GEOPHYSICAL MODELLING OF THE NI-CU MINERALISED JACOMYNSPAN ULTRAMAFIC SILL, NORTHERN CAPE, SOUTH AFRICA

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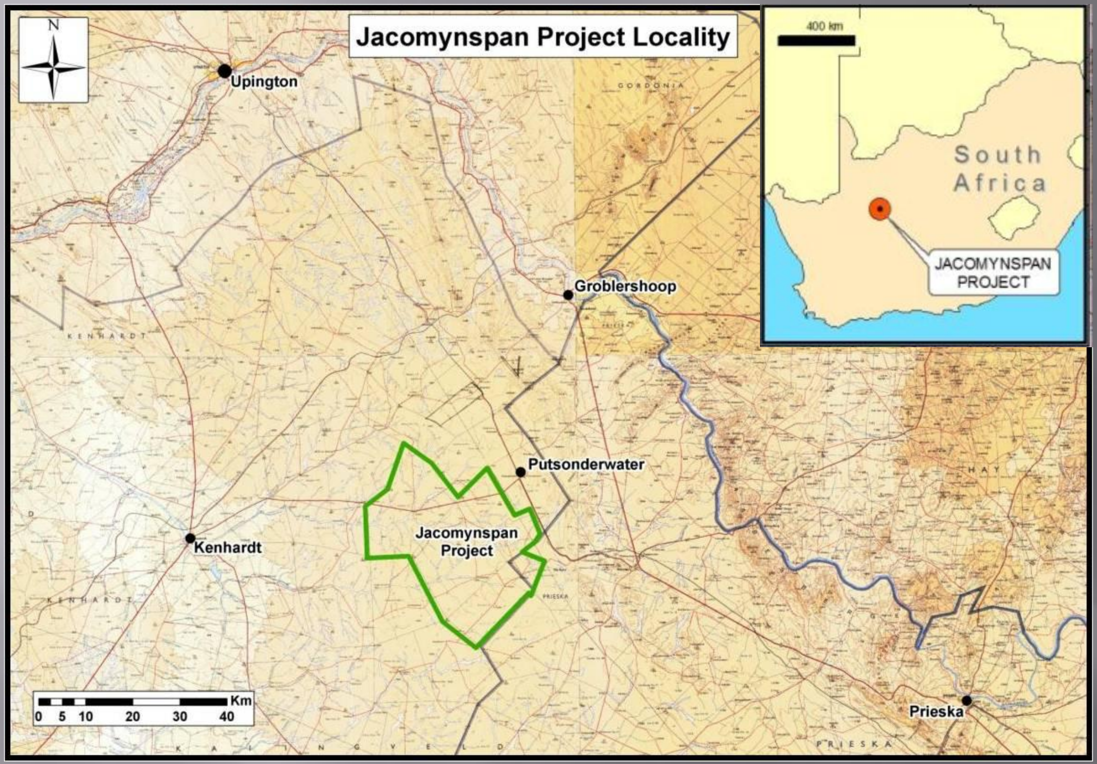
Introduction – Project Locality



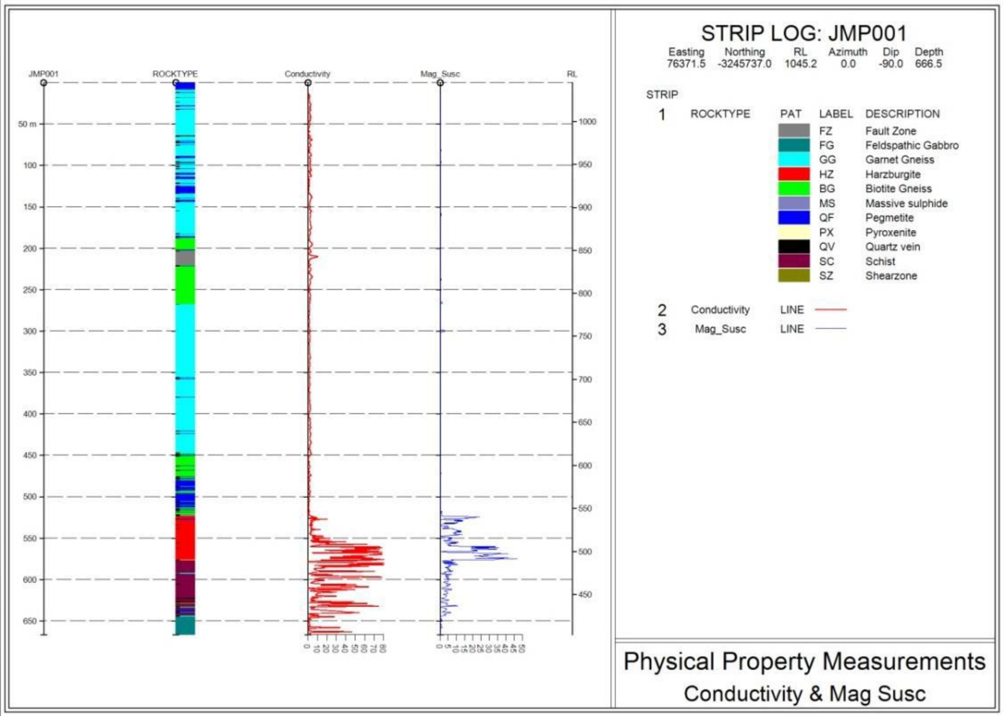
- This talk is based on some geophysical work done on a known Jacomynspan Ni-Cu deposit in the Northern Cape province of RSA.
- The deposit was discovered during an airborne EM survey by Geoterrex in 1971, using the INPUT EM System on behalf of Anglo American Prospecting Services (Proprietary) Limited over the Prieska – Kenhardt area.
- Project not viable according to Anglo American in 1974.
- Various other companies undertook limited prospecting after its discovery.
- African Nickel South Africa took over the project around 2011 and had access to Anglo American database and state-of-the-art equipment.
- The three basic platforms for geophysical methods – airborne, ground and borehole were applied between 2011 and 2013 at the project area using state-of-the-art equipment with the presenter being part of the individual survey teams.

Geology

- The Jacomynspan Ni-Cu sulphide mineralisation is hosted within a 100m thick steeply dipping tabular, differentiated, sill of mafic to ultramafic composition intruded into country gneissic rocks of the Namaqualand Metamorphic complex.
- The sill is predominantly composed of tremolite schist (metamorphosed pyroxenite) containing lenticular bodies of harzburgite. Massive sulphide veins and stringers are occasionally present within the harzburgite.
- The sulphide minerals are a typical magmatic assemblage of pyrrhotite, chalcopyrite and pentlandite.
- the harzburgite generally hosts net-textured mineralization with up to 50% of mineralization by rock volume. Massive sulphide veins and stringers are occasionally present.

Cross section of the Jacomynspan mineralised Ultramafic sill

Physical property measurements



- Physical property studies (mag susc and conductivity) carried out on historic drill core indicated that the net-textured harzburgite has elevated magnetic susceptibility of 0.03 SI.

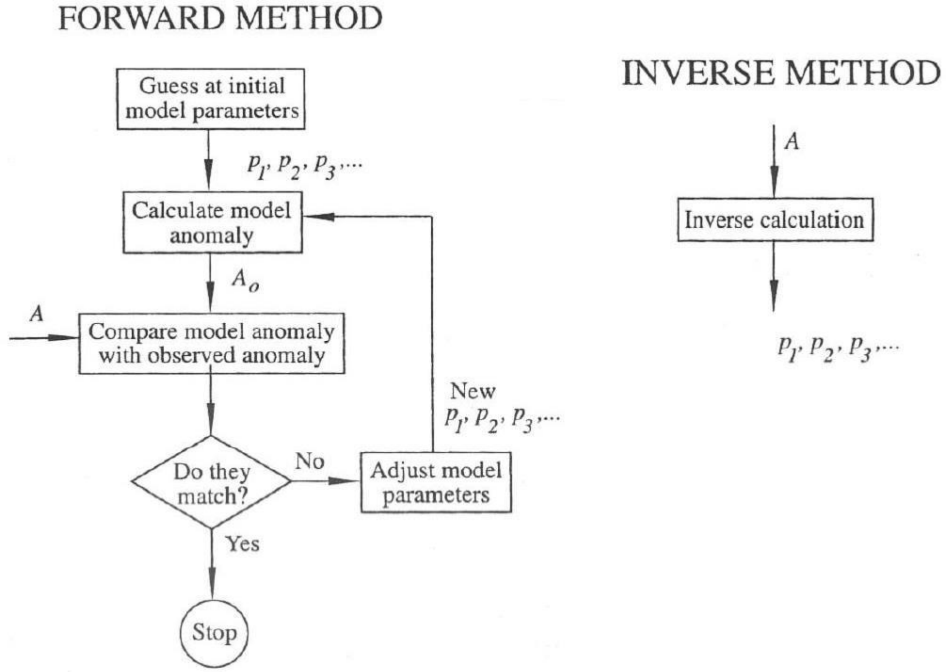
- the successful application of geophysics depends on gaining knowledge of the physical properties of the Earth section being examined.

- Contrasting physical properties between host environment and the target must be identified in order to enable selection of the appropriate geophysical technique.

Geophysical Inversion of Data

- In exploration, geophysical inversion usually means producing an earth model which is in agreement with geophysical survey data, in a timely and cost effective manner.
- Geophysical inversion is a non-unique process meaning different models can produce the same response. For example, a broad dense body close to the surface creates a gravity response that is similar to a very dense compact body deeper in the earth.
- A *priori* information must be included in the inversion (e.g. smoothness, geology, drilling, geophysical data etc.) in order to constrain the process.
- Integrating other information improves reliability and greatly increases the acceptance of the inversion into the exploration process.
- From a practical perspective, these processes must be robust and easy to use.

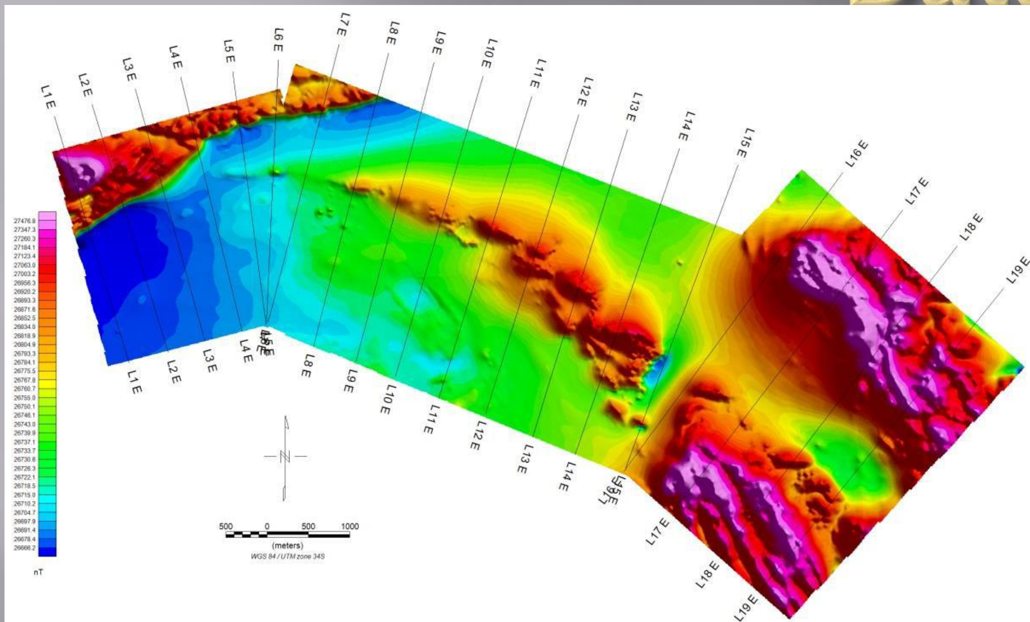
Methods of Modelling Geophysical Data



- The inverse problem is complementary to forward modelling. It helps determining what distribution of physical properties yields a measured field response best.
- It needs and allows the inclusion of a 'starter model' which is given by the forward model into which has been incorporated the *a priori* information on the source body.

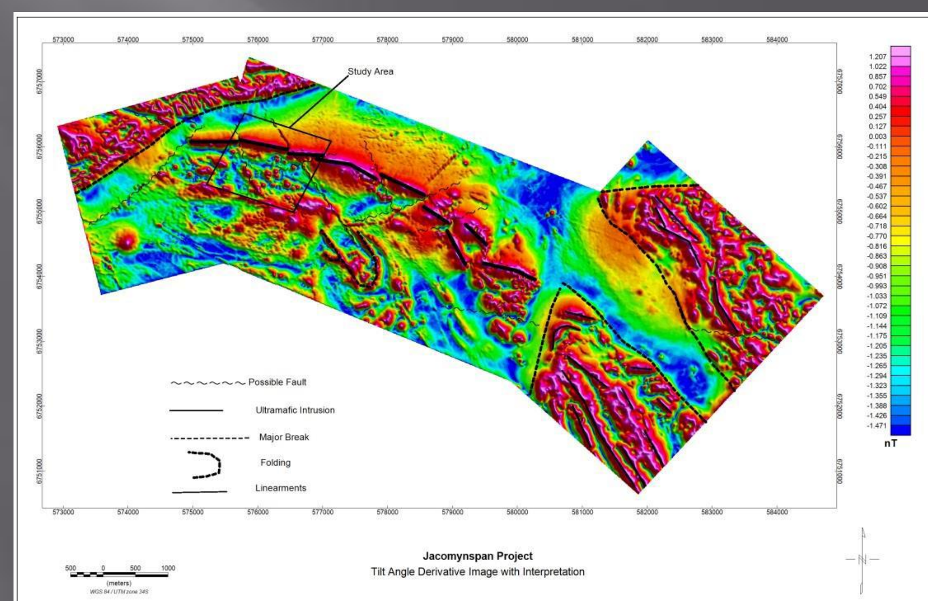
Comparing the forward and inverse method. ***A*** *represents the measured anomaly, and* ***Ao*** *the calculated anomaly. Parameters* ***p1***, ***p2***, *… are the source attributes (e.g. depth, thickness, density), (Blakely, 1995).*

High Resolution Aeromagnetic Data

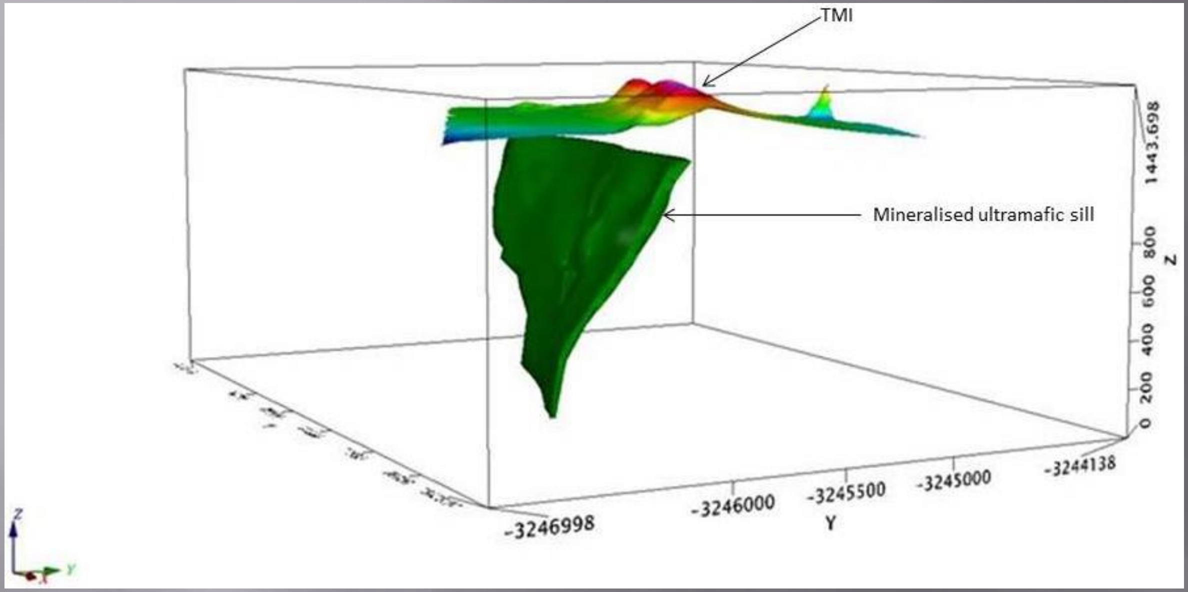


- A high resolution aeromagnetic data was acquired at 30m line spacing and a terrain clearance of 30m.
- The east-west trending ultramafic rocks over the main target zone are visible in the tilt angle derivative image.

- Since the Jacomynspan Ni-Cu sulphide deposit has a coincident magnetic and EM response, Cooper's Mag2dc, Stettler's Magmodintrp and Geosoft's VOXI Earth Modelling software were used for modelling the high resolution aeromagnetic data.
- 19 synthetic lines oriented perpendicular to strike were created for modelling using Mag2dc software



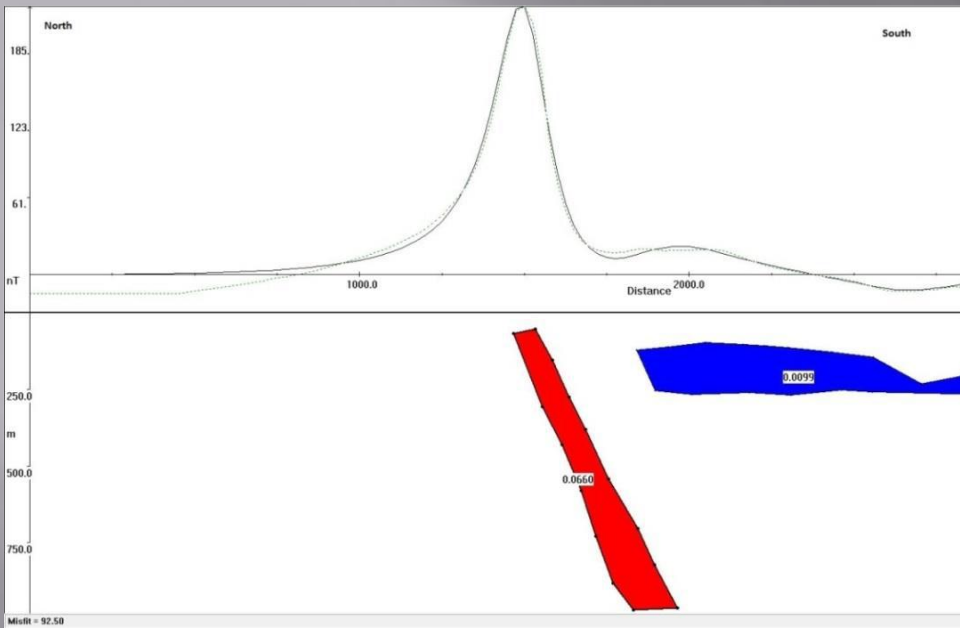
The 3-Dimensional starting Model



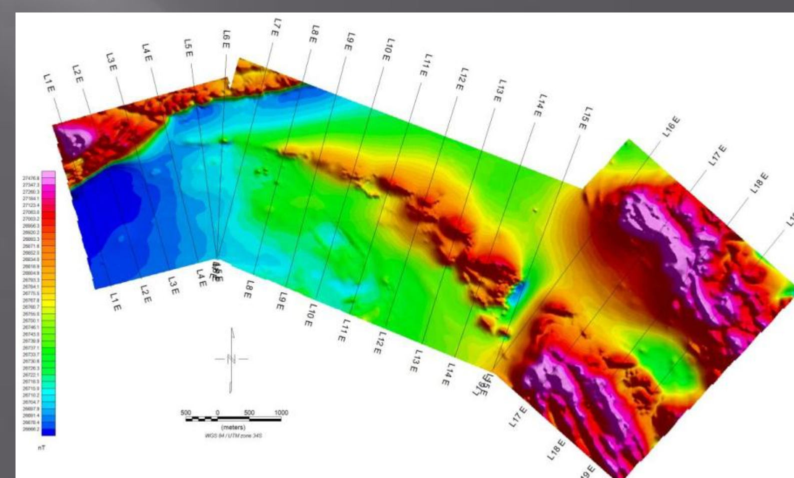
- The 3D geology model of the sill was created in Micromine software using drilling results from historical (1970s) drilling.
- The model was exported as a DXF file and imported into Geosoft together with the TMI image as shown

- This geological information was incorporated into the modelling process via the model objective function.
- The geology model and the associated measured physical property values were combined to make reference model m_{ref}.
- This model represents the best guess for the true distribution of the physical properties.
- During the inversion process, the challenge is to find a model that fits the data and is also close to this reference model.

Mag2DC Modelling of the high resolution aeromagnetic data

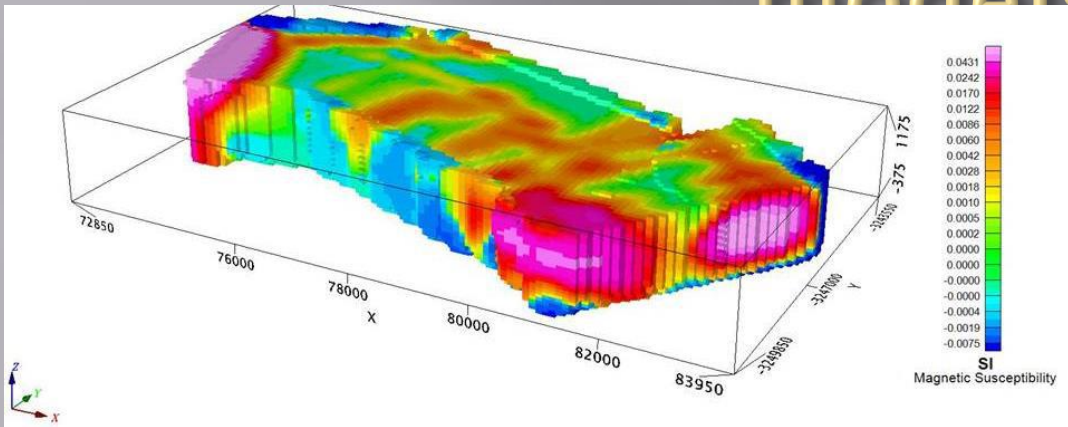


- The forward modelling process involves calculating a corresponding magnetic response from a postulated geological ‘starter’ model which in turn is compared to the observed magnetic field response while adjusting the regional field during the process.



- The modelling results produced a close fit between the calculated response (green dotted profile) and the measured TMI response (black profile).
- A body representing the ultramafic sill which steeply dips to the south at around 68^0 with a large depth extend of over 900m was modelled in agreement with the known geology.

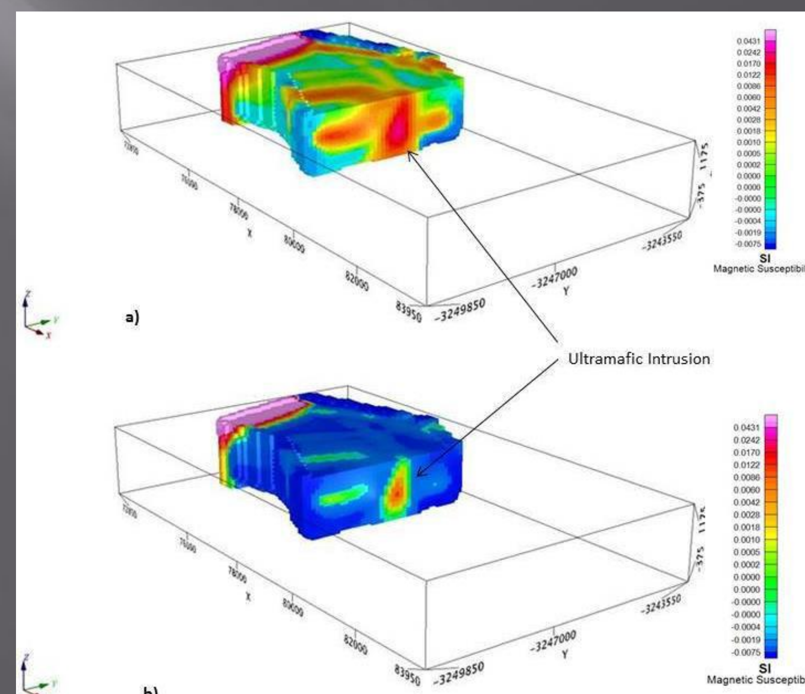
Creating a 3D model representation from Mag2DC models



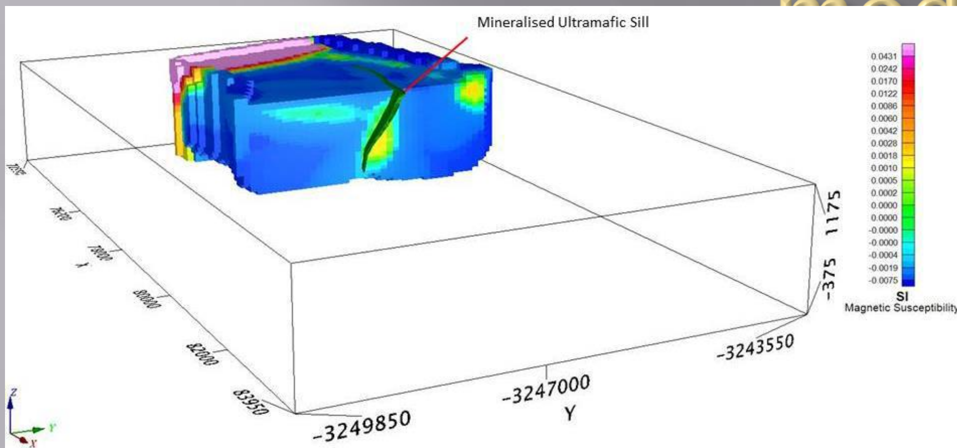
The final 2.5D model for each line was exported in Mag2dc as an ASCII file. The algorithm 'Magmodintrp' written in FORTRAN 77 by Prof Edgar Stettler was then used to extract the cross sections of the final model giving an X, Y, Z file.

- This XYZ file was then imported into geosoft and gridded in 3D to come up with a 3D magnetic susceptibility starter model.

- The smooth model can be clipped along the X-axis to the mineralised mafic to ultramafic intrusion of the study area.
- A colour tool in Geosoft can be applied to clearly map the ultramafic.

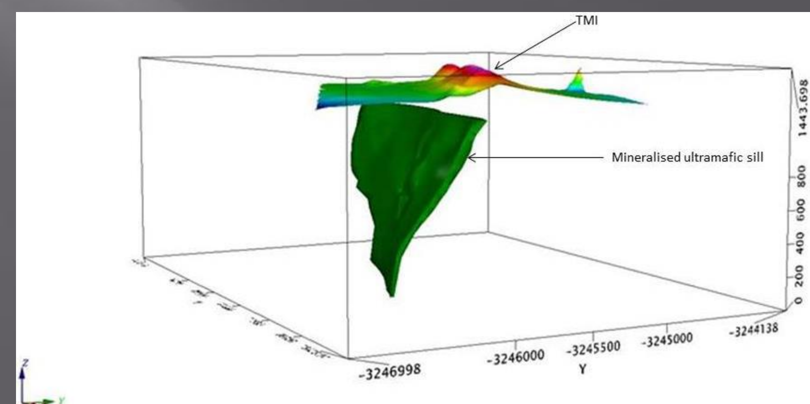


Integrating the 3D model representation Micromine Geology model



- Integrating the 3D model representation with the Micromine geology model of the poorly mineralised tremolite schist shows that the intrusion has been clearly mapped as shown

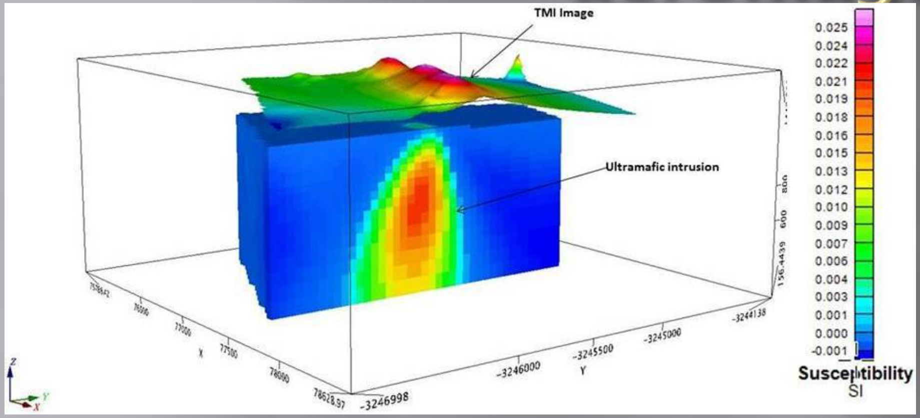
- It must be noted that this is still only a ‘starter’ model and can now be subjected to 3D least squares or other inversion techniques such as the ones available in Geosoft.
- However, the 3D model already represents the interpreter’s best information on the most likely imitation of the true geology and the inversion only needs to make final minor corrections to obtain the best fit between observed and calculated total magnetic field values.



Geosoft's VOXI Modelling

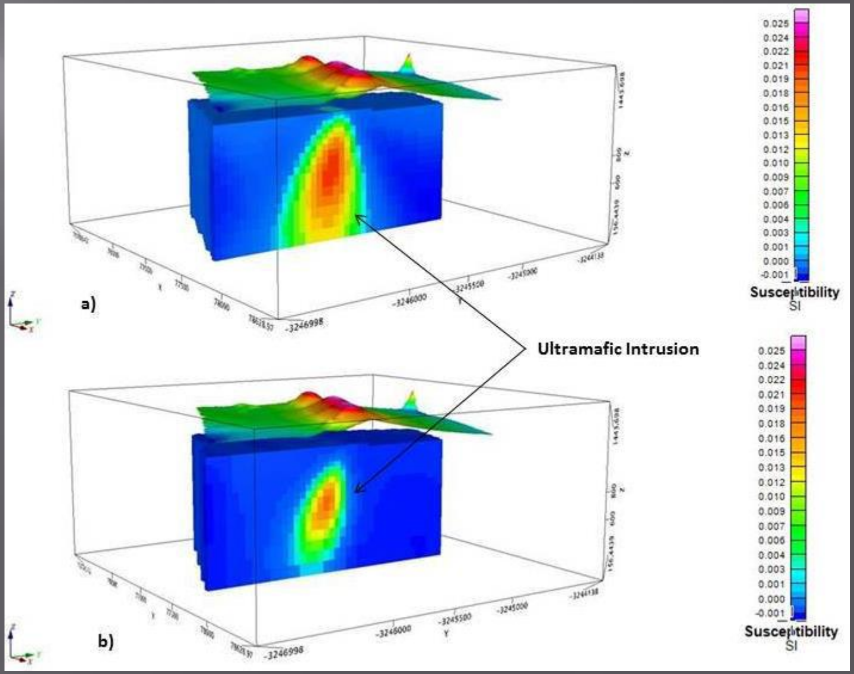
- VOXI Earth Modelling is a Geosoft® geophysical inversion software service that generates 3D voxel models from airborne or ground gravity and magnetic data using cloud computing.
- The inversion process of VOXI Earth modelling software can be explained starting with the forward and inverse problem represented by the following equations:
- $\boldsymbol{G[m] = d}$ *forward problem* and $\boldsymbol{G^{-1}[m] = d}$ *inverse problem* where $\boldsymbol{G}$ is some geophysical phenomena, $\boldsymbol{m}$ is the earth model and $\boldsymbol{d}$ is the geophysical data.
- However G^{-1} does not exist, therefore the inverse problem becomes one of optimising the closeness of the predicted model and its forward calculated response to what we have observed and what we assume in the model to look alike .
- In VOXI, the idea is therefore to quantify the closeness between the predicted model response and the observed data using the data misfit equation.

Geosoft's VOXI modelling of the aeromagnetic data

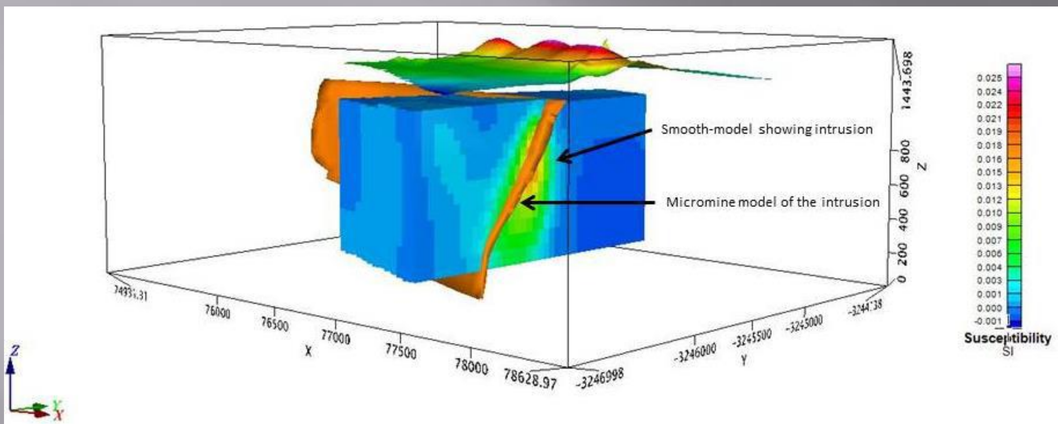


Voxel inversion, by definition, divides the earth into a number of voxel (cubic) elements and solves for their associated physical properties (magnetic susceptibility in this case).

- The unconstrained smooth model inversion results for the study area above clearly maps the Jacomynspan ultramafic intrusion which has elevated values of the magnetic susceptibility.
- The Iterative Reweighting Inversion Focus constraint normalizes and sets the outcome of the previous inversion as the weight constraint for the next inversion.
- It allows the model to be refined in order to emphasize positive or negative anomalies (in this case the positive was emphasised)

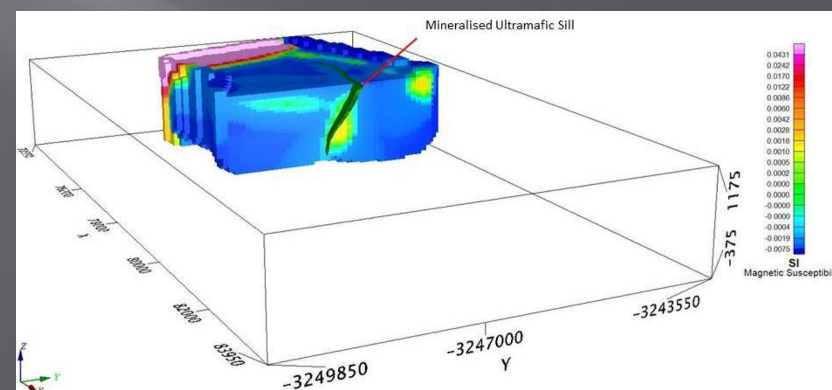


Integration of the 3D smooth model inversion results with the Micromine Geology model



- Integrating the VOXI smooth model inversion results with the Micromine Geology model of the mineralised ultramafic sill shows a direct correlation as can be seen to the left.

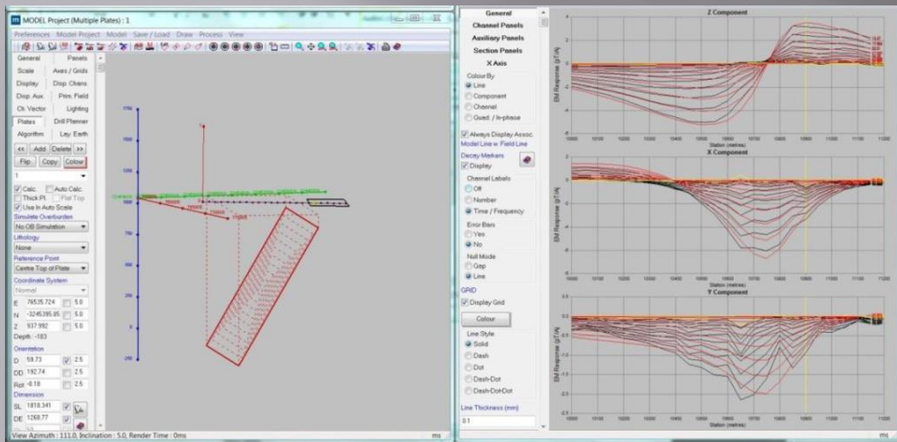
- However the slightly magnetic material south of the sill which has been resolved by the Mag2dc inversion process shown on the right does not appear on the VOXI inversion results.

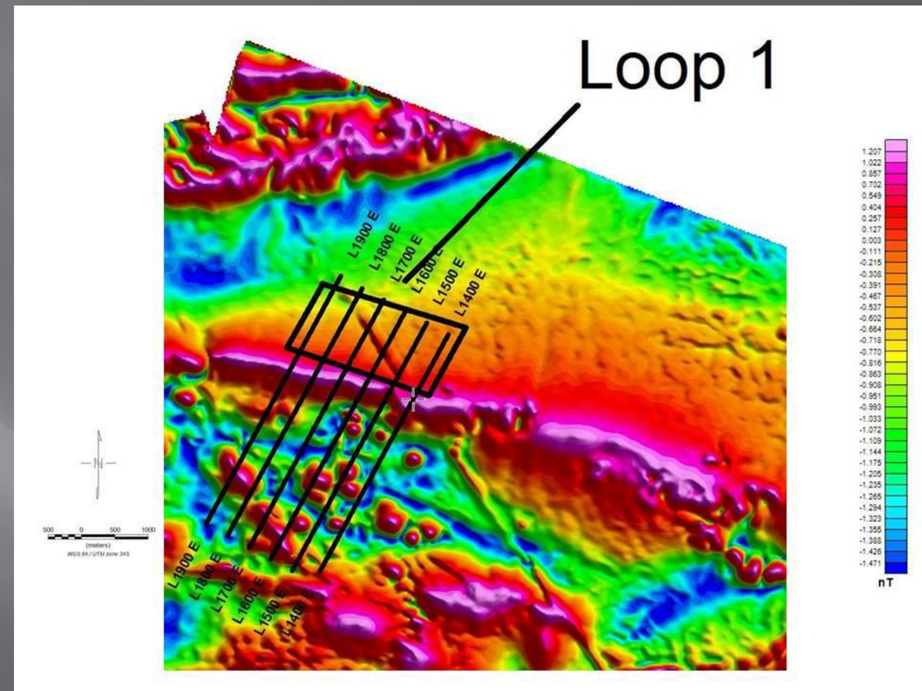


Modelling of Fixed Loop Ground EM and DHEM data

- Fixed loop ground and Downhole EM data for the project area were modelled using EMIT's Maxwell software. Ground EM data were acquired using a Low Temperature SQUID sensor while DHEM data were collected using EMIT's Digi Atlantis system.
- Procedure for modelling DHEM and ground EM data in Maxwell software is almost the same.
- The plate parameters are modified to represent the target based on the anomalous data taking into account the *a priori* information that is available from the 3D Micromine geology starter model and physical property measurements.
- A forward model is then calculated while adjusting the conductance until there is a response and moving the plate until a reasonable fit is obtained for a single line.
- With these forward 'starting' parameters determined, the EM plate can now be inverted for the Easting of Plate Centre (E), the Northing of Plate Centre (N), Elevation of Plate Centre (Z), Dip (D) and Dip Direction (DD) while constraining the inversion.

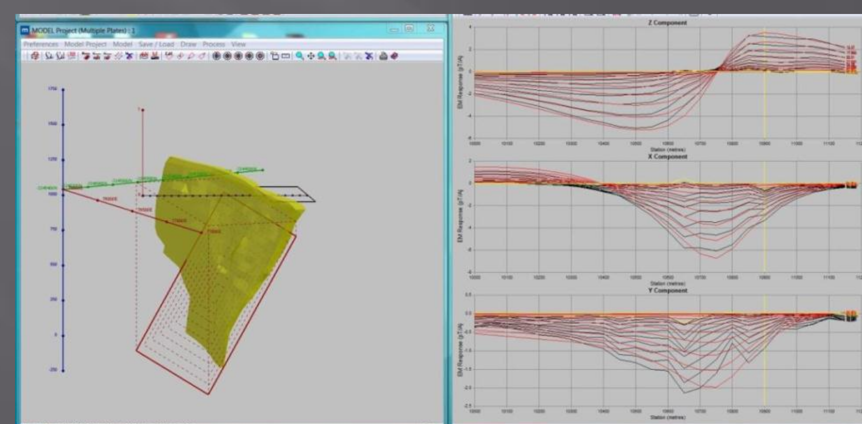
Plate Modelling of Fixed Loop Ground EM data



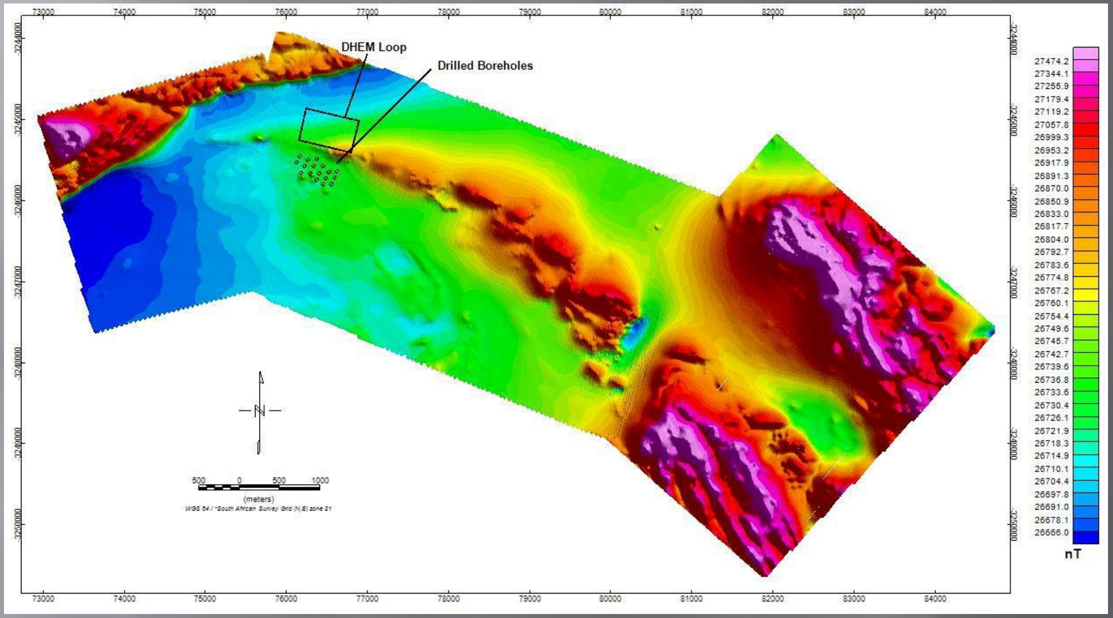


- The right window show the measured EM response profiles in black and the modelled EM response in red for the three components Z, X and Y.

- The modelled EM plate in red integrated with Micromine geology model of the mineralised ultramafic sill in yellow showing a direct correlation.

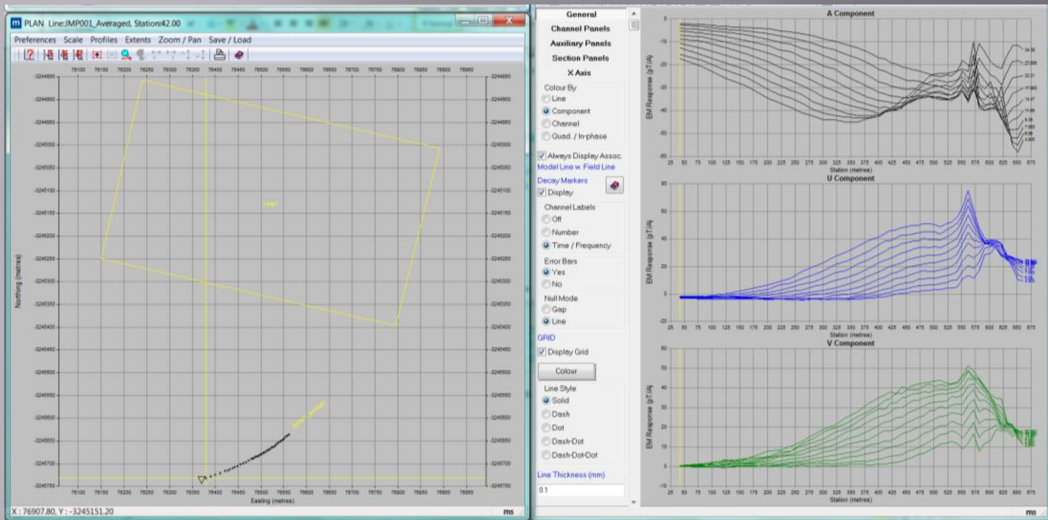


DHEM Survey



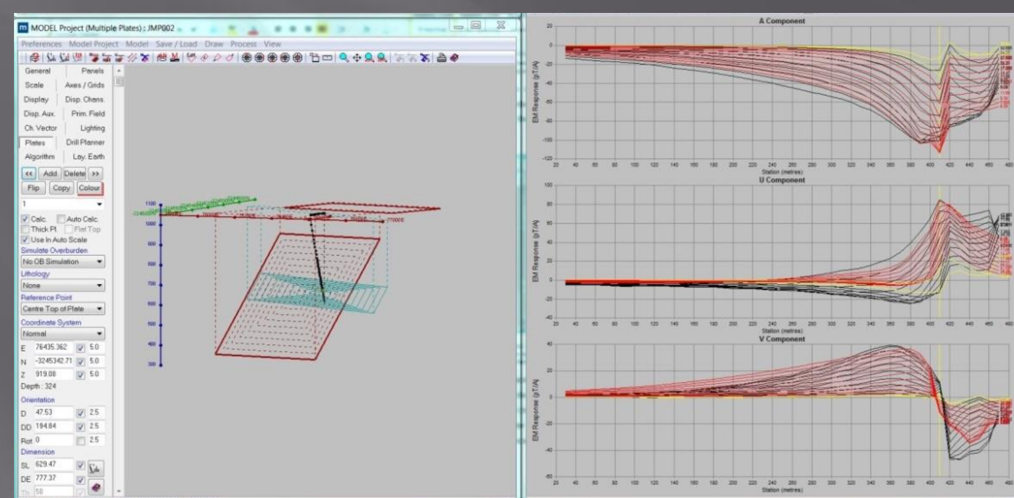
- DHEM surveys were carried out on selected holes in order to provide a vector towards conductive, well mineralised harzburgite at depth
- Out of the 17 boreholes drilled, 12 were selected for DHEM survey
- From the ground EM surveying carried out on the main target zone and the drilling results, information regarding the target and positioning of the fixed loop was available to ensure good coupling with the target.

Modelling of Downhole EM data

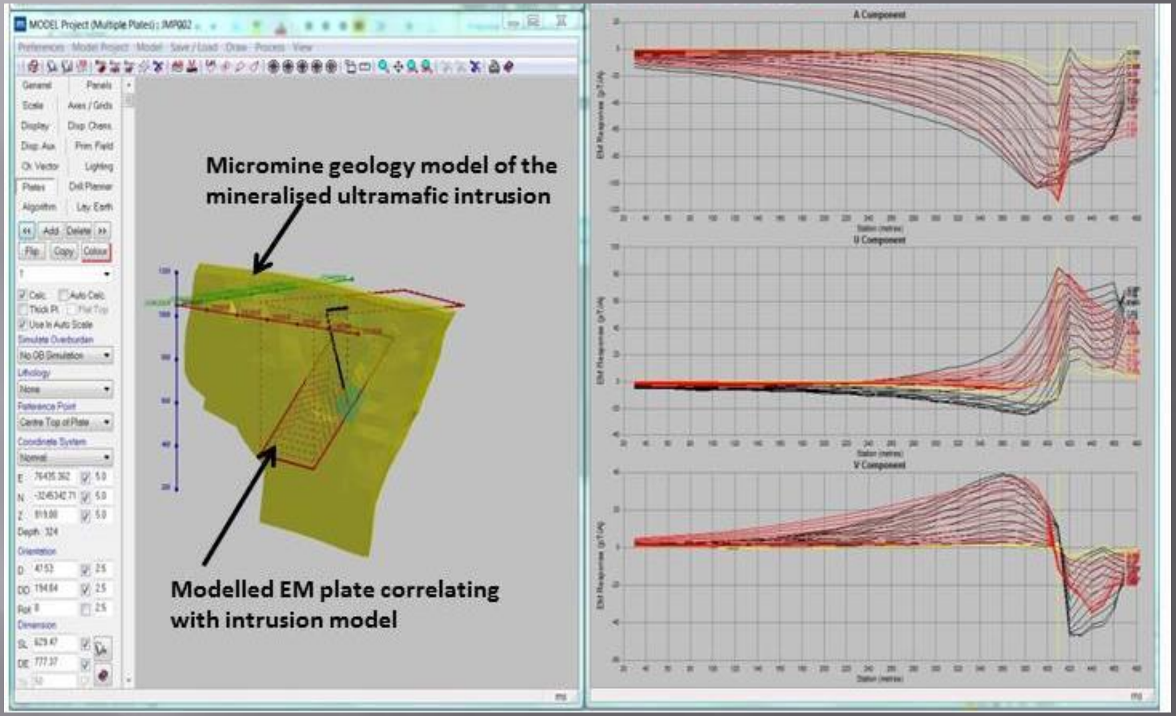


- For the DHEM data the measured components are designated by **A**, **U** and **V** instead of **X**, **Y** and **Z** as for ground EM.
- The transmitter loop position is shown as a yellow rectangle and the borehole trace in black in the plan view on the left hand side while the late time channel data are shown as traces for the 3 components on the right side

All the modelled boreholes intersected the poorly mineralised tremolite schist with only a few intersecting the well mineralised harzburgite which the modelling tries to resolve.



Integrating the modelled DHEM plate with the Micromine Geology model



Modelling results for borehole JMP002 showing the modelled EM plate integrated with the Micromine geology model of the mineralised ultramafic intrusion. The right hand window shows the measured EM response profiles in black and the modelled EM response in red for the three components A, U and V.

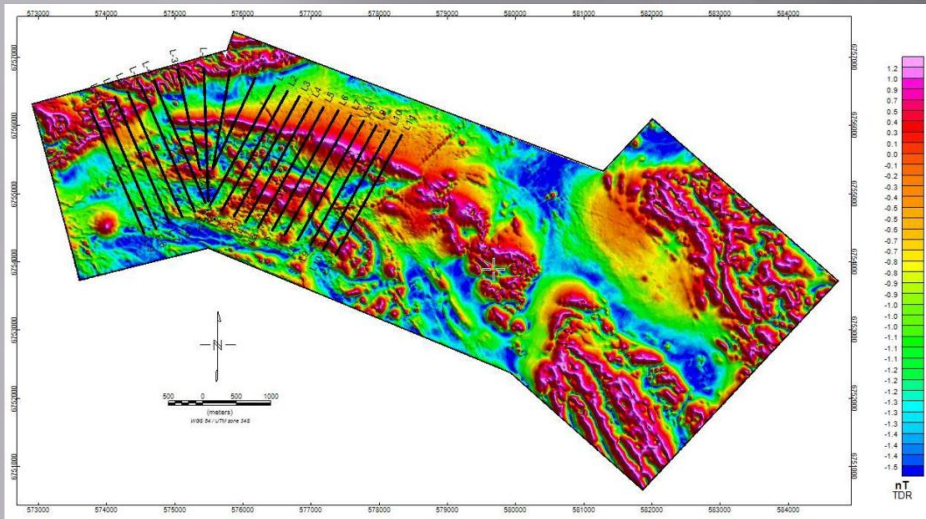
Audio-frequency Magnetotellurics (AMT)

- Determining subsurface conductivity (or its inverse, resistivity) at crustal scales can be carried out using magnetotelluric methods that involve surface measurements of orthogonal electric and magnetic field variations
- The Audio-frequency Magnetotellurics (AMT) method that was executed on the study area involves measurement of electromagnetic fields that are generated in the atmosphere and magnetosphere.
- With additional drilling, it became clear that the better grade Ni mineralisation occurs in ‘pockets’.
- Although the EM techniques were successful in mapping the better mineralised parts of the intrusion to depth of about 400m, it was however decided to map the deeper localised high grade zones.
- AMT survey was carried out on the main target zone to image deep geological structure, near surface geology, and map the better mineralised parts of the intrusion.

AMT Modelling

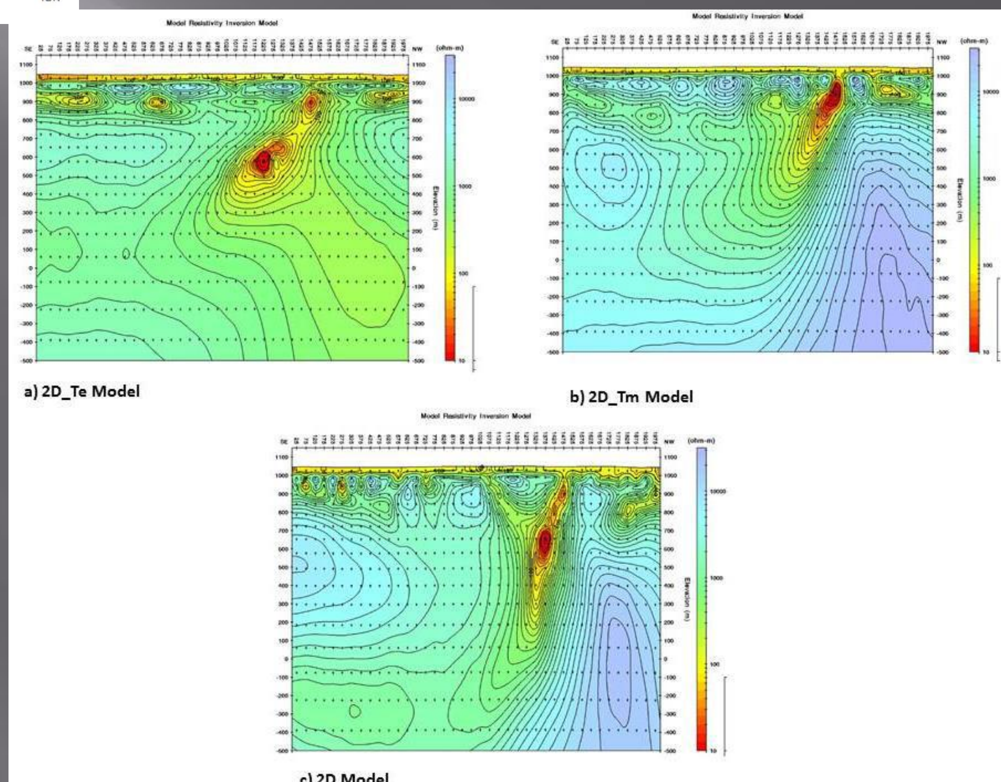
- Detailed images of conductivity structure at depth can be obtained by inverting AMT Cagniard Resistivity and Impedance Phase.
- 1-D and 2-D modelling programs were used to convert the measured results to profiles of resistivity versus depth
- 2D inversion models have several advantages over 1D models in that the 2D inversion shows two dimensional shaped structures (for example, edges associated with contacts at depth).
- In 2-D modelling the subsurface is discretized into squares on a distance-depth plot in log-log scale.
- Smooth-model inversion mathematically “back-calculates” from the measured data a likely location, size and depth of the source or sources of resistivity changes. Zonge 2D inversion algorithms allow for various types of input model parameters and geometry constraints to yield the most reasonable model

AMT Modelling



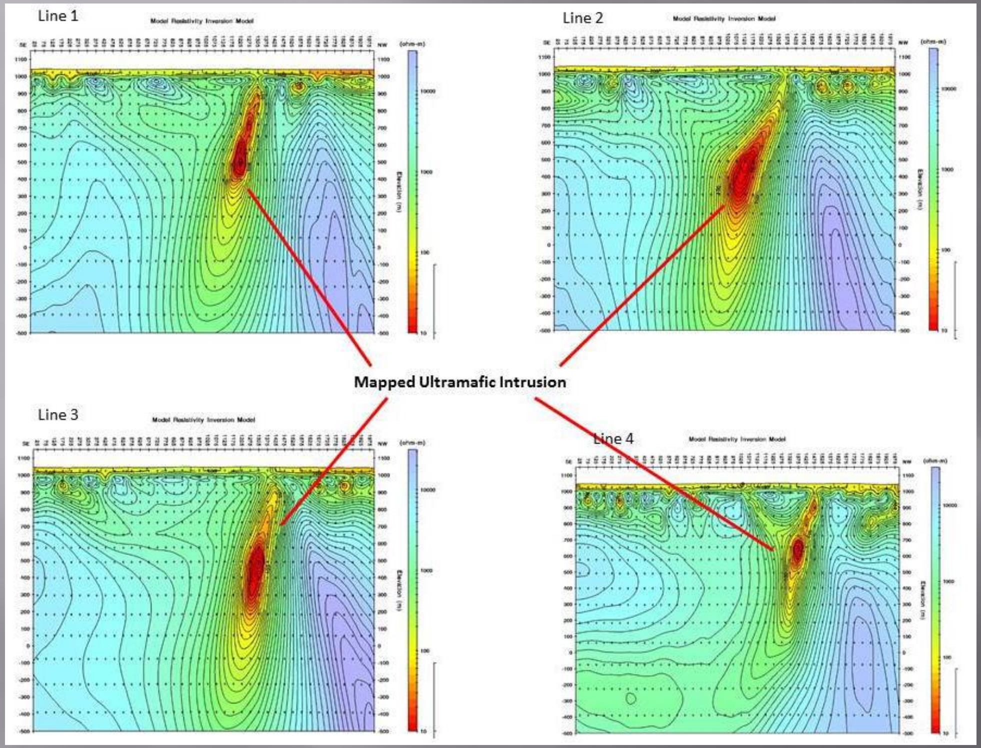
- 2D Smooth-Model Inversion Sections for line 4 clearly mapping the intrusion is shown below.
- It is clear that the general appearances of the three models are the same, but there are significant differences in the finer detail.

- Since the T**e** model is good at mapping deep conductors it is apparent in (**a**) that there is a strong conductor which has been mapped at depth.
- The T**m** model is good at mapping structure and the ultramafic sill was clearly mapped.
- 2D model with equal weighting on the T**m** and T**e** components and is usually the best model in terms of mapping both structure and conductors.

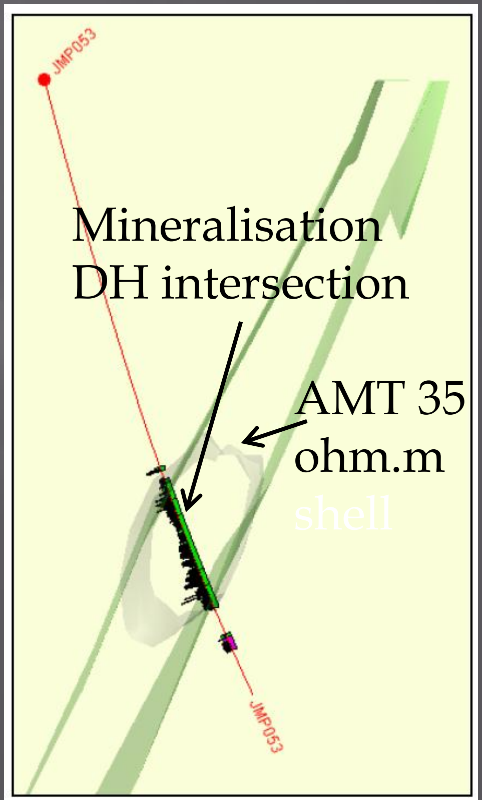


a) 2D_Te Model
b) 2D_Tm Model
c) 2D Model

AMT 2D Models



- The Jacomynspan ultramafic intrusion was clearly mapped on most of the surveyed lines as can be seen on the four lines above.
- The mineralised ultramafic intrusion was clearly mapped as steeply dipping to the south on all the four lines



Conclusion

- The mineralised ultramafic sill which has elevated values of magnetic susceptibility was clearly mapped in both the 3D model representation from Mag2dc modelling and Geosoft's VOXI 3D smooth model inversion correlating very well with the Micromine geology model of the mineralised ultramafic sill.
- However, the slightly magnetic material south of the sill was resolved by the Mag2dc inversion process but not with the VOXI inversion process.
- The modelled EM plates were very large with a large strike and depth extent dipping steeply to the south correlating very well with the Micromine geology model of the mineralised ultramafic sill. In order to better constrain the targets, an assumption was made that at late decay times the currents would be focused in the centre of the large EM plate giving an indication of the most conductive part of the intrusion.
- Inversion models of AMT Cagniard Resistivity and Impedance Phase data provided detailed images of the conductivity structure at depth. The mineralised ultramafic intrusion which has elevated values of conductivity compared to the country gneissic rocks was clearly mapped as steeply dipping to the south on most of the lines

Acknowledgements

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- All the people and organisations who contributed in acquiring the data are acknowledged.

Thank you