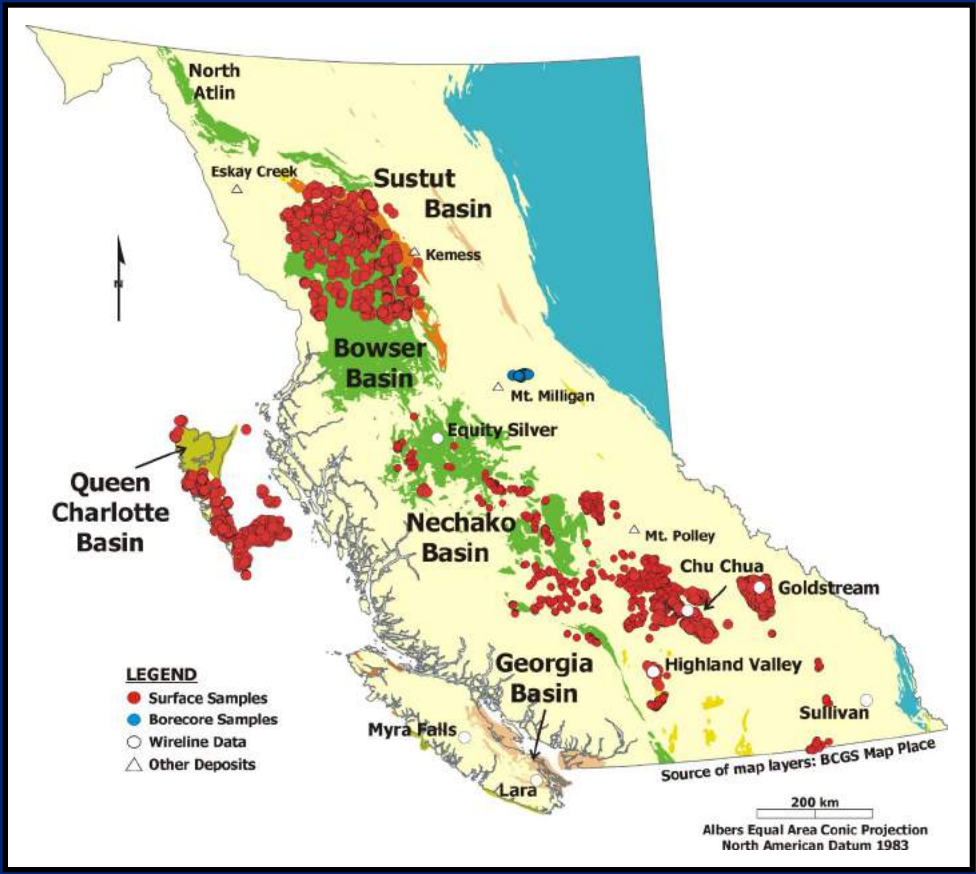
Geoscience BC

Geoscience BC Report 2008-9



Final Report for Geoscience BC Project 2006-015

Development and Application of a Rock Property Database for British Columbia

Mira Geoscience

Geoscience BC Report 2008-9

Development and Application of a Rock Property Database for British Columbia

Mira Geoscience

Part 1:
Development and Application of a Relational Rock Property Database System for British Columbia

Part 2:
Application of Physical Rock Property Data for British Columbia: Mt. Milligan Case Study

Mira Geoscience

... modelling the earth

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Development and Application of a Relational Rock Property Database System for British Columbia

Geoscience BC

Report #: 2008-9a

Geoscience BC Project #: 2006-015

CAMIRO Project #: 06-E02

November 7th, 2008

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1. Introduction

Physical rock property data, systematically recorded and comparable using standard formats, is integral to successful interpretation of subsurface geology from geophysics. This project represents a foundation in building a useful database for British Columbia. This data release is the result of a significant amount of work by Mira Geoscience and the Geological Survey of Canada to produce a standardized, high quality dataset of nearly 900,000 data points for the province. A significant amount of industry data remains to be added to the database.

In April 2006, CAMIRO submitted a Proposal for 'Development of a Rock Property Database for BC' to Geoscience BC. In August 2006, the Proposal was accepted after confirmation that a significant amount of data existed to be entered into the database. Project 2006-015 started up in October, 2006 when Mira Geoscience was contracted by the Canadian Mining Industry Research Organization (CAMIRO), for a one year project involving the assembly and organization of physical rock property data for the Province of British Columbia. A large amount of rock property data exist for BC, however this data was in various hardcopy and digital formats, archived at many locations across the country 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 related to borehole surveys from the 1990's, mapping of BC basins, TGI-3 program, and recent surveys in the Nechako Basin.

The strategy was to compile the various rock property data for BC into "RPDS" (Rock Property Database System), a database application developed over the last 9 years by a consortium of industry and government agencies, and managed by Mira Geoscience. Data delivered in this project are in two formats: (1) summary database files on DVD to be downloadable from Map Place and (2) files accessible from the Mira Geoscience server through the RPDS website. RPDS is an Oracle-based relational data management system, which 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 Mira Geoscience's website was considerably improved through a separate contract with the GSC.

Approximately 881,064 physical property measurements from borehole wireline, borecore, and surface sample data from across BC have been procured from both government and industry sources. This data has been entered into RPDS at Mira Geoscience, adding to the existing archive of greater 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 are included on the DVD provided with this report. In addition, all data in RPDS are currently publicly available through an online web interface at: www.mirageoscience.com/rpds.

A significant amount of work was required to bring all data to 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.

The remainder of this document describes the specific project deliverables, a description of the project datasets, a summary of the RPDS application including the generation of the statistical summary output tables, as well as a description of the digital files included on the DVD with this report.

2. Project Deliverables

Deliverables provided throughout the duration of the project timeframe:

1. Abstract and location map at project start (Oct. 2006)
2. Progress report (Nov. 2006)
3. Poster presentation at Roundup 2007 (Jan. 2007)
4. Entry of all available data for BC into RPDS (Oct. 2006-Jan.2008) and availability of data through the web interface on the Mira Geoscience web server.

Final deliverables are:

5. A workshop during Roundup 2008 for geoscience and industry users on how to access, use and apply the database (Jan. 2008). The workshop outline (Appendix 1) and workshop proceedings are included on the DVD with this data release (Appendix 2).
    a. Demonstration of the database system (presented by Sharon Parsons).
    b. An application study on how to analyze the data and to apply it to a field problem in the Mt. Milligan area (UBC study - presented by Nigel Phillips and Dianne Mitchinson).
6. A summary report formatted to Geoscience BC standards to be submitted as a report on field activities (Nov. 2008).
7. A final report in digital format including: original input data from all sources for British Columbia with ready access to metadata, and physical rock property data and its correlative geology (this document and accompanying files).
    a. A copy of the original input data from all parties re-formatted and organized into a manageable folder structure.
    b. Copies of various summary tables generated by RPDS in Microsoft Excel and Access format. The summary tables include: (a) general information metadata tables describing the characteristics of the BC data and (b) statistical summary compilations of the physical rock properties of all boreholes/samples.

3. Project Data

3.1. Data Distribution

RPDS currently houses 881,064 physical rock property records from borehole wireline, borehole drillcore and surface sample data within British Columbia. Physical properties measured in boreholes include: density, magnetic susceptibility, conductivity, resistivity, density count, gamma ray count, IP, total field magnetics, spectral gamma-gamma ratio, SP, SP Gradient, single point resistivity, temperature, and temperature gradient. All data have been entered into RPDS and meta-classifications, unit conversions, and coordinate system conversions have been applied, as well as general data quality assessment and control. The following sections describe the datasets in more detail. Tables 1a, 1b, and 1c summarize the BC data in RPDS. The spatial distribution of data collected from BC and entered into RPDS is shown in Figure 1.

3.1.1. Wireline Data

Borehole wireline data (Figure 1, open circles) from 23 holes consisting of 198 logging runs, logged from 1986-1994, were provided by the Borehole Geophysics Group at the Geological Survey of Canada in Ottawa. Mira Geoscience traveled to Ottawa to collect the digital and hardcopy data archived on multiple DVDs and over 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 hardcopy logging field 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 was acquired from supplementary hardcopy documents, open file reports, and personal communication with GSC contributors. Where available, hole trace and assay files were generated manually from hardcopy corelogs 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 coordinate conversions, and 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. An additional 8 holes logged by the

GSC in the Fraser Delta region (data largely for geotechnical purposes) were not entered at this point in time as the data was missing critical information such as processed data files and corresponding geological rock descriptions.

3.1.2. Surface Sample Data

Originally, physical property measurements from 3,666 surface samples were provided by the Geological Survey of Canada in Vancouver from various areas across BC. The data were formatted and entered into RPDS. In a later phase of the project, new surface sample data totalling 13,554 samples (Figure 1, red circles) were supplied by the GSC-Vancouver which included an updated version of the previously supplied data. The older data were then deleted from the database and the new data entered. This new dataset contained mainly magnetic susceptibility and density measurements with a small population of conductivity measurements. The new 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 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 lithologies 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 Randy Enkin's group at the GSC in collaboration with Mira Geoscience.

In addition to the surface sample data supplied for this project, 118 density and velocity measurements from the Sullivan Deposit already existed in RPDS. This data is included in the output data files provided with this report.

The surface sample data is a very important part of the database, particularly because it covers a large areal extent of the province, compared to local borehole data. This data allows us to characterize the density and magnetic susceptibility of mappable rock units.

3.1.3. Borehole Core Data

The borehole drillcore data (Figure 1, blue circles) were provided courtesy of Terrane Metals Corp. The dataset was received as one Excel spreadsheet but needed a significant amount of reformatting and data preparation due to the large number of boreholes provided and to data storage artefacts 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. Similarly to the surface sample data, this dataset was attributed with rock code descriptions, master lithologies assigned, measurements converted from 10^{-3} SI to SI, negative and zero values were removed, and unique sample IDs (Location ID) were assigned.

(a)

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 (Randy Enkin, Carmel Lowe, Bob 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 (Darren O'Brien)	BC	12,541	M
Chu Chua	GSC-Ottawa (Jonathan 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

Table 1. Distribution of data from BC collected and entered into RPDS summarized by (a) data type, (b) physical property, and (c) location. *SS-surface sample, BC-borecore sample, BH-borehole wireline data. †M-magnetic susceptibility, D-density, DC-density counts, C-conductivity, R-resistivity, GC-gamma counts, SG-spectral gamma-gamma, IP-induced polarization, SP-self potential, SPG-self potential gradient, T-temperature, TG-temperature gradient, V-Velocity.

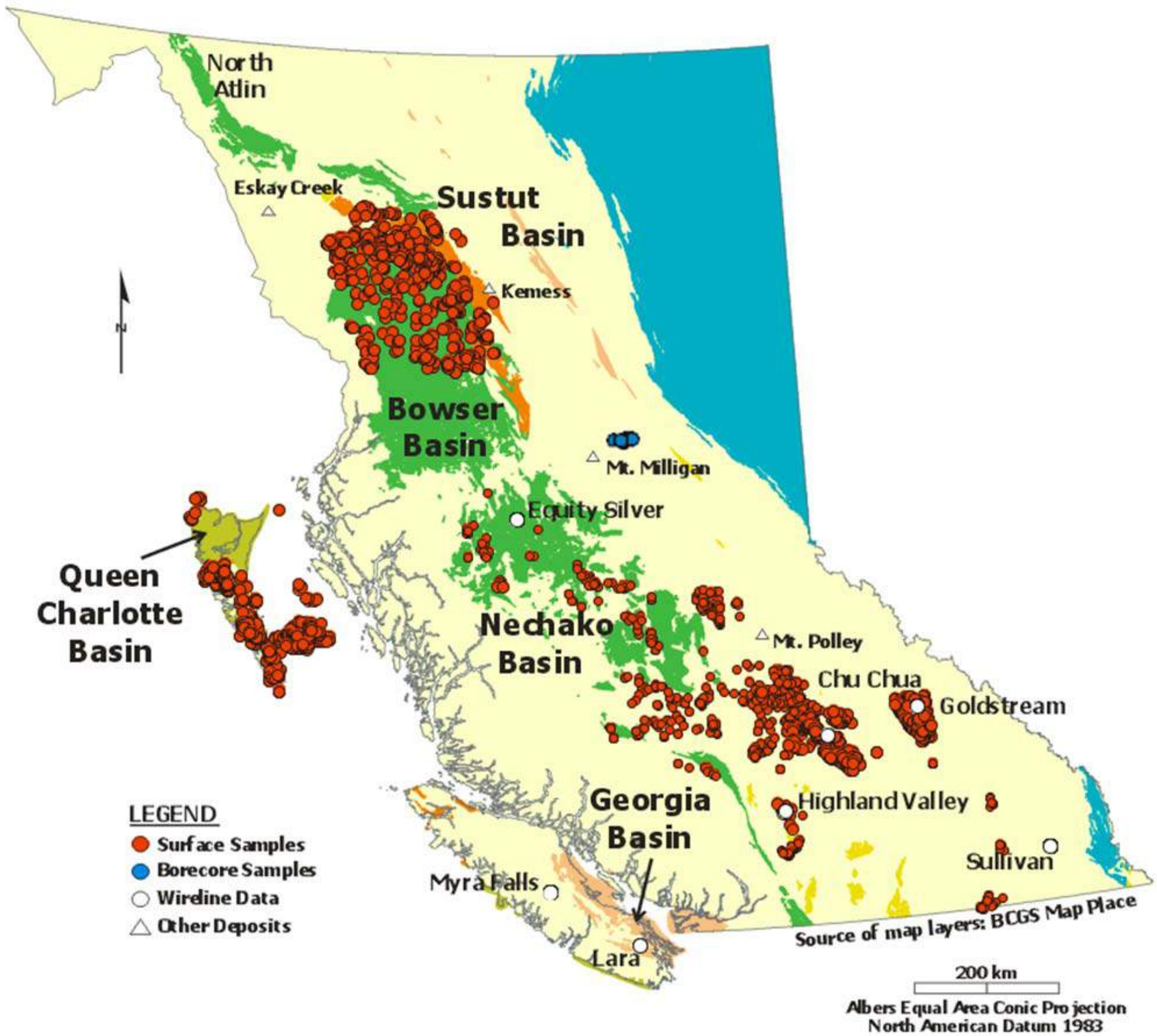

Figure 1. Spatial distribution of data from BC entered in RPDS. The source of base layers is the BCGS Map Place web server. Map coordinates are in NAD83 Albers equal area conic projection. Surface samples are denoted by red circles, borecore samples by blue circles, and borehole wireline locations by white circles.

3.2. Data on DVD Archive

This section summarizes the data contained on the DVD included with this report (Appendix 2). Within the root directory 'Geoscience BC – Archive', data have been organized into three sub-directories: ‘Input Data’, ‘Output Statistical Summary Tables’, and ‘Posters & Presentations’ (Figure 2).

1. Input Data - contains three sub-directories organized by data type: ‘Borehole-Wireline Data’, ‘Borehole-Core Sample Data’, and ‘Surface Sample Data’.
    a. ‘Borehole – Wireline Data’ – contains a series of sub-directories organized by borehole name. Each borehole directory is divided into further sub-directories containing the formatted data entered into RPDS as follows:
        i. AsciiFiles – lithology logs and look-up tables ± formation ± assay ± hole trace
        ii. LiveRunData – default logging runs
        iii. MetaData – Excel files containing borehole and logging run metadata, which were manually entered into RPDS.
        iv. ZipFiles – compressed ZIP files of a) all raw data acquired for that borehole and b) all processed data available for that borehole in addition to the default logging runs.
    b. ‘Borehole – Core Sample Data’ and ‘Surface Sample Data’ – each contain two further self-explanatory sub-directories: ‘Original Files from Source Provider’ and ‘Import Files for RPDS’.
2. Output Summary Tables
    a. Metadata_BHBC.xls - General metadata information entered into RPDS for each borehole site from both wireline and borecore data types.
    b. Metadata_Data_SS.xls - General metadata information and actual physical property data entered into RPDS for each surface sample site.
    c. RegionalProperties_BHBC.xls - Physical property population statistics from borehole wireline and borecore data.
    d. RegionalProperties_SS_*.xls (4 files) - Physical property population statistics from surface sample data per parameter. Four files representing the four physical properties measured on surface samples: conductivity, density, magnetic susceptibility, and velocity.
    e. Master_Lithology.xls - Summary of unique lithologies per area with Master Lithology Classification applied.

f. GeoscienceBC_data_deliverables.mdb - Microsoft Access database containing the 8 files listed above as database Tables.

3. Poster & Presentations

    a. Poster_Roundup07.cdr - copy of the poster prepared for Roundup 2007 in CorelDraw 9 Format
    b. Poster_Roundup07.pdf - copy of the poster prepared for Roundup 2007 in Portable Document Format
    c. RPDSDemo_Roundup08.ppt - copy of the PowerPoint presentation presented at the Rock Properties Workshop at the Roundup in 2008. The presentation was followed by a live demonstration of the RPDS web interface.
    d. Folder: RoundUp08 - Rock Properties Workshop - copies of all presentations presented at the Roundup Workshop, including abstracts and other files printed as part of the Workshop handouts.

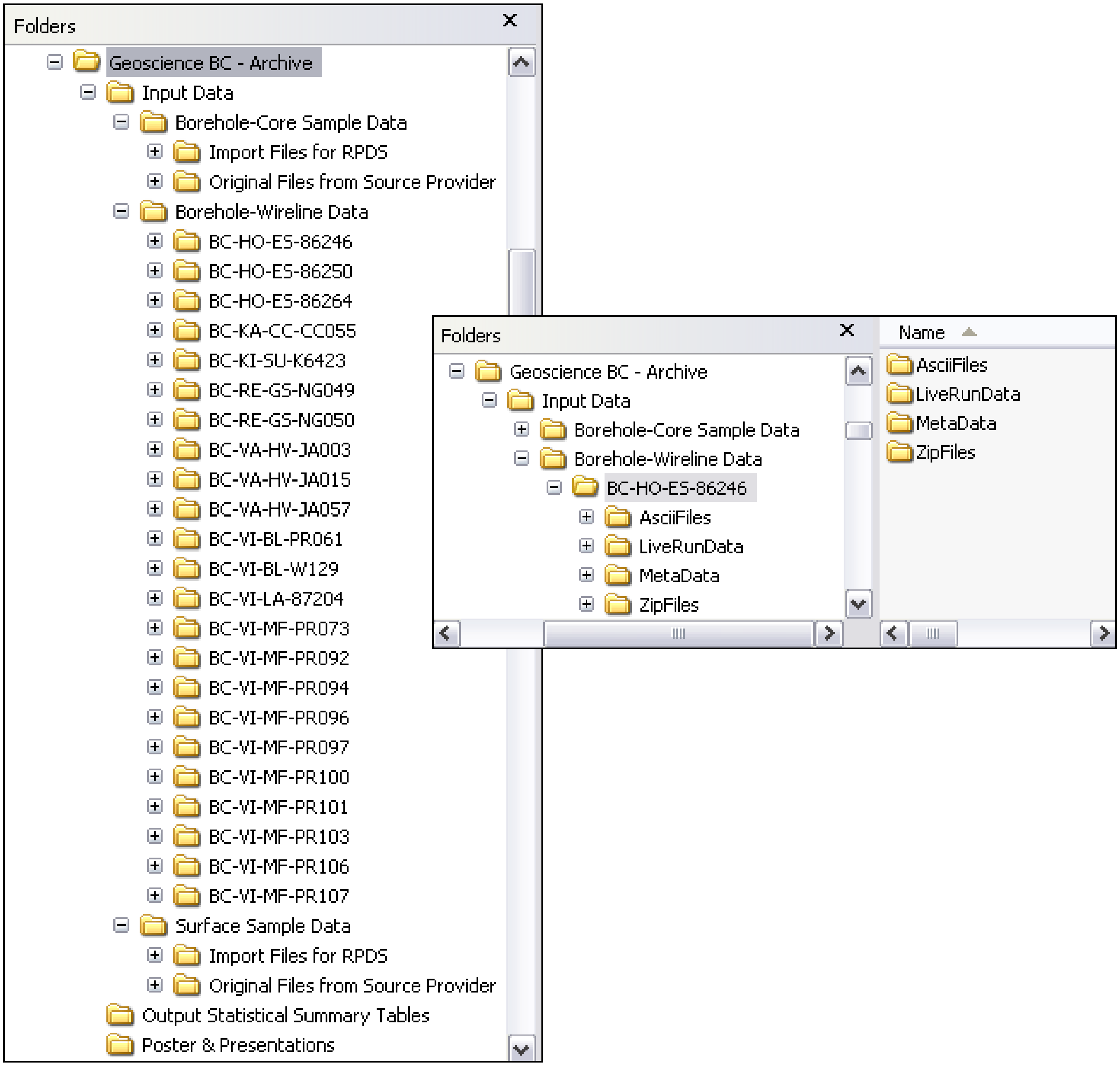

Figure 2. Directory structure of data contained on the DVD included with this report. Inset shows organisational structure of borehole wireline data.

4. RPDS Application

4.1. General Overview

RPDS is designed to act as an integration platform to combine geophysical and geological data in order to effectively query rock property statistics for specific rock types across geographic areas. This allows for answering questions such as: What is the average density of basalts in the Chilcotin area? 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. Figure 3 illustrates this distillation process showing physical property logs for a theoretical borehole at depth including the associated lithology, formation, and alteration information. Firstly, RPDS creates “geologic intervals” for common occurrences of lithology, formation, and alteration type (a geologic signature). For example, the first geologic interval is L1-F1-A1, the second is L2-F1-A2, and so on. 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, calculating population statistics for that specific geological signature at that depth. The next phase of data distillation combines each common interval, for example, all intervals with an L2-F1-A2 geologic signature (yellow zones on Figure 3) are combined, further summarizing the data. Next, the area classification (Country-Province-Area-Deposit) of each borehole is assessed and physical properties for all common geologic intervals across all holes within the same geographic area are combined. Therefore physical properties of rocks with L2-F1-A2 signatures in the Sudbury deposit will not be combined with those having the same L2-F1-A2 signature in the Sullivan deposit. Finally, this information is combined with the sample data having the same geological signature for the same area. Therefore, all occurrences of L2-F1-A2 in any borehole or sample within the Bowser basin area in British Columbia 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.

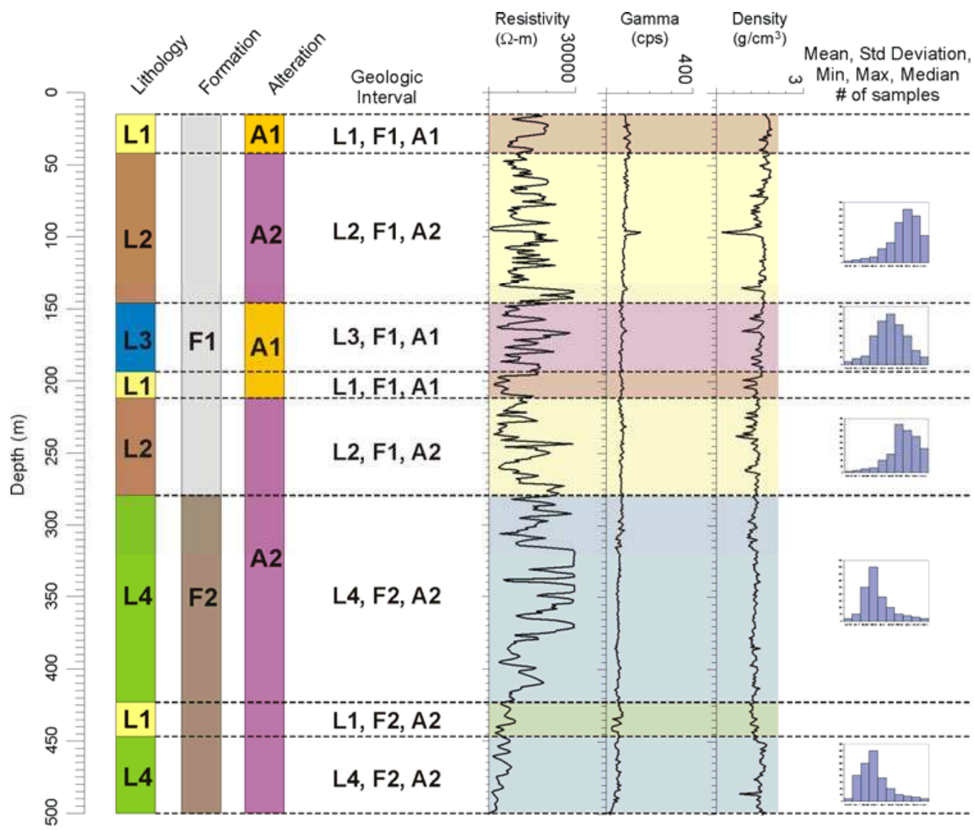

Figure 3. Schematic diagram of a theoretical borehole showing the data distillation process performed in RPDS.

4.2. 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 simplified data model showing the sequence of tables used to generate the summary statistics described in the previous section is shown in Figure 4.

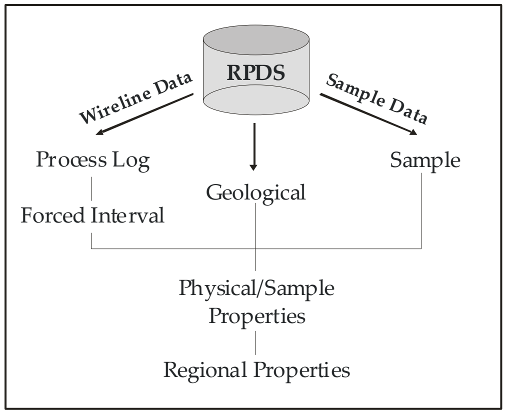

Figure 4. Schematic diagram of the simplified RPDS data model, leading to the generation of the Regional Properties summary table.

The storage of borehole wireline physical property data in RPDS is based on the concept of logging runs. Logging run data is stored in the Process Log Table, which contains the calibrated and processed logging run data for each borehole. This data is considered the "live data" in RPDS and is used for calculating the population statistics. Raw data is 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 10cm. 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 borehole core samples originating from boreholes, and surface samples of varying origin.

Geological information for borehole wireline, borecore, and surface samples are stored separately in the database in the Geological Property Table. This table includes information on lithology, alteration, formation, geologic age, assay analyses, as well as space for storing core photos which 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 naming, 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 is combined with the borehole and sample data to produce the comprehensive Physical/Sample Properties Table.

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 lithologic interval encountered in the borehole (as described in Section 4.1). 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, IP, resistivity, self potential, self potential 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 where physical property data is 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, min, max, standard deviation, median, number of samples) for each physical property, for each unique geological combination in the same regional geographic area. Data for BC represented in the Regional Properties Table is included on the DVD provided with this report (Appendix 2).

4.3. Web Interface

All data within RPDS are publicly accessible through a map-based web query interface at: http://www.mirageoscience.com/rpds (Figure 5). 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 cross-plots, and metadata. Queries can be refined by physical property parameter, geological parameters, location information, location type (wireline vs. core vs. surface sample) 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 visualisation prior to download and various file format export options. Finally, complete help documentation and a step-by-step tutorial on interface functionality is available through the interface.

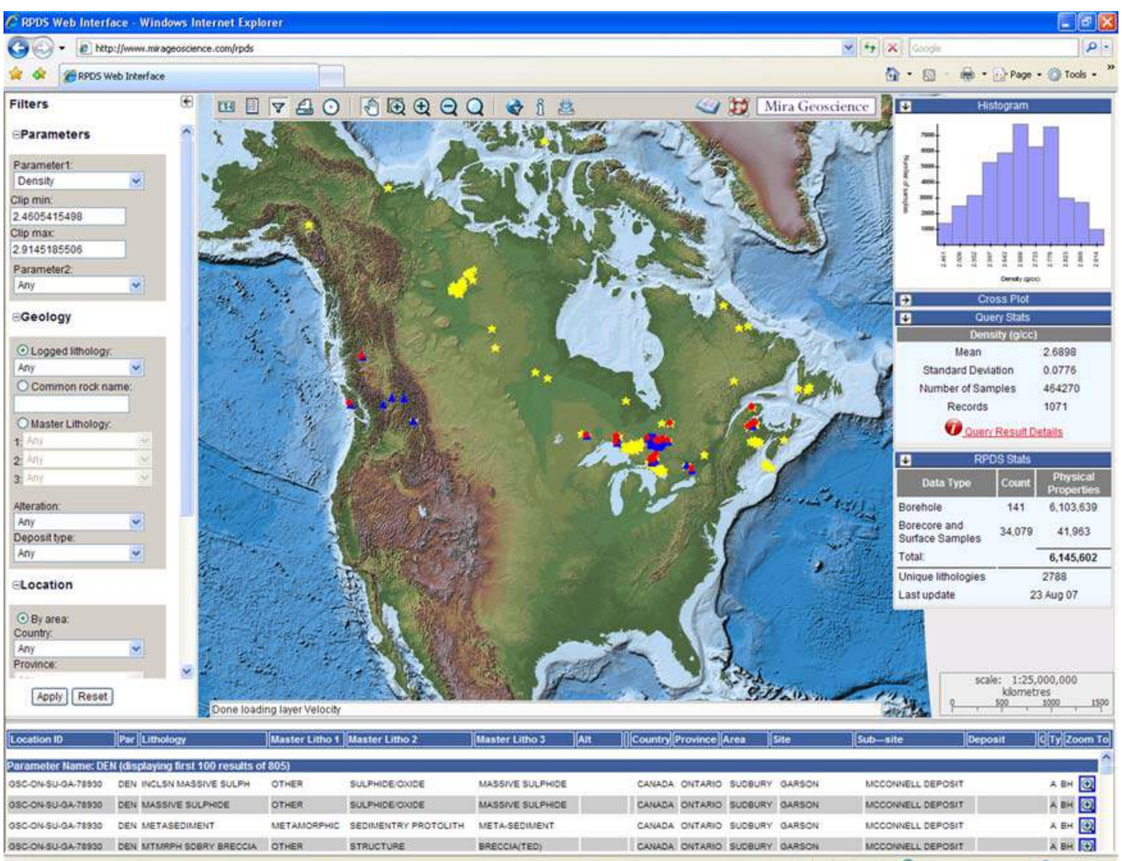

Figure 5. RPDS web query interface displaying the results of an example data filter.

5. Application Study

The University of British Columbia Geophysical Inversion Facility (UBC-GIF) compiled a characterization of the rock property environment of the Mt. Milligan ore deposit, using data from RPDS, in order to demonstrate the effectiveness of using physical rock property data in exploration models. The results of this study were presented as part of the Rock Properties workshop at Roundup 2008. Presentations from Nigel Phillips and Dianne Mitchinson are included in the conference proceedings on the data DVD (Appendix 2). A written summary of these two presentations, compiled by Tom Lane of CAMIRO, is provided in a separate report: Geoscience BC Report 2008-9b.

Appendix 1 - Rock Properties Workshop Outline

Short Course / Workshop for ROUNDUP 2008

Sunday January 27, 2007

Westin Bayshore Hotel Conference Centre

Salon 3

Vancouver, BC

Extracting Geology from Geophysics and the Application of Physical Rock Properties to Improve Exploration Targeting

Participants: CAMIRO, Mira Geoscience, University of British Columbia MDRU and GIF, Geological Survey of Canada, DGI, Schlumberger, Geoscience BC, BC Geophysics Society

Morning Session: Principles and Tools

8:20 to 8:30	Introduction – Tom Lane, CAMIRO
8:30 to 9:10	Overview of Borehole Geophysics: Advances in the Utilization of Physical Properties –*Unlocking knowledge and savings opportunities from exploration through production mining* – Mark Hammer, DGI Geoscience Inc.
9:10 to 9:50	Borehole Gravity Applications in the Petroleum Industry – Harold Pfutzner, Schlumberger
9:50 to 10:10	Coffee Break
10:10 to 10:40	Use of Rock Properties to Refine Inversions – Nigel Phillips, Mira Geoscience,
	Nick Williams, UBC and Dianne Mitchinson, UBC
10:40 to 11:10	Rock Properties and Drill Hole Targeting – John McGaughey, Mira Geoscience
11:10 to 11:30	Panel Discussion / Q&A: Use and Value of Rock Property Data – Morning Speakers
11:30 to 12:30	Lunch

Afternoon Session: Case Studies

12:30 to 1:00	Rock Property Database System: A Rock Property Data Integration Tool for BC – Sharon Parsons, Mira Geoscience
1:00 to 1:15	Rock Property Measurement and Compilation – Randy Enkin, GSC
1:15 to 1:50	Regional Applications to Models of Subsurface Structure - Mapping – Mike Thomas, GSC
	with R.G. Anderson, R. Enkin, K. Ford, P. Keating, C.Lowe, M. Pilkington, GSC
1:50 to 2:20	Improving Exploration Through Physical Property Analysis and Modelling: Example form Mt. Milligan Cu-Au Deposit – Dianne Mitchinson, UBC and Nigel Phillips, Mira Geoscience
2:20 to 2:40	Coffee Break

2:40 to 3:10	Synthetic Model Testing and the Titan 24 Distributed Acquisition Results at Kemess North: a Case History Leading to a New Discovery at the Kemess North Copper Gold Porphyry - Jean LeGault, Quantec Geoscience
3:10 to 3:40	Borehole Geophysics applied to Athabasca Basin Geology, Alteration and Uranium Mineralization - EXTECH IV Study – Jonathon Mwenifumbo, GSC
3:40 to 4:20	High Resolution Geological Interpretation and Regional Characterization as Developed from Comprehensive Physical Rock Property Analysis, Fort a la Corne, Saskatchewan, Canada – Susanne MacMahon, Innovation Geoscience, Shawn Harvey, Shore Gold, Chris Deisma, DGI Geoscience, Roxanne Leblanc, Innovation Geoscience
4:20 to 4:35	Way Forward to a National Rock Property Database – Tom Lane, John McGaughey

Appendix 2 - DVD Data Archive

See attached DVD

Mira Geoscience

... modelling the earth

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Application of Physical Rock Property Data for British Columbia: Mt. Milligan Case Study

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November 7th, 2008

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1. The Importance of Physical Rock Properties to Exploration

Advances of proven geophysical methods and techniques to interpret and visualize geophysical data require physical rock property data to relate the key geological aspects of ore deposits and their host rocks. Petrophysical analysis of specific ore systems is required to determine what geophysical techniques can best be used to target mineralization. The explorationist must start with a concept of the ore deposit model which then provides clear guidance about possible physical property contrasts and can guide selection of the appropriate geophysical methods, their appropriate use and how to interpret them. Various types of rock property data provide information on mineralogy, texture, grain size and porosity. Most importantly, different techniques exhibit contrasts that can then be imaged to reveal geometries between rock bodies.

The process starts with a concept exploration model then data needs to be acquired that includes measurements of rock samples, outcrops and drill core. A preferred method is to measure a range of parameters from probes lowered into boreholes. Borehole measurements require planning for a budget as part of drilling programs, access to a representative number of boreholes, cost and time, calibration of instruments and attention to the consistency of type of data received. If such a plan is considered prohibitive, a company can measure selective borehole cores and representative rock types to guide initial interpretations of geophysical surveys. Any program needs communication between the geologist with respect to the geological model and the geophysicist with respect to the geophysics. For all rock property data measured, a spreadsheet needs to be set up to record the geophysical parameter, the location by GPS coordinates, the rock type and the geological formation. It is also useful to record mineralogy, modal geochemistry alteration type as a confirmation of the rock type. Metadata is always important to enter into data files such as the method of geophysical measurement.

The integration of all geological, geophysical and geochemical data into a 3D GIS model is the next step and constitutes around 80% of the work. The whole earth models that are constructed should provide structural geometry, lithological units, and alteration among other aspects. Geophysical data can be modeled synthetically as a forward model that krigs and smooths the geophysical data. The geophysical model is then compared to reference models, 2D models of isosurfaces of geophysical parameters that are fitted to geological maps and sections. There are several programs available to invert geology-geophysics into 3D images, VPmg and Geomodeller. A number of geophysical inversion codes recover geophysical rock properties to the whole earth model. These inversions may be unconstrained or constrained relative to the geological patterns of the reference models. In constrained inversions the rock property data is krigged to fit the geological boundary constraints. The inversion models give guidance on what geophysical parameters have sufficient magnitude and contrast such that a geophysical survey would reveal drill targets.

At early stages of exploration it is useful to construct synthetic forward models and inversions based on known geophysical surveys and rock property measurements. If these models suggest that the ore type target could be detected geophysically, this exercise would provide rationale to fund new geophysical surveys and rock property measurements.

2. What is Measured?

Measured physical rock property data are a means of linking geophysical surveys to subsurface geology. The advent of forward modeling and inversion of geophysical data along with the ability to rapidly compute large amounts of data on desktop computers now enables us to numerically modify geophysical data in 3D that approximates the geometry of geological bodies.

To inform these computer models it is important to redraw geological maps and cross-sections in terms of the geophysical properties of the geological units. These geological – geophysical reference maps should be simplified to emphasize units with distinct densities and / or magnetic properties and boundaries with physical contrasts. Other parameters such as resistivity, conductivity and chargeability may be mappable parameters. Direct rock property measurements of this type of data are less available. Reference maps can then guide the computer models to select a forward model or inversion that best fits the geology.

Solutions for forward models and inversions of geophysical data are non-unique, in other words several geological geometries can explain a geophysical anomaly. Preferred geometric solutions can be identified by preparing a likely geological geometry that corresponds to the known distribution of physical rock properties for rock units. Data for density and magnetic susceptibility are more commonly measured and available. Also inversions for gravity (density contrasts) and magnetics are more easily computable with existing codes. Rock property data for resistivity, chargeability and conductivity are less commonly measured. Also the computing time and complexity for electrical properties and conductivity are a greater challenge. Geophysical contract companies do provide these services however.

Sulphide geochemical analyses can be used as a proxy for chargeability. Electrical conductivity of samples can be directly measured in laboratories. Density is commonly measured by retrieval of a rock sample and measurement by weight in air – weight in water technique. An alternative indirect measurement of relative density is by borehole measurement of gamma-gamma and mise-a –la-masse. It is also common to measure seismic velocities and acoustic properties of rocks. Spectral gamma logs are means of correlation of rock units with radiometric surveys. Field spectral measurements are used to constrain airborne gamma spectral surveys. Table 1 lists a number of physical properties that are measured.

3. Physical Properties

Property	Method of Measurement	Units
Magnetic susceptibility	susceptibility meter	x 10 -3SI
Koenigsberger ratio	measured from oriented core	Kn = remanence/ ms x field
Density	wgt in air – wgt in water; spectral gamma gamma; gravity meter; borehole gravity meter	g/cm3
Conductivity		mhos/m; siemens/m (S m -1)
Resistivity	apparent resistivity with applied current	ohm meters x 104 or ohm m
Chargeability	transient voltage	millivolt/volt
Gamma Ray Spectrometry	MeV gamma rays; calculate eUranium, eThorium; ePotassium	eThorium v ePotassium (ppm) % potassium
Seismic velocity	elastic wave velocity	km/sec = v
Acoustic impedance		z = v x ρ
Porosity		%
Temperature Gradient	measure degrees centigrade	milliKelvin/m; ºc/m
Natural Gamma		cps

4. Correlation of Measurements with Rocks

4.1. Magnetic Susceptibility

Magnetic ground, airborne surveys and magnetic susceptibility data is commonly available and relatively inexpensive to acquire. High resolution airborne magnetic surveys are increasingly covering the land and can reveal the detail of geological structure within the 200 m of the surface. As a result inversions and 3D models of magnetic data are commonly used by exploration companies. Magnetic susceptibility is controlled by accessory minerals in a rock, principally terrimagnetic magnetite and pyrrhotite, distribution of which may not be uniform for such reasons as concentration in distinct layers, uneven hydrothermal alteration or variable conditions of differentiation, eg. oxygen fugacity in plutonic rocks. The upside of application of magnetics is that magnetic susceptibility measurements are easy to collect in the field and drill cores. The degree of variation of magnetic susceptibility is much greater than density, zero to 300 x 10^{-3} SI compared to 2.0 to 3.2 g/cm^3. As a result much more variation and apparent detail can be seen on high resolution magnetic maps, particularly first derivative maps. (Figs. 9 and 10 Thomas). Geological units can have varying amounts of magnetic remanence with a suppressed signal on airborne magnetics.. To understand the potential for remanence get type rock samples measured for magnetic remanence and induced magnetism. The relative dominance of remanence over induced magnetism is reported as Koenigsberg ratio or Q values.

4.2. Density

Density reflects mainly the principal minerals that constitute and define a particular rock type, eg. quartz, feldspar and pyroxene. In most rock types the defining mineralogy is essentially uniform, hence density characteristics are also uniform. For this reason density variation is a preferred method for mapping rock units. Intrepid Geophysics' surveys of the Broken Hill terrane reported that that mapping of the variance of the density, the standard deviation, is an effective way of mapping rock units. Gold exploration has found gravity effective at mapping the geometry and structure of greenstone belts and specific intrusion targets in greenstones or sedimentary formations. On the downside it is expensive to acquire ground and airborne gravity surveys in sufficient detail to image geology. The increasing access to airborne gravity gradiometer surveys means that in the future more density inversions will be possible. The AGG surveys have excellent resolution of 0.4mgal per 500 m. Ground follow-up can achieve 0.01 mgal over < 1 m. Noise related to topographic and bouguer effects hinders the use of this technique for detailed geology. Borehole gravity meters are being developed that can measure total bulk density over vertical intervals to depths of 2000 m. The bulk density data needs to consider density of the rock relative to the amount of pore space.

A comparison of magnetic susceptibility versus density can be used to differentiate mineralogy, rock types and alteration (Figures 1 and 2). Carbonate, quartz and amphibole are less dense then sulphides and hematite. Olivine falls in between. Magnetite and pyrrhotite have distinctively high magnetic susceptibility and density, in other words these parameters can map out mineralization. Density variations can be used to differentiate metamorphism, igneous zonation and weathering. One of the more useful tools is that alteration destroys magnetic susceptibility as a result of the destruction of magnetite and mafic minerals.

4.3. Electrical Conductivity

Conductivity is the most effective tool for Cu-Ni and other massive sulphides. Conductance, conductivity x thickness, is important to distinguish bodies of massive sulphide. Ability to detect high conductance, > 10^3 Siemens, is important for detection of nickel ores. Connectivity of conductive minerals is essential. Some minerals like magnetite have intrinsically high conductance, but commonly are not connected. The comparison of density to electrical conductivity is a useful way to distinguish sulphides from iron rich silicates and oxides that may form conductive patterns.

In uranium exploration in Athabasca large moving loop EM and airborne EM surveys have been effective mapping graphite zones and regional fault zones. Similarly in gold exploration in-loop helicopter EM surveys (Newtem and VTEM) are effective ways of mapping graphitic structural zones. Regional apparent conductivity can map out graphitic formations as a means of mapping regional geology from airborne EM surveys. In the Athabasca favourable basement terranes of metasedimentary rocks are mapped geophysically by low magnetic susceptibility and high apparent conductance in contrast to magnetic granitic terranes.

4.4. Grounded Electrical Methods (Electrical Resistivity and Induced Polarization)

Resistivity can be measured by probes in boreholes or directly from drill core. Resistivity is most effective in sedimentary basins. It has been most effectively employed to map alteration around uranium and gold deposits. 3D pole to pole distributed array acquisition and deeper seeking audio magnetotelluric surveys are able get the data required to do effective 2D and 3D inversions across alteration zones. Resistivity is less effective for direct ore targeting.

Induced polarization (IP) has a long history of use and is effective at mapping large areas of disseminated pyrite mineralization. The method images large areas of phyllic alteration with disseminated sulphides, as well as large pyrite–sericite alteration zones in volcanic systems. Geology – IP inversions take significant computational time and are still under development. Any targeting generated by inversions require thorough integration with deposit models and geology of the target areas. Complete borehole logging is needed to sort out alteration zonation and vectoring in such large alteration systems. IP probes can be used in boreholes. Geochemical analyses of sulphur and visual estimates of sulphides in boreholes are inexpensive proxies for borehole IP surveys. IP surveys are also effective for Ni-Cu-PGE veins with high electrical chargeability. Radio imaging (RIM) is a complimentary tool, used across two boreholes, that can image highly conductive veins.

4.5. Audio Magnetotellurics

Audio Magnetotelluric Surveys (AMT) are increasingly popular for mapping conductivity and resistivity below 700 m. It is being applied to deep nickel and uranium exploration and provides a deeper extension to shallower IP-DC resistivity surveys. The latest software is venturing into 3D imaging of conductivity and resistivity.

4.6. Radiometric Gamma Ray Surveys

Gamma rays penetrate approximately one half meter into the ground. Spectral gamma and magnetic surveys are useful for regional mapping of porphyry systems and some uraniferous terranes, for intrusions and uraniferous mineralization and boulders. The integration of magnetics with radiometrics in these surveys is quite effective for the corresponding detection of fault structures and magnetite-rich intrusive zones and potassic alteration. Such spectral gamma ray surveys are commonly calibrated by ground spectral surveys on outcrops. Existing spectral logging systems like Hylogger and hand-held short wave infrared instruments, PIMA II and ASD Fieldspec, provide rock property readings that can be integrated with airborne gamma surveys.

4.7. Seismology and Acoustic Velocity

Shallow 2D to 3D seismic surveys have been successfully employed for imaging complex fault structures in the Athabasca basin and complex fold and fault structures that control gold mineralization (eg. Yilgarn, western Australia). Also the low acoustic velocity of massive sulphides lends these ore bodies to be detectable in cross-hole seismic surveys as documented at Sudbury and Bathurst, New Brunswick. Faults and associated zones of rock weakness also appear as zones of low velocity in 2D and 3D surveys. Rock properties that are measured are relative seismic velocity in meters per second (m s^{-1}) and impedance (velocity + density) that is a measure of reflectivity. Crystalline rocks tend to have high velocities and impedance compared to sedimentary rocks. Plots of density versus seismic velocity are a useful way to differentiate different lithologies to identify the best impedance contrasts for potential seismic surveys.

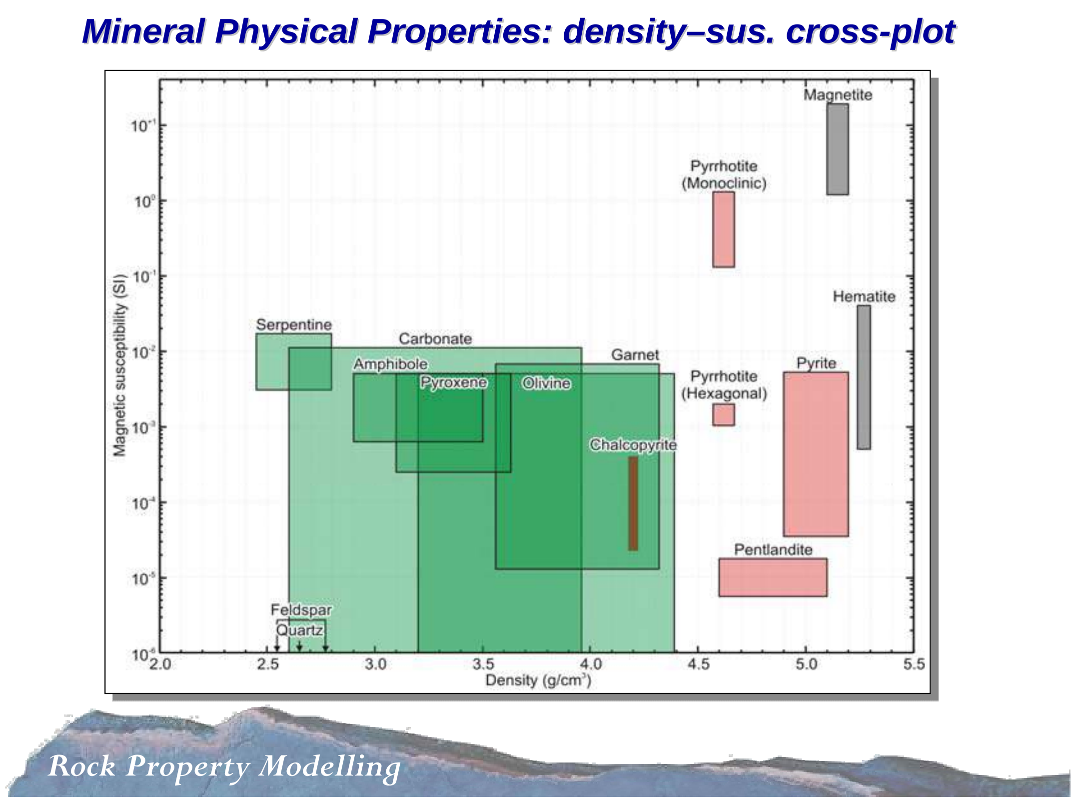


Figure 1. Mineral physical properties: density susceptibility cross-plot

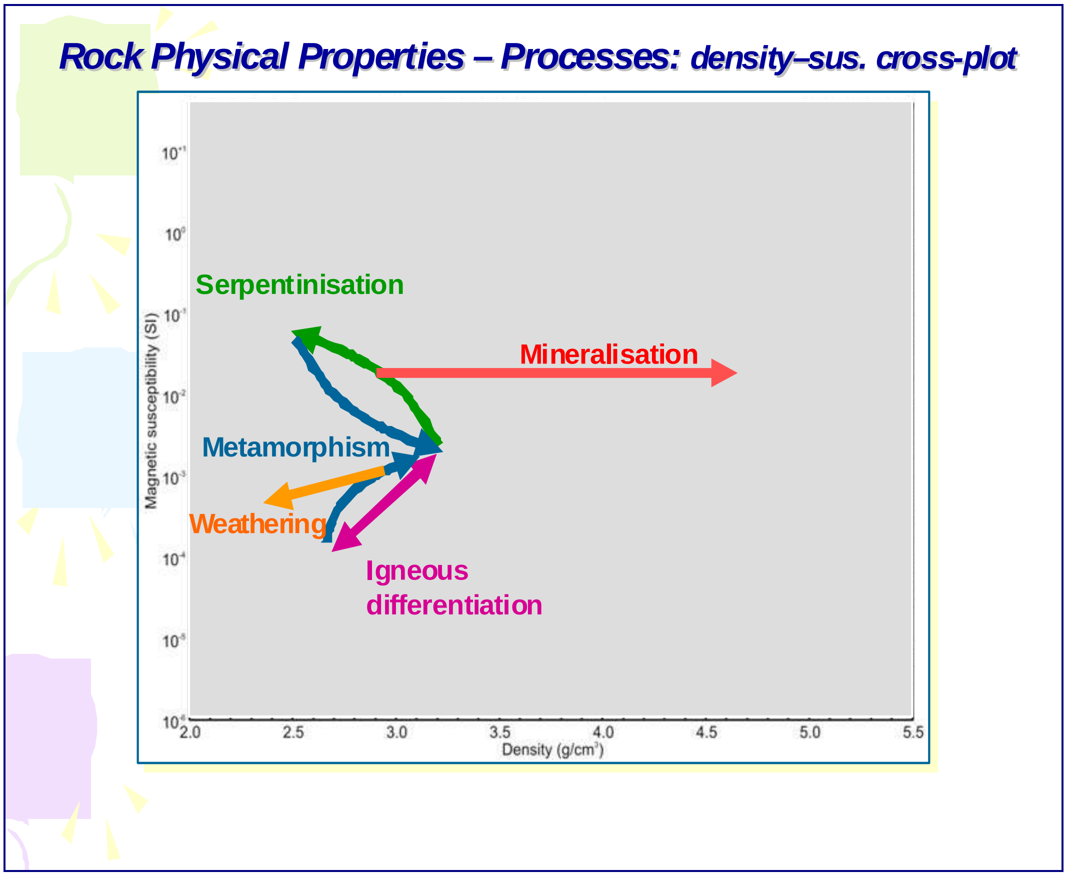


Figure 2. Processes of rock physical properties: density vs susceptibility cross-plot

5. Case Study of Mt. Milligan Porphyry

By Dianne Mitchinson and Nigel Phillips

5.1. Summary of Results Presented at Roundup Workshop

Terrane Metals Ltd. contributed 12,541 measurements from 180 boreholes along with geological descriptions and corresponding 2D and 3D models. Samples were measured every 1 to 2 meters down each borehole. From this data and local geophysical surveys an analysis was done of the application of magnetic susceptibility. The recommended steps of analysis are summarized along with representative illustrations.

Step 1 – Assemble Local and Regional Magnetic Surveys. High resolution surveys <200m line spacing are preferred (Figure 18).

Step 2 – Gather the corresponding Surface geology. Locally intrusions like the Mt Milligan monzonite can be correlated with magnetic anomalies (Figures 3 – 4).

Step 3 – Assemble representative cross-section(s) of the deposit geology. Before modeling geophysics it is absolutely necessary to have a good integration of the geology and an understanding of the deposit model (Figures 4 – 5).

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 2D and 3D characterization of the mineralization and associated alteration zonation.

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

Step 6 - Understand the behavior of magnetic susceptibility

a. Define the ranges and distribution of the susceptibility for different rock types and alteration assemblages (Figure 6 – 7).
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 (Figures 6 – 7).

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 andesites have low susceptibility. Potassic alteration in the monzonite has moderate susceptibility related to biotite and minor magnetite (Figure 8).

Step 8 – To examine the spatial relationships of magnetic susceptibility the physical properties are incorporated into inversion models. Modelling is done in three stages: 1. construction of a synthetic model, 2. Construction of a constrained inversion and 3. Interpretation of the inversions.

a. The synthetic model. The exercises by Dianne Mitchinson illustrated how synthetic models can be used to show expectations of detectability as target contrast, size and depth is changed. A series of synthetic models were constructed.

i. The mineralized stock has magnetic susceptibility (ms) of 32.3 x 10^{-3} SI compared to a background of 0.68 x 10^{-3} SI (Figure 11).
ii. Forward modeling of the distribution of ms data results in an annular geometry. The model uses a mesh of 2,525 m x 2,325 m with cell sizes 25 m on each side (Figure 11).
iii. An unconstrained synthetic model inversion generates a cone of anomalous ms that approximates the location of the intrusive stock. Higher ms values are at the top of the model and lower values at the bottom. Models indicate ms values similar to what was measured in boreholes (Figure 12).
iv. 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 (Figures 13 – 18).

b. Constrained inversions require significant input by geologists and communication with the geophysicist, The Mt Milligan demonstration provided a model of the deposit geology and the spatial distribution of magnetic susceptibility (ms) in boreholes, A series of inversion models were constructed with each case based on specific constraints as follows:

i. geological reference model for the monzonite stock (Figure 19)
ii. geological reference model for the stock margin (Figure 20)
iii. geometry of the magnetic body assuming uniform ms. This image provides significant detail on the shape of the magnetic altered margin of the stock (Figure 21)
iv. the geological contact. Note that the shape of the magnetic anomaly changes considerably compared to the unconstrained model (Figure 22).
v. drill hole controlled boundaries of the magnetic susceptibility. The borehole data significantly changes the configuration of magnetic bodies to steep planar zones (Figure 23).
vi. Interpolated reference and bounds where values are krigged. This version also shows a steep geometry that corresponds faults and dikes (Figure 24).

5.2. Conclusions from Demonstration Study

The study has demonstrated that a limited amount of data can be informative. However, the data needs to be well correlated and rock types identified. It is essential to examine and to 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 is good and the method robust. The constraint methodology depends on the inversion methodology, the amount and type of data and the exploration goal.

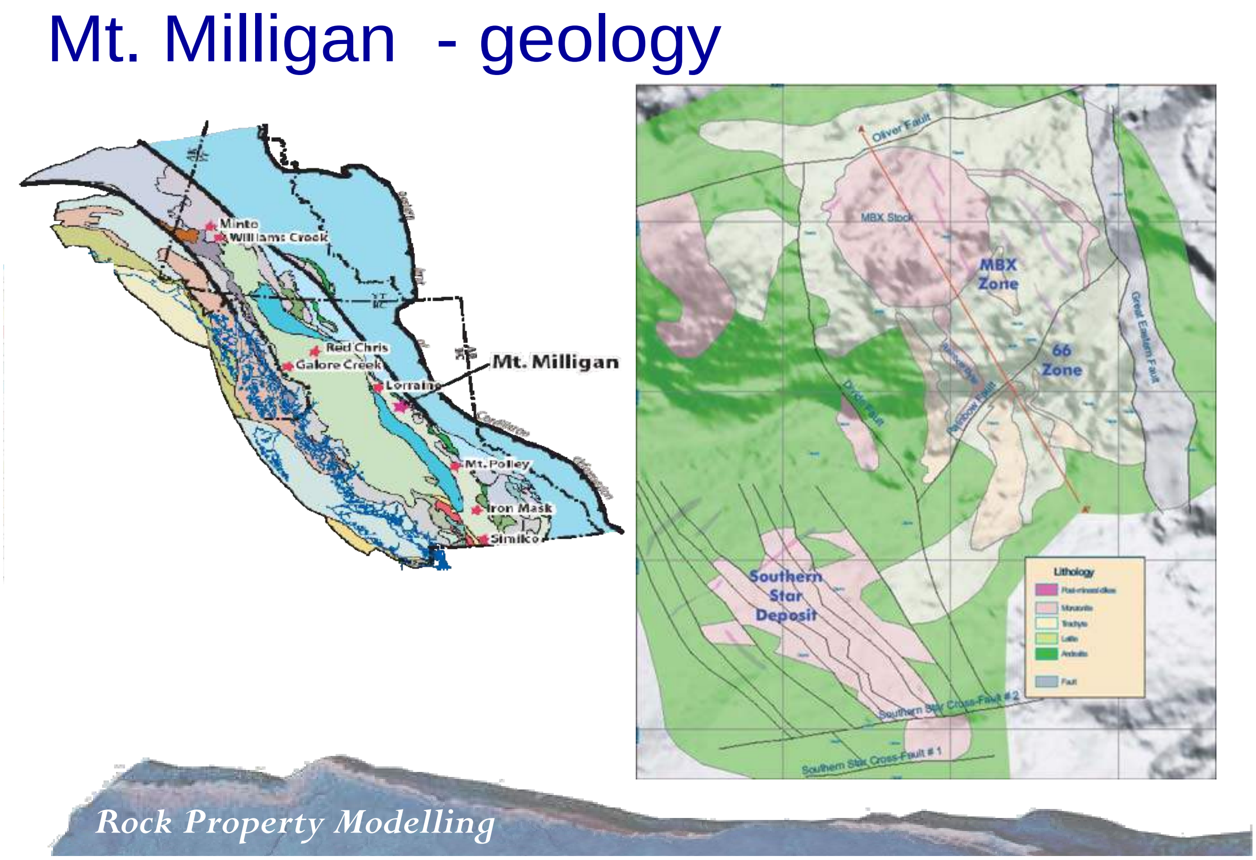


Figure 3. Mt. Milligan geology

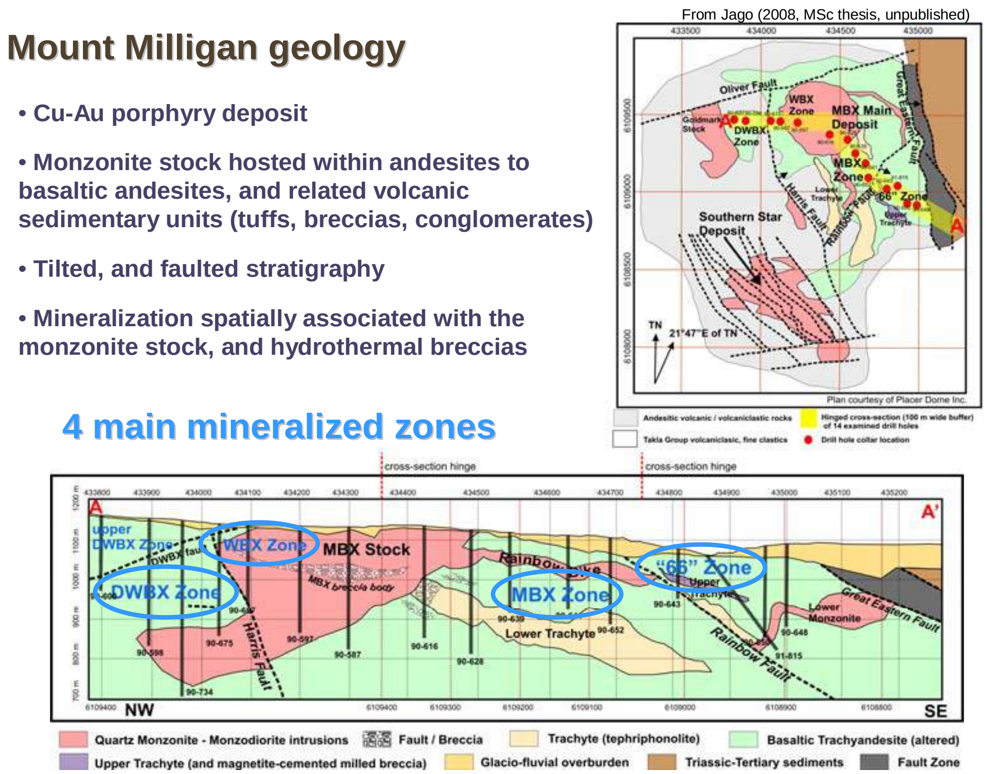
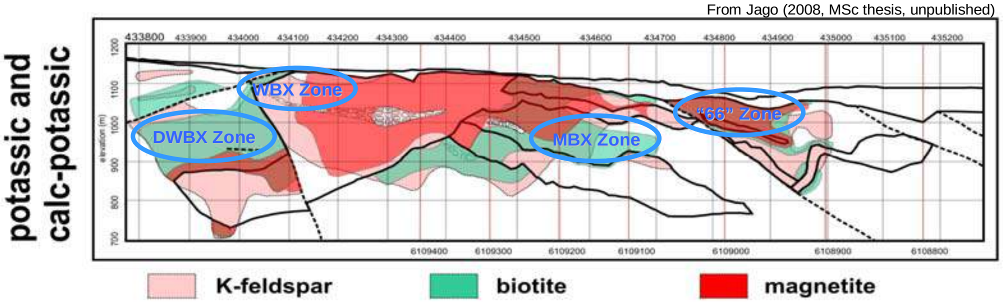


Figure 4. Mt. Milligan mineralization

Geology and alteration related to mineralization

- **What defines mineralized zones at Mount Milligan?**
  - **Boundaries of monzonite stock, and associated dikes**
  - **Mineralization in permeable units, hydrothermal breccias, conglomerates, upper and lower trachytes, faults**
  - **Proximal biotite-Kspar-magnetite-chalcopyrite (‘potassic’ alteration)**

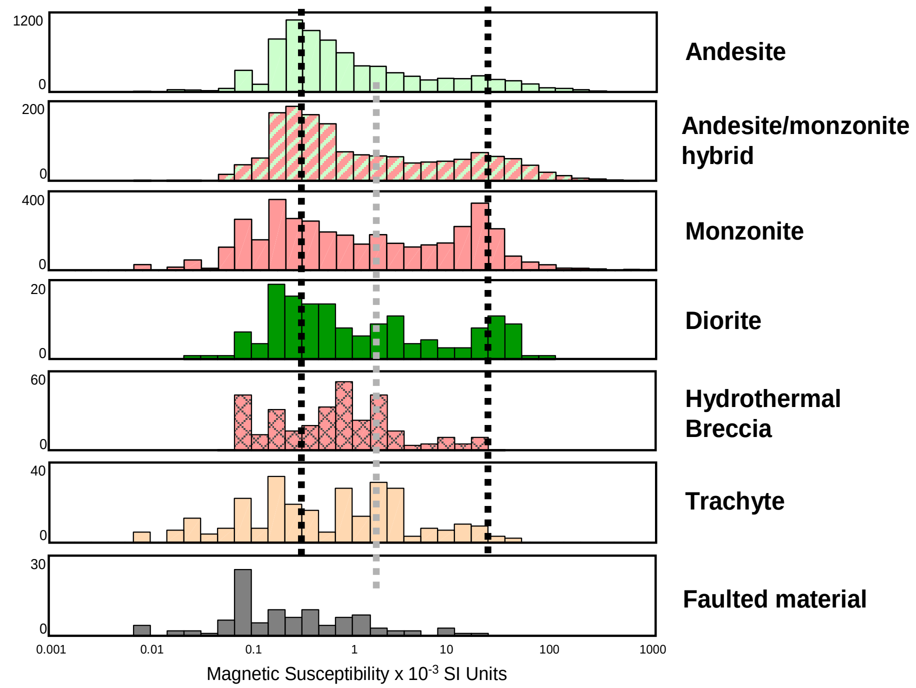
From Jago (2008, MSc thesis, unpublished)



  - **Distal epidote-albite-actinolite-pyrite (‘propylitic’ alteration)**
  - **Shallow, low T carbonate-sericite alteration (anomalously high gold grades; permeable pathways)**

Figure 5. Geology and alteration related to mineralization

Susceptibilty data for rock types mapped at Mount Milligan



Why multiple populations?

Figure 6. Susceptibility data for rock types mapped at Mt. Milligan

Consider alteration - may explain the various susceptibility populations observed in each rock type/sub rock-type

Unaltered vs altered andesites

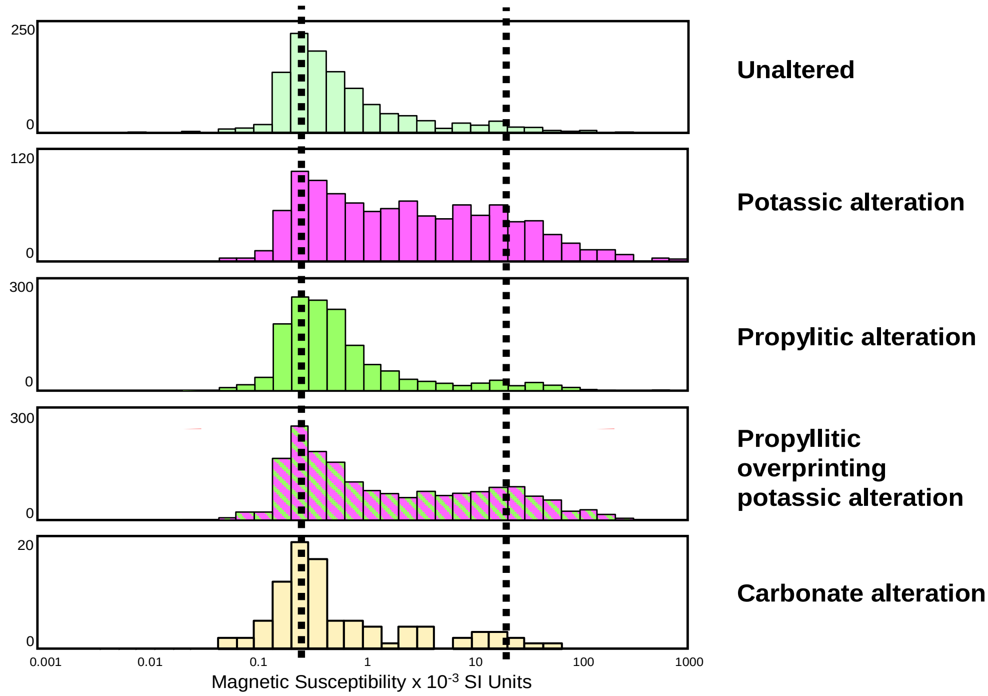


Figure 7. Unaltered vs altered andesites

Trends in magnetic susceptibility at Milligan

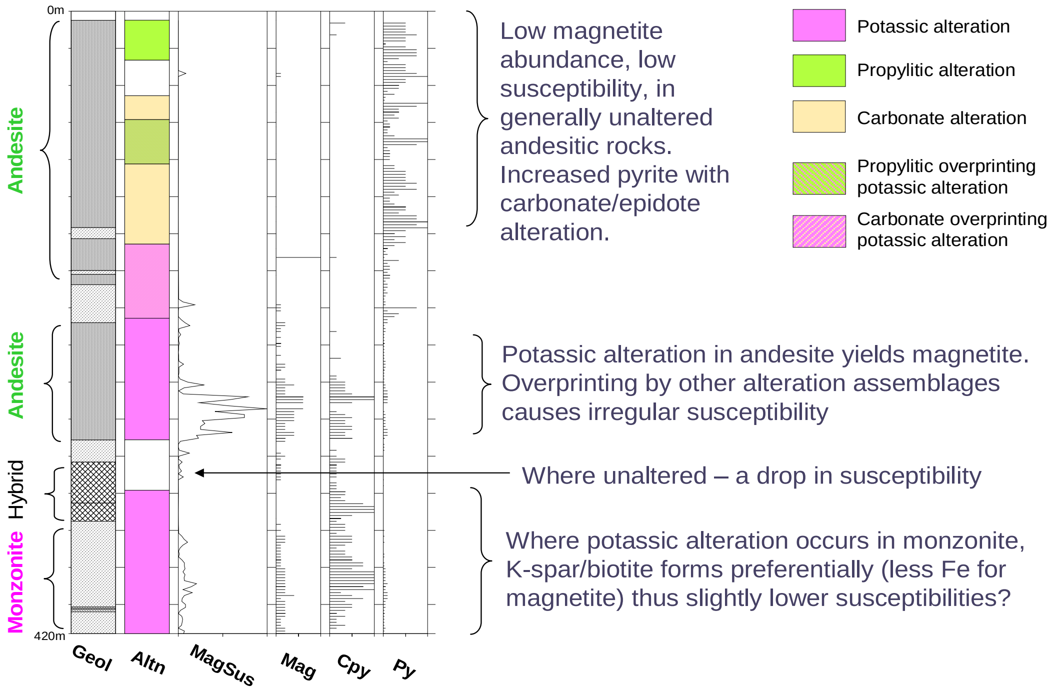


Figure 8. Trends in magnetic susceptibility at Mt. Milligan

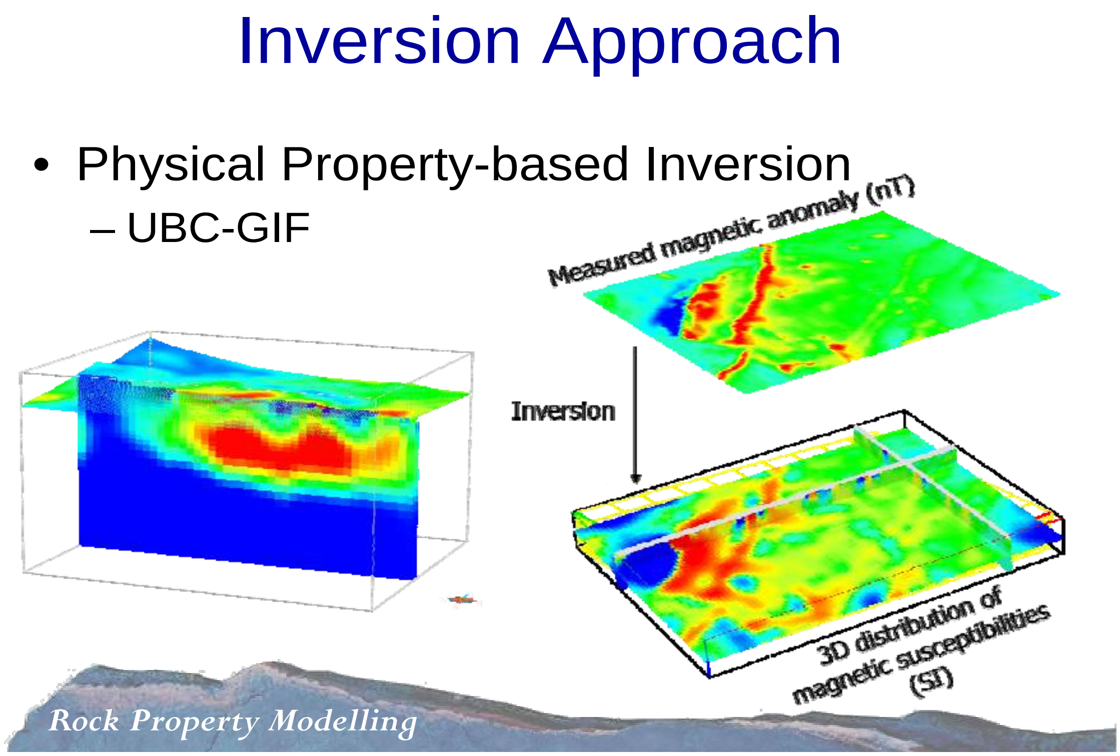


Figure 9. Inversion approach

Mount Milligan synthetic models for case study

Model features

– Used monzonite stock volume from Milligan 3D geologic model to build two synthetic models (mineralized stock and mineralized ‘shell’)

– Altered 2 initial models to explore variations (deeper, smaller, lower contrast)

– Susceptibility of *mineralized zones* (potassic alteration)

– Susceptibility of *background* (andesites, monzonites, propylitic alteration)

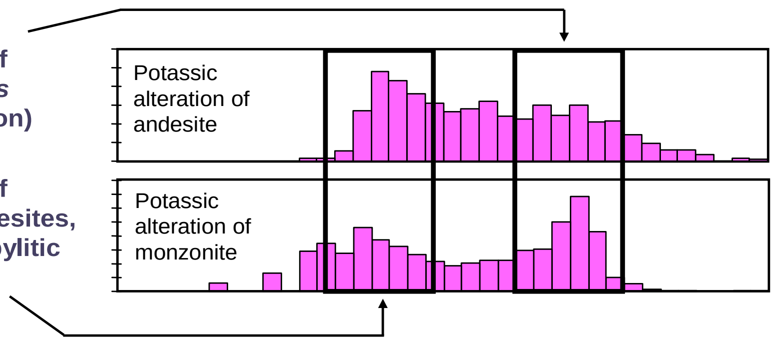
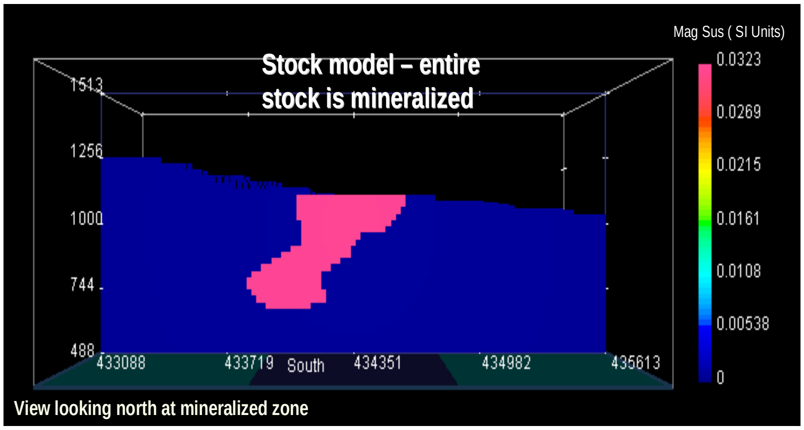


Figure 10. Mt. Milligan synthetic models

Mineralized stock, and mineralized shell models



Magnetic susceptibility values used:

Target:

0.0323 SI Units
(32.3×10^{-3} SI units)

Background:

0.00068 SI Units
(0.68×10^{-3} SI Units)

- Mesh 2525 m x 2325 m x 1025 m
- Cell size 25 m
- *Process:* synthetic Milligan model is forward modeled (12.5 m x 50 m spacing, 50 m height), noise and errors are assigned, and the resulting synthetic magnetic dataset is inverted

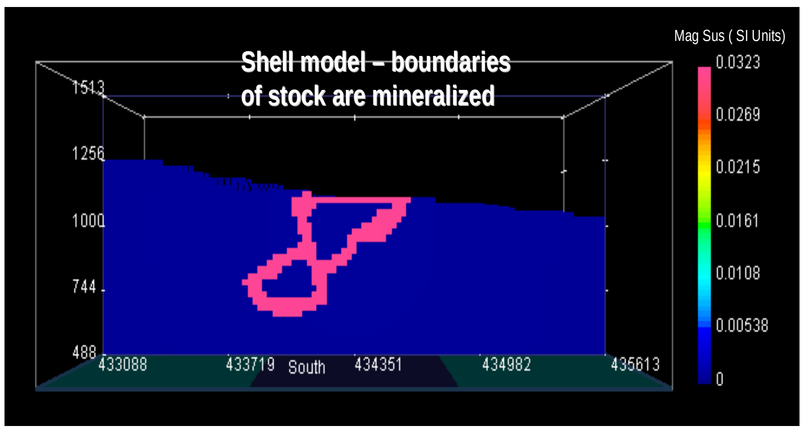
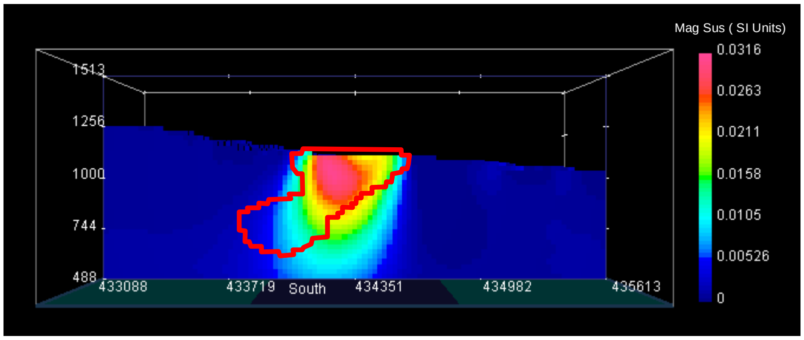


Figure 11. Shell models

Unconstrained synthetic model inversion result



- Deeper high susceptibility zone not well detected
- Max susceptibility values very close to true values

- Deeper high susceptibility zone not well detected
- Max susceptibility values close to true values
- The low susceptibility core of the shell model is detected

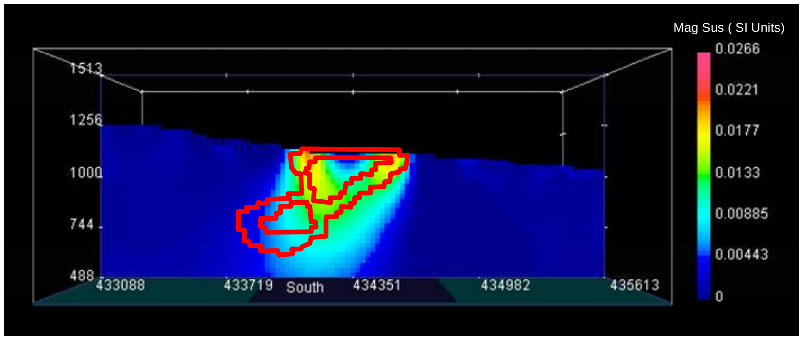


Figure 12. Unconstrained synthetic model inversion result

Variations to Milligan model

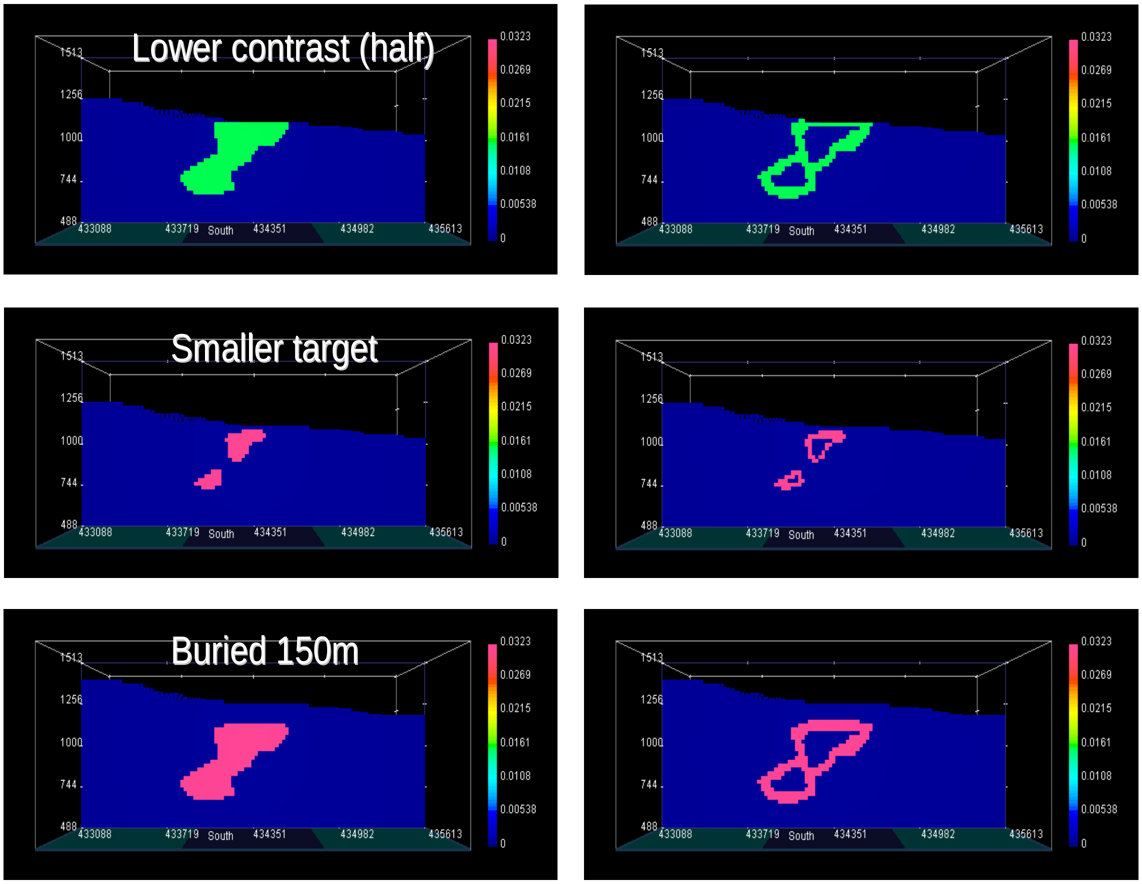
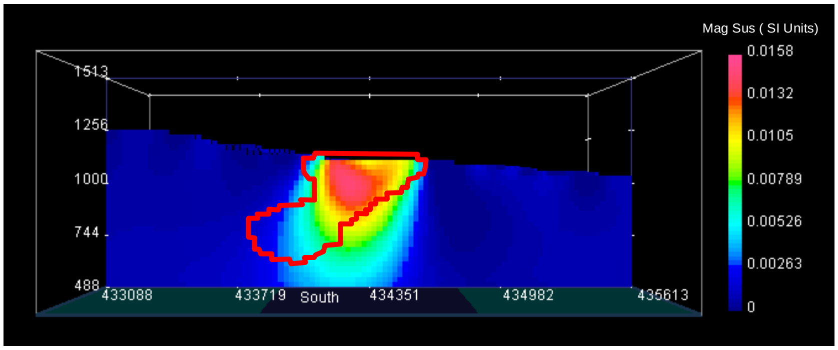


Figure 13. Variations to Milligan model

Detection of other targets - lower contrast



- Deeper high susceptibility zone not well detected
- Max susceptibility values close to true values
- Despite lower contrast, target is still well-detected

- Deeper high susceptibility zone not well detected
- The low susceptibility core of the shell model is detected
- Despite lower contrast, target is still well-detected

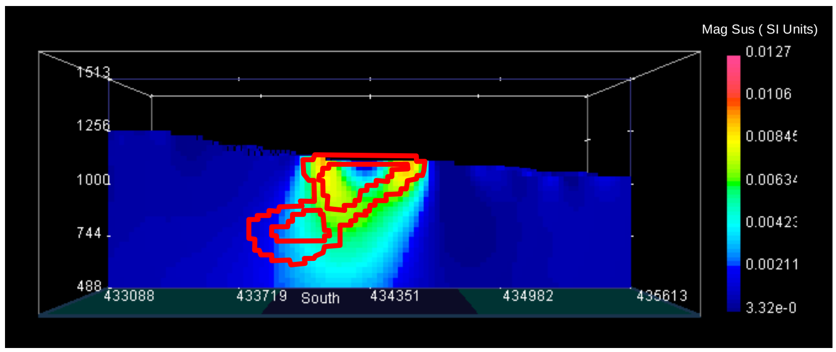
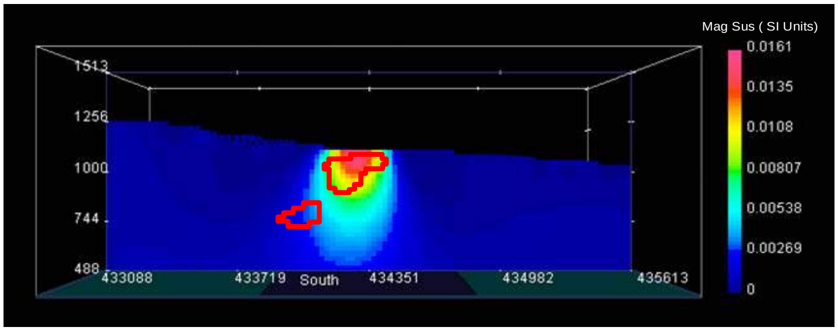


Figure 14. Detection of other targets - lower contrast

Detection of other targets - smaller target



- Deeper high susceptibility zone not detected
- Max susceptibility values much lower than known values

- Deeper high susceptibility zone not detected
- Low susceptibility core undetected
- Max susceptibility values much lower than known values

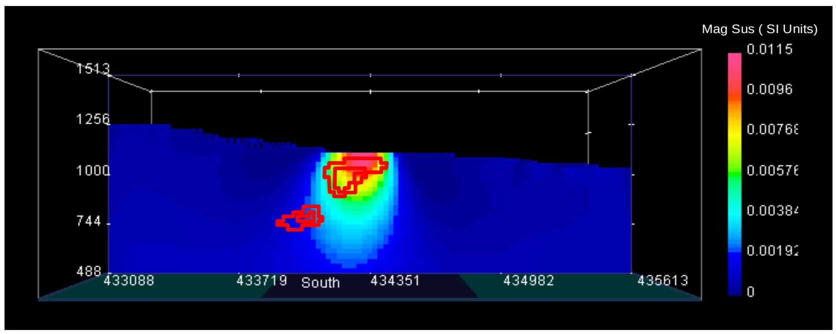
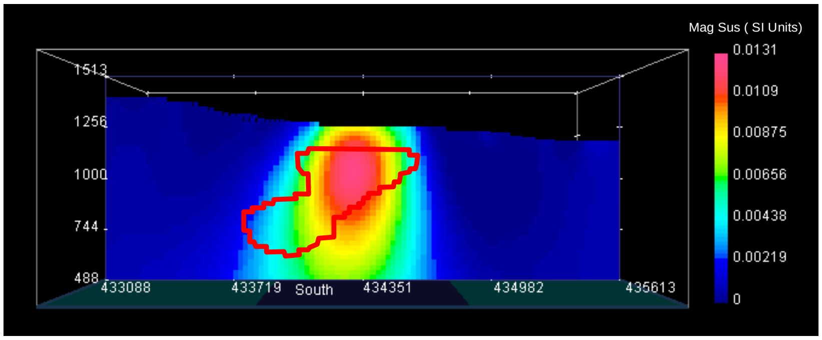
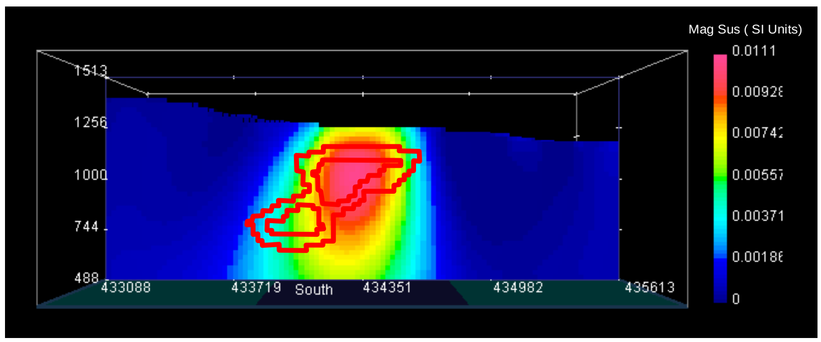


Figure 15. Detection of other targets - smaller targets

Detection of other targets – buried 150 m



- Target not as distinct under 150 m cover
- High susceptibility extends to depth
- Susceptibility values much lower than known values



- Target not as distinct
- Low susceptibility core not detected
- High susceptibility extends to depth
- Susceptibility values much lower than known values

Figure 16. Detection of other targets - buried 150m

Detectability of a Milligan-like target

- Examples of info to be derived from synthetic modeling:
  - Recovered susceptibility for deeper, and smaller targets are low
  - Buried target - targets at depth not obscured, but may be smoother, and susceptibility spreads to depth
  - Smaller anomalies - if too deep, or too close to another anomaly, won't be easily detected
  - Lower contrast - may still be significant enough to be detected

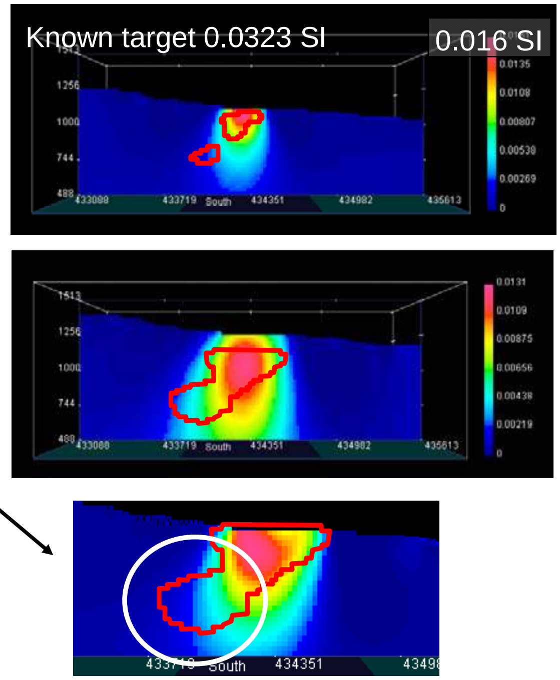
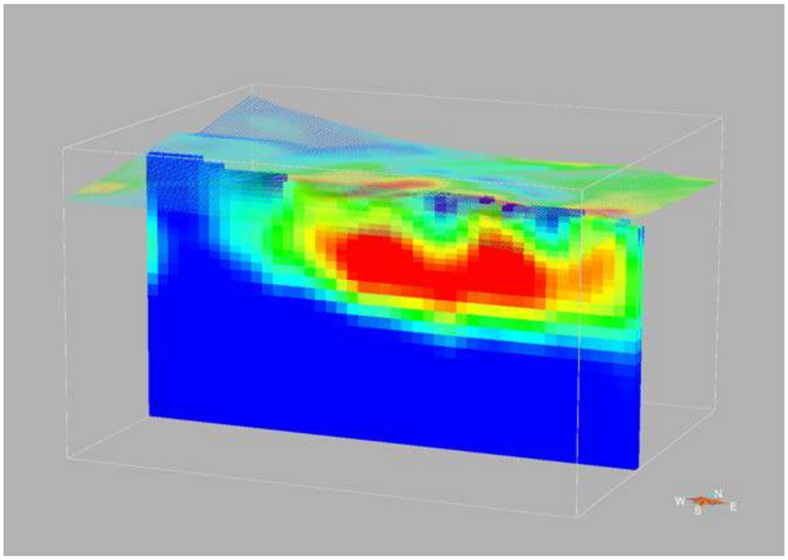
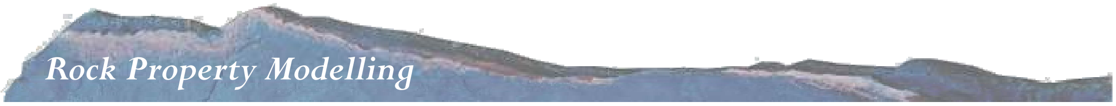


Figure 17. Detectability of a Milligan-like target

Mt. Milligan – unconstrained inversion result



(a)



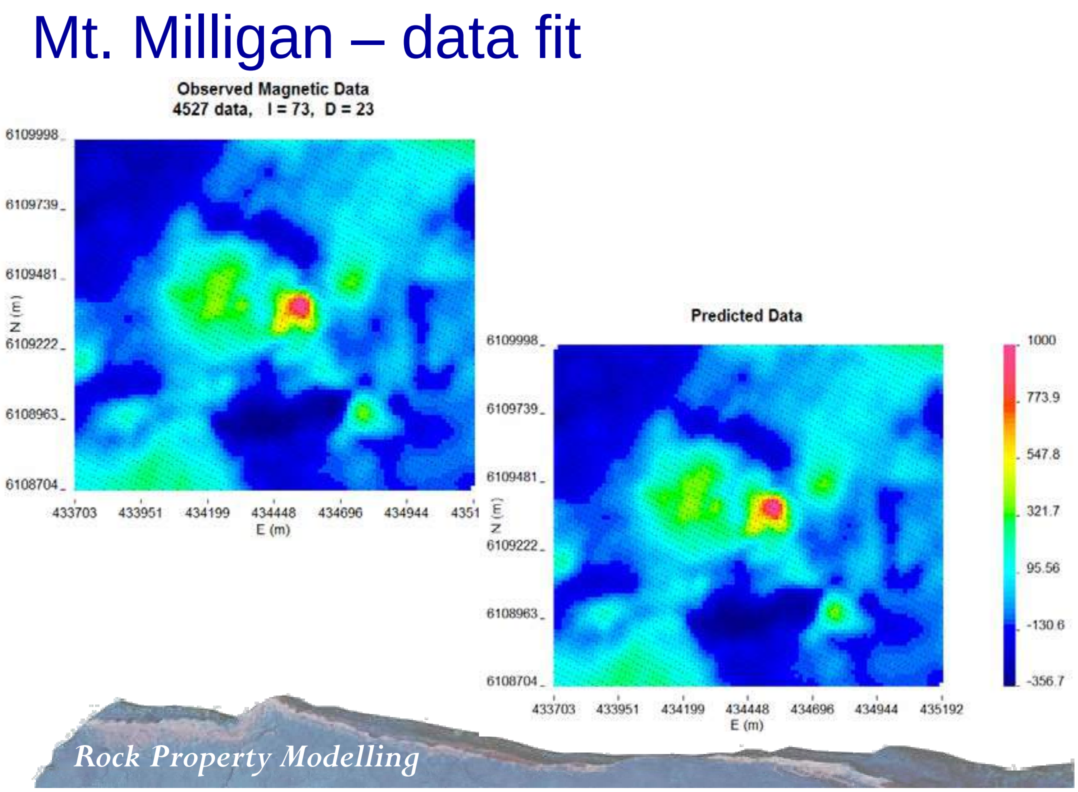
(b) 

Figure 18. Mt. Milligan unconstrained inversion result (a) and data fit (b)

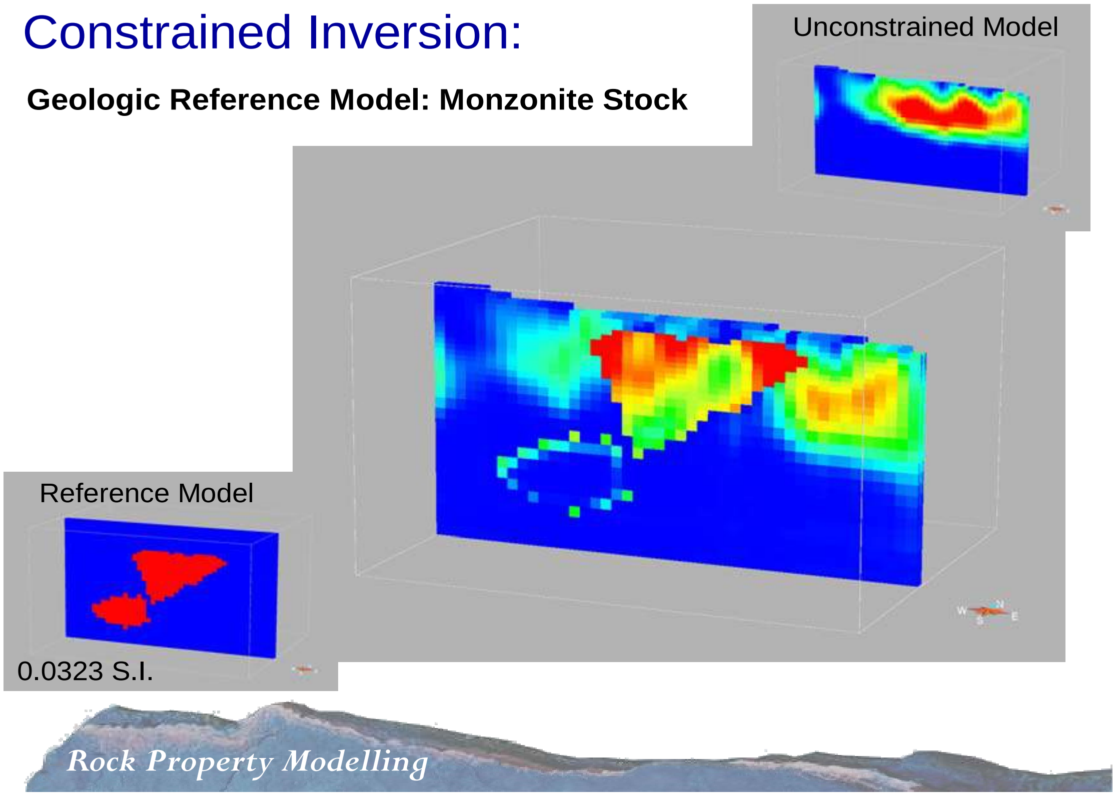


Figure 19. Constrained inversion geologic reference model for monzonite stock

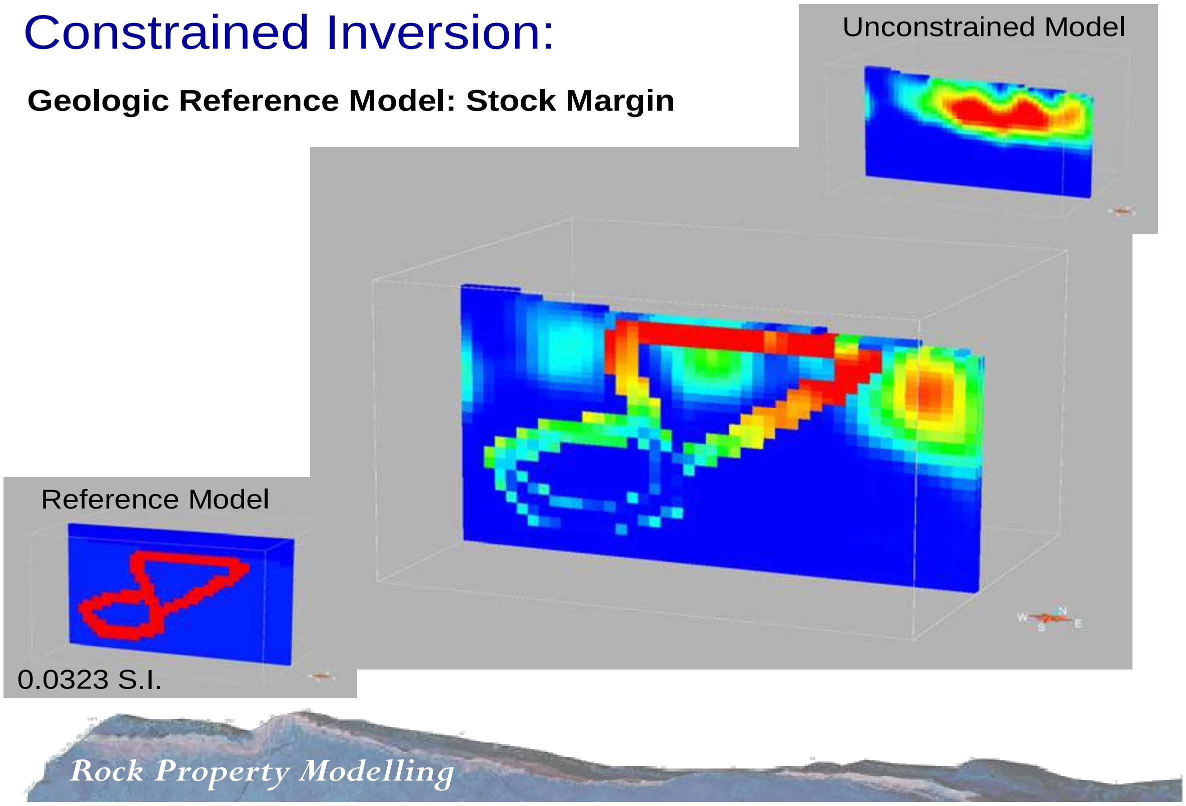


Figure 20. Constrained inversion geologic reference model for stock margin

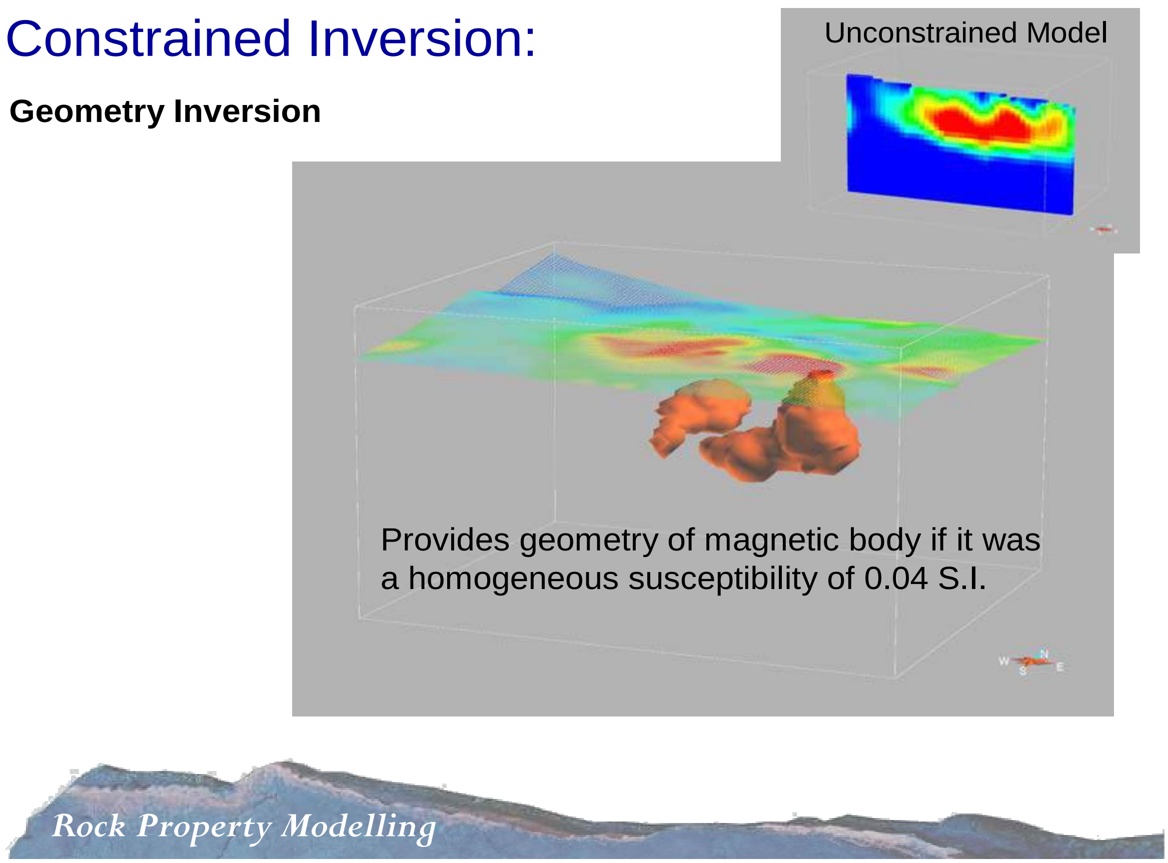


Figure 21. Constrained inversion: geometry inversion

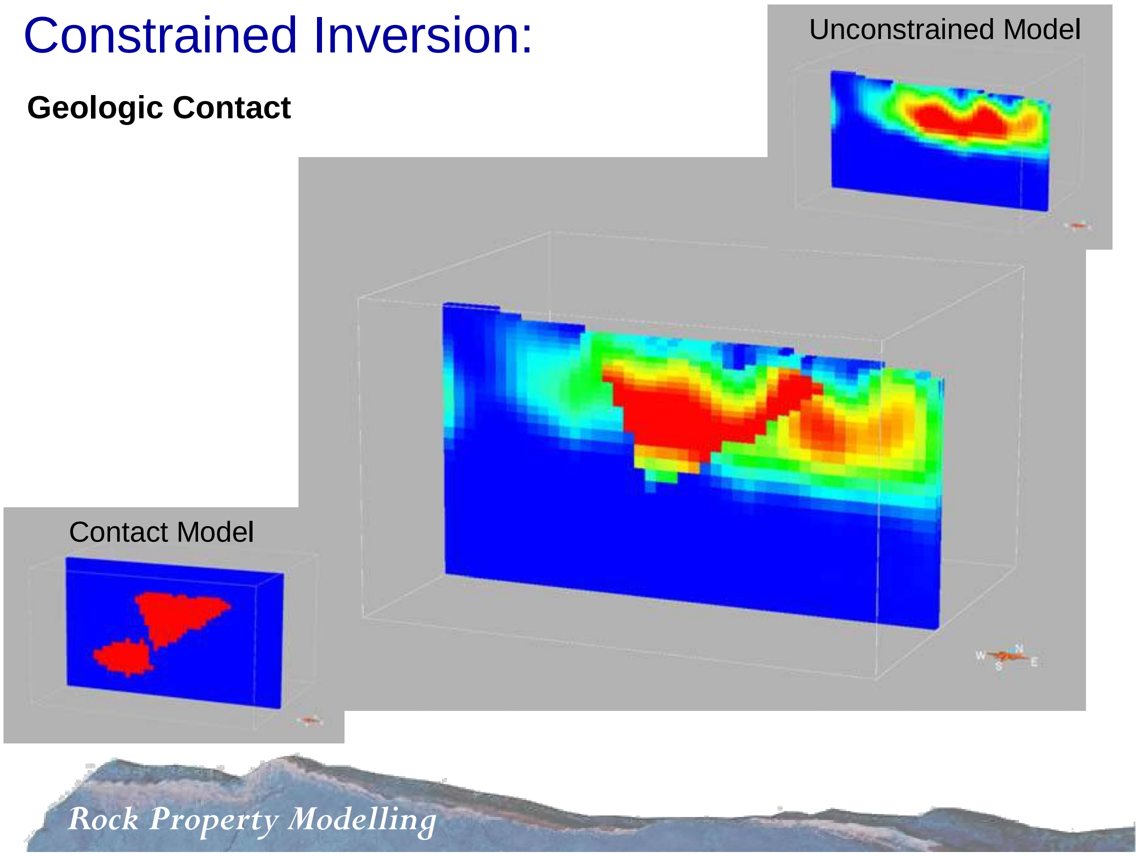


Figure 22. Constrained inversion: geologic contact

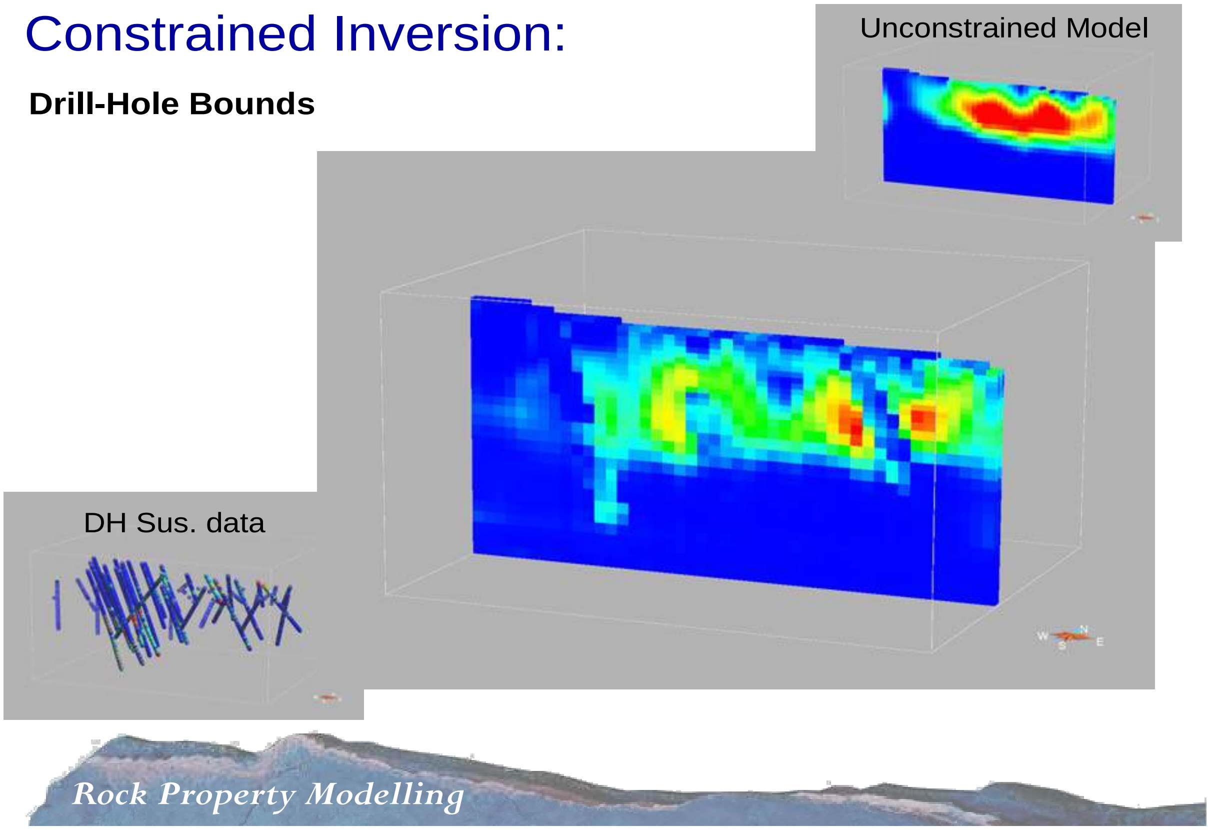


Figure 23. Constrained inversion: drill-hole bounds

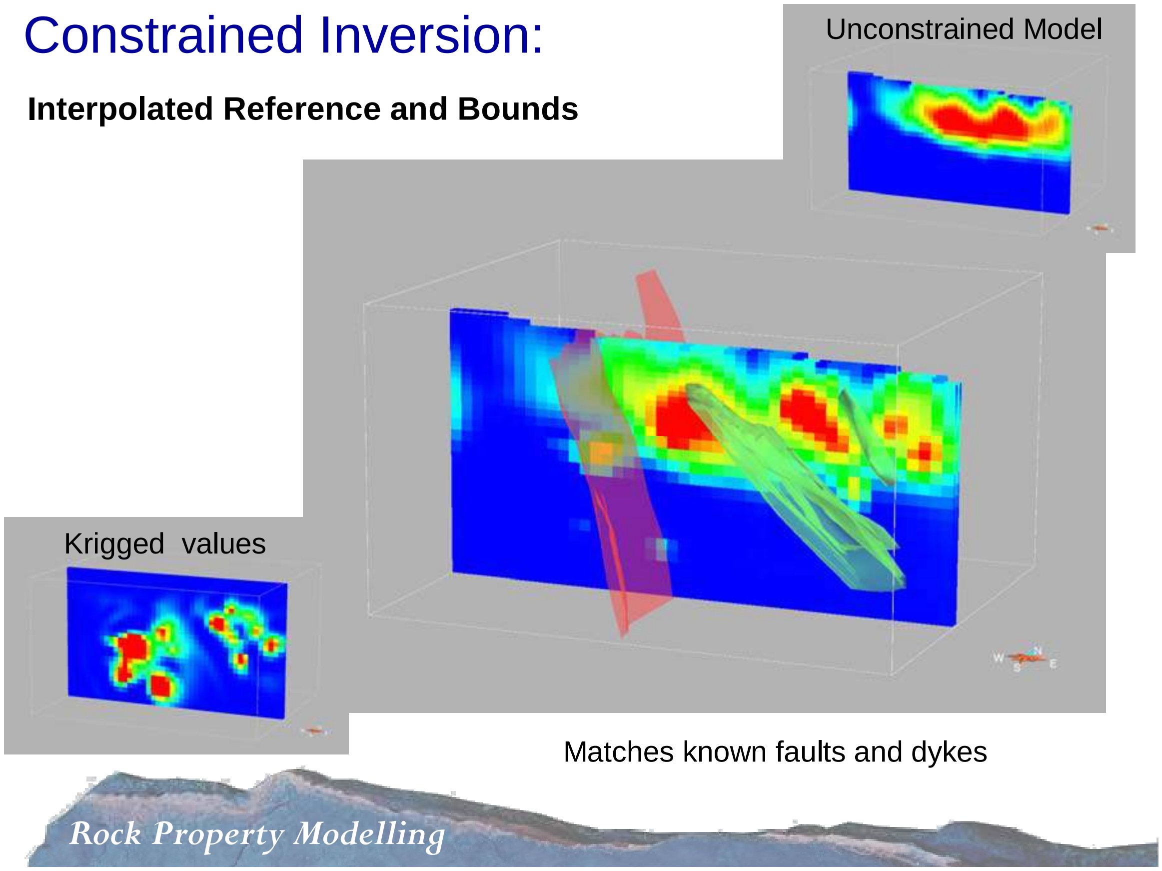


Figure 24. Constrained inversion: interpolated reference and bounds