7 Inversion results (continued)

Constrained inversion - kriged reference model from 50% of drill-hole data

A reference model was created using down-hole density values from half of the drill-holes. This was to investigate the possibility of using inversions constrained by drill-hole data as it becomes available to direct subsequent drilling. This reference model is shown in Figure 12.

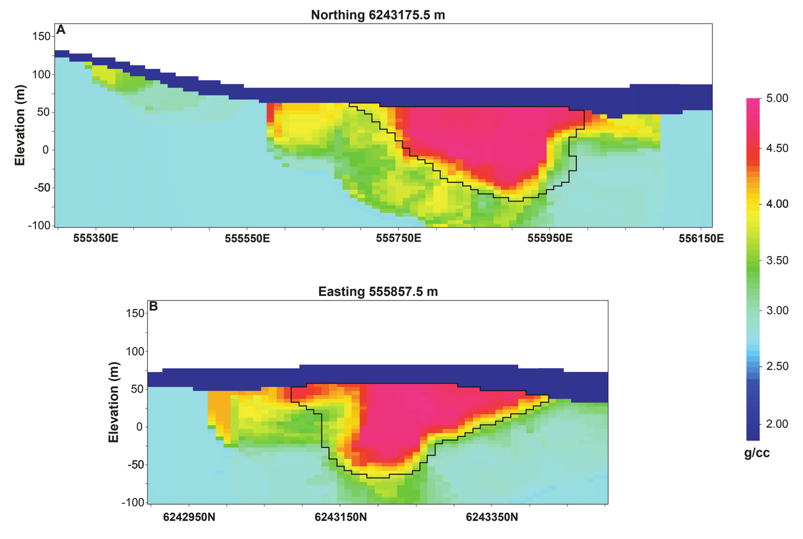

Figure 12: Reference model using 50% of down-hole data.

The model produced by the inversion which used the reference model in Figure 12 is shown in Figure 13. It essentially resembles the reference model used to guide the inversion. Just as for the inversions constrained by all the down-hole data, the gravity data is too sparse to improve upon the detail in the reference model.

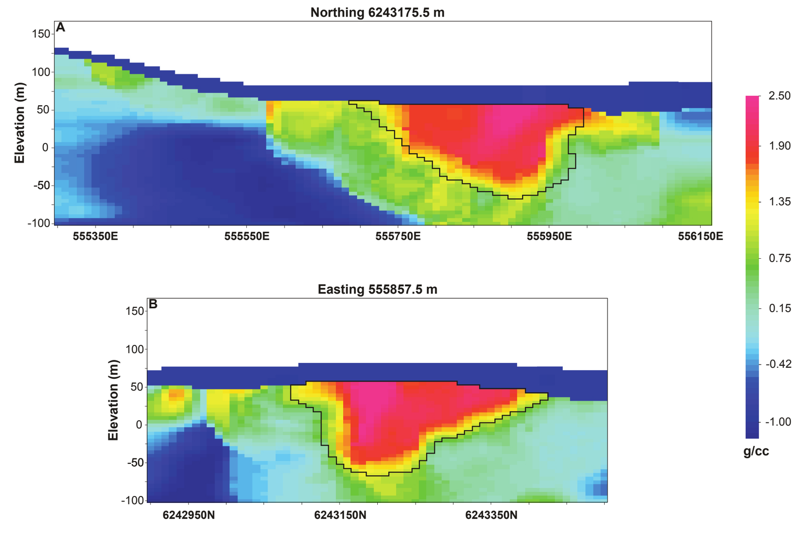

Figure 13: Inversion result using reference model built from 50% of the down-hole data (the model in Figure 12).

Inversion of dense set of synthetic data

The reference model created by kriging all the down-hole density data (Figure 7) was used to generate a set of synthetic gravity data on a 10x10m grid of observation locations. The data are shown in Figure 14. This data-set was inverted, along with synthetic data calculated for this model at the locations of the actual observations over the Ovoid (which are shown in Figure 14).

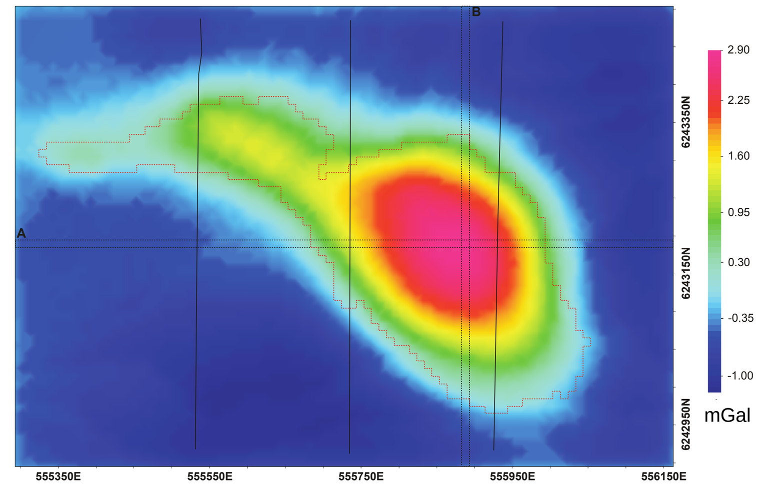

Figure 14: The synthetic data generated from the model made from all the down-hole data (the model in Figure 7). The solid lines show the locations of the actual gravity observations over the Ovoid. (The dashed lines indicate the locations of the displayed sections through the inverted models. The red line is the outline of the Ovoid.)

8 Inversion results (continued)

The result of the unconstrained inversion of the synthetic data-set over the 10x10m grid is shown in Figure 15. The result of the unconstrained inversion of the synthetic data along only the three lines of actual observation locations over the Ovoid is shown in Figure 16. Comparing these two results (and the result of the unconstrained inversion of the actual gravity data over the Ovoid - Figure 9), it is clear that the resolving power of the gravity data-set over the Ovoid is limited. In particular, the maximum densities in the model in Figure 16 are considerably less that the densities of the massive sulphides of the Ovoid, and the location of the centre of the dense region in the model is off-set to the east of the true centre of the Ovoid. The maximum densities in the model occur beneath the easternmost survey line.

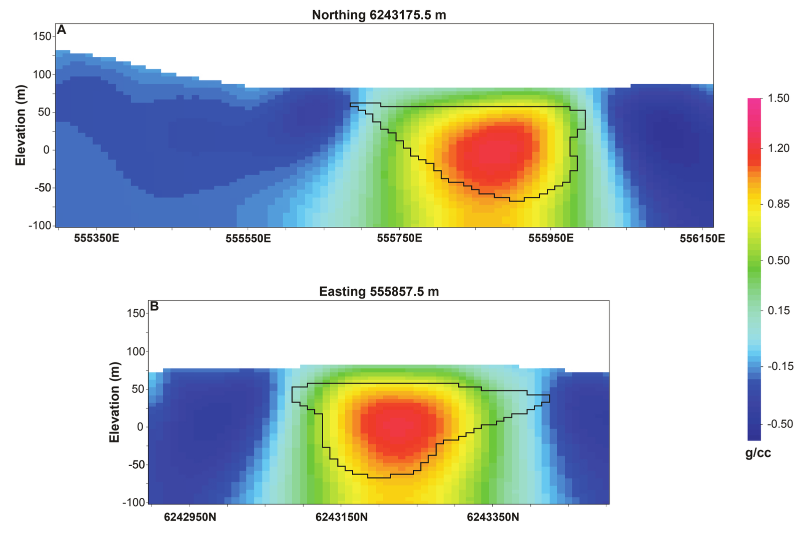

Figure 15: Unconstrained inversion result for synthetic data on 10x10m grid.

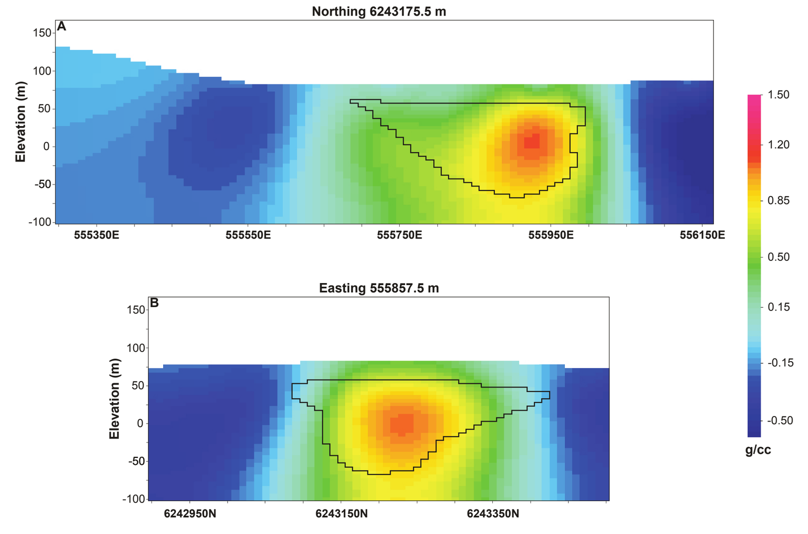

Figure 16: Unconstrained inversion result for synthetic data only at the actual observations locations (3 lines).

To mitigate the mis-location of the centre of the dense region in the model constructed from inverting the synthetic data from only the three survey lines crossing the Ovoid, the length-scales of the flatness weighting in GRAV3D were modified from their default values to 80m, 40m, and 20m in the EW, NS, and vertical directions. This variation in the weighting of the smoothing regularization was chosen to reflect the different separations of the observation locations in the along-line and across-line directions. The model resulting from this inversion is shown in Figure 17. The centre of the dense region in the constructed model now coincides with the centre of the Ovoid.

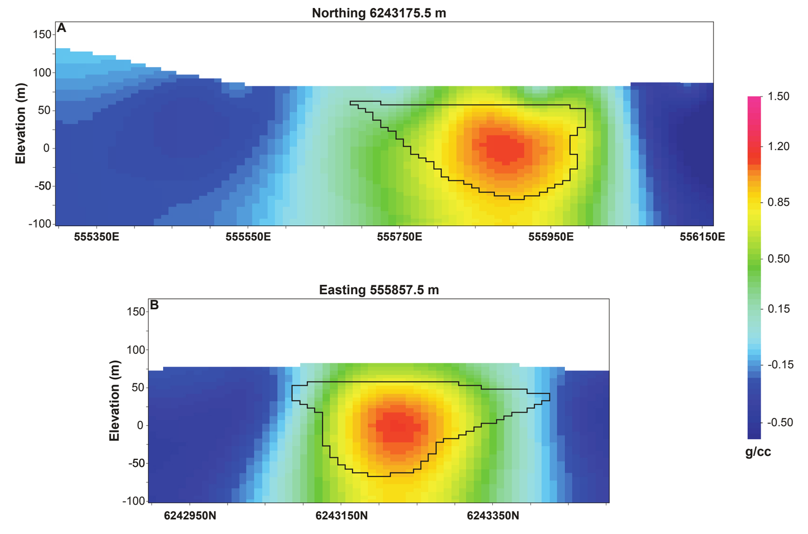

Figure 17: Unconstrained inversion result for synthetic data only at the actual observations locations (3 lines), but with increased smoothing in the across-line direction.

9 Magnetic and susceptibility data

The magnetic data at Voisey's Bay were collected during ground and airborne surveys. The airborne magnetic data were collected along 142 north-south flight lines flown at a ground clearance of approximately 150m with a line spacing of 200m. Data were collected roughly every 3.5m along the lines. Only 3 lines directly crossed the Ovoid and Mini-Ovoid. The ground magnetic data (Figure 18) were collected along 71 north-south lines separated by 100m with data acquired every 12.5m, meaning 6 lines crossed the Ovoid.

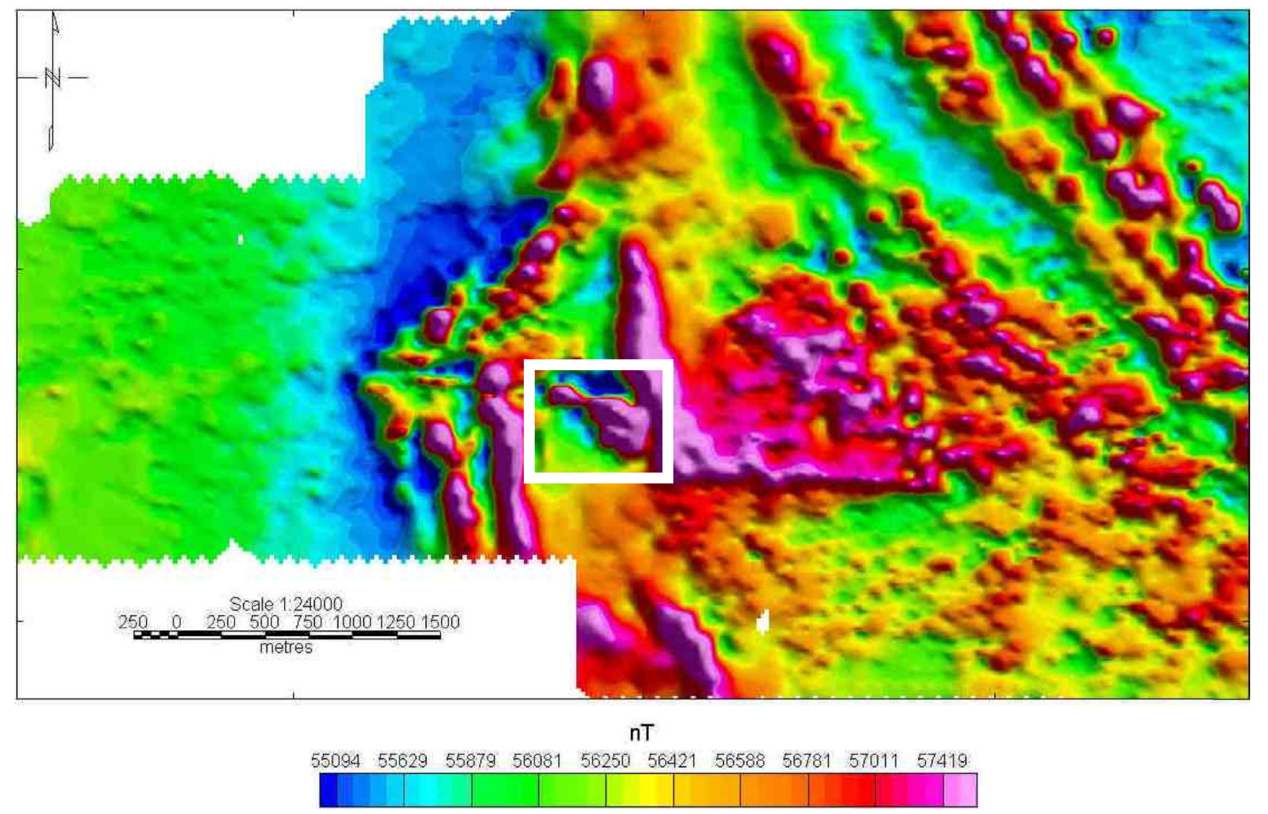

Figure 18: The ground magnetic data from the Voisey's Bay area. (The white box indicates the region immediately around the Ovoid.)

Magnetic susceptibility values of a small set of samples from the Voisey's Bay area were measured. Measurements were made using a standard AC bridge susceptibility meter at both 700 Hz and 19 kHz, and using a new DC process. For samples abundant in conductive substances, such as massive sulphides, the alternating current used in most commercial meters can induce eddy currents within the sample which in turn produce fields unrelated to the magnetic susceptibility. To test these effects a DC susceptibility meter was developed using a handheld fluxgate magnetometer and two oppositely wound solenoids connected in series to a DC power source (Figure 19). The two solenoids produce equal and opposite magnetic fields. When a sample is placed in one of the solenoids a secondary magnetic field is induced and the field between them is no longer zero as measured by the magnetometer. A current is then passed through a smaller coil, the same size and shape as the sample, in the opposite solenoid and is adjusted until the resulting magnetic field is once again zeroed. The susceptibility of this smaller coil is equal to that of the sample and can be easily calculated.

The AC and DC meters were tested using samples of varying sulphide content. The results of the two methods agreed for samples with no or little sulphides (25-30%) and massive sulphides. For the 50% sulphide samples the DC method found susceptibilities higher then when using an AC meter.

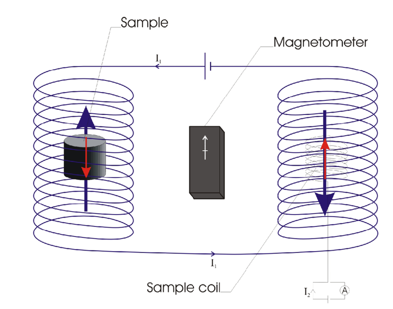

Figure 19: Schematic diagram of the DC susceptibility meter.

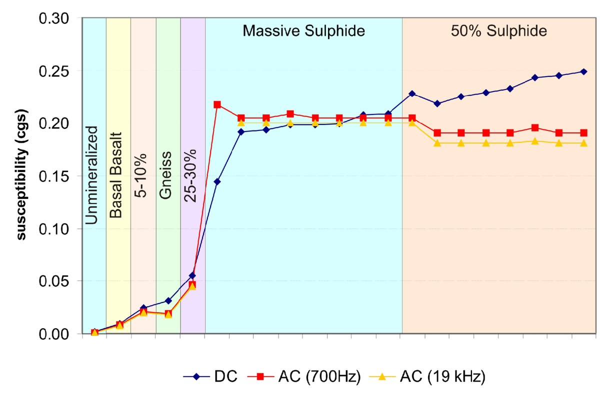

Figure 20: Susceptibility measurements using AC and DC instruments.

10 Magnetic inversion results

So far, only unconstrained inversions of the ground and airborne magnetic data have been performed (Figure 21). The program MAG3D of the UBC - Geophysical Inversion Facility is being used. The intention is to build reference models using the susceptibilities of the down-hole samples in the same way as for the density data, and to constrain the inversions with these models.

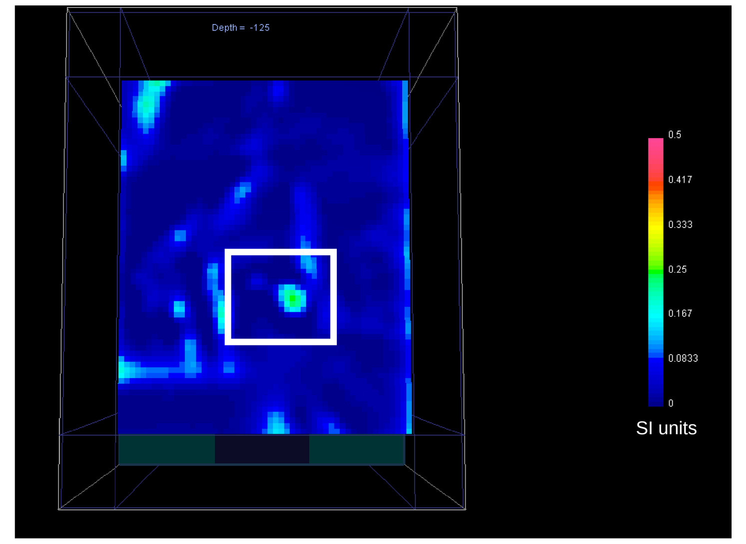

Figure 21: The result of an unconstrained inversion of the ground magnetic data. The white box indicates the area immediately around the Ovoid.

11 Conclusions

We have used reference models and weighting of those reference models to incorporate geological information into typical minimum-structure, under-determined inversions of potential field data. The reference models were built from known down-hole physical property values. Variogram analysis and kriging were used to interpolate the physical property values between the drill-holes. The variances from the kriging process were also used to weight the reference models in the inversions. Incorporating known geological information into the inversion process enables more geologically meaningful results to be obtained.

The next phase of this project involves constrained inversions of the magnetic data, both by the susceptibility and remanent magnetization measurements, and by the models obtained from the gravity inversions.

12 Acknowledgments

We would like to thank Voisey's Bay Nickel Company Ltd. for their support of this project, and Brian Bengert and Robert Wheeler of VBNC for their input throughout this project. We would also like to thank the University of British Columbia - Geophysical Inversion Facility for the use of their inversion programs GRAV3D and MAG3D. We are also grateful to Prof. Joseph Hodych for his advice and encouragement.

13 References

Evans-Lamswood, D.M., Butt, D.P., Jackson, R.S., Lee, D.V., Muggridge, M.G., Wheeler, R.I., and Wilton, D.H.C., 2000, Physical controls associated with the distribution of sulfides in the Voisey's Bay Ni-Cu-Co deposit, Labrador: Economic Geology, v. 95, p. 749-769.

GRAV3D; A Program Library for Forward Modelling and Inversion of Gravity Data over 3D Structures, version 2.0 (2002). Developed under the consortium research project Joint/Cooperative Inversion of Geophysical and Geological Data, UBC-Geophysical Inversion Facility, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia.

MAG3D; A Program Library for Forward Modelling and Inversion of Magnetic Data over 3D Structures, version 2.0 (2002). Developed under the consortium research project Joint/Cooperative Inversion of Geophysical and Geological Data, UBC-Geophysical Inversion Facility, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia..

Naldrett, A.J., Keats, H., Sparks, K., and More, R., 1996, Geology of the Voisey's Bay Ni-Cu-Co deposit, Labrador, Canada: Exploration and Mining Geology, v.5, p. 169-179.