Paper 103

Optimizing Geophysical Inversions for Archean Orogenic Gold Settings

Mitchinson, D. E. [1], Phillips, N. D. [1]

1. University of British Columbia

ABSTRACT

Geophysical inversion methods offer an opportunity to remotely explore for Archean orogenic gold deposits. A synthetic modeling study based on the geology and physical properties of the Hislop orogenic gold deposit, near Matheson, Ontario, was undertaken to explore the capabilities of inversion to resolve important gold-related features relevant to the Archean orogenic gold environment. Preliminary synthetic modeling work indicates that a vertical faulted contact between an ultramafic rock, and a mafic rock unit can be imaged to depth in the subsurface by inversion of magnetic data at a <1 km scale. A 60 m wide, vertical syenite intrusive between mafic and ultramafic rock units is well-located at the surface, but poorly located at depth. Discrepancies between the true physical property models and recovered inversion models are predominantly due to inversion sensitivities, depth weightings, and choice of model norm used in the regularization. The recovered models are improved significantly by bounding magnetic susceptibility values to within the known range of values for the Hislop deposit model. Changing reference models and directional smoothing parameters also improves the model, but on a more local scale. Results from this study provide useful preliminary guidelines for inverting magnetic data within an Archean orogenic gold setting, and gives some indication of the results that can be expected from magnetic inversions in this environment before and after basic geologic constraints are provided.

INTRODUCTION

Geophysical inversion is currently used in exploration for a range of mineral deposit types. Although inversion would constitute a powerful tool in exploration for Archean orogenic gold deposits, which commonly occur in areas of extensive overburden, there are few examples of inversion modeling in this mineral deposit setting.

Two related avenues of research are being pursued to define the usefulness of inversion of various geophysical data as a method to explore for Archean orogenic gold deposits, and to determine how to tune the inversion process to this specific mineral deposit setting. The first involves physical property studies of rocks and hydrothermal alteration mineral assemblages characteristic of this mineral deposit setting. Petrophysical contrasts between likely mineralized, and unmineralized rocks are necessary to yield a geophysical target, and as such they must be identified and understood. The second research component focuses on synthetic modeling. Results from synthetic modeling work indicate if, and how well, geological features related to gold mineralization can be resolved using geophysical inversion under a range of geological scenarios, physical property contrasts, and survey and inversion parameters. The Hislop gold deposit, near Matheson, Ontario, acts as a case study deposit for this physical property and synthetic modeling work.

Geology of the Hislop gold deposit

Gold mineralization at Hislop (Figure. 1) is considered to be related to an elongate, northwest-trending 30 m - 100 m wide, alkalic syenite intrusive occurring at the contact between a mafic and ultramafic metavolcanic unit (Berger, 2002). The majority of gold at Hislop is associated with disseminated pyrite within a strongly Fe-carbonate-altered, brecciated equivalent of the ultramafic unit adjacent to the southwest margin of the syenite (Prest, 1956; Berger, 1999, 2002). Lesser gold occurs within quartz veinlets, stockworks and fractures in mafic volcanic flows north of the syenite, as well as in association with porphyritic rhyolite dikes potentially related to the syenite.

Physical properties of the Hislop gold deposit

The first step in any geophysical study is to understand the rock types that are being targeted, and to define their characteristic physical property ranges. Physical property values for a rock must be distinct from those of surrounding rocks in order to be distinguished in geophysical data. One difficulty in targeting Archean orogenic gold deposits using geophysics is that, although gold itself is a conductive and dense mineral, it is

In "Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration" edited by B. Milkereit, 2007, p. 1099-1103

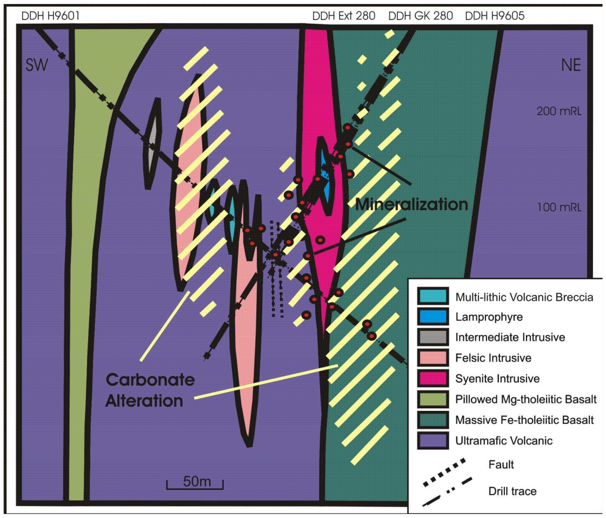

Figure 1: Cross-section, facing northwest, through the Hislop gold deposit, showing carbonate altered, and mineralized rocks.

usually low grade and thus does not contrast significantly enough from its host rocks to be directly detected by geophysical methods (Doyle, 1990). This means that other petrophysically distinct vectors to gold are required.

Physical property analysis for Hislop deposit rocks indicates that there is potential to recognize syenite intrusions, porphyric rhyolite dikes, and Fe-carbonate altered mafic and ultramafic volcanic rocks, rocks considered to be prospective in this area, based on their typically low magnetic susceptibility values.

SYNTHETIC MODELING

Introduction

Although physical property work completed for Hislop establishes the usefulness of magnetic susceptibility point measurements in targeting prospective rock types, it does not necessarily suggest that prospective ranges of susceptibility can be readily isolated from 3D physical property maps of the subsurface generated from geophysical inversion of magnetic data. Geological features characterized by low susceptibilities may be obscured in inversion results for reasons other than a lack of physical property contrast:

Geological relationships - A feature may be indistinguishable as a result of its geometry (shape and size) and location in the subsurface.

Survey parameters - Survey parameters that may obscure geological features include survey scale, survey height, data spacing, and data errors.

Inversion parameters - The deterministic inversion algorithms used are written such that objects may be obscured or smoothed out, a bi-product of making the inversions converge by choosing a simple or smooth model result (Farquharson and Oldenburg, 1998).

Synthetic modeling helps to determine whether any of the parameters above will inhibit imaging of geological features expected in the Archean orogenic gold setting using geophysical inversion.

Objectives

Synthetic modeling work aims to answer a series of questions related to how well inversion is able to image features expected in the Archean orogenic gold setting:

1. Can a specific feature be imaged using default inversion parameters under given survey conditions?

2. How close is the recovered model to the true model?

3. How do the recovered model and the true model differ? What are the causes of these differences?

4. Through identification of causes of differences between the true and recovered models, can appropriate measures be taken to minimize these differences?

5. Can introducing geologic information into the inversion process improve model results? If so, in what ways, and by how much?

Methodology

Due to the well-defined relationships between Hislop geology and magnetic susceptibility, magnetic modeling was pursued. Two synthetic models have been focused on thus far in this research. The first model tested is a potentially mineralized "faulted" contact between mafic and ultramafic volcanic rock units. The second model incorporates a syenite intrusive at the mafic rock, ultramafic rock contact, invoking geology similar to that of the Hislop deposit. Preliminary results from synthetic modeling of these two geological scenarios are given in the presented poster.

3D geology models were generated based on the Hislop deposit, which were then populated with magnetic susceptibility data representative of rocks in the Hislop deposit stratigraphy to yield 3D magnetic susceptibility models (Figure 2a and 2b). The 3D physical property models were forward modeled in an inducing magnetic field to generate a synthetic magnetic dataset. These were subsequently contaminated with random noise and appropriate standard deviations were assigned. The data were inverted using the Mag3D inversion algorithm from the University of British Columbia-Geophysical Inversion Facility (UBC-GIF).

Measures of model "success" are calculated for the model results, in order to quantify the differences between the true and recovered models. The inversion is then constrained based on known physical property and geological information by manipulation of inversion parameters in an attempt to better resolve the expected geological model.

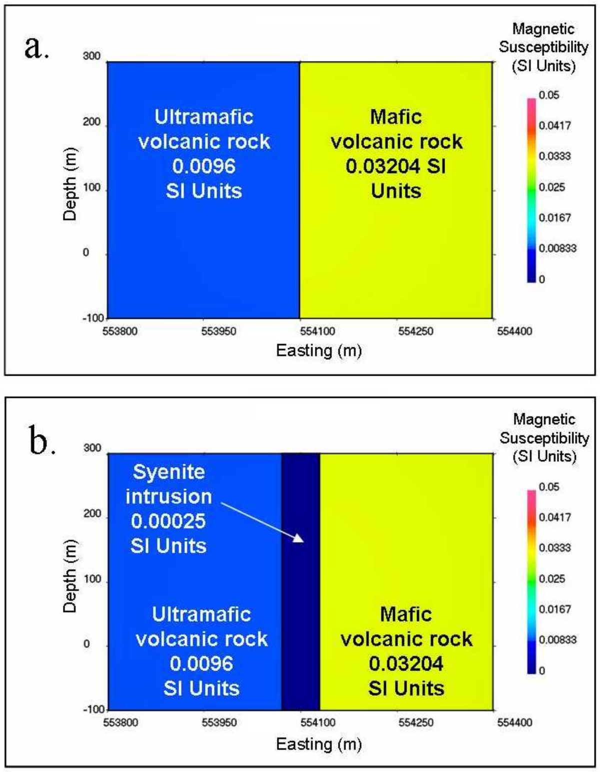

Figure 2: Cross-sections looking north through 3D magnetic susceptibility models associated with a) the faulted contact model, and b) the syenite intrusive model. Depth in m on the vertical axis and distance in UTM (m) on the horizontal axis.

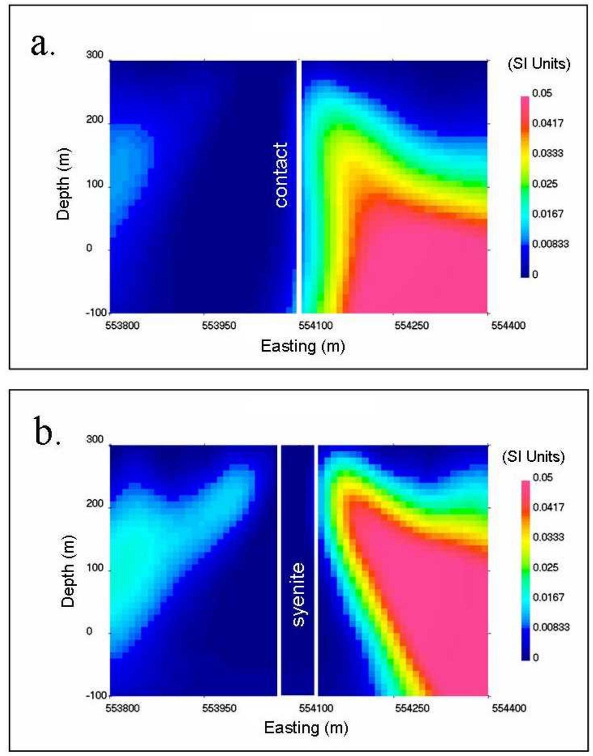

Figure 3: North-facing cross-section through the default 3D inversion results for a) the faulted contact model and b) the syenite intrusive model.

RESULTS

All results are derived from inversion of synthetic magnetic datasets generated from magnetic susceptibility models onto a mesh with 10 m^3 cells and dimensions 600 m × 600 m × 400 m.

Default inversion results

Figure 3a. shows the default inversion result for the faulted contact model. The location of a faulted contact at this scale of inversion is predicted by geophysical inversion in its approximate correct location.

Figure 3b shows the default inversion result for the syenite intrusive model. The true model is best estimated near the surface, with the mafic rock-syenite intrusive contact being most accurately resolved. The syenite is only modeled by the inversion to a depth of about 200 m, below which the geological contacts are poorly located.

Constrained inversion results

Inversion parameters, including reference model values, physical property bounds, and alpha values (directional smoothing factors), were manipulated to explore how the model changes with addition of prior geological knowledge (Figure 4, a-c, and Figure 5, a-c).

Inversion results for both the faulted contact model and the syenite intrusive model are affected similarly by adjusting basic inversion parameters. Defining a reference model that reflects expected subsurface magnetic susceptibility values cause the model to assume values closer to the true model than values estimated for the default model (Figures 4a and 5a). Geological contacts are slightly better located. Setting bounds on magnetic susceptibility values to within expected ranges drives the inversion to a result that is geologically realistic, with more accurately estimated physical property values (Figures 4b and 5b). Changing alpha weightings to achieve smoothing along the z and y axes to reflect known structural orientations, results in sharper contacts within the model, but causes unnecessary vertical exaggeration (Figure 4c and 5c).

In all of the model results, cells near the surface attain magnetic susceptibility values close to the default reference model (0 SI Units) or the assigned reference model, giving the impression of an overburden that does not actually exist in the true model.

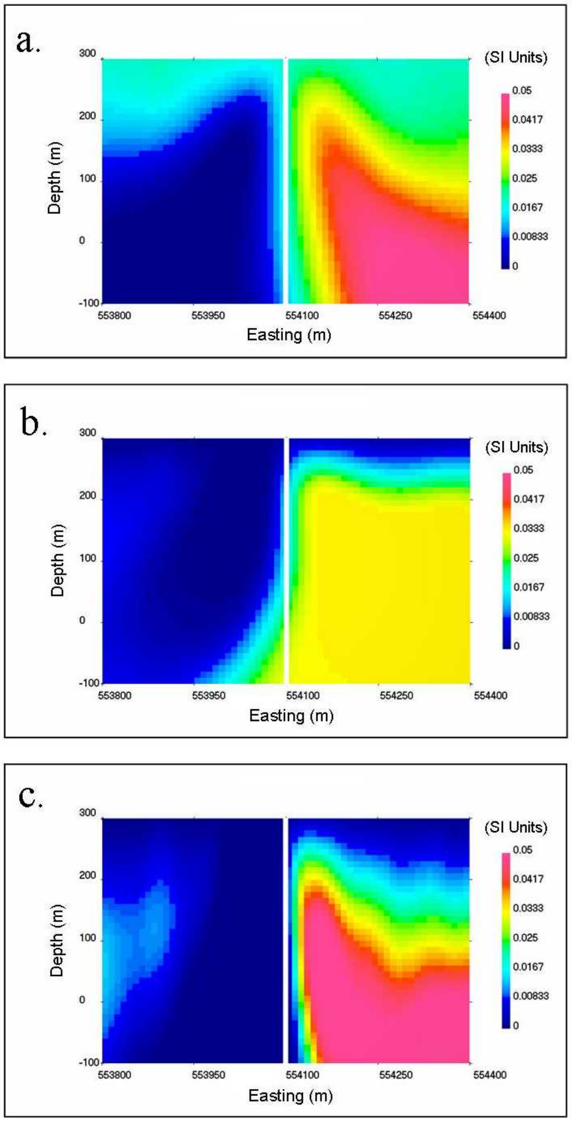

Figure 4: Inversion results for the faulted contact model after manipulation of inversion parameters. a) Reference model set to 0.02 SI Units (default value is 0 SI Units); b) Bounds set from 0 to 0.035 SI Units (default bounds are from 0 to 1 SI Units); c) α_z and α_y increased relative to α_x ($\alpha_z = \alpha_y = \alpha_x$ for default inversion).

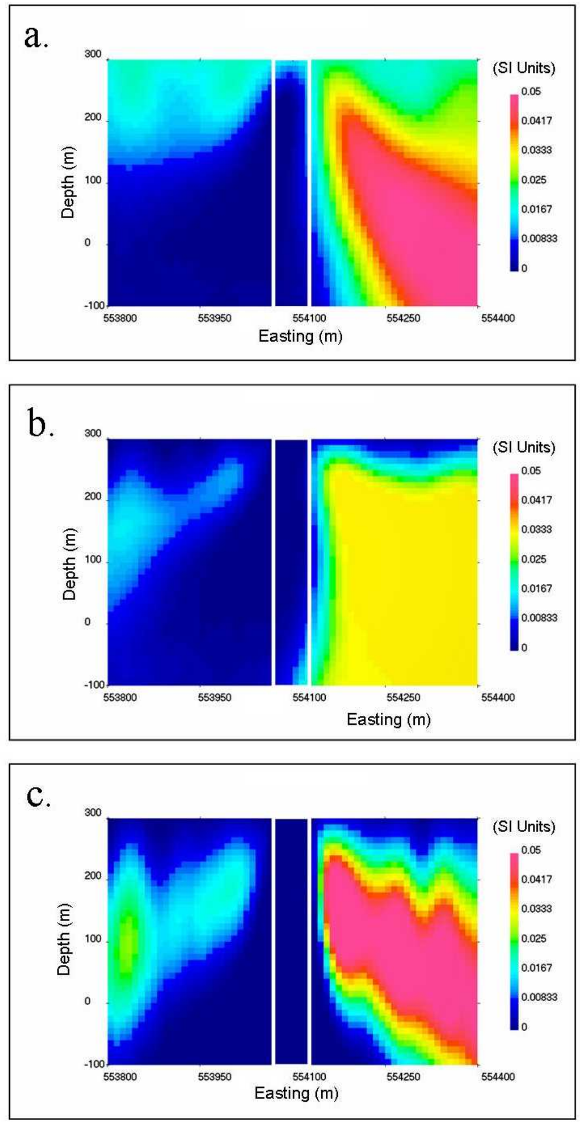

Figure 5: Inversion results for the faulted contact model after manipulation of inversion parameters. a) Reference model set to 0.02 SI Units; b) Bounds set from 0 to 0.035 SI Units; c) α_z and α_y increased relative to α_x .

DISCUSSION

Effects of inversion algorithm on the model

The differences between the true models and the inversion results are predominantly attributed to the smoothing caused by the L2 model norm chosen for the inversion algorithm. Synthetic modeling of the syenite intrusive model shows that inversion is unable to clearly detect the ultramafic rock-syenite intrusion contact. There is a subtle change in magnetic susceptibility across this boundary and smoothing brought about by the L2 norm calculation causes it to be obscured. It is possible to use an L1 norm to yield a more 'blocky' model (Farquharson and Oldenburg, 1998), but this is far more computationally demanding.

Susceptibility values near the surface of the model assume reference model values (0 SI Units for a default inversion), rather than the known value of cells near the surface. This is interpreted to be due to depth weightings applied to potential fields inversion which force higher susceptibilities to depth. This problem may be addressed through manipulation of default depth weightings used in the UBC-GIF inversion code (Li and Oldenburg, 1996).

Improving the recovered model by way of prior geological information

The resulting model in each geologic scenario was improved by changing basic inversion parameters based on prior geological information regarding the expected nature of the subsurface. The greatest improvements in the models were brought about by setting magnetic susceptibility bounds. This guides the model toward a more geologically reasonable result and removes some of the smoothing. Recovered susceptibility values are closer to those of the true model.

Defining a reference model improves estimation of susceptibilities, however surface cells assume the assigned reference value, which may be incorrect. Changing alpha weightings to create smoothing along the z and y axes is least effective in improving the model. Although it does sharpen known geological contacts, it brings about irregularities in the model not related to any known geological features.

CONCLUSIONS

Results from synthetic modeling studies can be used to aid decision making during the inversion process in order to optimize the process for imaging features specific to the Archean orogenic gold environment. Important gold-related features at Hislop that have the potential to be imaged using inversion include felsic intrusive rocks, Fe-carbonate-altered zones in mafic and ultramafic volcanic rocks, and near-vertical faults thought to control mineralization.

This work shows that low susceptibility zones characteristic of felsic intrusives and Fe-carbonate alteration zones are detected when their susceptibility contrasts significantly from the susceptibility of the host. Contacts between higher and lower susceptibility zones are better imaged when information regarding expected physical properties and expected orientations is input into the inversion.

Near-vertical contacts typical of Archean orogenic gold environments can be relatively well imaged to depth at <1 km scale if the physical property contrast between adjacent units is significant. Again, these contacts are better located when prior information is input into subsequent inversions.

Understanding the extent of geophysical inversion capabilities in a particular mineral deposit environment is a prerequisite to designing geophysical surveys adequately, constraining inversions, and knowledgeably interpreting inversion results.

Synthetic modeling provides a means to develop some expectations regarding what subsurface features will be imaged with inversion, and if inversion will cause features of interest to be manifested in unusual ways.

Through synthetic modeling, it is possible to determine which modifications to the inversion process will most likely yield more accurate and more realistic inversion results for a given mineral deposit setting.

REFERENCES

Berger, B.R., 1999, Geological investigations along Highway 101, Hislop Township: Ontario Geological Survey, Summary of Field Work and Other Activities 1999, Open File Report 6000, 5-1 – 5-8.

Berger, B.R., 2002, Geological synthesis of the Highway 101 area, east of Matheson, Ontario: Ontario Geological Survey, Open File Report 6091, 124p.

Doyle, H.A., 1990, Geophysical exploration for gold - a review: Geophysics, **55**, 134-146.

Farquharson, C.G., and Oldenburg, D.W., 1998, Non-linear inversion using general measures of data misfit and model structure: Geophysical Journal International, **134**, 213-227.

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

Oldenburg D.W., and Li, Y., 1999, Estimating depth of investigation on DC resistivity and IP surveys, Geophysics, **64**, 403-416.

Prest, V.K., 1956, Geology of the Hislop Township: Ontario Department of Mines, Annual Report 1956, **65**, 51p.