PDAC 2012 International Convention

DMEC workshop series:

Exploring undercover in a greenfield setting- the Quesnel terrain in east-central British Columbia

Wednesday, March 7, 2012
DMEC workshop series: Exploring undercover in a greenfield setting – the Quesnel terrain in east-central British Columbia

Chairs - Ken Witherly, Condor Consulting, Inc.
Charles Beaudry, Xmet, Inc.

Introduction

Decennial Minerals Exploration Conferences (DMEC) was created in 2007 as the legal entity responsible for managing the Exploration 07 conference and is the corporation that now holds the copyright for the proceedings of the conference. The Exploration 07 conference, held in September 2007, was the fifth and most successful of a series of conferences which have been held every 10 years since 1967. These meetings have been designed to summarize the advancements in the different fields of mineral exploration science and technology over the previous decade through a focused series of technology reviews and case studies given by world leaders in various aspects of geophysics, geochemistry, remote sensing and information processing and data management.

The fundamental objectives of DMEC are to promote the science and business of mineral exploration and the advancement of the geosciences. The board of directors and organizing committee of the corporation are all volunteers working actively in the mineral exploration industry and most are based in Toronto.

For 2012, we will be examining exploration undercover in a greenfield setting – the Quesnel terrain in east-central British Columbia that is being actively explored for Cu-Au porphyry deposits. Presentations will examine the geological, geochemical and geophysical methodologies being used to search for new deposits. This workshop is being organized in collaboration with Geoscience BC.

In addition, we have several talks which highlight the DMEC theme through commercial innovation and technology.
Program Schedule

13:00-13:10 Welcome/introduction


13:40-14:10 Dave Heberlein-Heberlein Geoconsulting-North Vancouver BC: Application of geochemistry to exploration undercover; an example from the Quest BC area

14:10-14:40 Dr. Bill Morris-McMaster University, Hamilton ON: From Geophysical data to Mineral Exploration Models

14:40-15:00 Break

15:00-15:30 C Beaudry-Xmet Inc, Toronto ON: Discovery of the Tortigny deposit; example of the successful use of GIS in exploration

15:30-15:45 Ken Witherly-Condor Consulting, In, Lakewood CO: Quest BC; an example of modern exploration undercover-Introduction

15:45-16:15 Thomas Bissig-MDRU/UBC, Vancouver BC: Geology of the Quest BC area; regional setting and deposit models

16:15-16:45 James Siddorn-SRK, Toronto ON: Use of aeromagnetics and gravity to explore for porphyry deposits under cover; example from the Quest BC area

16:45-17:15 Ken Witherly-Condor Consulting, Inc, Lakewood CO: An analysis of explorers’ assessments of the Quest BC exploration exercise

17:15-17:30 Wrap-up discussion

17:30 CLOSE
SPEAKER/CHAIR CONTACT DETAILS

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Short Biographical Notes

Charles Beaudry

Charles Beaudry is a mining executive with over 30 years experience in project generation, business development, exploration geochemistry and hands on project management including as Country Manager in Brazil for Noranda Inc. from 1996 to 2001. He has been involved in a number of deposit discoveries with Noranda/Falconbridge. He worked for AGIP Canada Inc., Aur Resources Inc. and Noranda/Falconbridge. Until recently, Beaudry was General Manager for New Opportunities for IamGold where he head the world-wide search for new acquisition opportunities and established a new exploration office in Colombia. He is currently president and COO of Xmet Inc. a junior mining company. Beaudry is a PGeo and holds a M.SC.

Thomas Bissig

Thomas Bissig graduated from the Swiss Federal Institute of Technology (ETH) in 1997 where he carried research on the tectonic evolution of the alpine suture zone in the Val Malenco, Northern Italy. After working for Barrick Chile Ltda., he initiated a PhD program at Queen’s University in 1998, examining the relationship of the Miocene geomorphologic evolution and magmatism to the high-sulfidation epithermal deposits in the El Indio-Pascua belt, situated at the Chile-Argentina border. In early 2002 until early 2004 he was a post doctoral researcher at the Mineral Deposit Research Unit (MDRU), University of British Columbia working on the Cuale VMS deposit west-Central Mexico and the Central Peruvian polymetallic belt. Between 2004 and 2007 he held an assistant professorship at Universidad Católica del Norte in Antofagasta, Chile. In late 2007, he assumed his current position, which is jointly funded by MDRU and Geoscience BC.

M. Stephen Enders

Currently the Principal Consultant for Renaissance Resource Partners providing strategic advice from discovery through closure for the mining industry, and on economic geology and mining engineering programs for universities worldwide.

He has held a wide variety of positions in the mining industry over the last 35 years including: exploration, development and operations in the uranium, gold and copper businesses. Steve has been the head of worldwide exploration for two of the world’s largest mining companies as President of Phelps Dodge Exploration Corp and most recently as Senior Vice President for Newmont.
Dave Heberlein

Dave Heberlein has been involved in mineral exploration since 1979. He holds a B.Sc. (Hons.) in Geology from the University of Southampton, England, and an M.Sc., (Geology ) from the University of British Columbia. He has extensive experience in exploring for both precious and base metal deposits and has worked extensively in both North and South America and Australia. Prior to joining Barrick Gold Corp. in 1994, he worked for a number of senior mining and consulting companies including: Metall Mining Corporation, Minnova Inc., Esso Minerals Canada Limited, BP Resources Canada Limited, Archer Cathro and Associates (1981) Limited and Placer Development.

From 1995 to 2002, he was Barrick’s Exploration Manager for Argentina and Chile. In this role he managed exploration in the world class El Indio gold belt including the El Indio and Tambo mines and the supergiant Pascua-Lama high sulphidation deposit. After returning to Canada in 2002 he became Barrick’s Chief Geochemist and was responsible for all aspects of the company’s global geochemical programs. A key component of this role was ensuring that the company’s exploration department used the most up to date geochemical methods and operated to the highest technical standards. This was achieved through a combination of research and development of new methods, training and implementation of a global QAQC program.

More recently he was Vice President of Exploration for Calibre Mining Corp; a Vancouver based Junior exploration company.

Dave started Heberlein Geoconsulting in December 2008. Since that time he has consulted for eight different clients and worked on projects from China, Chile, Mexico, Australia, USA and British Columbia.

Dr. W. A. Morris

After completing his undergraduate degree in geology at the University of Leeds, Bill Morris went on to become the second PhD student to graduate from the Open University, England. Bill then immigrated to Canada where he completed post-doctoral fellowships at the University of Western Ontario, and the Earth Physics Branch of Energy, Mines and Resources, Canada. After receiving a research contract from the federal government to study paleomagnetism of the Sudbury Structure Bill created Morris Magnetics Inc. Subsequently, Morris Magnetics has provided borehole magnetic surveys, rock property analyses, and potential field interpretation to a number of mining companies. In 1990 Bill joined the Geology Department at McMaster. Since then he has published papers on oil and gas (oil sands, conventional oil fields), mineral exploration (Hemlo, Sudbury, Baie Verte, Bathurst, Thelon) and environmental problems (mine tailings, particulate air pollution). Bill’s most important contribution, however, has been in
providing training for many of the current crop of consulting and mining company geophysicists.

James Siddorn

James Siddorn is a Principal Structural Geologist for SRK Consulting based in the Toronto office. James specializes in building 4D deposit to district scale models to evaluate the structural controls on ore distribution and is highly proficient in computer based 2D/3D GIS and geological modeling. He is an expert in deciphering deposit scale controls on ore plunge in Gold and Ni-Cu-PGE deposits and the district scale interpretation of geophysics for exploration targeting. James has extensive underground and surface mapping experience, combined with a broad mining experience focused on conventional and mechanised mining, including cut and fill, shrinkage, VRM and longhole mining. He has 15 years experience in the structural analysis of Au, Ni-Cu-PGE, Ag, U₃O₈, Tantalum, and Diamond deposits, with 12 years experience in Applied 3D Geological Modelling. James has taught more than 15 Applied Structural Geology courses to over 600 exploration and mining geologists and engineers. James holds a PhD in geology from the University of Toronto.

Ken Witherly

Ken Witherly has been involved in minerals exploration for over 40 years and has contributed directly to the discovery of a number of economic deposits. In 1999, Ken helped form a technology-focused service company that specializes in the application of innovative processing and data analysis to help drive discovery success.
Decennial Mineral Exploration Conferences Organization

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Innovation in Exploration
A Prerequisite for Success in Juniors to Majors

M. Stephen Enders
Honorary Lecturer, Past President
Society of Economic Geologists

Presented at the DMEC
March 7, 2012
Overview

• Current Situation
  – Majors vs. Juniors
  – Gold vs. Copper
  – Conclusions

• Innovation Paradigms

• Opportunities Right Now

• Exploration Protocols
The Current Situation

- Dearth of significant new discoveries of valuable mineral deposits
- Few new, robustly economic projects in the global development pipeline
- Aging ore bodies, declining grades, higher stripping, refractory ores
- Increasing environmental and social challenges
- Slow-followers to adapt new technology
The Current Situation

• Major companies are exploration-phobic
  – They just want to acquire discoveries and projects
  – Assume that the juniors will make the discoveries

• Junior companies are very inefficient explorers
  – Only ~30% are serious about creating wealth for others
  – Spend 50 to 75% of their funds “keeping the lights on”
  – Generally opportunistic in acquiring land positions
  – Typically quick & dirty with exploration protocols
  – Exploration finance has a very short-term focus!

• Exploration business paradigm is broken
  – Odds of success are 1:1,000 to 1:10,000
The Gold Industry

• Typically small deposits with short mine lives
  – Median is about 350,000 oz Au
  – Mean is about 1 to 2 Moz
  – Mine lives are typically 7 to 10 years

• Lower barrier to entry than other metals
  – Capex typically ranges from $50 to $500 million
  – Sophisticated marketing of final product not needed

• Fundamental challenges
  – Easy to deplete reserves faster than exploration can replace
  – Initial exploration to first production takes about 13 years
  – Discoveries that are material are rare and occasional
The Gold Industry

Actual Distribution of Gold Deposits
Total Resource, Reserve & Production

Cumulative Frequency

Median = 350,000 oz Au
The Gold Business

[Bar graph showing gold mined and discovered from 1997 to 2008, with annotations for Resources in Discoveries, 3-Year Average, Gold Exploration, and Gold Production.]

- Resources in Discoveries (3-Year Avg.)
- Gold Exploration
- Gold Production

- Grassroots + 75% of Late-Stage Explo (US$m)

- Gold Mined and Discovered (mil oz)

- Years: 1997 to 2008

Values:
- 1997: 80
- 1998: 80
- 1999: 80
- 2000: 80
- 2001: 80
- 2002: 80
- 2003: 80
- 2004: 80
- 2005: 80
- 2006: 80
- 2007: 80
- 2008: 80

- Gold Exploration:
  - 1997: $100
  - 1998: $200
  - 1999: $300
  - 2000: $400
  - 2001: $500
  - 2002: $600
  - 2003: $700
  - 2004: $800
  - 2005: $900
  - 2006: $1,000
  - 2007: $1,100
  - 2008: $1,200

- Grassroots + 75% of Late-Stage Explo (US$m):
  - 1997: $2,600
  - 1998: $2,700
  - 1999: $2,800
  - 2000: $2,900
  - 2001: $3,000
  - 2002: $3,100
  - 2003: $3,200
  - 2004: $3,300
  - 2005: $3,400
  - 2006: $3,500
  - 2007: $3,600
  - 2008: $3,700
The Copper Industry

• Typically very large deposits with long mine lives
  – Median is about 0.2 Mt Cu
  – Mean is about 3 to 4 Mt Cu
  – Mine lives are typically 15 to 20 years, some >50 years

• High barrier to entry than other metals
  – Capex typically ranges from $1.0 to $4.0 billion
  – Sophisticated marketing of final product is required
  – Very strong market controls on price

• Fundamental challenges
  – Difficult to deplete reserves faster than exploration can replace
  – Long timelines for project development and permitting
  – Initial exploration to first production takes about 27 years
  – Large global pipeline of sub-marginal projects
The Copper Industry*  
*data from R. Leveille

**Contained Cu by Deposit Type**

- **Porphyry** (n = 478)  
- **Magmatic** (n = 48)  
- **Sed-hosted** (n = 80)  
- **IOCG** (n = 65)  
- **Skarn** (n = 70)  
- **VMS** (n=387)

**PCD median = 1 Mt Cu**
The Copper Industry*  
*data from R. Leveille

Time to From Discovery to Start-Up

N = 110 deposits, post 1989 start-up or announced start-up
Median = 17 years
Mean = 23 year

years
The Copper Business

Resources in Major New Discoveries* Relative to World Copper Production, 1995-2007

- Copper Mined and Found (mil mt)
- Grassroots & Late-Stage Copper Exploration Budgets (US$m)
- Copper Production
- Copper Exploration
- Resources in Discoveries *

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Conclusions

Exploration is a probabilistic business

• Requires many “shots on goal”
• Manage the cost of failure
• Make good decisions quickly
• Importance of sharing the risk
• Seek innovative approaches
Innovation Paradigms - Challenges

• **Short-term focus**
  “The industry seems to be too busy expanding production and taking advantage of its current prosperity, which follows many lean years, to focus on truly fundamental long-term technological advances.”

• **Fear of change**
  − Lack of funding, talent and management support
  − Operational constraints or integration with legacy sites
  − Not invented here syndrome

• **Basic economics = high risk profile**
  − Mining is highly capital intensive with long payback periods
Innovation Paradigms - Opportunities

“The mining industry often considers exploration itself as a form of research.”

“Therefore, rather than investing research funds in the development of new technologies, the industry has invested heavily in exploration to find high-grade, large or other more-attractive deposits, which can lead to a better competitive position.”

The New Competitive Space:
Research & development of new technologies to improve efficiency, lower cost, and extend the lives of the giant/world-class deposits.
Opportunities – Exploration Technologies

• Geology
  - Models, structure
  - Basic mapping, structure
  - 4D Geological Frameworks

• Geophysics
  - Airborne systems
  - Deep penetration capabilities

• Geochemistry
  - Analytical tools
  - Thermodynamic-kinetic data
  - Dispersion and concentration

Drilling
  - Miniaturization
  - Real-time data
  - Hole to hole sensing

• Remote Sensing
  - Hyperspectral applications
  - Space-borne platforms
Opportunities – Exploration Business Models

• Major/Junior company alliances
  – OPM: other people’s money
  – OPE: other people’s expertise
  – Shared risks, benefits and synergies

• Portfolio management in exploration

• Balance geologic, political & business risks

• Follow appropriate exploration protocols
Identification of the most prospective terranes, belts and districts in the world for the discovery of significant Au deposits on a technical basis.

A ranked / prioritized source of exploration pipeline opportunities.

Example Ranking Criteria
- Structural architecture
- Metamorphic grade
- Gold endowment
- Exploration maturity
- Metallogenic zoning
- Magmatic suites
Exploration Protocols – Area Selection

Global Terrane and Regional Framework Studies
Exploration Protocols – Prospectivity

Data Compilation, Visualization & Interpretation

Landsat
Geophysics
Geochemistry
Geology
Topography

Legend
Prospectivity Score
- 101 - 111
- 112 - 122
- 123 - 133
- 134 - 143
- 144 - 154
- 155 - 165
- 166 - 175
- 176 - 186
- 187 - 197
- 198 - 207
- 208 - 218

Target Areas

Goal: 85% of Prospectivity In 10% Of The Terrain
• Rapid reliable reconnaissance tool
• Ultra-low gold detection and precision
Exploration Protocols – Geochemistry

Exploration Tool Box – Regolith Mapping

- Understanding regolith distribution + profile
- Knowing which data to trust
- Improved geochemical interpretation
Exploration Protocols – Geophysics

Exploration Tool Box – Airborne EM and Magnetics

- Resistivity depth slice mapping
- District scale reconnaissance tools
- Detailed lithologic and structural models
Exploration Protocols – Geophysics

Exploration Tool Box – Gradient IP/Resistivity

- Provides additional understanding of lithology and alteration patterns
- Integrated with other district data sets
- All used to identify, rate & rank targets
- To guide drill hole planning
Exploration Protocols – Drill Testing

Exploration Tool Box – Auger, RAB, RVC, Core

Drilling

Social Responsibility

Logging

Modeling
Final Thoughts

• Everyone needs exploration success
  – The majors, the mid-tier producers and the junior explorers
  – The majors would rather buy it, juniors would rather find it
  – And, the world just needs natural resources to survive

• Innovative approaches are required for all of us
  – Not just new technology
  – But better business models as well
  – To increase our probability of success as an industry

• There are great opportunities ahead of us
  – To integrate new technology & exploration protocols
  – And discover the next generation of ore deposits
Using Geochemistry in Covered Areas of British Columbia

By

David Heberlein

DMEC Workshop
March 7th, 2012
Talk Outline

- Types of cover and their geochemical implications.
- Dispersion and dispersal in residual domains.
- Glacial deposits and their implications for exploration geochemistry.
- Exploration in geochemically detached cover.
- Case History.
Covered Areas of BC
This is the challenge we face.

Thick transported cover that completely masks bedrock.

Stratified drift is geochemically disconnected from bedrock.

There is no geochemical link between the surficial sediments and bedrock.

Therefore conventional soil sampling methods are very unlikely to succeed.
Types of Cover

GEOCHEMICALLY CONNECTED

Recent Alluvium
Outcrop
Colluvium
Till Veneer
Fluvio-glacial
Till Blanket

GEOCHEMICALLY DETACHED

Controls: Terrain, climate, vegetation, glacial history.
Surficial Deposits at Mt Milligan

Legend
- Organic
- Colluvium_Organic
- Fluvial
- Fluvial_Glacioteral
- Colluvium_Rock
- Colluvium_Moraine_Veneer
- Moraine_hummocky
- Moraine_rolling
- Moraine_veneer
- Moraine_blanket

BC Geological Survey
Geochemically Connected

- Surficial materials that maintain a link with bedrock.
- Dispersal is typically mechanical (wind, water and gravity).
- Dispersal trains can be followed up directly (up-slope, up-stream, up-ice).
- Signals detected in soils and stream sediments.
- Conventional geochemical methods effective.
Differential Mobility

Modified from Fletcher, 1981
Colluvial Dispersal

- Occurs on slopes between ridge crest and drainage.
- Material moving down slope as a result of gravity and runoff.
Colluvial Dispersal

- B-Horizon Soil
- Aqua regia digestion
- ICP-OES
Stream Sediment Anomalies

Cu Log(10) Z-Score
- 2.53 - 0.03
- 0.04 - 0.32
- 0.33 - 1.07
- 1.08 - 1.57
- 1.58 - 2.0
- 2.01 - 6.24

0 5 10 20 km
Glacial Deposits

D.M. Maynard et al. Geoscience BC Map 2010-14
Glacial Sediments

Till: Geochemically connected or detached. Depends on depositional environment. Provenience usually known.

Outwash: Geochemically detached. Provenience usually unknown.
Stratified and Non-stratified Drift

- Basal or lodgement till sampled.
- Fine fraction geochemistry (silt+clay).
- L. leavy minerals (e.g. KIM'S, PIM'S).

[Diagram showing stratified and non-stratified drift with sections labeled A to D.]
Glacial Dispersal Trains

- Larger than their bedrock source, easier target to find.
- Size and shape of train controlled by:
  - orientation of ice flow
  - size & erodibility of bedrock source
  - influence of topography on ice flow
  - till thickness, number of till units
- May be affected by post-depositional processes.
- Till sampling suitable for regional reconnaissance exploration

McClenaghan, Exploration '07
Till Sampling

Sample weight depends on analytical methods:
- Till geochemistry - 2 to 5 kg
- Indicator minerals - 10 to 50 kg
  - Clay-rich till, sand content <20%, 25 to 50 kg sample
  - Sandy-till, sand content >30%, 10 to 25 kg sample

Fresh unoxidized till preferred

McClenaghan, Exploration '07
This is the challenge we face.

Thick transported cover that completely masks bedrock.

Stratified drift is geochemically disconnected from bedrock.

There is no geochemical link between the surficial sediments and bedrock.

Therefore conventional soil sampling methods are very unlikely to succeed.
Stratified Drift and Outwash Deposits

- Completely mask the underlying bedrock.
- There is no direct geochemical link with bedrock.
- Unknown thickness.
- Conventional methods are ineffective.

Can geochemistry see through these deposits?

D.M. Maynard et al. Geoscience BC Map 2010-14
Introduced Ions – Basic Requirements

Geochemical response
Trap site in soil
Water table
Ion migration
Dispersion mechanism
Release of ions (oxidation)
Mineralization

Geochemical signature at the surface varies according to the deposit type, type and depth of cover, surface environment.
Dispersion Mechanisms

- Diffusion.
- Hydromorphic.
- Advection (incl. Seismic dilatency pumping).
- Convection.
- Evaporation/Evapo-transpiration.
- Gas/Vapour Diffusion/Microbubble transport.
- Biological Processes.
- Electro-Chemical transport.
- Supercedency.
Introduced Ions - Concepts

- **Endogenic Signal** – The geochemical signal of the sample matrix.
- **Exogenic Signal** – The geochemical signal of introduced ions or elements.
- **Partial Extraction** – extracts loosely bound (labile) ions from the sample. Non-selective.
- **Selective Extraction** – extracts loosely bound ions from specific trap sites.
Reduced Chimneys & Electrochemical Transport

- Ground breaking research by Stew Hamilton of the OGS.
- Based on investigations of forest rings in northern Ontario then applied to buried sulphide mineralization in CAMIRO DPG project.
  - Oxidation of a reduced feature causes release of electrons at top of feature (cathode).
  - Released electrons cause upward deflection in earth's potential field.
  - Net charge cannot be sustained in aqueous systems. Oxidation of reduced feature is balanced by reduction of overburden column.
  - Oxidation is not a self limiting process.
Hamilton's Model (after Hamilton, 2009)

Redox Induced Spontaneous Potential

Aqueous solution

Reducing

Oxidizing

Electrolyte

Areas of ion accumulation

Ground Surface

Reduced Oxidation

Zn

Cu++

Oxidizing Sphinks

Current lines and direction of cation migration

Redox induced electrical dipole
Trap Sites

Components of the sample medium that have the ability to adsorb or otherwise trap mobile ions:

- Organic matter (humic and fulvic acids, chelation, complexation)
- Fe and Mn hydroxides (adsorption, co-precipitation)
- Clays (adsorption)
- Carbonates (adsorption, co-precipitation, neutralization)
- Silica (amorphous silica and silica gels)

These host the exogenic signal and can be targeted by chemical attacks.
Types of Chemical Extraction

- Partial Leach – A non-selective, weak chemical attack that digests ‘labile’ phases in the sample.

- Selective Leach – A weak chemical attack that targets specific trap sites in the sample.

- Sequential Extraction – A series of selective leaches starting from weakest and getting progressively stronger designed to determine the location (‘Trap Site’) of weakly bound ions.
Case History (GBC Report 2010-03)

Kwanika Central Zone:
Deeply buried Cu-Au porphyry mineralization.

- Tested a variety of generic and laboratory specific chemical extractions.
- Sampled the Ah, upper B, lower B and C horizons on two transects.
The project was carried out at the Serengeti’s Kwanika Cu-Au porphyry project in north-central BC.

It is located approximately 145 km northwest of Fort St James. And is road accessible from either Germansen Landing or Takla Landing.

The project lies in the Quesnel Terrain on the western margin of the Hogem Batholith.
Survey Area Geology

LEGEND
- Quaternary Cover
- Tertiary Cover
- Cache Creek Terrane
- Takla Gp. Andesite
- HOSEM INTRUSIVE SUITE
  - Monzonite
  - Monzodiorite
  - Diorite

Deposit outline – 0.2% Cu eq.
A cross section of the transect shows the overlying Quaternary and post-mineral cover.
Surficial Environment
Soil Profiles

[Image of two soil profiles with labeled layers: Ah, Bm, and C.]
A total of 9 samples were collected at each site.

These included material from the Ah, Ae, upper B, lower B and C horizons.

These were analyzed by a variety of generic and laboratory specific methods (blue).

The majority of the methods tested the upper B horizon where
2009 Results

Ah Horizon – Ultratrace >300 m of cover!

Geoscience BC Report 2010-3
2010 Results - Ah Horizon Copper

Ultra trace
Distilled Water
Sodium Pyrophosphate
Ah Horizon- Tungsten

Ultra trace

Distilled Water

Sodium Pyrophosphate
Summary

- Not all cover is equal. Some still has a geochemical connection to bedrock and conventional methods like B-horizon soils and stream sediments can be effective.

- It is important to understand the surficial geology and identify cover types. This will assist with correct sample medium selection.
Summary

- In geochemically detached cover, deep penetrating methods can work if the trap sites are known and the appropriate extraction used.

- At Kwanika organic matter from the Ah horizon is an effective trap. Ions can be extracted using a relatively weak modified aqua regia digestion.
Acknowledgements
From Geophysical data to Mineral Exploration Models

Bill Morris
MAGGIC
Direct detection of a mineral deposit through geophysical surveys is limited:

- To minerals that produce a diagnostic physical property signature (for example massive sulphides)
- To greenfields exploration
- To deposits that occur in near surface environment
- New Technology?
Most instances identification of a mineral deposit is indirect, that is we identify structures and mineral associations that are compatible with the possible occurrence of a specific type of commodity. This approach is applicable:

- To Brownfields exploration (best place to locate a new deposit is where prior deposits were known to exist)
- To finding deep seated deposits in mining camps
- To deposits that do not have a diagnostic signature:
  - A spatially limited deposit (thin veins)
  - Occurring in a diffuse concentration (porphyry copper)
To search for these more complex mineral deposit settings using geophysical methods we must:

- Have a valid mineral deposit model. Often this needs to be revised as new data become available, and may need to be tailored for application to specific mining camp.
- Use ALL data that is available: remote sensing, geophysics, field geology, and borehole logs.
- Have a comprehensive suite of physical rock property measurements.
  - (Geophysics maps physical property variations it is not geology)
GEOPHYSICAL MODELING

• In attempting to develop a better understanding of subsurface geology it is a common exploration strategy to use geophysical modeling techniques.

• For many geophysical measurements the value observed at any point represents the summation of signal from all sources.

• Through use of digital filtering followed by model development the geophysicist attempts to construct some estimate of the subsurface geology.

• It must be remembered that estimate is dependent upon a number of variables: flight line spacing, flight path, sensor sensitivity, sampling rate, etc.,

• In this presentation I report a number of different geophysical modeling approaches and I look to where we might go next
Unless certain controls other than the gravity and magnetic data are available the inherent ambiguities of the physically possible distributions of material which can produce the observed effects make accurate calculations meaningless even though the geophysical data may be of any desired precision.
GEOPHYSICAL MODELLING – Supervised Discrete Object Modeling

• Use geological and geophysical maps to estimate appropriate geometry for sub-surface anomalous source body.

• Effect of individual model estimated by three types of parameters: type of body, location of body, physical property contrast.

• Possible to fix, limit, or float individual parameter so that one can test geological hypotheses: fix body location and strike, allow dip to vary.

• PotentQ, MagMod, PB-Encom QuickMag
GEOPHYSICAL MODELLING – Supervised Discrete Surface Modeling

- Use geological maps to infer geometry of surfaces at depth

- Integrate any other information that is available: boreholes, seismic, EM inversion

- Integrate all data to construct a hypothetical geological model: Need to have some imagination of what is possibly happening… testing various hypotheses.

- Assign physical property data to provide “guesstimate” of what is happening in subsurface

- Can be 2D, or 3D
Inversion is a mathematical procedure whereby physical property distributions are produced describing an observed geophysical signature.

Outcome is controlled primarily by selection of algorithm parameters: smallness, smoothness, depth weighting.

No geological controls

Potential Field data is non-unique: Infinite number of solutions

- UBC-GIF, CGEM-GG3D, Geosoft VOXI, TechnoImaging EMVision,
Example: Non-uniqueness

$3 \text{km}^3$ Gravity inversion with a background of 2.67 g/cm$^3$

**Synthetic Model**

**Constrained Inversion Model**

**Unconstrained Inversion Model 1 (with noise)**

**Unconstrained Inversion Model 2 (no noise)**
Assigning properties to cells with data

- Any cell that contains data will be assigned property estimates based on the most reliable data type(s) in that cell

1. Surface samples
2. Drilling measurements
3. Drilling geology logs
4. Outcrop maps
5. Basement maps
6. 3D geology model
7. 3D domain model

Synthetic example, extrapolated constraints

- Point & interval observations: Mean & confidence intervals on the mean
- Area observations & interpretations: Weighted-average of property estimates for all rock types in each cell
- Volume interpretations: Provide default property values in different areas

Introduce geological constraints into inversion model: Surface geology, boreholes, physical property bounds

Nick Williams_ASEG09_Modelbuilder
Calculation of geological dip and strike from geophysical data?

- Intersection between geophysical features and topographic surface provides estimate of 3D pattern of physical property contrasts for near surface region.

- Use of three point solution. Know height three points on a common surface then we know dip of that surface.
Can we do the same with geophysical data?

The Bathurst Camp
Grenville age deformation of Sudbury Structure

Sudbury Olivine Diabase dikes; Simple dipping slab; Control most aspects of model, strike, location etc.; allow dip to vary to derive estimate of post-intrusion tectonic tilting
Document sense and amplitude of fault displacement
DISCRETE SURFACE MODELING

Incorporate prior geological knowledge into constraining geometry of lithological surfaces

2/17/2012

PDAC _ 2012 DMEC Review
Aeromagnetic data indicate that previous geologic map for region needs revision

Gravity data on series of profiles
Combining results from series of profiles gives pseudo-3D rendition of geological surfaces
Magnetic Remanence

APWP well known for period back to 580my

Therefore it is a simple exercise to derive orientation of remanence vector for any point in North America.
Convert Maps to geologic models

Assign physical properties to units

Rambler Structure
Baie Verte, Newfoundland

Geologically Constrained Inversion
Surface geology and boreholes
Convert Drill-hole information into voxels

3D Grids (voxel models) of physical properties
Check model by comparison with published geological models
Constraints from:

- 2D inversions of anomalies associated with 5 Mile and Three Lakes formations
- Distinctive outcrop pattern created by Ayagaaq Lake Quartzite
Can check inversion model by independent Discrete Surface Model on gravity data.
SUMMARY

• With the tools currently available we are capable of generating useful 3D models, but can be do better?

• Can we recognize lateral changes in physical properties that might vector towards a deposit?

• Can we identify mineral deposit “traps”?

• Possible but we need to begin incorporating a more rigorous approach to geological model development along with improving our geophysical inversion techniques.
SUMMARY

• Geophysicists map spatial variations of physical property parameters

• Geologists map silicate mineral variations

• Only way to link Geology to Geophysics is through physical property calibration measurements

• Need much better understanding of the effect of geological processes on physical property variations
Option 1: Use full 3D geological interpretation

- Create full 3D model of geological surfaces for whole volume
- Extremely powerful, but time, money, and data intensive
- Difficult to update or reproduce with new data
- Model is one interpretation → inversion tests one hypothesis

Joutel VHMS example sources: Fallara et al. (2003), Marquis et al. (2003), Oldenburg and Pratt (2007)
The GOCAD philosophy

- Quantitative understanding
- Multi-disciplinary data integration
- 3D from the beginning
- Leverage existing technology
- Continued R&D
SUMMARY

• It is essential that we incorporate all available data in our models:
  • Data must be integrated in a GIS database.

• Structure is an essential element of all geological maps and many mineral deposit types.

• Majority of observations are acquired on a 2D surface. By integrating this data with topography it is possible to derive estimates of morphology of “geological” contacts in the immediate subsurface by using 3pt solution calculations.

• Extending these geometries to the deeper subsurface can be achieved through integrated geologically and geophysically constrained forward and inverse modeling.
Thank You

SGES, McMaster 3D Visualization Facility

NSERC, NRCan_RAP, Pitney Bowes, Geosoft, Intrepid, Xstrata Nickel

Thelon, GEMS Northern Uranium Consortium and Charles W. Jefferson

This represents a compilation of work completed by:

Madeline Lee, Bill Spicer, Vicki Tschirhart, Peter Tschirhart, and Hernan Ugalde
Discovery of the Tortigny VMS Deposit: Multi Disciplinary GIS-Based Target Generation

C. Beaudry, M.Sc., P.Geo., géo
DMEC-PDAC Workshop, 7 March, 2012
Introduction

Data integration and exploration targeting relies on our understanding of ore deposits and how these deposits can manifest themselves in nature.

This presentation will outline the insights I discovered while doing early work on GIS (1994) at Noranda.

This will be followed by a real world practical example of a GIS compilation which quickly lead to a base metal discovery.
GIS Compilation and Targeting Process

- Inventory of available datasets
  - Topo: lakes, streams, roads, townships, etc.
  - Geology: lithologies, structures, outcrops, etc.
  - Geochemistry: rock, soil, streams
  - Geophysics: magnetics, INPUT, etc.
- Mineral Occurrences
- Identification of deposit model(s) through study of mineral occurrences
- Metallogenic Model of sought after mineralization
- Exploration Model of mineralization
- Generation of map layers with essential elements of exploration model
- Identification of targets through cross correlation of anomalies from map layers
- Prioritization of targets
Types of Data Integration Approaches

- The process can be manual (i.e. visual integration of layers) or automated (i.e. cell or pixel-based approach using summation of layer values).
- The process I used for Toilus was manual.
Automated Target Generation

GIS Vector to Raster Conversion

Vector Polygon Map

Co-Registered Raster Map Layers

ES Modeling

Halfmile Lake TGS Results

Bayes

0.5
1.3
5.4
4.0

Favourable Host
Favourable Horizon
Favourable Mineralization
Favourable Alteration
Manual Target Generation

- Manual approach based on visual superposition of anomalies.
- Advantages: More intimate relation to data. Subtle anomalies may become more obvious.
- Not restricted to a rigorous approach to target generation (intuition can play an important role)
- Disadvantages: Not practical for very large datasets.
Location of Troilus Belt
Troilus Project Case Study
Example of the use of GIS in Regional Exploration

- This Example Based on Information available in mid-90’s
- Troilus Greenstone belt located north of the Abitibi Greenstone belt near Chibougamau in Quebec (Canada).
- Formal exploration activities date to early 50’s with prospecting and drilling of showings.
- Belt was mapped in the 60 ’s.
- Various AEM surveys flown throughout the 60 ’s and 70 ’s.
Troilus Project Case Study
Example of the use of GIS in Regional Exploration

- Government did large lake sediment sampling survey in the 70’s.
- Belt was re-mapped in the 80’s
- Government did a regional INPUT MK VI survey in the 80’s.
- Government compiled all previous exploration work in the 80’s.
- Government did re-mapping of whole belt in 90’s
History of Discoveries

- **Baie Moleon Deposit** 1961 prospecting VMS
  184,000 t @ 3.4% Zn, 1.56% Cu

- **Lessard Deposit** 1971 prospecting VMS
  1.2 M t @ 3.35% Zn, 1.96% Cu, 42.9 g/t Ag, 0.72 g/t Au

- **Troilus Mine** 1987 Multi-method Porph.
  49 Mt @ 1.38 Au, 1.23 g/t Ag, 0.12% Cu

- **Tortigny Deposit** 1994 GIS - prospect. VMS
  496,000 t @ 2.24% Cu, 6.17% Zn, 0.24% Pb, 61.72 g/t Ag, 0.05% Co

- **DeMaures Deposit** 1996 Multi-method VMS
  350,000 t @ 7.8% Zn, 1.4% Cu, 22.0 g/t Ag.

- + Over 20 other VMS/porphyry mineral occurrences discovered since 1950’s.
History of Discovery of Tortigny Deposit

  - GIS compilation
  - Metallogenic model of VMS mineralisations
  - Proposal for staking of priority targets (6 claim groups)
- Mar. 1994
  - Complete staking of priority claims (circa 280 claims)
- July 1994
  - Initial ground reconnaissance of priority targets.
  - Geology of Tortigny Ext. claim group confirmed as favorable.
August 1994

- Discovery during reconnaissance prospecting of thin veinlets of chalcopyrite in a siliceous outcrop on Tortigny Ext.
- Discovery during follow up prospecting of high grade angular massive sphalerite boulders near the mineralized outcrop (15.1% Zn, 0.14% Cu, 0.3% Pb).

Amazingly it only took 8 months and less than US$50 K to make the discovery.
Sept.-Oct. 1994

- Stripping of the mineralized outcrop and delineation at surface of a folded massive sulfide lense intercallated within tuffaceous and graphitic sediments and enclosed between two thick basalt units.
- Best channel samples returned:
  - 4.0 m @ 4.57% Cu, 5.75% Zn, 135.5 g/t Ag
  - 6.0 m @ 0.52% Cu, 6.53% Zn

Conclusion

- The mineralization at Tortigny is very similar to the deposits at Baie Moleon and Lessard (De Maures had not been discovered yet) and also to many of the mineralized occurrences in the district.
Metallogenic Model of Troilus VMS deposits

- Deposits in Troilus greenstone belt different than traditional VMS environments because mineralization found in narrow tuff horizons within a dominantly mafic volcanic domain, whereas traditional model calls for bi-modal mafic-felsic volcanism.

- From the description of the principal known deposits and other occurrences we defined an empirical/genetic exploration model applicable to the district.
Exploration Model for Troilus-type VMS deposit

- Near the base of the Mezière Formation.
- Near or in a mapped felsic horizon.
- Near cross-cutting fault structures.
- Absence of diamond drilling.
- Near conductive INPUT bands.
- Isolated INPUT anomalies.
- Cu and/or Zn anomalies in lake bottom sediments.
- Presence of base metal mineralization.
Airborne Magnetic Coverage
INPUT Anomalies
Previous Drilling
Mineral Occurrences
Land Status
Initial Observations

A study of the data in the light of the metallogenic/exploration model indicated high favourability where the following conditions were met:

- In or near Felsic Volcanics
- Low magnetic pattern typical of Meziere Formation
- Input Anomalies
- Base Metal mineralization nearby
- Near major cross-cutting faults
- Cu and or Zn anomalies in lake sediments
- No previous drilling
## Actual Targets Generated

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<th>Table 4: Pinnacles target areas defined by compilation</th>
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Highest Priority Target
Highest Priority Target was Open
Initial Surface Expression

Figure 2.1: Local geology of the Tortigny area
Initial Drill Discovery

Figure 2.2: N-S cross-section through the Tortigny deposit
Delineation of the Tortigny Deposit

- A total of 42 diamond drill holes were collared by Xstrata (Noranda) on the deposit.
- Defined a resource down to 250 m vertical (deposit open at depth).
- The bulk of the mineralization located within the hinge zone of a F2 antiformal syncline.
- Resource estimate in 1997 was 496,000 tonnes @ 2.24% Cu, 6.17% Zn, 0.24% Pb, and 61.72 g/t Ag.
- Deposit was not considered attractive to Noranda because of limited dimensions and company farmed-out deposit, eventually coming under control of Beaufield Resources who have continued to develop property.
Tortigny Today

Hole TO-08-05
6.02% Cu 15.00% Zn
0.10 g/t Au 145.5 g/t Ag
over 12.55m.
Tortigny Today

Beaufield Expecting a new NI 43-101 Compliant Resource Shortly.
Tortigny Deposit Exploration Post-mortem and Conclusions

- GIS is a very effective tool to optimize regional grass roots exploration.
- When used with extensive datasets and realistic metallogenic models can quickly identify the best targets in an area for early follow-up.
- A very effective way to generate exploration targets.
- Deposit similar in many ways to other VMS deposits in camp; none are currently economic.
- VMS deposits can occur in a variety of settings and care must be taken in designing exploration programs for such deposits.
Geoscience BC:
Five Years of Data for Discovery

‘Lyn Anglin
President and CEO
History of Geoscience BC

• Exploration industry engagement with government in British Columbia:

• Rocks to Riches Program (2003)
  – Grant of $1.17 M to the Association for Mineral Exploration BC (was the BC & Yukon Chamber of Mines)

• Creation of Geoscience BC (2005)
  – Initial grant of $25 M to BCYCM
  – Second grant of $11.7 M (2008)
    Total = Minerals ($26M) and Oil & Gas ($10.7M)
Geoscience BC — Operations and Governance

- Not-for-profit BC society: mandate to attract mineral and oil&gas investment to BC
- Industry directed – volunteer Board of Directors and Technical Advisory Committees
- Small professional group: facilitates geoscience data collection, interpretation, marketing & outreach
- Low overhead; flexible and entrepreneurial approach to projects
- Investment income and partnership funding in addition to government grants
Advantages of Geoscience BC

- Flexibility – program design, partners, implementation
- Major regional programs, rapid data delivery, new techniques/methodologies
- Proposal-driven programs and student scholarships
- Engagement with industry, academia, government, First Nations, communities
- Complements government geoscience organizations

Footprint of GBC’s QUEST-style Projects
Geophysical Surveys

- QUEST & QUEST-West*
  - Gravity, EM and Magnetics
- QUEST-South*
  - Gravity
- Jennings River*
  - Magnetics
- Bonaparte Lake*
  - Magnetics and Radiometrics

- Detailed EM case studies
  - Huckleberry, Endako, Equity Silver, Bell, Granisle, Mt Milligan

* completed
Geophysical methods studies

• ZTEM case study*
  – Mt Milligan

• Rock properties case studies
  – Mt Milligan
  – Endako
  – Huckleberry

• QUEST data integration inversion and modeling*
  – Similar project for QUEST-West and QUEST-South now underway
  – See also Peter Kowalczyk’s talk tomorrow at 11:30

* completed
Regional Geochemical Surveys

- QUEST, QUEST-West and QUEST-South = > 275,000 sq km regional geochem infill sampling and reanalysis of archived samples
  - > 5000 new drainage samples
  - > 20,000 archived samples from previous govt surveys reanalyzed using current laboratory methods
- Partial map sheets in the Rockies were completed = > 19,000 sq km, > 1,300 sample sites
- NEW: 2010 - Vancouver Island archived moss mat stream samples to be reanalyzed, including PGEs on a subset of the samples
**Geochemical methods studies**

- Geochemistry in Covered Areas*
- Halogen Geochemistry in Surficial Exploration*
- Deep Penetrating Geochemical Methods
- Till Geochemistry & Surficial Mapping
- Placer & Lode Gold Classification
- Porphyry Indicator Minerals
- Isotopic Fingerprinting Study
- QUEST Geochemistry value-added projects
  - SiroSOM
  - Mapping under cover

* completed
Mineral Deposit and Mapping studies

- Mapping & Mineral Potential ⭐
  - Deer Park Map Sheet*
  - Parts of Vancouver Island
  - Whitesail Lake Map area*
  - Chilcotin Basalts*
  - Terrace/Kitimat area
  - Purcell Supergroup

- Mineral Deposits ⭐
  - MDRU Alkaline Project*
  - Adanac*
  - Taseko Lakes Area*
  - Red Chris
  - Bralorne-Bridge River District
  - Cariboo Gold District
  - Nicola Arc

* completed
Other studies

- Hyperspectral imaging case studies on MapPlace*
- ASTER Imagery for BC on MapPlace*
- Rock Properties database for BC*
- QUEST area MINFILE and Property File Updates on MapPlace*

* completed
New Regional Data – The “QUEST” Projects

Airborne Gravity:
- Area: 139,438 km²
- Line km’s: 77,989 km (2 km line spacing)
- 896 km strike length of the Quesnel Terrane

Geochemical Surveys:
- New sampling >5000 stream and soil
- Re-analyses >20,000 stream
- Area 275,000 km²

GBC airborne gravity and geochemistry data: www.geosciencebc.com
GSC Nechako airborne gravity data: http:\\gdinfo.agg.nrcan.gc.ca
New Regional Data – The “QUEST” Projects

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GSC Nechako airborne gravity data: http://gdcinfo.agg.nrcan.gc.ca

GeoScience BC
DMEC Workshop Series
Quest BC

Workshops using Quest Data

- Society of Economic Geology-Keystone, Colorado-2010
  - "Exploration in 2020-The Tools and Techniques to Explore Undercover"
- GBC-BCGS Vancouver-2011
  - “Exploration Undercover; a practical example using the QUEST study area”
DMEC Workshop Series
Quest BC
Geology of the Quest BC area: regional setting and ore deposit models

Thomas Bissig, Mineral Deposit Research Unit, University of British Columbia

Acknowledgements: Geoscience BC, and MDRU, Jim Logan, Paul Schiarrizza (BCGS).
Porphyry deposits in BC and Yukon

Various types of porphyry mineralization

Alkaline and Calc-alkaline affiliations, but alkaline Cu-Au association most important

Highland Valley porphyry Cu deposit is the largest Open pit mine currently operating in N. America

2 Principal episodes: U. Triassic to Mid Jurassic and Late Cretaceous to Eocene
Upper Triassic-Upper Jurassic Porphyries

- Most prolific metallogenic epoch
- Pre to syn accretion
- Early Calc alkalic Cu-Mo (Au) porphyries
- ~206-203 Ma Alkaline Cu-Au porphyries
- ~200 Ma Calc alkalic Cu-Mo and Cu–Au porphyries
- 190-180 Ma Alkaline Cu-Au porphyries
- <170 Calc alkalic Cu-Mo-Au porphyries (Island Cu)

Upper Triassic to Lower Jurassic Porphyry deposits
- Calc-Alkaline Cu-Mo (~210 Ma)
- Alkaline Cu-Au (206-203 Ma, mostly silica undersaturated)
- Calc-Alkaline Cu-Mo-Au (<201 Ma)
- Alkaline Cu-Au (~190-180 Ma)
- Unspecified Porphyry deposits
- Other deposits

Tectonic units/Terranes
- Triassic-Jurassic arc
- Quesnel, Stikine Terranes
- Paleozoic pericratonic fragments
- Metamorphic belt, mainly Yukon-Tanana/Stikine
- Slide Mountain terrane
- Cache Creek terrane: Mesozoic accretionary ass.
- Ancestral North America

Mod after Nelson and Colpron, 2007
Cretaceous to Eocene porphyries

All calc-alkaline, some Mo +/- W rich

In British Columbia concentrated along the Skeena Arch = major crustal break

Epithermal Au-Ag prospects present.
Triassic

Collapse of the back-arc Slide Mountains Ocean, and initial interaction of marine arc with continental margin

Formation of calc-alkalic and alkalic PCD along length of arc at end of magmatic episode

Tectonic setting at time of porphyry emplacement

Middle Jurassic
2nd stage of alkalic porphyry
Final amalgamation
Arc shifts to west
Sinistral strike slip & opening of N. Atl.

Triassic

Formation of calc-alkalic and alkalic, silica undersaturated, PCD along length of arc at end of magmatic episode

Early Jurassic

Formation of alkalic silica saturated PCD in localized area

Alkalic Cu-Au porphyries
Mt Polley, Milligan, Lorraine

Calc Alkalic Mo and Cu-Mo
Endako, Gibraltar

Extensive cover!

Geoscience BC Map 2009-4-1
Nechako basin: host to Late Cretaceous to Eocene porphyries and epithermal deposits and prospects

- Epithermal
- Porphyry Mo-Cu
- Carbonate hosted Au-Ag
- Other probable epithermal
Igneous associations

Porphyry Cu-Au-Mo deposit classification

Silica-undersaturated alkalic

Silica-saturated alkalic

Cu-Au

Cu-Au(-Mo)

Cu-Mo

SW Pacific calc-alkalic

High-K calc-alkalic

Arizona calc-alkalic

alkaline

sub-alkaline

Na$_2$O + K$_2$O (wt%)

SiO$_2$ (wt%)

Modified from Lang et al., 1995
Porphyry Mineralizing processes

LINKAGE BETWEEN PORPHYRY AND EPITHERMAL ENVIRONMENT

- Meteoric water
- Lepanto Au-Cu-As high-sulfidation epithermal
- Yerrington Cu-porphyry
- Brine-vapour separation and refluxing
- Deep external fluids
- 1000°C H₂O saturated carapace
- 1 km
- 2 km
- 3 km
- 4 km
- 5 km
- 6 km
- 7 km
- Lubr Hill Batholith
General alteration model
(calc alkalic type)

BAJO DE LA ALUMBRERA (1975, pre-mining)

Qz-mt +/- K-sfp, barren

Ep-chl (propylitic)

Bi-ksp +/- mt (potassic)

Qz-ser +/- clay overprint (phyllic +/- argillic)

Not shown: Advanced argillic/silicic lithocap

Se also Ulrich and Heinrich, 2002)
Classic mineralization styles (calc alkalic type)

Multiple vein generations, Quartz gangue

Breccias

Stockwork

Chuquicamata pit in March 2009
Classic calc-alkalic porphyry model

Hydrothermal Alteration Zones, Minerals, and Ores in a Porphyry Copper Deposit

Explanation:
- Chl - Chlorite
- Epi - Epidote
- Carb - Carbonate
- Q - Quartz
- Ser - Sericite
- K-feld - Potassium Feldspar
- Bi - Biotite
- Anh - Anhydrite
- Py - Pyrite
- Kaol - Kaolinite
- Alun - Alunite
- cp - Copper
- gal - Galena
- sl - Sulfide
- Au - Gold
- Ag - Silver
- mb - Molybdenite
- mag - Magnetite

Propylitic Chl-Epi-Carb

Phyllic

Potassic Q-K-feld -Bi + anh

Argillic Q-Kaol-Alun

Chl

Peripheral cp-gal-sl-Au-Ag

Low-Pyrite Shell py 2%

Low-Grade Core cp-py mb

Ore Shell py 1%

Pyrite Shell py 10%

cp .01-3%

mb .003%

A Chl-Ser-Epi-mag

B (Modified from Lowell and Guilbert, 1970)
Alteration and Porphyry Evolution

1: Potassic

2: Phyllic

3: Adv. Argillic

Camus 2003
Major alkaline porphyry and epithermal districts: Alkaline is a BC speciality

Alkaline porphyry deposits

Alkaline epithermal deposits
Alkalic vs Calc-alkalic porphyries

Alkalic districts typically have...

Several small deposits

N-Parkes

Potassic, calcic, sodic alteration, abundant mt, hematite dusting is typical. Phyllic and argillic alteration scarce and qz veins only in deposits related to silica saturated rocks. Generally low py.

Myarolitic cavity filled with Bn-cpy, N-parkes

Ab-ep-chl +/-carb, chl alteration, Mt Milligan

Complicated and apparently small alteration footprint.

Mt Polley NE zone

Breccias important in some deposits particularly in silica undersaturated types. May host high grade.
Magnetite-Apatite veins, Afton, BC

Pegmatite style K-fsp, coarse bi veins with late cpy, Copper Mountain, BC

Garnet-diopside-biotite cemented breccia Galore Cr.

Megacrystic Or-plag phyric monzonite. Galore Cr.
Alkalic porphyry Cu-Au deposits: Generalized alteration model

Alkalic lithocap
(albite - K-feldspar - sericite - quartz - carbonate ± tourmaline) - chargeability high, magnetic low

Skarn (mt skarn may form in limestone or reactive volcanic / volcaniclastic rocks, magnetic high)

Reddened propylitic halo
(hematite dusting of feldspars, negative S isotopes in sulfides, increasing magnetic susceptibility towards ore, Zn and Pb geochemical anomaly)

Legend - Alteration

Distal Propylitic (chlorite sub-zone: chl-carb±hm±epi)

Skarn (py-hm-mt-chl-carb-gt)

Skarn propylitic (epi-py)

Alkalic lithocap (ab-kf-ser-carb--py-tm)

Sodic (ab-qz-hm)

Outer Propylitic (albite-actinolite subzone: ab-act-qz-carb-py)

Inner Propylitic (actinolite-hematite-epidote subzone: ab-chl-act-epi-hm-qz)

Outer calc-potassic (Kf-chl-bt-ab-act-qtz-cp)

Inner calc-potassic (bt-act-mt-kf-ab-qtz-bn)

Based on Wilson et al. 2007
“Proven and probable reserves estimated [Jan 1/09]: 46.2 million t grading 0.34% Cu, 0.29 g/t Au and 0.95 g/t Ag, The current mine life is to the end of 2015.”
http://www.imperialmetals.com

NE zone Wight pit, NE zone
Silica undersaturated to saturated. Age: 203-200 Ma: Pre-accretionary
Three clusters of deposits with varying Cu:Au:Ag

NE zone; high Cu/Au with greatest Ag

SE zone has lowest Cu/Au

Central zone largest tonnage and site of initial mining

Compiled from Panteleyev et al., 1996; Logan and Mihalynuk, 2005; Rees et al., 2005; and Logan et al., 2007
Legend

- **Polymictic breccia and conglomerate**
- **Monzonite-monzodiorite**
- **Non- or weakly mineralized matrix-rich breccia**
- **Mineralized cement- and matrix-rich breccia**
- **K-feldspar-phyric monzonite**

- **Pit boundary**
- **Faults**
- **Long-section / x-sections**
- **DDH location and trace**

Modified from Imperial Metals, 2005
Alteration & Cement Distribution

Legend

- Pit outline
- Drill hole logged in this study
- Geological boundary
- Major faults

- Potassic / strongly potassic
  (K-feldspar, magnetite, ± biotite, ± epidote, ± chalcopyrite, ± bornite)
- Albite
- Propylitic (chlorite subfacies)
  (pyrite, chlorite, ± hematite, ± sericite)
- Propylitic (epidote - albite subfacies)
  (epidote, albite, chlorite, pyrite)
- Garnet
- Overburden
- Sulfate line

0.2% Cu contour

MDRU
Mineral Deposit Research Unit

Geoscience BC

Pass, 2010
Mt Milligan

590 Mt at 0.193 % Cu and 0.35 g/t Au

Silica saturated Alkaline porphyry, Age: 185-182 Ma: syn to post accretionary

Panoramic view over pre-mining deposit
- DWBX zone = Cu-rich, Au-moderate
- WBX zone = Cu-rich, Au-poor
- MBX zone = Cu- and Au-rich
- “66” zone = Cu-poor, Au-rich
Mount Milligan rocks

Volcanic host rocks, strong bi +/- mt alteration, Augite phenocrysts repl by sulfides

Flowbanded rainbow dyke: Sulfides in flow bands. Kspar +/- bi alteration

Ab-ep-act-carb alteration (inner propylitic)

Thin fracture controlling sericitization of feldspars, upper trachyte
Alteration geometry with ore grade
Late stage veins (Vb: qz-py-carb; VI py-chlorite), throughout the deposit

Fluids: Low density and salinity, no evidence for boiling, depth > 1.5 km

Nadretteite-Stibiopalladinite (Pd$_2$Sb-Pb$_2$Sb)
Sperrylite (PtAs$_2$) and others present.

Le Fort et al. 2011
Variation in trace elements in epidote and pyrite as S isotopic compositions

Epidote
- Decrease in Fe³⁺, Cu, Bi, REE fractionation
- Increase in Mn, Sr, V, Ga, Sb, As

Pyrite
- Decrease in Mn, Cu, Mo
- Increase in Co, Zn, Ag, Sb, Ti, Bi, As

Jago et al., in press
Nicola/Takla Gp. Quesnel Terrane

Location map of study sites

Legend:
- Sibine Terrane
- Quesnel Terrane

Symbols:
- Alkaline porphyry Cu-Au deposit
- Areas studied
- Probable future study sites
- City/town
- Road
- Lake

BCGS Geoscience map 2010-1 QUEST bedrock
Logan et al
Volcanic setting

- Nicola Group, Takla Group, Stuhini Group: Upper Triassic, basalts and basalt derived volcano sedimentary rocks.

- Volcanic host rocks are relatively proximal, subaqueous, locally possibly subaerial (Mt Polley, Lac La Hache)

- Coherent basalts have high magnetic susceptibility around “coeval” porphyry Cu-Au mineralization.

- Alkalic compositions of volcanic rocks may be restricted to vicinity of coeval ore deposits (?)
Highly oxidized parts of the arc are more likely to host a Mt. Polley
Oxidized rocks tend to be more alkalic

Magnetic susceptibility *10^{-3} SI units

Increasing oxidation state

Mt Polley, Lac La Hache
Mt. Milligan and NE of Bridge Lake

Augite without magnetite inclusions

Ongoing MDRU research; Bissig et al. 2010
**Quest Aeromagnetic Signatures**

**Mount Polley:** Relatively high magnetic intensity in Nicola Gr. volcanics

BC geomap (see www.geosciencebc.com)

Ongoing MDRU research; Bissig et al. 2010, Vaca et al. 2011
Mount Milligan: Generally subdued magnetic intensity in volcanics. Mag high corresponds to mid Jurassic (169 Ma) intrusion

BC geomap (see www.geosciencebc.com)

Ongoing MDRU research; Bissig et al. 2010, Vaca et al. 2011
Endako Mo porphyry: different mag signature compared to alkalic Cu-Au

Least-altered Phyllic (Quartz-sericite-pyrite)

Least-alt’d Casey Granite

Argillic (Kaolinite)

Potassic alteration

Kaol overprint

Magnetic susceptibility (x10^-3 SI units)

Casey Granite

Endako Quartz Monzonite

Courtesy of D. Mitchinson
Exploring the gap
Bedrock geology

Interpretation of bedrock geology on the basis of next to no outcrop

Logan et al. 2010. Geoscience BC report 2010-5
The different approach:
Interpreting bedrock geology on the basis of stream and lake geochemistry using statistics and neural network technology

K-feldspar megacrystic alkalic porphyry

K-feldspar pyrite vein cutting monzonite

K-feldspar megacrystic alkalic porphyry
Conclusions

- Dominantly porphyry Cu-Au and Cu-Mo, lesser epithermal affinity.
- Late Triassic in Quesnel Arc and Late Cretaceous to Eocene
- Alkalic porphyries have narrow footprint, are magnetite-rich and relatively pyrite poor
- Important differences between alkalic vs. calc-alkaline porphyries which influence exploration
Use of Aeromagnetics and Gravity to Explore for Porphyry Deposits Under Cover: Example from the Quest BC Area

James P. Siddorn, Ph.D., P.Geo.
Practice Leader
SRK Consulting (Canada) Inc.
Email: jsiddorn@srk.com
Uses of Aeromagnetics

- **Mapping geology.....what attributes?**
  - Lithology;
  - Structure;
  - Alteration;
  - Metamorphism; and
  - Mineralization.

- **Mapping geology.....why/how is it possible?**
  - Magnetic minerals are present in (almost) all ‘rock types’;
  - Magnetometers can measure tiny magnetic signals; and
  - Airborne surveys allow rapid and inexpensive coverage.

- **When do we need aeromagnetics?**
  - Poorly exposed areas.....help interpolate between outcrops;
  - Covered areas......provide some geological control; and
  - Well exposed areas......there are always surprises.
Magnetics as an Effective Mapping Tool
Aeromagnetic Expressions of Geological Features

Regional TMI

Intrusion & Graben (1)

Bedding & structure (2)

Extrusives & alteration (3)
Indirect versus Direct Targeting

- **Indirect targeting (most common):**
  - Interpretation & structural analysis of magnetic data assists by:
    - Highlighting suitable fluid conduits and traps; and
    - Recognition / interpretation of favorable host (& source) lithologies.

- **Direct targeting (magnetic signature associated with deposit):**
  - Kimberlites;
  - BIF’s;
  - Some porphyries & skarns;
  - Some IOCG’s.

Ernest Henry
IOCG Cu-Au
122Mt 1%Cu
0.5g/t Au
Interpretation - 1

- **Aeromagnetic interpretation should be broken down into three stages:**
  - OBSERVATION;
  - COMPILATION; and
  - INTERPRETATION.

- **All of the principles of geological mapping and interpretation apply equally to aeromagnetic data; and**

- **Decide on the:**
  - Scale;
  - Filters;
  - Resolution achievable and the resolution required; and
  - Time needed and time available.
Interpretation - 2

- **When relating lithology or stratigraphy to magnetics, think:**
  - Which rocks contain the magnetic minerals (field evidence, susceptibility measurements, petrology)?
  - Do these rocks always contain magnetic minerals in this area?
  - How and when did the magnetic minerals form?

- **Be wary of making the following generalizations:**
  - “The XYZ Formation is highly magnetic” - *Is it?? Always?? Everywhere?? Uniformly??*
  - “The igneous and metamorphic rocks will be more magnetic than the sedimentary rocks” - They are frequently not!!
  - “The mafic rocks will be more magnetic than the felsic rocks” - They are frequently not!!

- **Think in terms of the magnetic rock body in the ground….not the magnetic field it causes.**
- **Formulation of structural history consistent with observations.**
Structural Analysis – 1

• What can we get out of the data?
  • Distribution of structures (folds / faults etc), lithologies & alteration - form surface mapping - extend from 2D plan view to 3D Kinematics?
  • Relative timing?
  • Development of tectonic models (local & regional);
  • Predictive targeting:
    • Direct anomaly;
    • Direct structural analogy; and
    • Indirect structural targeting (new models?);
  • Extension of models outside immediate area to different areas or terranes.
Structural Analysis – 2

- **Key Questions:**
  - What structures occur?
  - What is their extent?
  - Relative geometry?
  - What strain was produced?
  - What P/T conditions did they form at?
  - What is the 3D geometry?
  - What was the tectonic driving force & history?
  - What is the relationship of all this to mineralization?

Ontario – Superior/Grenville Compilation, 400m line spacing, RTP1VD. Wabigoon subprovince.
Structural Analysis – 3

**Important Observations To Make:**

- Map structural traces (geophysics, field data, maps, remote sensing);
- 3D - fault dips (field data, magnetic profiles);
- Fault displacement vectors:
  - Relative displacements;
  - Kinematic indicators;
  - Associated structures (veins / R, R’ faults & fractures);
- Timing relationships:
  - Fault - fault relationships;
  - Displacement of marker units;
  - Absolute dates.
- Fault characteristics:
  - Thin, straight (brittle, shallow, low T);
  - Broad zone with discrete breaks (brittle-ductile zone - mod P & T); or
  - Broad zone, no breaks (ductile - deep, high T).
Structural Analysis – 4

- **Important Observations To Make (cont....):**

  - Associated features:
    - Folds (parallel / oblique);
    - 2nd order sediments / basins;
    - Associate intrusives / extrusives;
    - Veining / alteration; and
    - Recognition of fault hierarchy (1st order, 2nd order etc).

  - Strain variations inferred from block geometries:
    - Structures at block margins; and
    - Strain within blocks (possible modified stress fields).

  - Regional context:
    - Relationship of area to regional structures;
    - Setting (e.g. basin, mobile belt, arc etc.);
    - Orogenic events elsewhere at inferred time of faulting?
    - Pre-existing structures possibly reactivated?
Geological Models for Mapping

- Geological models are a **primary** component of the interpretation process for producing maps;
- In order to present an **interpretation** of the geology of the region, there needs to be a coherent framework of stratigraphic and structural principles that form the basis of the interpretation;
- A coherent regional geological pattern can be followed through the series of maps;
- Individual structures can be interpreted in both a time and space context. We can interpret when and how faults moved;
- The spatial distribution of mineral deposits in relation to structures becomes evident, and can be related to the geological evolution of the region, not just the geometry;
- Areas and structures with potential for reactivation at later times become apparent; and
- Cross-sections can be developed which provide a realistic 3D form consistent with the geological models.
Interpretation Flowchart

- Extract line data from 1VD image
- Extract Lithology data from TMI image. Divide area into major lithological packages.
- Add geological data from surface geology maps, drilling results – identify formations and marker units.
- Interpret faults – breaks, truncations etc. Annotate accordingly.
- Add geological data from surface geology maps, drilling results – identify formations and marker units.
- Improve on unit boundaries, annotate and connect marker units from magnetics.
- Add exploration model parameters.
- Add geological model parameters.
- Finalize map presentation, prepare cross-sections and block model, check geology for internal consistency.
Method

1VD data

Stratigraphic Form Line mapping

Fault/deformation zone mapping (including timing)

Fold mapping (including timing)

Total Field data

Lithology mapping

Integrated interpretation
Dataset Integration

Regional geophysics

Published literature

Local geophysics

Drillhole data

Regional mapping

Integrated interpretation
Example of Final Geological Maps
Final Geological Maps - Yilgarn

The Yilgarn Craton in Western Australia - a Late Archean Granite-Greenstone terrane.

Kambalda Ni deposits

St. Ives Au deposit

Junction Au deposit
Quest – The Problem?

Area is largely overlain by Quaternary cover.
**Reviewing the Geological History....e.g. Quest**

- **Stratigraphy:**
  - **Nicola Group (Southern Quesnel; Middle to Upper Triassic):** Pyroxene, feldspar-pyroxene and feldspar phryic basalt breccias, volcaniclastic units and sandstone;
  - **Takla Group (Northern Quesnel; Middle to Upper Triassic):** Augite-phyric and aphyric basalt breccia, agglomerate, tuff and flows; red fragmental basalt; tuffaceous argillite and siltite; conglomerate, sandstone, greywacke, siltstone and chert; local andesitic basalt; minor limestone and diorite;
  - **Cache Creek Complex (Lower Mississippian to Lower Jurassic):** Mafic volcanic rocks, limestone, argillite, chert, serpentinite;
  - **Slide Mountain Group (Lower Mississippian to Middle Permian):** Basalts and Mississippian chert-quartz sandstones and conglomerates
  - **Snowshoe Group:** Quartzite, schist, phyllite, gneiss, marble, conglomerate; and
  - **Chilcotin Group (Oligocene to Pliocene):** Columnar jointed olivine basalt.
Reviewing the Geological History….e.g. Quest

- **Deformation:**
  - Subduction and accretion of intermontane terranes to Laurentia, ca. 200 Ma;
  - Subduction and associated sinistral transpression with movement of Quesnel terrane northwards, ca. 185 Ma;
  - Subduction and associated dextral transpression, ca. 100 Ma; and
  - Dextral transtension and major dextral movement along the Denali-Tintina fault system, ca. 55 Ma.

Monger, 2008
Upper Triassic-Upper Jurassic Porphyries

- Pre- to syn- accretion;
- Early Calc-alkalic Cu-Mo (Au) porphyries;
- ~206-203 Ma Alkallic Cu-Au porphyries;
- ~200 Ma Calc-alkalic Cu-Mo and Cu –Au porphyries;
- 190-180 Ma Alkallic Cu-Au porphyries; and
- < 170 Calc-alkalic Cu-Mo-Au porphyries (Island Cu).

Modified after Nelson and Colpron, 2007
Quest - Datasets

Geotech VTEM Data, TMI, 4000 m line spacing

Geotech VTEM Data, 1VD, 4000 m line spacing
Quest - Datasets

GSC Aeromagnetic Data, RTF, 800 m line spacing

GSC Aeromagnetic Data, 1VD, 800 m line spacing
Quest – Form Line Mapping

Quest Area Form Lines

Quest Form Lines Vs. Mapped Geology

DMEC Workshop: Exploration Undercover in a Greenfield Setting
March 7, 2012
Quest – Fault Mapping

Quest Area Faults

Quest Faults with GSC 1VD magnetic grid
Quest – Comparison to Existing Fault

Quest Area Faults

BCGS Faults
Quest – Association with Gravity

Quest Area Faults with GBC Bouguer (2.67 g/cc) Gravity

GBC Bouguer (2.67 g/cc) Gravity
Mt. Milligan occurs at significant deflection in Quest fault network, from NW-SE to E-W.

590 Mt at 0.193 % Cu and 0.35 g/t Au

Age: 185 Ma

Deflection corresponds to alignment of Mt. Milligan, Chuchi Lake, Col, Kwanika, Takla-Rainbow, and Lorraine porphyries.
Quest – Mt. Polley Setting

Mt. Polley occurs within a fault duplex, trending WNW relative to main NW trending faults.

46.2 mt @ 0.34% Cu,
0.29 g/t Au, 0.95 g/t Ag

Age: 203-200 Ma
Quest – Mt. Polley Setting

Split in Mt. Polley syenite-monzonite intrusion related to fault network
Quest – Mouse Mountain Setting

Continuation/repetition of the Mt. Polley fault duplex
Quest – A Tectonic Model?

Reverse-sinistral transpression creating WNW or E-W pull-apart structures

Monger, 2008
Quest – A Tectonic Model?

Tectonic Setting of Stikinia

Reverse-sinistral transpression creating WNW or E-W pull-apart structures

Slide Courtesy of Jim Logan, BC Geol. Surv.
Quest – A Tectonic Model?

Multi-stage intrusive system
*Lorraine*

Stage 1
- Pyroxenite – leucosyenite dyke swarm,
- Late porphyry mineralization
- 180 Ma

Shearing
- Local shear zone formation, sinistral displacement

Tilting
- 40-60 degrees to the NE

Stage 2
- NW trending pyroxenite-leucosyenite dyke swarm
- 178.5 Ma

Reverse-sinistral transpression creating WNW or E-W pull-apart structures

Slide Courtesy of Fionnuala Devine
Quest – A Tectonic Model?

Examples from the Duckling Creek Syenite Complex

Reverse-sinistral transpression creating WNW or E-W pull-apart structures

Slide Courtesy of Fionnuala Devine
Flower Structures and Porphyry/Epithermal Deposits

PNG highlands – Compressional flower structure at bend along sinistral strike-slip plate boundary
Conclusions

• To produce an accurate, applied geological interpretation:

  • Think geologically – process/controls when defining geological elements from aeromagnetic data;
  • Focus your interpretation with an understanding of potential controls on the distribution of mineralization first;
  • Incorporate reality – structural settings/geometries, known geological relationships in the area (e.g. stratigraphic relationships);
  • Define your geological and structural history; and
  • Incorporate multiple datasets, e.g. existing geological mapping, drillhole data.
DMEC Workshop Series
Quest BC
Workshop Assessments

The Challenge of Exploration Undercover
DMEC Workshop Series
Quest BC
Workshop Assessments
The Workshop-Ground Rules

- Staking costs: $50/km²
- Geochemical sampling: $150/sample with analysis
- Geophysical surveys:
  - Aeromag: $35/km
  - Aeromag w radiometrics: $50/km
  - Airborne EM: (helicopter Time Domain): $165/km
  - Ground mag: $150/km
- Standard IP: (search depth-250 m): $3,500/lkm
- Premium IP: (search depth-500 m): $8,500/km
- Ground EM: $3,500/lkm
- Geologist: $1250/day (includes field support costs)
- Geochemist/Geophysicist: $1500/day
- Drilling: $175/m (includes permitting, supervision and reclamation)

A budget of $500,000 has been allocated for the project and management would like to see sufficient funds available for a 1000 m drill program.
The Workshop-Resources

- ARCGIS coverage's + Driver
- Maps + sections
- Experts
- Your team mates
The Workshop-GIS Coverages

- Geophysics
  - Grids & vector data
  - VTEM survey flight path – vector
  - VTEMS Profiles – vector
  - DEM for VTEM survey – Grid
  - TMI – Grid
  - TMI Tilt – Grid
  - Air Grav – Bouguer gravity – Grid
  - AdTau – Time constant VTEM – Grid

- Raster images
  - VTEM survey flight path
  - DEM for VTEM survey
  - TMI
  - TMI Tilt
  - Air Grav – Bouguer gravity
  - SFI[1] – VTEM dE/dT Ch10 early-time response
  - SFI[10] – VTEM dE/dT Ch10 mid-time response
  - AdTau – Time constant VTEM

- Geophysics 3D Inversion Modelling
  - Air grav interp – Sea level density
  - Air mag interp – Sea level susceptibility
  - Bedrock and deep overburden conductivity
  - Surface density and susceptibility domains
  - Surface density, susceptibility and conductivity domains
  - Density and Susceptibility Model 2D Depth Grids
    - Gravity – g/cm³
      - Gravity – Topo draped depth -0125
      - Gravity – Topo draped depth -0125
      - Gravity – Topo draped depth -1125
      - Gravity – Topo draped depth -1625
      - Gravity – Topo draped depth -2125
      - Gravity – Topo draped depth -2625
      - Gravity – Topo draped depth -3125
      - Gravity – Topo draped depth -3625
      - Gravity – Topo draped depth -4125
      - Gravity – Topo draped depth -4625
      - Gravity – Topo draped depth -5125
      - Gravity – Topo draped depth -5625

- Magnetics – SI
  - Magnetics – Topo draped depth -0125
  - Magnetics – Topo draped depth -0125
  - Magnetics – Topo draped depth -1125
  - Magnetics – Topo draped depth -1625
  - Magnetics – Topo draped depth -2125
  - Magnetics – Topo draped depth -2625
  - Magnetics – Topo draped depth -3125
  - Magnetics – Topo draped depth -3625
  - Magnetics – Topo draped depth -4125
  - Magnetics – Topo draped depth -4625
  - Magnetics – Topo draped depth -5125
  - Magnetics – Topo draped depth -5625
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<tr>
<th>Thurs/Fri</th>
<th>Oct 13/ Oct 14 - Workshop</th>
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<tbody>
<tr>
<td>8:30 - 9:00</td>
<td>Ken Witherly</td>
<td>Introduction to Workshop Purpose and datasets</td>
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<tr>
<td>9:00 - 12:00</td>
<td>all</td>
<td>Exploration Targeting in multidisciplinary teams</td>
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<tr>
<td>12:00 - 1:00</td>
<td>Working Lunch (provided)</td>
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<tr>
<td>13:00 - 14:00</td>
<td>all</td>
<td>Exploration Targeting in multidisciplinary teams</td>
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<tr>
<td>14:00 - 15:00</td>
<td>all</td>
<td>Prepare Presentation/Coffee Break</td>
</tr>
<tr>
<td>15:00 - 16:30</td>
<td>all</td>
<td>Team Presentations (10 min presentations per group)</td>
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<tr>
<td>16:30 - 17:00</td>
<td>Speakers</td>
<td>Group Discussion</td>
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DMEC Workshop Series
Quest BC
Workshop Assessments

Keystone-2010
A1, A2, B1, B2, C1, C3, C3

Vancouver-2011
Thursday
A1, A2, B1, B2, C1, C2
Friday
A1, A2, B1, B2, C1, C2

Totals
A-6; B-6 and C-7
# DMEC Workshop Series
## Quest BC
### Workshop Assessments

<table>
<thead>
<tr>
<th>Group</th>
<th>Geology</th>
<th>Geochem</th>
<th>Geophysics</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Strong development of geophysical model to guide selection of targets</td>
</tr>
<tr>
<td>A2 “Desperados”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Used magnetic results to modify the geology map and define targets</td>
</tr>
<tr>
<td>A3 “Rio Pinto”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Made use of geology, geochem and geophysics to define two target areas.</td>
</tr>
<tr>
<td>A4 “Stake by Night Resources”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Did a very detailed analysis of Mt Milligan data sets</td>
</tr>
<tr>
<td>A5 “CBX Resources”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Did a very detailed analysis of Mt Milligan data sets</td>
</tr>
<tr>
<td>A6 “A-Team”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Did a very detailed analysis of Mt Milligan data sets-defined the ‘donut’ structure that linked their projects with Mt Milligan</td>
</tr>
</tbody>
</table>
DMEC Workshop Series
Quest BC
Workshop Assessments-A2
Target Areas
DMEC Workshop Series
Quest BC
Workshop Assessments-A3

Target Areas Gravity
DMEC Workshop Series
Quest BC
Workshop Assessments-A5

Regional Gravity with Structure
DMEC Workshop Series
Quest BC
Workshop Assessments-A6

Priority Targets-Gravity

The “Donut”
DMEC Workshop Series
Quest BC
Workshop Assessments-A6

Matt-Geophysicist
Peter-Geologist
JJ-Geologist
Catherine-Geologist
Scott-Geologist
Lindsay-Geologist
DMEC Workshop Series
Quest BC
Workshop Assessments-A Composite
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>B1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Produced 14 targets which were ranked; referred to Mt Milligan as test case.</td>
</tr>
<tr>
<td>B2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Subdivided targets as alkalic cu-au and calc-alkalic cu-mo</td>
</tr>
<tr>
<td>B3 “Tymar Ventures”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Undertook structural assessment of mag/gravity to try and define plutons</td>
</tr>
<tr>
<td>B4 “Great Group 6”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>One of few groups to use the neural net inferred geology</td>
</tr>
<tr>
<td>B5 “Wing it Exploration”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Chose to focus on one follow-up block</td>
</tr>
<tr>
<td>B6 “Blue Sky Resources”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Focused on TMI-1stVD and geochem to define targets</td>
</tr>
</tbody>
</table>
DMEC Workshop Series
Quest BC
Workshop Assessments-B1

TMI & targets
DMEC Workshop Series
Quest BC
Workshop Assessments-B2

Au
DMEC Workshop Series
Quest BC
Workshop Assessments-B4
<table>
<thead>
<tr>
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<th>Geochem</th>
<th>Geophysics</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 “Reindeer Resources”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>One of few groups to use VTEM to develop target areas</td>
</tr>
<tr>
<td>C2 ”K-T Exploration”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Made the most complex assessment products; most number of targets</td>
</tr>
<tr>
<td>C3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>One of few groups to use VTEM to develop target areas</td>
</tr>
<tr>
<td>C4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Did fairly sophisticated analysis of geochem and used gov assessment files to assess previous work.</td>
</tr>
<tr>
<td>C5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Made use of neural net geology</td>
</tr>
<tr>
<td>C6 ”Tad Resources”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Defined their search criteria</td>
</tr>
<tr>
<td>C7 ”Cynical Exploration”</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Focused on mag highs</td>
</tr>
</tbody>
</table>
DMEC Workshop Series
Quest BC
Workshop Assessments-C1
DMEC Workshop Series
Quest BC
Workshop Assessments

Acknowledgment-
Thanks to the Teams!