Summary

Airborne and ground gravity and magnetic data, and airborne time domain data have been inverted to recover 3D distributions of density, magnetic susceptibility and electrical conductivity over an area 390km x 460 km in central British Columbia. Large scale gravity and magnetic inversions were first carried out to estimate the regional models. Data for 10 subvolumes were corrected for the regional background, inverted, and merged into a final detailed model containing 32 million cells. The airborne EM data were down-sampled along the acquisition line, inverted with a 1D algorithm using a laterally parameterized method and the results stitched together to generate a 3D model. A conductance rule was used to estimate the depth of penetration and a late-time background conductivity map has also been produced for the survey area. The resulting models provide guidance to the regional structure and prospective geology and location of alteration and mineralization. The final density contrast, magnetic susceptibility, and conductivity models have been integrated into a Common Earth Model ready for 3D GIS analysis, interpretation, and integration with geologic, drill-hole, and other geophysical information. The resulting physical property models can be used to guide regional targeting and help design more detailed, follow-up data acquisition.

Introduction

A program of regional geochemical and geophysical surveys designed to attract the mineral exploration industry to an under-explored region of British Columbia between Williams Lake and Mackenzie was undertaken as part of the Geoscience BC's QUEST Project. (http://www.geosciencebc.com/s/Quest.asp)

The primary focus was the Quesnel Terrane which is prospective for copper and gold porphyry deposits, and is locally covered by a thick layer of glacial sediments. The survey area and data blocks, which cover an area 390 x 460 km, are shown in Figure 1.

Airborne gravity, magnetic, and TEM data were acquired with the goal determining 3D distributions of density, magnetic susceptibility and electrical conductivity. These physical properties can be interpreted in terms of lithology and/or geological processes and their geometric distribution can help delineate geological structures and used as an aid to determine mineralization and subsequent drilling target.

Our goal was to invert these various data sets to generate 3D distributions of the physical properties and
combine the inversion results into a Common Earth Model ready for quantitative 3D GIS analysis and integration with additional geoscientific data. All of the results are made available to the private sector through the Geoscience BC website and are anticipated to stimulate further focused exploration for mineral deposits.

Methodology

Gravity Data: Airborne gravity data were collected along East-West flight lines by Sander Geophysics in 2008 using a line spacing of 2000m. The data, provided by Geoscience BC, were terrain-corrected using a density of 2.67 g/cm$^3$ and were in a gridded format with a 250m grid size. Additionally, surface gravity provided by the GSC (Geological Survey of Canada) was incorporated. These were upward continued to a height of 125 m above the topography. In all of the analysis in our work we used the SRTM database on a 90m grid for topography.

For the inversion, all data were assigned a standard deviation of 1 mGal which is $\sim$ 2% of the total range of terrain corrected data. To carry out the inversion we used the UBC-GIF algorithm GRAV3D (Li and Oldenburg, 1998a). Because of the large size of the problem, the solution was obtained in steps. First a regional inversion was performed using data on a 2000m grid and a correspondingly coarse mesh. Next, 10 subareas of the data were identified and a regional residual separation to be carried out. (Li and Oldenburg, 1998b). The volumes for the localized inversions used a finer mesh, 500m x 500m x 250m cells, and data sampled at 500m intervals. The localized inversions were merged into a final composite model of 32 million cells. The plan view map of the density contrast model, at sea level, is shown in Figure 2a.

Magnetic data: Helicopter-borne TMI data were collected by Geotech Ltd on East-West lines at a line spacing of 4000m. The data were corrected for diurnal variation and were leveled to a sensor height of 75m. In addition GSC magnetic data, comprised of 500 surveys with a line spacing of 800m and altitude of 305m above ground, were provided. The GSC data were collected over a time frame from 1947 to present. The UBC-GIF inversion algorithm MAG3D (Li and Oldenburg, 1996) was used. The processing steps were similar to gravity inversion involving workflow elements: large scale regional inversion; regional removal; localized inversions; merging localized inversions into one large volume. A planview map of magnetic susceptibility at sea level is provided in Figure 2b.

Airborne TEM data: Helicopter-borne VTEM data were collected by Geotech Ltd. along with magnetic data. The survey covered 46,500 square km in area and over 11,600 line kilometres. Due to the high rate of data sampling with airborne EM systems, the VTEM data were averaged before inversion to reduce the data spacing. The data were averaged using 5 soundings on each side of the central sounding. This achieved a spatial resolution similar to the nominal flight height (~60m) and is...
a value similar to the size of the EM system footprint for the VTEM system. Data, dBz/dt, were filtered for cultural noise, mainly powerlines, pipe lines and railways. The first 8 time channels of data were too noisy and hence we inverted 27 time channels spanning 99 to 9245 microseconds. The time channels were assigned a percentage plus a floor value prior to the inversion.

The soundings at each of 379,481 stations, were inverted using the UBC-GIF inversion code EM1DTM (Farquharson and Oldenburg, 1996). The 1D earth was represented by 30 layers increasing in thickness from 2.7m to 50m with a total depth of 700m. The survey area is large and hence the background geology varies markedly from one area to the next. To capture this variability we inverted the late time channels to get a best fitting halfspace and then used a smoothed version of that to generate a reference model at each sounding location. This provided a gradually changing background conductivity, resulted in more consistent models from sounding to sounding, and reduced misleading conductivity modelling artifacts. The smoothed background conductivity model is also a useful exploration product when displayed as a map as it shows lateral variations in conductivity that can be a guide to deeper, underlying geology. Additionally the 1D inversions, using all time channels, were carried out twice; once with an automatic method to estimate the tradeoff parameter, and then a second time using a globally smoothed tradeoff parameter for each sounding. The resulting models were more consistent from sounding to sounding and this allows for geologic features to be more easily interpreted. A 3D conductivity model which conforms to topography was constructed by interpolating 1D conductivity models produced from the AEM data at each station along and across survey lines. In order to eliminate structure at depth that is controlled only by the model objective function, we truncated the models at the depth when the cumulative conductance reached 6 Siemens. The result is shown in Figure 3.

Common Earth Modelling: Our goal was to develop physical property models so they can be incorporated into a Common Earth Model. To help accomplish this Gocad was used for data preparation, model integration, visualization, and interpretation. Having a common digital representation of the earth’s multiple physical properties and geology opens the door for practical interrogation. The results can be used for regional targeting based on explicit exploration criteria using 3D GIS methods such as proximity, intersection, and property queries. The density contrast and magnetic susceptibility models are already on a common 3D mesh structure so they can be directly evaluated together. The conductivity model is restricted to the top few hundred meters, and so isn’t well represented on this common 3D mesh structure. In order to have some form of the conductivity model in the Common Earth Model, the laterally varying basement conductivity values, found from inverting the late time channels, were sampled on the same lateral cell size and then extended vertically throughout the entire depth of the model.

The results, stored in a Common Earth Model, can now be interrogated. A generic task might be to find those regions in the model that have specific relative relationships between their physical properties. For instance, a massive sulfide would be expected to have high density, high magnetic susceptibility, and high electrical conductivity compared to its host. To facilitate inquiry we divide each property into three classes: high, medium, and low. With three properties and three units within each property, there are 27 potential combinations and each cell in the model is ascribed a value from 1 to 27. A surface map of these classification numbers is shown in Figure 4a. As an illustration for making practical use of this information, we now interrogate the classification volume to find cells that

![Figure 3: Conductivity model for Block C. The model is interpolated between the flight lines and conforms to topography](image-url)
are both dense and susceptible. These are projected onto a horizontal plane as shown in Figure 4b. Some of these cells are co-located with areas of known mineralization; other clusters would be prospective targets for further followup.

![Figure 4: a) Surface plan view of 27 discrete physical property classifications. b) The red dots denote cells that have high susceptibility and density. The blue areas indicate regions of known mineralization.](image)

**Conclusions**

Gravity, magnetic and electromagnetic data have been inverted to produce physical property values in a Common Earth Model. The deeper density and magnetic susceptibility cells can be interpreted within the models can be interpreted within the context of geology in order to help define large structures and intrusives. The laterally parameterized conductivity model will be useful in determining the thickness of the overburden and the depth of investigation estimate will guide reliability of the interpretations. Also, the background conductivity model may be useful in characterizing larger scale lateral variations of the near-surface. Given these models, more advanced 3D classification methods can be employed to help identify lithology, alteration, or mineralization, based on model or data driven exploration criteria (e.g. Weights of Evidence, Multi-Class Index Overlay, Self Organising Maps, Neural Networks, etc.).

**References**


Li, Y. and Oldenburg, D.W., 1996, 3-D inversion of magnetic data, Geophysics, 61, 394-408.

