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Executive Summary

Toward an Improved Basis for Beneath-Cover Mineral Exploration in the QUEST Area, Central British Columbia: New Structural Interpretation of Geophysical and Geological Datasets (NTS 093A, B, G, H, J, K, N)

M.G. Sánchez, Fault Rocks Consulting, Vancouver, BC, msanchez@faultrocks.com

T. Bissig, Bissig Geoscience, Vancouver, BC

P. Kowalczyk, PK Geophysics Inc., Vancouver, BC

Background

Geoscience BC's QUEST survey area in central British Columbia has a large amount of regional geophysical and geochemical data available to the exploration industry; however, despite the wealth of data, the bedrock geology remains poorly constrained, especially in the extensive areas covered by glacial drift in the Prince George area. The area is generally prospective for porphyry Cu-Au mineralization beneath covering glacial drift. Previous attempts to integrate geophysical, geochemical and geological information to constrain the geology beneath cover (Logan et al., 2010) provided results that were heavily biased toward interpolation between known outcrops and failed to take into consideration much of the geophysical and geochemical evidence. This study is focused on the interpretation of magnetic and gravity data and provides a fresh look at the structural architecture and the bedrock geology in the QUEST area and can be used as a base layer for exploration for Porphyry style deposits in this highly prospective area. See project deliverables for illustrations.

How to use the project deliverables

Explorers looking to utlize the findings of this project in their exploration efforts may find the pdf poster (QUEST_Poster_2015_15.pdf) a useful place to start as it highlights the final geological interpretation of the area. For more advanced users, this structural and geological interpretation of magnetic and gravity datasets provides a series of map layers interpreted at a scale of 1: 400.000 of a region including a 40 km buffer zone surrounding the QUEST area. The project deliverables are provided as two ArcGIS map packages for easy opening and navigation through the data. However, the bulk of the data can also be opened by other GIS software packages. One of the map packages (QUEST_InterpMap_2015_015.mpk) provides the principal map interpretations, whereas the other (QUEST_Analysis_2015_015.mpk) contains a complete suite of files produced during the data analysis and interpretation. The analysis map project (QUEST_Analysis_2015_015.mpk) is organized in a way that permits navigating through the datasets so that the work flow of data interpretation can be followed. For each of the map packages a presentation in pdf format is provided which explains the corresponding dataset and interpretation work flow (QUEST_InterpMap_TechPres_2015_015.pdf and QUEST_Analysis_TechPres_2015_015.pdf). Meta-data are provided in an Excel spreadsheet (Readme_Metadata_2015_015.xls) and the datasets and geophysical data processing methodology is detailed below.

Datasets used

The maps interpretations are primarily based on multiple geophysical datasets, including Geoscience BC's Bouguer and isostatic residual (IR) gravity grids, Natural Resources Canada's (NRCan) regional reduced-to-pole (RTP) aeromagnetic data (Geoscience BC, 2009; APPENDIX). In order to represent depth surfaces in potential-field data, upward-continued datasets were produced following a methodology similar to the one proposed by Jacobsen (1987), whereby a band-pass filter is used to separate causative sources at various depths. The method implies that, in order to isolate a regional field at a given depth (z0), the observed field is upward-continued to a height above the land surface equivalent to twice its depth ($2 \cdot z0$). For the definition of upward-continued residual levels, the authors followed the recommendations of Gunn (1997), which emphasize the use of geological constraints at the expense of spectral information (Spector, 1985). Three upward-continuation levels were selected for brittle crustal conditions of less than ~10 km depth (See Readme_Metadata_2015_015.xls). In accordance with a typical geothermal gradient of 30°C/km (Dragoni, 1993), these levels are located well below the Curie temperature of magnetite

(585°C) and have the potential to generate a magnetic response. Previously known geological constraints, such as maximum thickness of Quaternary drift cover and of the Chilcotin Group volcanic rocks (Andrews and Russell, 2010), were essential for the definition of shallower depth slices. In addition to these band-pass filters, a series of pseudogravity (PG) grids were used for non- and upward-continued RTP magnetic residuals. The PG transformation implies an approximate conversion of magnetic to gravity data by changing its rate of decay from the inverse cube of the distance to source to the inverse square of the distance to source (Hildenbrand, 1983).

Interpretation Method

Interpretation of the geophysical data sets was carried out at 1: 400,000 scale within a geographic information system platform (ArcGIS 10.2.2) using the North American Datum 1983 (NAD 83) Universal Transverse Mercator (UTM) Zone 10N projected coordinate system. The current methodology is focused on manually tracing lineaments and domains on NRCan's RTP aeromagnetic grid, including the series of new filters and transformations (APPENDIX). This process uses a systematic and iterative comparison of aeromagnetic data against airborne gravity, topography and geological map data. The methodology for this study did not employ any automatized structure detection algorithms.

The three principal interpretation layers are described below:

(1) Aeromagnetic lineaments: Correspond to high-frequency and variable intensity aeromagnetic discontinuities which commonly bound aeromagnetic domains (Sánchez et al., 2014, 2015). Lineaments were classified into three orders upon their spatial relation to aeromagnetic domains. Aeromagnetic lineaments that bound domains may correspond to a faulted lithological contact, plan view-elongated intrusive contact or ophiolite belt. Magnetic lineaments which occur within magnetic domains may represent local fault and fracture arrays, felsic or mafic dikes or major angular unconformities.

(2) Anomaly axis: Lineaments that correspond to the long axis of elliptical-shaped high intensity RTP aeromagnetic anomalies. These were classified in three groups depending on their aeromagnetic intensity. High intensity RTP aeromagnetic anomalies may represent local-scale intrusions such as mafic dykes, mafic plutons or a potassic-altered porphyry stock. These may also represent structural fabric (schistosity) or sedimentary layering.

(3) Aeromagnetic domains: Correspond to spatially-related areas of similar magnetic intensity and frequency (texture). Domains were assessed in a qualitative and quantitative manner for classification upon their magnetic intensity and frequency (texture) response. Spatial classification includes an Eastern, Central and Western belt of NNW-trending domains which may be correlated to a particular tectonic terrane (e.g. Cache Creek). Individual aeromagnetic domains may be correlated with a specific geological unit of consistent magnetic response (e.g. Hogem Plutonic Suite).

Aeromagnetic lineaments, anomaly axis and domain boundaries were first manually traced by using two pairs of high-pass filters: 1) analytic signal (AS) in combination with the horizontal-gradient magnitude (HGM) grid, and 2) 1VD grid in addition to the tilt-derivative (TD) filter. All four filters suppress deep, long-wavelength signals and accentuate or sharpen the near-surface responses that are useful for structural interpretation in drift- and/or basalt-covered areas (Gunn et al., 1997; Milligan and Gunn, 1997). The AS filter and the HGM grid help detect magnetic- and gravity-anomaly boundaries because both filters place their 'peak' amplitude signal over edges or geological contacts. Furthermore, as the amplitude of the AS signal is always positive, it works as an effective anti-remanence tool (Gunn, 1997). The 1VD grid and the TD filter are effective in accentuating the high-frequency signals that commonly arise from linear features such as faults, fractures, stratification, foliation and dikes.

Aeromagnetic lineaments

The interpretation in this study is based on a systematic, multi-dataset 'stacking' methodology; in which aeromagnetic lineaments are compared against various data layers to provide a measure of geological confidence. In order to evaluate the reliability of the lineament interpretation, individual magnetic lineaments were classified by assigning binary numeric values, depending upon whether they can be traced in each individual grid (Sánchez et al., 2014). The summation of these values results in a reliability scale (Reliability Index; RTP_SUM) with which most probable structures were detected (See QUEST_Analysis_TechPres_2015_015.pdf).

Lineaments were classified into three orders upon their spatial relation to aeromagnetic domains, including: Domain_Major (lineaments bounding major magnetic domains); Domain_Minor (lineaments bounding minor magnetic domains) and; Lineam_Major (lineaments occurring within a magnetic domain). This qualitative classification is better observed when compared, respectively, with three upward continued data filters: Residual Deep (RD); Residual Intermediate (RI) and; Residual Intermediate with High Pass filtering (RI_HP). Quantitative classifications considered mean values (RTP_MN) extracted from the RTP aeromagnetic grid using a 1 km buffer zone around individual lineaments. RTP grids for a series of positive and negative RTP intensity ranges are included in the analysis map package (QUEST_Analysis_2015_015.mpk). Aeromagnetic lineaments were further classified upon spatial and geometric parameters, including lineament orientations (AZIMUTH) and length (LENGTH). For structural geology purposes, offsets across magnetic lineaments were inspected in map-view and cross-section. Results were assessed against known local structural types and the regional structural and tectonic framework for the classification of magnetic lineaments into fault types and systems (Sánchez et al., 2014; Sánchez et al. 2015). These were named after published fault names or geographic locations (FZ or System).

Anomaly axis

The long axis of elliptical-shaped high intensity RTP aeromagnetic anomalies were assessed using both, high-pass filters and the non-filtered grid. These were classified in three groups depending upon their aeromagnetic intensity: High (> 500 nT); Intermediate (0 to 500 nT) and; Low (<0 nT). RTP grids for these three intensity ranges are included in the Analysis map package (QUEST_Analysis_2015_015.mpk). Anomaly axes were spatially classified and color coded by lineament orientation (AZIMUTH) and length (LENGTH). Detailed geological interpretations of anomaly axis lineaments were not included and remain "open" to the user.

Aeromagnetic domains

Areas of similar magnetic intensity and frequency (texture) were classified using a qualitative scale that combines magnetic intensity (TYPE) and texture (SUBTYPE). This scale organizes individual domains from a "Very High" to "Low" magnetic intensity and "texture" ranges. A quantitative approach to aeromagnetic domain classification considers the extraction of four statistical parameters, including the mean (MN), minimum (MIN), maximum (MAX) and standard deviation (STD) values for individual domains. These were sampled from the RTP grid, HGM magnetic grid and Isostatic Residual (IR) gravity data. The unfiltered RTP grid was used for extracting "intensity" information while the HGM of the RTP aeromagnetic grid was used for frequency ("texture") classification. The Isostatic Residual (IR) gravity grid was utilized to gather information on density contrasts of individual magnetic domains. The magnetic and gravity grids used for quantitative classifications are included in the Analysis map package (QUEST_Analysis_2015_015.mpk). Spatial analysis, includes area and perimeter length calculations.

BCGS geology overlapping magnetic anomalies

The geological map from the BCGS Open File 2013-04 map (Cui et al. 2013) was clipped using the RTP magnetic grid with cell-values greater or equal than 350 nT (GTE350) and values less or equal than -220 nT (LEneg220). Units clipped using GTE350 polygons were organized into a chronostratigraphic (time versus rock type) chart that better represent the link between rock physical properties and rock types, including ultramafic, metamorphic, intrusive, volcanic and sedimentary rocks. All geological unit names and further geological descriptions were maintained from the original Open File 2013-04 map file. The lithologies contained within these regions may represent the direct source of high intensity magnetic anomalies (e.g. Nicola Group). In a similar manner to aeromagnetic domain quantitative classification, the mean and standard deviation were extracted from the RTP grid, HGM magnetic grid and Isostatic Residual (IR) gravity data.

Statistical Analysis

Statistical analysis was performed using the software "Geospatial Modelling Environment" (GME, Version 0.7.3.0; Beyer, 2012). GME software uses R (www.r-project.org) to drive some of the analytical, statistical and graphing functionality.

Some general observations in regional data

Fault type interpretation was mainly based on the apparent offsets across magnetic domains, as well as upon existing geological map information (e.g. Cui et al., 2013). Kinematic types assigned to aeromagnetic lineaments have been grouped into three principal types, including early NNW-trending thrusts and reverse faults cut by younger N-trending dextral strike slip faults and NE-trending extensional faults. The data interpretation led to the identification of regionally extensive mostly NW striking magnetic domains which can be correlated to the known geology (see Technical Reports pdf files in project deliverables). These domains can be grouped into the eastern domains (corresponding to ancient North America) the central domains (corresponding to the Quesnel terrane) and western domains (corresponding to the Cache Creek terrane). The eastern and western boundary of the Central magnetic domain belt is interpreted as a series of thrusts or reverse fault systems. The Nicola Group and laterally equivalent Takla Group of the Quesnel terrane are, the most widely occurring mafic rocks in the QUEST area. Although these units have only been subdivided into two units in previous regional map compilations (Massey et al., 2005, Logan et al., 2010) they can be subdivided into eight roughly NNW-striking belts based on magnetic domains. In accordance with previous studies (Vaca 2012, Schiarrizza et al., 2009) generally magnetic and likely alkaline basaltic suites are located in the western part of the Quesnel terrane whereas less magnetic and more tholeiitic to calc-alkaline basaltic suites are located in a more easterly position. The former include the Mount Polley area (Central W 1 domain) where porphyry Cu-Au mineralization has been emplaced pene-contemporaneously with alkalic basaltic volcanic rocks (e.g., Logan and Bath 2006). In contrast, Mount Milligan, where porphyry mineralization post-dates the non-magnetic host rocks by more than 20 Ma, is located in a low magnetic domain (Central N domain) northeast of the magnetic domain in which Mount Polley is located. In agreement with recent mapping (Schiarrizza et al. 2014), the Gibraltar porphyry Cu-Mo deposit is located in the Central SW domain that forms part of the Quesnel terrane. The magnetic domain interpretation, thus, supports the re-interpretation of the geologic setting of Gibraltar which is located in the Quesnel arc terrane and not, as previously thought, in the oceanic Cache Creek terrane. Gibraltar porphyry Cu-Mo deposit sits within a step-over along a major N-trending dextral strike-slip fault (QUEST NS fault). Early Jurassic intrusive rocks from the Hogem Plutonic Suite are the most significant magnetic sources across the northernmost part of the QUEST area. The regional interpretation of magnetic domains suggests that the Hogem batholith related rocks extend further to the south than previously mapped. This is of exploration interest since numerous Cu-Au prospects (e.g., Lorraine) are associated with the Hogem batholith.

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APPENDIX

Potential Field Gravity and Magnetic processing

By Peter Kowakczyk, P. Geo.

Gravity data

The Geological Survey of Canada (GSC) gravity presented in this report was downloaded from the Natural Resources Canada (NRCAN) online data repository. GSC gravity data was downloaded from the 2km Canadian grid, and then interpolated down to a 500m grid cell size. This data was then merged with the Geoscience BC airborne gravity data released as the QUEST, QUEST SOUTH, and QUEST WEST data sets. Priority was given to the Geoscience BC Airborne gravity data as this has the highest resolution, and the GSC data was levelled to minimize differences between the GSC data and the Geoscience BC data. Note that the GSC data is primarily a ground gravity data set collected on variable station spacing on the order of 10km and the Geoscience BC airborne gravity is collected on a regular 2km flight line spacing. The two data sets do not merge exactly, a higher resolution of features is seen in the Geoscience BC data, but trends progress across the boundaries of the Geoscience BC data into the GSC data. Isostatically corrected bouger anomaly data is presented. This was selected as all the data sets had isostatically corrected data and some of the Geoscience BC airborne gravity data did not have bouger anomaly data. For interpreting geological features to depths of two or three kilometers, which is appropriate for mineral exploration problems, the isostatically corrected gravity data is easier to interpret as large regional anomalies due to variations in the thickness of the earth's crust are removed from the data.

The processing of the various derivative and tilt angle products was done using fourier filtering in the WinDisp geophysical analysis and map making program of Scientific Computing and Applications. This is a widely used program for processing gravity and magnetic data, with well tested and robust algorithms. For each derivative product, the individual source grids were processed separately and merged to prevent edge effects and artifacts along the stitch lines between grids. After merging the gridded data was reinterpolated to 100m grid cells to provide a smoothed image. These 100m cell grids were then presented as shadowed images, with illumination from the NW, NE and from above and saved as Geotiff images for analysis in ArcGIS.

A gravity layer extraction has also been done to prevent gravity anomalies that come from sources that are consistent with a source depth of 500m to 2500m depth. This is done using fourier filtering. The user should be aware that this is a process that removes high frequency anomalies that would come from depths less than 500m, and low frequency anomalies may come from depths greater than 2500m. However, it may still contain large, smooth, anomalies that come from a depth that is less than 500m, but which have the shape of deeper anomalies, and some large smooth anomalies that might have come from deeper sources but did not may be removed. Even with these ambiguities, depth filtering is a useful aid to interpretation. Note that no anomalies from deeper than 2500m will exist in the filtered results. However, a body with great depth extent but which exists close to surface will still present an anomaly caused by the parts of the body within the depth range of the layer extraction. No gravity layer extraction for depths less than 500m was done as the data does not contain high frequency components that would define near surface sources. This is a result of the frequency response of the airborne gravity meter used in the airborne surveys, and the wide station spacing of the ground gravity data.

Magnetic data

The magnetic data presented in this report is the GSC 200m Canadian magnetic grid downloaded from the NRCAN online repository. The gridded data was downloaded in a Geosoft grid format, in the desired NAD 83 UTM Zone 10N projection, with a default cell size of 274m x 274m. The various products included here have all been generated from this basic Residual Total Field (RTF) grid using this default cell size. The processing was done using fourier filtering in the WinDisp program of Scientific Computing and Applications. After being transformed to the target data presentation type each grid was further interpolated to 100m cells to make a visually smooth image. These 100m cell grids were then presented as shadowed images, with illumination from the NW, NE and from above and saved as Geotiff images for analysis in ArcGIS.

The project area is large enough that the direction of the ambient magnetic field varies significantly across the project area. To do a Reduction to the Pole (RTP) transform, it was necessary to use a varying direction of magnetization. This was done by processing overlapping 1 degree by 1 degree tiles with an appropriate inclination and declination in each tile, and smoothly merging them together to produce an RTP image of the magnetic field over the whole area. The user should note that a reduction to the pole will transform magnetic anomalies created by simple magnetic induction to anomalies as they would look at the north magnetic pole, they become symmetric and the effect of the earth's dipping magnetic field is removed. However, if significant remanent magnetization exists in a source body, then the final anomaly will still retain some of the character of a dipping magnetic field. In the study area, it has been noted that many volcanic rocks do in fact have significant remanent magnetization, so the shape of magnetic anomalies should be reviewed carefully when doing quantitative interpretation.

Magnetic layer extractions have been done for shallow (surface to 250m depth), intermediate (250m to 500m depth) and deep (500m to 2500m depth) layer responses. These are maps which contain magnetic data with a frequency response associated with source bodies at these depths. However, the user should be aware that there is leakage from shallow magnetic anomalies into deeper layer responses if the shallow body has a large smooth response appropriate for a deeper body. There is a fundamental ambiguity with regards to magnetic anomalies near surface sources can be spatially distributed to simulate the response from a deeper source body. However, deep sources cannot emulate shallow ones. So if an anomaly exists in a deep layer extraction, and not in a shallow one, then the source will be at least at the depth of the layer indicated. Similarly, shallow small targets cannot report to a deep layer.

There is in this data some along line striping of the images caused by poor interline levelling of the data. This has a high spatial frequency and largely reports to the shallow layer extractions. Thus the deeper layer extractions have a less noisy appearance and much high frequency magnetic clutter has been removed from them, while the deeper geologic response remains.
The data from each layer extraction has been processed to produce the following products:

- 1VD: First Vertical Derivative. This enhances and sharpens anomalies from smaller bodies, and makes it easier to follow the outcrop, or subcrop of the body. There is with each positive anomaly an associated negative part to the anomaly, and the exact shape of the anomaly is sensitive remanent magnetization if it is present.
- AS: Analytic Signal or Total Magnetic Gradient. This will produce anomalies along the edges of large bodies, or highs over narrow ones. It is not affected by the presence of remanent magnetization, and is always positive.
- TD: Tilt Derivative. This measures the tilt of the anomalous magnetic field and is insensitive to the amplitude of the magnetic anomaly. Thus it is not biased to strong or weak anomalies, and provides a normalized view of the edges of magnetic bodies or the strike of thin dyke like anomalies in a magnetic anomaly map.
- PG: Pseudogravity. The pseudogravity transform emulates a gravity field, thus the strength of an anomaly is related to the total magnetization of the source body. The untransformed magnetic field is produced by dipolar sources, and an anomaly falls off rapidly with distance from a source body. The pseudogravity transform emulates a monopole source, thus the fall off rates is slower and the area under the anomaly remains constant.
- HGM: Horizontal Gradient Magnitude. This is the amplitude of the horizontal magnetic gradient, taken in the direction of its maximum. It is a complement to the vertical derivative, and helps to map out contacts.

Data sources

Gravity Data

Citation 2015, Canadian Geodetic Information System, Gravity & Geodetic Networks Section, Geodetic Survey Division, Geomatics Canada, Earth Sciences Sector, Natural Resources Canada

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Aeromagnetic Data

Citation, 2015, Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada.