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Welcome to Exploration ’17

Chris Nind, General Chair

It is a pleasure to welcome you to Exploration ’17. The theme of the conference, integrating the geosciences, while not novel, is increasingly pertinent for geoscientists tasked with locating ore bodies in new frontiers and adding reserves to existing mining camps. Thoughtful application of new technologies and methods is necessary to improve success rates while minimizing the environmental impact of exploration and keeping project costs and timelines on budget. Geologists, geochemists and geophysicists need to access the full geoscience toolkit when exploring for deep and well camouflaged economic deposits. Exploration ’17 offers a wide range of plenary sessions, technical talks, case histories, posters and workshops that review the achievements of the past decade and look ahead to future exploration needs.

The exhibition provides delegates with opportunities to view and discuss current and new exploration technologies with developers and service providers. Attendees at the technical luncheon will hear about ongoing R&D focused on deep exploration technologies. The winners of the Frank Arnott Challenge will be honoured at our Gala Dinner. All exhibitors and delegates will be welcomed to our conference party at the Hockey Hall of Fame, to enjoy a uniquely Canadian mix of mining, hockey and beer/wine.

This conference would have been impossible to put together without the help of an excellent team. A special thank you to Micki Allen (Conference Manager), Jenna McKenzie (Conference Sectretary), John McGaughey and Charles Beaudry (Technical Committee), Ken Witherly (Case Studies), Edna Markham-Mueller (Workshops), Victoria Tschirhart and Mike Thomas (Editors), Hernan Ugalde and Iris Lenauer (Posters) and Greg Hollyer (Marketing). Thank you to the chairs and co-chairs of our technical sessions, and all of the authors and speakers who have contributed to the excellent technical program. It is not possible to attend all of the talks, but the full length papers have been uploaded onto a USB memory stick that each delegate will receive in their delegate bag. Short abstracts for each talk are printed in this guide book.

We are extremely thankful and encouraged by the large number of sponsors of Exploration ’17, particularly Lockheed Martin (Platinum Level), the three Gold Level sponsors: Cameco, SGS and BHP. The logos for all of our sponsors will be on display during the conference.

Thank you to our exhibitors. A short description of each exhibitor is printed in this guide. We encourage you to visit them during the conference.

Chris Nind
General Chair, Exploration ’17

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TABLE OF CONTENT

AT A GLANCE

	Room	October 21	October 22		October 23
Fairmont Royal York Hotel	Tudor	**Workshop 1** Uncertainty in 3D Modelling and Inversion	**Workshop 6** Advances in Geophysical Technologies		
	Quebec	**Workshop 2** Integrated Spectral Geology	**Workshop 5** Application of Indicator Mineral Methods to Bedrock and Sediments		
	Confederation	**Workshop 3** Advanced Concepts in Evaluating and Interpreting Geochemical Data	**Workshop 4** Integrated Interpretation - Modelling of Geological & Geophysical Data for Mineral Exploration		
	Territories				
	Ontario				
MTCC	104 A&B				
	104 C&D				
	105	Exhibitor Setup		Icebreaker Reception and Trade Show	Trade Show
	106				
	107			Poster Session 1	Poster Session 1
	Bassett Theatre		**PM:** Open Forum: Exploration Technology – The Evolving Business Context		**AM:** Plenary Session 1: State of the Art **PM:** Plenary Session 2: Integrating the Geosciences

October 24	October 25	October 26	October 27
		Workshop 8 Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting	**Workshop 13** Data Integration for the Next Generation of Mineral Exploration Models
		AM: Workshop 9 Status and New Developments in Field Portable Geochemical Techniques and Site technologies for Mineral Exploration **PM: Workshop 11** Assay Quality Control: The Master Class	**AM: Workshop 14** Geochemical and Infrared Spectral Data Integration for Alteration **PM: Workshop 15** Making Your Case: Clear, Memorable & Compelling Characterization and Targeting
		AM: Workshop 7 Seismic Methods & Exploration **PM: Workshop 10** The Future of Mineral Exploration Drilling and Sampling	**Workshop 12** SEG DISC 2017, EM Fundamentals and Applications
Technical Luncheon	Gala Dinner		
AM-1: Airborne Geophysics **AM-2:** Ground & Borehole Geophysics **PM:** Geophysical Processing & Inversion	**AM-1:** Technical Innovation 1: Geophysical Waves & Potentials **AM-2:** Technical Innovation 2: Drilling, Samples & Geology **PM:** Technical Innovation 3: Geophysical Diffusion		
AM-1: Geochemistry **AM-2:** Analytic Methods **PM:** Spectral Geology and Remote Sensing	**AM:** Best Papers from the EAGE Conference on Geophysics for Mineral Exploration and Mining, Barcelona 2016		
Trade Show	Trade Show		
Poster Session 1 / Poster Session 2	Poster Session 2		
Case Studies / Case Studies – Frank Arnott Awards	**AM-1:** Targeting – Deep or Under Cover **AM-2:** Targeting – Mine Site to Camp Scale **PM:** Integrated Interpretation		

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Technical Luncheon

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Icebreaker

DIAS GEOPHYSICAL

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RioTinto

SGL

Coffee Breaks

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Closing Reception

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Conference Party at Hockey Hall of Fame

SCINTREX

Field School

Sudbury, Ontario ▪ October 16–20, 2017

The study area of the Exploration ’17 field school will be Vale’s WD-16 polymetallic deposit, north of Sudbury, Ontario.

Numerous geophysical methods and geochemistry have already covered this undeveloped deposit and this field school will present a unique opportunity for the attendees to integrate the geology of a deposit with geophysics and geochemistry.

The Field School will be held at Vale Technical Building in Sudbury as well as on site at the WD-16 deposit. Field school attendees will be lodged at a local hotel in Sudbury.

The WD-16 polymetallic deposit is located 45 minutes north of Sudbury and the trainees will be transported to the project site from Sudbury and back.

During the five days of the field school, the following presentations and field demonstrations will be given; either on the grounds of the Vale Technical Building or at the WD-16 project site. Demonstrations of modern exploration equipment will be conducted by major industry suppliers.

- The geology of the Sudbury Igneous Complex
- Ground magnetics and its applications and results on the WD-16 project
- Ground gravity and its applications and results on the WD-16 project
- Induced polarisation and its applications and results on the WD-16 project
- Physical properties and their applications and results on the WD-16 project
- Airborne electromagnetics and its applications and results on the WD-16 project
- Ground electromagnetics and its applications and results on the WD-16 project
- Geochemistry of the WD-16 project

In addition to the field school material, synthetic maps of all the geophysical methods, geology and geochemistry, as applied on the WD-16 project, will be handed out to the attendees, and Vale will give each attendee a copy of Dr. Peter Lightfoot’s book titled Nickel Sulfide Ores and Impact Melts, Origin of the Sudbury Igneous Complex, published by Elsevier, 2017.

The registration fee includes a hotel room for 4 nights in Sudbury, breakfast and box lunch during the field school, a farewell dinner, local transportation and the return bus fare between Toronto and Sudbury. The group will depart from Toronto in the morning on Monday, October 16 and return in the afternoon on Friday October 20.

We look forward to seeing you.

Richard Lachapelle B.Sc. P.Eng.
Field School Chair

SOCIAL EVENTS

Social Events at Exploration17

Time	Event	Room
Sunday 22 October 2017		
18:00 – 19:30	Icebreaker Reception and Trade Show	MTCC Rooms 105, 106 & 107
Monday 23 October 2017		
12:00	SGS Presentation & Lunch	Fairmont Royal York Hotel (Confederation 3 Room)
12:00 – 14:00	The KEGS Foundation Special Luncheon	The Overdraught, 156 Front St. W.
15:30 – 17:30	Drinks, Trade Show & Posters	MTCC Rooms 105, 106 & 107
18:00 – 22:00	SCINTREX'S 50TH BIRTHDAY PARTY	Hockey Hall of Fame
20:00	Martinů piano trio by GF Instruments	Fairmont Royal York Hotel (Confederation 3 Room)
Tuesday 24 October 2017		
12:30 – 13:45	Technical Luncheon Guest Speaker: Richard Hillis, CEO, Deep Exploration Technologies	Fairmont Royal York Hotel (Ontario Room)
15:40 – 17:30	Drinks, Trade Show & Posters	MTCC Rooms 105, 106 & 107
19:00 – 23:00	Gala Dinner Frank Arnott Award Winners	Fairmont Royal York Hotel (Ontario Room)
Wednesday 25 October 2017		
15:40 – 17:30	Farewell Social	MTCC Rooms 105, 106 & 107

Icebreaker and Closing Reception

MTCC Rooms 105, 106 & 107
18:00 – 19:30, Sunday 22 October 2017

Icebreaker Reception and Trade Show
15:40 – 17:30, Wednesday 25 October 2017

Closing Reception – Farewell Social

Andrew Boniwell Trio

Andrew has been a pianist on the Toronto jazz scene since 1980. A multiple time participant in the Downtown Toronto Jazz Festival he has also appeared at the Distillery Jazz Festival, JVC Jazz Festival, Guelph Jazz Festival and the Barrie Jazz Festival. Jim Galloway, past Director of Downtown Toronto Jazz Festival called Andrew and his jazz quintet "a good example of the fine talents right here on our own doorstep".

Andrew's quintet 'The Uncertainty Principle' features some of Toronto's finest jazz musicians including alto sax player Richard Underhill (JUNO winner 2003) and Artie Roth (double bass) who will join Andrew at Exploration 17 to provide trio music to groove to and chill by. The trio will laying down some cool jazz standards and some funky jazz tunes, always keeping it toe tapping, intimate and soulful.

SGS Presentation – Using Qemscan Data in Exploration: How to Add Value to Your Project!

Fairmont Royal York Hotel - Confederation Room 3
12:00, Monday 23 October 2017

Join us at starting at 12:00 pm (Lunch buffet served at 12:00pm with presentation to follow at 12:30 pm) for a delicious buffet lunch and listen to sara prout's ((Ph.D.) Senior Mineralogist, Vancouver Operations for SGS Canada) riveting talk on how QEMSCAN mineralogy can produce large volume, low cost, quantitative mineral abundance data providing confidence and detail on domain definition and block modelling.

Most benificial to:
Exploration Geologists
Resource Geologists
VPs of exploration
Project decision makers

We look forward to welcoming you to our Presentation on Monday

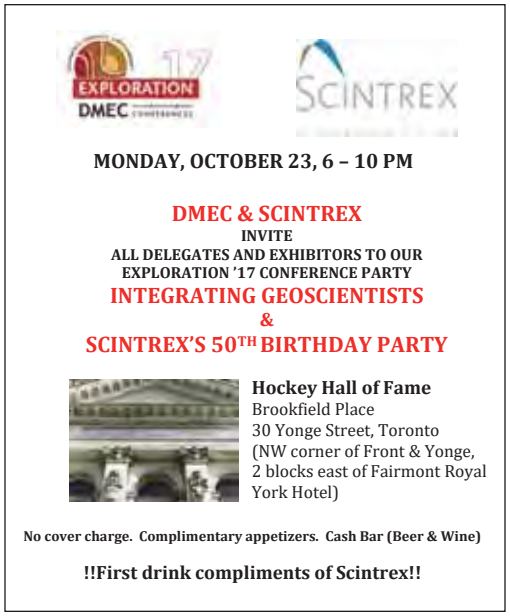
Integrating Geoscientists & Scintrex's 50th Birthday Party

Hockey Hall of Fame - Brookfield Place
30 Yonge Street, Toronto
18:00 – 22:00, Monday 23 October 2017

DMEC & Scintrex invite all delegates and exhibitors to our Exploration '17 conference party Integrating Geoscientists & Scintrex's 50th Birthday Party

No cover charge. Complimentary appetizers. Cash Bar (Beer & Wine)

First drink compliments of Scintrex



Special Luncheon: Saluting Geophysical Pioneers and Veterans

The Overdraught
156 Front Street West, Toronto
12:00 – 14:00, Monday 23 October 2017

Organized by The KEGS Foundation in connection with Exploration ’17, on the 50th anniversary of Exploration ’67 and the 150th anniversary of Canada Buffet lunch; cash bar

Make a reservation online at www.kegsfoundation.org
Or contact sreford@kegsfoundation.org

Martinů piano trio

Fairmont Royal York Hotel - Confederation Room 3
20:00, Monday 23 October 2017

GF Instruments, Brno, Czech Republic invites you to a special concert of Martinů piano trio (Prague) for Exploration 17 Toronto

- Petr Jiříkovský – piano
- Pavel Šafařík – violin
- Jaroslav Matějka – cello
- Joseph Haydn – Trio in C major
- Bohuslav martinů – Trio in D minor
- Franz Schubert – adagio from trio in e-flat major
- Antonín DvoŘák – trio in b-flat major

Technical Luncheon

Fairmont Royal York Hotel, Ontario Room
12:30 – 13:45, Tuesday 24 October 2017

Guest Speaker:
Richard Hillis, PhD
CEO, Deep Exploration Technologies Cooperative Research Centre,
Adelaide, SA, Australia

Richard Hillis is CEO of the DET CRC. He graduated BSc (Hons) from Imperial College (London) and PhD from the University of Edinburgh. Richard was previously Mawson Professor of Geology and Head of the Australian School of Petroleum at the University of Adelaide. He has published ~200 research papers and has been involved in establishing and selling/listing several technology and resources companies. Richard is currently a director of AuScope, an NCRIS company, and of the CRC Association. He is also a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE).

Abstract:
Towards 'Prospecting Drilling'
The Deep Exploration Technologies Cooperative Research Centre (DET CRC) is a $AUS 155M research initiative funded by the Australian Government and the mining industry. The period from its conception to completion spans, almost exactly, the period since the previous decennial mining exploration conference. This luncheon talk will reflect on the challenges of a multi-disciplinary, multi-organisational, multi-locational and multi-sponsor research initiative of this scale. It will also discuss the technologies developed, focusing on coiled tubing drilling and real-time sensing and their potential to enable a revolutionary new approach to mineral exploration beneath barren cover, i.e. 'prospecting drilling': cheap, safe, environmentally-friendly and extensive, continuous drilling programs that map mineral systems beneath cover, enabling progressive vectoring towards mineral deposits.

Gala Dinner

Fairmont Royal York Hotel, Ontario Room
18:30 – 23:00, Tuesday 24 October 2017

A delicious 3 course meal with wine in Ontario Room, Fairmont Royal York Hotel - Cocktails 6:30 – 7:00 pm, Dinner 7:00 – 11:00 pm – and Music provided by the Andrew Boniwell Trio.

We will also take time to say

CONGRATULATIONS!

The top 3 ranking teams have been selected!
1st & 2nd place standing will be announced
at the awards dinner, Exploration '17

WORKSHOPS

Saturday 21 October 2017

Time	Event
08:00 – 09:00	Workshop Registration – Fairmont Royal York Hotel
09:00 – 16:00	Workshops – Fairmont Royal York Hotel **Workshop 1** Uncertainty in 3D Modelling and Inversion, The Centre of Exploration Targetting, presented by Prof. Mark Jessell, Dr. Mark Lindsay, Dr. Li Nan, Dr. Vitaliy Ogarko, Evren Paykuz-Charrier, Jérémie Giraud **Workshop 2** Integrated Spectral Geology, presented by Lori Wickert, Dave Coulter, et al **Workshop 3** Advanced Concepts in Evaluating and Interpreting Geochemical Data, presented by Eric Grunsky et al

Sunday 22 October 2017

Time	Event
08:00 – 09:00	Workshop Registration - Fairmont Royal York Hotel
09:00 – 16:00	Workshops – Fairmont Royal York Hotel **Workshop 4** Integrated Interpretation - Modelling of Geological & Geophysical Data for Mineral Exploration, presented by Tim Chalke, John McGaughey, Dianne Mitchinson, Glenn Pears, Mark Jessell and Pim van Geffen **Workshop 5** Application of Indicator Mineral Methods to Bedrock and Sediments, presented by Beth McClenaghan, GSC, & Dan Layton-Matthews, Queen's University **Workshop 6** Advances in Geophysical Technology, presented by Dennis Woods et al

Thursday 26 October 2017

Time	Event
08:00 – 09:00	Workshop Registration – Fairmont Royal York Hotel
09:00 – 12:00	Workshops – Fairmont Royal York Hotel **Workshop 7** Seismic Methods & Exploration, presented by Bernd Milkereit & Gilles Bellefleur **Workshop 8** Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting, presented by Randy Enkin (GSC), David Clark (CSIRO), Clive Foss (CSIRO), and David Pratt (Tectomet Exploration) **Workshop 9** Status & new developments in field portable geochemical techniques and site technologies for mineral exploration, presented by Lemière (BRGM) & Uvarova (CSIRO)
12:00 – 13:00	Workshop Registration – Fairmont Royal York Hotel
13:00 – 16:00	Workshops - Fairmont Royal York Hotel **Workshop 8** (continued) Improving Exploration with Petrophysics **Workshop 10** Future of Mineral Exploration Drilling and Sampling, presented by DET CRC **Workshop 11** Assay Quality Control: The Master Class, presented by Lynda Bloom & Charles Beaudry

Friday 27 October 2017

Time	Event
08:00 – 09:00	Workshop Registration – Fairmont Royal York Hotel
09:00 – 12:00	Workshops – Fairmont Royal York Hotel **Workshop 12** SEG DISC 2017, EM Fundamentals and Applications, presented by Doug Oldenburg & KEGS **Workshop 13** Data Integration for the Next Generation of Mineral Exploration Models, presented by NSERC-CMIC Mineral Exploration Footprints Research Network **Workshop 14** Integration of Geochemical and Infrared Spectral Data for Alteration Characterization and Targeting, presented by Dick Tosdal, Federico Cernuschi, Carsten Laukamp, Eric Grumsky and Xiaodong Zhou
12:00 – 13:00	Workshop Registration – Fairmont Royal York Hotel
13:00 – 16:00	Workshops – Fairmont Royal York Hotel **Workshop 12** (continued) SEG DISC 2017, EM Fundamentals and Applications **Workshop 13** (continued) Data Integration for the Next Generation of Mineral Exploration Models, presented by NSERC-CMIC Mineral Exploration Footprints Research Network **Workshop 15** Making Your Case: Clear, Memorable & Compelling, presented by Prof. David Beatty

Workshop 1 Uncertainty in 3D modelling and Inversion

3D Geoscience Team, Centre for Exploration Targeting, UWA
8:00–17:30
Saturday October 21, 2017

Presenters from the Centre for Exploration Targeting
Prof Mark Jessell, Dr Mark Lindsay, Dr Li Nan, Dr Vitaliy Ogarko,
Evren Paykuz-Charrier, Jérémie Giraud

This workshop will introduce industry, government and research end-users to the latest developments in 3D geological modelling and inversion, with particular reference to new workflows that enable us to characterise and analyse geological uncertainty in 3D. The workshop will introduce the basics of 3D geological modelling and uncertainty analysis using implicit modelling codes. Workshop participants will have the opportunity to use first-hand these techniques applied to the 3D geology of a complexly deformed terrain. The transfer of geological uncertainty into geophysical inversion codes will be presented as an example of using knowledge on uncertainty to downstream applications.

We will provide an overview of the key drivers and methods that have been used to characterise regional 3D geology, with particular emphasis on the strengths and weaknesses of currently available systems. This will incude an introduction to new workflows for 3D modelling that allow estimation of geological uncertainty. Participants will have the opportunity to discuss how these methods can lead to downstream application for drilling optimization, resource estimation, process simulation and prospectivty analysis.

Participants will gain hands-on experience in using a three-stage approach for developing their understanding of uncertainty in 3D geological model space: 1) Manual tuning of key geological parameters to provide alternate hypotheses using an implicit modelling code (we will use the GeoModeller system) 2) Systematic evaluation of uncertainty using parameter sweeps of multiple inputs 3) Monte Carlo analysis of uncertainty for complex geological models.

The workshop will present an overview of the fundamentals of a new workflow integrating geology, geophysics and petrophysics while quantifying the related uncertainty. We discuss how these geoscience disciplines are integrated in a statistical framework to improve imaging through inversion of geophysical data. This approach allows results and related uncertainty to be evaluated in a statistical way. This will include hands-on experience in using prior knowledge of petrophysical and geological uncertainty as constraints for joint inversion of geophysical datasets.

Each session will close with a group discussion that covers current capabilities and future trends in combining geological and geophysical uncertainty, including improved data to geometry engines, new visualisation and analysis tools for uncertainty estimation, and extension of these techniques to other downstream applications.

Workshop on Uncertainty in 3D modelling and Inversion

3D Geoscience Team, Centre for Exploration Targeting, UWA
Saturday October 21, 2017

Time	Event	
08:00 – 09:00	Registration	
09:00 – 09:15	Introduction	Mark Lindsay
09:15 – 09:45	History of 3D modelling and inversion	Mark Jessell
09:45 – 10:30	Introduction to geological uncertainty	Evren Pakyuz-Charrier
10:30 – 11:00	*coffee/tea*	
11:00 – 12:30	Hands-on exercise: manual tuning, parameter sweeps and data uncertainties in 3D	Nan Li & Evren Pakyuz-Charrier
12:30 – 13:00	Group discussion	All
13:00 – 14:00	*lunch*	
14:00 – 14:45	Introduction to petrophysical uncertainty	Jeremie Giraud
14:45 – 16:00	Hands-on exercise: geologically and petrophysically constrained inversion	Vitaliy Ogarko & Jeremie Giraud
16:00 – 16:45	*coffee/tea*	
16:45 – 17:15	Group discussion	All
17:15 – 17:30	Wrap-up	Mark J & Mark L
17:30	*close*	

Participants will be provided with demonstration licenses for all software used for installation on their own Windows 64 bit machines prior to the workshop. **No computers will be provided.**

*Note – full day workshops include two coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 2 Integrated Spectral Geology

8:00–16:00
Saturday October 21, 2017

Presenters
Lori Wickert – Remote Sensing Geologist, Geological Spectral Imaging
Dave Coulter – Consulting Geologist, Spectral Xplorer
Xiaodong Zhou – Consultant, Spectral Geology and Remote Sensing
Sasha Pontual – Director, Principal Geologist, AusSpec International
Benoit Rivard – Professor, Remote Sensing, University of Alberta
Jeff Harris – Remote Sensing Geologist, Geological Survey of Canada

This workshop is designed to familiarize the project geologist with all aspects of remote sensing data that could be incorporated into a mineral exploration project, and to provide practical experience in how to use the derived information in conjunction both alone and with other geological information to maximize exploration success. Remote sensing data can be at all scales and could include regional scale optical or radar satellite borne data, airborne hyperspectral, surface or sample derived spectral information or newer hyperspectral core scanning or imaging data and results, depending on the project.

The workshop will consist of a series of lectures and interactive sessions led by consultants and researchers recognized for their expertise in their field. The morning session will introduce and build on spectral geology theory as it applies to mineral exploration; with a focus on data quality, what data to collect, as well as how to collect and use it in conjunction with other remotely sensed data sources. Afternoon sessions will focus more on sensors, particularly on case studies, and remote sensing targeting and data integration. This will include focused presentations on the primary satellite and airborne imaging systems and their applications, uses and limitations in mineral exploration; as well as a review and assessment of the data, results and information which can be derived by hyperspectral core imaging technology. Case studies will be used whenever possible to demonstrate actual data use and interpretation strategies. Overall, the objective of this workshop is provide a hands-on and experience to the participant, working with data derived from 'real' projects with integrated datasets at multiple scales for different commodities whenever possible. This will illustrate how data is turned into information which is then used as a tool to foster mineral exploration success for any commodity or application.

Prerequisites:
Geological, some prior knowledge of alteration systems and mineral deposits would be beneficial. Participants should bring their own laptops to facilitate exploring course data; software for use for data when needed will be supplied.

Course Duration: 1 Day (Morning & Afternoon) – includes coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Course Materials: Digital course notes and select data sets.

Technology Support from:
Spectral: ASD & Spectral Evolution
Core Scanning: CoreScan, TerraCore

Participants will be provided with demonstration licenses for all software used for installation **on their own Windows 64 bit machines** prior to the workshop. **No computers will be provided.**

Workshop 3 Advanced Concepts in Evaluating and Interpreting Geochemical Data

8:00–16:00
Saturday October 21, 2017

Course Presenters
Natalie Caciagli, Juan Carlos Ordonez-Calderon, Eric Grunsky, Qiuming Cheng, Raimon Tolosana-Delgado, Cliff Stanley, Jennifer McKinley, June Hill.

Participants of this workshop will learn methods for data analytics in geochemistry. Over the last decade there has been a rapid growth in the application of data analytics for data-driven business decisions in virtually every industry. In the next 10 years the mining industry will have to rapidly adopt and apply the power of data analytics to the ever-growing volume of geochemical data sets. However, geochemical data have unique mathematical properties and should not be analyzed without consideration of its structure. Geochemical data are "compositions"; and by definition, must sum to a constant (e.g.100%) and therefore none of the components (elements/oxides) are free to vary independently. This special property of geochemical data can lead to erroneous results when standard data analytics methodologies are applied.

The workshop will introduce several methods to circumvent problems arising from the compositional nature of geochemical data. Classical raw elemental ratios resolve the constant sum problem and are useful to model processes controlled by stoichiometry. However, these raw ratios restrict geochemical data to positive numbers which limits the application of most data analytics methods; typically developed for variables that are free to range in the positive and negative real number space. Alternatively, log-ratios of compositional data solve the constant sum problem and range across the entire real number space. The log-ratio transformations make geochemical data amenable to an arsenal of data analytics tools available to unlock the valuable information contained in data sets, allow for "process discovery" and subsequent "process validation"

The workshop will cover the application of; applying ratios and logratios to compositional data; molar element ratio methods; multivariate methods including principal component analysis, cluster analysis, discriminant analysis, classification and regression trees, linear/non-linear geostatistics and random forests.

Course Duration:
1 Day (Morning & Afternoon) – includes coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 4 Integrated Interpretation; Modelling of geological and geophysical data for mineral exploration

Mira Geoscience Team
8:00–16:00
Sunday October 22, 2017

Presenters from Mira Geoscience
Tim Chalke, John McGaughey, Dianne Mitchinson, Glenn Pears

Invited presenters
Mark Jessell, Pim van Geffen

Target Audience:
Geologists, Geophysicists, Explorationists. (people attending Saturdays workshop on Uncertainty in 3D modelling and Intersion)

Exploration is becoming harder, with greater focus at depth or under cover. Decisions need to be made to eliminate ambiguity and decrease uncertainty within 3D models, supported and cross-validated by multiple data sets. An integrated interpretation is not a simple approach, but provides answers to geoscientific questions which are stronger than individual elements interpreted on their own. In terms of integrating geological and geophysical data, the essential goal is to interpret the available geophysical data in terms of geological domains. In turn, these domains can then be assessed in a meaningful way technically and with standard business logic to assess return on investment.

The integrated process requires a common sense approach to interpretation that is flexible, adaptive and objective driven. It is paramount to maintain focus on the geological objective. The methodology is not an exact formula or workflow; particularly when multiple geophysical surveys are involved. Understanding the relationships between geology, geophysical responses and rock properties is the key to success. First, you must identify how geophysical signatures relate to geology to develop a geological basis for your interpretation. Following this, rapid 3D geological modelling and geologically based forward modelling and inversion are essential for model validation and quantitative integration of data. We review the principles of this common-sense integration framework with selected case study examples and demonstrate some of the 3D modelling techniques.

This workshop is complementary and acting as a series with the Saturday workshop titled *Uncertainty in 3D modelling and Inversion*. Presented by UWA CET.

Workshop on Integrated Interpretation; Modelling of geological and geophysical data for mineral exploration

Mira Geoscience Team, Sunday October 22, 2017

Time	Event	
08:00 – 08:30	Registration	
08:30 – 09:45	Introduction to Integrated Interpretation	Tim Chalke and John McGaughey
09:45 – 10:00	Overview of Saturday workshop on Uncertainty in 3D Modelling and Inversion	Mark Jessell
10:00 – 10:30	*coffee/tea*	
10:30 – 12:00	Tools and methods for Integrated Interpretation	Dianne Mitchinson Glenn Pears Pim van Geffen
12:00 – 13:00	*lunch*	
13:00 – 14:30	Break out session; working through selected case studies	All
14:30 – 15:00	*coffee/tea*	
15:00 – 16:00	Case studies and demos	Dianne Mitchinson Tim Chalke Pim van Geffen

*Note – full day workshops include two coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 5 Application of Indicator Mineral Methods to Bedrock Sediments

8:30–16:30
Sunday October 22, 2017

Course Conveners
Beth McClenaghan, Geological Survey of Canada
Dan Layton-Matthews, Queen's University

Course Description

This one-day short course will review principles, methods, and developments the application of indicator mineral methods to mineral exploration around the world by providing presentations by some of the most experienced practitioners in the field. Indicator mineral methods applied to exploration for a broad range of deposit will be reviewed, including gold, diamonds, VMS, porphyry copper-gold, rare metals, and tungsten. Topics will also in include heavy mineral sample processing methods and microanalytical techniques.

Schedule: Sunday October 22, 2017 – 8:30 to 16:30

Time	Event	
08:30 – 09:00	Introduction to indicator mineral methods, sample processing, and quality control	Beth McClenaghan, Geological Survey of Canada
09:00 – 09:30	Microanalytical analysis of indicator minerals as applied to mineral exploration	Dan Layton-Matthews, Queen's University
09:30 – 10:00	Trace element chemistry of silicates and oxides as indicators to metamorphosed base metal sulfide deposits in the Cambrian Kanmantoo Group, South Australia	Paul Spry, Iowa State University
10:00 – 10:30	*coffee/tea*	
10:30 – 11:00	Overview of tourmaline as an indicator mineral in exploration	Andy McDonald, Laurentian University
11:00 – 11:30	Lithosphere thickness determinations and kimberlite diamond potential	Michael Seller, De Beers
11:30 – 12:00	Overview of magnetite as an indicator mineral	Sarah Dare, University of Ottawa
12:00 – 13:00	*lunch*	
13:00 – 13:30	A review of scheelite chemistry and its use an a discriminator in ore-deposit settings, use as an indicator mineral and monitor of ore-forming processes	Dan Kontak, Laurentian University
13:30 – 14:00	Instructive oddities from 40 years of indicator mineral exploration	Stu Averill, Overburden Drilling Management Ltd.
14:00 – 14:30	*coffee/tea*	
14:30 – 15:00	Porphyry indicator minerals (PIMS) and porphyry vectoring and fertility tools (PVFTS)	Jamie Wilkinson, Imperial College London and David Cooke, ARC Centre of Excellence in Ore Deposits (CODES)
15:00 – 15:30	Indicator mineral signature of the Strange Lake REE deposit, Labrador, Canada	Beth McClenaghan, Geological Survey of Canada

*Note – full day workshops include two coffee breaks and a full lunch
Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 6 Advances in Geophysical Technology

8:00–16:00
Sunday October 22, 2017

Presenters
Mal Cattach, Gap: high-powered transmitters
Chris Nind (retired): gravity state-of-the-art and beyond
Circe Malo Lalande, GDD & Simon Mann, Zonge (Aust): IP instrumentation
Roger Sharpe, Quantec: Titan24 and Orion3D developments
Syd Visser, SJ Geophysics: Volterra system development
Jim Macnae, RMIT: magnetic sensors for EM geophysics
Andreas Chwala, IPHT: SQUID receivers in EM exploration
Ronny Stolz, IPHT & Anre Vorster, DeBeers: SQUID magnetic gradiometers
Yves Lamontagne, Lamontagne: recent UTEM developments
Ben Polzer, Vale: Vale EM technology development
Andrew Duncan, EMIT: flexible TEM instrumentation
Kurt Sørensen, SkyTEM: developments of the SkyTEM system
Louis Polome, Spectrem: recent Spectrem-Plus developments
Ron Bell, IGS & Johannes Stoll, MGT: UAV's in exploration
Jan Francke, Groundradar: ground penetrating radar systems

This workshop brings together many of the world's leading geophysical instrumentation inventers and developers, to discuss their approach to geophysics and geophysical exploration. What ledthem over the past decade to invent and continually develop the most advance geophysicalsensors and systems available today. There will be presentations on specific instrumentation, andoverviews of other commercially available systems, particularly where the new developments ofthe past decade fit in with the continuum of geophysical equipment advances that have occurredover the past 60 years and longer.

Technology marches on in the human experience and geophysical advances both lead and takeadvantage of technological innovation in the wider public domain. Increased computing power andsatellite navigation are two classic examples of this trend, which have had their impact in previousdecades. Recent major advances in communication technology is a leading driving force behind themost recent increase in the sophistication of the new generation of geophysical equipment.

Software development is a key component of advances in geophysical technology, and thesedevelopments will also be highlighted where they are connected to hardware advances. However,the full gambit of software development in data processing and interpretation is a subject in itsown right, and will not be covered in this workshop.

Course Duration:

1 Day (Morning & Afternoon) – includes coffee breaks and a full lunch

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Abstracts:

Design considerations for the development of a high-powered geophysical transmitter: Mal Cattach, Gap Geophysics: The past decade has seen a significant effort by geophysical contractors to produce technologies and systems to aid in deep exploration. Sensors, survey platforms and processing strategies have been enhanced. Transmitter performance has also increased while a focus on safety systems, including automatic shutdown and remote deactivation, has made the transmitters safer to use. The next generation of equipment will continue to achieve high power limits, combined with real time analytics on signal quality while decreasing size and weight to drive exploration in remote and hard to access areas.

Fleas on a Camel: Advances, Challenges and Opportunities in Gravity Applications for Resource Discovery and Characterization: Chris Nind: Today's state-of-the-art gravity measuring devices are wonderfully engineered and extraordinarily precise instruments, capable of measuring and monitoring local changes (positional or temporal) at the parts per billion level – in effect, a flea on a large camel – with both relative and absolute measurement methodology. These minute variations in gravity have major implications and consequences in the exploration for natural resources, the study of crustal inhomogeneity, environmental monitoring and safety.

The end of the Bronze Age for IP surveys: Circé Malo Lalande, Régis Desbiens, Instrumentation GDD; Simon Mann, Zonge (Australia): During the past decade, significant improvements have been made relating to Resistivity and IP surveying, largely due to more flexible instrumentation and software, fullwave recording, GPS synchronisation amongst others. Such developments have allowed new ways of organizing Transmitter and Receiver dipoles resulting in very flexible arrays and methods providing better signal, coverage and processing options than previously available. Geophysicists are now able to be more creative in designing arrays to meet targeting and budgetary aims and overcome difficult surveying conditions. The collection of accurately synchronised full wave data alone provides improved capability to remove noise, glean additional data, interpret unwanted effects and improve data quality.

A decade of technological advances in distributed IP & Resistivity. Why it was needed. What was achieved. Roger Sharpe, Robert Gordon, Andrey Zhurba & Emily Data, Quantec: DC and IP surveys were radically re-invented in the late '90's (Sheard, 2001) with the advent of distributed acquisition systems (DAS). This redesign was spurred by the miniaturization of computational and recording resources. This allowed for the development of systems incorporating data improvement techniques such as monitoring the current, collecting data as a time-series for post processing using FFT analysis, and using hybrid combinations of 100% duty cycle transmitted current with time-domain data presentation. The new systems provided a clear advantage in terms of S/N (and hence effective depth of investigation) over conventional single instrument practices (Goldie, 2007). The DAS configurations and instrumentation have become a recognized industry standard over the past decade; particularly with respect to the development of 2.5D and 3D DCIP systems with capabilities being continuously expanded.

The Volterra Acquisition System: A multi-sensor system: Syd Visser, Ross Polutnik, Kalen Martens & Shawn Rastad, SJ Geophysics: The focus during the past decade has been the development of an industry leading full-waveform acquisition system. The result is a highly flexible, untethered, distributed acquisition system capable of collecting geophysical measurements both on the surface and within the borehole environment.

Utilizing different sensors any geophysical dataset can be acquired including IP, EM, MT, CSAMT, and MMR/MIP. For ground surveys, customized survey designs are now the norm for solving challenging exploration problems. Within the borehole environment, up-dip BHEM surveys are becoming as routine as down-dip holes.

Magnetic Field Sensors for EM Geophysics: James Macnae & Lachlan Hennessy, RMIT: Good EM sensors, whether B or dB/dt have noise levels far below 1 pT/Hz. Inductive magnetometers achieve this, have intrinsically lower noise than coils of the same weight, and in practice achieve similar data noise levels to SQUIDS. Their only drawback is a small temperature dependence affecting ultra-low base frequency performance in time domain. Several other "room-temperature" potential measurement technologies are approaching useful noise levels, including magnetostrictive, Nitrogen-Vacancy, and atomic interferometers.

SQUID based receivers for electromagnetic exploration: Andreas Chwala, Matthias Schmelz, Thomas Schönau & Ronny Stolz, Leibniz-IPHT; Viatcheslav Zakosarenko & Matthias Meyer, Supracon: Some exploration targets, mostly the ones with long time constants, are easier to detect by measuring the magnetic field instead of its time derivative. As a consequence, Superconducting QUantum Interference Devices (SQUID) are almost perfectly suited for this task due to their high sensitivity and perfectly flat frequency response. New technologies and read-out schemes for SQUIDs are evolving which enable new EM receivers with highest sensitivity, and overcome the limits in terms of slew rate and dynamic range of earlier SQUID instruments.

New developments in magnetic gradiometry: Ronny Stolz, Vyascheslav Zakosarenko, Matthias Schmelz, Markus Schiffler, Thomas Schoenau, Andreas Chwala & Hans-Georg Meyer, Leibniz-IPHT; Anre Vorster, DeBeers; Matthias Queitsch & Matthias Meyer, Supracon; Louis Polomé, Spectrem Air: Vector magnetometry for geomagnetic surveys is still a big challenge with today available high sensitive sensors like Superconducting QUantum Interference Devices (SQUID). Here, SQUID based gradiometry overcomes the limitations of vector magnetometers. In this work recent SQUID gradiometer technologies are introduced as well as full tensor gradiometers which are already used for mineral exploration, detection of UXO, and archaeology. Finally, new approaches for high-resolution magnetometers suitable for geomagnetics will be presented.

On-time EM measurements: UTEM system developments: Yves Lamontagne & Rob Langridge, Lamontagne Geophysics: The UTEM hardware evolved over the last ten years by improving the efficiency of the transmitter and also its fidelity to the 0.01% level. On the receiver side the introduction of simultaneous 3-axis multi-transmitter measurements at frequencies well below 1 Hz made it possible to resolve deep high conductivity targets. Newly developed 3D modelling tools are increasingly used in exploring earth volumes with complex conductivity structures.

Geophysical surveying using raw time series recording: Ben Polzer, Vale Canada Limited: For the past decade Vale have developed a series of instruments and processing techniques for EM and IP based on the acquisition of high-quality raw time series in the field, followed by post processing on a PC. This approach has a number of advantages over traditional methods which acquire and stack data live, including improved opportunities for noise reduction, survey efficiency and flexibility.

Development of flexible TEM systems: Andrew Duncan, EMIT: A wide range of instruments have been developed in the last decade for carrying out TEM and other electrical geophysics surveys. Transmitters and their frequency of operation, sensors, receivers, signal processing and data processing are all evolving and having significant impact on the value of TEM data. With an emphasis on productivity, data quality, flexibility, interpretability and value to consumers of TEM data, this presentation discusses the evolution of TEM instrumentation and processing software with examples.

Developments of the SkyTEM System: Kurt Sørensen, University of Aarhus & Bill Brown, SkyTEM: Although the market for airborne transient surveys has being under strong pressure from a declining mining index several improved and new systems have been introduced. During the last decade the airborne transient systems have gone through several remarkable developments in order to enhance the signal-to-noise ratio and to increase the speed and behavior of the carrier frame in the airspace.

Today low drag systems of small sizes with moments of 1.000.000 NIA, surveying speeds reaching 150 km/hrs and with noise suspending devices of high quality are routinely used. There is no doubt, that new development trends along these issues will be seen in the future.

Recent SPECTREMPLUS developments: Louis Polomé, David Khoza, & Carel Lubbe, Spectrem Air: One of the key challenges in airborne geophysics, particularly airborne electromagnetic (AEM), is to generate a high resolution geological / structural map, a good delineation of targets under thick cover while still retaining very good mapping capabilities for near surface geology. The main focus at SPECTREM AIR in the last few years has been on the design and manufacturing a new patented high-current transmitter. This work was done in combination with the development of an enhanced stable high drag towed bird hosting new receiver's components.

The future of resource exploration: more data in less time for lower cost with unmanned aerial systems (UAS): Ron Bell, IGS; Johannes Stoll, MGT: Autonomously operated unmanned vehicles are manifesting the rapid acquisition of large volumes of multi-variate low cost, high definition geoscience data while simultaneously enhancing safety and diminishing risk. Recent advances in sensor and drone technology coupled with modernized regulations governing the civil use of the national air space are inspiring innovation in the application of drones to the geoscientific mapping. Arguably, drones are the future of resource exploration.

The past, present and future of GPR: Jan Francke, Groundradar: GPR has earned a poor reputation in mining as one of the most oversold techniques. The reality is that whilst many claims are unrealistic, modern instruments can far surpass assumptions in suitable environments. Dramatic advancements have been made in the last decade in terms of improving SNR, the design of small antennas, equipment portability, and data processing. Entire systems operating at 30 MHz are now pocket-sized and weigh less than 1 kg. The cost of radar instruments has also dropped, enabling multifold acquisition. New processing approaches examine complex attributes of dielectric and resistivity distributions, providing greater insight than previously possible. Given a suitably resistive environment, penetration to 100 m+ is realistic given current technology, with upcoming hybrid EM-GPR systems reaching considerably deeper.

Workshop 7 Seismic Methods and Exploration

8:00–12:00
Thursday October 26, 2017

Presenters
Bernd Milereit, Gilles Bellefleur

In many parts of the world, exploration for mineral deposits is moving progressively but persistently to greater depths, relying on knowledge gained from previous exploration campaigns but also on new exploration tools and techniques to efficiently guide deep and costly boreholes. With encouraging results recently obtained in various mining camps, seismic methods continue to make valuable contributions to deep mineral exploration worldwide. This workshop will build from successful seismic case studies presented during Exploration 17 and will address technical aspects of the seismic workflow with a particular focus on state-of-the-art methods that have proven impacts and/or open new frontiers in mineral exploration. Four general topics will be covered including:

- New trends in seismic data acquisition and processing
- Seismic methods in ongoing exploration programs
- Rock physics and quantitative analysis
- Ambient noise and seismic interferometry

The workshop will include keynote presentations covering those topics and most importantly, plenty of time for discussion. The aim of the workshop is to bring together industry, academia, and research funding agencies to discuss novel developments, share experiences, and generate new way-forward ideas. Please join us in the morning of Thursday October 26, 2017, for an exciting half-day workshop on seismic methods for mineral exploration.

Schedule

Time	Event	
08:00 – 08:05	Welcome & Introduction	Bellefleur, G. and Milkereit, B.
08:05 – 08:30	Seismic for Mineral Resources – a Mainstream Method of the Future	Urosevic, M., Bona, A., Ziramov, S., Pevzner, R., Kepic, A., Egorov, A., Kinkela, J., Pridmore, D.Dwyer, J.
08:30 – 08:55	Setting the Foundation – Integrating Seismic Reflection into Zinc Exploration Workflows	Hewson, C., and Moynihan,C.
08:55 – 09:20	Applications of Seismic Methods as a Tool for Uranium Exploration and Mine Planning	O'Dowd, C., Wood, G., Keller, C., and Fitzpatrick,A.
09:20 – 09:45	Enhancing Bandwidth in Seismic Data Acquisition for Mineral Exploration	Snyder, D. B.
09:45 – 10:10	Seismic Interferometry: Cost-effective Solution for Mineral Exploration?	Malinowski, M., and Chamarczuk, M.
10:10 – 10:25	*coffee/tea*	
10:25 – 10:50	Developing Cost-effective Seismic Mineral Exploration Methods	Malehmir, A., Maries, G., Bäckström, E., Schön, M., Marsden, P.
10:50 – 11:05	Petrophysics and Seismic Characteristics of Host Rocks and Alteration of VMS and Porphyry Deposits: Examples from Lalor and New Aton	Bellefleur, G., Schetselaar, E., Wade, D., White, D., and Dueck, P.
11:05 – 11:20	Active Source Seismic Imaging in the Kylylahti Cu-Au-Zn Mine Area	Finland, Heinonen, S., Malinowski, M., Gislason, G., Danaei, S., Koivisto, E., Juurela, S., and the COGITO-MIN Working Group*
11:20 – 11:35	Passive Seismic Interferometry for Subsurface Imaging in an Active Mine Environment: Case Study from the Kylylahti Cu-Au-Zn Mine, Finland	Chamarczuk, M., Malinowski, M., Koivisto, E., Heinonen, S., Juurela, S., and the COGITO-MIN Working Group*
11:35 – 11:50	Seismic Imaging of the Kylylahti Cu-Au-Zn Ore Deposit Using Conventional and DAS VSP Measurements Supported by 3D Full-waveform Seismic Modeling	Riedel, M., Cosma, C., Komminaho, K., Enescu, N., Koivisto, E., Malinowski, M., Luhta, T., Juurela, S., and the COGITO-MIN Working Group*
11:50 – 12:00	Discussion	Milkereit, B. & Bellefleur, G.
Seismic Workshop Reception		
18:00 – 18:20	Faculty Club	University of Toronto

Course Duration:
Half Day (Morning) – includes one coffee break

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 8 Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting

8:20–16:20
Thursday October 26, 2017

Presenters
Randy Enkin (GSC), David Clark (CSIRO), Clive Foss (CSIRO), David Pratt (Tensor Research)

This full-day short course will present the principles and technology of rock physical property measurements and how these data can be used to interpret subsurface geology and target drilling for exploration success. The morning session will present an overview of the subject: What are the mineralogical, lithological, and alteration sources of geophysical anomalies? How do you measure rock physical properties in the laboratory – density and porosity, magnetic susceptibility and remanence, electric resistivity and chargeability? What is the state of rock physical property compilations, and how do you use them? What modern down-hole logging measurements are available, and how do you use these data sets? How can petrophysical data and geological models be integrated to generate predictive geophysical exploration models that are appropriate to local geological settings, rather than reliant on look-alike signatures of known deposits from different settings? We will present practical methods of incorporating rock physical properties into geophysical inversions to produce more realistic geological interpretations. Case studies from a variety of scales and deposit types will be presented.

In the afternoon, particular emphasis will be placed on the origin, measurement, and application of magnetic remanence for magnetic survey analysis. Remanent magnetization is as common and significant as induced magnetization, which together contribute in roughly equal parts to the crustal-sourced variations we measure with magnetic field surveys. Currently remanent magnetization is mostly ignored other than in what are considered special cases, where it dominates and has to be addressed. New software capabilities allow one to routinely recognize, analyse and interpret remanent magnetization effects in magnetic field data, and can now interpret that data with two eyes instead of just one. Unattended, remanent magnetization is a hazard in magnetic field interpretation, particularly in misplacing and misorienting drill targets. However, when properly treated, remanent magnetization is one of the most informative physical properties, potentially carrying information about the age of a rock, and its thermal, alteration, structural and mineralization histories. This workshop briefly reviews the characteristics of remanent magnetization in rocks, and presents the tools to detect and recover remanent magnetization information from interpretation of magnetic field data

Course presentations and additional information on available technologies will be provided in a manual. The workshop will communicate to the explorationist the importance and power of physical rock property data for geological interpretation and targeting in the subsurface.

Schedule

Time	Event	
08:20 – 08:30	Introduction	Randy Enkin
08:30 – 08:50	Mineralogical, lithological, and alteration sources of geophysical anomalies	Bill Morris
08:50 – 09:10	Rock physical properties measurements in the laboratory	Randy Enkin
09:10 – 09:30	Down-hole logging measurements and applications	Vince Gerrie
09:30 – 09:50	Interpretation of downhole physical property logs	Peter Fullagar and Vince Gerrie
09:50 – 10:10	Typical and exotic rock physical property distributions	Randy Enkin
10:10 – 10:25	*coffee/tea*	
10:25 – 10:50	Case Study: Thelon Basin	Vicki Tschirhart
10:50 – 11:10	Case Study: Porphyry Copper	Ken Witherly
11:10 – 11:30	Case Study: Conclurry District. IOCG and SEDEX/BHT	Jim Austin
11:30 – 11:50	How are rock physical properties used in geophysical inversion modelling?	Peter Fullagar
11:50 – 12:00	Discussion	
12:00 – 12:20	Magnetic effects of alteration in mineral systems	Dave Clark
12:20 – 12:40	Overview of methods for estimating total and remanent magnetization of geological sources.	Dave Clark
12:40 – 13:00	Case Study: Remanence in Magmatic Ni-Cu-PGE	Jim Austin
13:00 – 14:00	*lunch*	
14:00 – 14:20	Micro-magnetic mapping	Suzanne McEnroe and Nathan Church
14:20 – 14:40	Challenges in 'ground-truthing' magnetizations interpreted from magnetic field data	Jim Austin, Clive Foss, Dave Clark
14:40 – 15:00	A practical guide to estimating magnetization direction from magnetic field data (Helbig)	Clive Foss
15:00 – 15:20	*coffee/tea*	
15:20 – 15:40	Software resources to recover remanent magnetization from magnetic field data	Dave Pratt
15:40 – 16:00	Mapping magnetizations at regional scales	Clive Foss
16:00 – 16:20	The way forward - Summary, review and discussion	Ken Witherly

*Note – full day workshops include two coffee breaks and a full lunch

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Workshop 9 Status and New Developments in Field Portable Geochemical Techniques and Site Technologies for Mineral Exploration

8:00–12:00
Thursday October 26, 2017

Presenters from the Centre for Exploration Targeting
B. Lemiere (BRGM) and Y. Uvarova (CSIRO)

This workshop aims at reviewing field portable and on-site geochemical techniques applicable to mineral exploration, with a focus on those which appeared or made major advances over the decade. Their contribution to faster and more efficient decision-making in mineral exploration, and their reliability, will be discussed with experts on case studies.

Portable or field technologies for the analysis or characterisation of solid samples and minerals comprise pXRF, pXRD, pNIR-SWIR and pMIR, µRaman, and LIBS. These are based on handheld or field transportable instruments and are particularly adapted to grassroots exploration or light or remote field camps, but also provide critical real-time information at drilling camps. Field transportable instruments applicable to water geochemistry for exploration include ASV, polarography, and ion exchange electrodes. All these techniques allow analysis of commodity and pathfinder elements. They also provide information on lithology or environmentally important elements.

At drilling or mining camps, more integrated technologies can provide near real-time critical information, together with consolidating the site information for resource appreciation, geometallurgy or site baseline information.

Analytical devices and solids preparation equipment were adapted since decades to the rougher conditions of field labs in order to shorten analysis delays. A game changer is the ground-breaking technology developed by CSIRO, Imdex and Olympus within Deep Exploration Technologies CRC which aims at integrating continuous cuttings and drilling fluids sampling with multi-sensor analysis (XRF, XRD, delivering chemistry and mineralogy) and consolidated on a cloud-based platform with results returned to the geologist, allowing decisions made in near real time. This technology is currently retrofitted to diamond drilling. Core scanners include hyperspectral, gamma and XRF sensors, can analyze core as it is being drilled, building extensive core data sets before logging or lab analyses.

One of their key benefits of field and on-site technologies is the possibility to adjust sampling plans, test hypotheses based on ongoing results, and make fast decisions on exploration work — especially drilling and sampling. This is particularly important for remote locations, where sample logistics to the laboratory may become long and demanding. These technologies are fast improving but cannot yet fully compete with laboratory analyses in terms of sensitivity, precision and accuracy due to compromises in sample preparation, instrument performance and work environment. However, field and on-site results must only achieve the level of confidence expected from the decision. Most mineral exploration decisions are based on flexible thinking rather than on a preset framework of investigations.

Course Duration:
Half Day (Morning) – includes one coffee break

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Workshop 10 Future of Mineral Exploration Drilling and Sampling

13:00–16:00 Thursday October 26, 2017

Presenters

Richard Hillis (DET CRC)
Anton Kepic (Curtin University/DET CRC)
David Giles (University of South Australia/DET CRC)
Yulia Uvarova (CSIRO/DET CRC)
Milovan Urosevic (Curtin University/DET CRC)
Steve Hill (Geological Survey of South Australia)
Aaron Baensch (Olympus)
Mike Ravella (Boart Longyear)
James Cleverley (Reflex)

This workshop will summarise outcomes from the Deep Exploration Technologies Cooperative Research Centre's (DET CRC) 8-year, 2010-2018, $62M cash/$154M cash and in-kind program to develop new technologies for mineral exploration beneath barren cover. The focus will be on DET CRC's key technology pillars of:

1. coiled tubing drilling: the advantages of coiled tubing drilling and DET CRC's new coiled tubing drill rig for mineral exploration;
2. real-time downhole petrophysical sensing for conventional diamond drilling and for coiled tubing drilling, and;
3. real-time top-of-hole geochemical and mineralogical sampling for conventional diamond drilling and for coiled tubing drillisng.

These technologies combined with the software architecture to analyse results from drill holes worldwide in real-time will enable a revolutionary new approach to mineral exploration beneath barren cover. We term this new approach 'prospecting drilling', i.e. extensive, continuous drilling programs of multiple holes that progressively map mineral systems beneath cover, enabling geophysical and geochemical vectoring towards deposits during a single drilling campaign. We will discuss the concept of prospecting drilling and the underpinning scientific rationale with examples of the footprints of mineral deposits in Western Australia and South Australia.

Course Duration:
Half Day (Afternoon) – includes one coffee break

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Workshop 11 Assay Quality Control: The Master Class

13:00–16:00 Thursday October 26, 2017

Presenters

Lynda Bloom
Charles Beaudry

Starting in 1999, securities regulators worldwide implemented disclosure rules that required assay quality control data to be reported. Almost 20 years later, there is confusion about what to measure, data evaluation and reporting. In 2015, following a review of NI43-101 reports by the TMX and OSC, poor QA/QC disclosure was in the top 10 common disclosure issues. This Master Class will clarify definitions of QC failure, use of Gage R&R to evaluate precision and testing for bias. The objective is to make the vast amounts of collected QC data "actionable" so that confidence in assay data is improved and regulators are satisfied with the disclosure.

Course Duration:
Half Day (Afternoon) – includes one coffee break

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Workshop 12 SEG DISC 2017
EM Fundamentals and Applications

8:00–16:00
Friday, October 27, 2017

Presenter
Doug Oldenburg & Canadian Exploration Geophysical Society ("KEGS")

The goal of this course is to provide fundamental understanding about EM geophysics so that practitioners can decide if an EM technique can help solve their problem, select which type of survey to employ, and set realistic expectations for what information can be gleaned. Case histories, spanning applications from hydrocarbon and mineral exploration to environmental and geotechnical applications, are used as an underlying framework to bind the material together.

Each case history is presented in a seven-step process that begins with the description of the geologic or geophysical problem to be solved and ends with the impact of the EM geophysical survey to help solve the problem. At points in the middle, we investigate the details of the particular EM survey, some fundamentals of electromagnetic induction, and techniques for processing/inverting the data. The ability to move seamlessly between these different levels of information, so that relevant questions or concepts can be addressed, is facilitated by new open-source numerical software, interactive simulations, and the "textbook" resource http://em.geosci.xyz.

The case histories pertain to problems in resource exploration, environmental and geotechnical areas and are contributed by experts worldwide. We successively look at surveys that make use of steady state, time and frequency domain fields arising from controlled or natural sources. The course is designed to be of interest to a broad audience, including researchers, practitioners, and industry geoscientists, and accessible to those with little background in EM.

Course Duration:
1 Day (Morning & Afternoon) – includes coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 13 NSERC-CMIC Mineral Exploration Footprints Research Network: Data Integration for the Next Generation of Mineral Exploration Models

8:30–16:30
Friday October 27, 2017

Speakers

CM Lesher, MD Hannington, and AG Galley
NSERC-CMIC Mineral Exploration Footprints Research Network

R Linnen, G Olivo et al.
Footprint of the Canadian Malartic Disseminated Gold System

K Ansdell, K Kyser et al.
Footprint of the McArthur River – Millenium Unconformity Uranium System

P Hollings, C Hart, S Gleeson et al.
Footprint of the Highland Valley Porphyry Copper System

J McGaughey et al.
Common Earth Modeling and Data Integration Methods and Workflows

The objectives of the Mineral Exploration Footprints Network have been to:

1. enhance the ability of the Canadian mining industry to recognize the "footprints" of ore systems from high-grade cores to most distant cryptic margins,
2. develop methods that truly integrate (not just layer) 3D multivariate, multiscale data that define ore system footprints, and
3. define workflows that allow researchers and industry explorationists to interact more effectively in accomplishing these goals.

Multi-disciplinary teams from 20 Canadian universities and 30 mining and mining service companies have defined hydrothermal-magmatic footprints for the Canadian Malartic disseminated Au deposit, the McArthur River-Millennium unconformity U deposits, and the Highland Valley porphyry Cu deposit. New and reprocessed, QAQC-controlled geological, structural, lithogeochemical, mineral chemical, hyperspectral, petrophysical, geophysical, and multi-media surficial data have been collected for each site, along cross and long sections and from the same samples, in order to facilitate comparison of different data types and integration.

All data have been interrogated within self-consistent 3D Common Earth Models that allow researchers to define which parameters are most useful in identifying deposit footprints. Cutting-edge data analytics not normally used in mineral exploration have been used determine spatial data clusters and to generate rules defining how the data interact to define subtle footprint characteristics. Joint and constrained geophysical inversions, using not only petrophysical data, but proxies derived from other data sets, have been developed to separate hydrothermal footprint signatures from background lithologies.

Although method development has been restricted to data dense rock volumes centered on cross- and long sections that have maximized recognition of interrelationships between commonly disparate data sets (e.g., potential field versus point data), the results have been applied to 3D geophysical data in more sparsely populated rock volumes to define the full extent of the ore system footprints.

The purpose of this workshop is to describe results to date, the methodologies used to achieve the results, and plans for the final year of the project.

Schedule

Time	Event	
08:30 – 08:40	Welcome and Introduction	Lesher/Hannington/ Galley
08:40 – 10:00	Data Integration Methods	McGaughey
10:00 – 10:30	*coffee/tea*	
10:30 – 12:00	Canadian Malartic Disseminated Gold System: Footprints, Vectors, and Data Integration	Linnen/Olivo
12:00 – 13:00	*lunch*	
13:00 – 14:00	McArthur River – Millennium Uranium System: Footprints, Vectors, and Data Integration	Ansdell/Kyse
14:30 – 15:00	*coffee/tea*	
15:00 – 16:30	Highland Valley Porphyry Cu-(Mo) System: Footprints, Vectors, and DataIntegration	Hollings/Hart/Gleeson

Course Duration:
1 Day (Morning & Afternoon) – includes coffee breaks and a full lunch

Workshop attendees do NOT have to be registered for the Conference itself to register for the workshops.

Workshop 14 Geochemical and Infrared Spectral Mineralogical Data Integration for Mineral Exploration

8:00–12:00
Friday October 27, 2017

Speakers
Dick Tosdal, Federico Cernuschi, Carsten Laukamp, Eric Grunsky and Xiaodong Zhou

This workshop is intended for exploration geologists, geochemists and spectral geologists.

The advances in geochemical analytical techniques and instrumentation have provided geoscientists a variety of multielement geochemical data to characterize lithology-alteration-mineralization for targeting. Some of these advances are 1) ICP-MS near total digest whole rock geochemical analysis which allows detection of low level ore metals and pathfinders to reveal larger footprint of mineralized systems, and, of the immobile elements to identify protoliths of the host rocks, as well as the major elements for quantification of the alteration mineralogy; 2) field portable XRF analyzer for non-destructive, real time elemental analysis to assist logging and mapping and 3) micro XRF spectrometer for non-destructive elemental mapping at 25 micron to 0.5 millimeter resolutions over up to 12 inch long ½ or ¼ drill core or hand samples to reveal the abundance and textural characteristics of sulfides and major to trace elements distribution.

In recent years, systematic infrared spectral mineralogical data has become readily available as a result of more widely used field portable infrared spectrometers, and more significantly, of the technical breakthrough and successful commercial implementation of high resolution hyperspectral core imaging systems that provide non-destructive, semi-quantitative modal mineralogy, including phyllosilicates, sulfates, carbonates etc, along with their textural characteristics whereby the style and intensity of important indicator minerals, mineral chemistry and crystalinity can be mapped at sub millimeter resolution of drill core and field samples. Such data sets have provided new knowledge of alteration footprint, zonation and paragentic relationships to mineralization in porphyry, epithermal, Carlin and greenstone environments, and contributed to exploration successes.

This workshop aims to discuss the fundamentals, methodologies, case histories and practical considerations for integrating multielement geochemical and infrared spectral mineralogical data for more effective targeting.

There will be a panel discussion after the presentations.

Workshop 15 Making Your Case: Clear, Memorable & Compelling

13:00–16:00
Friday October 27, 2017

Convener
David Beatty, Rotman School of Management

In today's fast-paced business world, effective communication among top managers and throughout their organizations is critical to achieving high performance. Too often, however, reports, memorandums, conversations, presentations, and speeches lack the clarity and rigor necessary to make the best strategic decisions and to ensure that they are fully implemented to reach the company's overall business targets. And preparing these communications frequently consumes far too much valuable management time.

CMC programs solve these problems and build strong skills for participants and their organizations.

Making Your Case (MYC) Program Highlights

The **MYC** program will make a significant and lasting improvement in participants' strategic skills in thinking and writing.

Program Objectives

The **MYC** program is designed to build participants' skills to deliver the right messages to the right audiences in the right way. The program will develop their logical thinking and writing skills.

Workshop Design

The workshop is highly interactive. During the sessions, David Beatty will discuss tools and approaches that will build participants' skills and they will work on exercises individually and in teams to reinforce the learning and insights. Participants are invited to work on and develop solutions for current individual or team projects. Throughout the sessions, we encourage people to be serious about learning but also to have some fun.

Expected Benefits

Participants and their organizations benefit in several important and valuable ways:

- Enhance individuals' and teams' abilities to think and write logically and clearly
- Improve business solutions through more effective problem solving
- Increase the effectiveness of communications through careful targeting

The program is based on the way McKinsey & Co, the world's leading strategy consulting company, thinks, talks, works and acts. The tools have been in use for over half a century so they are well proven and widely used.

NAVIGATE DIGITALLY:
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EXPLORATION 17

DMEC Decennial Mineral Exploration CONFERENCES

INSTRUCTIONS FOR DOWNLOADING THE APP:

1. Download the Chameleon Event App using the url http://meaurl.com/chameleon or QR code below.
2. Once downloaded, select the 'event search' button.
3. Type in Exploration 2017, and choose it from the list when it appears.

Opening Forum

Sunday, October 22, 2017

Bassett Theatre, 4:30 – 5:45 pm

Exploration Technology – The Evolving Business Context

PANELISTS

David R. Beatty C.M., O.B.E., F.ICD, CFA

Chair Clarkson Centre for Board Effectiveness,
Rotman School of Management, University of Toronto

Over his career, Prof. David Beatty as served on 40 different boards of directors in Canada, America, Mexico, Australia and England and been chairman of 9 public companies. He has chaired 6 mining company boards including Orogen Minerals on the ASX, Inmet Mining, and Western Coal on the TSX and served as a Director of Goldcorp, Thistle Mining, Walter Energy and Western Garnet. David was the founding Managing Director of the Canadian Coalition for Good Governance (2003–2008), an organization that represents 50 institutional investors with ~C$2 trillion of assets under management.

David is now a Professor at the University of Toronto's Rotman School of Management where he teaches corporate strategy and corporate governance. He is the creator of the Canadian Directors Education Program (DEP) and remains curriculum overseer. The DEP has trained ~5,000 Canadians in partnership with 11 other Canadian universities in a rigorous 12-day course.

In 2013, David was inducted into the Order of Canada, the nation's highest civilian honor and in 1994 he was made an Officer of the Most Excellent Order of the British Empire by Her Majesty Queen Elizabeth II at Buckingham Palace for his services to Papua New Guinea.

Hugh de Souza PhD, PGeo

Director of Geological Services, Business Development
SGS Minerals, Toronto Area

Hugh de Souza is currently Director of Geological Services, Business Development with SGS Minerals. In this role he provides technical advice on geochemical, mineralogical and other SGS services applied in exploration and mining. In addition, he is involved in implementation of new technologies such as Hyperspectral Core Scanning and laser ablation ICP-MS. He has managed SGS geochemical, mineralogical and diamond labs over the last 20 years and has worked on the development of new mineralogical and geochemical methods for mineral exploration. Prior to that he was with the Ontario Geological Survey and carried out post-doctoral work at the Universities of New Brunswick and Geneva. He holds a BA Honours in Environmental Sciences (Lancaster), MSc in Geochemistry (Leeds) and a PhD in Isotope Geology (Edinburgh).

Dan DiFrancesco

Business Development Manager – Gravity Systems,
Lockheed Martin, Niagara Falls, NY

In his 30 years with Lockheed Martin, Dan has been responsible for the design, integration and testing of complex gravity gradiometer instruments and systems for submarine navigation, arms control treaty verification, and commercial mineral and hydrocarbon exploration. These roles have included serving as Chief Mechanical Engineer with responsibility for mechanical design elements, environmental analysis, system integration, field testing of systems, and customer support. Dan holds four US patents for Gravity Gradiometer System design and applications; has authored over 30 technical, peer-reviewed articles on geophysical technology; and is a member of the ASEG, EAGE, PDAC and SEG. He has also served as the Program Manager and Technical Director for numerous government and commercial programs and is presently the Business Development Manager for the Lockheed Martin Gravity Business unit located in Niagara Falls, NY. Dan also has overall responsibility for Business Development for Lockheed Martin's corporate interests in the broader oil and gas and mining sectors. Dan received a BS-Mechanical Engineering from LeTourneau University in 1982.

Cam McCuaig PhD

Principal Geoscientist, Geoscience Centre of Excellence
BHP Billiton, Perth, WA, Australia

Cam graduated with Honours in Geology Energy and Fuel Science from Lakehead University, followed by a PhD in Geology from the University of Saskatchewan. He then enjoyed 10 years with SRK Consulting, becoming a Director of the Australasian practice, focusing on exploration across all scales, project evaluation, geology-resource and geology-mining linkages. In 2005 he became the inaugural Director of the Centre for Exploration Targeting (CET) at the University of Western Australia, undertaking applied research with the minerals industry focused on the science of exploration targeting and building the next generation of mineral explorers. Under his leadership the CET built a team reaching a peak of 90 staff and students and undertook $60M of research on projects spanning 6 continents. CET research outcomes directly impacted on resource base growth for partner companies, led to commercialization of targeting tools in leading software providers, and provided the technical basis for the formation of two new exploration companies. Cam was a founding member and co-author of the UNCOVER initiative in Australia aimed at enabling exploration and discovery in covered terranes. In 2013 Cam was awarded the Gibb-Maitland medal from the Geological Society of Australia for contributions to Western Australian geology and mineral resource exploration. In August 2016, Cam joined BHP Billiton as Principal Geoscientist in their internal Geoscience Centre of Excellence providing expert guidance on mineral systems across all scales to help maintain and grow a high quality resource base. Cam's career has taken him to 41 countries on 6 continents, working in a wide variety of mineral systems from Archaean to Neogene in age.

Gregory Paleolog

Senior Vice President, Multi-Physics CGG,
Mississauga, Ontario

Gregory Paleolog, is a Senior Vice President of CGG with leadership responsibility for the Multi-Physics business line. He holds a Bachelor of Science Honours degree in Earth Sciences from Carleton University, and began his career with Dighem Surveys in Mississauga, Canada performing data processing and field project management activities on helicopter electromagnetic surveys in various countries around the world. Over the course of his 28 years of experience in the airborne geophysical industry, Mr. Paleolog has served in a progression of managerial and leadership roles with Dighem and later with Geoterrex-Dighem, Fugro Airborne Surveys and subsequently with CGG. CGG's Multi-Physics business line provides non-seismic geophysical services to the mining and oil&gas exploration sectors worldwide.

MODERATOR

Chris Nind, ICD.D,

PGeo (Limited), General Chair, Exploration '17

Chris Nind is a senior geophysicist located in the GTA. He is the General Chair of Exploration '17 and the Past President of the Canadian Geophysical Exploration Society (KEGS).

Chris was the President & CEO of LaCoste & Romberg – Scintrex Inc from 2004–2013. Prior to Scintrex, he held senior management positions at Fugro Airborne Surveys, Dighem Surveys and Geoterrex, in Canada, Australia and USA. He began his career as a field geophysicist on gravity, electromagnetic and IP surveys in 1977.

Chris is a member of the Institute of Corporate Directors and a graduate of the Canadian Directors Education Program.

TECHNICAL SESSIONS

Technical Session Chairs and Co-Chairs

Airborne Geophysics:
Jean Legault & Asbjorn Christensen

Geochemisty:
Stephen Cook & John Barr

Case Studies:
Ken Witherly & Circé Malo Lalande

Ground & Borehole Geophysics:
Glenn Chubak & Jim LoCoco

Analytic Methods: Hugh De Souza

Geophysical Processing & Inversion:
Peter Fullagar & Doug Oldenburg

Spectral Geology & Remote Sensing:
Xiaodong Zhou & Richard Bedell

Best Papers from the EAGE Conference on Geophysics for Mineral Exploration and Mining, Barcelona 2016:
Michael Zhdanov & Micki Allen

Targeting – Deep or Under Cover:
Chris Wijns & Dick West

Targeting – Mine Site to Camp Scale:
Alan King & Joel Jansen

Integrated Interpretation:
Tim Chalke & Mark Lindsay

Technical Innovation 1:
Geophysical Waves & Potentials: James Macnae & Richard Hillis

Technical Innovation 2:
Drilling, Samples & Geology: Richard Hillis & David Hatch

Technical Innovation 3:
Geophysical Diffusion: David Hatch & James Macnae

Case Studies – Frank Arnott Awards:
Ken Witherly & Tim Dobush

Technical Luncheon Guest Speaker:
Richard Hillis, CEO, DETCRC

Monday 21 October 2017

08:30 – 12:15	**Plenary Session 1:** State of the Art - MTCC Bassett Theatre **Chair:** John McGaughey
08:30 – 08:40	Introduction
08:45 – 09:10	**Ground and Borehole Geophysics** Dennis Woods
09:15 – 09:40	**Airborne Geophysics** Greg Hodges
09:45 – 10:10	**Geochemistry** Paul Agnew
10:15 – 10:45	Coffee Break
10:45 – 11:10	**Remote Sensing and Spectral Geology** Dave Coulter
11:15 – 11:40	**Modelling and Inversion** Colin Farquharson
11:45 – 12:10	**Exploration Targeting** Cam McCuaig
14:00 – 15:25	**Plenary Session 2:** Integrating the Geosciences – Panel Discussion MTCC Bassett Theatre **Chair:** Charles Beaudry Cam McCuaig, Ken Whitherly, Lynda Bloom

Tuesday 24 October 2017

08:30 – 10:10 Technical Sessions – MTCC

Airborne Geophysics

Room 104 A&B

Chairs: Jean Legault & Asbjorn Christensen

Time	Event
08:30 – 08:50	**The Amaruq Deposits – Building a Customized Toolset and using a Flexible Geomodel: Optimization from Discovery to Mine Development** Olivier Cote-Mantha, Agnico Eagle
08:55 – 09:15	**Synthetic Data As Control For Processing Full Waveform TEM Data** Magdel Combrinck
09:20 – 09:40	**Advances in Airborne Gravity and Magnetics** Derek Fairhead
09:45 – 10:05	**Airborne Gamma: Ray Spectrometry in 2017** Richard Fortin

Geochemistry

Room 104 C&D

Chairs: Stephen Cook & John Barr

Time	Event
08:30 – 08:50	**Review of the Molar Element Ratio Lithogeochemistry Toolbox for Use in Mineral Exploration and Mine Development** Cliff Stanley
08:55 – 09:15	**Advances in the use of Geochemical Data for Regional Exploration** Eric Grunsky
09:20 – 09:40	**Indicator Mineral Chemistry as an Exploration Tool** David Cooke
09:45 – 10:05	**Advances in Exploration Geochemistry, 2007 to 2017 and beyond** Peter Winterburn

Case Studies

Bassett Theatre

Chairs: Ken Witherly and Circé Malo Lalande

Time	Event
08:30 – 08:50	**The Amaruq Discovery – Agnico Eagle's near-term future in Nunavut** Denis Vaillancourt, Agnico Eagle
08:55 – 09:15	**Geophysical Results over the Santo Domingo IOGC Deposit, Region III, Chile** Francis Moul, Capstone
09:20 – 09:40	**Alturas: A unique discovery within a mature district** Marian Moroney, D. Astorga, Barrick
09:45 – 10:05	**The world-class Roberto gold deposit (Eleonore Mine)** Arnaud Fontaine, INRS & Christine Beausoleil, Goldcorp
10:10 – 10:40	**Geophysical Overview of Lalor VMS Deposit** N. Akaranta, Hudbay

10:40 – 12:20 Technical Sessions – MTCC

Ground & Borehole Geophysics

Room 104 A&B

Chairs: Glenn Chubak and Jim LoCoco

Time	Event
10:40 – 11:00	**Magnetotellurics: Status Quo and Quo Vadimus** Alan Jones
11:05 – 11:25	**Advances in Slimline Borehole Geophysical Logging** Jim LoCoco
11:30 – 11:50	**Advances in Ground and Borehole EM Survey Technology** Andrew Duncan
11:55 – 12:15	**Progress of the Electrical Resistivity and IP Method** Jonathan Rudd

Analytic Methods

Room 104 C&D

Chair: Hugh De Souza

Time	Event
10:40 – 11:00	**Parts per trillion gold in groundwater – can we believe it and what's anomalous** J. Buskard
11:05 – 11:25	**Advances in the use of Isotopes in geochemical exploration** Kurt Kyser
11:30 – 11:50	**Status & developments in field portable geochem techniques & technologies** Bruno Lemière
11:55 – 12:15	**Advances in ICP-MS Technology & the Application of Multi-element Geochemistry** Jamil Sader & Shawn Ryan

Case Studies

Bassett Theatre

Chairs: Ken Witherly and Circé Malo Lalande

Time	Event
10:40 – 11:00	**Resultant-magnetization based magnetic field interpretation** Clive Foss, CSIRO/Tensor
11:05 – 11:25	**The Use of Geophysics in the Ring of Fire, James Bay Lowlands** Des Rainsford & Peter Diorio
11:30 – 11:50	**The "Flatreef" PGE-Ni-Cu-Au deposit on Turfspruit farm, South Africa** S. Kekana
11:55 – 12:15	**The Geophysical History of Discoveries in the James Bay Lowlands** Scott Hogg, SHA

14:00 – 15:40 Technical Sessions – MTCC

Geophysical Processing & Inversion

Room 104 A&B

Chairs: Peter Fullagar & Doug Oldenburg

Time	Event
14:00 – 14:20	**Electromagnetic Data Processing: signal, noise, SPM and AIP** Jim Macnae
14:25 – 14:45	**Advanced Modeling of Electromagnetic Data** Elliot Holtham
14:50 – 15:10	**Iterative Forward Modelling and Inversion of Geophysical Data** Glenn Pears
15:15 – 15:35	**Advances in the 3D inversion of magnetic data in the presence of strong remanent magnetization** Yaoguo Li

Spectral Geology and Remote Sensing

Room 104 C&D

Chairs: Xiaodong Zhou & Richard Bedell

Time	Event
14:00 – 14:20	**Multi-scale Integrated Application of Spectral Geology and Remote Sensing** Xiaodong Zhou
14:25 – 14:45	**Automated Hyperspectral Core Imaging – a Revolutionary New Tool** Brigette Martini
14:50 – 15:10	**Hyperspectral Outcrop Imaging of the Orange Hill Porphyry Copper Deposit, Alaska** Raymond Kokaly
15:15 – 15:35	**Thermal Imaging for Exploration and Mining** Richard Bedell

Case Studies – Frank Arnott Awards

Bassett Theatre

Chairs: Ken Witherly & Tim Dobush

Time	Event
14:00 – 14:20	**Introduction: FAA Award** Ken Witherly & Tim Dobush
14:25 – 14:45	**Challenge – Case Study 1** TBA
14:50 – 15:10	**Challenge – Case Study 2** TBA
15:15 – 15:35	**Challenge – Case Study 3** TBA
15:40 – 16:00	**Challenge – Case Study 4** TBA

Wednesday 25 October 2017

08:30 – 10:10 Technical Sessions – MTCC

Technical Innovation 1 – Geophysical Waves & Potentials

Room 104 A&B

Chairs: James Macnae & Richard Hillis

Time	Event
08:30 – 08:50	**Advances in Seismic Reflection as an Exploration Tool in Hard-Rock Mining** HiSeis Pty
08:55 – 09:15	**3D Borehole and Tunnel Seismic Techniques. Application to Optimized Mine Development** Vibrometric
09:20 – 09:40	**Advances in Airborne Gravity Gradiometry at Gedex** Gedex
09:45 – 10:05	**Advances of AGG technologies in CGG** CGG **Extending the limits of GPR penetration** GroundRadar

Best Papers from the EAGE Conference on Geophysics for Mineral Exploration and Mining, Barcelona 2016

Room 104 C&D

Chairs: Michael Zhdanov & Micki Allen

Time	Event
08:30 – 08:50	**Demonstrating why 3D seismic data are assets for exploration and mine planning: Kevitsa Ni-Cu-PGE, northern Finland** Malehmir et al
08:55 – 09:15	**Integration of Borehole and Seismic Data into Magnetotelluric Inversion: Case Study over The Kevitsa Ultramafic Intrusion, Northern Finland** Kieu et al
09:20 – 09:40	**Paradigm Change in Interpretation of AEM Data by Using a Large-scale Parallel 3D Inversion and Moving Sensitivity Domain Approach** Ĉuma, Cox & Zhdanov
09:45 – 10:05	**Integrated modeling of geophysical and petrophysical data for imaging deeper crustal structures in northern Sweden** Bastani et al

Targeting – Deep or Under Cover.

Bassett Theatre

Chairs: Chris Wijns & Dick West

Time	Event
08:30 – 08:50	**Porphyry Targeting Under Atacama Gravels, Northern Chile** David Wood
08:55 – 09:15	**Exploration under total cover; a case study from NW Botswana** James Kidder
09:20 – 09:40	**Brownfields and Beyond - Undercover at Neves-Corvo, Portugal** Dick West
09:45 – 10:05	**Seafloor Mining Exploration Technology & Methods** Peter Kowalczyk

10:40 – 12:20 Technical Sessions – MTCC

Technical Innovation 2 – Drilling, Samples & Geology.

Room 104 A&B

Chair: Richard Hillis & David Hatch

Time	Event
10:40 – 11:00	**The use of core imagery in modelling geometallurgical properties** Geosoft **Truth Machine 2.0** Reflex
11:05 – 11:25	**Geological Logging with X-ray Vision** Olympus Scientific Solutions **Analytic Geochemistry** Bureau Veritas
11:30 – 11:50	**SA Drilling Program** Geol. Survey of South Australia **'Prospecting Drilling': A Technology-Enabled Revolution in Mineral Exploration** DETCRC
11:55 – 12:15	**Exploration Data Analytics, Uncertainty and Security** CSIRO **Developments in LA-ICPMS** TMVC Research Hub & CODES

Targeting – Mine Site to Camp Scale

Bassett Theatre

Chairs: Alan King & Joel Jansen

Time	Event
10:40 – 11:00	**Mining BIG Data: the Future of Exploration Targeting** Guy Desharnais
11:05 – 11:25	**Data Integration for the Next Generation of Mineral Exploration Models** CM Lesher
11:30 – 11:50	**Mineral Exploration using Natural EM Fields** Jansen & Cristall
11:55 – 12:15	**Machine Learning for Near-Mine and In-Mine Prediction: A Powerful New Tool for Geoscientists** Erwan Gloaguen, Lorenzo Perozzi, Antoine Caté, Nathalie Schnitzler, Shiva Tirdad

14:00 – 15:40 Technical Sessions – MTCC

Technical Innovation 3 – Geophysical Diffusion

Room 104 A&B

Chairs: David Hatch & James Macnae

Time	Event
14:00 – 14:20	**ARMIT – A New Generation of TDEM Sensor** Abitibi Geophysics
14:25 – 14:45	**Low frequency AEM and AIP with B and dB/dt sensors** Monex Geoscope & Thomson Aviation
14:50 – 15:10	**Orion3D DCIP and MT Examples** Quantec **Advances of AEM Technologies in CGG** CGG
15:15 – 15:35	**The Transient Phase Method for Classifying Super Conductors in HTEM Profiles** Triumph Instruments **2.5D airborne EM inversion** Intrepid

Integrated Interpretation

Bassett Theatre

Chairs: Tim Chalke & Mark Lindsay

Time	Event
14:00 – 14:20	**Exploration Success Under Cover; Victoria Norte, Chile** Matt Hope
14:25 – 14:45	**The West African Exploration Initiative (WAXI): 10 years of integrated research for development** Mark Jessell and the WAXI Team
14:50 – 15:10	**Unravelling Tropicana – where, what, how and why?** S. Occhipinti, I.M.Tyler, C. Spaggiari, K. Martin, M. Doyle
15:15 – 15:35	**Earth model construction in challenging geologic terrain: Designing workflows and algorithms that makes sense** E. de Kemp, M. Jessell, L. Aillères, E. Schetselaar, M. Hillier, M. Lindsay, B. Brodaric

Abstracts

Plenary Session 1: State of the Art
MTCC Bassett Theatre

Monday 21 October 2017 08:30 – 12:15

Chair: John McGaughey

Ground and Borehole Geophysics 2007 to 2017: Into the Next Dimension

Woods, D. [1]

1. Discovery International Geophysics Inc.

ABSTRACT

Major advancements have been made with ground and borehole geophysics over the past decade with instrumentation, survey procedures, and interpretation by modeling and inversion. The goal of all of these advancements has been to increase the resolution and depth (range) of geophysical results in order to provide better knowledge and understanding of the geology of the subsurface. The key to success in mineral exploration is a detailed and correct knowledge of the earth in the area of interest, where mineral resources are suspected or even known about from previous drilling and surface geological investigations. Obtaining a more detailed and clearer understanding of the geology of the subsurface requires increased amounts and quality of geophysical data. Hence, the ever advancing sophistication and perfection of geophysical instrumentation (e.g. increased signal-to-noise); complexity of survey procedures (e.g. three component and three dimensional data acquisition); and higher density 3D modeling and inversion tied to known physical properties of the subsurface. This paper will focus on two aspects of these advancements over the past decade: the increase in signal-to-noise, of instruments and of final results; and the continuing push into a 3D understanding of geology by 3D data acquisition and interpretation procedures.

Airborne Geophysics

Hodges, D.G. [1], **Christensen, A.N** [2]

1. Sander Geophysics
2. Nordic Geoscience

ABSTRACT

Exploration, and by extension exploration geophysics, has always been cyclical. The last 10 years have seen the highest levels of activity seen in more than 15 years, and the lowest as well. However, technical development continued at a robust pace, mostly carrying forward developments started in the decade previously, particularly gravity gradiometry and helicopter time-domain EM. The drive for gravity gradiometry has been to lower noise and better resolution, and in helicopter EM, to wider range of sensitivity in a wide range of systems. Magnetic and gamma-ray spectrometry surveying has seen a modest increase in instrumentation quality. All-in-one systems offering some kind of gravity and EM with magnetic and gamma ray have been on the fringe of the industry for some years, and remain there at present, Unmanned aerial systems (drones) might be the next big thing, offering surveys with the smaller instruments with greater safety and lower costs, but flight regulation is still the main restriction.

Geochemistry – State of the Art 2017

Paul Agnew, I. [1]

1. Chief Geologist, Technical Support and Technology Development, Rio Tinto Exploration Pty. Ltd, 1 Research Avenue, Bundoora, VIC, 3095, Australia

ABSTRACT

The past decade has seen declining discovery rates despite periods of record exploration expenditure. Geochemistry, along with other search technologies, has not been able to arrest this trend. As exploration moves inexorably into areas of post mineral cover, many conventional geochemical techniques have a diminishing role to play. New geochemical techniques and technologies are urgently needed. There are outstanding opportunities both now and into the future for geochemistry to continue to support successful exploration, including; maximizing value from existing legacy geochemical data, ultra-low detection limits, portable / real time analytical and spectral equipment and a rapidly developing capability in mineral chemistry for fertility assessment and vectoring.

Advances in Spectral Geology and Remote Sensing: 2008–2017

D. Coulter, Consulting Geologist, Exploration Remote Sensing

ABSTRACT

Over the past decade the field of exploration remote sensing has undergone a fundamental transformation from processing images to extracting spectroscopic mineralogical information resulting in the broader field of Spectral Geology and Remote Sensing (SGRS), which encompasses technologies that contribute to the definition, confirmation, and characterization of mineral deposits. SGRS technologies provide information on the mineralogical and alteration characteristics of a mineral orebody by assisting with the identification of features on the surface, in field samples, and in the subsurface through core spectroscopic measurements and imaging. This contributes mineralogical composition for field mapping and orebody characterization with non-contact, non-destructive measurements at high sampling density that no other technology can accomplish. Application of spectral geology and remote sensing technologies varies depending on the scale of exploration, surface exposure, and alteration type, but may include the use of high resolution satellite multispectral imagery, airborne hyperspectral imagery, surface and core point spectral analysis, or hyperspectral core imaging. SGRS technologies augment human vision by making measurements far beyond the sensitivity of human eyes, providing accurate and densely sampled mineralogical information that contributes to more efficient and accurate field mapping and core logging. When integrated with other exploration data, geologic observation, and engineering and geometallurgical analyses, SGRS data contributes to both upstream and downstream efficiencies. Although the exploration and mining business cycle has impacted expenditures for research and develop of exploration related technologies, SGRS capabilities continue to grow based on demand for new instrumentation and capabilities from the broader geospatial and spectroscopy community.

Modelling and Inversion for Mineral Exploration Geophysics: A Review of Recent Progress, the Current State-of-the-Art, and Future Directions

Farquharson, C.G. [1], **Lelièvre, P.G.** [1]

1. Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL.

ABSTRACT

Many developments have occurred in computer modelling for mineral exploration geophysics over the past decade, both in terms of new techniques being devised and previously underutilized techniques being adopted by industry. As in the past, the continuing improvement in computer performance has facilitated most of the developments. 3D forward and inverse modelling are now possible for essentially all geophysical data-types used in mineral exploration. Inversions can be carried out for meshes with many more cells than was ever before possible, and more sophisticated, more capable, more complex modelling and inversion approaches contemplated. There have also been significant developments in computer modelling for structural geology, particularly in automated ways of constructing interface-based geological models. Some of the more sophisticated geophysical modelling and inversion approaches being developed are specifically targeted at constructing geophysical models that are consistent with these geological models. The minimum-structure, Occam's technique is still the workhorse of inversion for mineral exploration geophysics. This is in large part due to its reliability and robustness. Variations on the minimum-structure approach enhanced with new capabilities are being developed, and some recently developed variations are now seeing uptake by industry. Strategies for integrated imaging, that is, constructing a multiple-physical-property Earth model consistent with multiple geophysical data-types, have been devised: joint inversion, using either a coupling between physical properties based on subsurface spatial variation or coupling based on physical property information; cooperative inversion; and post-inversion lithologic segmentation. Constrained inversion and inverting magnetic data for the magnetization vector are experiencing increased use by industry. Development of inversion methods that produce geophysical models that can be more easily integrated with geological models will continue. Possibilities include geophysical inversion done directly on the interface-based geology models, meaning both geologists and geophysicists would be working with the same, truly integrated Earth model; joint inversion of structural geological data and geophysical data to give a model consistent with both these geological and geophysical data-types; and level-set, clustering or litho-type techniques to construct geophysical models more like a 3D geology map of the subsurface. Geological and geophysical modelling capabilities will also continue to be improved, in particular, the speed with which geophysical data can be synthesized for a given Earth model, and the ease with which an Earth model can be built, manipulated and refined in a graphical environment. Minimum-structure inversion, for a single physical property and using a fine rectilinear mesh, will remain a very practical option for many typical, real-life situations. The relative benefit of using more sophisticated and complex approaches will depend on the range and quality of data available, the complexity of the subsurface under investigation, and the level of detail and sophistication required in the constructed model to answer the exploration question. The developments over the last decade have greatly increased the range of capabilities available to us in our geophysical forward and inverse modelling toolkit. The next decade will see further such developments, with the developments that are truly useful finding their place in industry alongside the now-familiar minimum-structure inversion.

Exploration Targeting

McCuaig, T. C. [1], [2], **Sherlock, R.L.** [3]

1. BHP, 125 St. Georges Terrace, Perth, Western Australia 6000
2. Centre for Exploration Targeting and ARC Centre of Excellence for Core to Crust Fluid Systems; School of Earth Sciences, The University of Western Australia, Crawley, Western Australia 6009
3. Mineral Exploration Research Center, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada

ABSTRACT

Exploration success has declined in modern time with fewer quality discoveries and increasing costs on a per unit metal basis. This to some extent reflects the greater maturity of brownfields districts and a reluctance of many companies to conduct greenfields exploration. Increasingly the minerals industry is focused into mature districts or areas which are remote, covered or have high political risk. Exploration is becoming increasingly technically challenging and more expensive. Therefore, more effective targeting across a range of scales is essential to increase success rates and potentially reverse or slow the trend of increased discovery costs.

Approaches to exploration targeting generally fall somewhere on a spectrum between empirical and conceptual targeting. Empirical targeting focusses on recognising patterns in spatial datasets, or known geologic controls and using these criteria as guides to ground selection. Conceptual targeting focusses on understanding the processes controlling the distribution of the commodity of interest and predicting how and where these processes would combine to create an economic deposit within an earth system. These approaches are complementary and should be employed in tandem.

Exploration is an exercise in scale reduction, and has a number of natural business decision points that map to scale. These can be summarised as:

1. Regional-scale targeting: what basin/belt/arc / district has the potential of hosting a substantial mineral system?
2. Camp/Cluster-scale targeting: where within the basin/belt/arc / district could a number of deposits be clustered?
3. Prospect/Deposit: where is there an orebody of sufficient quality within the camp or cluster of deposits?

These decision points integrate a trade-off between the relative inputs of prediction and detection technologies and the concomitant escalation of expenditure with decreasing scale. Although the direct cost of targeting at broad regional scales are relatively low, the opportunity cost of making suboptimal decisions at this scale is extremely high. Target generation and ranking systems must take into account these differences across scale, appropriately capture uncertainty, and separately consider below-ground (geological) factors versus above-ground (access, infrastructure) filters. No matter the approach to targeting taken or the scale at which the work is undertaken, an assessment of the residual endowment of an area for the size of deposit targeted must also be evaluated, i.e. does it remain to be found?

Airborne Geophysics
Room 104 A&B

Tuesday 24 October 2017 08:30 – 10:10

Chairs: Jean Legault & Asbjorn Christensen

Airborne EM an important exploration method for revealing geological insights into the subsurface

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1. CSIRO/Geoscience Australia
2. Aarhus geophysics

OUTLINE

Airborne electromagnetics (AEM) is an important exploration method for revealing geological insights into the subsurface. Airborne electromagnetics has proven to be particularly useful for mapping geological structures and has played a significant role in places such as the central parts of Africa, South America and Australia, where approximately 80% of the landscape is covered by regolith and sedimentary basins, the outcrop is rare and mineral deposits are hidden beneath barren cover. The method's non-invasive nature and its extensive ground coverage make it a particularly powerful tool at the early stages of green-field exploration.

Airborne electromagnetic surveys commissioned by exploration companies for mineral exploration purposes are mostly perceived as 'anomaly detectors'. For further interpretation it is essential to comprehend the main local geological and survey-specific factors that influence the electromagnetic response. The aim of any given observation is to understand the procedures and assumptions used to derive models of conductivity and depth from the measured data, and then develop processes to infer geology, lithology and other characteristics of the subsurface from the models which honour the data.

Geophysicists assessing AEM models are often faced with the conundrum of determining how geologically sensible a proposed model is and how it compares to many other possible solutions. One way is to explore thousands of plausible models that fit the data through stochastic processes. The statistical analysis permits quantification of the degree of uncertainty and a probable distribution of conductivities at depth.

To make the information translatable to other disciplines, it is necessary to process AEM measurements and integrate them with ancillary information. The combination of data integration and AEM's extensive area coverage enables transfer of local geological understanding to a broader region. Previous work has demonstrated there also is great value in reprocessing legacy data that is often abandoned.

Using representative synthetic data to analyse effects of filters when processing full waveform airborne TEM data

Combrinck, M. [1]

1. Tau Geophysical Consultants, Canada

OUTLINE

Airborne time domain electromagnetic (ATEM) surveys have reached the stage where full waveform streamed data are recorded and delivered in addition to traditional survey products. One result of this advance in technology is that the line between the acquisition and processing phases has become more flexible and many parameters that used to be hardwired in acquisition can now be adapted during the processing phase. In order to make use of this opportunity the interpreter needs a clear description and understanding of the system specific corrections required to isolate geological responses as well as the effects of filters and other digital signal enhancement options that are available.

Validating procedures on a synthetic data set is one way of ensuring that all geological responses falling within similar parameter ranges would be accurately presented after processing. In this study the effects of three time-series and four spatial filters were analyzed. Streamed full waveform data were simulated by adding measured high altitude data to synthetic models. The various filters were applied and the deviations from the true models compared with that of the unfiltered data. The results were evaluated based on whether the filtered results showed more or less deviation than the unfiltered data from the original noise-free models.

Advances in Airborne Gravity and Magnetics

Fairhead, J.D. [1], **Cooper, G.R.J.** [2] **and Sander, S.** [3]

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3. Sander Geophysics www.sgl.com

OUTLINE

This contribution reviews the advances of gravity (including gradiometer) and magnetic methods of exploration during the last decade. The review is restricted to airborne methods of data acquisition since they are the most common method of acquisition. During this period gradiometer (FTG & AGG) methods have 'come of age' and both systems are providing gravity tensor data that image shallow targets as never before. This in part has been due to a significant reduction in instrument and processing noise levels. For gravity acquisition systems, their improvement in design and performance has led to better acquisition in turbulent air conditions. This now makes it possible to jointly conduct gravity and magnetic drape surveys. Improvements in processing and interpretation have gone hand in hand with improvements in acquisition. The greater use of the phase signal in the form of the tilt and local wavenumber derivatives in structural mapping, the benefits of finite depth estimation and a more stable downward continuation method are discussed.

Airborne Gamma-Ray Spectrometry in 2017: solid ground for new development.

Fortin, R. [1], **Hovgaard, J.** [2], **Bates, M.** [3]

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2. Radiations Solutions Inc., Mississauga, Ontario.
3. Sander Geophysics, Ottawa, Ontario.

OUTLINE

Decades of development and operational usage have brought airborne gamma-ray spectrometry (AGRS) to maturity. This has been recognized by the publication in the 1990s of standard guidelines that have been accepted by industry and governments and that are in worldwide use today. Over the last decade, while still based on the same proven system configuration favoring high volume detector arrays, commercial systems have been upgraded with digital electronics and are reaching an unprecedented degree of robustness and consistency. This renewed data quality offers the possibility to re-visit data processing and interpretation ideas that appeared previously interesting, in theory, but challenging to implement in practice. It also allows investigating new approaches in data collection that are now technologically available to practitioners.

Three of these ideas are reviewed here. They were selected because elements of solution, in the form of models and processes, have been presented before and are available. Combined with the renewed consistency of AGRS detection systems and the processing power now available to end-users, further development and standardization of these processes could lead to tangible benefits and improved end-products. 1) In the standard data processing methods, the ground is considered infinitely flat. This is obviously never the case in nature, and, on the contrary, the terrain may be quite significant. Approaches have been suggested to include terrain in data processing. 2) By considering the differential signal between each individual detector of the system's array, directional information on the origin of the signal can be extracted and included in the mapping process to potentially enhance spatial resolution. 3) Typically, only information from single photopeaks relating to Potassium, Uranium and Thorium are used for data processing. Modern AGRS systems, however, record full spectra containing many distinct photopeaks of Uranium and Thorium. Data processing scheme to make use of all this information should be reviewed and standardized. This will increase counting statistics and improve data accuracy. Improvements to end-product quality should offer better contrast when targeting mineral deposits with AGRS, either directly or through alterations or geochemical dispersal. But, the increased readability and significance of end-products will also convey the value of AGRS for framework mapping of surficial geochemical variations and allow an insightful integration within bedrock and surficial mapping projects, providing more layers of information that will be useful at the planning, field work and compilation phases.

Analytic Methods
Room 104 C&D

Tuesday 24 October 2017 10:40 – 12:20

Chair: Hugh De Souza

Parts per trillion gold in groundwater: can we believe it, what's anomalous, and how do we use it?

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2. CSIRO Mineral Resources, Perth, Australia

ABSTRACT

There is a pressing need for new exploration tools to target and vector towards mineralization in covered terrains. Groundwater provides a valuable and under-utilized geochemical sampling medium, and represents an important and cost-effective tool to expose covered terrains up to systematic exploration. For Au exploration, researchers agree the best hydrogeochemistry pathfinder is dissolved Au itself, with additional potential from other pathfinders (albeit non-unique) such as As, Ag, W and Mo. Despite Au's relatively low solubility, with rigorous field protocols and appropriate analytical methods, explorers can respond to dissolved Au directly with robust parts per trillion (ppt) level analyses.

Even with ppt-level analyses, a practical implication of Au's low solubility is that a deposit's dissolved Au signature is generally weaker than seen in other more mobile pathfinders, producing a smaller detectable footprint, which must be considered when designing exploration programs. Using purpose-drilled groundwater sampling bores, explorers can collect groundwater samples at the density required to respond to dissolved Au where existing bore hole coverage is otherwise insufficient. In addition to its use at the regional scale, with even tighter sample density, hydrogeochemistry also shows promise at the project scale, allowing for 3D modelling of pathfinder dispersion.

For hydrogeochemistry to be widely adopted for Au exploration, explorers need confidence in ppt-level dissolved Au analyses, and the context to understand their significance. This paper aims to address these topics and provide a straightforward starting point for Au explorers interested in applying hydrogeochemistry by: (i) summarizing examples of regional sampling programs and more focused case studies to illustrate how covered Au deposits create measurable dissolved Au footprints distinguishable from background; and (ii) sharing examples of dissolved Au analyses being integrated into exploration at the regional and project scales.

As seen in the results, the distribution of dissolved Au in the regional- and project-scale programs shows remarkably similar and easy to interpret high-contrast, low-frequency anomalies against relatively low backgrounds. These are desirable attributes of any geochemical pathfinder. When combined with the benefits of hydrogeochemistry versus other geochemical exploration tools (e.g. groundwater can create larger footprints requiring fewer samples to detect, and groundwater can recharge from depth to reflect deeper mineralization), dissolved Au is a powerful pathfinder ideally suited for Au exploration in covered terrains.

While this paper focuses on the use of dissolved Au, additional pathfinders can provide valuable information, including indications of lithological changes, hydrothermal alteration, and different styles of mineralization, as well as opportunities to use secondary pathfinders when sample density or local conditions may not result in detectable dissolved Au signatures.

Advances in the use of Isotopes in geochemical exploration: Instrumentation and applications in understanding geochemical processes

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We are all saddened by the death of Dr. Kurt Kyser on August 29, 2017, during a field trip in Bermuda. His contributions to geochemistry were outstanding and he will be greatly missed by the global geoscience community.

We are grateful to Dr. Matthew Leybourne, an associate professor at Queen's University and a colleague of Dr. Kyser, for agreeing to present this paper on Dr. Kyser's behalf.

OUTLINE

Among the new techniques to unravel fluid histories from deposition to later alteration and the role of the biosphere in forming and modifying ore deposits is isotope tracing. The isotope systems being used include H, Li, B, C, N, O, S, Mo, Cu, Zn, Ni, Sr, Tl, Pt, Pb, and U, all of which reflect different, but overlapping, processes that address both ore formation and the footprint of the ore system. Although the traditional light isotopes and Pb isotopes have been used to understand the origin of metals and the evolution of ore deposits, other isotope systems are novel ways to trace metal migration during both primary and secondary dispersion processes, understand barren areas that lack a critical process, and to reveal precise redox mechanisms. For example, 238U/235U ratios of uranium minerals from volcanic-, metasomatic-, unconformity- and sandstone-related uranium deposits vary as a function of the type of uranium deposit primarily because of the redox processes involved. 7Li/6Li ratios in muscovite and chlorite associated with mineralizing events in most deposits are distinct from background ratios, with the lowest values reflecting the beginning of hydrothermal alteration systems whereas the highest values are indicative of the terminal flow of hydrothermal fluids. The isotopic composition of carbon indicates microbial interactions with the deposits, which may be the process by which elements are mobilized out of the deposits and into the surrounding environment for us to use as vectors to ore. The goal is to be able to use isotopes to reflect a definitive process that occurs in association with the deposit and not in barren systems, and then to relate these to something that is easier to measure, namely elemental concentrations.

The advent of novel and automated preparation systems have facilitated the use of isotopes as tracers in mineral exploration, as costs for isotope analyses have dropped and the turn around time for the analyses has dramatically improved. For example, analyses of the light isotopes involving combustion or pyrolysis, which was traditionally laborious and slow, now can be done robotically, cheaply, and quickly. There are automated prep systems for the extraction of elements of interest, which decreases the time, and hence the costs, required for metal isotope analyses. As new generations of explorationists and environmental scientists are becoming more comfortable with the application of isotopes to effectively trace processes involved in geoscience, and new technologies for rapid and inexpensive analyses of isotopes are continually developed, novel applications of isotope tracing are becoming more mainline.

Status and new developments in field portable geochemical techniques and on-site technologies for mineral exploration

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OUTLINE

There is an ongoing need to be innovative with the way we undertake mineral exploration. Recent technological advances that have enabled successful mineral exploration include on-site or portable instruments, on-site laboratory technologies, various core scanners, and technologies for fluid analysis. Portable or field technologies such as pXRF, pXRD, pNIR-SWIR, μRaman, and LIBS, aid in obtaining chemical and mineralogical information. Spectral gamma tools, a well-known technology, recently took advantage of improved ground and airborne (drone) instruments, to complement hyperspectral imagery. Novel, ground-breaking technology Lab-at-Rig®, was developed by CSIRO, Imdex and Olympus at the Deep Exploration Technologies CRC, and is currently being retrofitted to diamond drilling. Cuttings are separated from drilling fluids in a Solid Removal Unit (SRU), producing one meter composite mud which is sub-sampled, dried and analyzed by both X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) sensors that deliver the chemistry and mineralogy of a sample, respectively. These data are automatically uploaded to a cloud-based storage platform and subjected to a range of statistical analyses with results returned to the geologist in a matter of seconds, allowing decisions to be made in near real time. At a mine site, core scanners become a useful tool to analyze meters of core as it is being drilled. Core scanners include hyperspectral and XRF systems, such as Corescan, HyLogger and Minalyzer, for example. Fluid analyses are not as common as analyses of solid materials, but there are advances in such technologies as ASV, polarography, and ion exchange electrodes aiming for analysis of commodity or environmentally important elements.

With all available portable, field and on-site technologies it is now possible to collect data at the exploration site or while drilling. Certainly, field and on-site analyses cannot yet compete with laboratory analyses in terms of sensitivity, precision and accuracy due to compromises in sample preparation, instrument performance and work environment. However, field and on-site results must only achieve the level of confidence expected from the decision. Most mineral exploration decisions are based on flexible thinking rather than on a preset framework of investigations. One of the key benefits of real-time analyses, or short delay analyses (less than a day) is the possibility to adjust sampling plans, test hypotheses based on ongoing results, and make fast decisions on the exploration process — especially drilling and sampling. This is particularly important for remote locations, where sample logistics to the laboratory may become long and demanding.

Advances in ICP-MS Technology and the Application of Multi-Element Geochemistry to Exploration

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OUTLINE

There have been several advances in ICP-MS analytical technologies in the last decade (2007 to 2017). Collision/reaction cell ICP-MS and triple quadrupole ICP-MS instruments can produce lower detection limits for select elements that experience interferences with a standard quadrupole instrument (i.e., Se and As). Triple quadrupole ICP-MS instruments in particular, can eliminate virtually all polyatomic or isobaric interferences for highly accurate measurements of some element isotopes systematics that are of great interest in mineral exploration, namely Pb/Pb. Laser ablation ICP-MS has become more popular as an effective analytical tool to measure mineral grain trace elements, which could assist in vectoring to mineralization or exploration drill targets. The ablation of a spot on a Li-borate fused glass disk paired with XRF analysis has also gained popularity as an alternative to total whole rock characterization packages that employ several separate digestions and analytical methods. While there have been several advancements in ICP-MS technologies in exploration geochemistry in the last decade, they have not been widely accepted or implemented. This slow adaptation could be due to the extended recession in the mining industry over the last 5 years, which is not currently over. It is also possible that standard ICP-MS data (i.e., no collision/reaction cell) is still fit for purpose. This stands in stark contrast to implementation of ICP-MS in the previous decade (1997 to 2007), which was transformational for the industry.

Consideration of all elements from large multi-element ICP-MS analytical suites for mineral exploration can be an extremely powerful tool in the exploration toolkit. The discovery of the White Gold district, Yukon is a prime example of how the utilization of soil geochemical data, when plotted spatially, can vector to gold mineralization. The presence of Au+As+Sb soil anomalies were key to delineating mineralization, especially when accompanied by publicly available geological, geographical, and geophysical data. Additionally, elements and element ratios not typically considered in Au exploration including Ni and U were utilized to determine the lithological and structural controls on mineralization. The availability of multi-element ICP-MS data was also useful in the discovery of the Cascadero Copper Taron Cesium deposit. Ore grade Cs was discovered only because Cs was included in the multi-element ICP-MS exploration geochemistry suite. Before the availability of ICP-MS, it is unlikely that this deposit would have been discovered.

Best Papers from the EAGE Conference on Geophysics for Mineral Exploration and Mining, Barcelona 2016
Room 104 C&D

Wednesday 25 October 2017 08:30 – 10:10

Chairs: Michael Zhdanov & Micki Allen

3D seismic data are an asset for exploration and mine planning: Kevitsa Ni-Cu-PGE deposit, northern Finland

Alireza Malehmir [1], Ari Tryggvason1, Chris Wijns [2], Teemu Lindqvist3, Pietari Skyttä [4], Emilia Koivisto [3] and Markku Montonen [5]

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OUTLINE

Kevitsa is a disseminated Ni-Cu-PGE (platinum group elements) ore body in northern Finland, hosted by an extremely high-velocity (6.5-8.5 km/s) ultramafic intrusion. It is currently being mined at a depth of approximately 100 m using open-pit mining method. The life of mine is expected to be nearly 20 years, with the final pit depth reaching at around 550-600 m. Based on a series of 2D seismic surveys and given the expected life of mine, a high-resolution 3D seismic survey was justified and acquired in winter 2010 prior to the start of the mining operation. Various researchers and teams have exploited these data since the acquisition because of the unique nature of the host rock and the data being challenging to interpret however rich in reflectivity. Here, we first present the earlier 3D reflection data processing results and then complement them by 3D first arrival traveltime tomography that was recently conducted. The combined results help to provide constraints on the nature of some of the reflectors within the intrusion. It for example shows how the tomography results can be correlated with rock quality data and for further planning of the pit. In particular, we observe a major fracture system, resolved by the tomography results and running in the northern parts of the planned pit, with the reflection data providing better information on its depth extent, estimated to be at least 600 m with a lateral extent of 1000 m. The fracture system appears to spatially limit the lateral extent of the economic mineralisation and partitioned mainly within the intrusion. It can be related to the paleostress regime forming similar features in the study area and will likely be important for mining at deeper levels. Using the Kevitsa 3D seismic data set, we argue that 3D seismic data should routinely be acquired prior to the start of mining activities to not only maximize exploration efficiency at depth, but also to optimize mining as it continues towards depth. 3D seismic data are valuable and can be revisited for various purposes but difficult to impossible to be acquired with high quality when mining commences.

Integration of Borehole and Seismic Data into Magnetotelluric Inversion: Case Study over The Kevitsa Ultramafic Intrusion, Northern Finland

Kieu, D. T. [1], **Kepic, A.** [1], **Le, C. V. A.** [1]

1. Deep Exploration Technologies and Curtin University

OUTLINE

Inverse magnetotelluric (MT) problems nearly always have non-unique solutions. Typically, smoothness criteria to the earth model are added to produce a stable solution. However, this process tends to produce unrealistic geological models. In reality, the subsurface geology tends to be composed of distinct rock units that are better defined by sharp boundaries rather than diffuse or smooth boundaries. Thus, inversion algorithms that can build an earth model including groups that may reflect rock units should be more accurate. We present the application of fuzzy clustering as an added constraint within the inversion process to guide model updates toward earth models that are 'blocky'; thus, resembling geological units. Fuzzy clustering divides the simulated model into clusters based on the similarity of model features. Our technique utilises the ability of fuzzy logic to resolve 'unclear' situations common in geology. Hence it is better than a 'hard' clustering technique such as K-means method. Moreover, fuzzy clustering naturally enables the inclusion of additional prior information in the inversion process, such as petrophysical information from borehole data. The integration of this information produces geo-electrical distributions that fit MT data and simultaneously honour the prior information. Consequently, the model is likely to be more representative of the true rock units. We applied this technique to the case study of the Kevitsa Ni-Cu-PGE (platinum group elements) deposit within the Kevitsa ultramafic intrusion in northern Finland. The geological structure in this area is complex, but the physical properties of the units are reasonably well defined. The borehole data shows that this area can clearly be divided into distinct conductive and resistive environments. The conductive zones relate to ore-zones or/and carbonaceous phyllite; the various host rocks are resistive. In this case, the conductive distribution of this environment does not smoothly change; therefore, inversion of MT data with smooth constraints to this area will not produce a representative or accurate model. In contrast, our algorithm resolves these issues by using a fuzzy clustering technique that references borehole data to divide the model into groups during the inversion approach. The inversion models produced appear to create "cluster" classes that include the ore zones and carbonaceous phyllite relating to the conductive zones. The inverted cluster generated model compares better with borehole and seismic reflection data than using a smooth model approach.

Paradigm Change in Interpretation of AEM Data by Using a Large-scale Parallel 3D Inversion and Moving Sensitivity Domain Approach

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1. TechnoImaging, LLC
2. Consortium for Electromagnetic Modeling and Inversion (CEMI), University of Utah

OUTLINE

Three-dimensional inversion of airborne electromagnetic data is a challenging task due to the large amounts of data collected over relatively large areas. In this paper, we present a 3D inversion algorithm based on a moving sensitivity domain approach using the integral equation method coupled with a multistep regularized conjugate gradient inversion. The developed method can be used for 3D inversion of both frequency domain and time domain electromagnetic data. The time domain data are inverted following transformation of the frequency domain fields to the time domain. To tackle the computational demands, along with the reduction of the problem due to the moving sensitivity domain approach, we also parallelize the problem over the data using Message Passing Interface (MPI) and OpenMP. The workflow of the interpretation includes 1D inversion to obtain a background structure that serves as an input to the 3D inversion. The background is either a half space, unique under each data point in the case of frequency domain, and layered background in the case of time domain inversion. We demonstrate the effectiveness of the developed method and computer software by a frequency domain example of permafrost mapping near Ft. Yukon, Alaska, regional airborne time domain survey in Kamiskotia, Ontario, and a time domain mineral exploration survey.

Integrated modeling of geophysical and petrophysical data for imaging deeper crustal structures in northern Sweden

Mehrdad Bastani. [1], **Ildiko Antal Lundin** [1], **Shunguo Wang** [2] **and Johan Jönberger** [1]

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2. Uppsala University, Department of Earth Sciences, Villavägen 16, SE-752 36 Uppsala, Sweden

OUTLINE

The Geological Survey of Sweden (SGU) conducted geophysical measurements and intensive geological studies in an area between city of Kiruna and Vittangi village in northern Norrbotten, Sweden. The main objective of study was to improve knowledge of the geology using modern methods, thereby creating supporting material for the exploration and mining industry in the region. In the summer of 2012 a 74-km-long reflection seismic profile was acquired between Kiruna and Vittangi for imaging bedrock contacts and the geometry of structures at depth. In 2014 the seismic profile was followed up with magnetotelluric (MT) measurements aimed at modelling the variation in electrical resistivity of the upper crustal structures. In this study we present models from the 3D inversions of MT, magnetic and gravity field data. We compare the results with those from the reflection seismic data to reveal some of the details of the physical properties, the geometry of upper crustal structures and the bedrock in the study area. The analysis of the models to a depth of 5 km along five selected sections demonstrates a reasonable correlation between the modelled physical properties, although some differences are observed. The reflection seismic and susceptibility models have better resolution in imaging shallower structures such as folds and smaller-scale structures, due to denser data sampling and higher sensitivity. However, the deeper structures (>2 km) seen in the reflection seismic image correlate better with the density and resistivity models. Towards the eastern part of the area very low-electrical resistivity structures seen in the resistivity model coincide with a zone dominated by sulphide and graphite mineralisation. We propose a more detailed ground and airborne survey to identify potential areas for exploration.

Case Studies
Bassett Theatre

Tuesday 24 October 2017 08:30 – 10:10; 10:40 – 12:20

Chairs: Ken Witherly and Circé Malo Lalande

The Amaruq Deposits – Building a Customized Toolset and Using a Flexible Geomodel: Optimization from Discovery to Mine Development

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2. Agnico Eagle Mines Limited, Toronto, ON, Canada

OUTLINE

The Amaruq deposits are in the Kivalliq region of Nunavut, northern Canada, 50 kilometres northwest of Agnico Eagle's Meadowbank mine. The claims cover 116,716 hectares on
Inuit-owned and federal crown land. The region is underlain by Archean supracrustal rocks of the Woodburn Lake group. Gold mineralization is hosted in mafic and ultramafic sub-volcanic rocks interlayered with fine-grained clastic rocks, chert, graphitic iron-rich mudstone and iron formation.

In April 2013, Agnico Eagle acquired 100% interest in the virgin gold prospect. Since then, Amaruq has quickly grown to a satellite mine development project to the Meadowbank mine. The aggressive exploration program has included 272,000 metres of drilling (1,065 holes) as well as fieldwork, prospecting, geochemistry and an airborne VTEM survey covering 81,000 hectares from 2013 through 2016. A 100-metre-spaced till sampling survey has been using arsenic as an efficient gold pathfinder leading to new targets.

The exploration tools and techniques have been carefully developed for the Amaruq exploration program; their effectiveness is continually being weighed and the program adjusted. At each stage, careful field observations have been made at local and regional scales. Geophysical surveys using airborne and ground-based MAG and EM have been useful for following subsurface rock units and determining drill targets. With up to 10 drill rigs working concurrently, it has been important to establish and maintain good drill core logging practices including careful observations; maintaining uniformity via a simple legend, a core library, and identification charts; using portable XRF equipment for lithotyping; and taking good quality photographs of all core. The identification of marker horizons has been key to unravelling the geometry of the rock sequence. Leapfrog Geo™ software has been used to create implicit 3D models in real-time as the drill campaign progresses, so the team has been able to determine drill targets in 3D, and use the model for continual resource re-estimation. On-site portable XRF assaying of samples from the systematic till geochemical survey has given immediate feedback for tracking gold pathfinder elements (e.g., arsenic), speeding up the siting of targets in the regional exploration program.

The best understood deposit on the property, Whale Tail, is a newly recognized specimen of hybrid, stratabound- and vein-type iron-formation-hosted gold deposits. Whale Tail and Mammoth have been shown to form a continuous mineralized system 2.3 kilometres long, between surface and 730 metres deep locally, which remains open at depth and along strike. Recent drilling and mapping have shown the nearby V Zone to be a significant set of mineralized structures dipping shallowly to the southeast from surface to at least 540 metres depth, with locally abundant visible gold. Regional reconnaissance prospecting has identified several gold-anomalous areas outside of the Whale Tail – Mammoth area that warrant further exploration.

An indicated open pit resource at Amaruq was estimated at 2.1 million ounces gold (16.9 million tonnes grading 3.88 g/t gold), almost all in the Whale Tail deposit, and an inferred resource (at both open pit and underground depths) was estimated at 2.1 million ounces of gold (11.7 million tonnes grading 5.63 g/t gold), evenly divided between the Whale Tail deposit and V Zone, as of December 31, 2016. An internal technical study in 2016 led to the company's mid-February 2017 approval to develop a satellite open pit mine at Amaruq (subject to the receipt of final permits). Initial mining will be from a pit in the Whale Tail deposit followed by a pit at V Zone.

Geophysical Results at the Santo Domingo IOGC Deposit, Region III, Chile

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1. Condor North Consulting ULC, Vancouver, BC, Canada
2. Condor Consulting Inc, Lakewood, CO, USA

OUTLINE

The Santo Domingo IOCG deposit is located in the Sierra Santo Domingo, approximately 130 km northeast of Copiapó, in Region III, northern Chile. The deposit is approximately 30 km east of the Atacama Fault System which controls the occurrence of many IOCG deposits in the Chilean Iron Belt (CIB). The deposit contains total Proven and Probable Mineral Reserves of 391.7 Mt @ 0.30% Cu, 0.04 g/t Au, and 28.3% Fe (Magnetite) in three ore bodies (Santo Domingo Sur, Iris, Iris Norte) and is owned 70% by Capstone Mining Corp. (Capstone) and 30% by Korea Resources Corp.

The ore bodies are hosted in a sequence of volcanics and volcanoclastics of the Punta del Cobre Formation in contact with limestone of the Chañarcillo group. The mineralization offers a good target for gravity, magnetic, electromagnetic, and electrical methods due to shallow depth and favourable physical property contrasts relative to the country rock.

The discovery of the Santo Domingo deposit was the result of a large regional exploration effort by Far West Mining Ltd. (Far West) and BHP Billiton Ltd. The field exploration program was initiated with a regional Falcon airborne gravity-gradiometer (AGG) survey in 2002. Once interest was narrowed to the deposit area, Far West conducted several ground geophysical surveys including ground magnetics and electromagnetics (TEM). After acquiring the project, Capstone commissioned the flying of two airborne electromagnetic surveys (VTEM and ZTEM).

We present results from the airborne Falcon AGG, VTEM, and ZTEM surveys as well as the ground magnetic and TEM surveys. The methods are compared to demonstrate the efficacy in detecting the ore bodies.

Alturas: A unique discovery within a mature district through integrating sound geological practices, multidisciplinary expertise and leading technology

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2. Inversiones Barrick Conosur Ltda, Chile
3. Minera Barrick Misquichilca, S.A., Peru

OUTLINE

Discovery of a high-sulfidation epithermal system at Alturas represents the culmination of over 30 years of geological understanding combined with the application and integration of multi-disciplinary geoscientific techniques at all exploration stages and scales.

The Alturas deposit is located in the gold rich El Indio belt of central-northern Chile. The belt is defined by the overlap of two prolific magmatic belts; the Eocene-Oligocene in the north and the Miocene in the south, both of which host multiple world class (porphyry copper) deposits. El Indio belt has been the focus of over 30 years of exploration by many experienced explorers, resulting in a series of world class gold discoveries. These discoveries have evolved from outcropping high sulfidation veins (El Indio-Tambo, 1976 discovery), to basement granite hosted deposits (Pascua Lama, 1995 discovery), to felsic volcanic hosted disseminated deposits (Veladero, 1998 discovery) and most recently the semi-concealed Alturas deposit, announced in 2015, reflecting the global trend towards concealed discoveries. Over the exploration history, the knowledge of the belt and the deposit types has evolved and the lessons learned reapplied, which culminated in the Alturas discovery.

A dedicated, methodical, multi-year exploration campaign commenced in 2010 to re-evaluate the economic potential of this prospective, yet perceived mature, 150Km long belt. This commenced with a belt wide 1:25,000 geological mapping campaign and the generation of 42 systematic (2Km spaced) transects. Combined with remote sensing (multi- and hyper-spectral), regional magnetic surveys and targeted geochronology, a three-dimensional compilation generated 19 geologically-defined targets, with Alturas being the top ranking of the high sulfidation targets. Following this regional campaign, a targeted program of geological mapping over 10 square kilometers, supported by spectral, geochemical and geophysical data acquisition, defined individually subtle anomalies which, when integrated into a conceptual geological model, collectively provided a compelling case for a concealed target. From the onset of drilling, innovative technology was incorporated, including digital collection of geological data (surface and drill core), core scanning (high resolution photography, hyperspectral imagery and geotechnical data), portable x-ray fluorescence (pXRF) analyzers and optical high resolution imagery of drill hole walls. These data sets were integrated to generate a robust three dimensional geological model which to date has supported the delineation of a 6.8Moz inferred Au resource (Barrick, 2017).

The Éléonore gold mine: Exploration, Discovery and Understanding of an emerging gold district in Eeyou Istchee James Bay, Superior Province, Northern Québec, Canada

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** Now BRGM (Bureau de Recherche Géologique er Minière), Orléans, France

OUTLINE

The Eeyou Istchee James Bay municipality was always considered less prolific for major gold discoveries than the Abitibi region mainly because of the scarcity of greenstone belts and presence of high-grade metamorphism. Conceptual models, including potential for porphyry systems, and influence of metamorphic gradients on hydrothermal fluid circulation were tested by Virginia Gold Mines near a Cu-Ag-Au-Mo showing hosted by the Ell Lake diorite and discovered by Noranda in 1964. A trail of mineralized boulders, including one that provided a grab sample at 22.9 g/t Au, was identified in 2002, and followed up-ice to the source area, leading to the discovery of the Roberto deposit in 2004.

The property was acquired by Goldcorp Inc. in 2006, production started in October 2014 and commercial production was achieved on April 1, 2015. In June 2016, the Éléonore mine had mineral reserves of 4.57 Moz (23.44 Mt at 6.07 g/t Au), measured and indicated gold mineral resources of 0.93 Moz (5.14 Mt at 5.66 g/t Au) and inferred mineral resources of 2.35 Moz (9.73 Mt at 7.52 g/t Au).

Mainly hosted by <2675Ma sedimentary rocks, the deposit is located 1.5 km south of the interpreted tectonometamorphic contact between the Opinaca (paragneiss to migmatite) and La Grande Subprovinces (volcano-sedimentary belts and syn- to late-tectonic intrusions). A multidiplinary approach is presented here to decipher stratigraphic relationships as well as structural, metamorphic and magmatic events relative to the establishment of the distinct geological setting and hydrothermal footprint. This approach is based on extensive detailed surface and underground mapping, core logging, lithogeochemistry, 3D modelling, and U-Pb geochronology. These have led to the identification of ore zones characterized by a diversity of mineralization styles including i) stockwork of quartz, dravite veinlets with microcline, phlogopite replacement zones with pyrrhotite, arsenopyrite, and löllingite (5050 and 5010 zones), ii) quartz, actinolite, diopside, hedenbergite, muscovite, schorl, arsenopyrite-löllingite-pyrrhotite veins, hydrothermal breccia and amphibolite-biotite schist (6000, 7000, 8000 and hangingwall zones), iii) more atypical metamorphosed high-grade ore in paragneissic rocks (e.g. 494 zone) and lower grade replacement zones and pegmatite dykes (North zone). A common metallic signature of the various ore zones including Au-As-B-Sb (±Bi-W-Te-Sn-Mo-

Se) was identified as well as lithogeochemical proxy for the hydrothermal system. The ubiquitous presence of gold-rich löllingite inclusions within arsenopyrite overgrowths, as well as pyrrhotite, actinolite, diopside, hedenbergite, biotite and microcline, and post-ore deformation indicate that the bulk of gold mineralization has recorded prograde metamorphism and coeval deformation followed by retrograde metamorphism.

Gold mineralization in the Éléonore mine and adjacent properties (Cheechoo and Éléonore South) suggests that the Opinaca/La Grande tectonometamorphic contact and in particular the ~5 km area, located immediately to the south of the contact, is a promising area. Gold mineralization locally occurs in 2620-2600 Ma pegmatite dykes and within or in the vicinity of a 2612 Ma reduced granodiorite/tonalite intrusion. The Éléonore mine area has recorded by i) long-lived Au-bearing hydrothermal activity associated with regional metamorphism, coeval deformation, reduced magmatism (~2612 Ma Cheechoo granodiorite/tonalite), and injection of numerous leucogranite and pegmatite veins and dykes, coeval with ii) polyphase deformation recorded by sedimentary rocks next to a major tectonic contact with a migmatitic domain. In this context, gold mineralization share analogies with hypozonal orogenic gold deposits as well as reduced intrusion-related gold systems.

The discovery of the Roberto deposit was the result of standard field exploration methodology including a combination of systematic prospection around historical showings, sampling of erratic boulders, glacial flow directions to track sources of gold-bearing ones, extensive geophysical (magnetic, induced polarization surveys) and geochemical surveys (soil and lake sediments), mechanical stripping with channel sampling, and drilling were essential in the discovery and for the development of the Éléonore mine.

Geophysical Overview of Lalor VMS Deposit

Newton, O. [1], **Vowles, A.** [2]

1. Hudbay Minerals Inc., Flin Flon, MB, Canada
2. Independent consultant

OUTLINE

The Manitoba exploration team of Hudbay Minerals Inc. (Hudbay) identified the Chisel Basin within the Snow Lake belt as having high potential for a large Volcanogenic Massive Sulphide (VMS) discovery. The basin has historically hosted six past producing VMS mines: Chisel Lake, Chisel Open pit, Chisel North, Photo, Ghost, and Lost.

In 2003, with knowledge of favorable stratigraphy down plunge of Chisel North mine, Hudbay's geophysical group designed a surface time-domain electromagnetic survey, targeting deep conductors in this region. The survey consisted of four large loops planned to systematically cover the Chisel Basin. Two anomalies of interest were identified, a north and a south anomaly. The south anomaly was drilled and intersected non-economic stringer chalcopyrite, pyrite and pyrrhotite. The north anomaly remained untested, at the time. In 2007, an 800m by 800m model was created for the untested north anomaly. Drilling began in March to test the electromagnetic anomaly and the first hole DUB168 intersected appreciable widths of zinc-rich massive sulphides (7.62% Zn and 0.30% Cu between 781.74m and 826.87m (45.13m), including 17.26% Zn and 0.19% Cu over 16.45m).

Lalor mine was placed into commercial production in 2014 and as of January 1, 2017 (HudBay Minerals Inc., 2017) has proven and probable mineral reserve of 14.2 million tonnes (5.12% Zn, 0.69% Cu, 2.61 g/t Au and 26.50 g/t Ag). Exclusive of mineral reserves as stated above, Lalor Base Metal Zone contains indicated resources of 2.1 million tonnes (5.34% Zn, 0.49% Cu, 1.69 g/t Au and 28.10 g/t Ag) and inferred resource of 545,300 tonnes (8.15% Zn, 0.32% Cu, 1.45 g/t Au and 22.28 g/t Ag) and Lalor Gold and Copper-Gold contains indicated resource of 1.75 million tonnes (0.40% Zn, 0.34% Cu, 5.18 g/t Au and 30.61 g/t Ag) and inferred resource of 4.1 million tonnes (0.31% Zn, 0.90% Cu, 5.02 g/t Au and 27.61 g/t Ag). Following the Lalor discovery, Hudbay encouraged testing of various geophysical equipment and technology over the Lalor deposit. The goal was to evaluate and determine which geophysical equipment could improve future exploration success in identifying VMS deposits of similar size, geometry and depth. The surveys conducted over the Lalor deposit include Airborne (VTEM, ZTEM, HELITEM, HeliSAM), Surface (TDEM, AMT/MT, IP, Seismic, ELF) and Borehole (BHEM, Gravity, Physical Property Logging) surveys.

The main geophysical lesson learned from the Lalor discovery process was that favorable areas which appear fully explored by numerous historical drillholes and geophysics grids may be inadequately tested at depth, due to limitations of the available data. Also, that short grid lines may be insufficient to record the full response from deep flat lying anomalies. These lessons will aid in planning future VMS exploration programs for Lalor-type deposits.

Resultant-magnetization based magnetic field interpretation

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OUTLINE

Magnetic field inversion allowing freedom in direction of magnetization has become much more widely used lately, despite having only recently been considered impractical or at best unreliable. Uncertainty in direction of magnetization which drives the requirement for this capability arises from the contribution to the magnetization of a rock from remanent magnetization oriented in an unknown direction. The scalar Koenigsberger ratio of the strength of remanent to induced magnetization is insufficient to characterize this vector relationship, and I suggest that this be supplemented with the apparent resultant rotation angle (ARRA), which is a measure of difference between the local geomagnetic field and resultant (total) magnetization direction. I present case studies which show that for well-defined and well-isolated compact anomalies, there is considerable stability of estimated magnetization direction. A case study of a more complex distribution of multiple magnetizations illustrates that complexity can be managed with user-guided inversion. I suggest that some rotation of magnetization away from the present field direction is the norm rather than a special case, and that most magnetic field inversion studies would benefit from at least inspection and consideration of an optimum magnetization direction solution in addition to standard induced-magnetization-only solutions that are commonly generated. Recovery of magnetization direction from magnetic field analysis or inversion is strongly dependent on the distribution of magnetization, with elongate sheets posing particular difficulties. This study shows that inversions are capable of recovering consistent estimates of magnetization direction, regardless of shape detail for elongations of up to 6 times the closest approach of measurement.

The Use of Geophysics in the Ring of Fire, James Bay Lowlands — the Chromite Story

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3. Scott Hogg & Assoc., Toronto, ON, Canada

OUTLINE

In less than a decade the "Ring of Fire" (RoF), an area of Archean supracrustal and mafic to ultramafic intrusive rocks in the James Bay lowlands that is partially covered by Paleozoic sediments and almost completely blanketed by glacial drift, has been transformed from virgin territory to a potentially world-class polymetallic mining camp awaiting development. This paper concentrates on the chromite discoveries and the geophysical methods used to detect and define the deposits. Although the initial indication of chromite was serendipitous, the recognition of the significance of the discovery and the realignment of geophysical programs to take advantage of the characteristics of the mineralization and associated host rocks led to the rapid discovery of six chromite ore bodies. Physical rock property data indicate why gravity, magnetic and EM methods were effective in exploring for this type of deposit. Typical ground and airborne responses are presented and discussed. Airborne gravity gradiometry was able to define mafic and ultramafic rock units, including the host rocks of the chromite mineralization, but had insufficient resolution to detect the deposits themselves. In a region almost devoid of outcrop, airborne gravity was able to improve geological understanding by distinguishing between magnetic granitoid rocks and mafic/ultramafic rocks with similar magnetic responses. 3-D inversion of airborne magnetic and gravity data creates voluminous voxel data sets which are hard to visualize conventionally. Multi-parameter classification of the 3-D models, combined with knowledge of physical rock properties, demonstrates how rock units may be predicted and delineated. Four of the six deposits, discovered so far, are near-surface and amenable to direct geophysical detection. As exploration in the vicinity of known deposits in the RoF matures, work will likely focus on deeper deposits and geophysics will be required to define favourable stratigraphy which, along with tighter integration of deposit models, structural geological controls and lithogeochemistry, could be used to locate otherwise blind targets. However, at a regional scale, additional ultramafic intrusions with chromite potential remain to be explored via the conventional ground geophysical methods that appear to be required to effectively target mineralization. While the emphasis of this paper has been the chromite discoveries, the short history of the RoF has shown that explorationists need to be open to the unexpected and be prepared to take advantage when the opportunity arises.

Discovery of the deep "Flatreef" PGE-Ni-Cu-Au deposit on Turfspruit farm, Northern Limb, Bushveld Igneous Complex, South Africa

Kekana, S [1], Broughton, D. [2], de Wet, B. [3], Williams, N. [4], Nielsen, S. [5], Grobler, D. [1]

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2. Ivanhoe Mines, Vancouver, BC, Canada
3. POB 818, Buderim, Queensland, Australia
4. Barrick, Vancouver, BC, Canada
5. Nielsen Expl & Devl Ltd, POB 299, Paihia, Bay of Islands, New Zealand

OUTLINE

Ivanhoe Mines' Platreef Project is located in the southern sector of the Northern Limb of the Bushveld Complex. The Complex comprises a regionally extensive, generally steeply dipping sequence of pyroxenite-norite-harzburgite at the base, which hosts PGE-Ni-Cu-Au mineralisation and is termed the Platreef. Following acquisition of the project in the early 2000's, an initial stage of exploration through 2003 resulted in definition of a large, low-grade open-pit resource. Its development would have required relocation of a local townsite. These factors combined with encouragement from deep exploration on AfriOre's Akanani project to the north prompted Ivanhoe's commencement of a deep drill programme at Turfspruit, in early 2007. The programme continued intermittently into 2010, a time during which industry and academic geologists generally held that the southern sector of the Platreef contained only sub-economic resources.

However, by mid-2010 several drill holes in the northern part of Turfspruit had intersected an apparently consistent mineralised zone at the top of the Platreef, which appeared to be flattening westwards. An initial "selectively mineable" estimated mineral resource of small tonnage but high grade, provided encouragement for Itochu Corporation to purchase a 2% stake in the project for $US10 million. This funding supported drilling that, in conjunction with in-house geologically constrained geophysical (magnetic) inversions, resulted in the definition of a major underground high-grade PGE-Ni-Cu-Au resource, named the "Flatreef". In early 2011, an Itochu-led consortium purchased an additional 8% share in the project for $US280 million. By late 2011 thirty drill rigs were active on the project, resulting in the definition of Indicated and Inferred Mineral Resources. In 2012, a geologically constrained inversion of an airborne gravity gradiometer survey resulted in identification of a southwards extension of the flat-lying portion of the deposit, and additional Inferred mineral resources. The project is now under development with shaft-sinking in progress. Keys to success were persistence, willingness to drill-test new ideas in the face of negative "wisdom", funding, and support from in-house geophysical expertise.

The Geophysical History of Discoveries in the James Bay Lowlands from the Victor Kimberlite to the Ring of Fire Copper and Nickel deposits.

Hogg, R.L.S [1], **Munro, S** [1]

1. Scott Hogg & Associates, Toronto, Ontario, Canada

OUTLINE

The James Bay Lowlands is a large remote area of Northern Ontario with very limited access. The Archean basement rocks lie beneath a layer of Paleozoic limestone, up to 300 m thick, that is topped by glacial till and bog. This setting, without outcrop or hard geological knowledge, presented a blank slate well suited to airborne geophysical exploration. This paper presents the aeromagnetic survey methodology and analysis techniques that evolved from the initial kimberlite aeromagnetic program carried out by Selco in 1979 through the 1989 DeBeers discovery of the Victor kimberlite and the 1993 Spider/KWG discovery of the older sub-Paleozoic Kyle series kimberlites and eventually the Ring of Fire. Without property constraints the exploration methodology was a cycle of survey-interpret-drill then move on and repeat as discoveries and finances permitted. After 3 cycles of kimberlite discovery a Spider/KWG/DeBeers partnership encountered VMS copper mineralization in 2001. An airborne EM survey in 2003 identified a number of excellent prospects and the most technically promising became the Noront Eagles Nest MMS nickel deposit that began the Ring of Fire saga. These greenfield discoveries, in a blind geological environment beneath limestone cover, illustrate the potential effectiveness of geophysically directed exploration.

Geochemistry
Room 104 C&D

Tuesday 24 October 2017 08:30 – 10:10

Chairs: Stephen Cook & John Barr

Molar Element Ratio Analysis of Lithogeochemical Data: A Toolbox for Use in Mineral Exploration and Mining

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ABSTRACT

Over the last half century, lithogeochemical data analysis has evolved substantially, and a number of useful quantitative tools are now available to the explorationist to facilitate a variety of exploration tasks. Today, many mining companies are using lithogeochemistry as validator to assist explorationists in regional-to-property scale mapping, and drill core logging. However, lithogeochemical data are also capable of being used to classify rocks, and assist in a number of other tactical and strategic exploration activities, including: correlation of stratigraphy on cross-sections, development of mineral zoning models in plan and section, determination of host rock geochemical affinity and depositional environment, understanding the genesis of both host rocks and mineral deposits, and identification of precipitation mechanisms for mineralization. Clearly, lithogeochemical data analysis is now making substantial contributions to mineral exploration efforts.

Molar element ratio analysis is one of the principal methods used by explorationists today to evaluate lithogeochemical data. This approach is one of many that avoid the effects of closure, the constraint that element concentrations sum to unity. Unfortunately, closure adds mathematically induced variance to lithogeochemical data that obscures the effects of rock-forming processes. However, two distinctive advantages of molar element ratio analysis, relative to other material transfer techniques that also avoid closure are that: it examines data in a molar context, allowing investigation of rock compositions in terms of the minerals comprising the rocks and the chemical reactions that alter the rocks, and it can consider more than two samples at a time, allowing rapid investigation of large lithogeochemical datasets.

Molar element ratio analysis consists of four basic tools that provide substantial insight into the lithogeochemistry (and mineralogy) of the rocks under investigation. These tools consist of: (i) conserved element analysis, (ii) Pearce element ratio analysis, (iii) general element ratio analysis, and (iv) change of basis rock classification. Conserved element analysis is useful in creating a chemostratigraphic model for the host rocks to mineral deposits, whereas Pearce and general element ratio analysis have primarily been used to identify the major mineralogical and metasomatic controls on rock compositions, and to investigate and quantify the extent of material transfer processes that formed the host rocks and mineralization. Change of basis rock classification converts element concentrations into mineral concentrations, allowing lithogeochemical data to be

interpreted in terms of minerals and used to provide proper names to rocks, an important activity because of the implications that rock names have on genetic processes and mineral deposit models.

This paper provides a review of the theoretical foundations of each of these four tools, and then illustrates how these techniques have been used in a variety of exploration applications to assist in the exploration for, evaluation and planning of, and the mining of mineral deposits. Examples include the evaluation of lithogeochemical datasets from mineral deposits hosted by igneous and sedimentary rocks and formed by hydrothermal and igneous processes. In addition, this paper illustrates a more recent geometallurgical application of these methods, whereby the mineral proportions determined by the change of basis rock classification are used to predict rock properties and obtain ore body knowledge critical to resource evaluation, mine planning, mining, and mine remediation.

Advances in the Use of Geochemical Data for Mineral Exploration

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ABSTRACT

Multi-element geochemical surveys of rocks, soils, stream/lake/floodplain sediments, and regolith are carried out by governments and mineral exploration companies at continental (0.5 – 50 million km2), regional (500 – 500,000 km2) and local (0.5 – 500 km2) scales. The chemistry of these materials is defined by their primary mineral assemblages and their subsequent modification by comminution and weathering. A geochemical database, with 50 or more elements determined to sufficiently low detection limits, represents a multi-dimensional geochemical space that can be studied using multivariate statistical methods from which patterns reflecting geochemical/geological processes are described (process discovery). These patterns form the basis from which probabilistic predictive maps are created (process validation).

Processing geochemical survey data comprised of many thousands of samples requires a systematic approach to effectively interpret the multi-dimensional data in a meaningful way. When assembling large datasets from various sources, care must be taken to understand the nature of the sample media, the methods of sample collection and preparation, the laboratory digestion procedures and the analytical instrumentation methods. Problems that are typically associated with the interpretation of multi-element geochemical data include closure, missing values, censoring, merging, levelling different datasets, and adequate spatial sample design. Of particular significance is the effect of stoichiometry within the logratio framework that has been developed to deal with compositional data.

Recent developments in advanced multivariate analytics, geospatial analysis and mapping provide an effective framework to analyze and interpret the information inherent in geochemical datasets. Geochemical and geological processes can often be recognized through the use of data discovery procedures such as the application of principal component analysis after compositionally appropriate data imputation and transformation. Classification and predictive procedures, at the continental, regional and camp scales, can be used to confirm lithological variability, hydrothermal alteration, and mineralization. Studies of multi-element geochemical survey data of lake/till sediments from Canada and of floodplain sediments from Australia show that predictive maps of bedrock and regolith processes can be generated. Upscaling a multivariate statistics-based prospectivity analysis for arc related Cu-Au mineralization from a regional survey in the southern Thomson Orogen (northern New South Wales and southern Queensland) to the continental scale, reveals a number of regions with similar (or stronger) multivariate response and hence potentially similar (or higher) mineral potential throughout Australia.

Porphyry indicator minerals (PIMS) and porphyry vectoring and fertility tools (PVFTS) — indicators of mineralization styles and recorders of hypogene geochemical dispersion halos

Cooke, David R. [1,2], **Agnew, Paul** [3], **Hollings, Pete** [4], **Baker, Michael** [1,2], **Chang, Zhaoshan** [5], **Wilkinson, Jamie J.** [6,7], **White, Noel C.** [2,8]], **Zhang, Lejun** [1,2], **Thompson, Jennifer** [1,2], **Gemmell, J. Bruce** [1,2], **Fox, Nathan** [2], **Chen, Huayong** [9], **and Wilkinson, Clara C.** [6]

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ABSTRACT

In the past decade, significant research efforts have been devoted to mineral chemistry studies to assist porphyry exploration. These activities can be divided into two major fields of research: (1) porphyry indicator minerals (PIMS), which aims to identify the presence of, or potential for, porphyry-style mineralization based on the chemistry of magmatic minerals such as plagioclase, zircon and apatite, or resistate hydrothermal minerals such as magnetite; and (2) porphyry vectoring and fertility tools (PVFTS), which use the chemical compositions of hydrothermal minerals such as epidote, chlorite and alunite to predict the likely direction and distance to mineralized centers, and the potential metal endowment of a mineral district. This new generation of exploration tools has been enabled by advances in laser ablation-inductively coupled plasma mass spectrometry, short wave length infrared data acquisition and data processing, and the increased availability of microanalytical techniques such as cathodoluminescence. PVFTS and PIMS show considerable promise for porphyry exploration, and are starting to be applied to the diversity of environments that host porphyry and epithermal deposits around the circum-Pacific region. Industry has consistently supported development of these tools, in the case of PVFTS encouraged by several successful "blind tests" where deposit centers have successfully be predicted from distal propylitic settings. Industry adoption is steadily increasing but is restrained by a lack of the necessary analytical equipment and expertise in commercial laboratories.

Advances in Exploration Geochemistry, 2007 to 2017 and beyond.

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ABSTRACT

Mineral Exploration under relatively young, exotic cover still presents a major challenge to discovery. Advances and future developments can be categorized in four key areas, 1) understanding metal mobility and mechanisms, 2) rapid geochemical analyses, 3) data access, integration and interoperability, and 4) innovation in laboratory-based methods.

Application of "regolith-style" surface mapping in covered terrains outside of the conventional lateritic terrains is achieving success in terms of reducing background noise and improving geochemical contrasts. However, process models for anomaly generation are still uncertain and require further research. The interaction between the surface environment, microbes, hydrocarbons and chemistry is receiving greater attention. While significant progress has been achieved in understanding the role of vegetation, interaction with the water table and cycling of metals in the near surface environment in Australia, other regions of the world, for example the till covered terrains in the northern hemisphere and arid colluvium covered areas of south America, have seen lesser progress. In addition to vegetation, the influence of bacteria, fungi and invertebrates are less well studied with respect to metal mobilization in cover. Field portable-XRF has become a standard field instrument, though more often used in a camp setting. Apart from tweaking of analytical quality, the instruments have probably reached their peak with instrument add-ons, such as cameras, beam-limiters. wireless transmission and GPS as differentiating tools. Their future rests in automated application in unconventional configurations and better integration of these data with other information such as spectral analyses. Pattern drilling persists in industry, but has benefitted from innovative application of field portable tools and lithogeochemical and mineral chemistry to provide near real-time results and assist in a shift toward more flexible and targeted drilling in Greenfields settings.

Innovation in the laboratory is also developing. More selective geochemical analysis and imaging of fine particle size fractions, resistate mineral phases and isotope analysis is faster and more accessible than ever before, and branching into the application of genomic analysis (and data analysis) as a mineral exploration tool is on the horizon. As a common problem in geoscience, the supply of suitable trained geochemists into industry persists, although some needs, particularly at junior level, will be met by recent initiatives at various universities at graduate level. Unfortunately, the current economic climate has had a significant impact on R&D and retention of geochemistry skills by industry. Whilst the future is positive, significant investment is required to develop the next generation of geochemical exploration tools and concepts.

Geophysical Processing & Inversion
Room 104 A&B

Tuesday 24 October 2017 14:00 – 15:40

Chairs: Peter Fullagar & Doug Oldenburg

Advances in Electromagnetic Data Processing: noise, signal, SPM and AIP

James Macnae [1]

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ABSTRACT

Most of the breakthroughs in electromagnetic geophysical data processing in the past decade have been in the data-rich field of airborne electromagnetic (AEM) surveys. These advances have progressed on five separate fronts: signal, noise, superparamagnetism, inductive induced polarization, calibration and QC. Signal characterization studies have allowed quantitative corrections to signal distortions in the early delay time, producing dynamically corrected data more consistent with modelling. Composite waveforms have been used to fill spectral gaps in simpler transmissions. More recently, full waveform modelling and inversion has improved on earlier approximations to actual waveforms, producing excellent fits to "raw" data exactly as measured. Noise has been reduced on several fronts: there have been improvements to electronics and sensor intrinsic noise, rotation noise has been reduced through novel suspension systems, and strategies devised and advanced for the removal of unwanted signals, predictable or transient in nature. Partially or exactly predictable but unwanted signals may arise from the powerline network, from cultural conductors such as pipelines or fences or components of the AEM system itself; and from submarine VLF communications. Transient signals most commonly come from sferic activity, the sources of which are now extensively monitored. AEM primarily has been used in the past to estimate conductivity, to a lesser extent static magnetic permeability and minimally for dielectric permittivity. Recent processing developments that allow for frequency dependent physical properties can now provide estimates of superparamagnetic susceptibilities and Cole-Cole induced polarization (IP) parameters. The IP parameters include DC or preferably AC conductivity, with three additional parameters including chargeability reasonably well defined but with very limited resolution of the frequency dependence and Cole-Cole time-constant.

Future advances in processing are still needed to permit operation of AEM and airborne IP (AIP) systems at much lower base frequencies than the current 25 Hz limit for good AEM data. Very limited advance is expected in terms of airborne transmitter output, specifically dipole moment and current stability in the immediate future. Significant advances however should come through rotation or rotation rate monitoring of sensors, where preliminary results have been very positive. Alternatively, several research groups have been attempting the mechanical isolation of sensors from rotation excitations, using fluid suspension systems. Total field magnetic sensors with limited bandwidth have been used to eliminate airborne rotation noise, but are limited to measuring one magnetic component in the direction of the earth's field. A worthwhile advance proven in theory in the 1990's but only implemented in data acquisition for the ZTEM airborne tilt-angle system is the use of local and remote electromagnetic base-stations to help predict and hence remove the effects of unwanted signals.

Advanced Modelling of Electromagnetic Data

E. Holtham [1], D. Marchant [1], M. McMillan [1], E. Haber [2]

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ABSTRACT

In the time since Exploration '07, the quality of collected ground and particularly airborne geophysical data has improved tremendously. New airborne geophysical surveys such as ZTEM are being routinely flown, and IP measurements are now being extracted from airborne data. Many service providers are also starting to offer drone solutions which show much potential. In addition many advances in both forward modelling and inversion of electromagnetic data has made the 3D electromagnetic inversion problem tractable, even with large number of sources as seen in airborne surveys. Improved data acquisition combined with advancements in inversion allows the practicing geophysicist working with the data and ultimately making interpretations the ability to extract the maximum value from these new high quality datasets and models. With a suite of tools to accurately model large electromagnetic surveys, a high priority will be placed in the future on integrating the results with other geoscience data and coming up with underlying patterns through machine learning. In this paper, we examine the current state of the art for modeling different 3D electromagnetic surveys, and then focus on future opportunities to maximize the value of geophysics within the exploration framework.

Advances in geologically constrained modelling and inversion strategies to drive integrated interpretation in mineral exploration

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ABSTRACT

Mineral exploration is becoming more difficult, with a developing focus on discovery under cover and at greater depth. In order to better understand a mineralization system, careful assessment and integrated interpretation of all available data is required to provide information about lithology, structure, and alteration. The need for integration is blurring the traditional roles of geological modelling and geophysical inversion. This paper presents an interactive approach for developing geological models from geophysical data in order to effectively integrate geological and geophysical data.

There is inherent ambiguity in all mineral exploration datasets. The impetus for integrated interpretation is to reduce ambiguity and maximize the benefit from various types of collected data. In terms of integrated geology and geophysics, the essential goal is to interpret the available geophysical data in terms of a 3D geological model populated with physical properties. The key to integrated interpretation is therefore to develop

an understanding of the relationships between geology, geophysical responses, and rock properties. Those relationships can then be used to model 3D geological domains. Geologically-based forward modelling and inversion of geophysical data plays a vital role in quantifying these relationships, but it is important to emphasise that inversion is only one part of the interpretation process.

The availability of 3D inversion algorithms over the past several decades has given way to acceptance of inversion, particularly unconstrained inversion of geophysical data sets as a standard product. These inversion results are typically overlain on geological interpretations, sometimes revealing correlations amongst various geophysical and geological data but without truly integrating the data sets. The next generation of integrated interpretation involved constructing a geological model, attributing it with rock property data, then presenting it to inversion as a geological constraint. Although this approach facilitates a numerical integration of geological and geophysical data, the inversion results are not always sensible because of the ambiguity of the initial geological model which is the basis for the starting model for geophysical inversion. This approach still considers the geological modelling component of interpretation independently of geophysical interpretation. To truly integrate geological and geophysical data, 3D geophysical forward modelling and inversion needs to be at the core of the interpretation process, testing geological ideas from the outset, and used recursively to develop a 3D geological model that agrees with the geophysical data. This interactive interpretative process also facilitates the development of plausible 3D geological models from geophysical data in areas with limited geological information.

As software and technology evolve, the capability and efficiency of modelling and inversion tools is ever increasing. Inversion algorithms which provide lithology-based inversion options offer a flexible basis for integrating geology and geophysics, but effective use of these tools requires an interactive approach to forward modelling and inversion. The process of integrated interpretation therefore demands a shift in mindset when it comes to geophysical inversion. Rather than inverting a geophysical data set once, many forward modelling and inversion runs are required to test different geological hypotheses and to develop an understanding of the relationships between the geological, geophysical and petrophysical data. Integrating geological and geophysical data, particularly in cases with limited subsurface control, is interactive and requires a practical, adaptive, and objective-driven approach to interpretation. The culmination of this process is a three-dimensional model which combines geological and other information to achieve the exploration goals.

The paper illustrates the interplay of geological modelling with geophysical forward modelling and inversion to achieve integrated interpretation in case studies from Mount Dore in Queensland and Cave Rocks in the Eastern Goldfields of Western Australia.

From susceptibility to magnetization: Advances in the 3D inversion of magnetic data in the presence of significant remanent magnetization

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ABSTRACT

Since Exploration'07, tremendous advances have been made in the inversion and quantitative interpretation of magnetic data in the presence of significant remanent magnetization. The advances have occurred on many fronts such as data processing, inversion methodology, as well as practical applications, with contributions from academia, government agencies, exploration and service industries. These advances have significantly extended the utility of 3D magnetic inversions on a wide range of scales in mineral exploration. Theoretically, the single most significant challenge posed by the presence of strong remanent magnetization arises from the unknown direction of the total magnetization, which is the vectorial sum of the induced and remanent magnetization components. As a direct consequence, the commonly used assumption of equating the magnetization direction to that of the inducing field is no longer valid and renders the inversions based on this assumption invalid. Accordingly, the development of methods to tackle this challenge falls into different categories including various mix-parameter inversions and generalized inversions, with the latter containing three subcategories: estimating the total magnetization direction for use in inversions, inverting for the magnitude of magnetization from direction-insensitive data derived from total-field anomaly, and directly inverting for magnetization. By far the most diverse development has occurred in the magnetization inversion. A commonality among the diverse approaches is the effort to limit the variability of magnetization and, thereby, reduce the ambiguity by incorporating geological, petrophysical, or statistical constraints. This paper will review the development and advances along these threads in the last decade, showcase successful applications to illustrate these approaches, and discuss future directions.

Ground & Borehole Geophysics
Room 104 A&B

Tuesday 24 October 2017 10:40 – 12:20

Chairs: Glenn Chubak and Jim LoCoco

Magnetotellurics: Status Quo and Quo Vadimus

Jones, A.G. [1]

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OUTLINE

The natural source electromagnetic technique magnetotellurics (MT) is still a somewhat esoteric method, principally in the academic domain, that has not reached its enormous potential. It was proposed conceptually in the 1940s and 1950s simultaneously in Japan, France and Russia, and early developments were primarily related to theory and to hardware; the first commercial application of MT was for geothermal studies. Well into the 1970s the electric and magnetic time series were often digitized from paper records, processing was relatively unsophisticated using Fourier transform spectral methods, and interpretation was often based on one-dimensional approaches. From the early 1980s onwards there have been tremendous advances in instrumentation, processing, analysis, modeling and inversion to the extent that magnetotellurics is now a relatively robust and somewhat established mapping tool used for imaging three-dimensional electrical conductivity variations from the near surface (100 m) to deep within the mantle (1,000 km), both on land and in marine environments. Diverse commercial applications include environmental geophysics (using very high frequency radio-MT, RMT), geothermal, mining and hydrocarbon studies (using high frequency audio-MT, AMT), deep crustal studies (using convention MT), and lithospheric mantle studies (using long period MT, LMT). Particularly marine MT has advanced spectacularly over the last decade for the direct detection of hydrocarbons. At this time three-dimensional inversion is being applied more and more routinely, even to profile data, thanks to codes generously made freely-available. However, appreciation and understanding of the inherent difficulties in 3D MT inversion is in its infancy, especially of how to treat galvanic distortions.

The three main limitations of MT currently limiting its broader adoption and application are (1) insufficient sensors, (2) inadequate methods for treating heavily noise contaminated data, and (3) inability to model the Earth at the scale of conductivity variation. Advances on all three of these should occur over the next decade. For (1), we are typically spatially undersampling our targets of interest, and there really needs to be a huge reduction in cost of especially electric field electrodes, but also magnetic coils, and attendant recorders. For (2), MT is hampered in semi-urban environments, and often in rural environments, due to contamination from anthropogenic EM noise sources, such as AC power sources, DC trains, cow fences, pumps (especially DC), leaky transformers etc., and also some natural EM noise sources, such as frequent lightning strokes. Although MT time series processing advanced significantly in the 1980s with the implementation of robust processing schemes, these are inadequate when noise contamination dominates the time series. Finally, the lateral variations in conductivity can be at the electrode line-length scale, or even electrode scale, yet our current capability limits inversion to 200 cells in both lateral directions so our smallest cells are at larger scales. Multi-scale inversion methods need to be developed that mimic the physics of induction.

Advances in Slimline Borehole Geophysical Logging

Jim LoCoco [1], Timo Korth [2], Wendy Alpers [3], Bruno Legros [3]

1. Mount Sopris Instrument Company, Inc.
2. Advanced Logic Technology, Sa
3. Advanced Logic Technology, Sa
4. Advanced Technology, Sa

ABSTRACT

The last 10 years in slimline borehole geophysics has seen numerous advancements. Borehole imagery logging has reached resolutions that allow investigators to visualize true-color borehole wall attributes, grain size features, rock fabric, and structural integrity. These slimline tools allow us to perform high resolution fracture characterization, casing thickness evaluation, along with many other applications. Acoustic televiewer amplitude logs are semi-quantitative and proportional to rock strength. Advances in data acquisition systems allow increased logging speeds, even at very high circumferential and vertical sampling intervals.

Nuclear Magnetic Resonance (NMR) logging has evolved with much smaller diameter tools, running on standard commonly available geophysical wirelines, thus allowing entry into the mining and ground water communities. These tools operate in a borehole, like an inside-out MRI scanner, to provide direct sensitivity to hydrogen (groundwater and hydrocarbons). The tool projects a magnetic field several inches beyond the borehole axis, creating a cylindrical-shaped "sensitive region" from which the NMR signal is captured. This thin sensitive region is ideally located within the undamaged region of the formation, where the rocks and sediments are not disturbed by drilling. Direct detection and quantification of groundwater (including capillary and clay-bound water) is possible, along with detection and quantification of hydrocarbons and fluid diffusion, precise determination of porosity and water content, Estimation of permeability, mobile/bound water fraction, pore-size distributions, and sensitivity to geometric and geochemical pore-scale properties.

Advances in slimline borehole gravity tools over the past several years has found importance in mining applications, including bulk density determination, rock properties, and verification of surface and airborne gravity anomalies. Borehole gravity measurements have been used for detecting the presence of oil and gas & reservoir mapping, delineating salt domes, in addition to typical applications to determine density with greater investigative area than traditional radioactive source tools.

Advances in borehole Spectral Induced Polarization (SIP) are revealing its unique sensitivity to interfacial properties of porous materials. SIP is sensitive to fundamental pore geometric properties controlling fluid flow and recent case histories indicate the measurement can be a good estimation of permeability. Numerous authors have described links between SIP parameters and permeability. SIP methods are also very sensitive to changes in the interfacial properties that result from biogeochemical processes occurring in porous media due to natural and enhanced mechanisms. Many papers that link SIP properties to biogeochemical alterations of mineral surface area and/or mineral surface chemistry have been published in recent years. It is now considered a unique geophysical method regarding its sensitivity to geochemical and

biogeochemical processes. This provides unique opportunities to monitor geochemical and biogeochemical processes associated with remediation strategies for example. One of the most exciting opportunities is related to biomineral transformations resulting in sulfide mineral formation.

New generation downhole Energy Dispersive X-ray Fluorescence (EDXRF) spectrometry tools have been developed further in the determination of minor and major concentrations of elements in borehole. These instruments can aid in ore body/seam mapping (Ni, Cu, Zn) and the estimation of tracer elements, blast hole profiling, and grade control. EDXRF can also potentially help address issues related to mineral recovery programs.

Well-calibrated slimline downhole spectral gamma geophysical logging tools are yielding near quantitative results in real time. Advances is scintillation material and tool characterization have contributed to recent advancements. Borehole properties such as diameter, fluid, casing and probe diameter strongly influence the outcome spectral gamma logging tools. From recent Monte Carlo simulations, it appears that borehole diameter, probe diameter, borehole fluid and casing thickness have a significant effect on the observed gamma spectrum, above 300 keV. Calibrations for these effects are now implemented in newer tools built over the last decade or so.

Geophysical well-log analysis and presentation software, along with 3D modeling and database programs have advanced significantly, becoming an advanced universal borehole, mine site or well-field data tool box. It's more common nowadays for petrophysicists, mining engineers, geologists, researchers, and drillers to combine data into one layered summary for use and interpretation in multi-disciplinary applications.

Advances in Ground and Borehole EM Survey Technology to 2017

Duncan, A. [1]

1. Electromagnetic Imaging Technology Pty Ltd

OUTLINE

It is fair to say that, during the last decade, EM survey technology has been driven in directions to facilitate the detection, discrimination and interpretation of more difficult, notably deeper, conductive targets.

EM surveys for VMS, magmatic sulphide and other metalliferous targets are now being carried out at lower frequencies than in previous decades, in an effort to help detect and discriminate conductive targets. A range of relatively high current transmitter systems are now being used in the EM surveying market to assist with detection of targets at depth or some distance off-hole. Sensor technology likewise is being pushed to perform better over the spectrum of interest, with emphasis on improvements at low frequencies – below 5 Hz and as low as 0.1 Hz.

GPS-synchronized, time-series receivers with powerful processing architecture are now ubiquitous. They add value and flexibility to a survey via the speed and ease of timing synchronization, storage of large volumes of raw data and the processing operations.

This presentation will summarize advances in surface and borehole EM surveys in the past decade and give a basis for the directions currently being taken by users of EM data and instrumentation developers. In particular, topics summarized will be:

- Sensor architecture and performance
- Data acquisition system architecture and performance
- Transmitter systems
- Logistical issues with borehole and surface EM equipment
- Collection and processing of time-series EM data
- Array EM systems

Where possible, examples of new approaches will be presented using data collected. Alternatively, the justification for new approaches will be put forward by modelling their performance and their logistical or economic advantages.

Progress of the Electrical Resistivity and Induced Polarization Method

Rudd, J. [1], **Ritchie, T.** [2], **Sharpe, R.** [3], **Barrett, J.** [4]

1. Dias Geophysical Limited
2. Geophysical Resources and Services Pty Ltd
3. Quantec Geoscience Limited
4. SouthernRock Geophysics S.A.

OUTLINE

The 3D IP and resistivity method has seen significant growth and development over the last 10 years and we predict that this trend will continue. Early surveys can best be described as augmented 2D surveys and were often limited by the availability of equipment. Today, several organizations offer full 3D surveys, and the number of available channels for this application is steadily growing. The main inhibitor to the growth of the 3D DCIP technology during this past decade has been a historically sluggish mineral exploration market.

Sensor technology has largely remained static with porous pots, steel stakes, and metal mesh/foil electrodes being used selectively in various environments and applications. Transmitter technology has seen significant advancement with the introduction of higher powered systems, cleaner current waveforms and integrated safety systems. The challenge in signal transmission remains with the variability in ground contact conditions, which drives the required voltage and current capabilities of the transmitter.

Receiver technology has perhaps seen the greatest improvement through the use of distributed systems, the development of wireless technology, and the resulting flexibility in the design and deployment of 3D arrays. There are significant differences amongst the various available 3D IP and resistivity systems, so it is important to understand how these differences inform and influence the final interpreted models.

The processing and interpretation of the high volume of data that 3D surveys generate is a significant challenge. Strategies for data quality control and processing algorithms are largely brought forward from 2D survey technology, and we will see significant improvement in this area going forward. 3D QC and interpretation methods remain relatively immature, but the advantage of multi-directional, high volume data sets is still clearly seen in the accuracy and resolution of models.

3D IP and resistivity technology has matured significantly over the last 10 years. Several new systems and survey approaches provide the industry with improvements and greater choice, and have made this type of survey more affordable. 3D surveys will add significant value in medium to advanced stage exploration, and will also bring value through the resource development stage. We predict that 3D IP and resistivity surveys will follow a similar path to what 3D seismic surveys travelled, and will become a staple in every stage of mineral exploration where the IP and resistivity method is effective.

Integrated Interpretation
Bassett Theatre

Wednesday 25 October 2017 14:40 – 15:40

Chairs: Tim Chalke & Mark Lindsay

Multiscale Integrated Interpretation Leading to Exploration Success Under Cover; A Case Study from Northern Chile

Hope, M. [1], **Farrar, A.** [1], **Ireland, T.** [1], **Jones, S.** [2]

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2. University of St Andrews, Irvine Building, North Street, St Andrews, Fife, KY16 9AL, United Kingdom

ABSTRACT

The search for giant ore deposits is moving into ever more challenging environments, with lack of exposure and more cryptic mineralisation signatures likely becoming characteristics associated with the next wave of major discoveries. This exploration reality demands a modification of traditional exploration approaches and increasing integration of diverse data to maximize the opportunity of discovery success. Research continues to uncover new understanding of these cryptic signatures, however this is unlikely to deliver us the silver bullet. Fortunately for the exploration geoscientist, the abundance of quality datasets at multiple scales, in addition to high quality and user friendly 3D visualisation tools, means we are better placed than ever to respond to these challenges by optimizing what we already have via fully integrated interpretation.

The Greater Victoria District (GVD) is a largely covered project area, located in the world-class porphyry-Cu mineral province of the Domeyko Corridor, Northern Chile, and provides an ideal case study of integrated interpretation at multiple scales in a mineral system framework, leading to discovery of a large, mineralised, magmatic hydrothermal system. Chile is blessed with quality regional datasets and the GVD has been subject to near continuous mineral exploration for over 20 years. This work has left a wealth of geoscientific information for future explorers to utilise and is representative of many projects in highly prospective districts. All the historical data from regional satellite gravity and Landsat data, down various scales to available historical drillhole assays and fluid inclusion work, have been interpreted collectively and combined within 3D visualisation software wherever possible.

This review was interpreted in tandem with traditional field mapping of sparse outcrop and available drill spoils left at surface. This allowed planning of targeted data acquisition to answer key geological questions flagged by the process and ensure the relevant characteristics of the mineral system could be inferred. The resulting information, when integrated in 3D, allowed recognition of a large, previously untested anomalous zone, interpreted to reflect a hydrothermal alteration system with potential for a giant ore deposit. Recent exploration drilling of this covered target known as Pampa Vaquillas, confirms a previously unknown, mineralised hydrothermal system, located in one of the world's premier mineral belts. A highly integrative and mineral systems driven approach to the geoscience datasets has led to this exciting exploration result.

The West African Exploration Initiative (WAXI): 10 years of integrated research for development

Jessell, M.W. [1,2] **and the WAXI Team***

1. Centre for Exploration Targeting, School of Earth Sciences, the University of Western Australia, 35 Stirling Hwy, Crawley, 6009, WA, Australia
2. Institut de Recherche pour le Développement, Laboratoire Géosciences Environnement Toulouse, UMR-CNRS 5563, 14 avenue Édouard belin, 31400 Toulouse, France

ABSTRACT

The eleven-year AMIRA International Project P934 'West African Exploration Initiative' (WAXI), now in its third phase, has the dual aims of scientific research focused on increasing our understanding the tectonic and regolith settings of ore deposits, and the development of the research and training capacity of West African geological surveys and universities. We describe the drivers for the WAXI initiative, as well as key research and capacity building outcomes. The WAXI project is a public-private partnership that has brought together seventy of the principal stakeholders in the domain of minerals exploration in West Africa:

- The government surveys and departments of mines of eleven West African states (Burkina Faso, Ghana, Guinea, Ivory Coast, Liberia, Mali, Mauritania, Niger, Sierra Leone, Senegal and Togo)
- Eight West and South African universities (from Burkina Faso, Côte d'Ivoire, Ghana, Liberia, Mali, Senegal and South Africa)
- Thirty-four international mining companies
- Researchers from twelve European and Australian research institutions
- AMIRA International, an independent association of minerals companies that develops, brokers and facilitates collaborative research projects
- NGOs based in Burkina Faso, Ghana and Luxembourg
- A professional training centre based in Burkina Faso.
- National research and aid agencies in South Africa, France and Australia

This initiative demonstrates the significant research and development achievements that can be made when the different stakeholders in the minerals sector (industry, academia, government and non-government organisations) work together to achieve their diverse goals.

The WAXI project in numbers:

- 12 countries
- 73 partners over 11 years
- 76 Postdoc, PhD, Masters and Honours Projects, half of them African
- 76 International Publications
- 650 GB exploration geoscience database
- 1800 person-days of technical training in West Africa
- 650,000 km2 of geophysically constrained geological mapping

Unravelling Tropicana — where, what, how and why?

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1. Centre for Exploration Targeting, School of Earth Sciences, University of Western Australia
2. Geological Survey of Western Australia, Department of Minerals and Petroleum, Western Australia
3. AngloGold Ashanti, Australia

OUTLINE

The Tropicana gold deposit is located east of the Archean Yilgarn Craton within the Albany-Fraser Orogen. It is hosted in Neoarchean rocks, including granitic rocks with subduction-zone affinities that formed between 2722 –2554 Ma during the 'Atlantis Event'. The early history of the Atlantis Event event overlaps with komatiite-hosted Ni development within the Eastern Goldfields Superterrane of the Yilgarn Craton. Later metamorphism and magmatism during the Atlantis Event overlaps with orogenic Au development within the Eastern Goldfields Superterrane as part of regional-scale prograde greenschist facies metamorphism. Neoarchean gold mineralization within the Albany-Fraser Orogen is currently only known within the 'Tropicana Zone', and occurred at about 2520 Ma as part of a retrograde greenschist facies event that coincided with the development of a northwesterly-directed fold-and-thrust belt above the flat-lying Plumridge Detachment. The extent of the Plumridge Detachment is investigated in this paper, and extend northwards, towards the Archean Yamarna Greenstone Belt linking it to the Yamarna Shear Zone which forms the boundary between the Burtville and Yamarna Terranes.

Earth model construction in challenging geologic terrain: Designing workflows and algorithms that makes sense

de Kemp, E.A [1] Jessell, M.W. [2], Aillères, L. [3], Schetselaar, E.M. [1], Hillier, M. [1], Lindsay, M.D. [2] and Brodaric, B. [1]

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2. Centre for Exploration Technology (CET), University of Western Australia, Perth, Australia
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ABSTRACT

Workflows are essential for establishing a successful community of practice. In the challenging domain of exploration for minerals in ancient orogenic belts there is currently a major gap in the 3D model development workflow. The essential exploration requirements for 3D modelling beyond the head frame in brownfields of mature mining camps or in greenfields of frontier regions must support rapid multi-realization calculation of geologically reasonable models. The current workflow supporting this task has been adapted from the hydrocarbon exploration industry and is not suited to handle the combined problem of data sparseness at depth and geologic complexity that is typical of the mineral exploration domain. Geological reasonableness is an essential quality of a model which resonates with the acquired knowledge of the geologist. Much of this knowledge however remains un-encoded in the constraining data such as the core geological relations, the full range of geologic observations and corresponding feature producing events as well as the character of controlling processes that sum up to produce the final configuration of a complex geologic model. The key to achieving geologically reasonable models is in designing a sensible workflow that complements what has been a more data driven approach with procedures that better capture all the knowledge we can derive from the terrain of interest. The high degree of uncertainty in these models will also require a workflow for better modelling of sparse data with a mixture of algorithms and approaches in a simulation environment that can produce a number of realizations based on natural ranges of observational data and possible geologic histories.

Spectral Geology and Remote Sensing
Room 104 C&D

Tuesday 24 October 2017 14:00 – 15:40

Chairs: Xiaodong Zhou & Richard Bedell

Multi-scale Integrated Application of Spectral Geology and Remote Sensing for Mineral Exploration

Xiaodong Zhou [1], Constanza Jara [2], Marc Bardoux [2] and Celia Plasencia [2]

1. Spectral geology and remote sensing consultant
2. Barrick Gold Corporation

OUTLINE

Corescan mobile lab based high resolution hyperspectral core imaging system, Worldview-3 and Pleiades space borne high resolution imaging systems represent some of the most significant advances with successful commercial implementation in the past decade in the field of visible-infrared spectroscopy and remote sensing technology.

Such advances have empowered field geologists with new insights for targeting through improved multi-scale alteration and structural characterization of ore systems.

Corescan high resolution hyperspectral mineralogical and textural data allows objective, fast and cost effective, semi-quantitative analysis of alteration minerals and mineral sub-species, style, intensity, spatial zonation, as well as alteration paragenesis in relation to mineralization of ore systems, whereby assists the delineation of system footprint and the identification of vectors for targeting from drill hole to deposit, district and regional scales.

At sub-meter resolution, Worldview-3 and Pleiades satellite imageries prove to be cost effective for surface lineament analysis in rugged terrains from outcrop scale to deposit and district scales to help define structural framework and, combined with surface alteration mapping, identify ore control structures for targeting.

In addition, and not least important, progress has been made in improved field application of older technologies such as ASD field portable spectrometer, Hymap and Probe airborne hyperspectral imaging systems, as well as Aster and Landsat space borne multispectral imaging systems.

Understanding the fundamental capabilities and limitations of these technologies, continuously refining target alteration models and a field driven approach is critical for effective field application from data collection, data interpretation and synthesis analysis to data integration for targeting.

Examples for epithermal high sulfidation, Carlin and porphyry exploration will be discussed to illustrate these advances and remaining limitations and challenges.

Automated Hyperspectral Core Imaging — A Revolutionary New Tool for Exploration, Mining and Research

Harris, A. C. [1], **Martini, B. A.** [2], **Carey, R.** [3], **Goodey, N.** [3], **Honey, F.** [3]

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3. Corescan Pty. Ltd., 127 Grandstand Rd., Suite 1, Ascot, WA, 6104, Australia

OUTLINE

The advent of high spatial and spectral resolution hyperspectral core imaging into the minerals industry presages a revolution in quantifiable mineralogical identification and mapping of core, chips, soils and other geological samples from borehole to deposit scales. Technological advances in the past decade, including increased processing capacity combined with precision robotics in high-resolution spectrometers, have resulted in new generations of high-speed hyperspectral core logging systems becoming available. These multi-sensor platforms integrate reflectance spectroscopy, photography and 3-D laser profiling to generate image and point-based datasets at rates routinely exceeding 400m/day. At 500-µm spatial resolution, 510 spectral bands (from 450-2500nm) and ~200,000 spectral pixels per meter, the Corescan® system represents one such imaging system. Diagnostic absorption features related to molecular scale chemistry and mineral structure are detected and measured in the spectral signatures derived from these hyperspectral imaging systems. Spectral classification and mineral identification algorithms process each spectral pixel and compare the response to an established mineral library. The identification algorithms classify each pixel and determine the relative abundance (or purity) of the minerals present, which is then used to produce visual mineral abundance maps as well as numerical abundance logs. Chemistry and crystallinity parameters can be calculated for specific mineral groups by analyzing spectral absorption features at particular wavelengths. Inherently, this requires large volumes of data storage and significant processing speeds, both of which are now readily available including the ability to provide near real-time processing for mineralogy on-site in operational environments. Application of hyperspectral scanning technology makes deposit-scale petrographic studies possible, provides quantifiable outputs that confirm observations commonly made regarding zonal arrangement of alteration in ore deposits, and can refine and provide new insight into hydrothermal processes and exploration models. Ultimately, this technology provides consistent, objective mineralogical information and refocuses the geologist from being a data collector to a data interpreter and synthesizer. The combination of detailed mineralogical and chemical data in three dimensions on orebody scale promises to deliver new insights into the mineralogical and chemical characteristics, 3-D spatial variability, and genesis of orebodies—case studies from copper porphyry, orogenic gold and epithermal style deposits will be used to demonstrate these new insights and viability of hyperspectral core imaging.

Hyperspectral Outcrop Imaging of the Orange Hill Porphyry Copper Deposit, Alaska, USA

Kokaly, R.F. [1], Hoefen, T.M. [1], Graham, G.E. [1], Kelley, K.D. [1], Johnson, M.R. [1], Hubbard, B.E. [2], Goldfarb, R.J. [3], Buchhorn, M. [4],and Prakash, A. [4]

1. U.S. Geological Survey, Denver, Colorado, USA
2. U.S. Geological Survey, Reston, Virginia, USA
3. School of Earth Sciences and Resources, China University of Geosciences, Beijing, China
4. University of Alaska Fairbanks, Fairbanks, Alaska, USA

OUTLINE

Application of hyperspectral imaging to mineral exploration has been expanding in the past decade, with airborne imaging spectrometer data collected at increasingly higher latitudes, field-based scanning of exposures, and operationalized imaging of drill core and hand specimens. Field-based hyperspectral imaging offers the promise of mineral information at the centimeter scale which could be used to guide field sampling in exploration, to assess open pit bench faces, and for highwall mapping. Multi-scale hyperspectral data sets spanning laboratory, field, and remote sensing scales, though rarely collected, allow direct validation of mineral maps produced at the outcrop scale using results obtained from laboratory scanning of samples and core and mineral maps derived from airborne imaging spectrometers.

In July, 2015, tripod-mounted, field-based HySpex™1 systems (HyLab, University of Alaska Fairbanks; www.hyperspectral.alaska.edu), covering the visible/near-infrared (VNIR; 400-1000 nm) and shortwave infrared (SWIR; 1000-2500 nm), were used to scan a Cu-Mo-Au mineralized outcrop Orange Hill, Alaska. The hillside, approximately 1000 m wide and 100 m high, was imaged at 7 cm pixel size in the VNIR and 30 cm pixel size in the SWIR. Areas of light and dark rocks in the outcrop were measured with a field spectrometer in order to convert the HySpex data from radiance to reflectance using empirical line correction. The reflectance data were analyzed with the USGS PRISM (Processing Routines in IDL for Spectroscopic Measurements) software to map mineral distributions across the hillside. For selected hand samples, a laboratory imaging spectrometer system Corescan™ (Corescan Pty Ltd, Australia) was used to collect hyperspectral data with a 0.5 mm pixel size. In addition, geochemical, XRD, and electron microprobe analyses were performed on the samples. At the regional scale, HyMap™ (HyVista Corp., Australia) airborne imaging spectrometer data were collected over the Orange Hill deposit and nearby deposits at 6 m pixel size.

Airborne hyperspectral data indicate that muscovite is the dominant mineral associated with kilometer-scale magmatic-hydrothermal alteration at and around the Orange Hill porphyry Cu-Au-Mo deposit. Finer-scale mapping from field-based HySpex scans detect muscovite as well as additional minerals, including gypsum and chlorite, consistent with existing geologic information determined during past regional mapping. Analysis of the Corescan imagery shows the same distribution of hydrothermal minerals within multiple field samples. An empirical relation to mineralization is shown through detected variations in the wavelength position of the 2200 nm muscovite absorption feature; higher wavelength position was correlated with higher Cu concentrations in stream sediments and locations of known occurrences of mineralization and deposits. Computed wavelength positions of the muscovite absorption were found to be consistent between the field, lab, and airborne levels of hyperspectral imaging.

Airborne hyperspectral remote sensing in Alaska faces many challenges, which include a short acquisition season and poor illumination due to low solar elevation. Additional complications are encountered in the identification of surface minerals because minerals of interest commonly are exposed on steep terrain, further challenging reflectance retrieval and detection of mineral signatures. We overcame these obstacles by taking a multiple steps in our calibration process. First, the radiance data were converted to apparent surface reflectance using the radiative transfer correction program ATCOR-4 (ReSe Applications, Zurich, Switzerland). ATCOR-4 incorporates a digital elevation model to account for the local slope and azimuth of each pixel and to adjust the illumination. Apparent surface reflectance computed using ATCOR-4 was further adjusted using ground-based reflectance measurements from a calibration site for a single flight line that was designed to cross the other flight lines in the data collection. This step removes residual atmospheric contamination. Finally, for each of the normal flight lines, the area of overlap with the ground-calibrated tie line was used to empirically adjust the apparent surface reflectance. The result is a nearly seamless mineral map produced from the PRISM analysis of the reflectance data.

Field-based hyperspectral scanning of outcrop and mine walls, as tested by HySpex in our study, can provide mineral compositions at the tens of centimeters scale. These data can be collected rapidly over moderately large areas and, with processing, could be utilized for guiding sampling, informing material processing, and assisting development of 3-dimensional deposit modeling throughout exploration and mining activities. A significant challenge to wider application of hyperspectral data at this scale is posed by the need to georegister the fine scale images to a 3D topography. Coordinated collection of terrestrial lidar can provide the data needed to register hyperspectral imagery and derived mineral characterizations. 'Structure-from-Motion' (SfM) photogrammetry may provide a lower-cost solution but requires more time spent on setup and post-processing.

1Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Thermal Infrared Sensing for Exploration and Mining — an update on relevant systems for remote acquisition to drill core scanning

Bedell, R. L. [1,2], **Rivard, B.** [3], **Browning, D.** [2], **and Coolbaugh, M.** [1]

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2. TerraCore, Inc.
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ABSTRACT

Thermal Infrared or Long Wave InfraRed (LWIR) sensing using satellite, airborne, field, drill core and laboratory systems is advancing rapidly and is the most critical new frontier in spectral applications for exploration and mining. LWIR can directly distinguish silicate mineralogy, the foundation of the Earth's crust, and can directly detect certain ore systems. Although the technology has existed for some time it has been relatively expensive and data signal to noise was relatively low. Advances over the last decade have resulted in increasing improvements in signal to noise with commensurate higher spectral and spatial resolution, and importantly at lower cost.

Low spatial resolution satellites have provided single or broadband thermal data for decades, and while signal to noise is low, increasingly sophisticated processing techniques such as wavelet transforms can provide new results from historic archives that are important to exploration.

Broadband thermal night-time airborne surveys have provided information that has included mapping under pediment to identify buried faults and shallowly buried siliceous targets.

Intermediate spatial resolution hyperspectral airborne instruments provide better signal to noise, with higher spatial and spectral resolution, but until recently have seldom been employed in operational activities. However, examples include mapping intrusive compositions, siliciclastic and carbonate sedimentary lithologies, and hydrothermal systems.

Outcrop resolution studies involving tripod-mounted thermal scanners have resulted in detailed lithologic and hydrothermal silica mapping. Hand held spectrometers, widely available for the visible to near infrared VNIR-SWIR, are not as widespread in the community and thus have not been as extensively employed in the thermal.

Recently, operational thermal core imaging technology has provided petrographic level information. The ability to map silicate mineralogy, and strong carbonate responses, has significantly increased the reach of hyperspectral alteration mapping. Examples from a variety of deposit types will be presented.

In summary, a discussion of different ore deposit types and the contribution LWIR can make in their understanding of ore genesis, definition, and exploration will be provided. Practical information on how these technologies can be directly applied to other data for a coherent geologic model are discussed.

Targeting – Deep or Under Cover
Bassett Theatre

Wednesday 25 October 2017 08:30 – 10:10

Chairs: Chris Wijns & Dick West

Porphyry Targeting Under Atacama Gravels, Northern Chile

Wood, D. [1], **Trott, M.** [1]

1. Quantum Pacific Exploration, Las Condes, Santiago, Chile

OUTLINE

An integrated, mineral system approach was used for the interpretation of geophysical, geochemical and spectral data at a project-scale case study. This approach demonstrates how map layers relevant for vectoring to and within porphyry copper mineral systems can be created in areas of extensive gravel cover using independently derived data sets. An immediate implication being that robust porphyry copper targets can be developed rapidly and at a reasonable cost without necessarily relying on more costly and time consuming methodologies like pattern drilling or detailed ground geophysics. In addition, the integration of these layers contributes to an overall narrative regarding prospectivity. The map layers comprise bedrock geology, distribution and intensity of alteration mineralogy and assemblages, illite crystallinity, porphyry alteration footprints from trace element patterns, green mineral vectors and a 'black map' layer within which economic potential is empirically considered as nil. These layers are designed to provide the greatest possible amount of geological context and understanding of porphyry related processes in an area mostly covered by gravel. The map layers together are a direct decision making tool for commitment to further exploration expenditure or not. Our case study builds a compelling scenario of multiple, magmatic-hydrothermal related alteration systems in an area of extensive post-mineral cover, the data components of which comprised a modest expenditure outlay. We aim to leave the reader with the question "is there sufficient evidence to justify further exploration and expenditure commitment, and if so, what next?"

Exploration under total cover; a case study from NW Botswana

Kidder, J. [1], **Jones, S.** [2]

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ABSTRACT

Total cover (100% cover) presents both a challenge and an opportunity. A challenge, in the sense that mineralisation is not visible at the surface and that the cover greatly reduces the effectiveness of traditional geochemical sampling techniques, and an opportunity in that large deposit may be hidden beneath the cover. While with partial cover it is still possible to answer many of the geological questions vital to assessing the prospectivity of an area. In this sense total cover represents one of the last frontiers of mineral exploration.

Exploration companies have a history of utilizing soil geochemistry and other traditional geochemical methods to great effect in a variety of non-covered plays. However with thick cover, the effectiveness of surface samples remains unproven, yet there is a requirement in covered exploration for an unambiguous method of 'direct detection'.

There are few existing case studies for exploration of total covered plays, with the majority focused on gold exploration in Western Australia. The lack of a known test bed (mineralised deposit with total cover) means trailing many techniques, often with considerable expense, in order to identify a reliably unambiguous method of 'direct detection'. This paper serves as a case study of the exploration methods used and their relative effectiveness in the thick Kalahari cover of NW Botswana. Many of these methods were not fully established and required development of both the technique and technologies required to effectively undertake the method.

Ultimately, the effectiveness of undercover exploration will always be at loggerheads with both project deadlines and budgets. Balancing the quality of data with cost is key to efficient and effective covered exploration. Establishing early in the project regolith composition and stratigraphy as well as the regional water regime (including water table) is important for both program design and data interpretation. A staged exploration program with 'exit' decision points is vital, with early decision points reachable with limited boots on the ground. Key geophysics and geochemical sampling programs should be undertaken in campaigns, reducing the requirements for big logistical footprints in country and allowing for staged appraisal (linked to decision points) following each campaign until the ground is proved effectively unprospective or an economic intercept is established. Due to variability in the regolith of covered environments many more case studies will be needed to establish a measured approach to undercover exploration.

Brownfields and Beyond — Undercover at Neves Corvo, Portugal

West, D. [1], **Penney, M.** [2]

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ABSTRACT

The Iberian Pyrite Belt in Spain and Portugal is a world-class volcanogenic massive sulfide (VMS) terrain that hosts one of the world's largest accumulations of massive sulfides and stockwork mineralization (>1700 Mt total reserves (Tornos et al, 1999) within 90 deposits). One of the largest deposits is the Neves Corvo Cu-Zn-Pb deposit which is in southern Portugal and was discovered in 1977 because of drill testing a gravity anomaly. Within a two-year period of that discovery, four of the six known ore bodies had been found within this VMS complex. The rate of discovery slowed significantly after that initial success due to the complexity of the thrusted geology and the significant depth of the ore bodies. A variety of exploration methods have been tried within the Neves Corvo complex and the belt, encouraged by the disparity in discoveries between the Spanish and Portuguese sides of the belt. The most recent discovery at Neves Corvo was the Semblana deposit in 2010 at a depth of approximately 830 m because of persistent and innovative exploration in the shadow of the Neves Corvo headframe.

During the first twenty years after the discovery of Neves, gravity was the primary tool with electromagnetic and electrical ground surveys used in combination with airborne TEM and magnetic surveys to increasingly probe deeper depths and larger areas around Neves Corvo. Geologic models for the deposits and structures improved significantly during this time also, but discovery was elusive. After 2006, deeper probing TEM, airborne gravity and ZTEM were conducted and integrated with the historical data to cover larger areas faster to focus efforts on the most prospective areas within the existing tenements. Drill testing was followed by borehole TEM to increase the effective radius of the boreholes. A brownfields 3D seismic survey was contracted over Neves Corvo while the Semblana deposit was discovered and proved to be the most effective geophysical method in detailing the extent of the Lombador and Semblana massive sulfide lenses as well as identifying detailed structures and helping to improve the geologic model between drill holes in the area. Wireline logging of drill holes was done to determine the petrophysical attributes to improve the velocity model and to better understand the seismic impedance across bedding and faults and between the massive sulfides and host.

This review provides insight into the effectiveness of the individual geophysical methodologies used for mapping massive sulfides and structures at depth as well as the benefits of integration and 3D visualization of all existing data sets. Exploration is very challenging in areas of complex geology and at great depths, but the Neves Corvo example confirms the common knowledge that a combination of integration, best methods and team work increases the chances of discovery. This review also highlights the observation that 3D reflection seismology is the best exploration tool for exploring deeply within this belt.

Sea Floor Mining Exploration Technology and Methods

Peter Kowalczyk [1], **Boris Lum** [1]

1. Ocean Floor Geophysics Inc., Burnaby, BC, Canada

ABSTRACT

The world's oceans have always both challenged and helped humanity, providing food for our table, linking settlements around the globe and driving the weather systems that influence our daily lives. Now we are finding mineral and energy resources on the ocean floor that will be as important to mankind as the resources we presently exploit on land. The oil industry has already moved offshore. However, the methods and capital required to exploit offshore oil and gas are not appropriate to find and develop seafloor mineral and gas hydrate deposits. To find and exploit them, exploration methods used on land have been re-invented for the sea.

Exploration activities must be economical and the scale of operations must be appropriate. In the past, humans have gone directly down to the seafloor to explore and map it, or have used crude machines to retrieve samples. This is expensive, high risk to human life, and not always successful in deep water. Today, robotic devices have replaced using people on the seafloor, increasing safety and increasing the periods of active operations near or at sea floor. Using robots and remotely operated sensors, we can map, sample, and mine the seafloor. Robotic systems provide economies independent of scale. The size of individual operations can be adjusted to provide a profit without building and operating gargantuan projects.

Remotely operated and autonomous underwater vehicles (ROVs/AUVs) are central to this process. Ship borne sonar and multibeam systems map the seafloor at scales of about 1:50000 or smaller. Sonar, and particularly synthetic aperture sonar can map the seafloor at scales of 1:100 using AUVs/ROVs. Water chemistry sensors, magnetometers and cameras can be operated on vehicles tasked for other purposes. Sampling can be done using ROVs, and drilling done using robotic seafloor drills. 3D seismic cubes can be acquired using small hydrophone arrays easily deployed from small vessels. Electromagnetic systems and interpretation algorithms exist to map both shallowly buried and seafloor massive sulfide deposits and gas hydrate deposits. Positioning of subsea vehicles and installations is not simple, but off the shelf transponder systems are available, and subsea sonar based navigation systems allow multiple assets to be located within a transducer array. These systems are becoming smaller, less expensive, and deployable from general purpose vessels rather than specialized purpose built ships.

The principal economic targets today are seafloor deposits of gas hydrates, submarine massive sulfides, and polymetallic nodules. The geologic signature of these deposits is understood. Best practices to find and exploit them are well known or are being developed. The impact of robotics is that "bigger is not necessarily better", and that exploration can be done cost effectively and safely using smaller, reliable, more capable, and less expensive equipment. Mining at sea, long delayed, is about to become an established industry.

Targeting – Mine Site to Camp Scale
Bassett Theatre

Wednesday 25 October 2017 10:40 – 12:20

Chairs: Alan King & Joel Jansen

Mining BIG Data: the Future of Exploration Targeting

Guy Desharnais, Ph.D., P.Geo, Jean-Philippe Paiement M.Sc., P.Geo

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OUTLINE

Exploration expenditures will increasingly be shifting to deeper domains and blind targets as the "easy discoveries" are progressively exhausted. The mining industry's discovery rate has fallen significantly in the past decade because of this, which begs the question: "have we fully optimized the exploration targeting process?" The application of the rapidly evolving science of machine learning coupled with increasingly powerful computers have resulted in process optimizations and breakthroughs in many other industries such as medicine and transportation. The minerals industry is poised to drag their datasets into the 21st century to unlock the predictive capability of these powerful algorithms. Many mining or exploration companies have large amounts of historical data, within which clues to mineralized systems are hiding. Unfortunately, much of these data are in a poor state, often on paper, and require a significant investment to digitize and validate them. In terms of new data capture, the advancement of geophysical-survey technology and hyperspectral core logging tools have been in-step with our technological capability to store and process this rich data. Significant advancements have been made in the past decade to convert this 1- or 2-dimensional data into the 3D realm through inversions, stochastic modelling and implicit modelling. Our capability to harness these massive databases and establish vectors to ore, however, has been limited by the human brain's limited capacity to see patterns in multidimensional data. However, this is a particular strength of machine learning. Unlike other industries where data is collected where it is most useful, we don't have drill hole data where we want to discover new deposits. The clustered nature of the data around known deposits is a major challenge for the application of the many algorithms readily available, and we must rely more heavily on indirect measurements such as geophysics, geochemistry, extrapolation and interpretation. Further research is needed to establish what are the most robust and productive algorithms that will enable prediction of ore bodies. Careful consideration of the inputs by human geologists is required to ensure that the model does not merely predict what is already known, or provide spurious results. This requires high quality geoscientific data, solid interpretations, a good dose of common sense, and in most cases several iterations to understand what the software is predicting.

NSERC-CMIC Mineral Exploration Footprints Research Network: Data Integration for the Next Generation of Mineral Exploration Models

CM Lesher [1], MD Hannington [2], AG Galley [3], and the Mineral Exploration Research Network

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OUTLINE

The objectives of the Mineral Exploration Footprints Network are to: 1) enhance the ability of the Canadian mining industry to recognize the "footprints" of ore systems from high-grade cores to most distant cryptic margins, 2) develop methods that truly integrate (not just layer) the multi-scale 3D geological-structural-lithological-mineralogical-geochemical-petrophysical-geophysical data that define ore system footprints, and 3) develop workflows to assist researchers and industry explorationists to more effectively interact to accomplish these goals. Multi-disciplinary teams from 18 Canadian universities and 23 mining companies are defining the hydrothermal-magmatic footprints of the Canadian Malartic disseminated Au deposit, the McArthur River and Millennium U deposits, and the Highland Valley porphyry Cu deposit. New and reprocessed/QAQC-controlled geological, structural, whole-rock geochemical, mineral chemical, hyperspectral, petrophysical, geophysical, and multi-media surficial data have been collected for each site along cross and long sections. The new data were collected from the same samples in order to facilitate comparison of different data types and data integration. All data have been interrogated within self-consistent 3D Common Earth Models (CEMs) that allow researchers to define which parameters are most useful in identifying deposit footprints. Cutting-edge data analytics not normally used in mineral exploration have been used determine spatial data clusters and to generate rules defining how the data interact to identifying subtle footprint characteristics. Joint and constrained geophysical inversions have been developed to separate hydrothermal footprint signatures from background lithologies, using not only petrophysical data, but proxies derived from other data sets. The results have been combined within CEM space to define new exploration indices. Although method development work has been restricted to data dense rock volumes centered on cross- and long sections through the research sites, allowing researchers to maximize recognition of interrelationships between commonly disparate data sets (e.g., potential field versus point data), the results will then be applied to more sparsely populated rock volumes in order to recognize and understand the full extent of the ore system footprints. To date the "composite"hydrothermal-magmatic footprints have been defined in 2D at the Canadian Malartic and Highland Valley sites and in three dimensions at the Millennium-McArthur site. At Canadian Malartic multiple alteration halos have been defined using geochemical-mineral chemical-hyperspectral-petrophysical data not only in the host metasedimentary rocks, but also in associated mafic dikes, which provide a greater geochemical contrast and are therefore a more sensitive indicator of ore-related alteration. At Millennium innovative processing techniques are being developed to extract physical property information from legacy 3D-3C seismic data to identify alteration and vertical structures, and fusion of geochemical and 3D pole-pole resistivity data will characterize how host rock resistivity varies as a function of alteration intensity and mineralization. At Highland Valley feldspar staining, visible-near IR spectral analysis, multi-element ICP analysis, and petrologic methods have been integrated with detailed geologic-structural-vein mapping to extend the known alteration footprint out to ~10 km from the mineralized centres. NSERC-CMIC Exploration Footprints Network Contribution #105.

Mineral Exploration using Natural EM Fields

Jansen, J. [1], **Cristall, J.** [1]

1. Anglo American plc

OUTLINE

The understanding of the geological processes behind the formation of mineral systems has advanced remarkably over the past two decades and has initiated a re-think with respect to the optimal geophysical methods required to both target and delineate economic ore bodies. The mineral system concept of McCuaig and Hronsky (2014) proposes four critical elements that must combine in various scales over space and time: whole lithosphere architecture, transient favourable geodynamics, fertility, and preservation of the primary depositional zone. They conclude that "[the mineral system concept] focuses mineral exploration strategies on incorporating primary datasets that can map the critical elements of mineral systems at a variety of scales, and particularly the regional to camp scales needed to make exploration decisions."

With exploration evolving to take a holistic view of the complete mineral system in targeting, geophysics has adapted to making greater use of techniques that can explore scales ranging from deposit to lithospheric. While the geophysical toolbox is filled with many techniques, only a few of them are capable of the depth investigation required to expand our view past the deposit scale: active- and passive-seismics, and methods that make use of the Earth's natural gravitational, magnetic, and EM fields. Gravity and magnetics are ubiquitous in datasets ranging from continental to prospect scales and the use of seismic techniques in mineral exploration is growing. But nothing compares to natural field EM methods if the goal is 3D conductivity imaging to kilometres depth combined with ease of data collection. Over the past decade, these have become mainstream in mineral exploration, and recent advances in the joint inversion of ground and airborne data are making natural field EM methods an even more powerful tool for resolving complete mineral systems.

Examples of natural field EM techniques applied to a variety of mineral systems over the past decade are presented, beginning with a crustal scale MT transect across the Gawler Craton and the super-giant Olympic Dam IOCG deposit of South Australia, and followed by illustrations from porphyry systems (Collahuasi, Pebble, El Salvador, Los Bronces, Cobre Panama, Resolution, Santa Cecilia, and Morrison) that dominate this paper owing to the economic significance of porphyry copper-gold deposits globally and because of their amenability to large-scale conductivity imaging. Further applications to sedimentary copper (Frontier and Kansanshi), magmatic polymetallic sulphide (Voisey's Bay), and unconformity-related uranium (McArthur River) deposits are also presented. Together these examples demonstrate the value that natural field EM geophysics can bring to the exploration decision making process when interpreted in context of mineral systems.

Reference:

McCuaig, T.C, and Hronsky, J.M.A, 2014, The mineral system concept: the key to exploration targeting: Economic Geology, Special Publication 18, p. 153-175.

Geophysical data assimilation for grade modeling at different scales

Gloaguen, E. [1], **Tirdad, S.** [1], **Perozzi, L.** [1,3], **Bouchedda, A.** [1], **Caté, A.** [1,3], **Blouin, M.** [1,3], **Giroux, B.** [1] **& Dupuis, C.** [2]

1. Institut National de la Recherche Scientifique, centre Eau, Terre et Environnement, Québec
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3. geoLEARN (www.geoLEARN.ca<http://www.geolearn.ca/>)

OUTLINE

In the mining industry, the accurate assessment of the grades of ore is obviously a priority for resources and reserve estimation. For decades, geophysical data have been used as a qualitative tool for exploration. Indeed, deterministic least-squares approaches that have been used to analyze those data only permit their qualitative interpretation. However, these data have a much richer potential if one can use appropriate tools to anaylze them. Hudbay Minerals and its partners have acquired multiple airborne, surface and in-hole geophysical data permitting the inference of quantitative estimates of mining parameters. Here, in the first example, we used machine learning algorithms to translate geophysical log data into gold grades, while in the second example we present a workflow allowing the inference of the 3D density model and its uncertainty from surface gravity data at the resolution of the log data. In the first case, we showed that machine learning allows to predict the probability of gold to be above a given cut-off. In the second one, it is demonstrated that one can use the raw gravity data to model the density in 3D at the resolution of a smallest mining unit.

Advances in Seismic Reflection as an Exploration Tool in Hard-Rock Mining

Joe Dwyer, Don Pridmore and Greg Turner

HiSeis Pty Ltd

OUTLINE

Seismic reflection has been used in the petroleum industry as an exploration and production planning tool for decades with stunning success. Early application of the seismic reflection method by miners in the 1980's and 1990's had varied success, however, in general the seismic method was largely considered unreliable in imaging hard-rock geology.

Following the successful completion of a gold exploration project using seismic methods in the West Australian Goldfields in the early 2000's, the Centre for High Definition Geophysics (CHDG) at Curtin University in Western Australia was established in 2006 with funding through the Western Australian Government's 'Centres of Excellence in Science and Innovation' program. The CHDG conducted over 35 separate geophysical field trials over the next four years supported by a range of prominent industry partners. These trials provided clear demonstration that seismic reflection works in complex geological environments.

Based on the highly successful work of the CHDG, in April 2009 HiSeis Pty Ltd was formed by Curtin University to commercialise the technology and intellectual property developed within the CHDG. HiSeis was established to advance the application of modern seismic reflection to provide high-resolution 3D images in complex hard rock geology to assist miners solve geological problems.

The application of high resolution seismic reflection to map mineralisation and surrounding geology and structures in hard rock environments has progressed significantly in the last decade, primarily driven by HiSeis' actions. However, mineral prospecting using reflection seismic is not straightforward and the traditional petroleum approach for seismic is not suitable in the complex geological terrains that most mines are located. Major improvements in equipment, design, field practice, processing and understanding has seen the seismic reflection technique emerge as a cost-effective tool for high-resolution, three-dimensional structural and lithological mapping. Advancements in the last decade by HiSeis have identified the critical elements to successfully apply seismic in complex mineral environments

Discoveries of large near-surface deposits are becoming increasingly rare and the reserves of most economic minerals are in decline. The exploration for and exploitation of mineral resources has had to move to greater depths, providing a market for innovative, high resolution, deep exploration techniques such as modern reflection seismic. Modern reflection seismic offers mineral explorers and miners the only geophysical method that can image deep structures with the precision required for targeting and for discovering new resources. Advances in the application of reflection seismic in hard-rock mineral exploration are now providing high resolution 3D images of the geology that are routinely obtained at depths well in excess of those typically achieved using more conventional geophysical methods.

In this paper we present and briefly discuss the results and lessons learnt in hard rock seismic after more than a decade of dedicated investigations by HiSeis and the CHDG. Case study examples from the application of reflection seismic in a variety of mineralised settings will also be presented.

3D Borehole and Tunnel Seismic Techniques. Application to Optimized Mine Development

Calin Cosma, Ph.D., Vibrometric

Vibrometric, Helsinki, Finland & Toronto, Canada; calin.cosma@vibrometric.com

OUTLINE

Innovative borehole and tunnel seismic techniques became essential components of resource characterization efforts and are capable of reducing the uncertainty associated to mine planning and development while bearing little or no influence on ongoing production and operating procedures. Vibrometric performed seismic site characterization projects and associated R&D work for over 30 years and is the leading Finnish expert in seismic investigations for detailed characterization of hard rock sites. The case histories and methodological outlines presented refer to: Finding Mineralized Zones and Delineating them laterally and in-depth; Mapping Lithological Contacts and Structural Features (Faults, Dykes and Folds); Inferring Rock properties (Elastic moduli, Changes in porosity, Fluid content) and Determining Fracture and Stress Orientation (Anisotropy).

Advances in Airborne Gravity Gradiometry at Gedex

Baker, K., Carroll, K.A., Dickson, B., Hatch, D., Main, B.,McTavish, D., Pefhany, S., Sincarsin, G., Sincarsin, W., Sinton, J., Tomski, I., Wong, H.

Gedex Systems Inc. Mississauga, Canada

OUTLINE

The Gedex High-Definition Airborne Gravity Gradiometer (HD-AGG™) was designed and developed to deliver measurements of the gravitational field with improved signal-to-noise and resolution. Modeling and practical experience have demonstrated the value that this improved data quality will have on the discovery of resources and mapping of geologic features previously not visible. For instance, an economic massive sulphide with a thickness of 40m and buried at 100m would be detectable with a low-noise, high resolution AGG system. The fundamental challenge in measuring accelerations due to changes in sub-surface geology is that the noise in the airborne environment is more than 7 orders of magnitude greater than signal. The Gedex HDAGG™ system measures the gravity gradient utilizing a pair of balance beams each of which is centered on a pivot spring. With these beams mounted on the same axis and balanced to the nanometer scale, the sensor is largely insensitive to rotational and translational motions. The Gedex system consists of these proprietary sensors, a flight cryostat, and an isolation system together with proprietary and non-proprietary software. The commercial target for the system is a post-processed performance of 1 Eo/root-Hz in the bandwidth from 0.001 to 1 Hz. System components were described and the performance of the prototype elements shown, by Carroll, Hatch and Main (2010). Based on simulator and airborne trials of the individual elements integrated as a system, Gedex reconfigured and built a new two-axis system, with improvements designed to further improve noise performance in the airborne environment. While the primary objective was improvement in balancing techniques to position the centre of mass on the axis of rotation in the gravity gradiometer sensors (balance beams), improvements were also made to the isolation mount, the cryostat, auxiliary measurements used in the post-processing, and in final data processing. Due to the benefits of measuring more than one component, and the orientation of the sensor, the system was also upgraded to a 2-axis system, which effectively responds to (Gzz-Gxx)/2, and (Gzz-Gyy)/2. A series of test flights with the 2-axis system in early-2016 yielded dramatically improved results over the original prototype. This improved performance allowed smaller sources of noise to be identified and reduced. As a result, subsequent test programs have resulted in progressively lower noise levels being measured in more turbulent environments. This paper will review some of the improvements made, discuss test results, and the path forward.

Advances of AGG technologies in CGG

CGG

CGG, Mississauga, Canada

OUTLINE

Falcon® AGG technology at CGG has been improved continuously over the years since its first successful commercial flight in 1999. In 2005, the first helicopter-borne AGG test was flown with the digital Falcon AGG system that offers a reduced noise floor as well as reduced weight and size. Falcon Plus, introduced in 2015, reduced the noise floor to half of that of the standard Falcon. Full Spectrum Falcon, introduced in 2016, merged the Falcon AGG and strap-down gravimeter (sGrav) to obtain broadband gravity data with the shortest wavelength (typically 100 – 300 m) and the long wavelength (from 20 – 30 Km to hundreds of km). Most recently, CGG Multi-Physics and Lockheed Martin have entered an exclusive agreement to develop the next generation gravity gradiometer, FTG Plus. FTG Plus has a sensitivity goal of 0.5 E/$\sqrt{}$Hz in a bandwidth from 0.0001 to 5 Hz. FTG Plus will open doors to many new applications that demand much higher sensitivity and resolution than is currently achievable.

Extending the limits of GPR penetration

Jan Francke, GroundRadar

GroundRadar Consultants

OUTLINE

Unique amongst geophysical tools for its high resolution and diversity of applications, ground penetrating radar (GPR) has seen renewed interest for mineral exploration due to the availability of new instruments which allow deeper penetration than previously possible. A well-established tool for tropical weathering sequences (nickel laterites and bauxites), mineral sands, paleochannels and some iron ores, the next-generation of GPR is now being applied to a wider range of deposits, including graphite and coltan exploration to depths exceeding 100 m. These systems are well-suited for extreme environments, being completely wireless, weighing less than 4 kgs and being operated using an iOS or Android app. The simplification of the technology has also lowered survey costs to a fraction of what they were previously. Emerging hybrid EM-GPR instruments may extend penetration ranges many times deeper, by working in the 300 kHz – 30 MHz range. New processing approaches are extracting more complex information from radar profiles than simple interpretations of reflections, yielding information on volumetric water content and resistivity profiles.

Technical Innovation 2 – Drilling, Samples & Geology
Room 104 A&B

Wednesday 25 October 2017 10:40 – 12:20

Chair: Richard Hillis & David Hatch

Use of core imagery in modelling geometallurgical properties

Randall, S. [1], **Dobush, T.** [1], **Jackson, J.** [2], **Nguyen, A.** [3]

1. Geosoft , Toronto, ON, Canada
2. JKTech, Indooroopilly, QLD, Australia
3. SMI-JKMRC, The University of Queensland, Australia

OUTLINE

Exploration companies, conducting diamond drilling as part of their exploration projects, are spending 100's $ per meter to understand the subsurface. To gain greater value from this critical dataset, many are now scanning these cores with hyperspectral and visible sensors. This in turn creates an opportunity to use this data as an input in modelling geometallurgical properties when combined with Test Based and Mineralogical studies. JKTech and Geosoft will present potential workflows for advancing characterization of the subsurface to enable the prediction of how the material will respond to processes within the mining value chain.

Truth Machine 2.0: The Discovery Business and Near-Real Time Decisions

James S. Cleverley, REFLEX

REFLEX, Imdex Ltd, Balcatta, Western Australia

OUTLINE

At some point in the mineral discovery process you will need to drill a hole; this is a critical test of the hypothesis designed to support a decision. The drill hole is often known as the Truth Machine, and the act of drilling is a lifecycle that includes drilling, sampling, analysis, interpretation to decision. As the minerals industry embarks on the next cyclical upswing we are also seeing the effects of digitisation on the business. What does this mean for the traditional Truth Machine? How will digital transformation drive the design of Truth Machine 2.0? In this talk we will explore the future business of minerals discovery and the impacts that technological and digital innovation will have on the way we find and drill for new mines.

Geological Logging with X-ray Vision

Aaron Baensch, Principal Geologist

Olympua Scientific Solutions, International Mining Group

OUTLINE

Olympus Scientific Solutions continues its commitment to the geoscience & minerals industry, with the delivery of its cutting edge, 5th generation portable X-ray Fluorescence (pXRF) analyser and revolutionary portable X-ray Diffraction (XRD) systems. In this talk we will highlight the recent and significant advances in ruggedization, revolutionary processing and productive new pXRF platform and how we are integrated these technologies into the DET CRC Lab-at-Rig® concept that Reflex are commercialising.

Advancements in Analytical Geochemistry at Bureau Veritas Minerals

Jamil A. Sader, PhD, Corporate Geochemist

Bureau Veritas Minerals, 9050 Shaughnessy St., Vancouver, BC V6P 6E5 Canada,
jamil.sader@ca.bureauveritas.com

OUTLINE

Several analytical firsts have been developed at Bureau Veritas Minerals. Among those is the implementation of laser ablation ICP-MS analysis paired with XRF for routine geochemical analysis. Benefits include the elimination acid-related digestion issues, no upper limits, and total whole rock characterization with detection limits lower than many acid digests. Secondly, Artificial Neural Network modelling of data collected from various spectral devices such as Fourier Transform Infrared Spectroscopy (FTIR), has enabled prediction of geochemistry, geomet, mineralogy, mine data and other physical properties at extremely low sample costs. Lastly, BV has developed an innovative software application, MineDSI, which allows visualization of, and interaction with, several types of down-hole data in one location.

South Australia Mineral System Drilling Program: What We Learnt from the Collaboration Towards Mapping Mineral Systems Under Cover

Steve Hill

Geological Survey of South Australia

OUTLINE

Although South Australia is fortunate to host a highly prospective part of the Earth's crust, we share the challenge for making new mineral discoveries in areas of covered mineral exploration targets. The collaboration with DET CRC, South Australian Government and the wider research community, mineral exploration industry and exploration service sector, as part of the Mineral System Drilling program has been a world-first success. The technology research and development and "pull through", the communications strategy and the geological insights have been major highlights. This presentation focusses on an assessment the highlights as part of mapping and testing the 1590 Ma mineral system in the Gawler Craton that is closely associated with the Olympic Domain IOCG mineral systems and associated Gawler Range Volcanics (GRV) complex, and how this now sets the stage for Australia's continental-scale drilling programs as part of the proposed National Drilling Initiative (NDI).

Prospecting Drilling': A Technology-Enabled Revolution in Mineral Exploration:

Richard Hillis, CEO

Deep Exploration technologies CRC, Australia

OUTLINE

The Deep Exploration Technologies Cooperative Research Centre (DET CRC) is a $155M research initiative funded by the Australian Government and the mining industry in order to address declining success in mineral exploration beneath barren cover. This presentation will focus on DET CRC's coiled tubing (CT) drilling and real-time sensing projects and their potential to enable a revolutionary new approach to mineral exploration beneath barren cover, i.e. 'prospecting drilling': cheap, safe, environmentally-friendly and extensive, continuous drilling programs that map mineral systems beneath cover, enabling progressive vectoring towards deposits

Exploration Data Analytics, Uncertainty and Security

Rob Hough

CSIRO

OUTLINE

With new disruptive technologies now promising or already producing real-time data stream and with the increasing need to consider very large scale data-sets in regional exploration, data analytics will provide a new product suite for the explorer. The integration of data provides avenues for probabilistic predictions and for objectivity in geological logging that can be further supported through computational automation. In CSIRO, we are actively mixing geoscience with algorithm and software developments, often from other sectors of the data sciences, to support exploration decision making in data rich environments. New developments in the consideration of uncertainty quantification in geological simulations and in the preservations of security of data across boundaries (e.g. tenements) coming from sectors like banking and energy, provide real opportunities for reduced risk in decision making by explorers whilst realising the potential benefits of data sharing whilst maintaining data privacy for a given company.

New developments in Laser-Ablation-ICPMS in the field of mineral characterisation

Leonid Danyushevsky [1], Sebastien Meffre [1], David Cooke [1], Ivan Belousov [1], Ashley Norris [2]

1. TMVC Research Hub and CODES, University of Tasmania
2. Norris Software, Tasmania

OUTLINE

The presentation will cover recent developments in LA-ICPMS applications within the R&D program conducted by CODES Analytical Laboratories, which include: 1) LA-ICPMS imaging of metal distribution within minerals; 2) algorithms for high-throughput mineral characterisation based on LA-ICPMS scanning of rock samples; 3) approaches to characterising metal deportment and sizing micro-inclusions in minerals using LA-ICPMS; 4) development of new calibration reference materials for analysis of sulphide minerals; 5) new instrumentation developments to enable fast through-put and high spatial resolution of LA-ICPMS; and 6) new developments in automated LA-ICPMS data processing. We will also discuss new applications for using mineral chemistry as an exploration tool.

Technical Innovation 3 – Geophysical Diffusion
Room 104 A&B

Wednesday 25 October 2017 14:40 – 15:40

Chairs: David Hatch & James Macnae

ARMIT — A New Generation of TDEM Sensor

Roman Wasylechko, Abitibi Geophysics

Abitibi Geophysics Inc, Val d'Or, Quebec

OUTLINE

At DMEC '07 Abitibi Geophysics presented on InfiniTEM, a loop configuration, which is optimized to explore for deep, dipping conductors under overburden. Continued research over the past decade has yielded ARMIT, a new sensor technology that measures B-field and dB/dt simultaneously. The demand for measured B-field increased as it was shown that dB/dt was not responding to super conductive sulphides. The ARMIT development was in partnership with RMIT University of Melbourne, Australia where Dr. James Macnae and his team designed and built the prototype sensor.

Low frequency AEM and AIP with B and dB/dt sensors

Duncan Massie, Paul Thomson

Monex Geoscope &Thomson Aviation

OUTLINE

We have developed and field tested an airborne receiver collecting both B and dB/dt field data at lower frequencies than conventional airborne EM. The measured B field data is theoretically more sensitive to good conductors and induced polarization effects than data collected by a dB/dt sensor, even if such data is integrated to estimate a pseudo-B field. The main challenges in getting good data at low frequency lie in minimizing the effects of sensor rotation in the earth's magnetic field. Rotation effect minimisation can be addressed through innovative suspension systems and subtraction of predicted rotation effects. These predictions rely on very accurate measurements of 3D rotations.

Orion3D DCIP and MT Examples

Gordon, R., Sharpe, R.

Quantec Geoscience Limited

OUTLINE

The Orion3D technology was first initiated in 2006 and trialed in 2007. The first commercial implementation was 2011.

Orion3D is the first ever distributed acquisition system (DAS) -based full 3D data acquisition system that includes both IP and MT.

There are several unique features of the system including a large footprint of 2 x 2 km to optimize DC and IP depth of investigation in the 500 m to 800 m depth range; and an ostensibly equal number of in-line and cross-line receiver dipoles that maximizes coupling with an target.

Survey results will be shown from a number of exploration situations globally including epithermal gold, IOCG and a copper-gold porphyry system. Case studies reveal the advantage, of true 3D vs 2D or 2.5D acquisition. True 3D is defined to mean acquisition where receiver electrodes sample the current in orthogonal directions and a large number of receivers (300) are deployed (using a DAS) to optimize the footprint geometry. For every current injection, all receivers are active. This results in a true omnidirectional coverage for each current injection and gives multiple intersecting current paths over the entire survey with a very large number data points acquired. The result is greater coupling with complicated 3D geology and structure which enhances resolution and target detection at both shallow and deep depths. The omnidirectional coverage provides a better 3D inversion result because there is no acquisition directional bias and each cell in the inversion volume is sensitive to multiple omnidirectional current paths.

Examples which show this increased definition through a high correlation with drill results from actual field surveys will be discussed following a brief description of the technology.

Advances of AEM Technologies in CGG

Adam Smiarowski, CGG

CGG

OUTLINE

The past decade of development on airborne electromagnetic (AEM) systems by CGG has focused on extending the bandwidth of measurements and increasing the range of geologic targets that can be detected. CGG's Helitemc was developed with this in mind. Helitemc brings a newly developed receiver in plane with the transmitter, substantially decreasing distance to the targets and increasing signal. The new receiver architecture dramatically reduces coil motion noise and allows operation at lower base frequencies. The coil motion has been decreased such that 12.5 or 15 Hz base frequencies can be used (an industry first!) and longer transmitter pulses can be employed allowing for the better energizing of stronger conductors. The longer measurement time of CGG's 12.5/15 Hz system allows detection of long decays and improves discrimination of strong conductors. The addition of CGG's MultiPulse™ configuration results in the AEM data having more high-frequency content and also helps increase the "geological bandwidth".

The Transient Phase Method for Classifying Super Conductors in HTEM Profiles

Steve Balch, Triumph Instruments

Triumph Instruments

OUTLINE

A method for identifying high conductance responses in HTEM profiles is developed in a manner analogous to the calculated phase in frequency domain EM. For a given time decay, the transient phase treats the sum of the off-time profiles as the quadrature response and the sum of the on-time profiles as the in-phase response. High conductance sources exhibit little measurable decay during the transmitter off-time and are better represented as a ratio of the quadrature to in-phase response. As conductance increases, the on-time to off-time ratio approaches "zero" as the quadrature response approaches zero and the in-phase response approaches its maximum. For conductor responses having a time constant longer than the sampled off-time, on-time measurements and transient phase estimates are better indicators of high conductance than lower base frequency off-time.

2.5D airborne EM inversion

Desmond FitzGerald, Intrepid Geophysics

Intrepid Geophysics

OUTLINE

The advantages of 2.5D (2D geology, 3D source) airborne electromagnetic inversion at a survey scale, in 3D geological mapping applications and the identification of conductive drilling targets compared to the more commonly used CDI transforms and 1D inversions or current limited 3D inversions are demonstrated using examples from different geological settings.

The 2.5D inversion application used in this work includes a new forward model algorithm using the Finite Element method. The application enables the accurate simulation of 3D source excitation for full domain models inclusive of topography, non-conforming boundaries and very high resistivity contrasts. The solution is accurate for a geo-electrical cross-section which is relatively constant along a strike length that exceeds the AEM system footprint.

The major innovation includes a new inversion solver with adaptive regularisation which allows the incorporation of a misfit to the reference model and the model smoothness function. The regularization parameter is chosen automatically and changed adaptively at each iteration, as the model, the sensitivity and the roughness matrices are changing, and in contrast to other inversion algorithms calculates the forward model only once at each iteration. As a result, the 2.5D inversion process runs three to five times faster than using conventional inversion algorithms.

Memory usage has been dramatically reduced and for speed the software has been parallelised using Intel MPI and can be used on standard computing hardware or computing clusters. As a result, data from surveys with survey lines lengths exceeding 200 kilometres can be inverted on high end laptop computers. The integrated software design allows the user to prepare a full survey inversion then execute this simply in a batch process. The user can visualise inversion progress at any time during process execution. A minimum of 3 km/hour of full inversion is achievable on a standard desktop.

We allow flexibility in the selection of components and in the estimation of noise. The integration of extra equations to model near surface IP chargeability in an automatic and fully integrated manner has also been achieved. A non-specialist can obtain a high value result from our 2.5D AEM inversion in terms of it achieving a more realistic geological section.

We show inversion examples from groundwater, minerals, uranium and geological mapping AEM survey projects and compare the results with known geology and drilling.

Apart from the technical achievement reported above, there are important simplifications and less cluttered outcomes we see - There are recurring artefacts we see in CDI and 1D inversions, that are either eliminated or completed revised when a 2.5D method is applied. The classic “anticline” like bodies are seen in 1D, these are resolved as either synclines, or deeper dipping structures with 2D. Typical depth of investigation in Australia’s more conductive environments is 500m+, and in Canada, results deeper than 800m+ are often achieved. So, in summary there is much improved mapping and target definition delivered by this inversion method when compared with the other more common transforms or inversion methods used on these projects.

POSTER SESSIONS

Schedule

Time	Poster Session	Room
Sunday 22 October 2017		
18:00 – 19:30	Poster Session 1	MTCC Rooms 107
Monday 23 October 2017		
10:00 – 17:30	Poster Session 1 (continued)	MTCC Rooms 107
Tuesday 24 October 2017		
10:00 – 12:20	Poster Session 1 (continued)	MTCC Rooms 107
14:00 – 15:40	Poster Session 2	MTCC Rooms 107
Wednesday 25 October 2017		
10:00 – 17:30	Poster Session 2 (continued)	MTCC Rooms 107

Exploration ’17 Poster Session 1

Exhibition Hall

Sunday Oct 22 (6:00 – 7:30 pm), Monday Oct 23 (10:00 am – 5:30 pm), Tuesday Oct 24 (10:00 am – 12:20 pm)

Author	Topic	General Topic	Panel #
Adams, C.J. & Dentith, M.	Magnetic Measurements on Diamond Drill-Core: Are We Really Measuring Magnetic Susceptibility?	Petrophysics	1
Arhin, E.	Gold in Plants- an appropriate sample medium for gold exploration in regolith dominated terrains	Biogeochem	2
Balch, S.J.	The Transient Phase Method for Classifying Super Conductors in HTEM Profiles	Airborne EM	3
Capriotti,J. & Li,Y.	Geomodeling with Minecraft: Geophysics meets video games	3D Modelling	4
Chon, H-T	Biogeochemical Orientation Exploration Surveys in Some Rare Metal Deposits in Korea; Case Histories	Biogeochem	5
Farrar, A. & Benavides, S.	Airborne Hyperspectral supported porphyry exploration in the Peruvian Andes	Remote sensing/ spectral geology	6
Francke, J.	Realistic Expectations of GPR Performance in Mineral Exploration	Geophysics/GPR	7
Gadd, M., Peter, J., Goodfellow, W., Jackson, S., Yang, Z.	Geology, Geochemistry and Mineralogy of Hyper-enriched Black Shale Deposits, Yukon	Geochemistry/ Mineralogy	8
Hildes, D., Turanich-Noyen, C., Washington, D., Lagersson, M.	Aerochem: An Introduction and Comparison with Traditional Stream Sediment Sampling	Geochemistry	9
Hildes, D.	Extremely Low Frequency (ELF) System: An Introduction and Case Studies	Ground EM	10
Gaucher, F.E.S., Smith, R.S.	Exploring for Copper–Gold Deposits Exhibiting a Wide Range of Conductivities with Time–Domain Electromagnetics at Opemiska, Canada	Ground EM	11
Hill, J.E., Barnes, S.J.	Integrating Spatial Information and Geochemistry for Improved Lithological Classification of Drill Hole Samples	Geochemistry	12
Hunt, J.P., Mutele, L., Billay, A.	Prospectivity Analysis of Granite-related Polymetallic Mineralization in the Bushveld Complex, Using Knowledge- and Data-driven Methods	Geochemistry	13
Ingerov, I., Ermolin, E.	Effective All-Season Method for Mining Exploration	Ground EM	14

Exploration ’17 Poster Session 2

Exhibition Hall

Tuesday Oct 24 (2:00 – 5:30 pm),
Wednesday Oct 25 (10:00 am – 5:30 pm)

Author	Topic	General Topic	Panel #
Devriese, S. G. R., Oldenburg, D. W.	Electromagnetic Methods for Oil Sands Characterization and Monitoring	Airborne EM	1
Konieczny, G., Miles, P., Smiarowski, A.	Breaking Through the 25/30 Hz Barrier: Lowering the Base Frequency of the HELITEM Airborne EM System	Airborne EM	2
Walker, S.E., Campbell, C., Legault, J.M., Izarra, C., Orta, M., Kwan, K., Whiting, B., Van Egmond, R.	Airborne Geophysical Results over the Dolly Varden High Sulphidation VMS and Low Sulphidation Epithermal Silver Deposits, near Stewart, BC	Airborne EM	3
Lindsay, M. D.* and Occhipinti, S.A.	Advances in mineral systems analysis: integrated interpretation, sulfur isotopes and geodynamic modeling	Ground EM/ isotopes/modelling	4
Lintern, M., Ibrahimi, T., Cornelius, A., Anand, R., Reid, N.	Biogeochemistry of the Northern Yilgarn Craton, Australia	Biogeochem	5
Maag, E., Li, Y.	Discrete-valued Inversion of Gravity Data over the Voisey’s Bay Ovoid Using Fuzzy C-means Clustering	3D Modelling/ Inversion	6
Mackie, R.A., Arne, D.A.	A New Simplified Multivariate Approach to Defining Geochemical Exploration Targets from Regional Stream Sediment Data	Geochemistry	7
Melo, A.T., Li, Y.	Geological Characterization by Applying Automatic Clustering to Multiple Geophysical Inversions	3D Modelling/ Inversion	8
Oviatt, N.M., Paulen, R.C., Gleeson, S.A., McClenaghan, M.B.	Drift Prospecting for Mississippi Valley-type (MVT) Deposits Using Indicator Mineral Methods: An Example from Pine Point, Northwest Territories, Canada	Geochemistry	9
Paulen, R.C., Stokes, C.R., Fortin, R., Rice, J.M., Dubé-Loubert, H., McClenaghan, M.B.	Dispersal Trains Produced by Ice Streams: An Example from Strange Lake, Labrador, Canada	Geochemistry	10
Shore, G.A.	3D IP/Resistivity Characterization of the Hasbrouck Peak Epithermal Gold System: Establishing a District Exploration Signature	Ground EM	11
Shore, G.A. (2)	Very Large Scale 3D DC Resistivity Mapping: Inferring the Location of Deep Structural Feeders Beneath Surface Hot-spring Manifestations	Ground EM	12
Safipour, R., Hölz, S., Jegen, M., Swidinsky, A.	Exploring for Mineral Deposits on the Seafloor with Transient Electromagnetic Systems	Marine EM	13
Sun, J., Li, Y.	Integration of Geophysical and Petrophysical Data Through Joint Inversion	3D Modelling/ Inversion	14
Yoon, S., Park, S.W., Chi, S.J., Jo, J., Yang, S.-J., Kalvig, P., Heo, C.-H.	Potential Target Minerals for Rare Earth Elements in Kringlerne District, Gardar Province, Greenland	Geochemistry	15

EXHIBITION

Trade Show North – Floor Plan

Exhibitors List

Company	Booth #
Abitibi Geophysics Inc.	105
Activation Laboratories Ltd.	503
Adrok Ltd	713
AGCOS Inc.	502
AGT SYSTEMS / UMAS	505
Advanced Logic Technology	207
ASD Inc	610
AustinBridgeporth	401
BHP	723
CGG Multi-Physics	304
Complete MT Solutions	603
Corescan	602
Crone Geophysics & Exploration Ltd.	307
Deep Exploration Technologies Cooperative Research Centre	406
DGI Geoscience Inc	606
Discovery International Geophysics Inc	605
DMT GmbH & Co KG	204
European Association of Geoscientists & Engineers	205
EON Geosciences Inc.	302
GEM Systems	500
Geomatrix Earth Science Ltd	202
Geonics Limited	104
Geosense	710
Geosoft Inc.	400
Geotech Ltd.	716
Geovista Ltd	305
GF Instruments	404
Groundradar Inc	301
Guideline GEO	201
HiSeis Pty Ltd	706
Instrumentation GDD inc.	300
IRIS	507
Korea Institute of Geoscience and Mineral Resources	707
Lake Central Air Services Inc.	101

Company	Booth #
Lamontagne Geophysics Limited	600
Loring Laboratories	609
Minalyze AB	720
Mining Intelligence	604
Mira Geoscience	708
Mount Sopris Instruments	206
New-Sense Geophysics Limited	506
Olympus	611
Ontario Geological Survey	721
Ore Research & Exploration P/L	608
Overburden Drilling Management Limited	504
Paterson, Grant & Watson Limited	714
Phoenix Geophysics Ltd	700
Pico Envirotec Inc.	103
Quantec Geoscience	607
Queen's University	100
Radiation Solutions Inc	303
Reflex Instrument Na	402
RMS Instruments	703
Royal Ontario Museum	719
Sander Geophysics Ltd	102
SciAps Inc	711
Scintrex Limited	200
SGS	107
SkyTEM Canada Inc	306
Society Of Exploration Geophysicists	718
Spectral Evolution	712
Spectrem Air	106
Supracon AG	715
TerraCore	704
Terraplus	405
Vektore Exploration Consulting Corporation	702
Vibrometric	407
Wireline Services Group	601
Zebra Earth Sciences Inc.	501

Exhibitors Information

Abitibi Geophysics Inc.

Abitibi Geophysics provides the highest quality geophysical data acquisition, processing and interpretation services to help our clients find precious and base metals, diamonds, uranium and other mineral resources. We have built an international reputation over 32 years, with safe acquisition and delivery of top-quality products at competitive prices, on time.

Our mission is to help you find a deposit through the intelligent application of geophysics. We help our clients select the most effective methodology and then design surveys to maximize your probability of success. Our data-acquisition is complemented with a full range of data compilation, modeling/inversion and interpretation services.

Company website: www.ageophysics.com

Booth #105

Activation Laboratories Ltd.

Quality, Innovation and Service are three words which best describe Activation Laboratories Ltd. (Actlabs). We have been recognized as one of the highest quality labs for over 30 years. Our worldwide locations specialize in performing high-quality analysis to many industries across the world. We are known as one of the most innovative laboratories developing new geochemical technologies for the discovery of blind mineral deposits. We also excel at providing routine assaying and environmental analysis requirements. Actlabs provides testing to meet various international standard methods. A Global Company with a local presence - no matter where you are located, we can help you with your analytical needs.

Company website: www.actlabs.com

Booth #503

Adrok Ltd

Adrok's goal is to make the world a better place by better understanding what lies beneath the earth surface. We endeavour to help our clients increase their exploration success.

We develop and use advanced technology to supply geophysical services for locating, identifying and mapping subsurface natural resources (oil, gas, water and minerals).

We provide our clients with measurements of the subsurface natural resources, rock types and rock sequences before drilling.
We call our technology Atomic Dielectric Resonance.
We call our services Predrilling Virtual Logging ® .
We work hard to help our clients reduce exploration risk and increase exploration value.

Company website: www.adrokgroup.com

Booth #713

AGCOS Inc.

AGCOS Inc. is based in Toronto, Canada and is a leading manufacturer of geophysical ground and marine EM instruments and accessories for investigation of electrical properties distribution from 0 to 150,000m depth interval and wide range of onshore and offshore applications, including mining, oil&gas, geothermal, groundwater and kimberlites exploration, geological engineering, wide range of subsurface mapping, monitoring, research, studies, analysis and scientific investigations. AGCOS offers full spectre of geophysical services, including cost-effective and quality ground EM surveys, data collection, processing and interpretation, field training, consulting, project technical support and equipment & software sales

Company website: www.agcos.ca

Booth #502

AGT UMAS

Since 1990 AGT Systems has served its client base primarily in Russia and its former republics with turnkey airborne, ground, borehole and marine geophysical systems and earth science software. Institutions, private industry and governments benefitted from the A-Z service that included deep training and long term, personal technical support. Although we still continue to grow these areas, our expertise combined with a pool of dedicated personnel under UMAS in Ankara expands the airborne side to a wider market which includes North Africa, the Middle East, Indonesia and Malaysia. And now we offer contract services with not only conventional airborne geophysical systems but also AAVs and autogyros combined with other technologies including LiDAR, TIR and hyperspectral imaging.

Company website: www.agtsys.ca

Booth #505

Advanced Logic Technology

Advanced Logic Technology (ALT) & Mount Sopris are the world's most experienced and innovative suppliers of borehole geophysical logging systems and software. New products to talk about at Exploration 2017 include several new downhole tools : induced polarization, optical televiewer with UV light, high temperature acoustic Televiewer , non-chemical source neutron generator tool, and small diameter gamma tools.
The slimline BMR (Borehole Magnetic Resonance) tool from NMRSA Australia is available for rental in North America & Europe from ALT & MSI. WellCAD 5.2 new features include a new NMR processing module, enhancements of the Image & Structure interpretation workspace, color classication algorithm. Stop by our booth 206-207 for more information or for demonstration of WellCAD.

Company website: www.alt.lu

Booth #207

ASD Inc.

ASD Inc., a PANalytical company, is the global leader in high-performance analytical instrumentation solutions, solving some of the most challenging real-world materials measurement problems. ASD spectrometers - unparalleled in providing laboratory-grade results in the field or on-site - are the instruments of choice for remote sensing, environmental sciences, agricultural, mining, pharmaceutical and pulp and paper industry applications, where results drive paradigm-changing insights, efficiency and profit. ASD's collaborative culture and world-class customer service put the best, fastest and most accurate spectroscopic and portable NIR instruments to work for industry and science in more than 70 countries around the world.

Company website: www.asdi.com

Booth #610

AustinBridgeporth

AustinBridgeporth is one of the world's leading Potential Field companies and provides airborne and land acquisition, processing and interpretation services which also includes LiDAR, radiometric and hyperspectral imagery. Operating in the hydrocarbon, mining, hazards and research industries, clients include Super Majors, National Oil Companies, and large and small independent operators. The team at AustinBridgeporth are experienced and reliable geoscientists who lead with vision and offer an exceptional service in technology and innovation.

Company website: www.austinbridgeporth.com

Booth #401

BHP

BHP is a world-leading resources company and among the world's top producers of major commodities including iron ore, metallurgical coal, copper and uranium. BHP also has substantial interests in oil, gas and energy coal. BHP's investment in exploration is driven by the importance of commodities for the world's future economic development. Innovative and disciplined exploration will be key to discovery of new deposits. BHP has a proud history of successful exploration, since it first started mining silver, lead and zinc in Broken Hill over 130 years ago. BHP is building on that legacy and developing new technology and methods to identify and develop deposits â€“ and to ultimately create future value.

Company website: www.bhp.com

Booth #723

CGG Multi-Physics

CGG Multi-Physics offers you an efficient way to generate an Earth model over your entire license area, even in difficult-to-access areas. This is done through proprietary and non-exclusive gravity, magnetic, electromagnetic and radiometric surveys with the most comprehensive range of advanced acquisition platforms in the air, on land, or at sea. Our multi-client library helps to further reduce exploration risk by contributing to an integrated understanding of geologic potential.

Company website: www.cgg.com/Multi-Physics

Booth #304

Complete MT Solutions

Complete MT Solutions (CMTS) offers the full spectrum of services for electromagnetic (EM) imaging of the Earth using the natural source magnetotelluric (MT) technique, from training to survey design to QC to acquisition to processing to analysis to modelling and inversion to interpretation, for targets from 100s m to 100s km in depth.

CMTS can value-add to existing legacy MT data by undertaking re-processing, re-analysis, re-inversion and re-interpretation using modern proprietary codes and approaches.

Company website: www.complete-mt-solutions.com

Booth #603

Corescan

Corescan is a global services company specializing in hyperspectral scanning, processing and analysis of drill core, rock chips and other geological samples for the mining industry. Corescan provides a turn-key core logging service using specialist geoscientists and advanced hyperspectral imaging technology.

Corescan's Hyperspectral Core Imager (HCI-3) integrates reflectance spectroscopy, visual imagery and 3D laser profiling to map mineralogy from greenfield exploration through to ore processing. HCI-3 provides geologists, metallurgists and engineers with rapid and reliable digital records of drill holes that can be shared electronically with geological experts or engineers within/external to the client as the need arises.

Company website: www.corescan.com.au

Booth #602

Crone Geophysics & Exploration Ltd.

Crone Geophysics is the developer and manufacturer of the Crone Pulse-EM Time Domain system, the leading ground geophysical tool for mapping and targeting Base Metals and other conductive geological units for the Mining and Mineral Exploration industry. Crone and it's affiliates conduct contract Borehole and Surface surveys with the system utilizing highly trained field crews, high quality support equipment, and unparalleled technical support and consulting/interpretation services from the people that designed the equipment.

Company website: www.cronegeophysics.com

Booth #307

Deep Exploration Technologies CRC

The Deep Exploration Technologies Cooperative Research Centre (DET CRC) was established in 2010 under the Australian Government's CRC Programme. The CRC Programme provides funding to build critical mass in research ventures between end-users and researchers to deliver

significant economic, environmental and social benefits to Australia. There are approximately 30 CRCs across Australia and all have been established to address major challenges that require medium to long-term collaborative efforts.

Mineral resources constitute more than 50% of Australiaâ€™s exports, but more than 80% of Australia's mineral production is from mines discovered more than 30 years ago.

In Australia and other relatively well-explored countries, mineral deposits with surface expression have largely been discovered and we are faced with the technically difficult and costly task of exploring at depth beneath barren cover rocks. It is this challenge of exploration through deep, barren cover rocks that DET CRC seeks to address.

With $155M of cash and in-kind funding from the Australian Government and its Participants, the DET CRC is the world's best-supported independent mineral exploration research initiative.

Company website: www.detcrc.com.au

Booth #406

DGI Geoscience Inc

DGI Geoscience Inc provides detailed knowledge of the sub-surface across North, South and Central America. We deliver accurate & cost effective structural, geotechnical, directional, hydrogeological & physical properties measurements inside drillholes. Beyond traditional benefits to exploration, this means old or new (DD and RC) holes can yield true strike-dip information for geotechnical/structural applications & can replace oriented core.

Our experienced teams designs & implements turn-key acquisition & interpretation programs to meet each project's specifics needs. We have English, French, Spanish & Portuguese speaking staff who can seamlessly integrate with your exploration, feasibility or production stage project.

Company website: www.dgigeoscience.com

Booth #606

Discovery Int'l Geophysics Inc.

Discovery Int'l Geophysics Inc. was established in 1996 through the alliance of two long-time industry professionals. Together, Dennis Woods and Brent Robertson offer over 60 years of combined experience in providing geophysical services. Since establishment, the emergence of Discovery as a leading geophysical contractor can be attributed to the diverse expertise of the principals, notably in the area of high-level geophysics and extensive field knowledge. These two qualities combined have generated a well-rounded consulting and contracting geophysical provider, offering first-rate advice, cutting-edge technology and innovative field procedures; highlighted by reliable field personnel operating with a strong work ethic.

Company website: www.discogeo.com

Booth #605

DMT GmbH & Co KG

DMT provides geophysical services and is one of the leading geophysical instrument suppliers for exploration and monitoring.

New: DMT Pilot 3D a vision aided positioning system with high quality 3D point cloud documentation.

SUMMIT X One the world's most flexible wired seismic acquisition system.

Geophysical instruments made by DMT:

- **SUMMIT X One**

One-channel exploration seismograph for high resolution seismic exploration

- **SUMMIT II Compact**

Multi-channel seismograph for LVL and engineering seismic applications

- **SUMMIT X Stream Pro**

24-channel seismograph all in one

- **SUMMIT M Vipa**

Three-channel seismograph for vibration monitoring including noise monitoring

Company website: www.summit-system.de

Booth #204

EAGE

EAGE is a professional association for geoscientists and engineers. Founded in 1951, it is an organization with a worldwide membership, providing a global network of commercial and academic professionals. EAGE unites more than 19,000 members worldwide, it is truly multi-disciplinary and international in form and pursuits. All members are professionally involved in (or studying) geophysics, petroleum exploration, geology, reservoir engineering, mining and civil engineering. EAGE operates the Oil & Gas Geoscience Division and the Near Surface Geoscience Division. The Head Office of EAGE is located in the Netherlands, with regional offices in Moscow, Dubai, Kuala Lumpur and Bogota.

Company website: www.eage.org

Booth #205

EON Geosciences Inc.

Offering mapping via high resolution airborne geophysical surveys, EON Geosciences represents the partnership of experienced professionals using a wide assortment of technologically advanced instruments. EON is the proud owner of a fleet of aircraft and geophysical equipment for airborne surveys. This enables us to have complete control over the care and maintenance needed to ensure quality results, delivered at competitive rates.

Based in Montreal, Quebec, Canada, EON was incorporated in 2007 and has flown over 1,500,000 line-kilometers of geophysical surveys since its inception.

Contact us today for your next survey project!

Company website: www.eongeosciences.com

Booth #302

GEM Systems

GEM Systems is a manufacturer and supplier of advanced magnetometers, gradiometers and magnetic sensors for Earth Science, Geophysics and other applications. With 35+ years in R&D, our technology and leadership is your key to success in applications such as Airborne Mapping, Geological Surveying, Mineral / Oil Exploration, and others. Given the increase in popularity of UAV platforms as a result of usability, minimal area for take-off/landing, payload capacity and autonomous capabilities, GEM Systems has specifically designed a lightweight and ultra-sensitive magnetometer for UAV applications. Consult today!

Company website: www.gemsys.ca

Booth #500

Geomatrix Earth Science Ltd.

Supplier of exploration geophysical instrumentation on a sale or rental basis. Rental items can be shipped world-wide. Major rental pool items include TDEM, IP & ERT, Gravity meters, Magnetometers, Radiometrics instruments

Company website: www.geomatrix.co.uk

Booth #202

Geonics Limited

Incorporated in 1962, Geonics Limited is a world leader in the research and development of electromagnetic (EM) geophysical instrumentation. The PROTEM TDEM Receiver, combined with any of five available transmitters, is optimally designed to cover a full range of applications, from shallow surface and in-mine investigations to deep, three-component surface and downhole exploration. For shallow soundings, PROTEM CM and G-TEM consoles offer convenience in portability. Industry-standard Ground Conductivity Meters address requirements for near-surface site characterization, including brine contamination, acid rock drainage and abandoned mine works.

Company website: www.geonics.com

Booth #104

Geosense

GEOSENSE is an independent Remote Sensing consultant who has gained global recognition of its top-quality remote sensing services. Over the last 30year we have built up a unique experience in the use of satellite, airborne and ground remote sensing technology for the mining and mineral exploration business.

Company website: www.geosense.nl

Booth #710

Geosoft

Since 1986, Geosoft has helped to advance exploration of the Earth's subsurface. The company provides geoscience technology, data services, and custom solutions for government, energy and mineral exploration, marine surveys, unexploded ordnance and the earth sciences. Thousands of geoscientists worldwide use Geosoft software to make discoveries through data. Visit www.geosoft.com.

Company website: www.geosoft.com

Booth #400

Geotech

Geotech is a privately owned company incorporated in 1981, with its corporate headquarters and research and development facility in Aurora, Ontario, Canada. Geotech is a global leader in technological innovation for airborne geophysical survey mapping, data processing, interpretation and analysis. The clarity of our data lets you see with accuracy and detail what's beneath the earth, from near the surface to great depths. We work closely with clients in many industries to identify and implement solutions that meet specific project goals.

Company website: www.geotech.ca

Booth #716

Geovista Ltd

Geovista logging systems have applications in mineral exploration, groundwater and geotechnical engineering.

We manufacture and supply equipment with renown dependability, including loggers, logging winches, combinable logging sondes, downhole geophones, Televiewers, borehole cameras, downhole P&S sonic velocity sondes and North Seeking Gyros for borehole direction surveys.

For many sondes, operators have options to log either in real-time viewing mode or in Memory mode with deferred viewing of data. In Memory mode, data can be acquired by using the rig wireline or simply while tripping out pipe. This latter option is useful in boreholes that are prone to collapse, potentially preventing logging by traditional methods.

Company website: www.geovista.co.uk

Booth #305

GF Instruments

GF Instruments exhibits the company's latest models of geophysical measuring instruments for field use. The range of products includes systems for 2D/3D resistivity, induced polarization imaging and for deep VES, electromagnetic conductivity meters with single- and multi-depth probes for depth ranges from 0.25 to 60 m, gamma-ray spectrometers for walking, car-borne and borehole surveys, and magnetic susceptibility meters for single- or multi-depth field surveys. Sale and rental offers are supported with online consulting and immediate instrument service.

Company website: www.gfinstruments.cz

Booth #404

Groundradar Inc

Groundradar specialises in the design and deployment of custom deep ground penetrating radar instruments designed for harsh exploration environments. Using technology such as real-time sampling receivers and swept-frequency transmitters, penetration to over 100 m is possible in suitable environments. Offering the deepest and safest GPR technology, Groundradar emphasises realistic performance expectations in each project setting. With 27 years' experience and tens of thousands of kms surveyed in 90 countries, Groundradar is the most experienced GPR operator worldwide.

Company website: www.groundradar.com

Booth #301

Guideline GEO

Through our world leading brands of geophysical equipment, ABEM and MALÅ, we offer best-in-class integrated end-to-end solutions to challenges worldwide. With a truly global footprint we draw on extensive experience since 1923 of innovative, field-tested and trusted solutions including: TEM, GPR, Resistivity, and Seismics.

Company website: www.guidelinegeo.com

Booth #201

HiSeis Pty Ltd

HiSeis is a leading international geophysical exploration company providing sub-surface imagery solutions to the hard-rock mining industry. The Company's innovative seismic technology and proprietary knowledge enables it to deliver results in complex geological environments.

HiSeis applies high-definition, three dimensional, seismic exploration techniques in a wide range of near mine environments to provide a high resolution 3D image of the geology which enables our clients to:

1. Generate drill targets;
2. Compress the timeframe to discovery;
3. Add to mineral reserves;
4. Significantly enhance geological models;
5. Improve life-of-mine planning;
6. Reduce mining costs; and
7. Mitigate mine site risks.

Company website: www.hiseis.com

Booth #706

Instrumentation GDD inc.

Instrumentation GDD inc. is a world leader in high-tech geophysical instrumentation for mining and mineral exploration geophysics. Since 1977, GDD has developed, manufactured and sold a wide range of Resistivity/Induced Polarization (IP) and Electromagnetic (EM) geophysical instruments. GDD's team, including researchers, engineers, technicians and geoscientists, never stops innovating and is always committed to facing challenges related to mining and exploration fields.The client satisfaction is first in their priorities list. GDD is renowned for its after-sales services and technical support as well as its rugged and reliable geophysical instruments. We are looking forward to meeting you at GDD booth # 300.

Company website: www.gdd.ca

Booth #300

IRIS Instruments

IRIS Instruments, a BRGM /OYO joint-venture based in Orleans, France, designs, manufactures and markets a wide range of geophysical instruments for environmental, groundwater, geotechnical and mining applications: Resistivitymeters for 1D sounding and 2D-3D imaging (SYSCAL types); Induced Polarisation systems for mining exploration (VIP, ELREC, FULLWAVER types); Magnetic Resonance Sounding (MRS) system for groundwater investigation (NUMIS type); Electro Magnetic equipment (PROMIS multi-frequency, multi-spacing system, VLF system) for lateral variation of resistivity surveys in mining and groundwater. IRIS Instruments supplies training and interpretation software for these geophysical products, in France or at customer's site.

Company website: www.iris-instruments.com

Booth #507

Korea Institute of Geoscience and Mineral Resources

Korea Institute of Geoscience and Mineral Resources (KIGAM) is a unique government-funded geoscience research institution which strives to secure a stable supply of energy and mineral resources, preserve geological environment and develop scientific technologies based on the field of geoscience for Korea's industry development and for national land security.

Company website: english.kigam.re.kr/html/en/

Booth #707

Lake Central Air Services Inc.

Lake Central Air Services Inc. (LCAS) is the world's leading modification & integration partner for the airborne geophysical survey industry. LCAS is widely known for their successful history of prototyping, designing, installing and certifying aircraft modifications including externally-mounted research equipment interfaces, aerodynamic performance improvements, and increased fuel capacity modifications. Each one of our products begins with a client's need to integrate a single or a suite of instruments to an airborne platform. With over 50 years of experience as an aircraft maintenance and manufacturing facility, we are able to work with a wide variety of aircraft.

Company website: www.lakecentral.com

Booth #101

Lamontagne Geophysics Ltd.

Lamontagne Geophysics Ltd. designs and deploys "always on" TEM systems for surface and down-the-hole EM surverying. Our UTEM systems provide a greater depth of investigation, higher resolution of conductive bodies and dependable interpretation. The unique waveform and design of our UTEM systems enable us to achieve these results. Other transient EM systems have reduced sensitivity to highly conductive targets. The Lamontagne UTEM system maintains a much more uniform target sensitivity and is an ideal choice for deep comprehensive coverage.

Company website: www.lamontagnegeophysics.com

Booth #600

Loring Laboratories Ltd.

Loring Laboratories Ltd. is a leading laboratory of coal and minerals in Western Canada. Having served the mining industry for 50 years, it specializes in the analysis of precious metals, base metals, and coal. Other services include fire assays, particle size analysis, and diamond separations. Our long-standing operating philosophy is that to succeed we must consistently meet or exceed our customers' requirements and expectations for the quality, turn around time, and cost of the services that we provide.

Company website: www.loringlabs.net

Booth #609

Minalyze AB

Minalyze develops geolytical core scanning instruments for field and mine operations

Company website: www.minalyze.com

Booth #720

Mining Intelligence

Comprehensive, accurate, and timely information at your fingertips. Mining Intelligence provides rich mining data that fuels industry insights, delivered through online applications and services. We offer solutions that include detailed property and company profiles with cost estimating data for all segments of the mining industry. Our tools aggregate data from multiple sources, producing one intuitive and innovative interface, driving decisions and productivity that save you time and increase your profitability.

Company website: www.miningintelligence.com

Booth #604

Mira Geoscience

Mira Geoscience is the market leader in 3D integrated modelling solutions for the minerals exploration and mining industry. We develop multi-disciplinary modelling software and provide expert training, or work as an extension of your geoscience team with our global team of consulting experts. We manage data from disparate sources with Geoscience INTEGRATOR; build geology, geophysics, geochemistry and structure into an integrated 3D model with GOCAD Mining Suite; and distribute it with our free 3D communications platform - Geoscience ANALYST. With nearly 20 years of multi-disciplinary software and consulting experience, we can help, regardless of the commodity type.

Company website: www.mirageoscience.com

Booth #708

Mount Sopris Instruments

Mount Sopris and ALT provide the world's most experienced and innovative suppliers of borehole geophysical logging systems and software. New products to talk about at Exploration 2017 include several new downhole tools; spectral induced polarization, non-chemical source neutron generator tool, and two new small diameter gamma tools. Acoustic televiewer tools for large diameter boreholes are now available from ALT. The new slimline BMR (Borehole Magnetic Resonance) tool is available for rental in North America from Mount Sopris. This fully contained, turn-key, trailer-mounted rental system produces in-situ bound, capillary, and free water logs along with widely accepted Hydraulic conductivity logs. WellCAD Version 5.2 is now available. Stop by our booths 206-207 for a demonstration of this new version.

Company website: www.mountsopris.com

Booth #206

New-Sense Geophysics Ltd.

New-Sense Geophysics Ltd. (NSG) is an airborne geophysics company was founded in 2005. NSG is an industry leader in helicopter surveys, delivering high quality aeromagnetic, magnetic-gradiometric, and radiometric surveys worldwide, specializing in high-altitude and mountainous terrains.

NSG's focus is safety, and is active member of IAGSA. In addition, NSG has developed its own set of tools, to enhance data quality while lowering survey risk.

NSG's unique dashboard is a portal allowing client and crew to monitor all aspects of the project. Integrated into the site, is a live data feed from NSG's autonomous operating base stations, a critical tool for operations in remote environments. The stations monitor in-block visual, diurnal, weather conditions.

Company website: www.new-sense.com

Booth #506

Olympus

Olympus provides an industry-leading portfolio of innovative test, measurement, and imaging instruments including: remote visual inspection, industrial microscopy, ultrasound, phased array, eddy current, and optical metrology instruments. Products include ultrasonic flaw detectors and thickness gages, videoscopes, microscopes, advanced NDT systems, X-ray fluorescence (XRF) analyzers, industrial scanners, probes, and accessories

Company website: www.olympus.com

Booth #611

Ontario Geological Survey

The Ontario Geological Survey (OGS) is the principal government organization responsible for collecting and disseminating geoscience information in Ontario. The OGS identifies economic opportunities, safeguards public health and safety and informs environmental and land-use planning. OGS collaborates widely to create a robust provincial geoscience "evidence base". OGS provides access to free geoscience data and information through 2 online portals: GeologyOntario and OGSEarth.

OGS activities and services include:

- Bedrock & Quaternary mapping;
- Geophysical surveying, rock properties data;
- Groundwater aquifer mapping;
- Surficial geochemistry surveys;
- Analysis of inorganic materials;
- Regional geological expertise;
- Drill core libraries;
- Province-wide mineral, metal, energy & aggregate resource inventories.

Company website: www.mndm.gov.on.ca

Booth #721

Ore Research & Exploration P/L

Since 1988 Ore Research & Exploration P/L has been producing gold, PGE, base metal and lithogeochem standards for the mining and analytical industries. These include both the OREAS range of commercially available CRMs and matrix-matched CRMs for numerous projects and operations worldwide. OREAS has pioneered innovations including an unparalleled level of homogeneity from naturally occurring ore. OREAS standards were recently ranked the most homogeneous among five CRM manufactures (Brand 2015; EXPLORE Newsletter). OREAS quickly responds to industry requirements with products like SuperCRMsÂ© with over 120 analytes, copper-soluble CRMs, lithium, REE and glacial till materials.

Company website: www.ore.com.au

Booth #608

Overburden Drilling Management

ODM's renowned mineral processing laboratory and experienced geological team, founded by Stuart Averill, has pioneered innovative indicator mineral techniques for gold, Ni-Cu-PGE, Cu-Zn-Pb, porphyry Cu, kimberlite (diamond), uranium and rare earth element exploration.

ODM is the only independent, commercial laboratory in North America to offer electric-pulse disaggregation ("EPD") services for the liberation of mineral grains from rock samples. When combined with our world-class mineral processing laboratory, ODM produces research-grade mineral separates for geochronology, isotopic studies and indicator minerals.

Company website: www.odm.ca

Booth #504

Paterson, Grant & Watson Limited

PGW was established in 1973 to provide consulting, data processing and interpretation services in exploration geophysics for mineral, hydrocarbon, groundwater and environmental applications. It specializes in:

- Design, tendering, supervision and quality control of geophysical surveys from a national scale to focused mineral targets; and
- Geology-driven Geophysical Interpretation that integrates all types of geoscience data, employs structural geology, and 2D/3D geophysical inversion and geological modelling, to map regolith, lithology, structure and alteration, and ultimately determine mineral potential and direct targets.

All of PGW's geophysical and geological staff are professionals registered with APGO or PEO.

Company website: www.pgw.on.ca

Booth #714

Phoenix Geophysics Ltd

Phoenix Geophysics is a geophysical manufacturing and contracting company founded in 1975. We are the world leader in magnetotelluric (MT) equipment and applications.

Our latest innovations, the MTU-8 receiver, along with the MTC-150 sensor deliver uncompromised, uninterrupted, broadband data from surface down to tens of thousand of seconds.

Phoenix systems are used in more than 100 countries for exploration and research.

Our clients are mining and oil companies, geophysical contractors, universities, research institutes, and government earth science agencies.

Company website: www.phoenix-geophysics.com

Booth #700

Pico Envirotec Inc.

Pico Envirotec is a Canadian company focussed in developing innovative and practical solutions for airborne and ground geophysical surveys. Pico is the only company in the world that can provide complete turn-key airborne systems along with all the ancillary equipment and an integrated pilot navigation system. Over the last two decades Pico has developed technologies in Radiometric, Magnetic and Transient EM on airborne platforms that optimizes operations and data quality. Besides the cutting-edge instrumentation, other services that makes Pico the world leader are customized systems, integration of other systems such as airborne gravimeters, assistance in installation/commissioning and unparalleled customer support.

Company website: www.picoenvirotec.com

Booth #103

Quantec Geoscience Ltd.

Quantec Geoscience Ltd. is a geophysical survey company, established in 1986,specializing in ground-based potential field, electrical and electro-magnetic earth imaging techniques. We offer SAFE, RELIABLE and ACCURATE turnkey solution to customers - from project planning all the way to final interpretation and targeting of the subsurface. Leading technologies today include ORION 3D, TITAN 24 and SPARTAN MT. ORION 3D provides true 3D images of the earth's resistivity and IP. The TITAN 24 DCIP & MT system has carried out over 400 surveys globally, imaging accurately to depths of 750m to 2000m. SPARTAN MT provides a flexible and cost effective magnetoelluric resistivity mapping approach for both 2D and 3D geologic scenarios.

Company website: www.quantecgeo.com

Booth #607

Queen's Master of Earth and Energy Resources Leadership

Queen's Master of Earth and Energy Resources Leadership is a new and unique program distinct from other programs world-wide. A part-time, 80 percent online, 20 percent residential 20 month professional degree. A program focused on enhancing integration across multiple fields within earth and natural resource management, including the geosciences, engineering, and the legal, policy, and business and finance realms.

Company website: www.queensu.ca/earthenergyleadership/

Booth #100

Radiation Solutions Inc

Radiation Solutions (RSI) manufactures low level radiation detection instruments for geophysical, environmental and industrial applications. The advanced technical features and ease of operation of RSI's airborne (RS-500, RS-607 UAV), mobile (RS-700), portable (RS-330, RS-350 backpack) and handheld (RS-230BGO, RS-125, RS-120) instruments allow for rapid, reliable and precise measurements. RSI systems are designed for superior data quality and operation in challenging environments.

Company website: www.radiationsolutions.ca

Booth #303

Reflex Instrument Na

Reflex is a leading global mining equipment, technology and services (METS) company. Our solution sets improve the process of identifying and extracting what is below the earth's surface for drilling contractors and resource companies - we let clients know where it is and what it is...now.

Our vision is to be the leading provider of real-time subsurface intelligence solutions to the global mining industry.

Company website: www.reflexnow.com

Booth #402

RMS Instruments

RMS Instruments is a Canadian company that specializes in the design and manufacturing of industry-leading adaptive aeromagnetic real-time compensators, data acquisition systems, VLF-EM receivers, and chart recorders, renowned worldwide for their outstanding performance and innovation. It provides complete airborne systems for geophysical exploration, environmental monitoring, and ordnance detection, and offers comprehensive systems integration and training programs. Founded in 1980, the Company is based in Mississauga, Ontario, with state-of-the-art, 30,000 square-foot design and production facilities. RMS Instruments' equipment has an unparalleled record of longevity and reliability operating in harsh environments.

Company website: www.rmsinst.com

Booth #703

Royal Ontario Museum

The Earth Sciences section of the Royal Ontario Museum houses an important petrology collection which is open to researchers in academia and industry. It contains valuable suites of rocks from across Canada and around the world including an outstanding suite of kimberlites, alkalic rocks from the diatremes of northern Ontario and, most recently added, the 15,000 piece Kirwin collection of ores. The Kirwin collection represents more than 140 different localities globally and is particularly strong in Asia-Pacific rim countries.

Company website: www.rom.on.ca

Booth #719

Sander Geophysics Limited

Sander Geophysics Limited (SGL) provides worldwide airborne geophysical surveys for petroleum and mineral exploration, and geological and environmental mapping. Services offered include high resolution airborne gravity, magnetic, electromagnetic, and radiometric surveys, using fixed-wing aircraft and helicopters.

Company website: www.sgl.com

Booth #102

SciAps, Inc.,

SciAps, Inc., is a portable analytical instrumentation company and innovation leader in the field of hand held LIBS, XRF and Raman for geological applications. SciAps offer a complete toolbox for field geologists, researchers and industry alike. SciAps is excited to present the new Z300 hand held LIBS analyser and X300 field portable XRF at Exploration 17. The Z300 offers broadband LIBS with class leading spectral range of 190-950nm and unique features such as elemental mapping using our GeoChem Pro app. We are dedicated to inventing, engineering, providing and servicing ruggedized, field portable instruments to measure any compound, any mineral, any element - anyplace on the planet. Come visit us at booth 12 to learn more!

Company website: www.SciAps.com

Booth #711

Scintrex Limited

Scintrex and Micro-g LaCoste, the gravity instrumentation experts. The new CG-6 Autograv™ gravity meter is much smaller, lighter and faster, with a user friendly remote table computer; making it very easy to operate. Our Borehole Gravity Surveys will provide you with valuable information, whether for reservoir management or bulk density determinations. Will a Gravity Survey provide the information you require? Let us demonstrate to you; as we offer pre-survey feasibility studies and survey planning. Our magnetometers can also provide exploration details you require. Stop by our booth to learn more about our services and products.

Company website: www.scintrexltd.com

Booth #200

SGS

Globally, SGS provides proven technical solutions at every stage of exploration for your project. Our network of offices and laboratories ensures that you have the expertise you need, right where you need it. We are a globally recognized leader in orebody modeling, resource audits, database management, analytical analysis, process design and Technical Report preparation, review and audit for a wide suite of commodities. The data gained from exploration stage testing and analysis performed at SGS allows you, your stakeholders and financers to fully understand the potential value and impact of your exploration program.

Company website: www.sgs.com

Booth #107

SkyTEM Canada Inc

We will let one of our clients speak for us. After collecting 21,000 line kilometres of airborne EM/mag data in only 43 days, Carlos Salas (Vice-President Geoscience BC) said: "SkyTEM312FAST is an incredibly efficient system, and we are impressed by the great results we have achieved so far. Not only does the SkyTEM system map the near surface we were looking for, it now seems the system has a much greater depth of penetration than we expected for resolving much deeper geology. The ability to review high quality data several times a week was also of benefit to our program."

Company website: www.skytem.com

Booth #306

Society of Exploration Geophysicists

The Society of Exploration Geophysicists is a not-for-profit organization committed to connecting and inspiring the people and science of geophysics. With more than 27,000 members in 138 countries, SEG provides educational and technical resources to the global geosciences community through publications, books, events, forums, professional development courses, young professional programs, and more. Founded in 1930, SEG fosters the expert and ethical practice of geophysics in the exploration and development of natural resources, characterization of near surface, and mitigation of earth hazards. For more information or to join, visit www.seg.org.

Company website: www.seg.org

Booth #718

Spectral Evolution

Established in 2004, SPECTRAL EVOLUTION is a leading manufacturer of laboratory and field portable spectrometers and spectroradiometers. SPECTRAL EVOLUTION field spectrometers and spectroradiometers are used worldwide in mining exploration, mineral identification, mining production, geological remote sensing, ground truthing, and a range of remote sensing applications. Our EZ-ID™ software provides real-time mineral identification using the two mineral spectral libraries. All data is saved in ASCII files for use with 3rd party application software without pre-processing. Our oreXpress™ instruments save geologists time and money in exploring for gold, copper, nickel, uranium, rare earths and more.

Company website: www.spectralevolution.com

Booth #712

Spectrem Air

SPECTREM AIR operates the most advanced fixed-wing airborne geophysical system, collecting high resolution Electromagnetic (EM), Magnetic and Radiometric concurrently. With the highest power and advanced processing, the SPECTREMPLUS system has the ability to simultaneously map shallow (1-100 m) and deep (100-1000 m) features with a high level of resolution. Our team of specialists provide integrated 3D solutions for geological mapping, minerals exploration targeting including oil and gas, geo-hydrological, geo-engineering applications.

Company website: www.spectrem.co.za

Booth #106

Supracon AG

Supracon is a provider of superconducting sensors (SQUIDs) a breakthrough technology in mineral exploration. Since 2005 the company has successfully established a portfolio of geophysical instruments. JESSY DEEP is the most sensitive receiver for transient electromagnetic measurements. The SQUID's unrivalled sensitivity provides the exploration community with data of deeper targets or ore bodies covered with a conducting overburden.

JESSY STAR is the world's first airborne SQUID system to record the complete gradient tensor of the earth magnetic field. Specially developed SQUID gradiometer sensors provide the exploration community with magnetic data of extraordinary sensitivity and tensor information never measured before.

Company website: www.supracon.com

Booth #715

TerraCore

TerraCore is a leading supplier of hyperspectral core imaging solutions to the mining and oil&gas industries. Our rugged and mobile systems can operate anywhere from laboratories to remote exploration camps, and rapidly and accurately collect hyperspectral data from all drill materials. SpecTir is the world leader in providing airborne hyperspectral imagery and geospatial solutions to the mining and oil&gas industries, and has a long pedigree of successful missions for commercial and governmental clients across the globe.

Company website: www.terracoregeo.com

Booth #704

Terraplus

Terraplus sells and rents geophysical instruments & software.

These include ground, UAV & airborne Magnetometers/ Gradiometers (potassium, overhauser, proton) with VLF; 2D/3D Resistivity & IP systems (standard, switching, distributed); Physical Property Measuring systems (magnetic susceptibility, conductivity, IP/resistivity, density); Borehole Logging systems (including acoustic & optical televiewers, sonic, gamma, resistivity/IP, & more), WellCAD presentation & processing software; Radiometrics (ground, carborne, airborne); Infrared Spectrometers; EM systems (TDEM, CSAMT, MT, HLEM); Ground Penetrating Radar, Seismic systems (seismographs, borehole, power sources), and more.

Our complete line is available at wwwterraplus.ca

Company website: www.terraplus.ca

Booth #405

Vektore Exploration Consulting Corporation

Vektore is an innovation-based exploration consulting and R&D company that understands that the market is about value. Value prompts exploration, and our values drive us to work with you.

1st value: We can and must transform the mineral industry for the better.

2nd value: Tools and methods must be user-driven to promote optimal user experiences and results.

It is our belief that structural geology workflow must be organized and simplified to align its best practices with core requirements for successful targeting in mineral exploration. We bring quality through innovation.

In alliance with Lightfoot Geosciences (lightfootgeoscience.ca) and B-Field Geophysics (bfg-exploration.com)

Company website: www.vektore.com

Booth #702

Vibrometric Canada Limited

Vibrometric is a consulting R&D company, specialized in geophysical studies for engineering, mining and environment.

Vibrometric is also a manufacturing company of highly specialized, state-of-the art seismic equipment as a result of sustained R&D activity of more than three decades.

We offer integrated consulting and / or contractual services, based on a range of hardware and software tools of proprietary design.

Since 1986, has its head office in Helsinki, Finland. Vibrometric Canada Limited was established in 1999.

Company website: www.vibrometric.com

Booth #407

Wireline Services Group

Wireline Services Group has acquired dowhole geophysical data from over 10 million meters of drilling across three continents. We have crews experienced in underground, surface, barge based and helicopter supported drilling programs.

We offer a versatile range of data acquisition platforms from ATV mounted to man-portable. We're able to provide downhole solutions for vertical, horizontal or up hole directional surveying.

WSG has a dedicated team of geologists and geophysicists who are mandated to provide the best solutions for our client partners. Our Data Services Team are happy to discuss how you can make the most of your data set.

Company website: www.wirelineservices.com.au

Booth #601

Zebra Earth Sciences Inc.

Zebra Earth Sciences Inc. is a privately owned and Canadian registered company that has served the geophysics community since 1992. Zebra's objectives are to introduce and implement efficient technologies and strategies that resolve problems and meet client requirements. Zebra offers a range of sales, rentals, consulting, training and survey services. Zebra is continuously researching new technologies and strategies within the geophysical community for the purpose to developing healthy and sustainable partnerships throughout the world.

Company website: www.zebraes.com

Booth #501

NOTES

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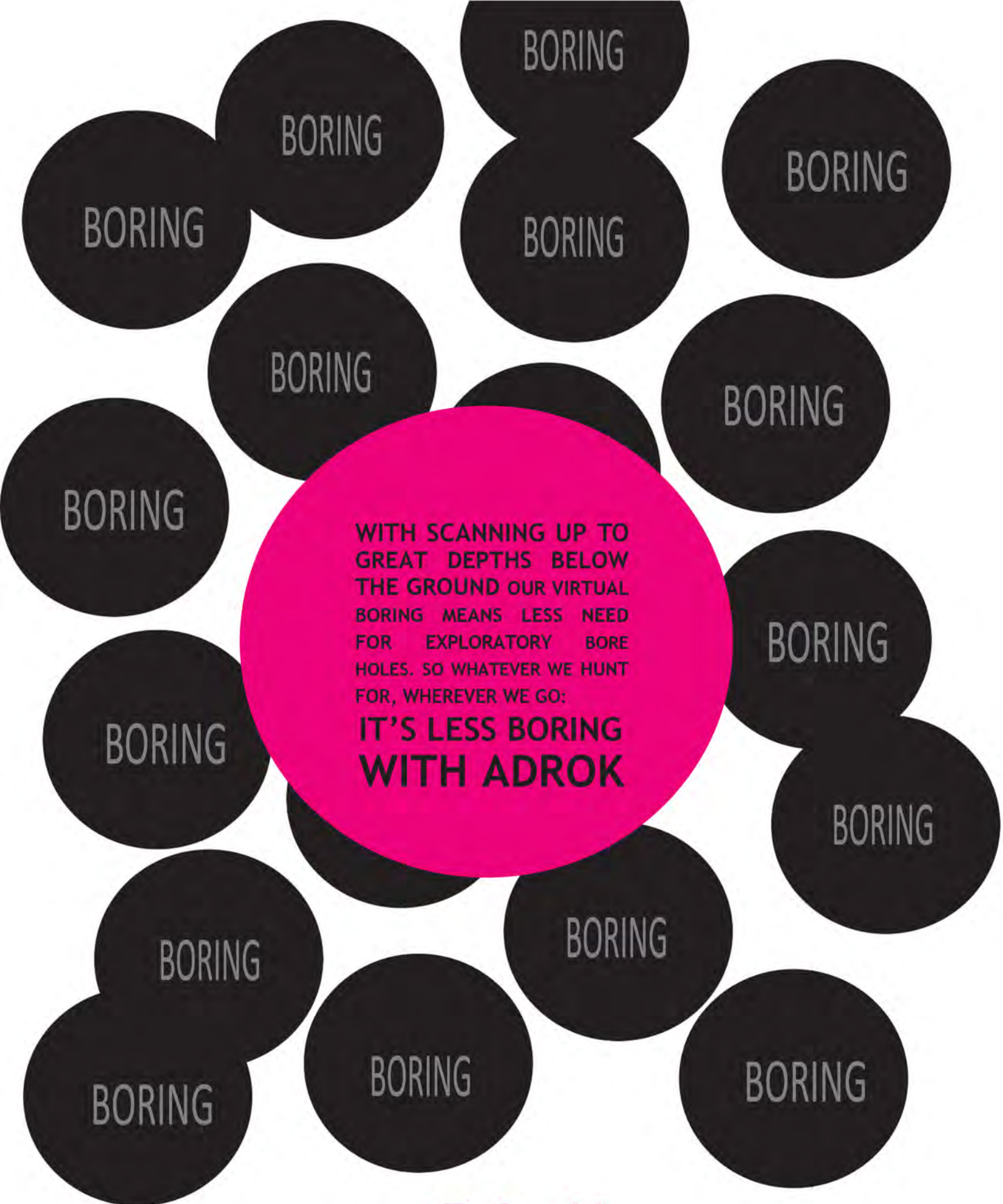

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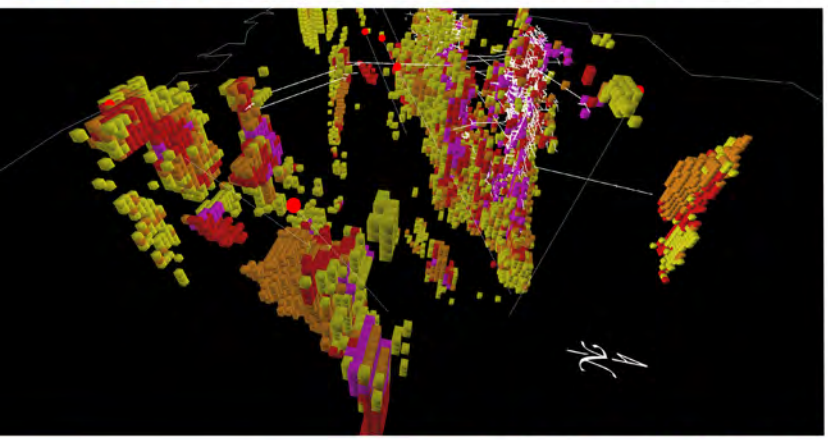

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WHEN YOU NEED TO BE SURE

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ADDENDUM FOR PROGRAMME

EXPLORATION 17

DMEC Decennial Mineral Exploration CONFERENCES

Page 127:

DGI Geoscience Inc	**Booth #605**
Discovery International Geophysics Inc	**Booth #606**
Quantec Geoscience	**Booth #100**
Queen's University	**Booth #607**
TerraCore	**Booth #405**
Terraplus	**Booth #704**

Page 130:

DGI Geoscience Inc	**Booth #605**
Discovery International Geophysics Inc	**Booth #606**

Page 135:

Quantec Geoscience	**Booth #100**
Queen's University	**Booth #607**

Page 137:

TerraCore	**Booth #405**
Terraplus	**Booth #704**