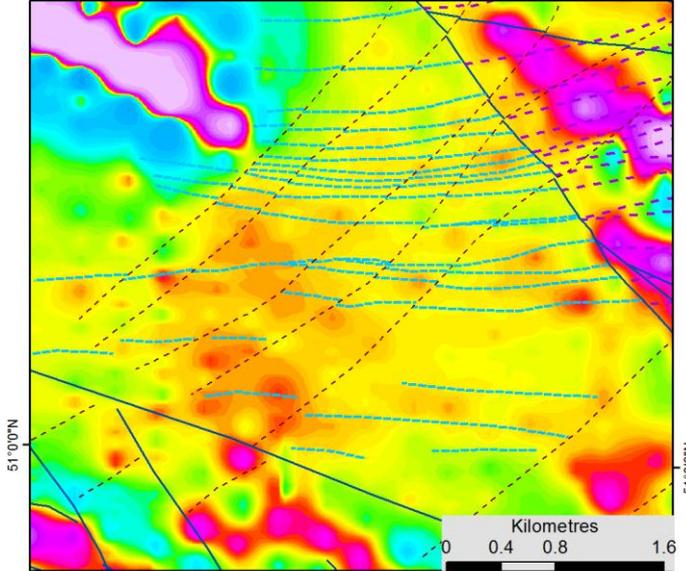
1) The Taylor expansion on profiles, although subtle, allowed to recover more signal on the sedimentary covered areas;
2) The addition of contours to the image helps on the definition of subtle structures.
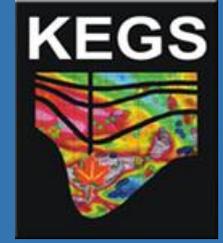
Case 2: Aid on 3D Geological Modelling

- A project where 3D modelling has been accomplished by means of compiling surface geology + borehole data and underground maps
- Then magnetics is brought as a means of redefining the initial model.

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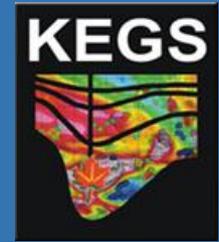
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Case 2: Modelling Methodology – Data input

Data comprises the following:

- Surface lithology observations, measurements of stratigraphic bedding, surface fault orientation measurements
- Interpretation of faults and lithology from surface observations and remote sensing and geophysical data
- Borehole data: lithology, faults (+ orientation if oriented core/televiewer is available)
- Underground maps
- Geological sections

Input data for lithological and structural modeling will have varying levels of certainty. The model is constructed to adhere to verified observation (e.g. surface/underground measurements) but will allow deviations from interpreted data.

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Case 2: Modelling Methodology – Fault Modelling
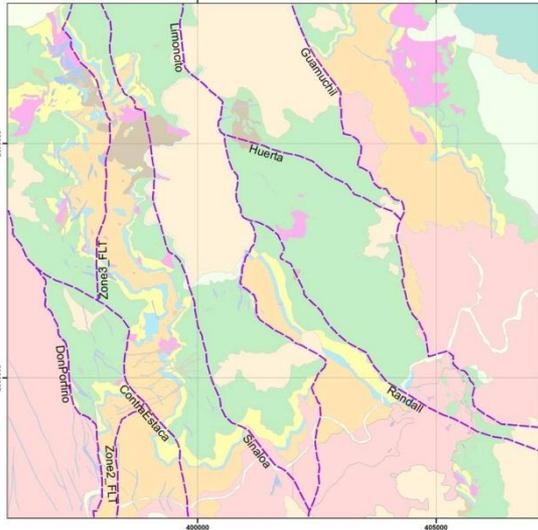
Define first-order faults in map view
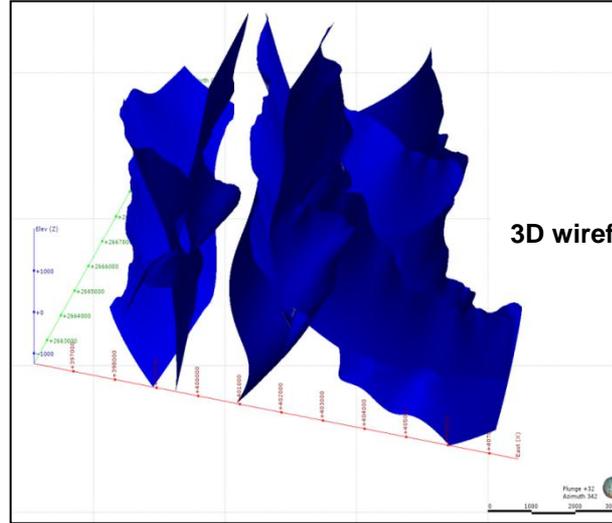
3D wireframes of faults

To create the structural framework of the geologic model, it is necessary to define the position and orientation of first order structures. Faults will be modelled from youngest to oldest, as the younger structure will offset the older structure. The modelled faults need to be extended to terminate at the model boundary, as the faults are subsequently used to subdivide the area of interest into fault blocks.
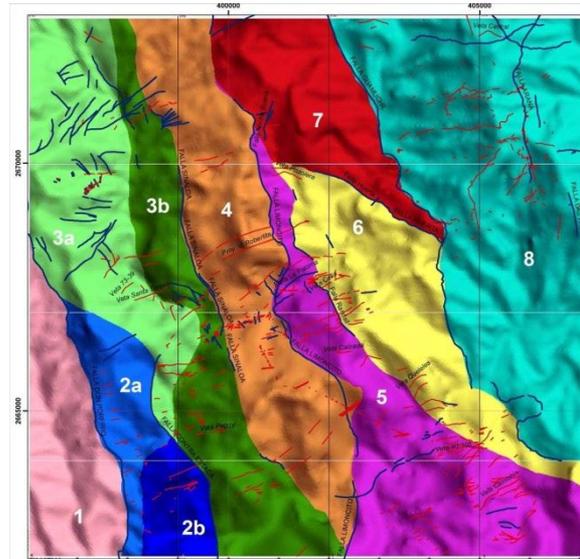

Fault blocks for lithology modelling

Case 2: Modelling Methodology – Lithology Modelling

Construction of the lithological contacts with borehole intersections.

Plunge +20, Azimuth 063
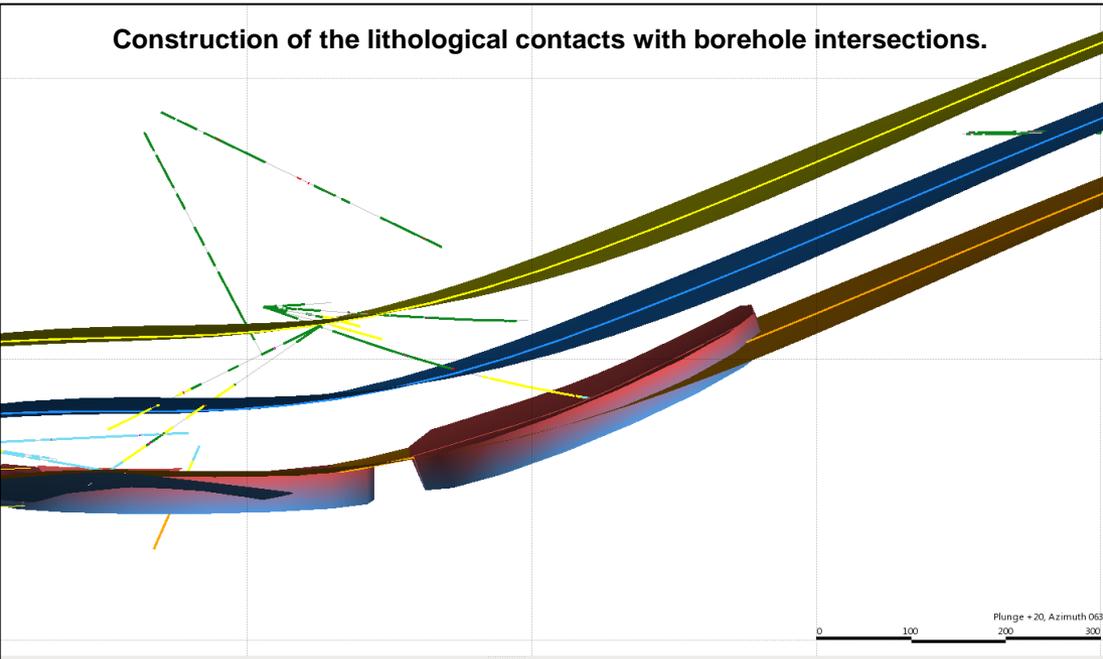
Lithological contacts are modelled within each fault block separately.

The position and orientation of lithological contact on surface and in boreholes are used to construct contact surfaces. Knowledge of the depositional environment (in weakly deformed sedimentary sequences) and dominant regional structures (e.g. orientation of folds and foliation in deformed rocks) is useful for extrapolating contact beyond observed extents.
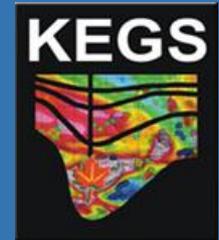
Case 2: Modelling Methodology – 3D Result

Oblique view of the Lithology model.
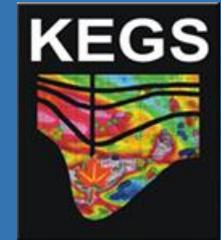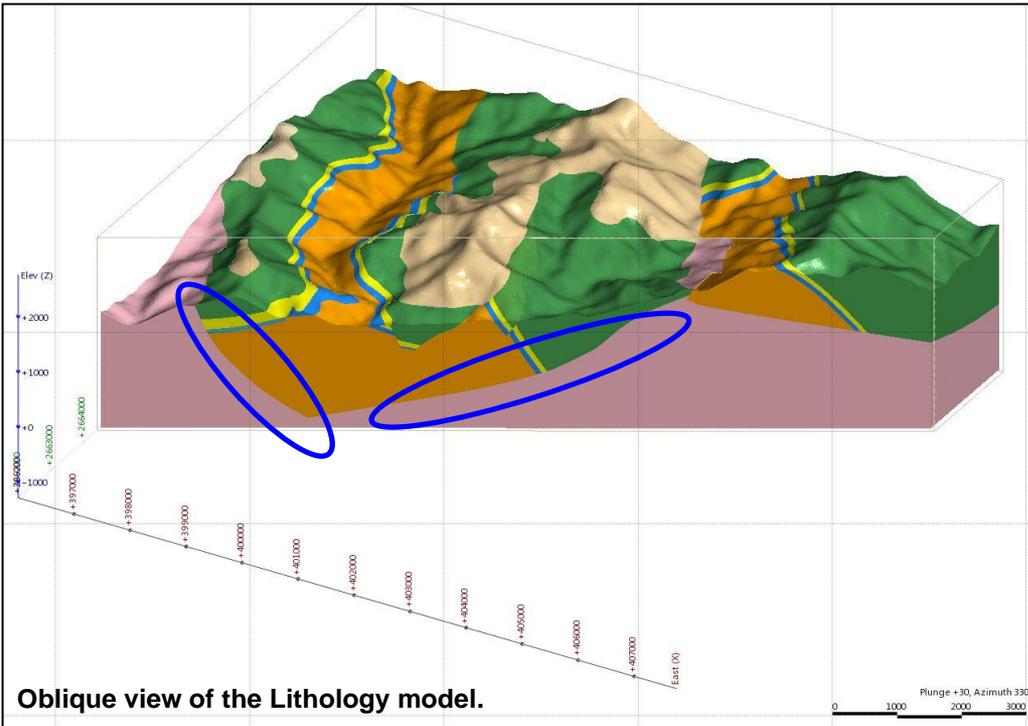
The geological model is then checked for internal consistency. In this process we analyze:

- Variations in layer thickness
- Offset direction and quantity along a fault

"Nice. These all looks good and fancy, but what about the geophysics?"

Case 2: Integration with Airborne Geophysics
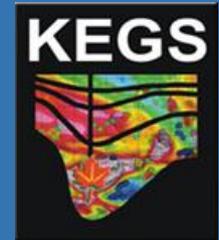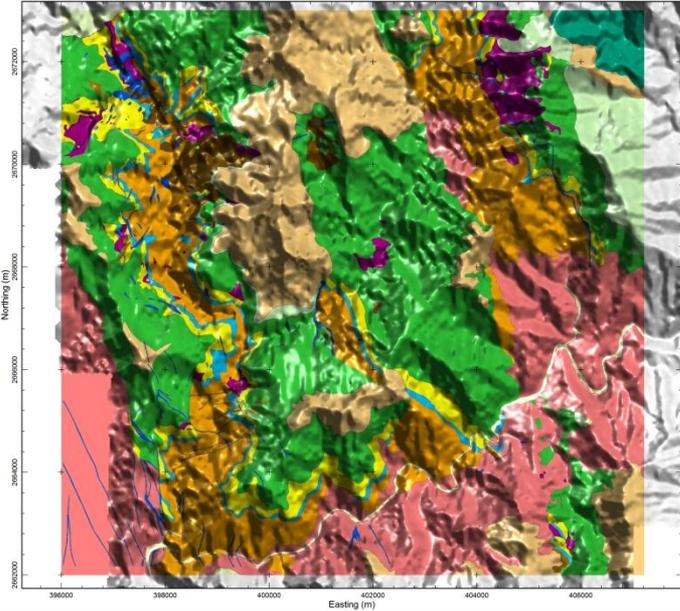
Geology of the Area
(Pink = granites;
Green= andesites;
Orange and light brown = rhyolites)
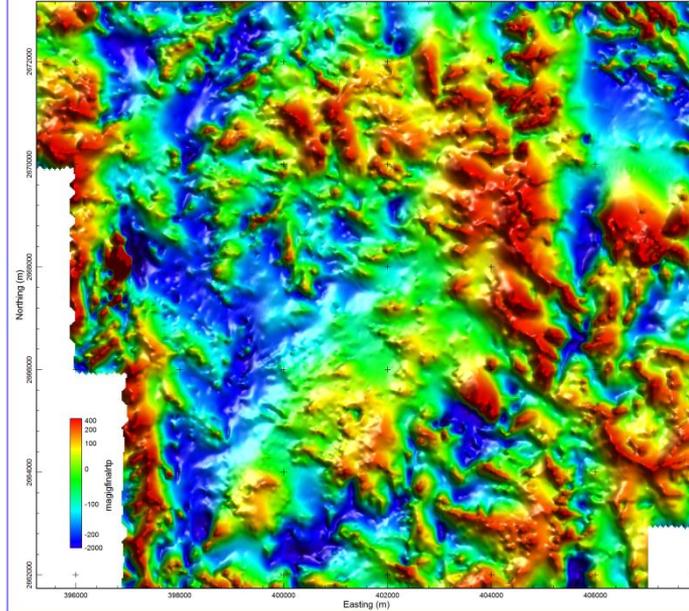
RTP Mag
100 m line spacing mag & spec survey

Case 2: Integration with Airborne Geophysics
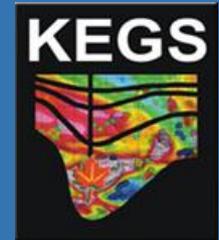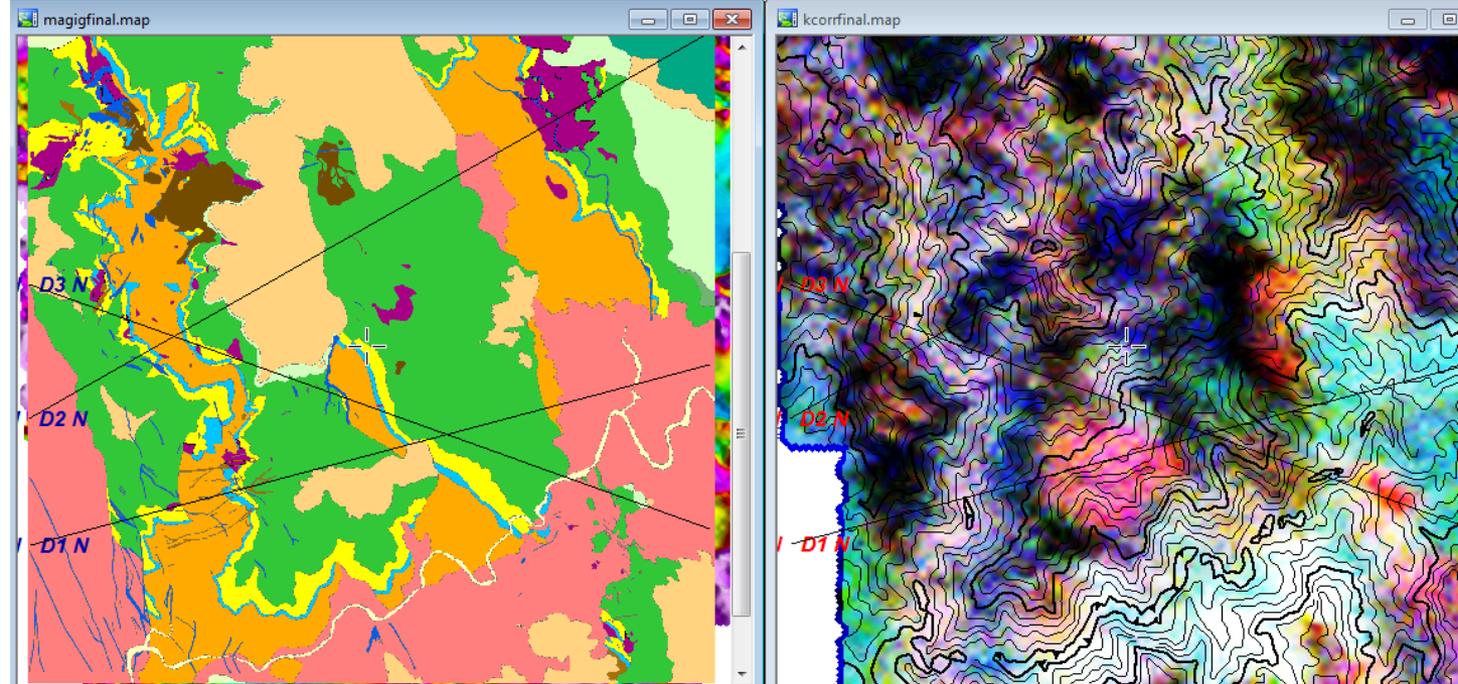
Geology of the Area
(Pink = granites; Green= andesites; Orange and light brown = rhyolites)

Ternary Spec
100 m line spacing mag & spec survey

Granite and rhyolite contacts seems to be well defined in the spec. Andesites are less clear.

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Case 2: Integration with Airborne Geophysics
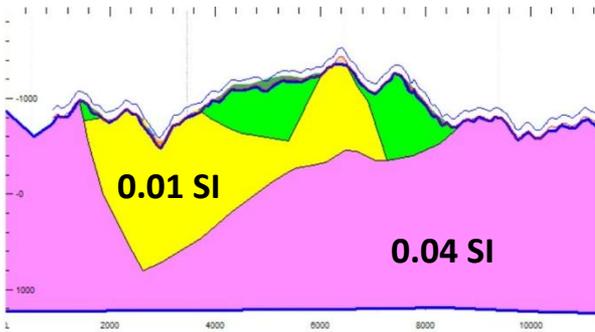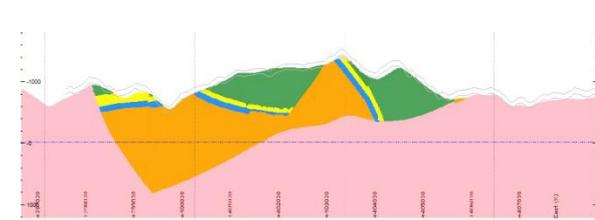
Section Line 1

Section Line 2

0.01 SI

0.04 SI

0.01 SI

0.02 SI
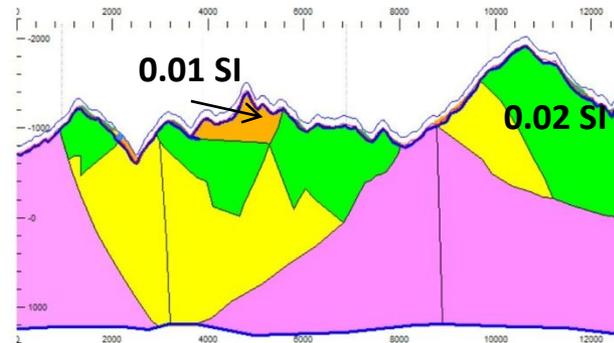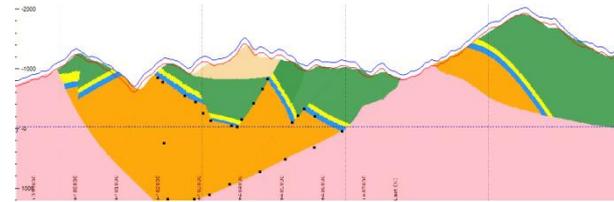
These sections show the extraction of the 3D Geological Model over 2 sections and digitizing in mag modelling software. Physical properties were not available, so they were assigned to match amplitudes.

Case 2: Integration with Airborne Geophysics
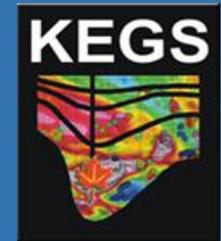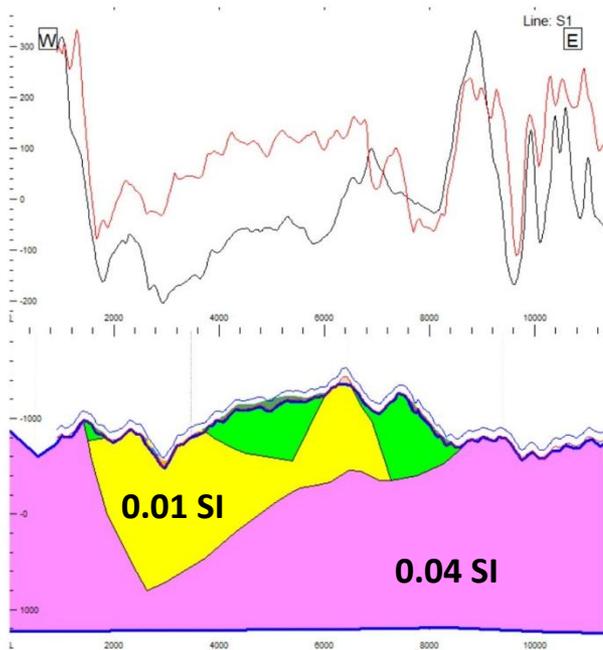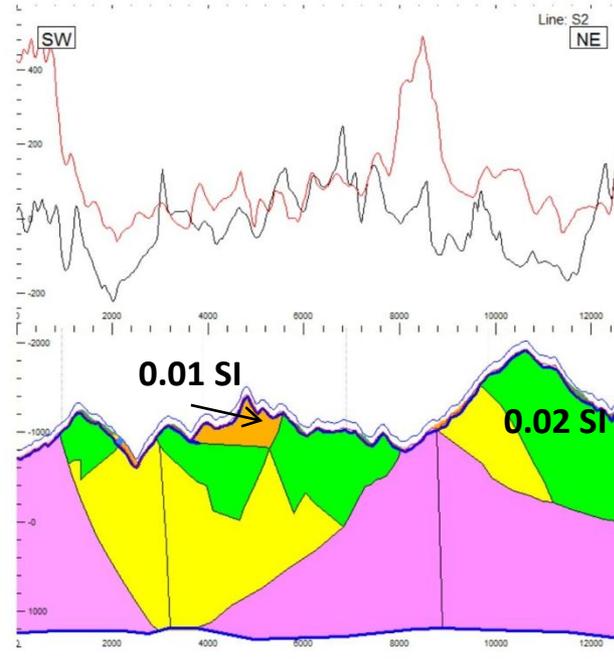
"Raw" Section Line 1   "Raw" Section Line 2

First iteration: we just assign some physical properties based on amplitude matching and try to be consistent…Then we inspect the model.

Line 1: we can match the amplitude of the basement anomalies; need to correct in the centre;

Line 2: Basement suscep seems too much…Either refine suscep or change the model.

Both: most of the signal comes from the topography!

Case 2: The "R" word…

Eocene vector

Current vector
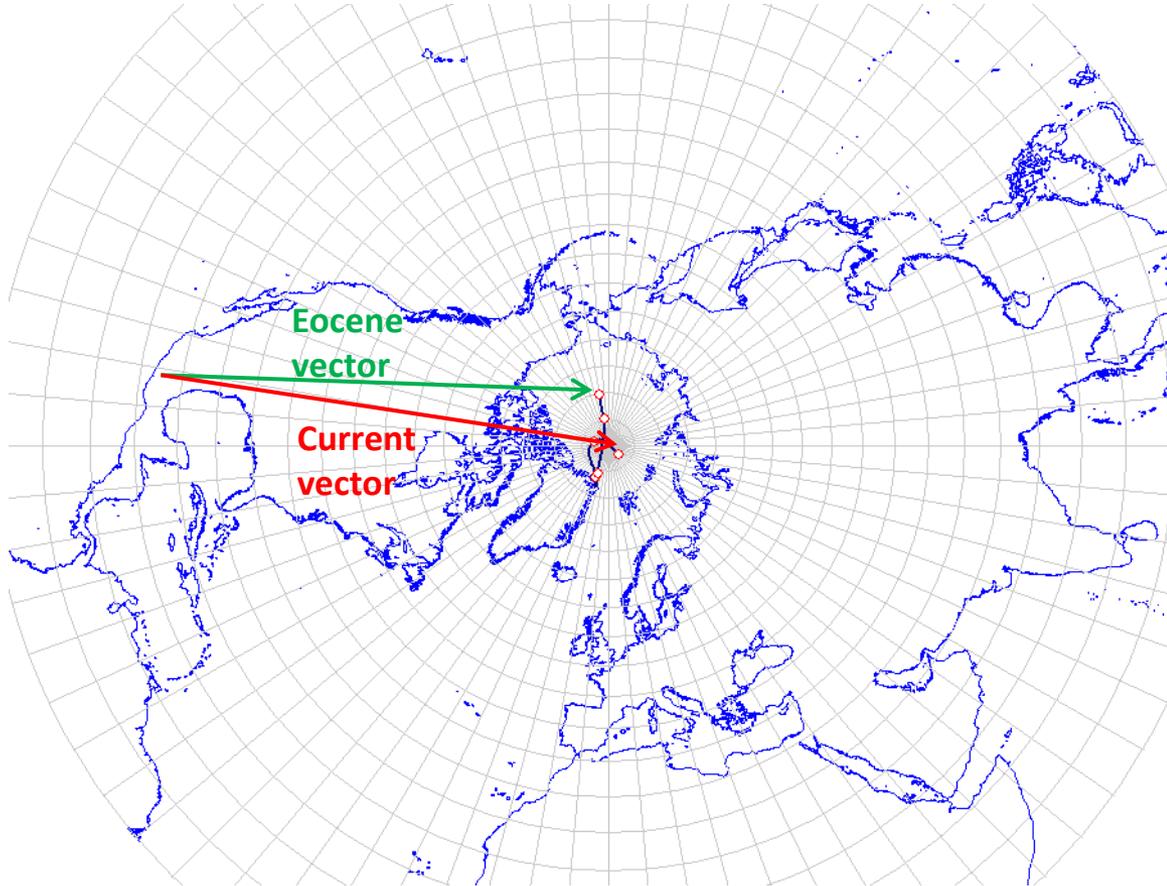
Current (Incl, Decl) for the site = (51,8)

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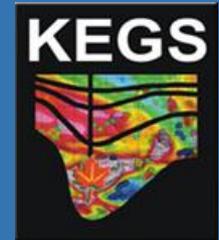
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Case 2: Modified Sections
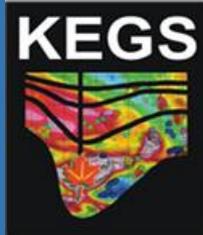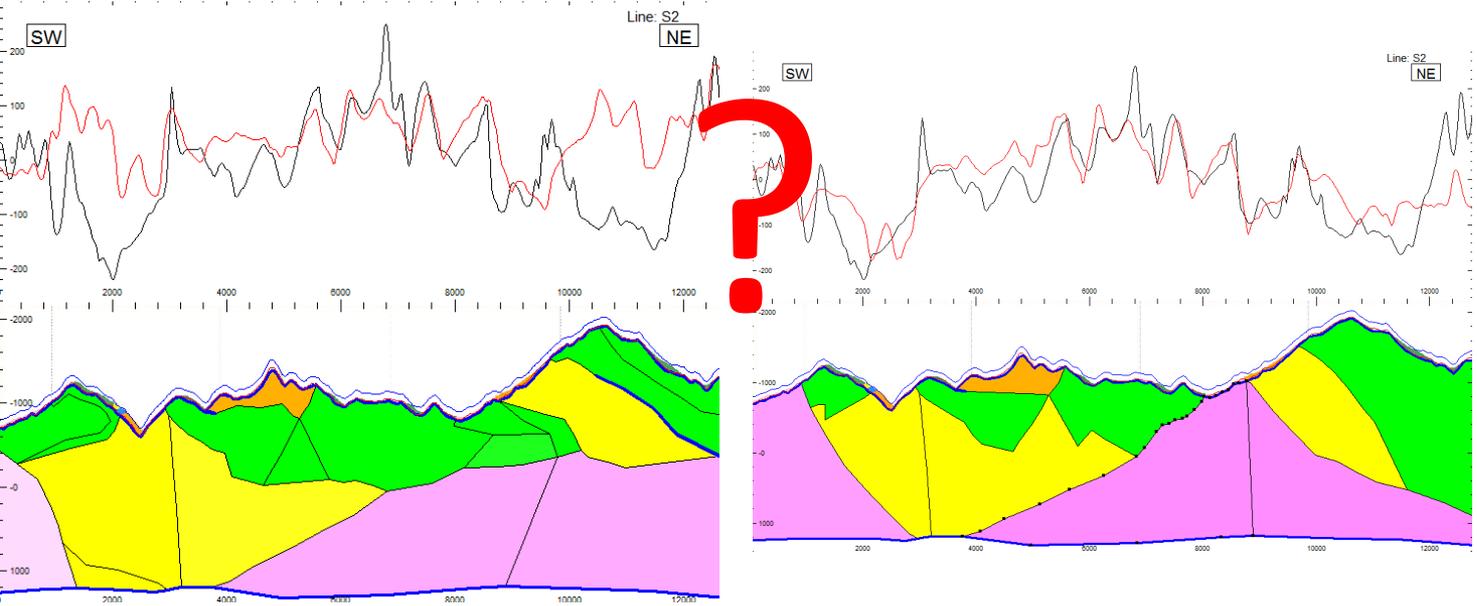
Option 1
- Requires changing the surface geology
- Need to go back to boreholes and surface mapping to see what is feasible

Option 2
- Minor changes in surface geology
- Quite a bit of gymnastics with remanence
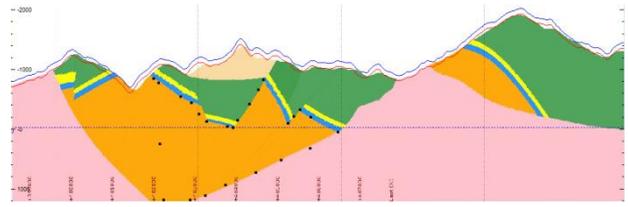

We need physical properties!

Case 2: Next step

Oblique view of the Lithology model.
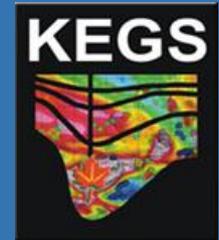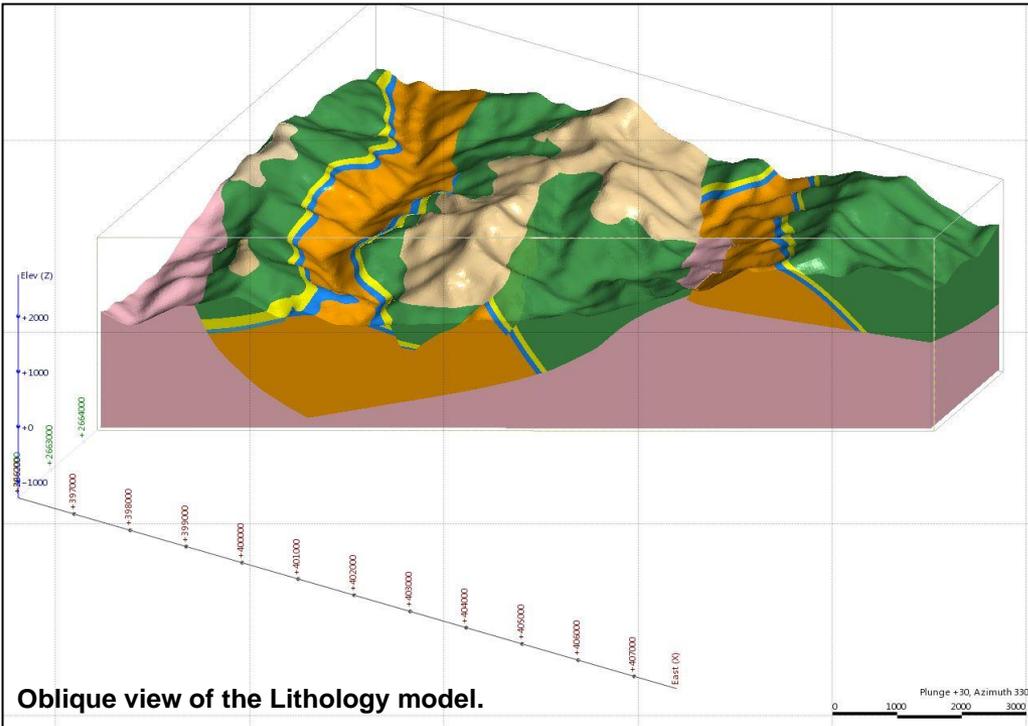
Once we solve the physical property issue and decide on which model to use, then the 3D model can be recomputed

Case 3: A complicated data integration one (in progress...)

- A project where substantial geophysical data is available, but geological control is scarce

- Geophysical data is re-interpreted for geological contacts and structures

- Structural geologist provides different scenarios, which will then be tested by modelling

# Case 3: A complicated data integration one (in progress...)

Regional Geology of the Area
(Light brown = gabbros;
Dark brown & yellow =
metasediments;
Purple = iron formations)

Mag RTP 2VD
100 m line spacing mag & EM survey
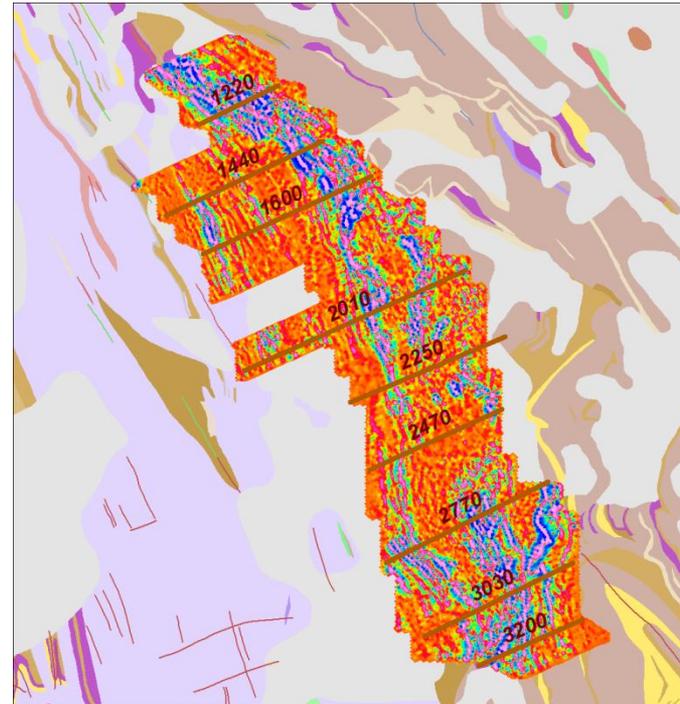
Legend
— Modelled sections
RTP2VD

0 1.5 3 6 Kilometers

Case 3: A complicated data integration one (in progress…)

- So from here we do the "standard"
  - Map contacts, structures
  - Run some EM Modelling (plates, CDIs)
- Ask for help…

# Case 3: A complicated data integration one (in progress...)

Top: extracted geology from the published map across one of the sections
Middle: EM CDI
Bottom: Geological cross-section. First attempt to understand the structure of the area

Case 3: A complicated data integration one (in progress...)
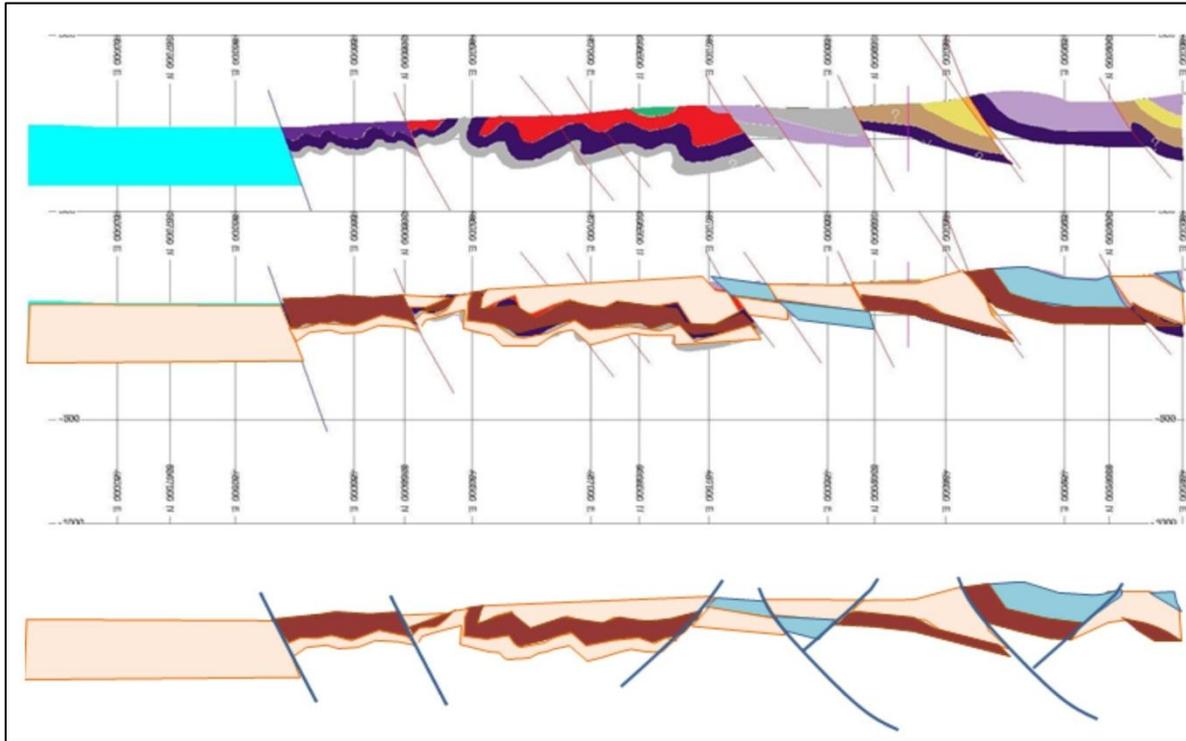
Top: First attempt to understand the structure of the area
Middle and top: Simplified geological cross-sections. 2 possible scenarios from the structural gurus.

What is next? Model the magnetic data and determine which of the 2 scenarios is the most likely. For that, we need proper magnetic susceptibility contrast, surface geology control on the sections...and illumination from the modelling gurus...

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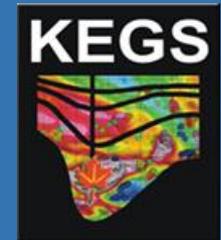
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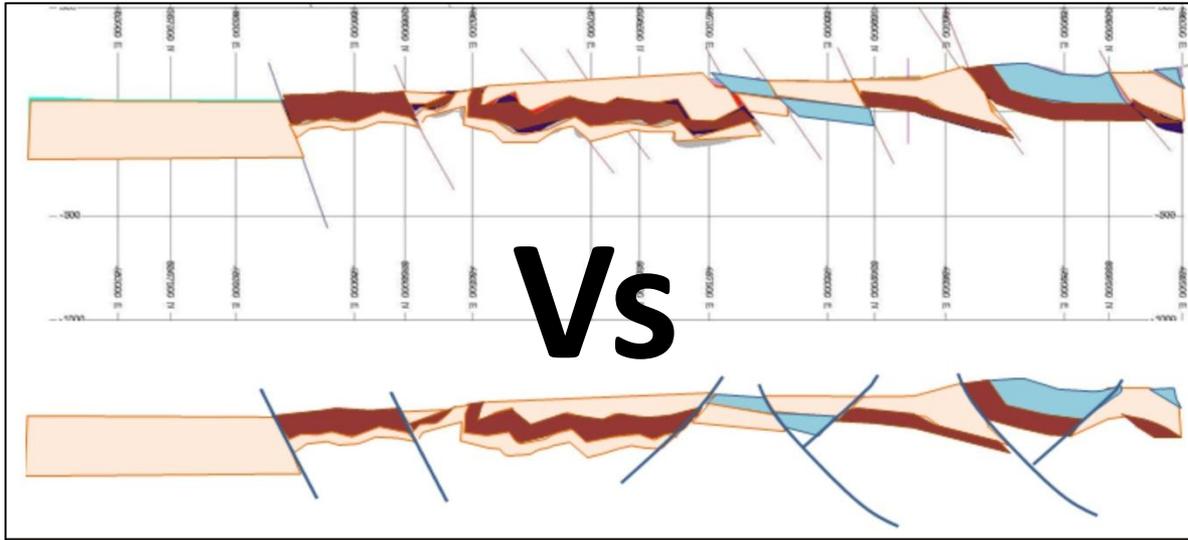
Case 3: A complicated data integration one (in progress...)


Implications for exploration?

- Depth of mineralized horizons;
- Once the kinematics and timing of mineralization is properly understood, this can allow focusing the exploration on either side of the main structures
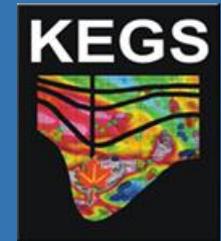
Summary & Conclusions

- What we "see" on each camp (geology, geophysics) is a function of how much physical property contrast there is between the units.

- It is quite common that a geophysical model "lumps" units that are transparent to each other. That doesn't mean that the geophysics is wrong, it is just the limitation of the methodology.
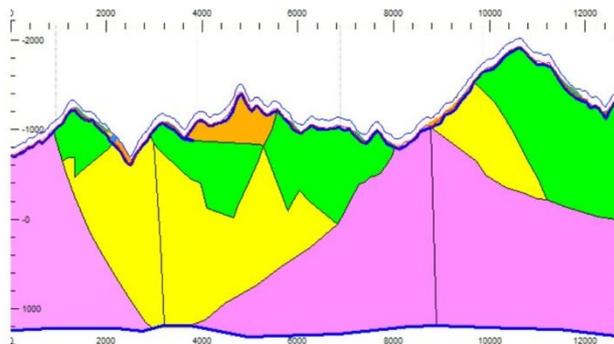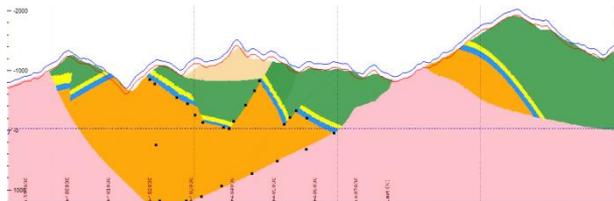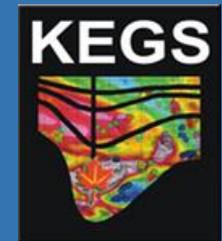
Summary & Conclusions
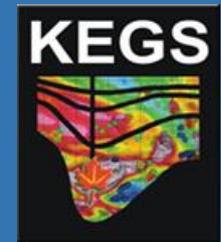
- Physical properties are critical for a successful modelling exercise;

- Same with the surface geology over the sections.

- Without them, we are back into the standard *"how much would you like it to be?"* scenario

- Remanence….once again, it doesn't stop at the oceans, and we can't neglect it. Physical property measurements must include at least NRM intensity, and ideally a few oriented samples.

Summary & Conclusions

- Finally, we need to refine communication between both sides of the equation:
  - Geologists need us to deliver state of the art processing that will allow them to see more;
  - Geophysicists need geological control;
  - More "**geophysics with geological tendencies**" will make for more realistic and efficient modelling
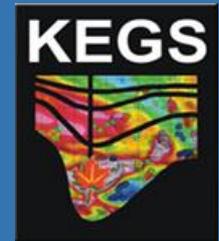
Acknowledgements

- Research needs data
  - Thanks To the 3 companies and Project Geologists we interacted with for the case studies shown

- Magnetization is not just induced; geophysics needs geology
  - Bill Morris for never giving up on these.

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