1 Summary

The results of constrained inversions of gravity and magnetic data from the Voisey's Bay deposit are presented. The inversions were done with a typical under-determined, minimum-structure inversion algorithm. The inversions were constrained using reference models derived from the drill-hole physical properties data-sets. The reference models were constructed by kriging the physical properties within each of the major rock units. In addition, the reference models were weighted during inversions by the variances from the kriging process. The extensive drill-hole information available at Voisey's Bay made this a unique opportunity to investigate the benefits of constrained inversion of potential field data in the exploration and deposit-delineation contexts. Benefits include the mitigation of the non-uniqueness of potential field inversions, and the possible guiding of drilling programmes by potential field inversion results which are constrained by drill-hole information as it becomes available.

2 Location and geology

The Voisey's Bay Nickel-Copper-Cobalt deposit is one of the most significant mineral discoveries in Canada in the past half century. The first significant mineralized zone found, the "Ovoid", is believed to contain proven and probable reserves of 30 million tonnes grading 2.85% Ni, 1.68% Cu and 0.14% Co. With the subsequent discovery of mineralized regions to the east and west of the Ovoid, the total mineral reserve estimates increased to 54 million tonnes of indicated mineral resources and 16 million tonnes of inferred resources.

Figure 1: The location of Voisey's Bay in Labrador, Canada.

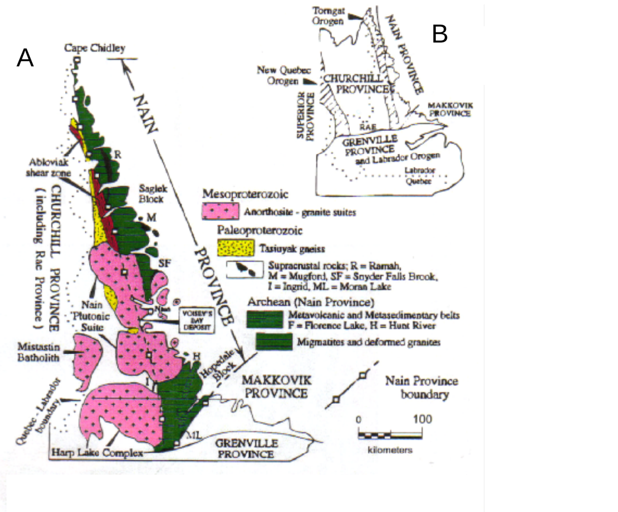

Figure 2: The regional geology of Voisey's Bay. A: major geological units; B: major litho-tectonic units.

The major litho-tectonic units of Labrador and Quebec are the Superior, Churchill, Nain, Makkovik, and Grenville provinces illustrated in Figure 2. The Voisey's Bay Ni-Cu-Co deposit is a part of the Nain Plutonic Suite, which is comprised of granitic, anorthositic, ferrodioritic, and troctolitic gabbroic intrusions (Evans-Lamswood et al., 2000). These intrusions lie along the Nain-Churchill boundary which separates the eastern (2.5 Ga) Archean Nain province from the western (1.8 Ga) Proterozoic Churchill province. The Voisey's Bay troctolite, host of the Ni-Cu-Co deposit, lies next to the Nain-Churchill boundary and is believed to be associated with the 1.8 Ga collisional suture between the two provinces (Naldrett et al., 1996) known as the Torngat orogen.

The Voisey's Bay intrusion lies between the Archean Nain orthogneisses to the north and the Proterozoic Tasiuayak paragneisses to the south. The intrusion consists mainly of weakly layered gabbros and troctolites that date between 1330 Ma and 1338 Ma. The intrusion is thought to consist of an upper chamber (Eastern Deeps chamber) connected to a lower chamber (Reid Brook chamber) through a conduit system of varying thickness.

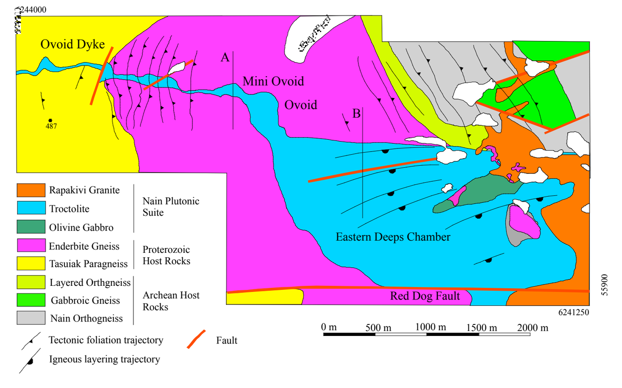

Figure 3: The geology of the Voisey's Bay intrusion (VBNC).

3 Geology (continued)

Contained within the troctolite intrusion are five zones of mineralization. The zones hosting Ni-Cu-Co deposits consist of the Reid Brook zone, Discovery Hill zone, Mini-Ovoid, Ovoid and the Eastern Deeps. The base of the Eastern Deeps chamber consists of fine-grained gabbros and intrusive troctolite breccias overlain by disseminated to semimassive sulfides, overlain by sequences of varied-textured troctolites and normal troctolites. The Eastern Deeps chamber is primarily a sub-vertical sheet having a horizontal feeder system with mineralization occurring at depths up to one kilometre.

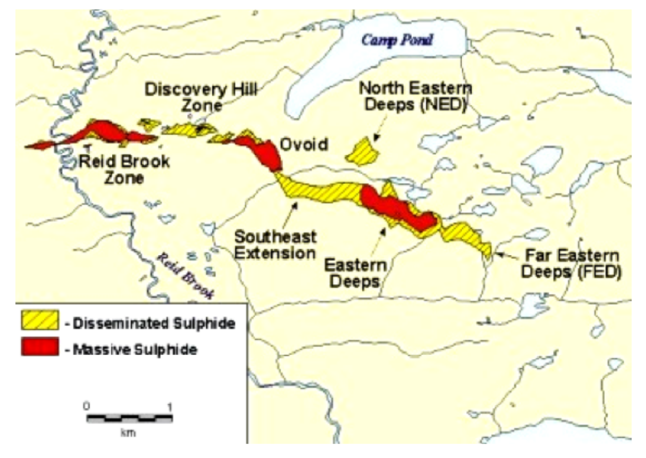

Figure 4: Simplified geological map of the Voisey's Bay deposits illustrating the distribution of disseminated to massive sulphide zones projected to the surface (Dept. of Natural Resources, Govt. of NL).

Approximately 1km west of the Eastern Deeps, the Ovoid is located beneath 20m to 30m of overburden and is commonly viewed as a bowl-shaped accumulation of massive sulphide. Having horizontal dimensions of 650m by 350m and a maximum thickness of 120m, the Ovoid overlies a thin breccia sequence followed by troctolite and enderbitic orthogenesis. The Ovoid, Mini-Ovoid and Discovery Hill zones are all mineralized along vertical to sub-vertical domain of the feeder dyke system. Further west, the Reid Brook complex is located at a depth of 400m and extends to depths in excess of 2km.

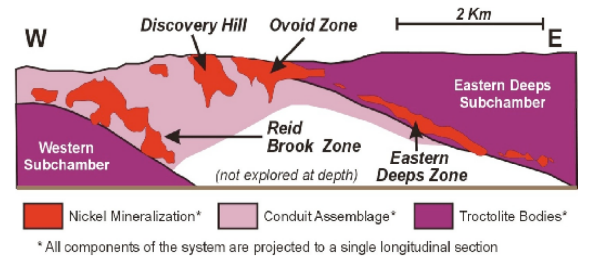

Figure 5: Simplified longitudinal section of the Voisey's Bay mineralized zone (Dept. of Natural Resources, Govt. of NL).

4 Gravity data

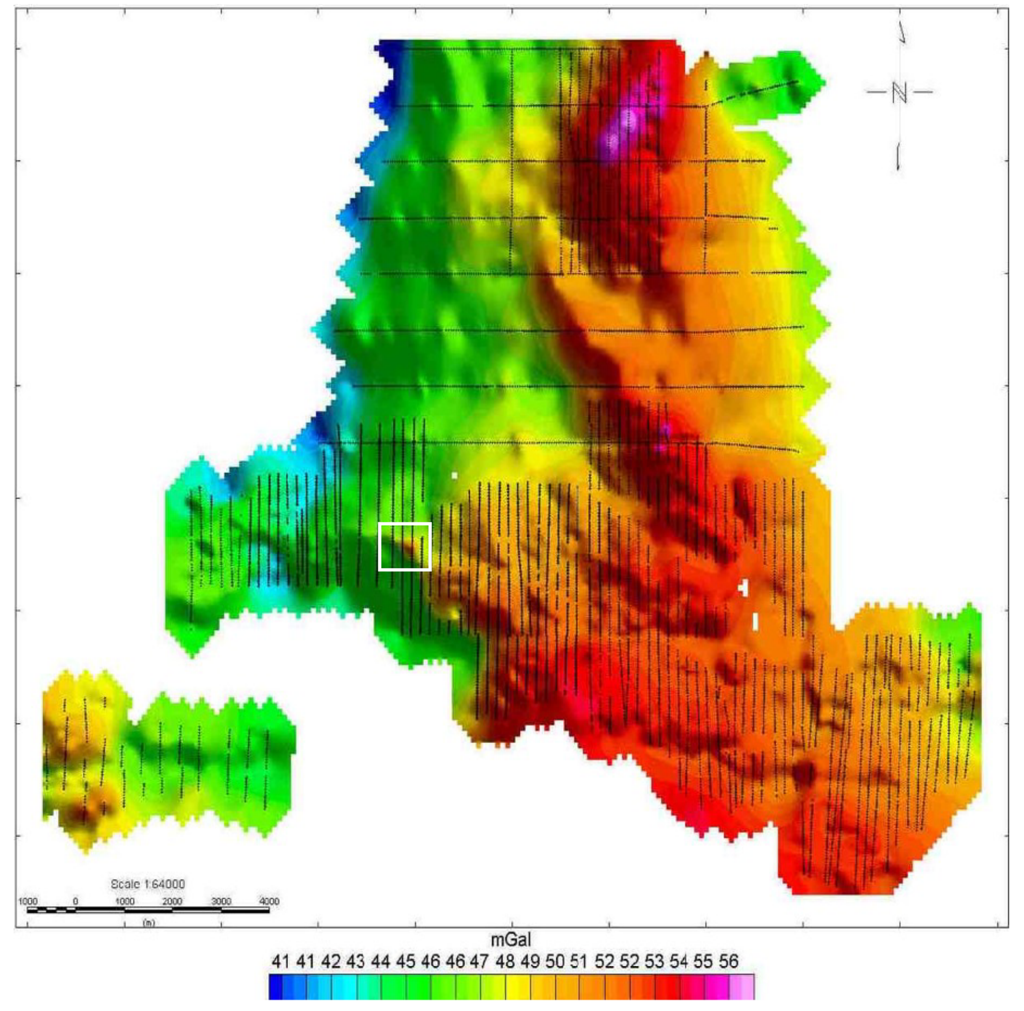

Figure 6: The ground gravity data-set from the Voisey's Bay area (terrain-corrected Bouguer anomaly). The dots indicate measurement locations. The white box indicates the region for the gravity inversions for the Ovoid.

The regional field was removed using standard continuation methods. The gravity field was upward continued to a level 500m above the surface. The residual field was calculated by subtracting the regional from the collected data. A constant error of 0.05 mGal was assigned to each data value based on the observational uncertainties documented for the gravity data.

5 Density data, kriging and reference models

Density values were available from over 500 drill-holes through and close to the Ovoid. Generally, the drill-holes were separated by 50m, with samples collected at 1m intervals in the vertical or sub vertical directions. The density values were determined from regression analysis of the geochemistry of the down-hole samples. (This was performed by VBNC.) The density data-set therefore consisted of calculated density values and their corresponding locations in the subsurface.

In this study, one of the objectives is to create 3-D geocellular models that will be used as reference models during the inversion process. The spatial continuity of density within the main rock units was estimated from the density data-set using variogram modelling. Densities were then interpolated between the drill-holes by kriging to give the geocellular reference density models. The variances from the kriging were adapted to use as spatially varying weights of the reference model within the inversions. This reduces the influence of the reference models away from the drill-holes.

The 3-D geocellular grid was segregated into the five main regions: the overburden, enderbitic gneiss, mineralized troctolite, unmineralized troctolite, and massive sulphide.

The top of the mesh was positioned above topography to ensure all topographic effects were included in the geocellular model. The mesh extended 610m north, 870m east and 540m vertically. The cell dimensions were 10m by 10m in the horizontal directions, and 5m in the vertical direction. These dimensions were chosen based on the distribution of drill-hole data. The total number of cells in the mesh was 286578.

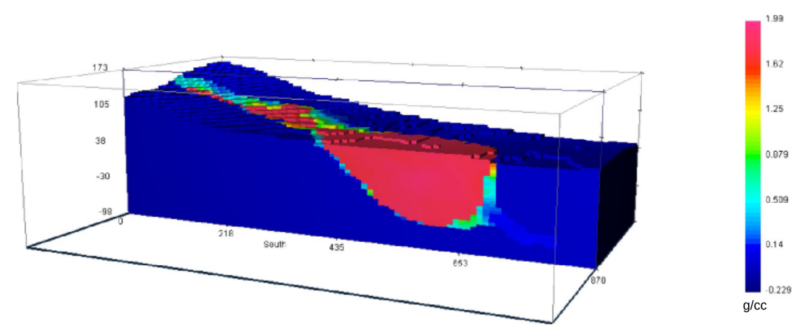

Figure 7a: View through the reference density model created by kriging 100% of the down-hole density data-set. The dense material is the massive sulphide making up the "Ovoid". The overburden has been removed from this figure. (Note the different colour scale from Figure 7b.)

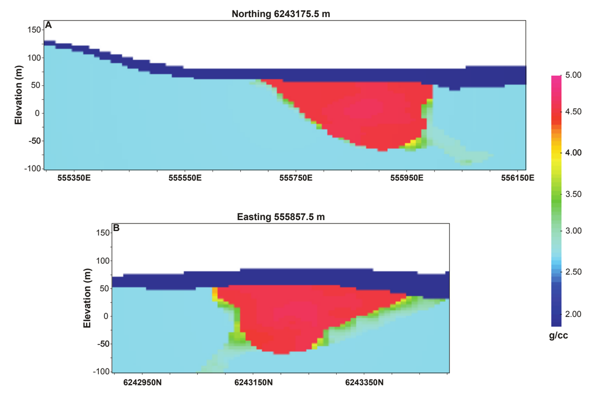

Figure 7b: Two sections through the reference density model created by kriging 100% of the down-hole density data-set. The low density unit is the overburden; the high density unit is the massive sulphide of the Ovoid. (Note the different colour scale from Figure 7a.)

Inversions were also performed with a reference model containing only information about the depth of overburden obtained from the drill-holes (and the average value of the density of the overburden). This reference model is shown in Figure 8.

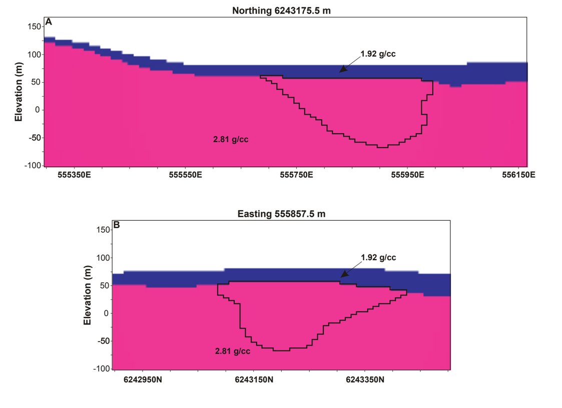

Figure 8: The reference model which contains only the information about the depth of the overburden.

The program GRAV3D from the UBC - Geophysical Inversion Facility was used for all 3-D gravity inversions presented here.

6 Inversion results

Unconstrained inversion

Inversion with no constraints using GRAV3D (with default smoothing parameters).

The observations were fit to a χ^2-misfit value equal to the number of observations. (This was the case for all inversions presented here. A value of 0.05 mGal was used for all measurement uncertainties.)

The constructed model shows a fuzzy, smeared-out representation of the dense Ovoid that is typical of unconstrained, minimum-structure inversions. (The closed black curve is the outline of the Ovoid.)

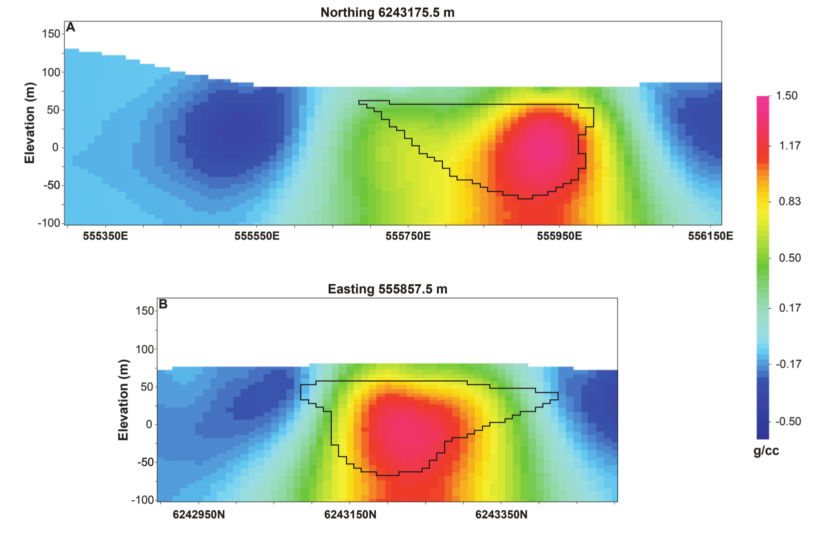

Figure 9: Result of unconstrained inversion.

Constrained inversion - overburden only

Inversion using the reference model in Figure 8, that is, the reference model with the overburden (thickness and average density) only. (The weighting of the overburden and "the rest" of the reference model during the inversion were 1000 and 0.001 respectively. The default values of the smoothing parameters were used.)

The manifestation of the Ovoid in the constructed model is still fuzzy and smeared-out, but it's top and depth extent are better defined.

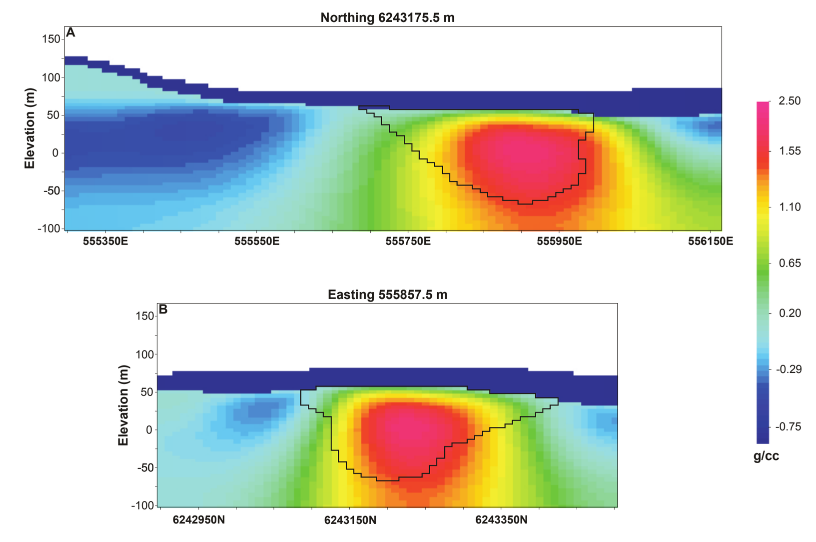

Figure 10: Result of overburden constrained inversion.

Constrained inversion - kriged reference model from 100% of drill-hole data

Inversion using the reference model in Figure 7, that is, the reference model created by kriging all of the down-hole density data-set.

The Ovoid is now very well defined in the constructed model, essentially matching the detail in the reference model. (The observed gravity data are reproduced to a χ^2-misfit equal to the number of observations.) The observations are too sparse (only three lines cross the Ovoid) to improve on the information content of the reference model.

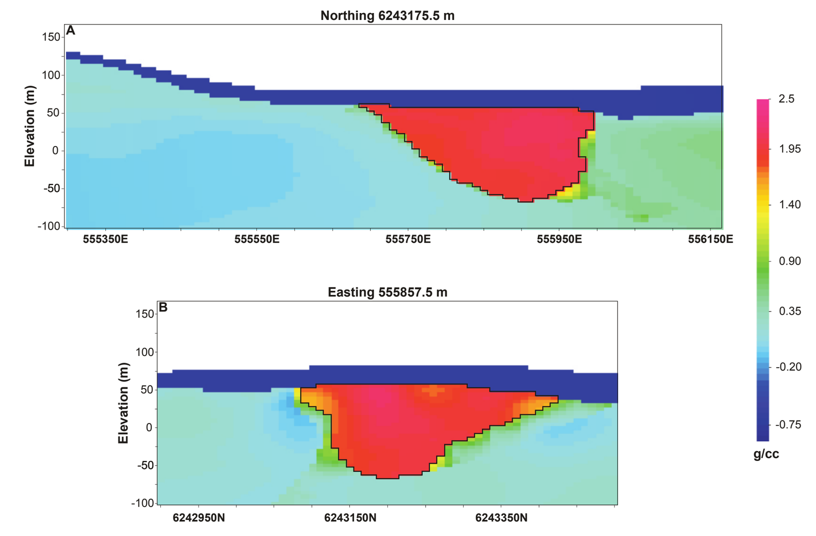

Figure 11: Result of inversion constrained by kriged model.