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Strategic Exploration with Airborne Gravity Gradiometry

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Introduction

Early stage and advanced exploration benefits from use of geophysics that expands knowledge and understanding of geological complexity not only on the surface and near-surface but also deep undercover. Usage of airborne geophysics extends this knowledge base from prospect to district scale leading to a greater understanding on the intricacies in resolving both complex geometries and their likely continued occurrence along structural trends away from initial discovery. However, not all geophysical methods allow clear mapping of geological controls on their distribution.

Magnetic and EM survey methods are fantastic at delineating clear changes in rock magnetization and conductivity and have enjoyed significant success in direct targeting exercises locating drill-ready anomalous responses. Relative responses, where strong, are clear and indicate a near surface depth relative to size of target. However, where the responses are weak, or where minimalistic, limits the use of such technologies for detection of deeper deposits and mapping of geological complexity. Magnetics and EM technologies also have limited use over areas where there is considerable surface infrastructure that invariably requires application of some form of data filtering in order to isolate and delineate the response from the subsurface.

Gravity methods delineate change in rock density; and as geology shows more change in density than change in either magnetization or conductivity, then gravity is a clear choice for mapping sub-surface geological complexity as presented by structural change. However, gravity survey methods are limited in terms of use. Ground gravity surveying is limited by presence of water bodies, unstable and steep sided terrain, and/or heavy vegetation cover leading to many surveys being best suited for capturing signal arising from deep undercover or regional scaled geology and having limited use in prospect delineation. Airborne Gravity surveys are limited by the need to account for accelerations due to aircraft motion and so, yield workable signature bandwidth akin to that retrieved from wide spaced ground surveys.

Airborne Gravity Gradiometry overcomes limitations set by usage of airborne and ground gravity. The instrumentation comprises mutliple pairs of acelerometers arranged on individual discs (Brewster 2016) that measures the rate of change of gravity in all directions of the field, i.e. both horizontal and vertical. The gradient response is determined as the difference between opposing pairs of accelerometers and with accleration due to aircraft motion being cancelled-out, the resultant gravity gradient measurement is wide signal bandwidth capturing the short to intermediate wavelengths arising from complex geology both shallow and deep undercover. Combining the gradient response from the multiple pairs of accelerometers allows clear delineation of the field change not only in both horizontal and vertical directions (Murphy et al 2023), but also as a high resolution conventional gravity field.

The strategic benefit from Airborne Gravity Gradiometry is detection and mapping of the subsurface density distribution revealed by geological structural change. As geological structural change is often more defined by density change than magnetization and conductivity, then this makes usage of Airborne Gravity Gradiometry key to successful exploration delineating buried structure hosting economic mineralisation.

This is discussed by making reference to public domain data sets that shows how gravity gradiometry is adept at mapping structure following known mineralisation trends but not detectable in magnetic and EM data.

Methodology

Data selection

Gravity gradiometry data recorded using the Full Tensor Gradiometer (FTG) technology (Murphy 2010) are selected for analysis and compared with final processed airborne magnetic and EM data . All data were acquired (Ugalde et al 2019) over the Bathurst Mining Camp in New Brunswick, Canada, a well established base metals mining district. The mineralisation style is VMS along both NNW and ENE structural trends and dominantly occurs at near surface. Magnetics and EM show clear responses over the many well known shallow deposits but have limited depth penetration.

Data analysis

The measured gravity gradient information are described as a Tensor, T_{ij}. T_{xx}, T_{xy} and T_{yy} map the rate of change in gravity in the X and Y directions, and when combined, map the total horizontal curvature of the field, THC. THC anomaly patterns have direct correlation with curvature as shown by geology, e.g. thrust folds. T_{xz} and T_{yz} map the vertical change in the X and Y directions. Their combination maps the total horizontal gradient (THG), accurately locating contacts between geological sources of different density, e.g. faulted contacts. T_{zz} and T_z (gravity) map density change in the vertical direction mapping rock types of different density and at differing depths. Table 1 summarises the geological structure type detected and their provenance using FTG technology.

Tensor component	Geology type detected	Application
T_{zz} & Gravity T_z	Lithologic change	Felsic v Mafic, sediment v igneous; alteration zones
T_{xx}, T_{xy} & T_{yy}	Domes, folds, ridges, channels, craters, cones, plutons	Mafic/Ultramafic intrusives, granites, weathered zones, placer lakes, sink-holes, thrust folds
T_{xz} & T_{yz}	Faults, unconformities, contact zones	Dykes, alteration zones, contact aureoles

Table 1. Tensor components and their corresponding geological meaning for key geological settings

FTG data are interrogated for depth sensitivity using a tensor migration workflow described by Brewster and Murphy (2020). The migrated components are analysed using the procedure described by Murphy et al (20023) to map primary structural character and lineament trends. The combined depth discrimination and structure mapping workflow produces meaningful tensor anomaly and geological observation maps for targeted depth windows or, as for this analysis, at nominated depths below surface where exploration objectives are focussed. Data analysis identifies depth sensitivity at 400m below ground. Mapped structures and contact lineaments follow clear distinct trends with ENE and NW to NNW being dominant.

Data correlation

The FTG data and analysed results are correlated with ground gravity to determine the uplift presented by the tensor data and then with coincident magnetic and EM data. Correlation with the ground data allows connection of deep regional sourced structuring with complexity expressed in the shallow section. Correlation with magnetics and EM data shows excellent agreement at mapping surface and near surface geology. However, where correlation is poor, the FTG signal shows clear coherency opposed to the rather benign signature patterns evident in the magnetics and EM (see Figure1). The minimalistic Magnetic and EM response is assumed to arise due to the limited depth penetration from these technologies. Depth analysis performed on the FTG indicates a 400m below ground depth sensitivty. Mapped structures and contact lineaments from the tensor components follow the established mineralisation trends.

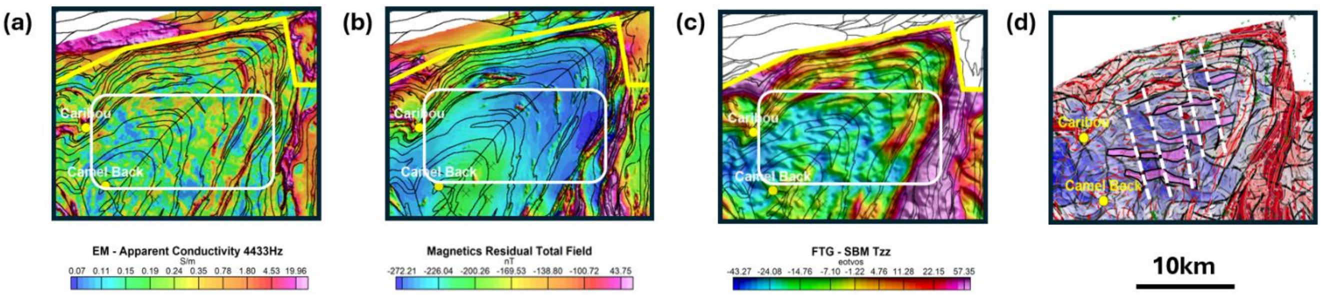

Figure1. Correlation of (a) EM, (b) Magnetics and (c) FTG data over the Bathurst Mining Camp. (d) FTG interpretation maps deep seated ENE structuring (pink) showing displacement along NNW trends (dashed white) at 400m depth. Interpretation not discernible from EM and Magnetic data (white box). Black overlay is known geology, geophysical data accessible from NRCan data repository.

Results and Conclusions

Airborne Gravity Gradiometry data acquired with FTG detects and maps structural trends from surface to deep undercover, often sensitive to geology not seen using either Magnetic or EM survey technologies. The example as presented in this paper serves to identify deeper prospectivity than previously considered for the Bathurst area. The strategic benefit to exploration by including Airborne Gravity Gradiometry has significance. Mapping clear structuring at depth allows increased understanding of complex structuring leading to a greater understanding on distribution and distribution mechanisms for mineralising fluids.

References

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