Development and Application of a Rock Property Database for British Columbia

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Introduction

Physical rock property data, systematically recorded and comparable in standard formats, are integral to successful interpretation of subsurface geology from geophysics. This project represents a beginning in building a useful database for British Columbia (BC). The data release is the result of a significant amount of work by Mira Geoscience Limited and the Geological Survey of Canada (GSC) to produce a standardized, high-quality set of nearly 900 000 data points for the province. A significant amount of work was required to bring all data to Rock Property Database System (RPDS) standards. The result was a significant 'in-kind' effort by Mira Geoscience and GSC staff that exceeded the budget of the project. The project would not have been possible without combined funding from Geoscience BC, Mira Geoscience, the Geological Survey of Canada, BHP Billiton, Terrane Metals and Teck Cominco. A significant amount of industry data remains to be added to the database.

Project 2006-015 started in October 2006, when Mira Geoscience was contracted by the Canadian Mining Industry Research Organization (CAMIRO) to assemble and organize physical rock property data for BC. A large amount of rock property data exists for the province but is in various hard-copy and digital formats, and archived at many locations across the country, thus making it difficult to amalgamate. One of the objectives of this project was to bring together all available data for BC into standard digitized formats on a common integration platform. The project focused on rock property data collected by the Geological Survey of Canada from various borehole surveys in the 1980s and 1990s, measurements related to mapping of BC basins, and the Targeted Geoscience Initiative and other recent surveys in the Nechako Basin.

The strategy was to compile the various rock property data for BC into the Rock Property Database System (RPDS), a database application developed over the last 8 years by a consortium of industry and government agencies, and managed by Mira Geoscience. Data delivered in this project are in two formats: 1) database files on DVD intended to be downloadable from BC Geological Survey's MapPlace, and 2) files accessible on 'RPDS' through the Mira Geoscience website. The database is an Oracle-based relational data management system that brings together geological and geophysical information, and facilitates interpretation of rock properties and corresponding geological description across geographic areas. This permits statistical and spatial characterization of the rock property environment for various ore deposit types in different geological settings. The significance of RPDS is that it provides a single repository for rock property data, as opposed to many disparate sources, thus allowing large-scale aggregation of data and in-depth analysis of rock property relationships. During the term of this project, public access to RPDS data through the Mira Geoscience website was considerably improved through a separate contract with the GSC.

Approximately 881 064 physical rock property measurements from wireline, drillcore and surface samples from across BC have been procured from both government and industry sources. These data have been entered into RPDS at Mira Geoscience, adding to the existing archive of more than 5 million rock property measurements. In addition to data archiving and management capabilities, RPDS also provides value-added summary tables of population statistics for various rock types across geographic areas. The summary tables for BC will be provided with the final project report. In addition, all data in RPDS are currently publicly available through an online Web interface at www.mirageoscience.com/rpds. All data from BC will be made available for the MapPlace website. The final report

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will include descriptions of the specific project deliverables and the project datasets; a summary of the RPDS application, including the generation of the statistical output tables; a description of the digital files; and all data on a DVD.

Project Data

Data Distribution

The Rock Property Database System currently houses 881 064 physical rock property records from borehole wireline, drillcore and surface samples within BC. Physical properties measured in boreholes include density, magnetic susceptibility, conductivity, resistivity, density count, gamma-ray count, induced polarization (IP), total field magnetic, spectral gamma-gamma ratio, self potential (SP), SP gradient, single-point resistivity, temperature and temperature gradient. All data have been entered into RPDS and meta-classifications, unit conversions, and co-ordinate system conversions have been applied, and general data-quality assessment and control completed. The following sections describe the datasets in more detail. Tables 1a–c summarize the BC data in RPDS. The spatial distribution of data collected from BC and entered into RPDS is shown in Figure 1.

Wireline Data

Borehole wireline data (Figure 1, open circles) from 23 holes, consisting of 198 logging runs between 1986 and 1994, were provided by the Borehole Geophysics Group at the Geological Survey of Canada in Ottawa. Mira Geoscience travelled to Ottawa to collect the digital and hard-copy data archived on multiple DVDs and more than 150 hand-written field logging sheets. Multiple DVDs were copied from GSC archives, which contained various ASCII-text files transferred from original logging tapes. These ASCII-text files contained raw and processed data per logging run and, where available, lithology files per borehole. Logging run metadata were photocopied from original hard-copy field logging sheets, which provided critical information pertaining to the logging runs as well as for deciphering raw data file names in order to associate the appropriate raw data with processed data files. Additional metadata were acquired from supplementary hard-copy documents, open file reports and personal communication with GSC contributors. Where available, hole trace and assay files were generated manually from hard-copy core logs, and paper maps were digitized to PDF format. Finally, data and metadata were formatted to RPDS import standards and entered into the system. This formatting involved applying geological and quality indicator classifications, performing unit and co-ordinate conversions, and completing minor data-quality control. Due to the multiple sources of information, a significant amount of work was required to prepare the data for entry into RPDS.

Surface Sample Data

Data on 13 554 new and recent surface samples (Figure 1, red circles) were supplied by GSC-Vancouver. This dataset contains mainly magnetic susceptibility and density measurements, with a small population of conductivity measurements. The data were provided as one large Excel spreadsheet. Prior to entry into RPDS, the data were classified and formatted to fit RPDS import standards. For example, magnetic susceptibility data were converted from 10^{-6} or 10^{-3} SI to SI, and density data were converted from kg/m^3 to g/cm^3. In some cases, rock codes and rock code descriptions were supplied in separate files. These rock descriptions had to be attributed and then master rock types assigned. Duplicate entries in the provided datasets were removed and unique sample IDs (Location ID) were assigned. Although RPDS uses an Excel spreadsheet for sample entry, each dataset required full reformatting prior to entry into the database system. A large part of the formatting was performed by R. Enkin's group at the GSC in collaboration with Mira Geoscience.

In addition to the surface sample data, 118 density and velocity measurements from the Sullivan deposit already existed in RPDS. These data are included in the output data files that will accompany the final report. The surface sample data are a very important part of the database, particularly because they cover a large areal extent of the province, compared to local borehole data. These data enable characterization of the density and magnetic susceptibility of mappable rock units.

Borehole Drillcore Data

Borehole drillcore data from the Mount Milligan Cu-Au porphyry project (Figure 1, blue circles) were provided courtesy of Terrane Metals Corp. The data were received as one Excel spreadsheet but needed a significant amount of reformatting and data preparation due to the large number of boreholes provided and data storage artifacts from the provider's own database system, which were inconsistent with RPDS standards. For example, the provider's database stored depth as a depth start and depth end range, whereas RPDS stores actual physical property data for samples at one depth value. As with the surface sample data, this dataset was attributed with rock code descriptions, master rock types were assigned, measurements were converted from 10^{-3} SI to SI, negative and zero values were removed, and unique sample IDs (Location ID) were assigned.

RPDS Application

General Overview

The Rock Property Database System (RPDS) is designed as an integration platform for combining geophysical and

Table 1. Summary of physical rock property data from British Columbia, collected and entered in RPDS, by **a)** data type, **b)** physical property, and **c)** location.

a) General data type

General data type	Count		
	Holes	Logging runs	Records
Borehole	23	198	854,851
Borecore Sample	179		12,541
Surface Sample			13,672
Total			**881,064**

b) Geophysical data summary

Parameter	Sample/borecore record count	Wireline record count		Total records
		Borehole count	Record count	
Density	2,483	12	19,064	21,547
Magnetic Susceptibility	23,644	19	127,516	151,160
Conductivity	27	4	11,956	11,983
Velocity	59			59
Resistivity		21	107,063	107,063
Density Count		8	26,637	26,637
Gamma Ray Count		17	55,101	55,101
Induced Polarization		11	50,122	50,122
Total Field Magnetics		10	55,551	55,551
Spectral Gamma-Gamma Ratio		20	45,856	45,856
Self Potential Gradient		11	55,459	55,459
Self Potential		11	53,979	53,979
Single Point Resistivity		10	55,976	55,976
Temperature Gradient		22	94,918	94,918
Temperature		22	95,653	95,653
Total Records	**26,213**	**198**	**854,851**	**881,064**

c) Data summary by location

Area of data acquisition	Data provider	Data type	Total records	Physical properties measured
Adams Lake	GSC-Vancouver (R. Enkin, C. Lowe, B. Anderson)	SS	559	M,D,C
Bowser & Sustut Basins		SS	1203	M,D
Cariboo		SS	1865	M,D
Chilcotin		SS	953	M,D
Coast		SS	81	M
Interior Plateau		SS	91	M
Kootenay Arc		SS	1268	M,D,C
Nechako		SS	6310	D,M
N. Cascades		SS	8	M
Omineca		SS	6	M
Queen Charlotte		SS	850	M,D
Rockies		SS	68	M
Skeena/Bulkley		SS	67	M
Thompson		SS	225	M,D
Sullivan Deposit	Previously in RPDS	SS	118	D,V
Mt. Milligan	Terrane Metals (D. O Brien)	BC	12,541	M
Chu Chua	GSC-Ottawa (J. Mwenifumbo)	BH	43,899	C,DC,IP,M,R,SG,T,TG
Equity Silver		BH	55,495	C,D,IP,M,R,SG,T,TG,GC
Goldstream		BH	80,762	DC,GC,IP,M,R,SG,T,TG
Highland Valley		BH	77,211	DC,GC,IP,R,SG,SP,SPG,T,TG,M
Lara/Buttle Lake		BH	170,971	DC,GC,IP,M,R,SG,T,TG
Myra Falls		BH	392,081	D,GC,M,MAG,R,SG, SP,SPG,SPR,T,TG
Sullivan		BH	34,432	C,DC,IP,M,R,SG,T,TG,GC,SPR

Data type abbreviations: SS, surface sample; BC, core borehole sample; BH, wireline borehole data

Physical properties measured' abbreviations: M, magnetic susceptibility; D, density; DC, density count; C, conductivity; R, resistivity; GC, gamma count; SG, spectral gamma-gamma; IP, induced polarization; SP, self potential; SPG, self potential gradient; T, temperature; TG, temperature gradient; V, velocity

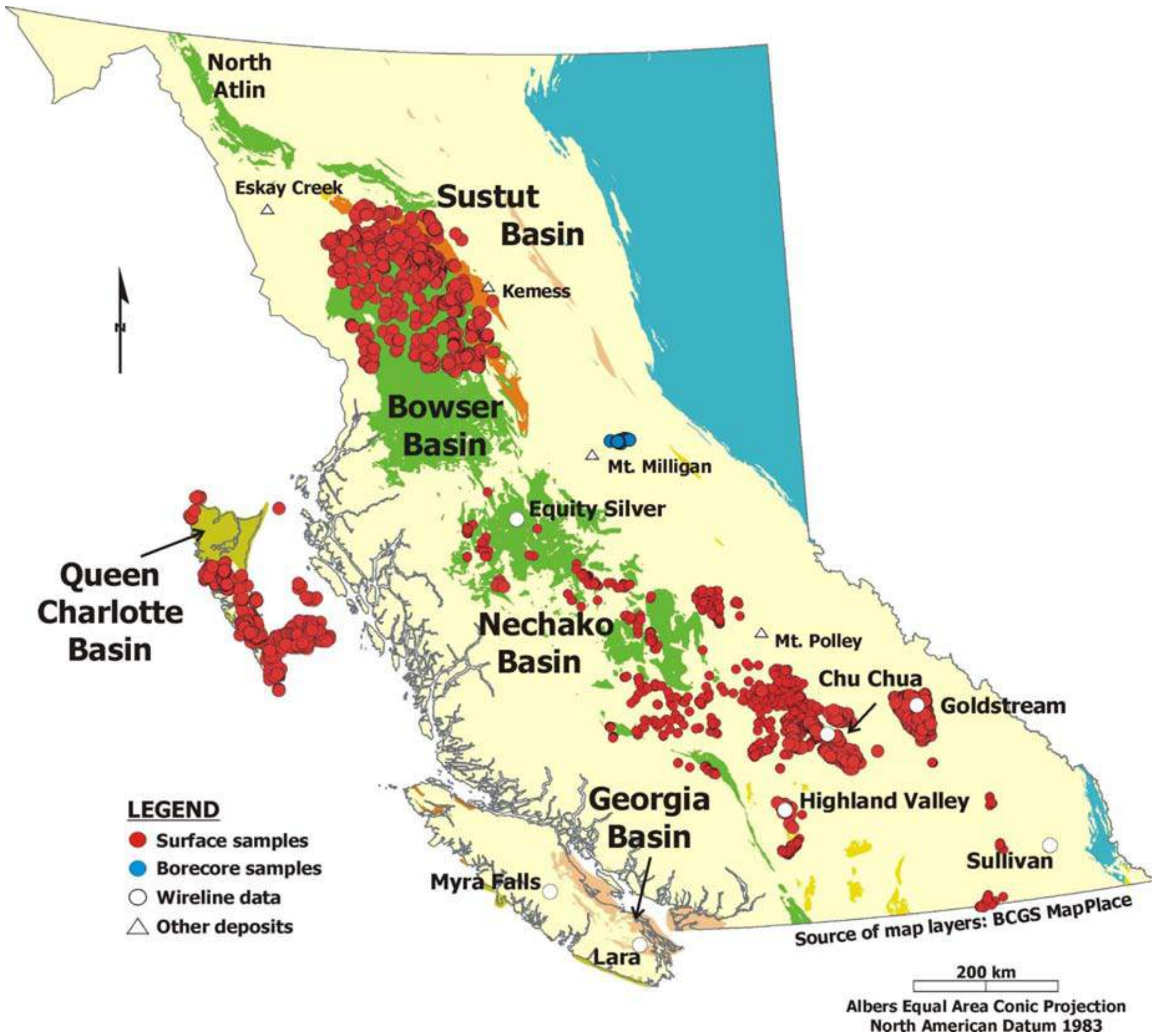

Figure 1. Spatial distribution of data from British Columbia entered in RPDS. The source of base layers is the BC Geological Survey MapPlace Web server. Map co-ordinates are in NAD83 Albers equal area conic projection. Surface samples are denoted by red circles, borehole drillcore samples by blue circles, and borehole wireline locations by white circles.

geological data to effectively query rock property statistics for specific rock types across geographic areas. This allows the user to answer such questions as “What is the average density of basalt in the Chilcotin Group?” or “What is the average resistivity of a rhyolite in a VMS-type deposit?” These types of questions are answered in RPDS by distillation of the large amount of data into manageable, interpretable, queryable data tables. Firstly, RPDS creates ‘geological intervals’ for common occurrences of geological information (a geological signature). This process is repeated at depth along the hole for each change in one of the geological variables. Then, for each interval, the physical property parameters are combined and population statistics calculated for that specific geological signature at that depth. The next phase of data distillation combines each common interval, further summarizing the data. Next, the area classification of each borehole is assessed and physical properties for all common geological intervals across all holes within the same geographic area are combined. Finally, this information is combined with sample data having the same geological signature for the same area. Therefore, all occurrences in any borehole or sample within the Bowser Basin area in BC are combined, providing, for example, one mean density value for a *Sandstone* with *Argillic Alteration* from the *Brothers Peak Formation* in the *Bowser Basin* area.

Data Model

Various tables in RPDS store information pertaining to all borehole and sample data entered into the database. This information includes physical property data and metadata related to the entire logging/sampling process (location, equipment, personnel, project descriptions, laboratory methods and processing/calibration history), as well as information related to geological units and associated geochemical and geotechnical data.

The storage of borehole wireline physical property data in RPDS is based on the concept of logging runs. Logging run data are stored in the Process Log Table, which contains the calibrated and processed logging run data for each borehole. These data are considered the 'live data' in RPDS and are used for calculating the population statistics. Raw data are stored elsewhere in the database for archival purposes only. The Process Log Table stores the physical property values from various depths as measured along the borehole. Since the depth intervals for each measurement may vary per logging run, it is important to normalize these values to a constant depth interval in order to correlate each of the parameters for different logging runs. This is performed in the Forced Interval Table of RPDS.

The Forced Interval Table interpolates the Process Log data for each physical property to a common reference sampling interval of 10 cm. Physical properties from the Forced Interval Table may be correlated since, as they are interpolated to the same depth, they represent measurements of the same rock sample.

In parallel, a significant amount of available laboratory measurements are stored in the Sample Table. This table accommodates the physical property data and all associated metadata from laboratory measurements of both drillcore samples and surface samples of varying origin.

Geological information for wireline, drillcore and surface sample data is stored separately in the database, in the Geological Property Table. This table includes information on lithology, alteration, formation, geological age and assay analyses, and includes space for storing core photos that are rapidly visible on-the-fly. Lithology is stored as the specific lithological unit name, using the local nomenclature from the data source. However, in addition to this name, a geological 'Master Lithology Classification' scheme has been developed to provide a more general hierarchical description of the unit. This allows for consistent and more practical data querying within the RPDS environment. The geological data are combined with the borehole and sample data to produce the comprehensive Physical/Sample Properties Table.

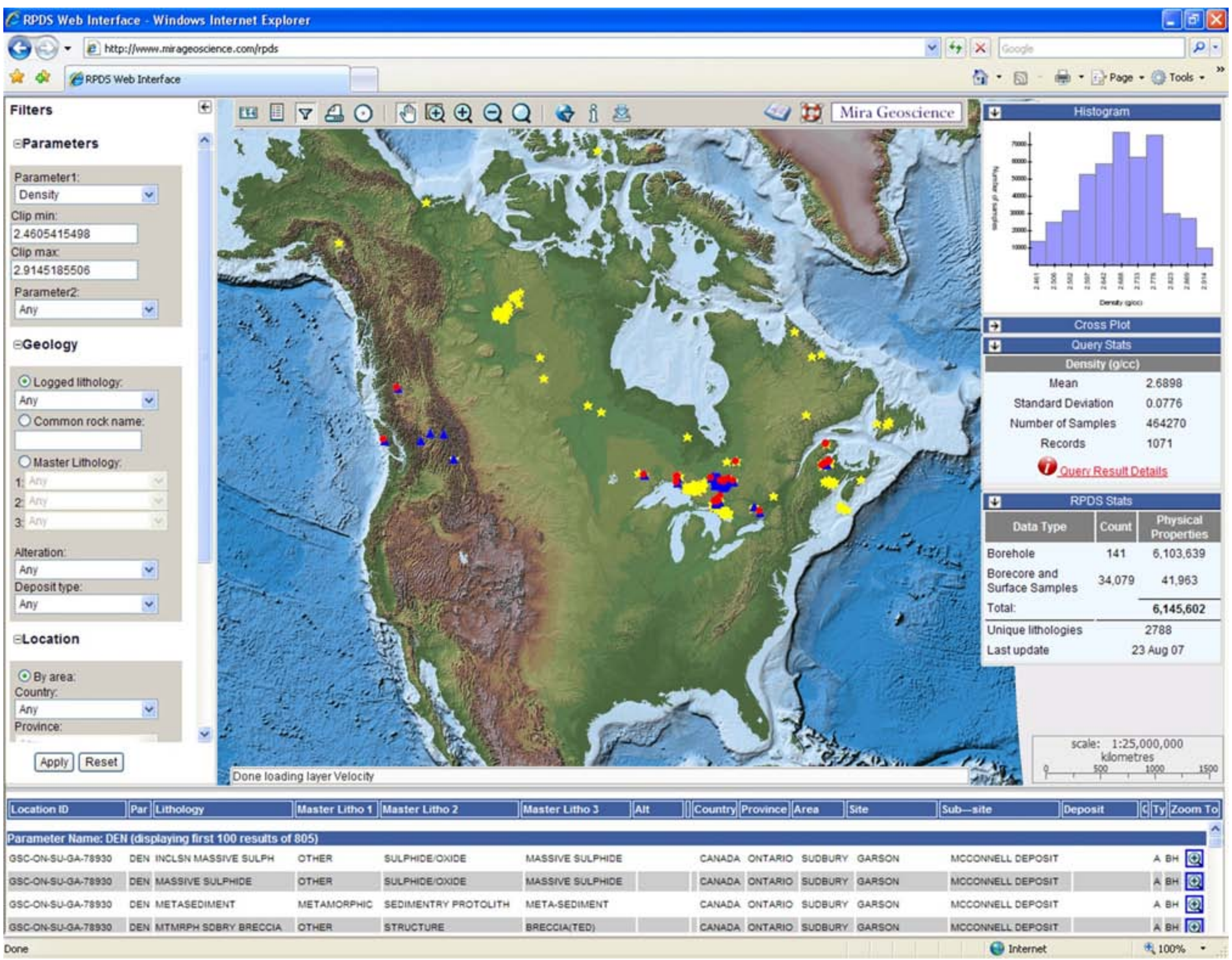

Figure 2. Rock Property Database System (RDPS) Web interface.

The Physical/Sample Properties Table is a composite table where logging-run data taken from the Forced Interval Table and sample data taken from the Sample Table are correlated with geological information. This is also where population statistics of physical properties as a function of geological classification are pre-stored for rapid query. This table lists, for each borehole, the mean values, standard deviations and sample counts for physical properties per unique lithological interval encountered in the borehole. At present, population statistics are calculated on the following 16 parameters, although others can be added to this list: gamma-ray, potassium, uranium, thorium, density, magnetic susceptibility, conductivity, temperature, temperature gradient, induced polarization (IP), resistivity, self potential (SP), SP gradient, velocity, neutron porosity and caliper. This table is further summarized in the Regional Properties Table.

The Regional Properties Table is the final step in the data distillation process, whereby physical property data are summarized and stored by combining mean physical property values from the same regional area that possess a common geological fingerprint (i.e., the same formation/lithology/alteration combination). Therefore, the physical properties of all occurrences of one geological unit in a borehole are averaged and combined with any other occurrences of that geological combination in the same area. As mentioned above, this provides one series of statistical summary values (mean, minimum, maximum, standard deviation, median, number of samples) for each physical property, for each unique geological combination in the same geographic area.

Web Interface

All data within RPDS are publicly accessible through a map-based Web query interface at http://www.mirageoscience.com/rpds. The Web interface is designed to communicate with the RPDS Oracle database to provide rapid, up-to-date query results on population statistics, including histograms, multiparameter crossplots and metadata. Queries can be refined by physical property parameter, geological parameters, location information, location type (wireline vs. drillcore vs. surface sample measurements) and data quality. The map interface also includes a series of pre-rendered map layers for rapid visualization. These layers include base maps, geological maps and various symbolized layers showing the data distribution per physical property parameter. In addition, all data and selected metadata can be downloaded directly from the website using the data downloading tools, which provide pre-rendered Log View plots for borehole data visualization prior to download and various file-format export options. Finally, complete help documentation and a step-by-step tutorial on interface functionality are available through the interface.

Case Study of Mount Milligan Porphyry

Terrane Metals Corp. contributed 12 541 measurements of magnetic susceptibility from 180 boreholes, along with geological descriptions and corresponding 2-D and 3-D models. Samples were measured every 1–2 m down each borehole. From these data and local geophysical surveys, an analysis was done of the application of magnetic susceptibility. The recommended steps of analysis are summarized below. Illustrations of these steps are included in the final project report.

Step 1: Assemble local and regional magnetic surveys: High-resolution surveys (<200 m line spacing) are preferred.

Step 2: Gather the corresponding surface geology: Locally, intrusions such as the Mt Milligan monzonite can be correlated with magnetic anomalies.

Step 3: Assemble representative cross-section(s) of the deposit geology: Before modelling the geophysics, it is necessary to have a good integration of the geology and an understanding of the deposit model.

Step 4: Assemble corresponding cross-section(s) of mineralization and alteration: As best as possible, there is a need to define the geophysical attributes of the deposit halo. This understanding starts with a 2-D and 3-D characterization of the mineralization and associated alteration zonation.

Step 5: Assemble spreadsheets of magnetic susceptibility data with location and geology of each sample: Each property measurement requires an associated location and rock description, preferably with associated major and accessory minerals.

Step 6: Understand the behaviour of magnetic susceptibility:

a) Define the ranges and distribution of the susceptibility for different rock types and alteration assemblages.
b) Identify unique ranges that can be distinguished from a large dataset. Are there unique physical property ranges for mineralized rocks?
c) Are there any relationships between susceptibility and mineralogy? Can susceptibility act as a proxy for mineral abundance?
d) Findings: Rock types have bimodal distribution of magnetic susceptibility. There is an absence of systematic patterns.

Step 7: Examine the variation of magnetic susceptibility in borehole logs. They found that the highest magnetic susceptibilities are with magnetite associated with potassic-altered andesite adjacent to the monzonite intrusion. Unaltered andesite has low susceptibility. Potassic alteration in the monzonite has moderate susceptibility related to biotite and minor magnetite.

Step 8: To examine the spatial relationships of magnetic susceptibility, the physical properties are incorporated into inversion models. Modelling is done in the following three stages:

1) Construction of a synthetic model: The exercises by Mitchinson and Phillips (2008) illustrated how synthetic models can be used to show expectations of detectability as target contrast, size and depth are changed. A series of synthetic models was constructed:
   a) The mineralized stock has magnetic susceptibility of 32.3 x 10^{-3} SI, compared to a background of 0.68 x 10^{-3} SI.
   b) Forward modelling of the distribution of magnetic susceptibility data results in an annular geometry. The model uses a mesh of 2525 m by 2325 m, with cell sizes of 25 m on each side.
   c) An unconstrained synthetic model inversion generates a cone of anomalous magnetic susceptibility that approximates the location of the intrusive stock. Higher magnetic susceptibility values are at the top of the model and lower values at the bottom. Models indicate magnetic susceptibility values similar to what was measured in boreholes.
   d) Experimentation with reduced contrast, smaller targets and burial at 150 m illustrate that detection would be more difficult. At depth, a similar target could be detected but the target would be smoother with less definition. Targets of small size could merge into the background. Deposits of similar size but lower contrast could be identified from surface surveys.
2) Construction of a constrained inversion: Constrained inversions require significant input by geologists and communication with the geophysicist. The Mount Milligan demonstration provided a model of the deposit geology and the spatial distribution of magnetic susceptibility in boreholes. A series of inversion models was constructed, with each case based on the following specific constraints:
   a) geological reference model for the monzonite stock
   b) geological reference model for the stock margin
   c) geometry of the magnetic body, assuming uniform magnetic susceptibility, that provides significant detail on the shape of the magnetic altered margin of the stock
   d) the geological contact (note that the shape of the magnetic anomaly changes considerably compared to the unconstrained model)
   e) drillhole-controlled boundaries of the magnetic susceptibility (the borehole data significantly change the configuration of magnetic bodies to steep planar zones)
   f) interpolated reference and bounds where values are kriged (this version also shows a steep geometry that corresponds to faults and dikes)

Conclusions from the Demonstration Study

The study has demonstrated that a limited amount of data can be informative. However, the data need to be well correlated and rock types identified. It is essential to examine and understand the relationship between rock physical properties and geology, alteration and mineralization. This demonstration shows that physical properties can be used to refine inversions in many different ways. As well, synthetic models can be used to test whether the geophysical method can be used to detect a deposit. The similarity of the different methods to constrain inversions implies that the data are good and the method robust. The constraint methodology depends on the inversion methodology, the amount and type of data and the exploration goal. The full project report and data are expected to be available on MapPlace by January 2009.

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