Use of Full Tensor Gravity Invariants in Detection of Intrusion-hosted Sulphide Mineralization: Implications for Emplacement Mechanisms

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Abstract

Geological and geophysical characteristics of the Budgell's Harbour prospect in Newfoundland, Canada were investigated over known geochemical and magnetic anomalies using Airborne Full Tensor Gradiometry (Air-FTG®). A total of 407 line-km were flown at a line spacing of 200m x 2000m. Several cylindrical, plug-like anomalies were generated that are interpreted to be associated with steeply dipping ultramafic intrusions.

An integrated interpretation focusing on geological models and gravity tensor invariants suggests a mechanism in which ultramafic magma was rapidly and forcefully emplaced. Radial fracturing caused by forceful eruption of these magmas is evident in horizontal tensor invariants. Particularly, the invariants of the gravity tensor provide a means in which individual and sub-vertical plugs, dikes, or diatremes associated with alkaline intrusions can be outlined and clearly distinguished from larger porphyry-like anomalies.

Introduction

An airborne gravity gradiometry survey was conducted at the Budgell's Harbour property in Newfoundland, Canada in the summer of 2007 in order to assist with mapping and delineation of anomalous soil geochemistry, and a magnetic anomaly that is associated with massive sulphide mineralization within the Budgell's Harbour Gabbro intrusion (BHG).

The property was initially explored in the 1970's as a VMS prospect. Several strongly anomalous copper soil anomalies were identified over a large area within and along the margins of the Budgell's Harbour intrusion with values up to 1500ppm copper.

Subsequent lake sediment sampling by the Newfoundland government reported high background Cu, Ni, Co, Au, Ag, and PGE anomalies on the property, consistent with a model comprising high nickel and chromium associated with ultramafic lamprophyres. Celtic Minerals subsequently acquired the property and investigated the potential for intrusion-hosted massive sulphide and disseminated mineralization. During the initial phase of their exploration, limited mapping, sampling, and drilling defined abundant lamprophyre dykes, particularly within the intrusion, and also within the country rock.

Airborne gravity gradiometry surveys have been successfully flown in the past for volcanic-hosted and intrusion-related, massive sulfide deposits in Canada, South America, and Europe. The application of airborne gradiometry in massive sulphide exploration is viable due to the fact that massive sulphide deposits are extremely dense compared to their host rocks; hence they become ideal gravity targets.

In addition to mapping and direct detection of the intrusive bodies associated with massive sulphides, full tensor gravity invariants resolve complex sets of structures that are linked to forceful and violent magmatic injection. The evidence for violent injection includes the presence of diatreme breccias and multi-directional lamprophyre dyke swarms.

This study presents the preliminary assessment results of the gravity gradient data in order to determine mineralization controls and depositional mechanisms over Budgell's Harbour Gabbro.

Geological Setting

The general geology of Budgell's Harbour and Notre Dam Bay areas well described in Dean, P.L. (1978); Harris, A., (1973); Helwig, J.A., (1967); Miller, H.G., (1976); and Prasad, J.N., (1981). The "Budgell's Harbour Gabbro" is a differentiated alkaline ultramafic intrusion that is probably related to a major fault system. Chilled marginal facies have been observed at several points near the contact with the surrounding lithologies. Observations at these points suggest that the present erosional level is just below the original roof of the intrusion.

A coarse flight line separation, government airborne magnetic survey covering the Budgell's Harbour area shows a distinct magnetic high associated with the known and interpreted location of the Budgell's Harbour Gabbro. A profile across the magnetic anomaly suggests a steeply dipping or plunging cylindrical source.

The apparent cylindrical shape, the tectonic setting, the suggested mechanism of magma generation, and the high volatile content support the hypothesis that the emplacement was forceful.

The anomaly is hosted in a Jurassic stratigraphic unit known as the "Budgell's Harbour Gabbro" (BHG). The BHG is composed of mela-gabbro (10-35% plagioclase and 65-90% pyroxene) peridotite, diorite, diatreme breccias and lamprophyre dykes (Figure 1).

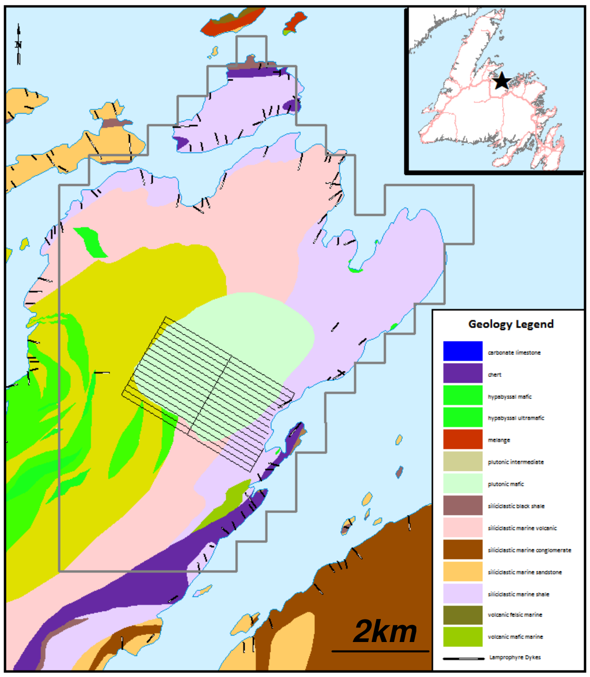

Figure 1. A Simplified geological map of Budgell's Harbour and Notre Dam Bay areas with an overlay of soil grid partly covering the Budgell's Harbour Gabbro. Modified from Helwig, J.A., 1967.

Data Preparation and Results

The measured gradient free air data was leveled, full tensor noise reduced (FTNR) and terrain corrected prior to evaluation and interpretation. Optimum density for terrain correction is critical to accurately separate geological signals from terrain related signals. A range of density corrections ranging from 2.0 g/cc - 4.5g/cc was analyzed to determine the best density value which closely removes the effect of terrain in the free air measured data.

Terrain correction was computed using a proprietary 3-D prism modelling package which uses grids and prisms to compute the gravity effect of each defined layer.
For this particularly study the density of 2.7g/cc was chosen as the optimum density to be used throughout the interpretation

The results for the five independent tensor components together with the vertical tensor component are displayed below (Figure 2). The vertical component Tzz is closely related to the sub surface geology; it directly delineates a ~ 4 km wide BHG intrusion. Tyz and Txz outline central axes of the BHG in north-south and east-west directions. Txx and Tyy delineate edges of the intrusion in east-west and north-south directions respectively. Txy maps all other features within the gabbro that are oriented at an angle with respect to north-south.

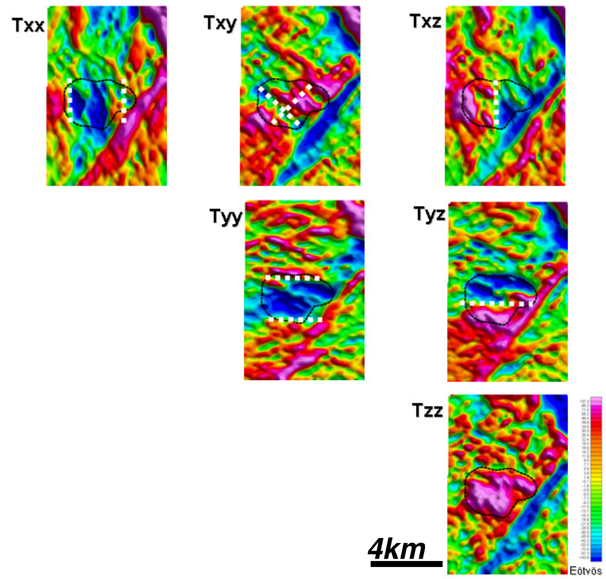

Figure 2. Terrain corrected (at 2.70g/cc) and full tensor processed images. Each tensor outlines different attributes of geology. Tzz locates Budgell's Harbour Gabbro (BHG). Txx and Tyy identify N/S and E/W edges of the BHG. Txz and Tyz identify central axes of the BHG. Txy shows 4 anomalies that point toward the center of mass of the BHG.

Rotational Invariants and Data Enhancement

Rotational invariants are computed from terrain corrected full tensor noise reduced and filtered tensor data. The data for this study was low pass filtered at 500m wavelengths in order to remove high frequency signals that are not necessarily related to the geology of interest.

The technique is primarily intended to improve the data quality by highlighting the density contrast between different geological features. In addition to highlighting density contrast, the rotational invariants provide an alternative way to visualize all six tensor components from a single image. Information such as contacts, lithological units, and 3D-shaped targets such as the intrusive bodies is greatly improved.

The enhancement technique computes the rotational invariant-1 (R-1) and rotational invariant-2 (R-2). The invariant tensors are rotated about the Z-axis and the computed response retains its shape and orientation regardless of the direction rotated. The technique was described by Pederson & Rasmussen (1990).

The Rotational-1 and -2 invariants are computed as follows:

$$R\text{-}1 = \sqrt{\left(\left(TxxTyy + TyyTzz + TxxTzz\right) - \left(Txy^2 + Tyz^2 + Tzx^2\right)\right)}$$

$$R\text{-}2 = \left(Txx\left(TyyTzz - Tyz^2\right) + Txy\left(TyzTxz - TxyTzz\right) + Txz\left(TxyTyz - TxzTyy\right)\right)^{1/3}$$

The computed R-1 in Figure 3A, highlights not only the contact between BHG and the host ultramafic, but also outlines small individual intrusions within the main intrusion. Figure 3B is the computed R-2 image, it enhances overall shape of the BHG intrusion. Individual density variations are distinguished from within the overall shape of the intrusion by suppressing the longer wavelength background signal. The cylindrical, plug-like shapes observed in these anomalies are interpreted to be caused by steep gradient which imply that these targets are vertical or sub-vertical.

R-1 computation provides a practical means in which follow-up targets could be selected and tested. A total of ten targets were selected and recommended for a ground follow-up (Figure 3B).

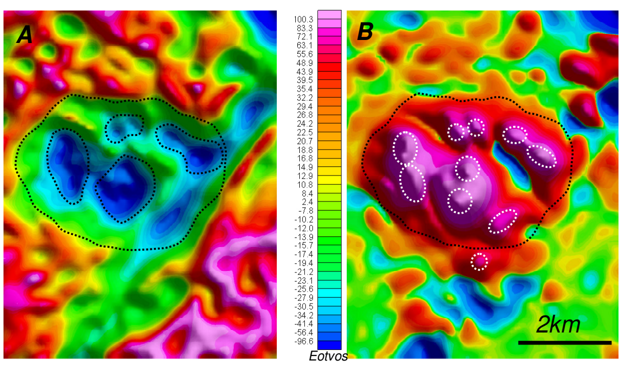

Figure 3: Computed Rotational Invariants; A. R-1 and B. R-2, outlining contacts, edges and shapes of various small individual intrusions of the Budgell's Harbour Gabbro.

Lineament Analysis

Generally, geologic features, such as faults, faults, lithological contacts, joints and fractures, etc. are reflected as lineaments in most potential field data. Gravity gradient data uses filtered and full tensor noise reduced data to compute the horizontal invariants from which the interpretation of lineaments is based. This computation uses a combination of two horizontal tensor components TxxTyyTyx and TxzTyz to produce lineament grids.

One of the most striking features from the FTNR processing is how it increases the signal to noise ratio of the two pairs of the horizontal components Txx, Tyy, Tyx and Txz, Tyz. The FTNR processing allows the extraction of information that may be visually difficult to discern in the Tzz data.

Horizontal invariants are computed as follows:

$$Invar\_TxyTxxTyy = \sqrt{\left(Txy^2 + \left(\frac{Tyy - Txx}{2}\right)^2\right)} \ldots(i)$$

$$Invar\_TxzTyz = \sqrt{\left(Txz^2 + Tyz^2\right)} \ldots\ldots\ldots\ldots(ii)$$

Equations i and ii are horizontal tensor invariants with respect to rotations about the z-axis. This means that just as it is true for Tzz, a map of invariants will look exactly the same for a given anomaly shapes no matter which direction the source is oriented.

A negative linear anomaly in Invar_TxyTxxTyy correlates with a positive linear anomaly in Invar_TxzTyz over the edges of BHG map (Figure 4A&B).

Detection of Complex Radial Structures

The computational and interpretation of the horizontal tensor invariants facilitate in detection of complex, multi-directional sets of radial structures that run almost perpendicular to the BHG intrusion (Figure 4C).

The radial structures have been interpreted to be linked with rapid and violent emplacement of magmatic intrusions. Recognition of these structures is of great importance because of their role in controlling sulphide mineralization in the Budgell's Harbour property.

The evidence for violent injection includes the presence of diatreme breccias and multi-directional lamprophyre dyke swarms. The Inva_TyyTxxTyx (Figure 4C) highlights these structures and their general trends by mapping their inflection points, showing linear low high low gravity responses.

The results from horizontal tensor invariants computation can be displayed as gridded images as well as individual lineaments (Figure 5). The horizontal invariants provide an alternative visual tool for tracking linear or near-linear trends in the data. A similar application of Linear Feature Analysis (LFA) is very well described in Hansen and de Ridder 2006 using magnetic data.

Conclusions

Full tensor processed, free air, and terrain corrected data generate a composite data set for which a detailed and a prospect-level interpretation can be done.

Rotational tensor invariants computations facilitate the removal of background gravity response therefore enhancing the intrusion-hosted sulphide mineralization from background geology.

Lineament analysis of the horizontal tensor invariants highlights both linear and multi-directional, complex structures associated with forceful injection of the magmas to the Budgell's Harbour Gabbro.

The lineaments derived from horizontal invariants provide an alternative visual tool for which linear or near-linear features and trends in the data can be tracked.

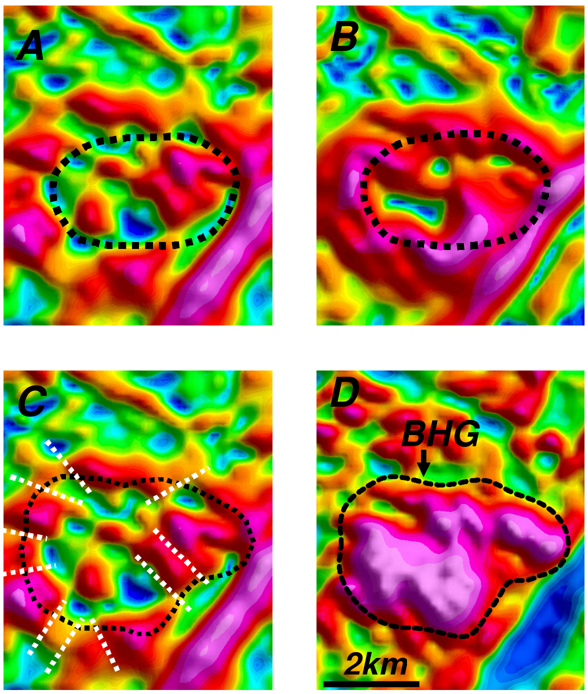

Figure 4: A. invariant TxxTyyTxy B Invariant TxzTyz C. Invariant TxzTyz showing the radial-like structures D. terrain corrected Tzz for comparison

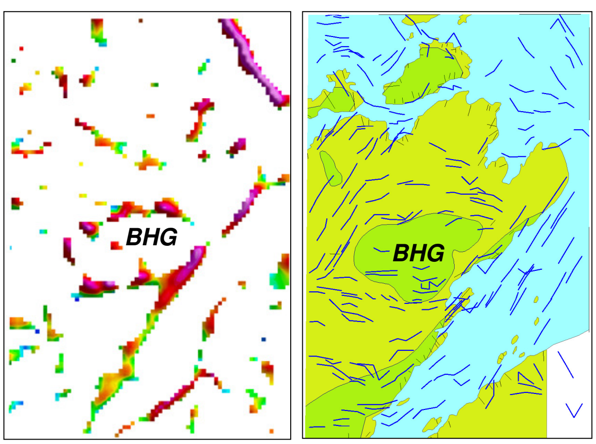

Figure 5: Computed Horizontal Invariants displayed as lineaments; A. A gridded image of the two horizontal invariants displayed as lineament features B. lineaments over geological maps of the property.

Acknowledgements

Bell Geospace would like to thank Celtic Minerals for granting permission to show this data.

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