An airborne gravity case study of the Podolsky Deposit, Sudbury Basin

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Introduction

A high resolution airborne gravity dataset covering the Podolsky Property, located on the northeast rim of the Sudbury Basin, has been used as the input for 3-Dimensional (3D) gravity inversion. An initial inversion without any project-specific constraints was followed up with an inversion incorporating information gleaned from interpretation of coincident magnetic data coverage over the property and from a priori knowledge of the geology of the area. The second inversion was deemed to provide a more reliable estimate of the bulk density distribution for the region. The results indicated that the high resolution airborne gravity data could be used for mineral exploration applications in this environment.

Geology

The Sudbury Basin in Ontario, Canada, is a Paleoproterozoic geologic structure that is host to a large number of Ni-Cu-PGE sulphide deposits (Pye et al., 1984). Sudbury and Norilsk, Russia, are the two largest sulphide nickel camps in the world. The deposits of the Sudbury Basin have been mined for more than 130 years, and the region continues to be a target region for active exploration.

The Sudbury Igneous Complex (SIC) structure is a deformed and thrusted multi-ring impact basin with horizontal dimensions of approximately 60 by 27 km, with the long axis oriented in the east-northeast direction (Figure 1). This complex hosts numerous Ni-Cu-PGE sulphide deposits within portions of the impact melt that collected in traps, as well as in radiating offset dykes along the footwall rocks, and within fractured and brecciated footwall rocks.

The Podolsky Property is being developed and explored by Quadra FNX Mining Ltd (http://www.quadrafnx.com) and is located on the northeast rim of the Sudbury Basin (Figure 1). The Podolsky Property hosts several copper-nickel-precious metal deposits including the Nickel Ramp Deposit. A 3D illustration of the known geological structure overlain with the Podolsky Property boundary is shown in Figure 2.

In the work that is described in this paper, we utilised airborne gravity and LiDAR data that were acquired during a recent airborne gravity survey flown by Sander Geophysics (Sander and Ferguson, 2010). We applied gravity inversion methods to resolve structural detail that was not identified with the earlier gravity prospecting carried out in this region. A sequence of inversions was carried out, with location-specific constraints being added to improve the reliability and accuracy of the results. Constraints were derived from an interpretation of the airborne magnetic data acquired by Aeroquest in 2004. Drill hole geological information was also used to constrain the bulk density values in the inversion. The purpose of this work was to demonstrate the information that can be extracted from high resolution gravity data in relation to the potential for copper-nickel-precious metal mineralization in the Sudbury region.

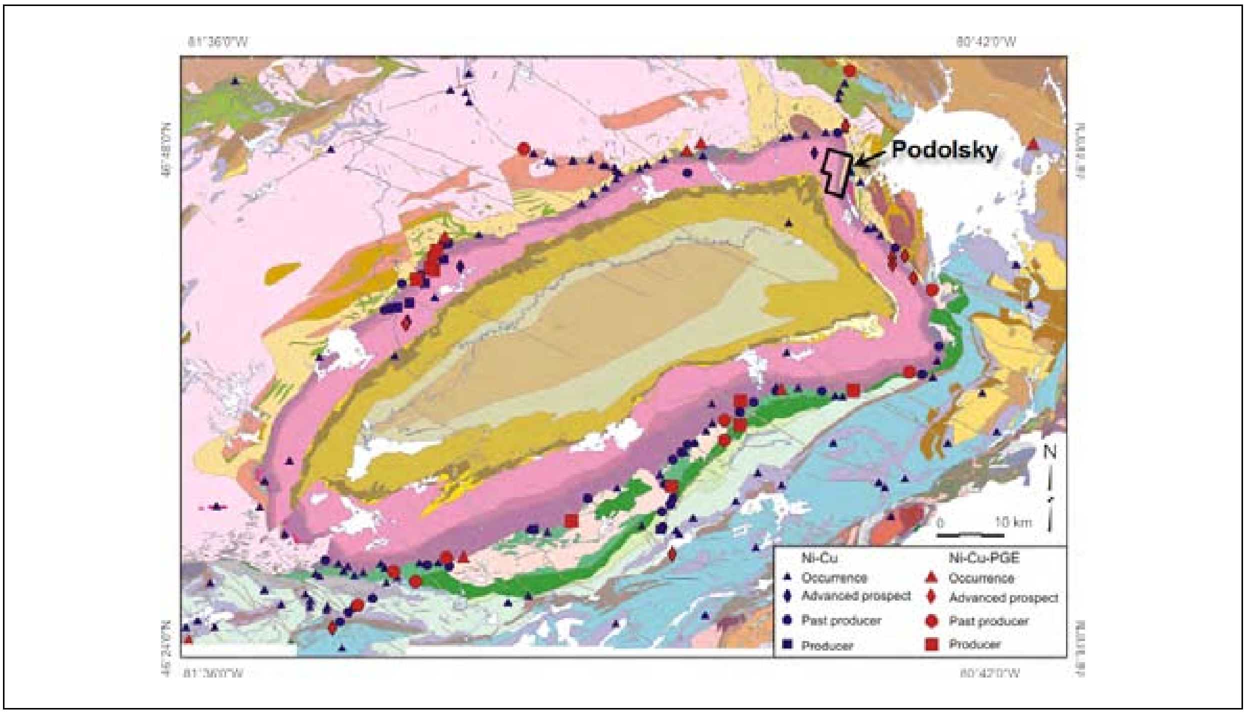

Figure 1. Sudbury geology, mine sites, and location of the Podolsky Property.

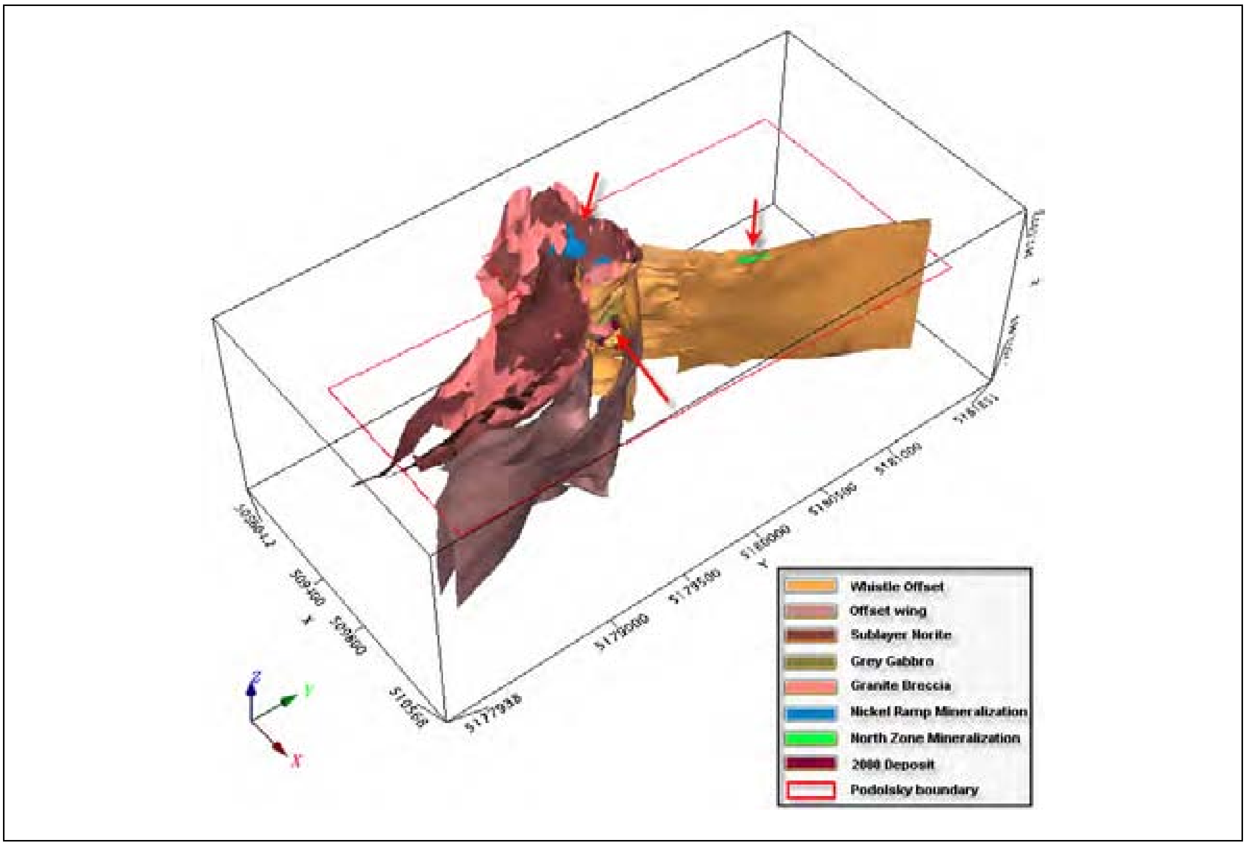

Figure 2. Perspective view of various geological features of the Podolsky structure with an overlay of the claim boundary. The mineralization is indicated with arrows. Data compiled by Quadra FNX Mining Ltd. The figure shows a region with approximate dimensions of 2 km (X, east-west), 4 km (Y, north-south), and 1.5 km (Z, vertical).

Airborne Gravity

The portion of the gravity field that is relevant to this study is a small fraction of the total measured gravitational field. Highly accurate measurements are required in order to resolve the geology with any degree of confidence. Improvements in airborne gravity instrumentation, coupled with large digital data storage capacity and high performance computing facilities, make it possible to develop more accurate and reliable interpretations of airborne gravity information.

An extensive literature covers the topics of levelling and reducing airborne gravity data to yield a coherent residual dataset for further processing and interpretation. We will not review or describe the steps in detail. Rather, a number of these data processing steps will be mentioned simply as a preamble to the inversion process.

The airborne gravity data were subjected to time based filtering and levelling. Gravity data reduction steps were then applied to remove portions of the total response which are of little interest for mineral exploration interpretation. Specifically, these included latitude, Free Air, Bouguer, terrain, Earth curvature, and tidal corrections (Blakely, 1996). The corrections that are specifically necessary for data acquired with an airborne system include the Eötvös correction and corrections for the vertical and horizontal acceleration of the aircraft (Swain, 1996).

LiDAR data for a high resolution terrain model were acquired concurrently with the airborne gravity data. This model allows accurate Complete Bouguer (terrain) corrections to be calculated and applied to the gravity data. Figure 3 shows the LiDAR-derived terrain model used for processing the Podolsky data, superimposed on the known geological structure.

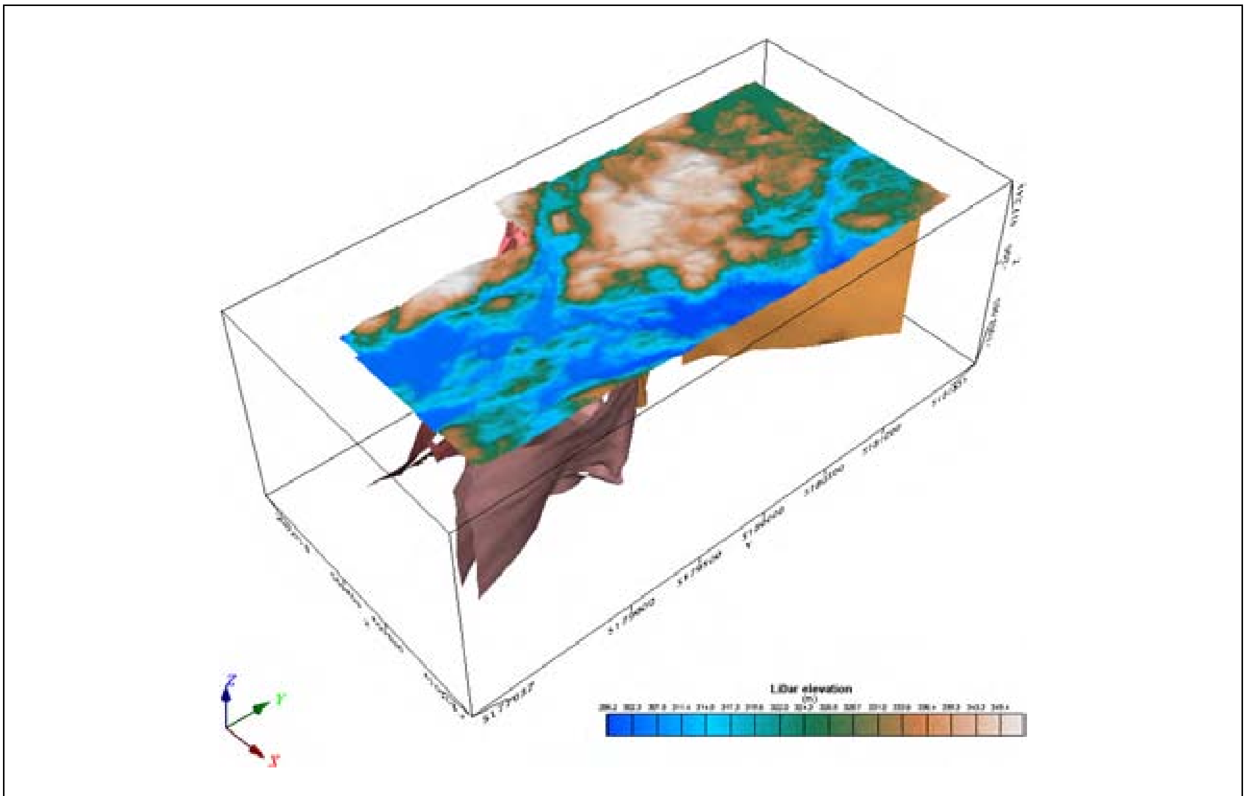

Figure 3. LiDAR surface elevation and subsurface geology data. There is approximately 50 m of topographic relief.

The terrain corrected airborne gravity data contained short wavelength features that were a combination of residual terrain artifacts, signals from near-surface geological sources, and acquisition system noise. To enhance the response of the longer wavelength features related to larger and deeper sources, a low pass filter with a cut-off half wavelength of 300 metres was applied. Images of the resultant data are shown in Figure 4 and Figure 5.

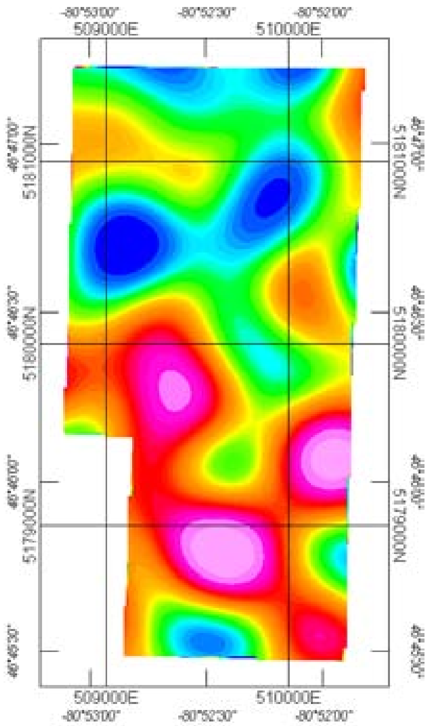

Figure 4. Image of Bouguer gravity data, low pass filtered with a half wavelength cut-off of 300 m. A colour scale for this image is shown in Figure 5. The dynamic range of the gravity data is approximately 5 mGal.

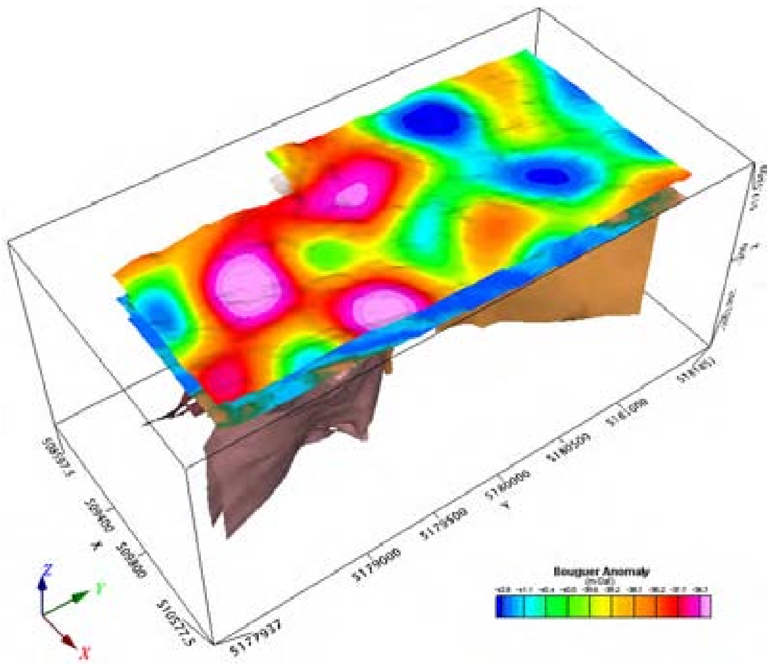

Figure 5. Perspective view of low-pass filtered airborne gravity data displayed above the LiDAR surface elevation data and subsurface geological structural data. A low pass filter with half wavelength cut-off was applied to the gravity data. The gravity and LiDAR data were acquired by Sander Geophysics in 2009 (Sander and Ferguson, 2010).

Airborne magnetic data were acquired over the Podolsky Property as part of an AeroTEM airborne electromagnetic survey by Aeroquest in 2004. These data (Figure 6 and Figure 7) provide additional information that could be used to constrain the gravity inversions that were carried out.

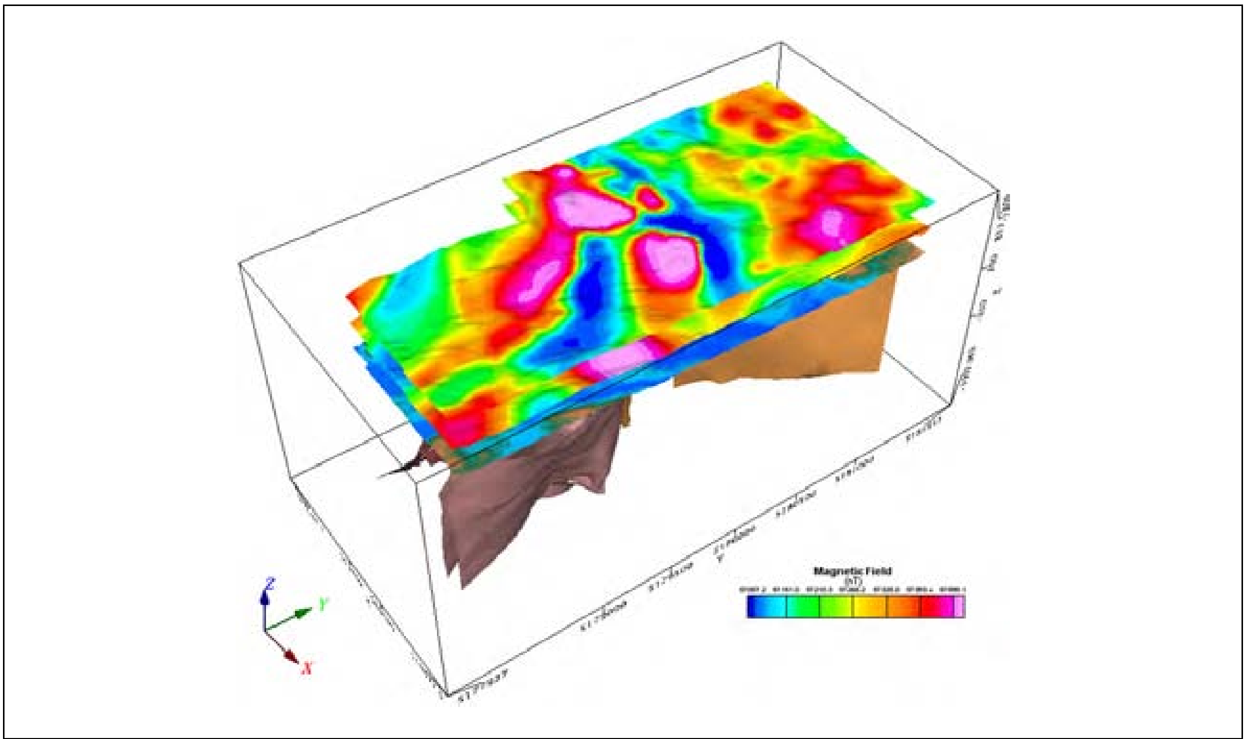

Figure 6. Image of total magnetic intensity (TMI) data shown above gravity, LiDAR surface elevation and subsurface geological information. The magnetic data were acquired by Aeroquest in 2004. The dynamic range of the TMI data is approximately 500 nT.

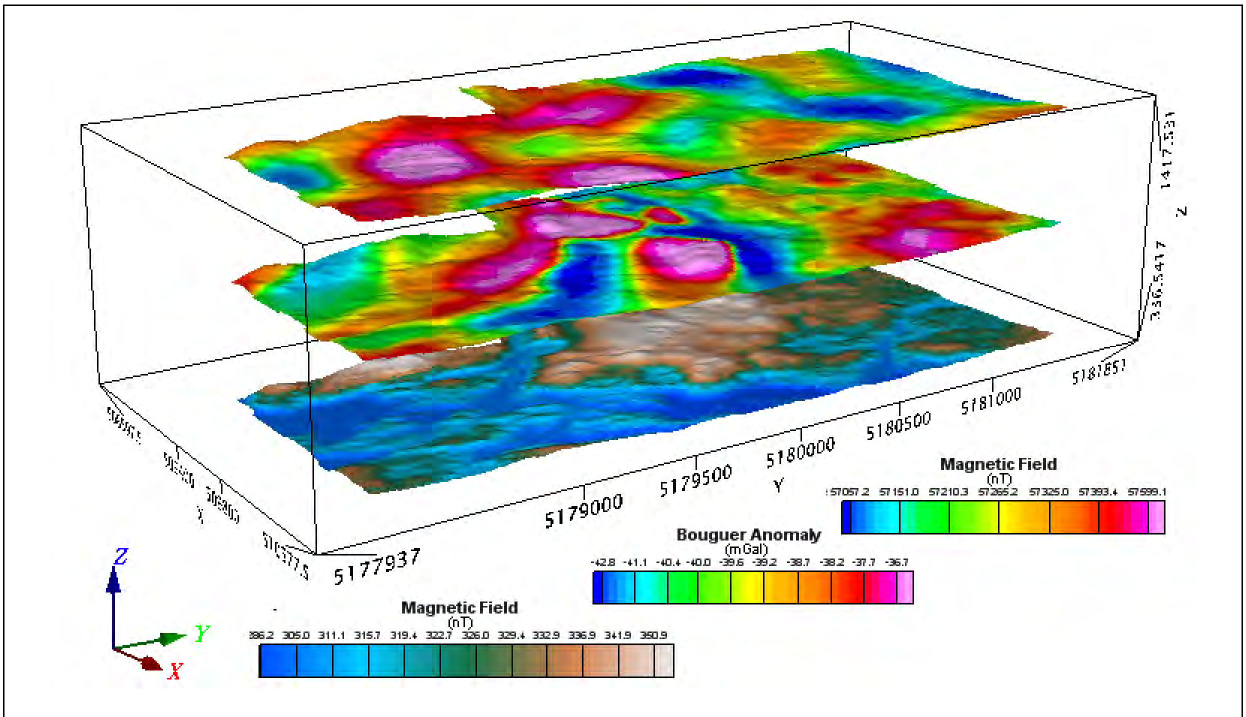

Figure 7. Perspective view of gravity (top) and magnetic (middle) images shown above an image of the LiDAR surface elevation data (bottom).

Gravity inversions

It has become possible with improvements to computer performance and software to routinely model gravity data using inversion methods. However, it is well known that gravity inversion is an ill-posed problem, and that any derived density model is non-unique. Therefore, after completing the pre-processing of the airborne gravity data, the real challenge in gravity inversion is not just to find a model which has a predicted gravity response in agreement with the observed data, but to find such a model which is consistent with other geophysical and geological constraints. In this section, we present the results of an inversion using very general constraints, and follow this up with the results of an inversion that incorporated the knowledge obtained from interpretation of the airborne magnetic data and a priori geological knowledge of the region.

Gravity inversion with general constraints

As a benchmark, an inversion with general constraints was performed using the methodology and software described by Li and Oldenburg (1998). The software has been tailored to operate in a multi-processor/multi-core environment, the details of which will be presented in a subsequent publication. For the purpose of clarity, Figure 8 shows the inversion model detail around the Nickel Ramp Deposit (refer to Figure 2 for the location of this deposit), looking from the SW with the Nickel Ramp Deposit shown in blue, the contact of the Sublayer Norite with the underlying footwall gneisses shown in brown, and an isosurface enclosing regions with density contrast of +0.6 g/cm^3 shown in green. Although we expected there to be a high density feature coincident with the mineralisation, there is an offset between the mineralization and the recovered high density region. Note however, that gravity inversion is an ill-posed problem and that this is just the "smoothest" model that "fits" the gravity data subject to very general constraints. To follow up this result, we utilised constraints derived from magnetic and geologic information from the region, and reviewed the outcome to see if this would lead an explorer more directly towards the dense, highly prospective mineralization known to exist in this location.

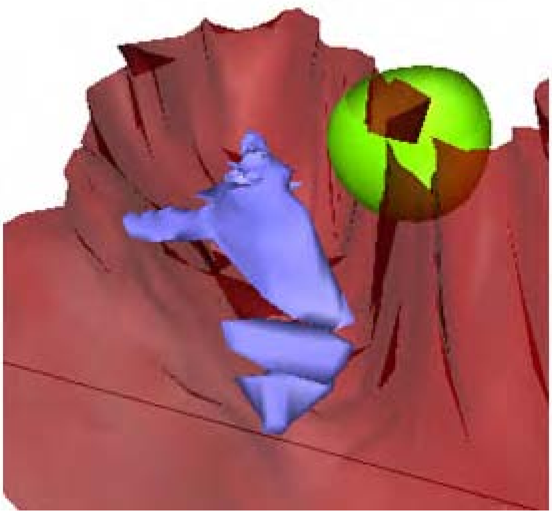

Figure 8. Perspective view of the immediate vicinity of the Podolsky Nickel Ramp Deposit, shown in blue, with the Sublayer Norite contact shown in brown (refer to Figure 2 for the location of this deposit within the Podolsky Property). The unconstrained smooth gravity inversion response in this area is shown as a green isosurface enclosing a density contrast +0.6 g/cm^3.

Geologically and geophysically constrained gravity inversions

Geological constraints can be introduced into inversions in many ways. In this study, we used the contact surfaces of geologic domains to facilitate changes in physical properties between domains. The formulation of the inversion algorithm ensures that such changes will only occur where they are required by the geophysical data (Li and Oldenburg, 1998). We also used the results of magnetic data inversion to further enhance the gravity inversion by using boundaries defined by rapid changes in the magnetic susceptibility values as potential boundaries in the density model. We utilised the principle that boundaries in one physical property domains are likely to be boundaries in another property domain. A constraint of this type can be used even when the actual relationships between the two properties are likely to be complicated and are unknown a priori (Lelièvre and Oldenburg, 2009; Lelièvre et al., 2009).

The outcome of including geologic constraints and auxiliary geophysical constraints in the inversion of the airborne gravity data is shown in Figure 9. Two density contrast isosurfaces are shown, one at +1.8 g/cm^3 in magenta and the other at +1.0 g/cm^3 in yellow. Comparing these results with the results of the previous inversion (Figure 8), we can see that the addition of specific constraints has given rise to a high density inversion anomaly that is significantly more consistent in location with the known high density region associated with the nickel mineralization. The fit to the observed gravity data remained the same. Of particular note, the density anomaly shown in Figure 9 no longer straddles the norite contact, and it has a density contrast which is higher and more consistent with our expectations for this type of mineralization.

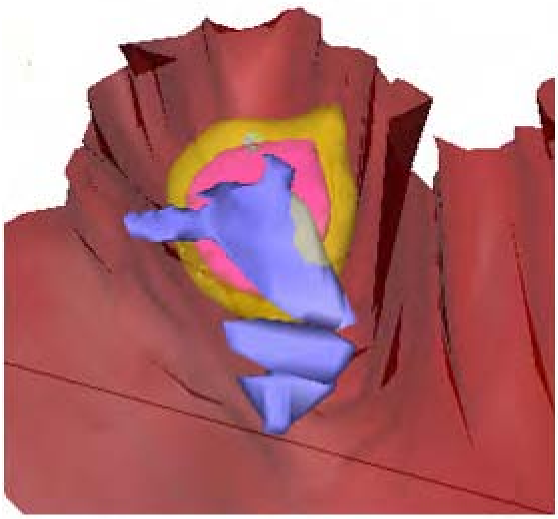

Figure 9. Perspective view of the immediate vicinity of the Podolsky Nickel Ramp Deposit, as per Figure 8, with the Podolsky Nickel Ramp Deposit shown in blue and the Sublayer Norite contact shown in brown. The geologically and magnetically constrained gravity inversion result is shown as magenta and yellow isosurfaces at density contrasts of 1.8 and 1.0 g/cm^3.

Conclusions

An interpretation of airborne gravity data has been carried out for the Podolsky Property. This interpretation was enhanced by having the data acquired using a slow moving helicopter-mounted airborne gravity system, concurrent acquisition of a detailed LiDAR terrain model, and the application of inversion processing methods in a modern high performance computing environment.

Inversion of the gravity data with general constraints led to an outcome of limited value. When supplemented by constraints from magnetic data inversions and from known geological contacts, the inversion results were deemed to be of greater reliability. It is worth noting that utilisation of boundaries from one inversion or from independent geological information in a cooperative fashion in a related inversion would likely improve the results obtained with multi-property classification methods such as those described by Walker (2010).

Acknowledgments

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thanked for collating the above information and performing a number of inversions to enhance the information encoded in the high resolution gravity data.

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