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Minerals
MIN24: Stable and Radiogenic Isotope Systems: Applications in Exploration and the Environment (AAG: 28th IAGS)

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Gregory Dipple, Shaun Barker, Ken Hickey, Ben Andrew

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John Mering, Shaun Barker

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2446 - Integrating Stable Isotope Analysis With Mineral Exploration to Image Hydrothermal Systems

Gregory Dipple - *The University of British Columbia*
Shaun Barker - *University of Wiakato*
Ken Hickey - *University of British Columbia*
Ben Andrew - *University of Waikato*

Recent advances in adopting cavity-enhanced laser absorption spectrometry for rapid analysis of carbonate mineral ^{13}C and ^{18}O contents in sulfide-mineral rich samples has allowed for data collection at a scale commensurate with mineral exploration programs. This allows imaging of large-scale hydrothermal systems in unprecedented detail and provides useful context for mineral exploration activities, but also presents challenges in data analysis and interpretation. In carbonate replacement and Carlin-style sediment-hosted deposits, km-scale ^{18}O haloes surrounding mineralization centres provide vectoring opportunities in exploration and delineate structural and stratigraphic controls on fluid flow. Detailed interpretations however, including quantification of fluid flow amounts, can be complicated by kinetic processes as well as complex and overlapping fluid flow systems. When coupled with paragenetic alteration studies, individual fluid flow systems can be identified. Paired analysis of wall rocks and hydrothermal vein sets allow the competing influences of hydrodynamic and kinetic dispersion to be evaluated. Dimensionless approaches to interpreting vein-wallrock pair data may yield insights in sample suites that lack clear spatial delineation with respect to fluid inlets, a common problem in large exploration datasets.

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2023 - Revealing the thermal structure of ore deposits using clumped carbon and oxygen isotopes

Shaun Barker - *University of Waikato*
John Mering - *University of Waikato*
Ben Andrew - *University of Waikato*
Gregory Dipple - *University of British Columbia*
Kate Huntington - *Department of Earth and Space Sciences and IsoLab, University of Washington*
Andrew Schauer - *Department of Earth and Space Sciences and IsoLab, University of Washington*
Stuart Simmons - *Energy and Geoscience Institute, University of Utah*

The thermal structure of hydrothermal ore deposits reflects the fluid temperature, distribution of fluid pathways (i.e. permeability structure), and duration and length of hydrothermal fluid flow. “Clumped” carbon and oxygen isotopes in carbonate minerals yield information about the precipitation temperature of those minerals. We demonstrate firstly that modern calcites precipitated in active geothermal systems in the Taupo Volcanic Zone yield clumped isotope temperatures consistent with the known temperature of calcite precipitation. We then analysed veins from several ore deposit types (Carlin-type gold; skarn; Mount Isa copper) which yield temperatures from 130 to 320 °C, consistent with the inferred temperatures of calcite precipitation in those systems, and show that differences in temperatures exist within systems. We suggest that coupling clumped and conventional stable isotope measurements in carbonate veins has the potential to constrain fluid flow models of hydrothermal systems, test modelling of reaction fronts, and allow fluid ^{18}O compositions to be determined from minerals by correcting for precipitation temperature.

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1670 - Stable Isotopes as an Exploration Tool: Tracking Cryptic Alteration Surrounding the Iscaycruz Zn (Pb-Cu-Ag) Skarn-CRD deposit, Central Peru

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Craig Hart - M*ineral Deposit Research Unit - University of British Columbia*
Gregory Dipple - *Mineral Deposit Research Unit - University of British Columbia*
Abraham Escalante - *Glencore*
James Mortensen - *Mineral Deposit Research Unit - University of British Columbia*

The Iscaycruz Zn-(Pb-Cu-Ag) skarn-carbonate replacement deposit is located within a sequence of Lower Cretaceous, layered carbonate and siliciclastic rocks in central Peru. The deposit is located on the western flank of a tightly compressed anticline (Escalante and Hart, 2011), within a larger northwest-trending thrust-fold belt in the Western Peruvian Cordillera (Wilson, 1963). Proximal stable isotope haloes have been identified surrounding central Peruvian deposits including the Antamina Zn-Cu skarn, Uchucchacua Ag-base metal vein, and Iscaycruz. Studies analyzing stable isotopes around mineral deposits observed consistent alteration haloes of carbonate rocks with relatively depleted $\delta^{18}O$ values proximal to the center of mineralization, as well as areas of higher degrees of fluid:rock interaction (Barker 2013). Prior work in the Iscaycruz district identified several stable isotope anomalies; however, an investigation between these anomalies and various stratigraphic units, orebodies, or sulfide accumulations has not been conducted. The primary goal of this study is to integrate visible and cryptic alteration around a known ore body and utilize the resulting identified relationships as an exploration tool for regional targets. A secondary goal is to evaluate sampling strategies to inform industry best practices. The initial sampling survey collected representative samples from contacts, structural intersections, and mineralized zones to assess the interactions between fluids and carbonate host rocks. The second sampling survey focused on regional sampling, Pb-isotopes, and prospective contacts north of the Santa Este pit. Results from the studies have confirmed the presence of distinct isotopic haloes around the two deposits studied and verified the validity of the main sampling strategy. Several regions in the prospective Santa Este Norte zone displayed isotopic anomalies similar to those surrounding the two deposits. Pb isotope results demonstrated that the mineralization at Iscaycruz shared a single fluid source, which was separate from veins of galena and pyrite near the Tinyag deposit.

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1506 - Defining the Carbonate Alteration Footprint of the Cortez Hills Carlin-Type Gold Deposit, Nevada Using ^{13}C and ^{18}O Stable Isotopes and Geochemistry

Christopher Herron - *UBC-Mineral Deposit Research Unit*
Gregory Dipple - *University of British Columbia*
Kenneth Hickey - *University of British Columbia*
Andreas Beinlich - *University of Curtin*

The Cortez Hills deposit is located along the Battle-Mountain Eureka Trend in North-Central Nevada and is a world-class Carlin-type (CTD) gold deposit. Visible and cryptic alteration associated with mineralization were used to define footprints, alteration haloes, mineralization targets and fluid pathways. Approximately 2,500 carbon and oxygen isotope analyses from mm- to m-scale using core, RC-chips, pulped rock and surface hand samples together with geology and geochemistry provided an integrated dataset for evaluating fluid transport and alteration in the Cortez Hills plumbing system. Visible alteration occurs proximal (0.1-0.5 km) and inside areas of mineralization. Invisible alteration occurs distal (1-5 km) and least altered (>5 km) areas relative to mineralization. Invisible alteration is described using carbon and oxygen stable isotopes, and CTD pathfinder elements (As, Au, Hg, Sb, Tl) as a vectoring tool. Oxygen isotopes represent the most far-field detectable feature of CTDs and are used to define the cryptic carbonate alteration of the Cortez Hills footprint.

Defining thresholds for carbon and oxygen isotopes, and CTD pathfinder elements were integral to map footprint and alteration haloes (background threshold), define mineralization targets (highly altered threshold) and map fluid pathways. Isotopes and pathfinder elements were described in order of greatest distance travelled outboard of economic gold ore zones and utilized as a vectoring tool for alteration and mineralization: ^{18}O>As>Hg>Sb>Tl-^{13}C>Au. The ^{18}O deposit footprint (background threshold) is >3.5 km and the pathfinder element alteration halo is 2 km in size. The ^{18}O mineralization target (highly altered threshold) is 1 km in width and 0.6 km in height. Low-angle faults were mapped as significant fluid pathways for the hydrothermal system with ^{18}O haloes. Carbonate alteration models produced were used to describe fluid transport and difference in scales (alteration haloes and mineralization targets) and these could improve CTD targeting and vectoring on a property to district-scale.

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1364 - New Isotopic and Thermal Constraints for Fluid Flow During Copper Mineralisation, Mount Isa, Australia

Benjamin S Andrew - *University of Waikato*
Shaun Barker - *University of Waikato*
John Mering - *University of Waikato*
Kate Huntington - *Department of Earth and Space Sciences and IsoLab, University of Washington*
Andrew Schauer - *Department of Earth and Space Sciences and IsoLab, University of Washington*
Peter Rae - *Glencore*
Gregory Dipple - *University of British Columbia*

A number of globally important styles of mineralisation are hosted in carbonate-rich rocks, including skarn, Carlin-type gold and Mississippi Valley-type Pb-Zn. Visible alteration associated with hydrothermal systems in carbonate rocks tend to be limited due to the effective neutralisation of acid in hydrothermal fluids by carbonate minerals. However, fluid-rock interaction beyond zones of mineral alteration in these systems is recorded by tracers such as $\delta^{13}C$, $\delta^{18}O$ and heat in ‘cryptic alteration halos’.

The Mount Isa Pb-Zn and Cu deposit, Northwest Queensland, Australia, is a world class example of a large carbonate-rich, sediment hosted mineral deposit. A long history of mining, exploration and research efforts means Mount Isa represents an ideal opportunity to test concepts of fluid flow as well as heat and mass transport over a large area in a data-rich environment.

Here we present a detailed 3D $\delta^{18}O$ model for Mount Isa based on existing exploration isotopic data and new analyses generated using a LGR CCIA-46 OA-ICOS at the University of Waikato. Spatial interpolation of $\delta^{18}O$ data identifies a number of geologically consistent features related to fluid-rock interaction. Further to this, the model has been integrated with new temperature data generated using clumped isotope thermometry to not only provide insights into fluid pathways but also the thermal structure at Mount Isa during copper mineralisation.

These new data provide important constraints with which to test predictions made by several hydrological models previously proposed to explain copper mineralisation at Mount Isa.

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1841 - Geochemical anomalies in till: Copper isotopes in process evaluation

Winterburn Alan Peter - *MDRU-University of British Columbia*
Marghaleray Amina - *PCIGR-EOAS-UBC*
Matthew Bodnar - *MDRU-UBC*
Rachel Chouinard - *MDRU-UBC*
Shane Rich - *MDRU-UBC*

Correct interpretation of geochemical responses in near-surface soil developed on till over mineralisation requires consideration of the processes responsible for their formation. Responses are often considered to have been developed by the progressive accumulation of ions that have migrated vertically through various mechanisms during oxidation of the mineralisation at depth.

Copper isotopes fractionate during the oxidation of sulphide materials with the heavier ^{65}Cu isotope being preferentially enriched in the dissolved phase, while the lighter ^{63}Cu isotope accumulates in the residual phases. Fractionation effects are well demonstrated in fossil and active supergene weathering and associated groundwater. If copper is migrating from a weathering sulphide deposit to the surface they would be expected to show enrichment in ^{65}Cu and hence positive $\delta^{65}Cu$ values.

Selected anomalous copper and background samples from B-horizon soils from over two porphyry and one VMS system were analysed for Cu-isotopes at the PCIGR, UBC. Samples, were analysed in triplicate by multi-collector-ICP-MS following hot multi-acid digestion including HF and partial digestion using 0.3N HNO_3. For anomalous samples, the partial extraction typically recovered <2% of the total Cu, significantly less than the concentration range difference between background and anomalous.

$\delta^{65}Cu$ for both total and partial extractions dominantly lie between 0 to -1 ‰, within the range of magmatic sulphides, with the partial extractions being marginally heavier. The consistent shift to the heavier signature may indicate mass dependent fractionation during the partial extraction. Fields for anomalous and background samples overlap. The data do not provide evidence for the migration of Cu from mineralisation at depth to the surface. Separate mineralogical and sequential analysis studies would support the derivation of the Cu-response from mineralised fragments entrained within the till. The consistent light signature can be explained by normal soil forming processes and weathering.

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2327 - Can Zn isotopes be used for surface geochemical exploration?

Sam Spinks - *CSIRO Mineral Resources*
Yulia Uvarova - *CSIRO Mineral Resources*

Zinc liberated from geological sources during surface weathering is ultimately sequestered by sinks such as Mn oxides and oxyhydroxides, which strongly adsorb Zn and other metals. This behaviour has been applied to geochemical mineral exploration studies where terrestrial ferromanganese crusts have been shown to have anomalously-high Zn/Mn ratios around known Zn-Pb deposits, reflecting high Zn availability. Previous environmental studies have demonstrated that Zn isotopically-fractionates during adsorption onto ferromanganese minerals, whereby isotopically-heavy Zn is preferentially-adsorbed. This poses the question if Zn isotopic compositions of terrestrial ferromanganese crusts can discriminate underlying isotopically-anomalous Zn deposits from surrounding non-mineralized lithologies. Here we present the first Zn (and Pb) isotope study of terrestrial ferromanganese crusts around a Zn deposit to test if Zn isotopic compositions can be a means of tracing isotopically-light hydrothermal Zn mineralization.

Our data show that, while adsorption of Zn onto Mn oxyhydroxides in terrestrial ferromanganese crusts generally favours heavy Zn isotopes, the magnitudes of isotopic fractionation varies in crusts overlying mineralized and non-mineralized areas. Fractionation factors in crusts overlying typically isotopically-heavy non-mineralized rocks are comparable with the predicted equilibrium fractionation onto birnessite. Conversely, magnitudes of fractionation in crusts overlying isotopically-light Zn-Pb mineralization, are much lower. We interpret this to reflect localized changes in isotopic complexation during hydrogeochemical mobilization of Zn around Zn-Pb mineralization.

These findings demonstrate that Zn mineralization that is isotopically-light compared to surrounding rocks give rise to isotopic heterogeneity in the surface Zn reservoir. This can be reflected by differing fractionation patterns following adsorption onto Mn oxyhydroxides in terrestrial ferromanganese crusts that overly different Zn sources. This highlights that the use of Zn isotopes may be a valuable future tool for surface geochemical mineral exploration.

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1204 - Biogeochemical exploration for Zn-Pb systems: a new trial of Zn isotopes

Nathan Reid - *CSIRO*
Samuel Spinks - *CSIRO*
Robert Thorne - *CSIRO*

Biogeochemical sampling was done at, and around (20 km radius), the Prairie Downs Zn-Pb Project, in the Capricorn Orogen of Western Australia. Spinifex (Triodia basedowii) was sampled along four transects over the fault hosting the Prairie and Wolf deposits, and where possible, coincident with regional groundwater sample locations to the north of the fault.

The geochemical composition for spinifex shows tight anomalism in Zn and Pb over the deposits with very little lateral dispersion. Spinifex also shows the same pattern in several other important elements such as Ag, As, Bi, Fe, Li, Na, Pt, Sb, Se, and Th. Some of these may be related to fluid flow along the fault and further testing is required to determine whether this is linked to mineralisation.

Related studies at this site have shown a greater contrast of background to mineralisation within both Zn and Pb isotopes. With the mineralisation having a much lighter Zn isotope concentration and plants are known to preferentially uptake the light Zn isotope, so we anticipate an even greater contrast between mineralisation and background. To that end, we have tested Zn and Pb isotopes over these deposits and this presentation will present the results of this testing and the comparisons to other surface media and the underlying mineralisation.

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1981 - Isotopic Analysis of Porewater Sulfate in an Ordovician aquiclude of the Michigan Basin

Jing Zhang - *University of Ottawa*
Ian Clark - *University of Ottawa*
Josué Jautzy - *University of Ottawa*

The low-permeability Paleozoic strata underlying the Bruce Nuclear Site – the proposed location for a deep geological repository (DGR) for low- and intermediate-level radioactive waste – has been extensively characterized for safety purposes. Beyond the confirmations of safety and long-term integrity, samples from the sedimentary package have been used in additional studies focused on enhancing the overall scientific understanding of deep-seated, diffusion-dominated sedimentary system evolution over geologic time. The goals of the current study were to: (1) gain insight into the paleofluid evolution by examining the $\delta^{34}S$ of sulfate in porewaters and sulfate-bearing minerals (i.e., anhydrite, gypsum), and (2) examine whether bacterial sulfate reduction (BSR) fingerprints could be found in the sulfate $\delta^{34}S$ records. Due to ultra-low water contents and low concentrations of sulfate within the sedimentary units of interest, sonification during filtration – and a method of analysis requiring combustion of the entire filter and sample in a large-capacity elemental analyzer – was adapted for these low-permeability materials. Positive excursions from the Paleozoic seawater curve for the $\delta^{34}S$ of porewater sulphate are: (1) interpreted here as evidence for bacterial sulphate reduction in zones of the Ordovician section that are accompanied by isotopic anomalies in the organic and inorganic carbon system, and (2) consistent with the presence of a deep, ancient bioreactor that appears to have been preserved since the Paleozoic.

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2436 - Constraining heatflow in hydrothermal systems using carbonate clumped isotopes: results from the Taupo Volcanic Zone and the Waihi Epithermal Au-Ag Deposit

John Mering - *University of Waikato*
Shaun Barker - *University of Waikato*

Recent analytical advances in stable isotope measurement allow for better constraints on temperature and fluid source in hydrothermal systems. Here, we demonstrate an approach, which combines clumped isotope thermometry and near infrared laser spectroscopy to identify thermal gradients in both active geothermal systems and epithermal Au-Ag deposits. Carbonate clumped isotope thermometry was carried out on samples from three geothermal fields in the modern Taupo Volcanic Zone (TVZ). Clumped isotope results for modern geothermal calcites indicate that minerals precipitated in equilibrium with fluids of meteoric origin and reflect borehole temperatures. On average, clumped isotope temperatures of TVZ samples are within 24 ºC of known values, over a range between 130 and 310 ºC. Valid clumped isotope temperatures in modern geothermal settings permit evaluation of ancient hydrothermal deposits of economic interest. Samples were selected from Waihi, a significant low sulfidation epithermal Au-Ag deposit, within the Miocene aged Coromandel Volcanic Zone. Clumped isotope estimates for temperature at Waihi were paired with laser spectroscopic measurements of $\delta^{18}O$ in carbonate minerals, and δD in phyllosilicates. The majority of $\delta^{18}O$ variability in carbonates across Waihi can be attributed to temperature differences, while the $\delta^{18}O$ composition of fluid likely varied by less than 3 per mil. Similarly, hydrogen isotope measurements of argillic phases indicate no more than 25 per mil variation of δD_{VSMOW} across the system. In volcanic-hosted systems, such as Waihi, where $\delta^{18}O$ values in carbonates track thermal changes with high fidelity, laser spectroscopy may be applied to rapidly generate data relevant to an exploration program. Specifically, a high density oxygen isotope dataset, validated by clumped isotope measurements, provides the means to vector toward upflow zones, where Au and Ag accumulate in economic concentrations.

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Minerals
MIN25: Exploration Case Studies - Out of the Box Concepts, Methodologies and Practices (AAG: 28th IAGS)

Paper ID

Paper Title

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KEYNOTE: Application of aiSIRIS© processed spectral data in porphyry-epithermal systems from early stage exploration to mine resource evaluation (./pdfs/rfg1780.pdf)
Timothy Baker, Sean Mckinley

2051

Case studies in advancing model driven greenfield exploration projects (./pdfs/rfg2051.pdf)
Charles Funk

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Re-examining Brownfield Mining Districts in the Discovery of New Resources for Future Generations: Case History - The Dolly Varden Silver Mining Camp, British Columbia, Canada (./pdfs/rfg1330.pdf)
Ben Whiting, Rob van Egmond

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Ron Yehia, Ray Lett, Dave Heberlein

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Olivier Cote-Mantha, Guy Gosselin, Denis Vaillancourt, Alain Blackburn

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Nathan Reid, Jens Klump, Brian Ballsun-Stanton, Alistair White, Adela Sobotkova, Petra Janouchova

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Nathan Reid, David Gray, Benjamin van der Hoek, Yulia Uvarova

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Sojen Joy, Ferdi Winter, Robin Preston, Mike Roberts, Unnikrishnan Purushothaman

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1780 - KEYNOTE: Application of aiSIRIS© processed spectral data in porphyry-epithermal systems from early stage exploration to mine resource evaluation

Timothy Baker - *Eldorado Gold Corp*
Sean Mckinley - *Eldorado Gold Corp*

The collection and use of spectral mineralogical data has increased substantially over the past two decades in exploration and mining as new instrumentation and data processing techniques have become available. Recently AusSpec International developed a new spectral data processing system called aiSIRIS© (a third generation artificial intelligence Spectral InfraRed Interpretation System) that provides spectral data interpretation through a cloud-based engine and expert review rather than the traditional non-expert, user-based approach. The spectra are subjected to rigorous QA/QC procedures and are presented in a consistent, multi-parameter, multi-mineral (commonly up to eight) output that is readily incorporated into a database. However, the major step change in this approach is the spectral contribution (SC) feature that numerically estimates the relative proportions of the spectrally-responsive minerals providing a percentage output. Although these data are not an absolute measure of the spectrally-responsive minerals for a sample, the numeric output provides an estimate of their relative variation in abundance. In this paper we present two case studies that illustrate the application of aiSIRIS© spectral data processing in early stage exploration and in an advanced mine scenario. In the exploration example, spectral data were collected by analysing historical soils over a known high sulfidation epithermal system. The results highlighted a previously unrecognized porphyry-centre and vectors to the different styles of mineralization were delineated through SC mineral zonation and spectral parameters such as white mica and alunite wavelength variations. In the mine environment, high density spectral data (over 85,000 measurements on 2m assay intervals) facilitated detailed 3D implicit modelling of SC data that enabled individual mineral mapping in a complexly zoned and multistage porphyry gold system. The results have been used to better constrain geological inputs into resource and reserve estimates, as well as geotechnical and geometallurgical evaluations.

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2051 - Case studies in advancing model driven greenfield exploration projects

Charles Walter Funk - *Evrim Resources*

Exploration is increasingly undertaken through the application of mineralisation models to target distal alteration footprints that commonly contain no evidence of economic mineralisation. The residual effect of a cycle of high commodity prices is most remaining undeveloped resources are uneconomic at present prices and new discoveries are required to justify development. The current exploration cycle is seeing renewed interest in greenfield exploration however the confidence to make investments by junior exploration and major mining companies alike is apprehensive at best.

Case studies from Evrim Resources over the last two years highlights contrasting approaches with variable success. In Sonora, understanding the geochemical and alteration signature of low-intermediate sulphidation gold veins immediately below the paleaosurface has allowed for the cost effective acquisition of un-drilled projects. Initial exploration can be undertaken cheaply but the higher cost of drill testing a mineralisation hypothesis has led to joint ventures to advance projects. This method notably led to a new discovery below outcropping barren quartz veins.

A separate model to generate high-risk greenfield opportunities was undertaken in 2016/17. Evrim undertook low cost analysis of government geochemistry surveys and identified an opportunity with a far greater execution cost than the company could afford to take forward alone. The opportunity was refined and marketed to potential partners as an alliance. The reputation of the geologists supporting the model, clear tollgates to measure success and 'size-of-the-prize' lead to an alliance deal. Similar proposals for other ideas failed at the internal review stage or failed to attract partners when marketed due to commercial terms, ability to access projects or competing interests.

In British Columbia the complexity of alkalic porphyry footprints allowed Evrim to rapidly advance copper projects to the drill stage by cost effectively compiling historic geophysical and geochemical data and systematically re-logging drill core to identify drilling targets.

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1330 - Re-examining Brownfield Mining Districts in the Discovery of New Resources for Future Generations: Case History - The Dolly Varden Silver Mining Camp, British Columbia, Canada

Ben Whiting - *The Belcarra Group*
Rob van Egmond - *The Belcarra Group*

Amongst the best approaches for the discovery of new resources is a re-examination of historic brownfields mining districts. This is particularly true when alternative interpretations of the geologic setting can be tested. As a “Case History”, recent work in the Dolly Varden Mining Camp has yielded excellent results. The Dolly Varden (1919-1921) and Torbrit (1949-1959) were high grade silver-lead-zinc mining operations located in The Golden Triangle of northwestern British Columbia, Canada.

There are several styles of mineralization, including siliceous exhalative horizons and epithermal quartz veins. The Dolly Varden-Torbrit Horizon (“DVTH”) is marked by a distinctive upper zone of jasper and quartz breccias and stockworks, with bladed barite pseudomorph textures and colloform banding, overlying a lower zone of smoky quartz and sulphides. Mineralization consists of acanthite, native silver, pyrargyrite, pyrite, galena and sphalerite.

Structurally, the deposits are hosted in Jurassic Hazelton Group volcaniclastics in a northward-plunging synform. Locally there are steeply dipping pre-, syn- and post-mineral faults, which offset the horizon. Northeast of the Torbrit deposit is located the Moose-Lamb Fault, which has been re-interpreted as a syn-basinal reverse fault. This is important because one of the new 2017 discoveries has been made in the footwall block to the north of Torbrit.

Hole DV17-063 yielded an intercept, with textures of a classic DVTH exhalative marker, for 22.74 metres (21.37 m true) grading Ag 433 g/t, Pb 0.74 % and Zn 0.72 % for a silver-equivalent of 476 g/t. Within this intercept is an interval of 7.15 metres (6.72 m true) grading Ag 1,181 g/t, Pb 1.83 % and Zn 0.26 % for a silver-equivalent of 1,272 g/t. The location of this intercept is 200 metres north and 220 metres deeper than the historic Torbrit Mine, thus opening up a new fault block for exploration and the opportunity to make new discoveries.

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1032 - Rapid field hydrogeochemistry part II: focus on mineral exploration methodology - results and lessons from two surveys in southern BC 2015-2017

Ron Yehia - *Vancouver, British Columbia*
Ray Lett - *Self*
Dave Heberlein - *Heberlein Geoconsulting*

Variations in ground and surface water chemistry can be valuable exploration guide to concealed minerals in bedrock and overburden. Portable systems can rapidly and economically analyses water samples in the field for many cations and anions allowing fast exploration target identification and follow-up during the same sampling campaign. In 2015 the Palintest® Photometer 8000, a system able to measure Al, Ca, Cl, Cu, F, Fe, Mg, Mn, K, Si and SO4 in water as low as 10 ppb by measuring the colour and light transmittance of a solution after the addition of metal-sensitive colour dyes was used for a hydrogeochemical survey near a Cu-Au mineralized porphyry prospect at Poison Mountain, British Columbia, Canada. A second hydrogeochemical survey southwest of Nazko, British Columbia in 2016, used the Palintest® Photometer 8000, and a Modern Water PDV6000Ultra voltammeter to measure trace elements in water samples. Elevated Cu and As levels were detected in water from streams draining two mineral prospects in the Nazko survey area Both studies, funded by Geoscience BC, addressed seasonal variability in the water chemistry and device reliability. Results from the surveys demonstrated that the field-portable devices are capable of detecting Cu mineralized bedrock in two areas of central British Columbia and have the potential for improving the efficiency of exploration follow-up.

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1091 - The Amaruq Satellite Deposit – From a grassroots discovery to Agnico Eagle's near-term future in Nunavut

Olivier Cote-Mantha - *Agnico Eagle Exploration*
Guy Gosselin - *Agnico Eagle Exploration*
Denis Vaillancourt - *Agnico Eagle Exploration*
Alain Blackburn - *Agnico Eagle Exploration*

The Amaruq satellite deposit is 50 kilometres northwest of Agnico Eagle's Meadowbank mine in the Kivalliq region of Nunavut, Canada. The property covers 116,716 hectares on Inuit-owned and federal crown land, almost adjacent to the 77,411-hectare Meadowbank property. In April 2013, Agnico Eagle acquired 100% interest in the virgin gold prospect. Since then, Amaruq has quickly grown from a grassroots discovery to a mine development.

The Amaruq area is underlain by Archean supracrustal rocks of the Woodburn Lake group. Gold mineralization, totaling 2.1 Moz Au indicated and 2.1 Moz Au inferred resources as of year-end, 2016, is hosted in mafic and ultramafic sub-volcanic rocks interlayered with fine-grained clastic rocks, chert, graphitic iron-rich mudstone and iron formation. Amaruq is interpreted as a hybrid, stratabound- and vein-type iron-formation-hosted gold deposit.

At each stage of the discovery, 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 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 to unravel the geometry of the rock sequence has been of key importance. Leapfrog Geo software has been used to create implicit 3D models in real-time, 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.

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2284 - KEYNOTE: Out of the Box – Airborne Geochemical Surveys

John C Barr - *Anglo American*

Peter Bradshaw - *FPX Nickel*

Work starting in the 1970's developed a system of collecting airborne particulates by aircraft (fixed or rotary wing) flying at approximately 100 m elevation by a system that was capable of collecting a sufficient mass of particulates every few seconds for later analysis. Research by others at that time showed that particles coarser than 10 microns have a short dwell time in the atmosphere and at an elevation around 100m were close to their source with thermals carrying the particulates into the air. On the aircrafts simultaneous recordings were made of particle count, particle loading, temperature in the air scoop, and when using a fixed wing aircraft vertical acceleration, plus temperature at one or two levels below the aircraft. There was also a switching devise to collect or reject particles from warm raising or cold descending air parcels. The collected particles were vacuum-impacted onto tape consisting of a flexible Mylar adhesive bottom layer, a thicker middle layer with perforations to retain the samples, and a Teflon cover tape. All parts were contained is a Perspex box and kept clean by a continuous stream of nitrogen. The tape was sent to the laboratory for laser ablation – inductively coupled plasma emission spectroscopy (LA-ICP-ES) analysis for up to 34 element. Sampling rate was approximately 400 samples/hour or a distance of 150 to 200m along the flight line at a flying speed of 60 to 80 line km/hr. The effectiveness and precise resolution of the plume sampling technique, the choice of particle size collected, and the sensitivity settings of the thermal switching thresholds could all be controlled by the operator in the aircraft.

Results from test areas over various styles of deposits in South Africa and Namibia are described.

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1206 - The adaptation of geochemical field workflows from pen and paper into the 21st century

Nathan Reid - *CSIRO*
Jens Klump - *CSIRO*
Brian Ballsun-Stanton - *Macquarie University*
Alistair White - *CSIRO*
Adela Sobotkova - *Macquarie Univeristy*
Petra Janouchova - *Macquarie University*

We have developed a geochemical sampling application for use on Android tablets and phones. This app was developed together with the Field Acquired Information Management Systems (FAIMS) at Macquarie University and is based on the open source FAIMS mobile platform. The FAIMS mobile platform has proved valuable for hydrogeochemical, biogeochemical, soil and rock sample collection due to the ability to customise data collection methodologies for any field research.

The FAIMS customisation allows for using inbuilt or external GPS to locate sample points, it incorporates standard and incremental sampling names which can be easily converted into an International Geo-Sample Number (IGSN). Sampling can be documented not only in metadata, but also accompanied by photographic documentation and sketches. Our customisation is augmented with dropdown menu fields specific to each sample type and user defined tags. The customisation also provides users with an overview of all records from a field campaign in a records viewer.

A particular challenge is the remoteness of the sampling locations, hundreds of kilometres away from network access. The first trial raised the issue of backup without access to the internet, so in collaboration with the FAIMS team and Solutions First, we commissioned a vehicle mounted portable server. The server installed in our field vehicle allowed us to back up, completely automatically, any data we collected while in the field, it has an uninterruptible power supply that can run for up to 45 minutes when the vehicle is turned off, and a 1TB hard drive for storage of all data and photographs.

This app has led to significant time savings in the field. A helicopter based survey was 250% more efficient compared to conventional means with the added benefit of no further data entry required in the evenings or at the end of trip.

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1205 - Real time hydrogeochemical analysis, a new tool for exploration while or after drilling

Nathan Reid - *CSIRO*
David Gray - *CSIRO*
Benjamin van der Hoek - *University of South Australia*
Yulia Uvarova - *CSIRO*

We have developed a prototype system that uses a variety of sensors to deliver chemical data of drilling fluids and groundwater in the field. This project aimed to provide real-time analysis of drilling fluids to provide fast feedback about drilling muds, cover/rock geochemistry and opportunities for drill optimisation.

The requirements for this new technology were split into three focus areas: (1) early detection (aquifer interception and drill bit wear); (2) monitoring/managing the drilling fluids; and (3) exploration hydrogeochemistry. The development of a working sensor array prototype has required several critical steps before useful chemical data can be presented to drillers and/or geologists. Ion selective electrode sensors have been chosen for this prototype based on their robustness, ease of use, limited interferences, ease of interpretation and applicability to the three focus areas.

The prototype system was deployed to the Mineral Systems Drilling Program in South Australia where 12 sensors collected data every 30 seconds for ~2500 m of diamond drilling. The data has shown when different additives were added to the system and when they have been consumed (which could lead to optimisation). It clearly shows the quality of the fluids over time, and there are indications that geological information can be extracted, which can be directly correlated with the drill core.

This research can lead to faster decision making during a drilling campaign by providing fast feedback on fluid parameters. This could ultimately reduce the cost of drilling and increase the speed of detection of deposit footprints under cover.

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1941 - Sweat, sap and emanations – what trees and snow can reveal about hidden mineralization.

David Heberlein - *Heberlein Geoconsulting*
Colin Dunn - *Colin Dunn Consulting Inc.*

Plant exudates include any materials that are transpired, excreted, secreted or otherwise leak out of plants or emanate from them. Trees and shrubs are leaky systems that transpire gases and liquids, and secrete some of their 'life-blood' liquids that can congeal on plant surfaces as sap. We have investigated their potential use as exploration sample media.

At the Woodjam Cu porphyry, 65 km northeast of Williams Lake, waxes leached from foliage samples were enriched in Cu, Mo and Zn over mineralization. The analysis of congealed sap collected from white spruce trunks indicated strong multi-element signatures including Cu, Mo and several pathfinder elements related to the underlying mineralization. Experience gained at Woodjam permitted refinement of methods on samples from a larger survey around the Endako Mo mine, 160 km west of Prince George, British Columbia. Saps collected soon after they had exuded from the trees had strong signatures in Mo, Re, Bi, U, REE, Th, K, Rb, P, Na, Mn, Cs, Ag and Sr.

Fluids transpiring through the stomata of white spruce foliage were collected by placing plastic bags over the twigs and foliage for a day. At Woodjam these fluids yielded significantly higher concentrations of Cu, Mo, As, Tl and S over mineralization than at background sites.

Over Au mineralization at Mt. Washington, Vancouver Island, compared to background sites the halogens (F, Br, Cl and I) were elevated in fluids transpired from mountain hemlock foliage. At the same sites, emanating gases were collected in buried devices containing activated charcoal and resins: evidence of elevated halogen concentrations near mineralization was compelling. Similarly, profiles of snow pack cored in April from a few sites in the same area yielded concentrations of Br and I that decreased upward, indicating a steady flux from beneath.

2165 - Opening a Forty Year Old Box, Geochemical Research Yet to be Done

Barry Warren Smee - *Smee and Associates Consulting Ltd.*

I began to study the electrogeochemical transport theory of Govett and Bolviken 42 years ago. The results of that study were published in the JGE 36 years ago.

Results from that research showed that:

•The theory of electrochemical transport of ions through exotic cover was valid. A laboratory tank study using the radio-isotope Zn65 produced double-peak responses in clay cover on either side of a small DC source. The depth of penetration of the isotope over was consistent with diffusion rates, aided by the small electrical charge. A redox front was not required.

•A field study over a VMS covered by glaciolucustrine clay showed that a surficial change in soil pH above the deposit can re-distribute pH sensitive elements such as Ca (Sr), Mn, and Fe that pre-exist in the soil; i.e., the pH sensitive elements moved away from the low pH and precipitated on the margins of this low pH, resulting in either double or single peak expressions. Closely spaced sampling was required to observe the patterns.

•A ratio of weakly leachable Ca over hot acid Ca left a positive Ca residual on the edges of the H+ influence. This indicated that the re-mobilized Ca mineral was different from the existing Ca mineral.

•A surficial expression of VMS mineralization could be seen in soil organic carbon. The inference was that soil micro-organisms play an important role in element distribution.

Many of these observations have been reproduced in different climatic zones. The theory is robust and must form part of a fundamental method of moving ions through cover.

Sampling vast areas in detail for a buried mineral deposit is not economically feasible, so the aim of future research should be to discover the fundamental changes in bacteria, minerals and vegetation that can be detected remotely.

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2231 - From Data to Knowledge - Augmented Reality to Augmented Earth Science

Matt Lato - *BGC Engineering*
Bill Burton - *BGC Engineering*
Ivy Li - *BGC Engineering*
Gerald Magnusson - *BGC Engineering*

The execution of successful resource development projects requires a common understanding of the geological setting and past, present, and future use of the land. This involves understanding complex earth science systems and the impacts of anthropogenic change through space and time.

Traditional means of communicating geological, engineering, and land use plans involves 2-dimensional (2D) maps and drawings; this is a significant challenge as resource development projects involve complex 3, 4 and 5D scenarios that may span hundreds of years with spatial extents greater than many metropolitan cities. 2D maps and drawings require specialized training to properly understand and contextualize; it is not an innate ability as humans think and experience life in 3D, not 2D. This poses a barrier to understanding in multi discipline settings. When communication of a resource development project is not completed successfully, it can result in opinions formed and decisions made on incorrect interpretations.

Significant advancements in the field of augmented reality (AR) is allowing a shared understanding of engineering plans. The advancements are also allowing a richer interaction with data. Tools developed to work in 2D, such as cross sections and stereonets, require parsing data into various projections. Holographic presentations of data can be brought into the user's environment, allowing new kinds of interaction.

Specific examples of enhanced communication between project teams, corporate governance, and stakeholders through our involvement with several mine sites using Microsoft's HoloLens will be shown. In addition, examples of applied earth science teaming with digital science to turn data into actionable knowledge will be presented.

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1097 - A paradigm shift for sampling and analysis using rapid regional surface geochemistry

Ryan Noble - *CSIRO*
Nathan Reid - *CSIRO*
David Cole - *CSIRO*
Carmen Krapf - *GSSA*
Ignacio Gonzalez-Alvarez - *CSIRO*
Ian Lau - *CSIRO*
Jess Robertson - *CSIRO*
Tenten Pinchand - *CSIRO*
Brian Ballsun-Stanton - *Macquarie University*

To generate new targets in greenfields mineral exploration using geochemistry three key activities commonly take place. Firstly, uniform sampling over a broad area, secondly, analyse samples and establish geochemical background, and finally identify areas of interest for further investigation. This process commonly takes months and is widely practiced. However, huge efficiencies can be delivered with some straight-forward technologies and pre-existing data to guide sample locations. We demonstrate these efficiencies at the remote Nullarbor Plain in South Australia. We were able to collect, analyse and conduct targeted infill sampling to generate a regional geochemical and proxy-mineralogical maps of soil and rock over an area of nearly 4000 km2. This all occurred in 7 days. The project tested grid sampling at 4 km intervals using a helicopter, with integration of tablets and mobile server for rapid data acquisition using the FAIMS android application. International geological sample numbers (IGSN) were used for searchable sample tracking. A field portable sample preparation (crush, mill and pellet press) set up was coupled with optimised pXRF and ASD analyses. Field sampling times were 5-6 minutes per site in a 3 person team to collect 5 sample media, and analytical preparation and processing time of 4 minutes per sample in a 3 person team. A machine learning model (Gaussian Process Regressor) used the relationship between geospatial data (160 features) and new pXRF data collected on-the-fly. The results demonstrate a better understanding of the regional geochemistry, quantitative assessment of variation and directed the infill sampling. With the model, we later demonstrated how the sampling spread would change and be reduced using the model to guide the sample location. This is a major shift in the way to sample an area to achieve an understanding of background and has significant economic benefits by reducing sample numbers.

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1286 - A Key role of MSG survey in finding Taipinggou Mo deposit in east Inner Mongolia

Mingqi Wang - *Beijing, China*
Yuyan Gao - *China National Chemical Engineering Group Corporation*
Lulu Yuan - *China University of Geosciences*
Fulong Lu - *China University of Geosciences*

MSG (Metals in soil gas) survey can be used to detected concealed metal deposits(Wang et. al.2008). Taipinggou is located in swamp forest landscape, east Inner Mongolia and MSG has not been tested in this terrain. The target for Mo mineralization was selected based on geochemical anomalies of Cu and Mo from regional geochemical mapping. 7 Km2 Detailed Geophysical and geochemical surveys were carried out to follow up the anomalies and locate the orebodies but the results are puzzling. The conventional soil survey with grid of 40 by 200m found a large Mo anomaly, which the highest Mo is more than 100ppm. However, the strong anomalies is distributed along valley floor (swamp), in which most peat and minerals were transported. It is obvious that the strong Mo anomalies in swamp were formed hydromorphically and could not be the indicators for Mo mineralizations. The IP delineated 5 low resistance bodies extending north-east. The strongest and biggest anomaly verified by drilling is related to massive pyrite without Mo and Cu mineralization. So MSG survey analyzing over 50 elements by ICP-MS at the grid of 40 by 200m was designed to detect possible concealed Mo mineralization. More than 50 elements were determined and the blank Mo about 30 elements in MSG samples can be used as indicators. The blank of liquid MSG collector was very low, from less than 0.001-0.008ng/ml for Mo and less than 5ng/ml for Cu. The highest Cu and Mo in loaded samples was 88659ng/L and 2.277ng/L respectively. A marked anomaly belt towards north-east including Mo, Cu, Ag,Pb ,Zn, Bi, Ni was detected. A totally concealed Mo orebody 100 m below surface and 180m in thickness was drilled in Zk706.

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2226 - Discovery of Crater Facies Kimberlites in the East Dharwar Craton – Analysis of the Transitional Sedimentation and Mantle Architecture

Sojen Joy - *De Beers Group Services*
Ferdi Winter - *De Beers Group Services*
Robin Preston - *De Beers Group Services*
Mike Roberts - *De Beers Group Services*
Unnikrishnan Purushothaman - *De Beers Group Services*

The Dharwar craton is known to host deeply eroded hypabyssal facies kimberlites of ~1100 Ma age. An integrated exploration campaign undertaken by De Beers Exploration using multiple methodologies including ground geophysics resulted in the first discovery of preserved large (~50 ha) crater facies kimberlites within the Raichur kimberlite field in Andhra Pradesh, south India, beneath the Meso-Neoproterozoic sedimentary cover.

The kimberlites are preserved beneath ~50 m of Limestones belonging to the Narji Formation and a thin layer of conglomerates belonging to the Banganapalli Formation. Based on mineralogical and geochemical compositions the rocks classify as Group 1 kimberlite. Incompatible trace element data indicate that the kimberlite magmas derive from enriched/undepleted, metasomatised, potentially shallow lithospheric mantle, with subsequent contamination by mantle and crustal rocks.

The sedimentation history reveals continuous deposition post kimberlite eruption. High energy mass-flow deposits interpreted as talus and debris flows immediately overlie primary volcanic kimberlite. The material from the tuff-ring deposit, along with fluvio-lacustrine sediments are interpreted as braided stream deposits associated with the formation of a crater lake. Low energy lacustrine deposits at the top of the sequence indicate the end of the crater sedimentation. The Banganapalli Formation, formed in a beach/shelf environment, lies immediately above crater sediments, and is in turn covered by the Narji Limestones of Kurnool Supergroup indicating the progressive submergence of the kimberlite. The submergence of the kimberlites along with the deposition of the Kurnool Supergroup led to the preservation of crater sediments.

Garnets from these kimberlites are dominated by moderate-chrome lherzolitic varieties with locally abundant sub-calcic harzburgitic compositions. The chrome diopside thermometry indicates a predominance of low temperature variants, consistent with the shallow spinel lherzolite source. These kimberlites sampled significantly thinner palaeo-lithosphere (160 km based on single grain clinopyroxene thermobarometry and numerical geotherm fitting) compared to the nearby Wajrakarur kimberlites.

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Minerals
MIN26: Towards Big Data: Applications of Data Analytics in Geochemistry (AAG: 28th IAGS)

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David Lawie

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2215 - KEYNOTE: Sorting the Signal From the Noise – Analytics In the Geosciences

David Lawie - *Imdex*

Modern geoscientific data, from exploration through to production, is sourced from an extremely broad range of sensing technologies that generate data of varying size and intrinsic information content. Data may comprise all levels of measurement, from nominal (rock type), ordinal (degree of alteration), interval (azimuth) and ratio (concentration) scales. Additionally, the data may be incomplete, vary in measurement precision with time and location, contain artefacts (closure) and be collected at vastly different spatial scales; from continental surveys to discrete meter(s) long sample increments, to continuous downhole logs.

How does the ever expanding field of 'Analytics' apply to these data? From Wikipedia, Analytics is defined as 'the discovery and communication of meaningful patterns in data' and 'often favours data visualisation to communicate insight'. As such, Analytics should hold no fears for the Geoscientist as we have been doing it for decades! What has changed is access to computing power, storage and ease of access to algorithms.

Analytics in Geoscience also needs to adapt to some peculiar requirements. Our data is typically not 'large', but is often incomplete. Analytics in exploration models out background to find the outliers; the 'sensors' need to be moved to the (remote) point of data collection and the analytics done at the 'edge' environment, not months later. Conversely, production seeks to eliminate outliers to better model background and also needs to link spatial and temporal data. The historical emphasis of Analytics in Geoscience has been on exploratory data analysis. To move to machine learning requires high quality nominal data for training which is typically unavailable or determined by imperfect 'human' sensors. These are issues, but there are also immense opportunities for the industry should the Data Scientists of the future be carefully guided by the Geoscientists once the novelty of the approach has worn off

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1133 - Metrics and Methods for Predictive Geologic Mapping and Mineral Systems from Geochemical Survey Data

Eric Grunsky - *China University of Geosciences / University of Waterloo*

Geochemical survey data have been routinely collected by government geologic surveys and the mineral and energy exploration industries over the past 50 years, at the camp, regional and continental scales. Many industry and government geochemical datasets have millions of elemental values derived from thousands of sample sites with up to 60 elements for each survey site. These large datasets offer the potential to “discover” and “predict” processes associated with primary rock formation, diagenesis, metamorphism, alteration and economic mineralization. An adequate sample design is critical in process discovery for geochemical survey data. Processes sampled at an adequate scale demonstrate geospatial coherence.

The use of machine learning analytics assists in the discovery of processes. Resource identification is enhanced through the use of multivariate and geostatistical methods that can identify and predict, statistically and geospatially, specific geochemical processes and subsequent exploration targets. Various “metrics” can be used for measures of association. These include coordinates derived from multivariate methods including principal component analysis, multi-dimensional scaling, plus many others. Process validation and prediction can be obtained by the application of “methods” including linear discriminant analysis, neural networks, random forests and others.

In the era of big data and machine learning analytics, it is paramount to understand the nature of the input data. Understanding the variability and consistency of input data is part of the essential knowledge required to carry out machine learning analytics. Successful machine learning and artificial intelligence methods rely on the establishment of training sets from which these methods can “discover” and “predict”.

Examples, from Canada, Australia and the USA, of geochemical/geological process discovery and validation are shown for geochemical surveys at the continental and regional scales, for predictive geologic mapping and regional mineral exploration targets. Examples of camp scale surveys demonstrate how specific processes associated with economic mineralization are identified and validated.

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2500 - Adding Value to Regional Till Geochemical Data in Central BC through Exploratory Data Analysis

Britt Bluemel - *Bonanza Geosciences*

The most efficient use of resources in mineral exploration is to add value to existing data products. The utility of geochemical data can be greatly improved by first level interpretation, because derivative data products (which are common in geophysics) can account for surficial processes, and therefore highlight areas that may have been otherwise overlooked.

For the past 11 years, Geoscience BC has supported the continued collection and chemical analysis of till geochemical samples in efforts to promote mineral exploration throughout British Columbia. Over 2,200 samples have been collected in central British Columbia by the BCGS, GSC, and Geoscience BC. The presentation proposed here will deliver three key findings:

1) All available till geochemical analyses in the TREK area have been evaluated and assessed for comparability and utility on an element by element basis; Data artefacts were visible between original survey areas, but their effects could be suitably circumvented

2) Till geochemical data, evaluated in Phase 1, was thoroughly interpreted using exploratory data analysis (EDA) techniques, such as multivariate outlier assessment. Further geochemical techniques, such as regression analyses, were employed to account for secondary surficial processes.

3) Robust, 2nd order geochemical derivative products (ground-truthed to known mineral occurrences) were generated. These derivative products delineate areas of increased mineral potential based on ranked multi-element anomalies.

Geochemical interpretation methods, such as clustering and regression analyses, allowed greater insight into the architecture of this till geochemical data. Data effects, such as changes in survey area, were overcome and the till samples were classified into provenance groups based on immobile and trace element chemistry. Anomalous samples were then identified in each provenance group based multi-element chalcophile outliers, and these anomalies were quantified using a robust regression analysis. The results have been ground-truthed to known developed prospects, and several targets were generated in areas without known mineralization.

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2076 - Comparison of Regional and Detailed Lake Sediment Geochemical Surveys in Ontario and Their Relevance to Mineral Exploration

Richard Dyer - *Ontario Geological Survey*

Lake sediment geochemical surveys have been completed over a significant portion of northern Ontario by the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS), primarily to support mineral exploration. The National Geochemical Reconnaissance (NGR) project (circa 1970's to 1980's) conducted by the GSC was done at a regional scale (approximately 1 sample per 13 km2). The OGS surveys (circa 1990's to 2000's) were done at a detailed scale (on average one sample per 2.5 km2) in which almost every lake in each survey area was sampled. There is overlapping coverage of the GSC and OGS surveys, and combined, there is almost complete continuous province-wide coverage across northcentral Ontario. The data from 2 areas, that contrast greatly in terms of mining history, were compared in detail, one in northeastern Ontario (Sudbury) and one in northwestern Ontario (Mine Centre). The Sudbury region has a long Ni-Cu mining history that continues today, whereas, the Mine Centre area (despite its name) has had relatively little mining activity. In addition to the difference in sample resolution between the GSC and OGS surveys, another significant factor that was considered was the sampling technique. The GSC utilized the Hornbrook (grab) sediment sampler whereas the OGS used a coring device that allowed quick retrieval of intact sediment cores from the lake bottom and consistent sampling of deep sediment that pre-dates anthropogenic contamination. The results of this study, which included both statistical and geospatial analysis and comparisons, has implications that relate to: 1) the integration of these surveys into province wide geochemical maps; 2) the cost/benefit of regional vs detailed surveys to map relevant geochemical anomalies of exploration interest; and 3) the exploration relevance of surface (or mixed) sediment geochemistry vs deep sediment geochemistry, within and outside landscapes impacted by mining activities.

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2045 - Domaining Hyperspectral Mineralogy and Geochemistry to Characterize Gold Recovery at Alturas Deposit, El Indio Belt, Chile

Carmina O Jorquera - *Barrick Gold*
Samantha Scher - *Corescan*

Alturas is an oxide high-sulfidation epithermal advanced stage exploration project in the El Indio Belt, Chile. Gold recovery, in this and other types of Au deposits, may be affected by the presence of Cu- and As-bearing sulfides and the occurrence of sulfosalts and clays. Therefore, the determination of mineralogical controls which differentiate Au that is cyanide-leachable and non-cyanide-leachable is tantamount to the successful mining of gold. Between 2014 and 2015, 57 diamond drillholes at Alturas were analyzed using the HCI-3 Corescan system from which spectral geologists interpreted 16 distinct minerals and their variations in mineral chemistry and crystallinity. Combining mineralogical data from Corescan and multielement geochemistry (4-acid digestion followed by ICP-MS analysis for 48 major and trace elements, as well as Au by fire assay and AAS) allowed for the definition of distinct domains which are characterized by specific mineral assemblages associated with recoverable and non-recoverable Au.

In addition to the impact on Au recovery, these domains predict other ore-body attributes. For example, there are implications for bench and block design based on the spatial variability of mineral and textural domains. Furthermore, there is a strong influence on ore processing through domaining the distribution of alteration and primary rock type; these parameters are linked to grinding, flotation and leachability via solubility, hardness, and the presence of minerals such as clays. Consequently, mineralogical domaining has larger implications to refine geological, geometallurgical and process optimization models in a predictive space.

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1909 - How Do I Log This? Hyperspectral Mineralogy and Geochemistry in the Epoch of Big Data.

Sam Scher - *Corescan*
Ronell Carey - *Corescan*
Brigette Martini - *Corescan*
Brenton Crawford - *Solve Geosolutions*
Tom Carmichael - *Solve Geosolutions*
Liam Webb - *Solve Geosolutions*

Mineralogical quantification is essential in the mine cycle from exploration through feasibility and process design to remediation. There is a natural linkage between mineralogy and geochemistry, whether mineralogy is indicative of favorable pressure-temperature-physicochemical conditions for metal precipitation or alerting geometallurgists of potential processing issues. The mineralogy in this study of a Cu deposit in central Chile was analyzed using hyperspectral core imaging. Eleven minerals and their variations in mineral chemistry are interpreted.

A common thought process in constructing logging schemes is to map lithology followed by the alteration assemblages and styles observed. The complexity of these observations, while valid and useful, will generally lead to extremely complicated models, oftentimes based on preconceived biases based on local dogma. Furthermore, these original alteration models may not be used throughout the project's evolution due to the needs of the group overseeing a particular stage of the project. At the study Cu deposit, the location and observed mineralogy dictated a designation of a structurally-controlled stratiform-Cu or IOCG deposit. While this model is partially confirmed based on 3D modelling constructed from the Corescan and geochemical data, the role of the host normal faults, and the mineralogy that defines them, suggests increased exploration potential.

The creation of an alteration model implicitly contains bias; however, this is distinct from a data-driven approach to logging and 3D model construction. The development of hyperspectral core imaging technologies in the past decade have allowed for large-scale interpretation of mineralogy in mineral exploration (one meter of core typically has ~200,000 pixels of data). When sufficient data is collected over a deposit, it is possible to apply unsupervised learning techniques to find natural groups in the data which reflect discrete mineral domains. The combination of this and geochemistry can revolutionize the way in which ore deposits are logged and modeled.

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1268 - Closure in Geochemical Data: Is it always such a hazard?

Clifford Read Stanley - *Acadia University*

‘Closure’ is the mathematical constraint that a system’s component concentrations sum to 100 %. Thanks to Felix Chayes, geoscientists have known for half a century that closure adds variation to compositional datasets and thus obscures the variations caused by material transfer processes. Subsequently, Tom Pearce and others have developed graphical, molar element ratio methods that avoid closure, thereby allowing recognition/quantification of material transfer processes. More recently, John Aitchison and others have developed alternative log-ratio methods that avoid closure in the statistical realm.

Unfortunately, efforts have not been made to assess the relative magnitudes of closure and material transfer, or to demonstrate under what conditions closure obscures the effects of material transfer. In this presentation, I derive an equation allowing such an evaluation. Functional analysis of this equation reveals that closure does not mask material transfer when: (i) the system size doesn’t change during material transfer, (ii) the concentration of the component undergoing material transfer is small, or (iii) the amount of material transfer of a component is large relative to system size. Thus, this equation confirms what geoscientists have known intuitively since the dawn of geochemistry, that trace element concentrations generally do not suffer from closure, but major oxide concentrations commonly do, an axiom that explains why miners can successfully extract low concentration ores from the earth without use of closure-avoiding data analysis methods.

Several datasets are examined that illustrate the above conclusions, and demonstrate that decisions to automatically employ closure-avoiding methods in geochemical data analysis may be ill-considered, as some components, and even some geological systems, do not suffer from closure. Strategies are also identified that allow the geoscientist to recognize, using conserved element analysis, which components of a system are affected by closure, and which are not, allowing them to take appropriate action to avoid closure, where necessary.

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1533 - Artificial Intelligence Applications in Exploration and Metallurgy: The Roles of Human Knowledge and Terminology

Clinton Smyth - *Minerva Intelligence Inc.*
David Poole - *University of British Columbia*
Chris Ahern - *Minerva Intelligence Inc.*

Many believe that machine learning, which is only one field of artificial intelligence (AI), is the key to successful deployment of AI in the minerals industry. This perspective overlooks the fact that, to be effective, machine learning typically needs hundreds to millions of training data records – more than are available in many of the problem domains of the minerals industry. Distinguishing between which problem domains might benefit from machine learning technologies and which might benefit from other AI technologies is important to making wise AI investments, both in deployment of existing technologies, and in researching and developing new ones.

For example, fine-tuning of a metallurgical plant is much more amenable to machine-learning solutions than is exploration targeting.

Where machine learning holds little promise for problem-solving in the near term, AI offers alternative technologies for the embedding and deployment of human knowledge within machines. Literature sources, including NI43-101 reports, store large volumes of human knowledge pertinent to mineral deposit discovery. Computer agents can be programmed to use this knowledge to identify exploration targets in very large multi-disciplinary data sets faster and more cost-effectively than human agents.

Key to representing human knowledge on computers is the use of well-defined terminology. The European Union has recognised this need, and, under their INSPIRE initiative, has recently legislated that standard lithological and mining-related terminologies be used by all municipal, provincial and federal producers of public mapping data in the EU.

Adoption of the INSPIRE minerals industry terminology standards, as they will be updated over time, within databases and scientific reporting inside and outside Europe will enable the broader application of AI technologies to mineral industry challenges than is currently possible.

This is illustrated by a territorial target generation project in the Yukon and a pilot terminology standardisation project in British Columbia funded by GeoscienceBC.

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1287 - Machine-assisted ore deposit mass balance evaluations in 3D

Shawn Hood - *CODES*

Many options exist for the representation of geochemical anomalies around ore deposits, and the majority of these involve different approaches to calculating, and representing, the upper and lower portions of element frequency distributions from compositional data. So-called positive and negative anomalies are taken to represent chemical deviation from local background values and are typically interpreted at metalliferous hydrothermal ore deposits as representing mass that has been added or depleted during metasomatism linked to metal deposition.

This contribution considers the representation of geochemical anomalism in 3D space by calculating the mass added or depleted during alteration of host rocks using Grant's Isocon (1985) formulas. While conventional mass balance work is traditionally done on a sample vs. sample basis, our methodology uses groups of protolith rocks and groups of altered rocks with comparable geological histories, leveraging an adapted approach developed by Ague and van Haren (1995) which includes a measure of confidence for results. Identifying sample pairs for altered and unaltered equivalents is challenging because the correlations between multivariate data may not be intuitive, and large amounts of data are laborious to interpret manually. Machine learning offers potential solutions to problems involving large numbers of data, many variables or features, and complicated relationships between variables. Furthermore, traditional mass balance approaches do not involve representing uncertainty related to the heterogeneity of lithological units.

Our methodology involves linking protolith rocks to their equivalent altered counterparts from large exploration and mining drill hole databases using machine learning algorithms. Interpreting the results gives insight into original protolith geometry, and adds confidence measures to derived data. By evaluating the geometry of our derived data around mineralisation zones, we seek to better understand the chemical processes at work during ore genesis.

1619 - China Land Quality Geochemical Information System

Liu Rongmei - *China Geological Survey*
Zhao linlin - *DRC of China Geological Survey*

China geological Survey has launched the Multi -objective regional geochemical survey and Land quality geochemical investigation for more than fifteen years cooperating with the local governments, and has generated geochemical bigdata on the multi-level soils, sediments, atmosphere and water. The geochemical bigdata provide multidimensional services for the study of the environment, potential evaluation of mineral resources, management and protection of land science, safe production of agricultural products and protection of soil environment.

The China land quality geochemical information system contents data entry subsystem?data management subsystem, data analysis subsystem, data publication subsystem and data service App which is developed by Development and research center of China Geological Survey. It is widely applied in the geochemical database construction, geochemical data analyzing and mapping, geochemical integration with environment data and data processing online by the geochemical survey staff and database manager at present.

Besides the basic function of the geochemical information software, the system also provides online geochemical symbology mapping, contour mapping and land quality evaluation of thematic mapping, data statistical parameters and histogram creating, the normal distribution curve and other statistical information based on the geochemical integrated database. Meanwhile the online maps can be released to the WMS and can be used by App.

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1125 - Mineralisation-related element dispersion and anomaly context from regional and prospect scale multi-element soil data

Alan William Mann - *Consultant*
Patrice de Caritat - *Geoscience Australia*
Richard Lilly - *University of Adelaide*
Graham Sylvester - *University of Western Australia*

Aqua regia (AR) partial digestion and Mobile Metal Ion (MMI) partial extraction of soils, both widely used in mineral exploration in Australia, commonly deliver analytical information for in excess of 50 elements. Degree of Geochemical Similarity (DOGS) is a relatively straightforward statistical methodology based on Spearman correlation which can be carried out in Excel, capable of assessing the similarity of soil samples based on their multi-element composition. Application of DOGS to the AR database for the National Geochemical Survey of Australia (NGSA), shows that felsic and mafic lithology can be successfully delineated, areas of marine carbonates discriminated from regolith calcrete and prospective locations for Sedex vs IOGC Cu and Coolgardie vs Ballarat style Au mineralisation mapped. Similar outcomes are obtained using the MMI analyses from the same survey. MMI reference soil samples over sites with known (outcropping) geology on the Yilgarn Craton show (via Spearman correlation factors and ranking diagrams) that soils over acid felsic rocks are systematically geochemically distinct from those over mafic and ultramafic rocks; intermediate felsic rocks and sediments produce soils whose characteristics are between these two extremes. MMI surveys at the prospect scale show the potential for the method to “map” soils against a geologically based reference, and to provide setting and context to commodity element anomalies such as Au and Cu obtained at the prospect scale

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1333 - Using regional geochemistry for environmental monitoring and risk assessment

Jennifer McKinley - *Queens University Belfast*

Regional geochemistry soil databases are increasingly being used to determine baseline guidance values for environmental monitoring and risk assessments for human health. The question raised in this research is whether the use of single component baseline or threshold geochemical maps is sufficient to provide an accurate interpretation. It is often assumed that single component geochemical maps represent absolute abundances. However, due to the compositional nature of geochemical data (the closed or constant sum problem), univariate geochemical maps cannot be compared directly with one another and as a result any interpretation based on them is vulnerable to spurious correlation problems. Despite the limitation of relative abundances, individual raw geochemical maps are deemed fundamental to several applications of geochemical maps including environmental assessments. However, there are examples in studies of the environment and health where the proportional nature of potentially harmful geochemical elemental data is acknowledged. For example, element toxicity is related to its bioavailable concentration, which is lowered if its source is mixed with another source. In this research, regional stream water and soil geochemical datasets are combined with environmental and health data to explore the pitfalls in using classical single component variables and maps to determine baseline guidance values. An alternative approach is presented emphasizing opportunities for using compositional data analysis, through the use of log-ratio and log-contrast approaches, for environmental monitoring and risk assessments for human health.

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1378 - Recognition of geochemical anomalies based on RPCA and GWR across the boundary areas of China and Mongolia

Mi Tian - *Key Laboratory of Geochemical Exploration, Institute of Geophysical and Geochemical Exploration (IGGE), Chinese Academy of Geolo*

The identification of stream sediment geochemical anomalies related to mineralization from background is critically needed for mineral exploration using data processing method in the diverse lithological background and geographically regolith terrains. In this research, a method based on robust principal component analysis (RPCA) and geographically weighted regression (GWR) was presented. The concentrations of rock-forming oxides, lithophile elements, organic carbon and total carbon were taken as proxies for parent lithology and regolith type to adjust for variations in background of trace element geochemical patterns. The concentrations of indicator variables were isometric logratio (ilr) transformed to open the compositional data. Robust principal component analysis was conducted, and then the principal components were taken as spatial independent variables and metallogenic elements (Cu and Pb) as dependent variables in GWR model, and the geochemical residuals were used to indicate local anomalies (Zhang et al., 2009). The 1:1000,000 stream sediment geochemical data across the boundary areas of China and Mongolia (Nie et al., 2013) were analyzed, and the result of GWR was compared with that of traditional method. It is found that the efficiency of GWR was highly improved compared with that of the traditional method, indicating that the proposed method can model and eliminate the background differences of elements due to lithological settings and geomorphic landscapes. Anomalies identified by GWR had stronger spatial association with the known deposits, and thus can be used as guides to new promising exploration targets.

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1017 - Pareto-lognormal modeling of worldwide size-frequency distributions for copper and other metals primarily mined from hydrothermal ore deposits

Frits Agterberg - *Geological Survey of Canada*

In recent years worldwide databases with size-grade information for worldwide metal and hydrocarbon deposits are increasingly becoming available in the public domain. It is of interest to statistically model the size-frequency distributions of these quantities worldwide as well as regionally. The two methods primarily used for metals in ore deposits and oil or gas field sizes are lognormal and Pareto-type modeling. Both the lognormal and the Pareto frequency distribution are statistically stable. The lognormal can be explained as resulting from a multiplicative form of the central limit theorem that for other quantities results in the well-known bell-shaped Gaussian distribution; and the Pareto is the end-product of processes that combined with one another produce hyperbolic upper tails on other types of frequency distributions for quantities that can assume very large values. In this paper it is shown that worldwide size-frequency distributions for copper and other metals primarily mined from hydrothermal deposits can be described by central lognormal distributions with Pareto-type upper and lower tails. Pareto distributions are frequently used in the economic and social sciences. Well-known examples of application include personal income and town size. Ore deposits have similar characteristic features in that they are of different types and their frequency distributions depend on geographic location as well as time of origin. This paper is concerned with estimating the mean and logarithmic variance of the central lognormal as well as the Pareto coefficients for the tails. Special attention is paid to the shapes of the frequency distributions in the transition zones between the lognormal and the Pareto's. Examples of application include worldwide size-frequency distributions for 2541 copper and 1476 zinc deposits.

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Minerals
MIN27: Footprints of Giant Orebodies - Mineralogical, Spectral and Geochemical Vectors to Discovery (AAG: 28th IAGS)

Paper ID	Paper Title
1351	Using quartz as a tool to aid vectoring in the lithocap environment - a case study from Mankayan, Philippines (./pdfs/rfg1351.pdf) David Cooke, Huayong Chen, Lejun Zhang, Zhaoshan Chang, Jennifer Thompson, Noel White
1402	Hemlo Au deposit, N. Ontario: chlorite mineral chemistry as a tool for exploring in greenstone terranes (./pdfs/rfg1402.pdf) Joseph Vrzovski, Pete Hollings, David Cooke, Emily Gorner
1470	Hydrothermal Apatite geochronology; Implications for porphyry exploration and new mineral potential in the American Southwest (./pdfs/rfg1470.pdf) Joshua Phillips, Sebastien Meffre, Jay Thompson, David Cooke
1583	Tourmaline: A tool for vectoring and fertility assessments in porphyry copper deposits (./pdfs/rfg1583.pdf) Francisco Testa, David Cooke, Nathan Fox, Lejun Zhang
1848	Trace-element characteristics of tourmaline from Canadian Co-Mo-Au porphyry systems (./pdfs/rfg1848.pdf) Christopher Beckett-Brown, Andrew McDonald, Beth McClenaghan
1494	Indicator mineral analysis of stream sediment samples as an exploration tool in an unglaciated vegetated area of east-central Alaska (./pdfs/rfg1494.pdf) Karen Kelley, Sarah Bala, Garth Graham, Heather Lowers, David Adams, Douglas Kreiner, Katharina Pfaff
1586	Igneous geochemistry and geochronology of the intrusive rocks of the central Wasatch Mountain Igneous belt, Utah, USA: implications for porphyry miner (./pdfs/rfg1586.pdf) Emily Smyk, Pete Hollings, Jennifer Thompson, Michael Baker, David Cooke
1873	Testing Airborne Hyperspectral Surveying for Mineral Exploration at High Latitudes: A Pilot Study over Porphyry Cu deposits, eastern Alaska Range, Alaska, USA (./pdfs/rfg1873.pdf) Garth Graham, Raymond Kokaly, Karen Kelley, Todd Hoefen, Michaela Johnson

1355	NIR Characteristics of Porphyry Copper Deposits (./pdfs/rfg1355.pdf) Nicholas H. Jansen, McLean Trott
1405	Extending the exploration footprint at Canadian Malartic, QC, through the integration of hyperspectral imaging and petrography of glacial clasts (./pdfs/rfg1405.pdf) Caroline Taylor, Martin Ross, Stephane Perrouty, Philip Lypaczewski, Benoit Rivard, James R. Clark, Gema Olivo, Robert Linnen, Robin Taves
2133	Plio-Pleistocene High-Sulfidation Epithermal Gold Mineralization at the La Bodega and La Mascota Deposits, Eastern Cordillera of Colombia (./pdfs/rfg2133.pdf) Alfonso Rodriguez Madrid, Thomas Bissig, Craig Hart, Luis Mantilla Figueroa
1525	Ore Pathfinders and Fertility Assessments in Lithocaps: a Case Study of the Veladero High-Sulfidation Epithermal Au-Ag deposit, Argentina (./pdfs/rfg1525.pdf) Lejun Zhang, Noel White, David Cooke, Huayong Chen, Francisco Testa, Aldo Vásquez, Simon Griffiths, Jennifer Thompson, Mike Baker
1412	The geochemistry of the alteration of the Red Lake Gold Mines Au deposit (./pdfs/rfg1412.pdf) Nicolas Derome, Pete Hollings, David Cooke, Michael Baker, Evan Orovan

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1351 - Using quartz as a tool to aid vectoring in the lithocap environment - a case study from Mankayan, Philippines

David Richard Cooke - *TMVC, CODES, University of Tasmania*
Huayong Chen - *Guangzhou Institute of Geochemistry Chinese Academy of Sciences*
Lejun Zhang - *TMVC, CODES, University of Tasmania*
Zhaoshan Chang - *EGRU, James Cook University*
Jennifer Thompson - *TMVC, CODES, University of Tasmania*
Noel White - *Hefei University of Technology*

Quartz is one of the most common minerals deposited in hydrothermal environments, and is used extensively in fluid inclusion and stable isotopic studies of ore deposits. Quartz can also incorporate trace elements by substitution into the crystal lattice, with Ti4+ substitution for Si4+ strongly controlled by temperature and pressure, providing an effective geothermometer in high temperature environments. The advent of LA-ICP-MS analyses has allowed the detection of low-level trace elements in quartz, and has revealed there may be direct substitutions for Si4+ (e.g., Ti4+, Ge4+), or coupled substitutions of trivalent (e.g., Al3+, Fe3+, B3+, Sb3+, As3+) and monovalent (e.g., Li+, K+, Na+, H+, Cu+) or pentavalent cations (e.g., P5+) into the quartz crystal lattice. This range of trace elements provides the opportunity to use quartz for vectoring and fertility assessments in ore-forming environments, because they include some of the common exploration pathfinder elements, as well as ionic species that are sensitive to temperature and/or pH.

The Mankayan lithocap, Philippines, hosts the Lepanto high-sulfidation copper-gold deposit and conceals the giant, high-grade Far South East porphyry copper-gold deposit. There are other smaller porphyry prospects in the district, and also significant Au-Ag resources in intermediate-sulfidation veins at Victoria and Teresa. Quartz is ubiquitous in the lithocap, where it is the dominant alteration mineral in silicic altered rocks (vuggy and massive quartz) and is an important component of quartz-alunite altered rocks. Quartz-cemented breccias are also common, and quartz veins are present locally. We have used cathodoluminescence to identify different textural varieties of quartz, and to determine the quartz paragenesis. LA-ICP-MS analysis of quartz from the lithocap has revealed systematic spatial variations in trace element contents and trace element ratios of over three orders of magnitude with distance from the Far Southeast porphyry and the Lepanto orebody, providing tools to aid in vectoring to the mineralised centres.

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1402 - Hemlo Au deposit, N. Ontario: chlorite mineral chemistry as a tool for exploring in greenstone terranes

Joseph Vrzovski - *Lakehead University*
Pete Hollings - *Lakehead University*
David Cooke - *University of Tasmania, Australia*
Emily Gorner - *Lakehead University*

As economic Au deposits are becoming increasingly harder to detect through traditional whole rock geochemistry, new exploration techniques are required in order to expand and better detect deposit footprints. In order to make new discoveries explorers are required to drill deeper targets which can lead to high cost and high risk exploration programs.

The Barrick Gold owned Hemlo Au deposit is a world class Archean Au deposit situated in Northern Ontario, Canada with historic production of >21 Moz of Au. The deposit has a strike length of ~3 km with a well documented alteration footprint surrounding mineralization. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of chlorite from within and surrounding the Hemlo gold deposit have identified major element variations in mineral chemistry that allow for the discrimination of deposit-proximal, deposit-distal and intrusion-related chlorite. Short wave infrared (SWIR) analysis of chlorite from around the Hemlo deposit can discriminate between deposit proximal and distal chlorite and could prove useful as an exploration tool when combined with mineral chemistry and traditional geochemical exploration techniques.

Major elements in chlorite surrounding the Hemlo deposit display spatial variations with deposit proximal chlorite being enriched in Mg relative to deposit distal and intrusion-related chlorite, which are both more Fe-rich. Chlorite from intrusions surrounding the Hemlo deposit have high Fe/Al ratios, where deposit-proximal chlorites have high Mg/Si ratios. Major element variations around the Hemlo gold deposit are interpreted to be indicative of a thermal gradient surrounding the deposit and provide a useful tool for identifying targets proximal to mineralization.

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1470 - Hydrothermal Apatite geochronology; Implications for porphyry exploration and new mineral potential in the American Southwest

Joshua Phillips - *CODES, University of Tasmania*
Sebastien Meffre - *University of Tasmania*
Jay Thompson - *University of Tasmania*
David Cooke - *University of Tasmania*

Increasingly, exploration focus on blind or unexposed deposits uses alteration mapping to understand fluid movement and vector towards buried deposits using conventional and/or lithogeochemical techniques. However, in ancient terranes it can be difficult to distinguish between multiple alteration events, potentially of different ages. The Superior District of Arizona that hosts the giant Resolution deposit, has widespread and varied styles of epidote ± chlorite alteration developed in basement rocks exposed over a strike length of more than 10 km in the range front to the west of Resolution.

In this study, a subset of epidote-chlorite altered samples were selected for apatite geochronology to help inform the age and origin of associated chlorite – epidote alteration. Magmatic and hydrothermal apatites were texturally classified and dated using an in-situ U/Pb LA-ICP-MS dating technique. Apatite textures were also validated against trace-element concentration to allow confidence in interpretations of magmatic or hydrothermal origins.

Age determination results reveal several generations of magmatic and hydrothermal apatites that formed from Paleoproterozoic to Cretaceous times, including a previously unrecognised widespread Mesoproterozoic hydrothermal event. The oldest apatites, hosted within the Paleoproterozoic basement schist record an event of similar age to the documented Mazatzal orogeny, partly responsible for assembly of the US continent at ~1600 Ma. The Mesoproterozoic hydrothermal apatites correlate well with magmatic apatite crystals from Grenville aged ~1100 Ma dolerite sills, suggesting the two are temporally, if not genetically related. Associated orthoclase-chlorite alteration in the Apache Basalt is mineralogically similar to that observed in other Proterozoic basins, such as the McArthur and Mt Isa basins of Northern Australia, making the Proterozoic basins of the Southwest US prospective for IOCG or sediment-hosted base metal-style ores

Laramide ages are also recorded by apatites in basement rocks of the Superior district, some of which are located more than 5 km from known porphyry deposits and may present further opportunities for discovery.

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1583 - Tourmaline: A tool for vectoring and fertility assessments in porphyry copper deposits

Francisco Testa - *CODES, University of Tasmania*
David Cooke - *CODES, University of Tasmania*
Nathan Fox - *CODES, University of Tasmania*
Lejun Zhang - *CODES, University of Tasmania*

The increasing world population and consequent larger demands of raw material presents major challenges for the mineral exploration industry. The discovery of new ore deposits will require prospecting of areas where mineralization is not evident, including deeper levels in the crust. For this reason, exploration techniques that have been used successfully over the past few decades need to be augmented with new techniques that aid in ore deposit detection. The compositions of alteration minerals in hydrothermal systems can vary systematically as a function of proximity to the centre of the deposit. Minerals of the tourmaline supergroup are stable in a wide variety of geological environments, and have significant variations in their major and trace element compositions, making tourmaline a robust tool for recording diverse geological processes and trace element zonation patterns. Tourmaline is particularly useful in this regarding as it occurs in numerous ore deposit types, and can therefore aid in ore genesis studies, and in deposit discrimination, fertility and vectoring assessments. We have analysed tourmaline from several ore zones in the Late Miocene to early Pliocene Rio Blanco-Los Bronces district of Chile (La Americana, Sur-Sur, Cerro Negro, and Las Areneras). Rio Blanco-Los Bronces is the largest accumulation of copper on planet Earth, with over 200 Mt Cu. Copper–Mo mineralization is hosted in a series of tourmaline-, magnetite-, and biotite-cemented breccias and porphyry-related stockwork-like veins. Tourmaline compositions vary in a systematic fashion with depth, providing vectors towards mineralization. Tourmaline compositions also vary with respect to the size of the resource from each ore zone, implying that there is potential for using tourmaline in fertility assessments to discriminate barren, weakly and well-mineralized systems.

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1848 - Trace-element characteristics of tourmaline from Canadian Co-Mo-Au porphyry systems

Christopher E Beckett-Brown - *Harquail School of Earth Science, Laurentian University*
Andrew McDonald - *Harquail School of Earth Science, Laurentian University*
Beth McClenaghan - *Geological Survey of Canada*

Tourmaline is a common accessory mineral in porphyry systems that shows promise as an indicator mineral for porphyry (Cu-Mo-Au) mineralization. It can accommodate a wide-range of elements many having partition coefficients close to unity, meaning that tourmaline is capable of recording physiochemical changes in fluid composition throughout the crystallization history of the mineral. As part of a broad study tourmaline from Canadian porphyry systems (Highland Valley Copper, Schaft Creek, Woodjam, and Casino) have been examined to document its relationship to mineralization and trace-element signatures. Three major textural types of tourmaline were observed: 1) disseminated, 2) vein, and 3) breccia all of which are associated with varying degrees of mineralization. Tourmaline grains can also exhibit highly variable growth histories, including oscillatory, patchy, and sector zoning that provide a record of evolving geologic processes. Major-element chemistry suggests that the bulk compositional variation involves Al – Fe substitution (i.e., continuum between oxy-dravite and povondraite). Trace-element analyses via laser-ablation show enrichments and distinct trends in redox sensitive elements (Mn, As, and Sb), high-field strength elements (Ti, Zr, Nb, Th) and large-ion lithophile elements (Sr, Ba) while rare-earth elements occur below detection (<0.01 ppm) can be attributed to the presence of inclusions (e.g., monazite). Tourmaline commonly exhibits multiple growth zones which are also reflected in distinct trace-element variations. Current trace-element analysis shows promise for differentiating tourmaline in mineralized zones from unmineralized zones. Defining characteristics of tourmaline trace-elements developing in mineralized porphyry systems will provide a baseline when examining tourmaline grains recovered from surficial sediment surveys (i.e. as pathfinders).

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1494 - Indicator mineral analysis of stream sediment samples as an exploration tool in an unglaciated vegetated area of east-central Alaska

Karen D Kelley - *USGS*
Sarah Bala - *USGS*
Garth Graham - *USGS*
Heather Lowers - *USGS*
David Adams - *USGS*
Douglas Kreiner - *USGS*
Katharina Pfaff - *Colorado School of Mines*

A pilot study using standard geochemical analyses and SEM-based automated mineralogy is designed to test its usefulness in an unglaciated and vegetated region (~220 km2) of east-central Alaska. Known deposits in the region include the Taurus, Bluff, and Pushbush porphyry Cu deposits/occurrences. The SEM method allows rapid (1-2 hours per sample) and accurate quantification of tens of thousands of mineral grains, and has traditionally been applied to glacial till samples. Our study tests the viability of the method using conventional stream sediment samples. Seventeen sediments in the deposit area and from background sites and seven rock core samples from the Taurus deposit were collected. Hypogene mineralized core contains 1,810-3,880 ppm Cu, 0.109-0.015 ppm Au, and 332-352 ppm Mo, and SEM-based automated mineralogy identified Cu sulfides, molybdenite, and trace sphalerite. The limited surface exposures lack visible Cu minerals, but company reports show up to ~300 ppm Cu in soils overlying mineralized zones. Stream sediment samples within ~1-2 km of Taurus contain 18-38 ppm Cu, 0.005-0.012 ppm Au, and 1-8 ppm Mo, which are relatively high compared to background sediments but low in absolute concentrations. These low Cu concentrations and the lack of Cu-bearing minerals identified by SEM-MPA in the stream sediment samples suggest that they do not survive as detrital minerals in the weathering environment typical of the region. Therefore, the best indicators are resistate minerals or other stable minerals associated with mineralization. Alunite was observed in the stream nearest the Taurus deposit. Topaz and other common porphyry Cu indicator minerals such as epidote, chlorite, apatite, titanite, rutile, and zircon are present in streams draining the deposit, but they also occur in background sediments. Ongoing electron microprobe and ICP-LA-MS studies are designed to test potential differences in mineral chemistry between sediments from mineralized versus barren areas.

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1586 - Igneous geochemistry and geochronology of the intrusive rocks of the central Wasatch Mountain Igneous belt, Utah, USA: implications for porphyry miner

Emily Smyk - *University of Tasmania*
Pete Hollings - *Lakehead University*
Jennifer Thompson - *University of Tasmania*
Michael Baker - *University of Tasmania*
David Cooke - *University of Tasmania*

The central Wasatch Mountains located in northeast Utah, USA, include the White Pine Fork and Park Premier porphyry deposits, hosted by the central Wasatch Mountain igneous belt (CWMIB). From west to east the CWMIB comprises the Little Cottonwood and associated White Pine intrusion; (ca. 29-30 Ma), Alta (ca. 33 Ma), Clayton Peak (ca. 35 Ma), Flagstaff, Valeo, Pine Creek, Mayflower and Park Premier stocks (all ca. 35-36 Ma). Earlier work used metamorphic mineral assemblages, stratigraphic reconstruction and fluid inclusion analyses to show a change in the emplacement depth of the CWMIB from 11 km in the west to less than 1 km in the east.

Petrographic and geochemical evidence reveals a magmatic evolution from the most primitive, eastern stocks (Clayton Peak stock 55-63 wt % SiO_2) to the youngest, most felsic Little Cottonwood stock (66-77 wt % SiO_2). The εNd compositions of the intrusions also decrease from the eastern stocks (-12.8 to -16.6 from the Alta stock and Pine Creek, respectively) to the western, younger stocks of the Little Cottonwood and White Pine intrusions, which have the lowest εNd values (-17.7 and -18.5, respectively). In addition to the increased paleodepth and residence time, Sm/Nd systematics from the Little Cottonwood and White Pine intrusions highlight an increased influence from crustal contamination relative to the eastern stocks.

This study of the geochemical evolution of the intrusions of the CWMIB associated with porphyry-related mineralization shows that the magma evolved over a ~7 million year period prior to mineralization. The relatively small size of the CWMIB porphyry systems may be attributed to a prolonged melt evolution in the western stocks coupled with increased crustal contamination.

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1873 - Testing Airborne Hyperspectral Surveying for Mineral Exploration at High Latitudes: A Pilot Study over Porphyry Cu deposits, eastern Alaska Range, Alaska, USA

Garth E Graham - *U.S. Geological Survey*
Raymond Kokaly - *U.S. Geological Survey*
Karen Kelley - *U.S. Geological Survey*
Todd Hoefen - *U.S. Geological Survey*
Michaela Johnson - *U.S. Geological Survey*

The U.S. Geological Survey recently completed an integrated imaging spectroscopy and geochemical investigation over unmined porphyry Cu-Au-Mo systems (including Orange Hill and Bond Creek) in the eastern Alaska Range, Alaska, USA. The multi-component study was designed to test the applicability of airborne remote sensing as a tool for regional mineral exploration at high latitudes. Spectral data were processed to 1) identify the spectrally predominant minerals, 2) define domains with different chlorite compositions, and 3) map the Al-OH 2,200 nm wavelength positions for muscovite-bearing pixels. This approach, although not optimized for geologic mapping, was successful in identifying hydrothermal alteration mineral assemblages associated with the porphyry deposits. The footprints of the deposits have unique spectral signatures that are related to variations in chlorite and muscovite abundance and composition. Most notably, the 2,200 nm absorption feature positions are several nm longer than outside of the systems. Electron microprobe analyses confirm that the wavelength shifts are the consequence of more phengitic compositions of some of the hydrothermal muscovite associated with the deposits. Additional areas with similar spectral signatures were also identified distal from known porphyry occurrences. Importantly, follow-up geochemical sampling confirmed that Cu-Mo+/-Au anomalies in rocks, sediments, and talus fines are also recognized in these distal areas as well. Collectively, the spectral and geochemical results support the use of airborne imaging spectroscopy as a tool to assist in guiding mineral exploration in the remote mountainous regions of Alaska and possibly other northern latitudes.

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1355 - NIR Characteristics of Porphyry Copper Deposits

McLean Trott - *First Quantum Minerals Ltd.*
Nicholas H. Jansen - *Quantum Pacific Exploration Chile Ltd.*
McLean Trott - *First Quantum Minerals Ltd*

Following the advent of field portable near infrared (NIR) spectrometers such as PIMA in the 1990's, application of such rapid mineralogical characterization and vectoring tools in the mineral exploration industry has increased steadily. In parallel, characterization of the NIR response around several ore deposit styles, and advanced processing techniques have improved substantially.

Porphyry copper deposits are a particularly favorable environment for the application of NIR techniques due to their abundance of alteration minerals with a NIR response and their large, well zoned alteration patterns. The authors have compiled, characterized, and contrasted several type sections from distinct porphyry copper deposits. The analysis includes the distribution of alteration minerals and extraction of key spectral features in conjunction with the deposit geology.

The results of the study establish which mineralogical and spectral features provide the most robust exploration tools when using NIR techniques. These features provide cost-effective, rapid-application and non-destructive vectors and criteria for exploring in the porphyry copper deposit family.

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1405 - Extending the exploration footprint at Canadian Malartic, QC, through the integration of hyperspectral imaging and petrography of glacial clasts

Caroline Taylor - *University of Waterloo*
Martin Ross - *University of Waterloo*
Stephane Perrouty - *Laurentian University*
Philip Lypaczewski - *University of Alberta*
Benoit Rivard - *University of Alberta*
James R. Clark - *McGill University*
Gema Olivo - *Queen\\\'s University*
Robert Linnen - *Western University*
Robin Taves - *University of Waterloo*

There is a growing need for exploration approaches designed to vector towards high-tonnage, near surface, low-grade gold deposits, particularly in glaciated terrains. The challenges include potentially indiscernible geophysical signatures undercover and limitations of detecting fine-grained indicator minerals in glacial sediments. This research aimed to develop a new approach to exploration in glaciated terrains. It involved hyperspectral imaging analyses integrated with detailed petrographic and mineralogical investigation on larger clasts from glacial sediments down-ice of the footprint of the Canadian Malartic stockwork-disseminated Au deposit. Hyperspectral imaging has been previously demonstrated to be a powerful tool to outline gold-related hydrothermal alteration in micas and to define a footprint that extends significantly beyond the gold mineralization itself. In this study, 2-4 mm and 4-8 mm clasts from 57 till samples were analysed using hyperspectral imaging. The results revealed the presence of both phengitic white mica (2205-2215 nm) and Mg-rich biotite (2241-2252 nm), similar to the hydrothermal alteration of the Canadian Malartic bedrock footprint. Forty-two pebbles that contain both mica footprint indicators were selected to perform further petrographic and mineralogical analyses to confirm potential bedrock sources. Among those pebbles, 38 have similar textural and mineralogical features to the Canadian Malartic deposit and its footprint. The dispersion of the 4-8 mm altered clasts in glacial sediments is approximately 70 sq km, and that for the 2-4 mm fraction is approximately 50 sq km. Therefore, the glacial processes during the last glaciation have produced an extensive secondary detrital surficial footprint down-ice of the Canadian Malartic deposit that is significantly more extensive than the identified hydrothermal alteration bedrock footprint (~13 sq km). This study is the first application of hyperspectral imaging analysis to glacial clasts, a straightforward, low-cost, and rapid technique for mineral exploration. CMIC-NSERC Exploration Footprints Network Contribution 172.

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2133 - Plio-Pleistocene High-Sulfidation Epithermal Gold Mineralization at the La Bodega and La Mascota Deposits, Eastern Cordillera of Colombia

Alfonso Luis Rodriguez Madrid - *Apex Geoscience Ltd.*
Thomas Thomas Bissig - *Goldcorp*
Craig Hart - *MDRU*
Luis Mantilla Figueroa - *Universidad Industrial de Santander*

The Plio-Pleistocene high- to intermediate-sulfidation epithermal gold La Bodega and La Mascota deposits (inferred resources in 2010 of 3.47 Moz Au, 19.2 Moz Ag and 84.4 Mlbs Cu at 2 g/t Au cut off) are hosted in Proterozoic gneisses and Mesozoic granites of the Santander massif, Colombia's Eastern Cordillera, Northern Andes. The youngest igneous rocks in the vicinity of the deposits correspond to granodiorite porphyritic dykes dated at 10.1 Ma. Mineralization exhibits NE-trending, NW-dipping structural control associated with the right lateral strike-slip La Baja fault. Mineralization at La Bodega is composed of vein networks and tectonic-hydrothermal breccias while at La Mascota it is largely contained structurally-controlled hydrothermal breccias.

Alteration and sulfide assemblages occurs in six distinct hydrothermal episodes within an

early porphyry-style phase and a late epithermal-style phase. Porphyry phase

comprises stages 1 and 2. Stage 1 is characterized by propylitic alteration with epidote, chlorite, calcite, specularite veins, minor pyrite, and chalcopyrite. Stage 2 (40Ar/39Ar on muscovite ~3.4 Ma) is characterized by phyllic alteration (sericite-illite, quartz, pyrite) associated with quartz-pyrite veins. The epithermal phase (Alunite 40Ar/39Ar ages constrain epithermal mineralization to between ~2.6 and ~1.6 Ma) comprises stages 3 through 6 and is related to multiphase hydrothermal breccia development and quartz-alunite alteration. Stage 3 is defined by presence of copper sulfides such as bornite, covellite, and chalcopyrite, stage 4 by wolframite, stage 5 by enargite, and stage 6 by sphalerite. Pyrite, quartz, and alunite are common to all epithermal stages. Residual vuggy quartz is scarce. Gold-silver mineralization took place during stages 2 through 5.

Primary fluid inclusion assemblages representative of hydrothermal stages 4 and 5 contain liquid and vapor rich inclusions suggesting boiling as an important ore-precipitating mechanism. Based on ?18O and ?D data, alunite was precipitated mostly from magmatic fluids.

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1525 - Ore Pathfinders and Fertility Assessments in Lithocaps: a Case Study of the Veladero High-Sulfidation Epithermal Au-Ag deposit, Argentina

Lejun Zhang - *CODES, University of Tasmania*
Noel White - *CODES, University of Tasmania*
David Cooke - *CODES, University of Tasmania*
Huayong Chen - *Guangzhou Institute of Geochemistry*
Francisco Testa - *CODES, University of Tasmania*
Aldo Vásquez - *Barrick Gold Corporation*
Simon Griffiths - *Barrick Gold Corporation*
Jennifer Thompson - *CODES, University of Tasmania*
Mike Baker - *CODES, University of Tasmania*

Porphyry deposits that are not deeply eroded may be associated with lithocaps – thick and laterally extensive subhorizontal zones of silicic and advanced argillic alteration (Sillitoe, 1995). High sulfidation (HS) epithermal Au-Ag (±Cu) deposits may be hosted in lithocaps in zones of silicic alteration (vuggy quartz, massive quartz), particularly in their fracture-controlled roots. The large areal extents of lithocaps, coupled with the possibility that not all lithocaps host HS mineralization, makes it difficult to predict and define the location of HS mineralization and to determine whether porphyry-style mineralization occurs in the underlying intrusive complex.

The Pascua-Lama-Veladero HS Au-Ag district is located in the Central Andean Cordillera Frontal of Argentina and Chile, at the northern end of the El Indio-Pascua Au-Ag-Cu belt, at elevations of 3950 to 4450 m above sea level. The Veladero deposit hosts 13.8 Moz Au and 226.2 Moz Ag (Barrick Gold Corporation, 2008). Veladero is hosted by intensely altered tuffs and polymict breccias of the Cerro de las Tórtolas Formation (16.0 ± 0.2 to 14.9 ± 0.7 Ma) and the Vacas Heladas Formation (12.7 ± 0.9 to 11.0 ± 0.2 Ma; Holley, 2012). Two adjacent ore bodies at Veladero, Filo Federico and Amable, strike NNW over a combined length of approximately 3 km (Charchaflié et al., 2007). Strong silicic alteration extends more than 3 km away from the centre of the HS ore zone, mainly occurring as vuggy and massive quartz, and quartz also occurs as breccia cement. LA-ICP-MS and cathodeluminescence analyses of quartz from Veladero have revealed that quartz trace element chemistry and texture can be used as effective tools to define HS mineralization targets and indicate the potential source intrusive centre in this lithocap environment.

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1412 - The geochemistry of the alteration of the Red Lake Gold Mines Au deposit

Nicolas Derome - *Lakehead University*
Peter Hollings - *Lakehead University*
David Cooke - *CODES*
Michael Baker - *CODES*
Evan Orovan - *CODES*

The Red Lake District located in the Archean Superior Province of Northwestern Ontario is one of Canada's largest gold mining districts, having produced over 20 million ounces of Au. The gold endowment of the district is dominated by the Red Lake Gold Mines (RLGM) orogenic Au deposit. RLGM is hosted by the Mesoarchean Balmer Assemblage, with mineralization having formed between 2722 and 2702 Ma. This study utilizes the trace element geochemistry of alteration minerals to increase the footprint of the deposit and vector towards mineralisation. The minerals being analyzed include chlorite, quartz, tourmaline and pyrite. Samples have been taken from three drillholes cross-cutting mineralization at RLGM, as well as from outcrop from the mine site, and up to of 7 km from the deposit, to observe how the chemistry changes from the deposit to background. Work to date shows that Sb and As concentrations in whole rock and chlorite increase approaching RLGM, however, Sb and As concentrations remain low proximal to mineralization at smaller satellite deposits. With pyrite, W concentrations increase approaching RLGM. Laser mapping of pyrite and other sulphides and arsenides shows that when Au is present, it is usually spatially associated with Te, Bi and Ag, and to a lesser extent, Cu, Pb and Sb.

Minerals
MIN28: Micro- to Macro-Biogeochemistry: Exploration, Processing, Remediation and the Environment (AAG: 28th IAGS)

Paper ID

Paper Title

2461

Microorganisms and Minerals: Opportunities and challenges (./pdfs/rfg2461.pdf)
Sean Crowe

2308

KEYNOTE: Undercover Investigations: Can experimental biogeochemistry provide important clues to vector towards buried mineralization? (./pdfs/rfg2308.pdf)
David Fowle

2178

Responses of the Soil Microbial Community to Weathering of Ore Minerals (./pdfs/rfg2178.pdf)
Rachel Simister, Bianca Lulianella-Phillips, Peter Winterburn, Crowe Sean

1832

Molecular biology in mineral exploration (./pdfs/rfg1832.pdf)
Bianca Iulianella Phillips, Rachel Simister, Peter Winterburn, Sean Crowe

2467

Microbial Communities in Exposed Soils from Hydraulic Fracturing Sites (./pdfs/rfg2467.pdf)
Jenifer Spence, Reilly Ische, Michael Bilek, Nikolaus Finke, Faride Unda, Rachel Simister, Shawn Mansfield, Sean Crowe

1940

KEYNOTE: Halogens as possible pathfinders to blind mineralization: examples from Lara and Mount Washington on Vancouver Island, British Columbia (./pdfs/rfg1940.pdf)
David Heberlein, Colin Dunn

1207

KEYNOTE: Biogeochemistry as a regional sampling tool to explore through the Eucla Basin (./pdfs/rfg1207.pdf)
Nathan Reid, Ryan Noble, David Cole, Carmen Krapf, Ignacio Gonzalez-Alvarez, Ian Lau, Jess Robertson, Tenten Pinchand

1181

Biogeochemical exploration of Mo and Pb deposits in Norway (./pdfs/rfg1181.pdf)
Belinda Flem, Clemens Reimann, Espen Torgersen, Malin Andersson, Tor Erik Finne, Ola Eggen, Peter Englmaier

2179

The Geochemical Signal for Airborne Plant Particulates and their use for mineral exploration (./pdfs/rfg2179.pdf)
John Barr

2081

Application of Synchrotron Spectroscopy to Environmental Monitoring and Biogeochemical Exploration: An Example from Seaweed in Howe Sound (./pdfs/rfg2081.pdf)
Lisa Van Loon, Neil Banerjee, Colin Dunn

1474

KEYNOTE: Biogeochemical anomaly detection for target scale mineral exploration in northern Finland (./pdfs/rfg1474.pdf)
Maarit Middleton, Dominika Miksova, Irene Hoffmann, Johanna Torppa, Raimo Sutinen, Peter Filzmoser

2334

Geochemical anomalies above the buried Garden Well gold deposit, Western Australia (./pdfs/rfg2334.pdf)
Melvyn Lintern, Ravi Anand, Nathan Reid

2470

Biogeochemical mapping at various scales using fpXRF (./pdfs/rfg2470.pdf)
David Cohen, Juee Vohra, Kiah Ostowari, Madeline Rincheval, Emma Cohen, Joe Schifano, Andreas Zissimos

2461 - Microorganisms and Minerals: Opportunities and challenges

Sean Crowe - *The University of British Columbia*

There are more than 10^30 microorganisms on Earth and through their growth and metabolic activities they drive fluxes of matter and energy at global scales. Over geological time-scales microorganisms have conspired with geological processes and transformed the Earth from its early anoxic state dominated by single-celled microbial life to its current well-oxygenated state teaming with complex multicellular aerobic life. In so doing, microbial metabolisms have dramatically altered the distributions of many elements at the Earth's surface and participated either directly or indirectly in the deposition of many of the world's largest ore deposits. Microorganisms are thus the world's most effective geochemists and we have much to learn from their ability to process mineral resources. New genomic and synthetic biology approaches provide powerful tools through which to interrogate and interface with the microbial world, but there remain many barriers and challenges to the routine application of these technologies to advance the mineral resource sector. In this talk I outline some of these challenges and propose solutions that would facilitate the broader application of genomics and synthetic biology to the full cycle of mineral resource development.

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2308 - KEYNOTE: Undercover Investigations: Can experimental biogeochemistry provide important clues to vector towards buried mineralization?

David Fowle - *University of Kansas*

Biogeochemically mediated processes have long been implicated in a variety of mechanisms influencing the dispersion and accumulation of metals in soils overlying buried mineralized systems. Typically these processes are invoked when secondary signals such as isotopic anomalies, high pH and redox contrast, gas flux and electrochemical anomalies are apparent. Often these clues are part of broader conceptual model that integrates electrochemical processes, expulsion of groundwater, dispersion of gas, and these biogeochemical cycles to explain these secondary features. It is not surprising however, that there is significant site specific heterogeneity to these signs that cloud the interpretation of selective extractions, stable isotopes and other geochemical exploration tools.

The question then arises can we gain a more meaningful understanding of what is going on above and proximal to deeply buried targets by a more deconstructionist approach? Is it possible or even reasonable to breakdown and individually study the biogeochemical effects on geochemical signals through through batch and/or column experiments? For example, carbon isotopic anomalies associated with copper supergene enrichments often exhibit depletions similar to those produced metabolically by methanotrophic bacteria who coincidentally have enzymatic requirements for Cu(II). This suggests a simplified experimental design might provide mechanistic insights into this process and avenues for geochemical and transport modeling. Here, I will present a summary of the insights gained from our flow-through columns experiments with a variety of ore types (Cu porphyry, Magmatic Ni, Cu-Zn VMS) and a consortiums of microorganisms chosen in part because of the favorability of their metabolic needs and the ore of interest. The work will be placed in the context of established extraction and leach protocols as well as integrated with future work such at metagenomics and calibrated biogeophysical techniques.

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2178 - Responses of the Soil Microbial Community to Weathering of Ore Minerals

Rachel Simister - *UBC*
Bianca Lulianella-Phillips - *UBC*
Peter Winterburn - *UBC*
Sean Crowe - *UBC*

In light of strong projected demand for metal resources into the foreseeable future, rates of new mineral deposit discovery are declining while existing deposits are being progressively mined-out. In a pilot study, we have pioneered the use of soil microbial community fingerprinting with modern DNA sequencing technologies to find buried mineral deposits. In a mesocosm experiment, soil was amended with concentrations of copper chosen to represent those that are routinely detected in geochemical surveys over buried mineral deposits (ambient or '(Am)') or very high levels of copper that might be expected in highly anomalous soils (high or '(Hi)'). Microbial-community DNA was extracted and the small sub-unit of the ribosomal RNA gene (16S rRNA) was tag sequenced. Analysis of these sequences reveals that the number of observed OTUs is 2265 ±105 (range 1993–2380), with an alpha diversity (Chao1 index) of 3438 ±327 (range 2808–3791), indicating that the sequencing coverage was sufficient to capture 65% of the microbial-community diversity. Treated samples grouped apart from controls, indicating that chalcopyrite ore and copper amendments changed the composition of the microbial community and that this change was easily resolvable through standard hierarchical-clustering analysis. The species that increased in response to chalcopyrite ore and copper amendment relative to controls included Rhodanobacteria sp., SC-I-84 sp. and Acidimicrobiales sp. These species have frequently been found in relatively high abundances in materials recovered from acidic waters, sulphidic mine wastes and other mine-related environments, as well as acidic biofilms anecdotally suggesting a link between the ecology of these species and the concentration of metals in their habitat. Exposure of soil microbial communities to ore constituents elicits a response detectable on laboratory time scales of several weeks. The strong microbial responses observed are encouraging signs for the use of microbial-community fingerprinting in mineral deposit exploration.

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1832 - Molecular biology in mineral exploration

Bianca Patrizia Iulianella Phillips - *Mineral Deposit Research Unit, University of British Columbia*
Rachel Simister - *Department of Microbiology and Immunology, University of British Columbia*
Peter Winterburn - *Mineral Deposit Research Unit, University of British Columbia*
Sean Crowe - *Department of Microbiology and Immunology, University of British Columbia*

Mineral exploration in Canada is becoming increasingly complex as the majority of undiscovered commodities are likely deeply buried beneath significant glacial overburden and bedrock, reducing the effectiveness of existing tools. The development of innovative exploration protocols and techniques is imperative to the continuation of discovery success. Preliminary experimentation has demonstrated the potential viability of microbial fingerprinting through genetic sequencing to identify the presence of mineralization and its geochemical signatures entrained in till. With the advent of inexpensive modern sequencing technology and large dataset evaluation techniques, microbiological approaches to exploration are becoming more quantitative, cost effective, and efficient. The integration of microbial community information with soil chemistry, mineralogy and landscape development propagates the development of an improved decision process in mineral exploration.

Initial results have demonstrated that the presence of low levels of metals (e.g. <200ppm Cu) as sulphide blended into till is sufficient to detectably change microbial community compositions in amended soil relative to background. Ongoing experiments include additional Ni and Cu amendments to till in addition to low level amendments between till and kimberlite matching the levels encountered in exploration. Soils over porphyry, kimberlite, and VMS deposits have undergone microbial community profiling. These community genome derived datasets have been integrated with trace metal chemistry, mineralogy, surface geology and other environmental variables including Eh and pH. The information from the combined datasets of microbial information with trace metal anomalies will determine whether microbial community shifts are correlated with geochemical signals. Strong associations between microbial profiles and anomalous trace element signals could lead to the use of microbial community profiling as a method for delineating ore deposits in glacially covered terrain, with potential for application into an entirely field based technique, as sequencing technology is progressively developed into portable platforms.

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2467 - Microbial Communities in Exposed Soils from Hydraulic Fracturing Sites

Jenifer Spence - *The University of British Columbia*
Reilly Ische - *The University of British Columbia*
Michael Bilek - *The University of British Columbia*
Nikolaus Finke - *The University of British Columbia*
Faride Unda - *The University of British Columbia*
Rachel Simister - *The University of British Columbia*
Shawn Mansfield - *The University of British Columbia*
Sean Crowe - *The University of British Columbia*

Hydraulic fracturing (fracing) uses large volumes of water that contain chemical additives, which are used to render the surface or ground water suitable for fracing operations. Spillage of these fluids introduces additives to soils, with possible deleterious effects on soil ecosystem services. Here we report microbes present in environmental soils and rhizospheres that may possess the capacity to bioremediate frac fluid components introduced to soils. We collected samples from pristine soils and soils that were exposed to fracing fluids. We employed next-generation amplicon sequencing of the 16S rRNA gene to profile microbial communities across our sample suite. At the phyla and class levels, both pristine and exposed soils displayed similar trends in microbial communities. At the genus level, the most abundant taxa differed between the pristine and exposed soils. The most abundant taxa in the exposed soils belonged to the Rhodanobacter and Acidithiobacillus genera. Conversely, the most abundant taxa in the pristine soils were unclassified Bradyrhizobiaceae and Subgroup 6 (Acidobacteria). Furthermore, some of the exposed soils had exceptionally low diversities, with Chao1 indexes as low as 295 OTUs. Within the exposed soils, the alpha-diversity values and the most abundant taxa displayed a high level of variability, most likely due to variability of exposure. In contrast, pristine soils showed very little variation in taxonomic composition. In summary, we have fingerprinted the microbial communities associated with pristine and exposed soils, which may serve as benchmarks for exposure to frac fluids.

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1940 - KEYNOTE: Halogens as possible pathfinders to blind mineralization: examples from Lara and Mount Washington on Vancouver Island, British Columbia

David Heberlein - *Heberlein Geoconsulting*
Colin Dunn - *Colin Dunn Consulting Inc.*

The halogens (F, Cl, Br and I) are common constituents of igneous, metamorphic and sedimentary rocks. They are particularly enriched in differentiated magmas; the hydrothermal fluids, volatile compounds and gasses derived from them play an important role in the mobilization and transport of metals in ore forming systems. In the primary environment they reside in a variety of hydrous minerals including micas and amphiboles where F can substitute for O and OH-.

These minerals weather and release their halogens as volatile vapours (Br and I) and/or their more stable compounds, or water-soluble ions (F and Cl) that disperse to form detectable anomalies in the surficial environment. This Geoscience BC-funded study investigated halogen signatures in vegetation at the till-covered VMS deposit at Lara near Chemainus, and at the exposed epithermal Au-Ag-Cu system at Mount Washington near Courtenay.

At Mount Washington, halogens in Yellow-cedar bark and Mountain hemlock foliage were compared with concentrations in Ah horizon soil and activated carbon collectors that were buried in the soil for 3 months. At Lara Douglas-fir, western hemlock and western redcedar were among the species sampled and compared

Analytical challenges caused by the organic-rich sample matrices had to be overcome. After experimentation with several approaches, warm water leaching of ashed material provided the best contrast and precision for Cl, Br and I.

Results showed that halogen concentrations in Ah horizon soils are influenced by water saturation and do not detect the mineralization. Mountain hemlock, however, showed compelling Cl, Br and I apical responses in foliage and in transpired fluids over the Mount Washington Au mineralization. At Lara western hemlock foliage defined halo-like responses centred on the Coronation Trend. Conclusions are that halogens may be effective pathfinder elements for the detection of shallowly buried sulphide mineralization.

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1207 - KEYNOTE: Biogeochemistry as a regional sampling tool to explore through the Eucla Basin

Nathan Reid - *CSIRO*
Ryan Noble - *CSIRO*
David Cole - *CSIRO*
Carmen Krapf - *Geological Survey of South Australia*
Ignacio Gonzalez-Alvarez - *CSIRO*
Ian Lau - *CSIRO*
Jess Robertson - *CSIRO*
Tenten Pinchand - *CSIRO*

As part of the Coompana regional geochemical sampling campaign ~300 pearl blue bush (Maireana sedifolia) and bladder salt bush (Atriplex vesicaria) were sampled on a 4 km grid pattern across an area 80 km by 40 km. The aim of this project was to develop rapid sampling techniques for regional greenfields mineral exploration. Biogeochemical sampling was one component of this project. The species selected were consistent across the area and were the subject of a previous study in the region. The focus area was over a large magnetic anomaly and the substrate is the Nullarbor Plain limestones, so exploration in this region is to determine whether surface geochemical media can detect lithology or anomalism beneath the limestones.

Samples were collected using leather gloves and electric shears. The shears were pre-contaminated with the plant before taking the sample to avoid cross sample contamination. Sample details were collected using the FAIMS android application. Thirty samples were randomly chosen across the grid to test leaves and twig chemistry, and the medium with the greatest chemical ranges for elements of interest was chosen to be assayed across all samples.

This presentation will show the results of the different biogeochemical media and the full survey. The biogeochemistry will be compared to soil and limestone geochemistry and we shall present the mineral exploration implications for this region.

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1181 - Biogeochemical exploration of Mo and Pb deposits in Norway

Belinda Flem - *Geological Survey of Norway*
Clemens Reimann - *NGU*
Espen Torgersen - *NGU*
Malin Andersson - *NGU*
Tor Erik Finne - *NGU*
Ola Eggen - *NGU*
Peter Englmaier - *University of Vienna*

Fifteen different sample media were collected at 41 sites along a 100 km transect crossing the Oslo rift. Along the transect there are two undeveloped ore deposits: Nordli Mo and Snertingdal Pb, both undeveloped. The response of 12 different plant materials (birch, spruce, cowberry and blueberry leaves and twigs, fern, horsetail, pine bark, moss), one mushroom (rufous milkcap) and soil C- and O horizon, to the mineralisations and lithological changes along the transect is studied. The majority of sample media yield a clear geochemical signal related to the two deposits (and some additional smaller mineralisations occurring along the transect). Together with the soil O horizon, spruce needles and horsetail are the best indicators for the Mo deposit. Fern and horsetail, together with the soil C horizon show the largest anomaly/background contrast over the Pb mineralisation. Compared to the plants the mushroom is enriched in Ag, Cs, Cu, Rb, Na and Cd and shows exceedingly high concentrations of the major nutrients K, P and S, while uptake of Ca is avoided. Both, horsetail and fern are enriched in rare-earth elements like Ce, La and Y, but to a different degree, and they invert the geochemical La/Ce ratio during uptake. The response of most media to lithological changes is surprisingly small.

The strong signal of most plants to the lPb deposit clearly demonstrates that plant Pb concentrations in a large variety of plant materials, including moss, are not necessarily influenced by external input of lead. Plant uptake from the substrate and local geogenic dust play the dominant role in determining Pb concentrations in all collected plant materials, the mushroom and the derived soil O horizon.

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2179 - The Geochemical Signal for Airborne Plant Particulates and their use for mineral exploration

John C Barr - *Anglo American*

The uptake of various elements by plant roots into the wood, bark, twigs and leaves of a variety plants and trees has been extensively studied by others. There is minor information of element content in saps and virtually nothing on plant particulates or what is leached from plants by rain. An objective of this work was to determine what elements are rejected by the plant as particulates and in what quantity relative to leaves or needles and can they provide, quite possibly a unique, airborne geochemical signal. The leaching of elements by rain and concentration in the extreme surface micro-layer which can then be sampled was also investigated.

A series of controlled laboratory experiments, using radioactive tracers of Zn, Pb, Cd and Mn added at various concentrations to plant roots, examined the uptake by various plants, including conifers. The subsequent concentrations in both the plant tissue and plant particulates were measured and compared, together with leachates from simulated rain that could accumulation in the extreme surface of the soil. Further studies in the field collected plant particulates from vegetation and airborne partioculates on traverses over known mineralization. These were undertaken using especially designed vacuum devises: a back pack collector; a devise mounted beneath a helicopter and dragged in a continuous line across vegetation; and rotary-wing mounted collectors. The collected particles were vacuum-impacted onto tape consisting of a flexible Mylar adhesive bottom layer, a thicker middle layer with perforations to retain the samples, and a Teflon cover tape. The tape was sent for laser ablation – inductively coupled plasma emission spectroscopy (LA-ICP-ES) analysis for up to 34 element. In the air sampling rate was approximately 400 samples/hour, so depending on the speed of the aircraft samples were taken continuously for 20 to 100m. Results from the lab and the field are presented.

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2081 - Application of Synchrotron Spectroscopy to Environmental Monitoring and Biogeochemical Exploration: An Example from Seaweed in Howe Sound

Lisa Van Loon - *Saskatoon, Saskatchewan*
Neil Banerjee - *Dept. of Earth Sciences, Western University*
Colin Dunn - *Consulting Geochemist*

During its seventy year history, the Britannia Mine located north of Vancouver on the east shore of Howe Sound produced more than a billion pounds of Cu and significant Zn, Pb, Cd, Ag and Au. Neglect after operations ceased led to it being the largest single point discharge of heavy metal pollution into a marine environment due to untreated drainage from the abandoned mine tunnels. In the early 1990's there was no seaweed growth for a distance of more than 1 km on either side of the drainage from the Britannia Mine into Howe Sound. Where it first appeared, it was stunted and samples yielded up to 1000 ppm Cu dry weight - more than 50 times background levels, attesting to the high degree of metal accumulation that the seaweed can withstand before concentrations become detrimental to growth. Remediation has been instrumental in regenerating Howe Sound's ecosystem. This inlet now has prolific growth of the rockweed species Fucus gardneri lining the intertidal zone. Recent work has shown a drastic decrease in metal accumulations in rockweed and a return to colonization near the drainage from the mine.

New methods using Synchrotron X-ray Fluorescence (S-XRF) are being developed for mapping elements in rockweed from this area. Micron-scale accumulations can be mapped revealing relationships between plant physiology and metal hotspots. For mineral exploration, rockweed anomalously enriched in a commodity metal (or its pathfinder elements) can provide focus for more detailed follow up to look for the source. Synchrotron XRF analyses of metal accumulations that are used in remediation can also assist in the discovery of new mineral sources. This project bridges the past to the future and brings the entire mine life into focus.

1474 - KEYNOTE: Biogeochemical anomaly detection for target scale mineral exploration in northern Finland

Maarit S. Middleton - *Geological Survey of Finland*
Dominika Miksova - *Vienna University of Technology*
Irene Hoffmann - *Vienna University of Technology*
Johanna Torppa - *Geological Survey of Finland*
Raimo Sutinen - *Geological Survey of Finland*
Peter Filzmoser - *Vienna University of Technology*

In northern Finland, orientation surveys were conducted to study the presence and strength of biogeochemical signals on top of six different types and sizes of previously drilled mineralizations including an Au-Co ore, IOCG and Ni-Cu-PGE deposits, and three exploration targets. The results indicate that significant mineralizations and especially their deeply seated lodes (down to 200 m depth) could be detected using the biogeochemical data, although, responses were weak on top of the exploration targets.

The biogeochemical data are generally compositional in nature. The present study focuses on compositional data analysis (CoDa) of the biogeochemical dataset from northern Finland. CoDa deals with relative instead of absolute information, which is done by using log-ratio transformations. Since the biogeochemical data include values below the lower (LDL) and above the upper detection limit values (UDL), the first task is to replace these values by meaningful numbers corresponding to the multivariate data structure. We make use of a CoDa approach which replaces LDL values, based on Tobit regression (see Martin et. al., 2012). Our approach is an extension also able to replace UDL values which are common for P, K, Mn and Zn in ashed concentrations. The procedures have been implemented in the software environment R.

Comparisons of univariate and multivariate (CoDa) replacement methods on the biochemical data set show that for subsequent multivariate data analysis methods, such as PCA, the multivariate data structure is much better recovered with the CoDa method. We apply the CoDa data processing on the Northern Finland biogeochemical dataset and demonstrate the differences in biogeochemical anomaly detection between traditional and CoDa transformed data.

References:

J.A. Martin-Fernandez, K. Hron, M. Templ, P. Filzmoser, and J. Palarea-Albaladejo (2012). Model-based replacement of rounded zeros in compositional data: classical and robust approaches. Computational Statistics and Data Analysis, 56, 2688-2704.

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2334 - Geochemical anomalies above the buried Garden Well gold deposit, Western Australia

Melvyn Lintern - *CSIRO*
Ravi Anand - *CSIRO*
Nathan Reid - *CSIRO*

Garden Well is a 4 Moz., shear hosted Archaean orogenic gold deposit concealed by a Tertiary palaeochannel up to 30 m thick and located 100 km north of Laverton in the Duketon Greenstone Belt in Western Australia. Gold mineralisation occurs as oxide ore down to 70 m below the base of the palaeochannel and hypogene ore as deep as 400 m. Vegetation is predominantly open woodland, dominated by Acacia and Casuarina. The area has a semi-arid climate. Initial soil sampling (0-0.1 m) did not reveal any definitive surface geochemical response, but surficial Au anomalies occur on the margins of the palaeochannel of up to 75 ppb Au in 2-6 mm lag. Sampling and multi-element analysis of vegetation, organic-rich surficial soil, sub-soil (0.1-0.2 m), groundwater, and ferruginous materials from drill cuttings was undertaken to investigate the presence of geochemical anomalies and, if so, to understand and interpret the process of metal dissolution, migration and precipitation, that lead to such anomalism. Strongly anomalous Au concentrations were found in the Acacia foliage, groundwater and in the ferruginous materials. Gold concentrations in foliage were coincident with Fe, Ti, Al, Re and Mo and were slightly displaced above the mineralisation closest to the surface. Groundwater was shallow (~ 5 m) and Au concentrations were some of the highest recorded in the north east Yilgarn. One interpretation from these data is that a biogeochemical mechanism is responsible for anomaly formation i.e. Au was taken up by roots from the shallow groundwater to create anomalies in the foliage. There is an accumulation of metal in the foliage and that the shallow groundwater containing Au, a possible source, is a plausible mechanism.

Strongly anomalous Au concentrations were found in the Acacia foliage, groundwater and in the ferruginous materials. Gold concentrations in foliage were coincident with Fe, Ti, Al, Re and Mo and were slightly displaced above the mineralisation closest to the surface. Groundwater was shallow (~ 5 m) and Au contents were some of the highest recorded in the NE Yilgarn.

One interpretation from these data is that a biogeochemical mechanism is responsible for anomaly formation i.e. Au was taken up by roots from the shallow groundwater to create anomalies in the foliage. There is an accumulation of metal in the foliage and that the shallow groundwater containing Au, a possible source, is a plausible mechanism.

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2470 - Biogeochemical mapping at various scales using fpXRF

David Cohen - *University of New South Wales*
Juee Vohra - *UNSW*
Kiah Ostowari - *Lendlease*
Madeline Rincheval - *Sydney Water*
Emma Cohen - *Saracen*
Joe Schifano - *GeoJoe*
Andreas Zissimos - *GSD*

The trace and major element composition of selected plant species and organs may be used to map the effects of various geochemical processes at a variety of scales. At the mineral deposit or mine-site scale, biogeochemistry has demonstrated a capacity to effectively map geochemical dispersion patterns, including the historical Sunny Corner Ag-Pb-Zn (radiata pine) and Woodlawn Cu-Pb-Zn mine-sites (green and black acacia), the Thackaringa Co-pyrite deposit (saltbush), the McKinnons Tank Au and other base and precious metal deposits of the Cobar Basin (cypress pine) and the Cyprus-style Cu deposits at Kokkinopesula and Kalavasos (brutia pine). In some cases, vegetation is better at detecting geochemical dispersion in areas of transported cover than surface regolith materials.

At the regional scale, multi-species biogeochemical patterns were found to be similar to adjacent stream sediments for a number of transition metals in the New England region of NSW, as well as in the needles of cypress pines in the Cobar Basin. Vegetation has generally not been included in regional to continental scale geochemical mapping programs due to the limited areal extent of most plant species, though regolith samples (soils and sediments) may also display a wide range of “genetic” types.

The on-going development of field-portable analytical devices, especially fpXRF, is providing opportunity to obtain real-time geochemical data for biogeochemical samples as well as conventional regolith materials, for a number of elements. There are, however, a number of analytical issues related to sample representivity and machine calibration specifically related to plant materials.

Minerals
MIN29: Exploration Undercover - Techniques, Technology and Strategy (AAG: 28th IAGS)

Paper ID

Paper Title

2022

Detecting the Teena zinc-lead shale hosted massive sulfide deposit: Surficial geochemistry in a mineral system context. (./pdfs/rfg2022.pdf)
Iain Dalrymple

1096

Testing ultrafine soils to improve near surface exploration through cover (./pdfs/rfg1096.pdf)
Ryan Noble

1348

Use of cover sequence geochemistry from regional and mineralisation-associated datasets to understand element transport mechanisms: Case study of the Eromanga Basin (Australia) (./pdfs/rfg1348.pdf)
Eline Baudet, Caroline Tiddy, David Giles, Steve Hill

1395

Exploration geochemistry: comparison between classic trace elements geochemistry, soil partial leaches, portable XRF, on soils and biogeochemistry in Western Europe Environment. Example from Li-Ta-Sn and W deposits (./pdfs/rfg1395.pdf)
Jérémie Melleton, Bruno Lemière, Virginie Derycke, Anne-Sophie Serrand, Eric Fournier, Eric Gloaguen, Frédéric Lacquement, Pascal Auger, Maarit Middleton, Vesa Nykänen

1614

Physical and chemical interfaces and indicator minerals for characterising and detecting the footprints of ore deposits in areas of deep cover (./pdfs/rfg1614.pdf)
Ravi Anand, Walid Salama, Mel Lintern

1763

Reduced chimneys: new perspectives on their formation and relevance to mineral exploration (./pdfs/rfg1763.pdf)
Stewart Hamilton, Konstantin von Gunten

2415

Hunting for REE minerals in northern Labrador: MLA-SEM analysis of surficial sediments down-ice from the Strange Lake deposit (./pdfs/rfg2415.pdf)
Derek Wilton, Mikayla Miller

1227

Upscaling deep buried geochemical exploration techniques into European business – UpDeep (./pdfs/rfg1227.pdf)
Maarit Middleton, Vesa Nykänen, Jeremie Melleton, Bruno Lemiere, Pertti Sarala, Peter Filzmoser, Paula Järvinen, Maria Rinkkala, Jens Rönnqvist, Simon Thaarup

1495

A plan for resourcing future exploration (./pdfs/rfg1495.pdf)
Adele Seymon, Robbie Rowe, Joe Cucuzza

1676

Geochemical challenges and discoveries of exploration undercover in China (./pdfs/rfg1676.pdf)
Xueqiu Wang, Bimin Zhang, Deping Yang, Ruihong Li, Mi Tian

1131

Drift prospecting in glaciated, thick overburden regions: A case study in the Ring of Fire area of Hudson Bay lowlands, Ontario, Canada (./pdfs/rfg1131.pdf)
Cunhai Gao, Dave Crabtree, John Menzies, Sandra Clarke

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1418 - Direct Detection of Drift Concealed Kimberlites using Surface Geochemistry and Landscape Evolution, NWT, Canada

Erika Mary Cayer - *MDRU - UBC*
Peter Winterburn - *MDRU-UBC*
Barrett Elliott - *Northwest Territories Geological Survey*

The evaluation of surface geochemical techniques and landscape evolution models to detect the presence of a kimberlite through cover was undertaken by collecting soil samples in a detailed grid crossing the DO-18 kimberlite (Peregrine Diamonds Ltd.), concealed by 5-20 metres of glacial sediments. Soil samples were analysed by ICP-MS following 4-Acid and Aqua Regia digestions in addition to field portable X-Ray Fluorescence (fp-XRF). Selected samples were analysed by Sequential Leach – ICP-MS. Influences of geomorphological processes on geochemical data were identified by mapping surficial material, soil type, topographic variation and vegetation. An east-west trending slope break divides the research site into a topographically high region in the north and a low-lying region in the south. The north consists of till and numerous frost boils, and the south comprises till, organics and glaciofluvial and glaciolacustrine sediments. 4-Acid and Aqua Regia digestion data display a dispersal of Cr, Mg, Nb, and Ni from directly above the kimberlite in the north, to the edge of the sampling grid, in the down-ice direction. Element co-variance and sequential leach data indicates that Mg and Ni are derived from olivine and its weathering products, and Nb from refractory minerals. Around 2-3% of kimberlite blended into the till would be sufficient to generate the low-level responses observed. Fp-XRF data exhibits a similar distribution in all elements except Mg, as concentrations are too low for reliable detection. Glacial transport of material from the kimberlite is hypothesized to have generated the geochemical response. Glaciolacustrine and glaciofluvial processes generated the lower topography in the south and diluted and/or buried the geochemical responses in the south.

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1468 - Surface Till Geochemical Exploration of a Concealed Kimberlite

Andrew Prior Wickham - *Mineral Deposit Research Unit, University of British Columbia*
Peter Winterburn - *Mineral Deposit Research Unit, University of British Columbia*
Barrett Elliott - *Northwest Territories Geological Survey*

In regions where recent glaciation has buried kimberlites under glacial sediments, surface geochemical detection methods are better interpreted when coupled with a comprehension of the landscape formation processes. The glacial, post-glacial, and cryoturbation processes that have affected the landscape have, in turn, affected the dispersal of geochemical signatures in the till. Research at the Kelvin kimberlite, Northwest Territories, will help to refine exploration practices, resulting in reduced costs whilst improving exploration success.

The Kelvin kimberlite (Kennady Diamonds) is located eight kilometers from the Gahcho Kué diamond mine in the Northwest Territories. The kimberlite is an inclined pipe cutting through granite gneiss host rock and sub-crops beneath a lake. It has a surface projection towards the NW more than 600m long concealed under bedrock and is not exposed at the bedrock-till interface. The site is covered in a veneer of till, 1-4m thick, and characterized by low relief (30m total), low shrubby vegetation, localised swamps, and frost boils.

Soil samples were collected from the oxidized upper B-horizon above the kimberlite, both up-ice, and up to 1 km in the down-ice direction. Samples were sieved to -180 microns and analyzed by four acid digest ICP-MS and aqua-regia digest ICP-MS. Analytical results indicate the soils to be highly immature and identify the presence of 2 subtle Ni-Cr-Mg±Nb trains originating from the lake side: one following the most recent ice direction to the west and extending for >1km from source; and a second response following an older ice movement to the NW restricted to a SE facing hill slope. The material for the trains was abraded by the ice from the kimberlite, now sub-cropping beneath a lake. The trains meet at the lake side and would have provided additional support to drill, what was initially targeted from geophysics.

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1040 - Geochemical Mapping of the Deerhorn Copper-Gold Porphyry Deposit and Associated Alteration through Transported Cover, Central British Columbia

Shane Rich - *Copenhagen, Denmark*
Peter Winterburn - *University of British Columbia*

Anomalous geochemical responses in the Ah soil horizon over the blind Deerhorn Cu-Au porphyry in central British Columbia (BC), were documented by Bissig et al. [1] and over similarly buried sulphide deposits by Eppinger [2] and Hamilton [3]. Improvements remain in our ability to interpret these geochemical responses so as to develop robust exploration tools for the discovery of economic, but concealed mineralisation.

Discoveries of porphyry copper deposits (PCDs) in BC have declined over the past 20 years. Undiscovered PCDs are predicted to occur in the Intermontane Belt, an assemblage of volcanic arc terranes considered important for hosting large porphyry deposits. The Deerhorn Cu-Au porphyry, located within this belt, is covered with up to 60 m of undisturbed moraine. Detailed regolith mapping based on a new classification scheme for BC, combined with aqua regia and deionised water assays, sequential leaching, physicochemical measurements and hydrocarbon analysis, was undertaken to determine the response in the till to buried mineralisation.

Geochemical relationships dependent on the regolith type were identified and are particularly evident in organic rich areas. To minimise background noise, data analysis was constrained to the dominent regolith unit: the undisturbed moraine (DrM), resulting in enhanced anomaly identification. Regolith mapping in advance of a soil survey can therefore allow targeted efficient sampling. Normalisation to organic carbon (Corg) to counteract the influence of organic matter on trace element variability resulted in anomalous response for elements As, Cs, Cu, Mo, Tl, U and W by conventional aqua regia on a 180-micron fraction B-upper-horizon soil. The response for six of these elements is peripheral to mineralisation in the surface environment. Multi-element evaluation is superior for mineralisation detection than individual element evaluation. Light hydrocarbon results indicate a surface response with a distinct depletion over mineralisation. Sequential leaching on selected anomalous Cu samples indicates that an aqua regia extraction was the optimal first choice for anomalous Cu detection.

Copper-Fe-oxide-bearing grains interpreted as oxidised sulphides were recovered from an anomalous Cu-bearing sample and confirm a contribution of glacial clastic transport. Visual screening for clastic fragments allows a reprioritisation of anomalous response. Anomaly formation is interpreted as a combination of clastic transport, ionic migration of H+, vegetation uptake and surface redistribution.

[1] Bissig et al. (2013) Geoscience BC Report NTS 093A/03, /06 [2]. Eppinger et al. (2013) Economic Geology 3, 495-527 [3] Hamilton et al. (2004) GEEA 4, 33-44

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1109 - Tracing fault-controlled fluids in areas of cover using regolith and spinifex chemistry, with implications for stratabound Pb-Zn mineralization

Paul Morris - *Geological Survey of Western Australia*

Whether the 400 km long Stansmore Fault in the regolith-dominated Ngururrpa area of northeastern of Western Australia acts as a fluid pathway to buried mineralization has been examined using the chemistry of the fine (< 50 micron; silt and clay) fraction of eolian sand and the chemistry of spinifex (Triodia sp) - an arid-zone grass - along two sampling transects. Where the position of the fault is well constrained by topography and geophysics, regolith coincident with the fault trace has higher concentrations of fluid-mobile (e.g. Cs, Li, K) and rare earth (RE) elements. A transect across a more structurally complex and less well constrained part of the fault shows changes in element concentration for both regolith (particularly REE) and spinifex (REE, B and Re) across one fault trace, and indicates the likely position of a previously undetected fault splay. On both transects, concentration variations for elements with similar fluid mobility indicate a higher flux for a number of elements including Zn, Tl and Cd coincident with known or inferred fault traces, indicating the possibility of concealed stratabound Pb-Zn mineralization. This is consistent with the occurrence of both SEDEX and MVT mineralization in this part of Western Australia. South of the Ngururrpa area, SEDEX mineralization has recently been discovered in carbonate-bearing rocks; lithologies of a similar age and composition in the Ngururrpa area are spatially related to regolith samples with anomalously high Zn concentrations. The Ngururrpa area lies at the eastern end of the Canning Basin, which hosts world class MVT deposits, all of which are located on or near to sub-basin bounding faults. The Stansmore Fault separates two sub-basins of the Canning Basin, and petroleum drilling near the fault trace has identified suitable host rocks (both in terms of age and composition) to MVT mineralization.

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1658 - The Geochemical Anomaly Pattern of the Shizishan Cu-Mo-Au Ore Field in Tongling Region, Anhui Province, China

Mingjie Xi - *Institute of Geophysical and Geochemical exploration, Chinese Academy of Geological Science*
Shengming Ma - *Institute of Geophysical and Geochemical Exploration, Chinese Academy of Geological Sciences*
Shuqi Hu - *Institute of Geophysical and Geochemical Exploration, Chinese Academy of Geological Sciences*

Located in the iron-copper-gold polymetallic ore belt of the middle and lower reaches of Yangtze River, the Shizishan ore field is composed of many typical porphyry-skarn type copper-molybdenum-gold polymetallic ore deposits, such as Dongguashan, Shizishan, Hucun and Cishan, the mineralization process of which is controlled by regional structure and magmatic activity.

The ore field is occurred in regional geochemical anomalies of copper, molybdenum, gold, silver, lead, zinc, arsenic, tungsten and tin. The element geochemical anomalies on the surface is consistent with the deep, the whole of which is occurred in the positive anomalies of ore-forming elements of Cu, Mo, Au and associated elements of Ag, As, Bi, Cd, W, S, as well as in the negative anomalies of Ba, Sr, Na2O. The positive anomalies of Cu, Mo, Au and the negative anomaly of Sr are produced corresponding to copper-molybdenum-gold polymetallic ore bodies of porphyry-skarn type, while the sulfur positive anomaly and Ba, Na2O negative anomalies covered the whole mineralization regions, and the existed deep anomalies of the drillings still implicate the possible concealed polymetallic mineralization bodies below 1700 meters of the deep ore field. The geochemical anomaly controlled by the Si-Ca interface between carbonate formation and silicate rocks mass occurs as stratified or stratoid beds. Ore-forming elements of copper, gold and sulfur is originated from high sulfur formation, while molybdenum is from magmatic rocks of Yanshan period, which not only supply ore-forming materials but also provide the important fluid and heat source for the activation and migration in mineralization process. The geochemical anomaly pattern of the Shizishan ore field will provide a methodological technique for the geochemical anomalies evaluation in Tongling ore district.

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1324 - Mapping and Modeling Geochemical Dispersion Above a Till concealed Polymetallic Volcanogenic Massive Sulphide Deposit

Matthew Alan Bodnar - *Mineral Deposit Research Unit*
Peter Winterburn - *MDRU*

Detailed surficial material mapping and soil sampling was completed over the concealed Lara polymetallic volcanogenic massive sulphide deposit, Vancouver Island, BC, Canada. A model of landscape evolution was developed to assist the identification of natural processes that govern geochemical responses in shallow soil in glaciated terrain. Upper B horizon soil and physicochemical property measurements were collected along four transects over the deposit and host-rocks. The -180 ?m fraction was analyzed by aqua regia ICP-MS/AES, fpXRF and for magnetic susceptibility. Select samples were analyzed by sequential extraction to establish the provenance of geochemical responses. Western hemlock bark samples from a subset of the grid were analyzed by modified aqua regia ICP-MS to determine the role of biochemical cycling.

Surficial materials including till, alluvium and colluvium were identified representing complex alpine glacial and paraglacial processes. Most recent glacial ice flow was valley controlled and sub-parallel to the strike of VMS mineralization as well as a 1-2 m wide pyrite-chalcopyrite stringer zone that occurs 150 m north of the VMS. The highest Zn response occurs over the Lara VMS; however, Cr, Ni, Co and Sc content and magnetic susceptibility indicate this is due to elevated gabbroic content in the till matrix. A response of Zn, Cu, Cd, Mo, Se, Hg, and Te occur over the pyrite zone. Sequential extraction indicate that geochemical responses are attributed to a clastic source. Zinc, copper, and cadmium in tree bark is most concentrated over alluvium. Geochemical responses in B horizon soil above the VMS and pyrite zone is interpreted to be caused clastic dispersion of mineralization and mafic host-rocks by glacial transport with negligible input by biochemical cycling. The results demonstrate that landscape mapping is critical for efficient and accurate interpretation of geochemical responses in recently glaciated covered terrain.

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2022 - Detecting the Teena zinc-lead shale hosted massive sulfide deposit: Surficial geochemistry in a mineral system context.

Iain James Dalrymple - *Teck Resources Limited*

The Teena zinc-lead deposit is the most significant zinc discovery for 25 years in the world-class Carpentaria Zinc province of northeast Australia, located 8 km west of Glencore's McArthur River Zn-Pb Mine. Stratiform and stratabound mineralization is developed within the same stratigraphic host sequence as McArthur River, over a 1.5 km strike extent, at depths of 600?–1000 m, yielding a current Inferred Resource of 58 Mt @11.1% Zn and 1.6% Pb, estimated in compliance to the JORC Code (Rox Resources, 2016). The mineralisation at Teena is one of several mineralised systems in the tenement package.

The highest grade stratiform mineralisation is developed in two lenses within the HYC Pyritic Shale Member, separated by a barren siliciclastic shale horizon. Overlying the HYC shale is the Barney Creek Formation, which forms a pyritic halo to the mineralisation and comes to within 250m of surface. Overlying this are the barren Reward Dolomite and Caranbarini Formation. Conventional surficial geochemical surveys define clear anomalism in both economic and associated elements overlying Teena, despite the barren stratigraphic units above the system. However, the anomaly at Teena is one of several anomalies identified in tenement-wide geochemical exploration.

This paper examines at the apparent relationships between the surficial geochemical response observed immediately above mineralisation at Teena and the mineralised system itself, to define the source of anomalism. The character of the anomalous response is examined in the context of the regolith development, the trace element characteristics of the stratigraphic horizon exposed at surface and the mineralization halo, in order to define a fingerprint for sub-basins permissive for sediment hosted massive sulfide mineralization. When rigorous geochemical anomaly definition linked to system formation is combined with regolith and stratigraphic context, false positives can be reduced, allowing for the robust targeting of responses related to covered sediment-hosted massive sulfide mineralisation.

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1096 - Testing ultrafine soils to improve near surface exploration through cover

Ryan Noble

Much of Australia's remaining mineral wealth is masked by a thick transported cover that poses a major challenge for future mineral exploration. Laboratory and field tests have shown target metal migration through cover is fine, transient and adsorbed to soil surfaces. To explore through this cover the fine soil fractions (<2 µm) host much of the adsorption sites and have the potential to show a better signature of buried ore. The problem is that the fine fraction is difficult to separate, the benefits have not been well tested and demonstrated and there are limited commercial providers, and so even though exploration companies have expressed interest in improving their geochemical exploration techniques, they are almost forced to follow routine methods. A robust experimental and field assessment of ultrafine (<2 µm) soil fractions was conducted. Tests included size fractions down to 200 nm, physical extraction methods, chemical assay methods and sample sizes among others, from more than 20 key mineral deposits in Western Australia. From these tests, a new ultrafine fraction workflow was established that includes separation of <2 µm soil fraction, along with particle size distribution, spectral mineralogy and other physico-chemical parameters. This presentation will show the findings of the test work as well as highlights of the orientation and regional geochemical surveys that were analysed with the resulting ultrafine fraction workflow to produce superior results. Key advantages of the technique are the small sample size, no nugget effects or below detection results for Au. Base metals are also effectively measured. The regional map shows how previously collected samples could be re-assayed to provide an easy and relatively inexpensive method to generate new targets through cover that were previously all below detection for Au; a valuable exercise when the economic climate is highly conservative.

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1348 - Use of cover sequence geochemistry from regional and mineralisation-associated datasets to understand element transport mechanisms: Case study of the Eromanga Basin (Australia)

Eline Baudet - *FII/UniSA*
Caroline Tiddy - *Future industries institute (FII)*
David Giles - *Future industries institute (FII)*
Steve Hill - *Geological Survey of South Australia*

Discovering new deposits to meet world metal demand is becoming increasingly difficult as surficial mineral deposits have mostly been discovered and exhausted. Exploration has now moved into buried terranes. Therefore, we need to develop new technologies and protocols that will decrease the costs and increase the efficiency of exploration for mineralisation that is overlain by extensive cover sequences. A limitation is our understanding of the processes responsible for variable geochemical and mineralogical signatures within cover sequences and their relationship to any underlying mineralisation.

The aim of this project is to further understand these processes through regional investigation of the Eromanga Basin (Australia) to define geochemical background and compare it with the geochemical signature of this basin above a known deposit. The Bulldog Shale and the immediately underlying Cadna-owie Formation have contrasting protolith mineralogy and chemistry and form a ~100 m thick package above the Prominent Hill iron oxide-copper-gold (IOCG) deposit.

These formations preserve elevated concentrations of identified IOCG pathfinder elements (e.g. Cu, Zn, Ce, La, Ba, Mo, W). The spatial distribution of elevated trace element concentrations in both the Bulldog Shale and Cadna-owie Formation highlight known zones of mineralisation. However, surface weathering of the Bulldog Shale appears to have been of significant influence impacting the mineralogy and inducing the redistribution of trace elements in two very distinct zones within the formation. No clear relationship with major elements that would suggest a particular mineral host have been found. Conversely, trace elements are associated with Al (micas and clay minerals) in the Cadna-owie Formation. We will show that the interplay of weathering versus element migration processes involved in the development of elevated geochemical signatures within the sedimentary cover impacts on the viability of using cover sequence materials as sample media in mineral exploration.

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1395 - Exploration geochemistry: comparison between classic trace elements geochemistry, soil partial leaches, portable XRF, on soils and biogeochemistry in Western Europe Environment. Example from Li-Ta-Sn and W deposits

Jérémie Melleton - *BRGM*
Bruno Lemière - *BRGM*
Virginie Derycke - *BRGM*
Anne-Sophie Serrand - *BRGM*
Eric Fournier - *BRGM*
Eric Gloaguen - *BRGM*
Frédéric Lacquement - *BRGM*
Pascal Auger - *BRGM*
Maarit Middleton - *GTK*
Vesa Nykänen - *GTK*

In Europe, exploration geochemistry is mainly restricted to classical soils geochemical analyses based on total or near total digestion of samples, despite the good results obtained in other areas with approaches related to selective and partial leaches, in particular to reveal anomalies linked to deeply buried deposits. Similarly, examples of biogeochemistry usage in continental Europe remain anecdotic. However, with the actual detection levels in analytical methods and the knowledge about metals accumulation reached in a large spectrum of plants, biogeochemistry has already been successfully tested in various environments and over distinct deposit types.

Within the UpDeep project (European Institute of Innovation and Technology - Raw Materials) framework which aims to develop the geochemical expertise on deep buried exploration in Europe, a comparison of some of these surface geochemical methods were performed in the vicinity of the Beauvoir rare-metals (Li-Ta-Sn-Be) granite and La Bosse stockwork (W), located in the Variscan French Massif Central.

One of the challenging questions of exploration geochemistry in Western Europe is the long-term anthropogenic contamination related to past mining activities but also agricultural and forestry activities, which can strongly affect the primary geochemical anomalies especially in soil horizons and plants. In the studied area, mining activities extended from Antiquity to the middle of the last century, and forestry has been conducted intensively.

Within the scope of testing different well documented approaches, around 160 samples of soils were collected, on which has been performed separately the following treatment: deionized water leach, sodium pyrophosphate leach, and Aqua Regia digestion on Ah horizon; and hot hydroxylamine leach, Ionic LeachTM (ALS) and Aqua Regia digestion on B horizon. Meanwhile, soil samples have also been analyzed by pXRF.

Moreover 84 samples of fern, 80 samples of bramble and 64 samples of Douglas fir were sampled in order to compare their respective geochemical signal. In this Western European context, selection of a homogenously distributed vegetation media represents a complex issue.

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1614 - Physical and chemical interfaces and indicator minerals for characterising and detecting the footprints of ore deposits in areas of deep cover

Ravi Anand - *CSIRO*
Walid Salama - *CSIRO*
Mel Lintern - *CSIRO*

Since traditional surface prospecting methods cannot meet the current demands for geochemical exploration in areas covered by thick transported cover, the cover itself presents an opportunity for exploration. We present some results to highlight this opportunity from gold and base metals deposits covered by Permian, Tertiary and Quaternary sediments in Western Australia and Botswana. The potential of cover as a sample medium depends upon whether metals were dispersed into sediments either during deposition or post-depositional weathering and diagenesis. There are two types of interfaces that may indicate mineralization. Physical interface sampling is based on the possibility of dispersion at or close to the unconformity by (i) mechanical dispersion of remnants of ferruginous duricrust, mineral grains and gossan fragments and (ii) hydromorphic dispersion after deposition of the cover by groundwater percolating through the coarse, basal sediments, along the unconformity itself and/or the upper residual material. These mechanisms result in lateral dispersion haloes at the base of cover in which there is no evidence of upward dispersion into soil. It is this sampling medium that may provide the under-cover prospecting tool similar to surface exploration that makes use of ferruginous gravel, lag, heavy minerals or stream sediment sampling. However, understanding of palaeotopography is essential for the interpretation of geochemical data. Chemical interface sampling is based on hydromorphic dispersion in post-depositional weathering products such as iron and Mn oxide minerals formed in sediments. In places, geochemical signature of mineralization may be present, even up to ore grades of Au. Our research has shown that detailed analysis down to the single mineralogical or textural level within cover materials can provide important signals of metal dispersion not necessarily realised at the larger scale

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1763 - Reduced chimneys: new perspectives on their formation and relevance to mineral exploration

Stewart Hamilton - *Ontario Geological Survey*
Konstantin von Gunten - *University of Alberta*

Reduced chimneys occur over buried geological features capable of oxidative weathering, including mineral deposits. By definition, they are anomalies in electrochemical potential in Earth materials and many have coincident electrical fields which have been attributed to electrical polarization of large electronic conductors in the subsurface (e.g. graphite or massive sulphide bodies). Charge separation results from spontaneous electron movement from deep reducing agents, along the conductor, to shallow oxidizing agents, thereby creating the electrical field, i.e. self-potential (SP). Return current in the form of ion movement in the groundwater electrolyte is theorized to be responsible for 'halo'-type geochemical responses in surface soils around the conductor. However, the Ontario Geological Survey (OGS) has documented cases where reduced chimneys and associated electrical fields exist (e.g. 'forest-rings'), yet with no buried conductor. Also, porphyry sulphide systems produce similar phenomena in the absence of continuous sulphide grain-to-grain interconnection.

In 2008, the OGS presented a model that better explains SP and soil-geochemical halos in the absence of large conductors and involves redox-induced spontaneous polarization of innumerable microscopic conductors. In a redox gradient, tiny conductors (sulphide grains, for example) would develop dipoles with electrical fields that are additive, lengthwise in series and widthwise in parallel, with negative polarity toward the oxidizing end of the redox gradient. The nature of the conductors was speculative in 2008 but it now appears that electrical bacteria may be the 'polarizing substance' within the redox gradient. Geobacter sulfurreducens is one of a number of organisms that can polarize during extracellular transfer of electrons to mineralogical oxidizing agents. The direction of polarity would be predetermined by the redox gradient and commonality confers a benefit on organisms by reducing energy loss related to rotational interference and by creating a macroscopic electrical field with a continuous flux of nutrients in the form of ions.

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2415 - Hunting for REE minerals in northern Labrador: MLA-SEM analysis of surficial sediments down-ice from the Strange Lake deposit

Derek Wilton - *Department of Earth Sciences, Memorial University*
Mikayla Miller - *Memorial University*

The Main-Zone deposit at Strange Lake is exposed in a single trench and delineated by over 240 drill holes. A variety of Rare Earth Element (REE) minerals have been identified in the 6 km in diameter granite plug that contains the Main Zone. As such the granite and its constituent REE minerals constitute a point source for a narrow glacial ice stream that extends to the northeast. Previous work has identified down-ice till geochemical anomalies up to 40 km down ice from the granite plug.

We collected a total of 67 surficial sediment samples along a grid that extends up to 30 km northeast from the Main Zone varying in width from 4 to 2 km. Five esker samples originating from near the Main Zone were also collected. 125-180 µm in diameter separates from each sample, weighing about 0.3 g each), were mounted in epoxy pucks, polished and analysed by SEM-MLA (Scanning Electron Microscope – Mineral Liberation Analyser).

A variety of REE minerals with significant concentrations were identified in the samples including allanite, galgenbergite, gittinsite, monzonite, and thorite. Gittensite appears to be fairly robust and thus has been used to monitor REE distribution in the samples. In both the till and esker samples, gittinsite contents (in terms of µm2 area in sample) are highest towards the eastern edge of the grid and lower closer to the trench. A possible explanation for this pattern of dispersal is that the sediment was transported by glacial waters away from the deposit and dumped at a distance where the water energy slowed.

The next phase of this project will evaluate whether the dispersed REE minerals in the surficial sediment samples can also be detected using satellite-based Remote Predictive Mapping (RPM) techniques.

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1227 - Upscaling deep buried geochemical exploration techniques into European business – UpDeep

Maarit S. Middleton - *Geological Survey of Finland*
Vesa Nykänen - *Geological Survey of Finland, GTK*
Jeremie Melleton - *French Geological Survey, BRGM*
Bruno Lemiere - *French Geological Survey, BRGM*
Pertti Sarala - *Geological Survey of Finland, GTK*
Peter Filzmoser - *Vienna University of Technology, VUT*
Paula Järvinen - *Technical Research Centre of Finland Ltd., VTT*
Maria Rinkkala - *Spinverse Innovation Management Ltd.*
Jens Rönnqvist - *Ab Scandinavian GeoPool Oy*
Simon Thaarup - *Geological Survey of Denmark and Greenland, GEUS*

The UpDeep project aims at developing geochemical expertise on deep buried exploration methodology and anchoring the knowledge accrued as a local surface geochemical business into Europe. Soil partial leaches and biogeochemistry have solid status in grass roots exploration in other continents, but have as yet gained only minor ground in Europe. Anthropogenic impacts and lack of continuous research are identified as the main factors contributing to their low acceptance. The driving-forces for these extremely low environmental impact sampling techniques are increased public environmental awareness and prolonged processes to gain land access permits. UpDeep focuses on scientific evidencing of soil partial leaches and biogeochemistry in mineral exploration as a collaboration of the research institutions GTK, BRGM, GEUS, VUT and VTT, and a geo-consulting company GeoPool to promote the use of surface geochemistry across Europe. UpDeep has utilized existing soil partial leach and biogeochemical data from Finland, and will acquire new datasets over known mineralizations in France and Greenland. The business feasibility and market study will be conducted by Spinverse.

We tackle several technical aspects of surface geochemistry including efficient sampling protocols and sample media selection, production of a surface geochemical standard reference material bank, and compositional data analysis. A web based data analysis and delivery platform will be constructed to facilitate quick delivery of results and continuous interaction in data interpretation between the geochemical consultant and an exploration company. An educational component on producing learning materials and proving classes for the exploration industry should increase awareness and understanding of the suitability of surface geochemical sampling media in different environments. The general business model will be modular to suit the needs of customers with backgrounds in surface geochemical exploration. UpDeep is a three year project (2017-2020, http://projects.gtk.fi/updeep/) funded by the European Information and Technology Raw Materials.

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1495 - A plan for resourcing future exploration

Adele Seymon - *AMIRA International*
Robbie Rowe - *NextGen Geological*
Joe Cucuzza - *AMIRA International*

It is common knowledge that the exploration search space has changed drastically from where the major historical metal discoveries were made. The exploration methodologies and toolkit of the past 60 years are not going to be sufficient to open up the new frontier of deep cover. Enhancing exploration success in this new search space requires key stakeholders of the exploration community to collaborate to address the challenges that come with exploring in areas of cover.

Although this is a global challenge, it has been recently considered in the context of Australia through AMIRA International's Roadmap for Exploration Under Cover. This Roadmap extended UNCOVER's efforts in this area; creating a mechanism that enhanced the collaboration between industry, academic and research organisations, government geological survey organisations, and other important stakeholders.

We present the key elements of the Roadmap. The challenges associated with exploration undercover were examined in depth and led to a programme of work that addresses research, technology development and new data acquisition that, collectively, are necessary to make a difference to our chance of discovery in areas of cover.

Three focus areas were prioritised based on their potential impact in the short term. These include understanding type, ages and depths of cover; characterising and mapping major mineral system footprints; and improving understanding of mineral systems across scales for different deposit types and commodities. The knowledge gained from these integrated studies will be a necessary condition to ensure discovery success.

The Roadmap proposed a plan on how this could be achieved. It describes a possible structure, the co-funding, skills and human resources required, and key activities in a single 15-year integrated programme. The proposed plan, if successfully implemented, could see new knowledge, technologies and data start being delivered within two years from commencement of the programme.

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1676 - Geochemical challenges and discoveries of exploration undercover in China

Xueqiu Wang - *Key Laboratory of Geochemical Exploration, Institute of Geophysical and Geochemical Exploration, Chinese Academy of Geological S*
Bimin Zhang - *Key Laboratory of Geochemical Exploration, IGGE*
Deping Yang - *Shandong Academy of Gological Science*
Ruihong Li - *Key Laboratory of Geochemical Exploration, IGGE*
Mi Tian - *Key Laboratory of Geochemical Exploration, IGGE*

In China, most of mineral deposits had been discovered by naked eyes in the outcropping areas before 1980s. However, the diverse regolith-covered terrains provide an additional geochemical challenge for mineral exploration in China. In recent years, nation-wide mineral exploration activities are now concentrating on concealed deposits in covered terrains. Exploration geochemistry has played and is playing more and more important roles in the new mineral discoveries in covered terrains after 1980s. A total of 2570 new ore deposits at the delineation targets by geochemistry were discovered from 1981-2015. Particularly 999 gold ores with approximately 4000 tons of gold reserve discovered by geochemistry, taking up 80% of the newly discovered gold ores, has made China become the first gold producer in the world. In 2016, a deepest gold ore body at a depth of over 2000 m was discovered by deep-penetrating geochemistry combining geological interpretation in totally covered region in Shandong province, eastern China. Penetrating geochemistry provides cost-effective mineral exploration methods for delineation of regional and local targets in cover terrains, because geochemistry using surface sampling and laboratory technology can recognize weak signals from blind mineral deposits, which cannot be seen by human naked eyes.

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1131 - Drift prospecting in glaciated, thick overburden regions: A case study in the Ring of Fire area of Hudson Bay lowlands, Ontario, Canada

Cunhai Gao - *Ontario Geological Survey*
Dave Crabtree - *Ontario Geological Survey*
John Menzies - *Department of Earth Sciences, Brock University*
Sandra Clarke - *Ontario Geological Survey*

Despite their location near the geographic center of the Pleistocene Laurentide Ice Sheet, the Hudson Bay Lowlands contain up to 100 m of till, subtill nonglacial and Holocene marine clay and peat deposits. In Ontario, significant chromite and nickel-copper- platinum group metals (PGE) deposits have been found in recent years in the McFaulds Lake area known as the Ring of Fire area along the western margin of the lowlands. In addition to the area proximal to the known chromite deposits, e.g., Black Thor, Big Daddy and Blackbird, significantly anomalous amounts of detrital chromite grains were also recovered in both till and stream sediments about 40 km to the south along the upper Attawapiskat River. Multiple calcareous silty tills occur along this river. Stratigraphical studies indicate that the anomalous detrital chromite grains are derived from the middle till of Late Wisconsinan. A small chromitite rock fragment or boulder was also recovered from the lower till correlated to the Early Wisconsinan. These 2 tills have ice flow directions toward the southwest. The anomalous chromite grains and the chromitite boulder are thus derived probably from an unknown source(s) to the northeast rather than the known chromite deposits located to the north. In contrast, the upper till known as the Winisk Till, which was deposited during the early Holocene Winisk ice streaming, has an ice flow direction to the south-southeast. Although responsible for the anomalous detrital chromite grains near the known chromite deposits, this till contains few chromite grains on the Attawapiskat River. As such, the current data available indicate good potential for finding additional chromite deposits in this area.

Minerals
MIN30: Mineral Exploration in Extreme Environments (AAG: 28th IAGS)

Paper ID

Paper Title

1342

Structural Mapping Through the Atacama Gravels Using Geomorphology: Implications for Exploration Under Cover (./pdfs/rfg1342.pdf)
Alexandra Brown, Peter Winterburn

1930

Solute sources and sinks in Atacama aquifers: implications for hydrogeochemical mineral exploration (./pdfs/rfg1930.pdf)
James Kidder, Matthew Leybourne, Daniel Layton-Matthews, Clinton Rissmann

2181

Collecting the Extreme Surface Soil layer by helicopter: An Efficient, Effective and Rapid Geochemical Method for Arid and Semi-Arid Terrain (./pdfs/rfg2181.pdf)
John Barr

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Duggan Lake regional drainage sediment and water geochemical survey, Barren Grounds, mainland Nunavut. (./pdfs/rfg1209.pdf)
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Mineral solubility modelling applied to interpreting stream and spring water chemistry in a mountainous region of British Columbia, Canada (./pdfs/rfg1428.pdf)
Ray Lett

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Snow geochemistry – a new environment friendly exploration method in the northern areas (./pdfs/rfg1086.pdf)
Pertti Sarala, Anne Taivalkoski

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1342 - Structural Mapping Through the Atacama Gravels Using Geomorphology: Implications for Exploration Under Cover

Alexandra E. Brown - *Mineral Deposit Research Unit, UBC*
Peter Winterburn - *MDRU UBC*

Development of new strategies and practical methodologies to detect and target copper porphyry deposits buried under transported cover is key to future discoveries. Past surface geochemical grid-style sampling of transported gravels in the Atacama Desert has proven ineffective because it does not consider metal transport, signal preservation or hydrogeochemistry in alkaline environments. We present a targeted geochemical sampling strategy for the discovery of buried deposits based on work performed at the buried Atlántida Cu-Au-(Mo) porphyry deposit, Atacama Region, Chile. Copper porphyry pathfinder metals such as Cu, Mo, Re, As, Se and Te, can be leached into groundwater from buried deposits. Using predictive chemistry of the fractionation of elements with changing Eh and pH conditions with increasing distance from the deposit, metals leached from deposits into groundwater can be used as geochemical vectors towards buried mineralization. Groundwater enriched in pathfinder metals can be transported to the surface by seismic pumping along structures. This forms distinct metal-rich anomalies on the alluvial surface. Identification of bedrock structures continuing through gravel cover is therefore fundamental to the application of an effective sampling strategy. Remote sensing at Atlántida indicated distinct geomorphological features on the alluvial surface produced by active structures. Mapping of these structures allowed for a targeted sampling campaign, applicable at a regional, district and target scale, with the placement of widely spaced (ex. 250m) sample lines on older alluvial fans along structural extent with closed spaced samples (50m) perpendicular to the structural trend. Gravel surfaces with a time accumulated response were sampled and analysed using a relatively weak geochemical digest coupled with ICP-MS. This strategy applies the understanding of metal transport and preservation in the Atacama Desert environment. By contrast, geochemical programs following a fixed grid pattern leaves sampling on structures to chance.

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1930 - Solute sources and sinks in Atacama aquifers: implications for hydrogeochemical mineral exploration

James Andrew Kidder - *Queens University*
Matthew Leybourne - *Queens University*
Daniel Layton-Matthews - *Queens University*
Clinton Rissmann - *Canterbury University*

An abundance of world-class copper deposits in the Atacama region of northern Chile, have made the country the world's leading copper producer. However, despite extensive exploration activities the region remains a conundrum, with mature outcropping exploration plays juxtaposed to largely unexplored, extensive areas of post-mineral cover. This total cover (100%) scenario thus creates an exploration opportunity in a belt of world-class fertility, which is hindered by the ineffectiveness of traditional geochemical techniques in covered settings and the commonly-uneconomical costs associated with grid drilling greenfield exploration plays.

Porphyry deposits of the Atacama region have served as a test bed for the use and effectiveness of hydrogeochemistry and isotopic vectoring in base metal exploration, with early work by Aravena et al. (1999) and Puyeo et al. (2001) followed by a comprehensive set of mineral exploration case studies, including: Cameron et al, (2002, 2005a, 2005b); Leybourne et al. (2006, 2007); Reich et al. (2008, 2009); Leybourne and Cameron (2008); Jorquera et al., (2014); and Rissmann et al. (2015, in press). To date datasets have been collected from porphyry, epithermal and strata-bound Chilean deposits.

Despite these studies, hydrogeochemistry remains an underutilised tool by many explorers, presumably due to a perception that data interpretation is intricate and complicated. This paper serves as a compilation of historical and current case studies and is intended as an overview of the most likely solute sources and sinks in the hyper-arid Atacama Desert as well as the resulting potential hydrogeochemical signatures that can be expected and interpretations that can be drawn from such signatures. The purposes of this presentation are to provide a single source guide to interpreting hydrogeochemical exploration datasets in the Atacama region.

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2181 - Collecting the Extreme Surface Soil layer by helicopter: An Efficient, Effective and Rapid Geochemical Method for Arid and Semi-Arid Terrain

John C Barr - *Anglo American*

The extreme surface soil micro-layer, such as can be collected by a “vacuum cleaner” has been demonstrated to be a very effective, efficient and rapid geochemical tool in arid and semi-arid terrain. This interface between soil and air represents the biggest Eh change in the whole soil column. Any element flux from depth, by any of the proposed mechanisms, could logically by represented at this interface and should have some unique geochemical properties. Following a number of tests in the 1980’s, production surveys were undertaken aimed at collecting this extreme surface micro layer using a devise under a helicopter. Samples were collected on a series of continuous strips.

The particles so collected were vacuum-impacted onto tape consisting of a flexible Mylar adhesive bottom layer, a thicker middle layer with perforations to retain the samples, and a Teflon cover tape. The tape was sent to the laboratory for laser ablation – inductively coupled plasmas emission spectroscopy (LA-ICP-ES) analysis for up to 34 element. Sampling rate was approximately 400 samples/hour and depending on the speed of the helicopter this translated into a sample interval of 20 to 100m. A unique feature of this system is that samples are collected continuously representing a “channel sample” so line spacing can be significantly wider than for conventional samples on a grid. Examples are presented from a survey in Namibia where the flight speed was 40 – 80 km/h, flight lines were 200m apart and approximately 5 samples/line km were collected. Approximately 2,500 km2 was covered and 5,800 samples collected. Follow-up of anomalies by conventional soil sampling and drilling are described.

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1209 - Duggan Lake regional drainage sediment and water geochemical survey, Barren Grounds, mainland Nunavut.

Wayne Jackaman

Conducting large, reconnaissance scale drainage sediment and water geochemical surveys in remote northern environments is challenging and has required modifications to traditional sampling strategies incorporated by other government funded surveys being conducted in more accessible regions where conditions are less extreme. Generally, these programs have maintained survey designs that are based on a one site per 13 km2 sample site density coverage. Field work often relies on helicopter support which consumes over 50% of a survey budget and this can be a major limiting factor when seeking funding approval for projects especially in remote locations where helicopter and fixed wing costs can be significantly higher.

To offset these budget constraints, new geochemical survey strategies have been developed suitable for mineral potential evaluation of the large and remote regions that remain unexplored in northern mainland Canada. The method incorporates the collection of indicator minerals in addition to stream sediments and waters. The ability of this method to effectively assess the geochemistry of larger drainage areas using heavy mineral samples significantly reduces overall sample site density requirements and subsequently, helicopter usage and project costs.

This presentation will highlight the successfully completion of a regional stream sediment, heavy mineral and water geochemical survey conducted southeast of Bathurst Inlet, in the central part of the Kitikmeot administrative region of Nunavut in 2012. A total of 260 samples, collected from 244 sites, provided multi-element analytical and mineralogical data for an extremely remote 14000 km2 survey area. The project was funded by the Geo-mapping for Energy and Minerals (GEM) Program at Natural Resources Canada (NRCan).

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1428 - Mineral solubility modelling applied to interpreting stream and spring water chemistry in a mountainous region of British Columbia, Canada

Ray E. Lett

In the Gataga District, a mountainous, rugged region of Northeastern British Columbia, Canada are several, sub-economic, sediment hosted exhalative lead-zinc-silver massive sulphide deposits with associated barite. Oxidation of the base-metal sulphides and pyritic shale host rocks generates acid ground water which, emerging as springs at the surface, forms impressively large gossans and other secondary mineral precipitates. A water sampling program in the Gataga District revealed two classes of spring water. Neutral to weakly alkaline spring water was found to be associated with gossans and with elevated sulphate, zinc, calcium, magnesium, nickel and cobalt. By contrast, the spring water associated with exhalative lead-zinc-silver sulphide mineralization was acid and often contained high barium, aluminum, lead and thallium concentrations.

PHREEQC thermodynamic modelling applied to the spring and associated stream water data predicted that many secondary minerals such as gibbsite, zinc hydroxide, lead hydroxide and iron hydroxide would be oversaturated with respect to the water chemistry and, hence, would be expected to precipitate around the springs and in stream channels. In fact, many streams have a copious white precipitiate that is mainly aluminium hydroxide. Although there are often high barium and sulphate levels in water, PHREEQC modelling predicts the barite is undersaturated are would remain in solution. Differences in the PHREEQC predicted secondary mineral assemblage for different springs and streams likely reflect absorption processes that capturing elements from the water into the sediment. PHREEQC modelling is valuable for predicting the partitioning of elements into aqueous and solid phases and the extent of trace element dispersion in mountainous drainages.

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1086 - Snow geochemistry – a new environment friendly exploration method in the northern areas

Pertti Sarala - *Geological Survey of Finland/Oulu Mining School*
Anne Taivalkoski - *Geological Survey of Finland*

Snow covers the landscape several months each year in the Northern Hemisphere and other cold areas. It increases the interest to use snow as a sampling media for mineral exploration. For example, in southern Fennoscandia the snow cover exists one to three months, but in the northern parts up to seven months. Snowing periods and the snow properties are constant in a regional scale, which gives a good foundation for large and comparable geochemical exploration. Snow sampling is easy and quick, and it does not cause any environmental impacts.

Although snow is composed of water coming from atmosphere, it includes both local and long-distance components like dust, metal ions, hydrocarbons and even mineral particles. The lowest part of snow cover gives the most stable sampling media because of the longest deposition history and the coverage of the upper snow layers. In addition, the lowest layer is in contact with the ground and is influenced by the gases and heat coming from the underlying soil and bedrock.

Soil gasses, originating in the bedrock and travelling through the sediment cover, accumulate into top soil and the bottom layer of snow. There are two ways to study a geochemical signal of snow: hydrocarbons and metal ions. The first ones can be determined using the Soil Gas Hydrocarbon (SGH) method, which is based on the classification of about 160 hydrocarbons into indicative groups for certain mineralization types. The second way is a direct analysis of the element concentrations in snow using high resolution ICP-MS. Certain gasses transport elements with them and these elements give a signature of the underlying buried mineralizations. Those are possible to detect with modern analytical methods (ppt levels of concentration). There are several examples of good signature of the snow geochemistry in relation with various mineralization types in Finland.

Minerals
MIN48: Hydrocarbons in the Exploration for Metaliferous and Non-Metaliferous Deposits (AAG: 28th IAGS)

Paper ID

Paper Title

2189

KEYNOTE: Hydrocarbons, Bugs and Chemistry, Linking Processes (./pdfs/rfg2189.pdf)
Peter Winterburn, Erika Cayer, Rachel Simister, Sean Crowe, Bianca Phillips

2260

KEYNOTE: Hydrocarbon and metal anomalies over petroleum and metal deposits (./pdfs/rfg2260.pdf)
David Seneshen

2462

Imaging buried kimberlite and sulfide bodies in northwestern Quebec using hydrocarbons and soil geochemistry (./pdfs/rfg2462.pdf)
Jamil Sader

2159

Subtle geochemical signatures – frontiers in partial extraction and passive soil gas analyses (./pdfs/rfg2159.pdf)
Ryan Noble, David Seneshen, Ravi Anand, Melvyn Lintern, Brian Townley, Tenten Pinchand

1346

Organic geochemistry: a pathfinder in copper porphyry exploration (./pdfs/rfg1346.pdf)
Pearce Luck, Rachel Chouinard, Shane Rich, Peter Winterburn

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2189 - KEYNOTE: Hydrocarbons, Bugs and Chemistry, Linking Processes

Winterburn Alan Peter - *MDRU-University of British Columbia*
Erika Cayer - *MDRU-UBC*
Rachel Simister - *Life Sciences - UBC*
Sean Crowe - *EOAS - UBC*
Bianca Phillips - *MDRU-UBC*

Geochemistry of fine fraction till from over the concealed DO-18 kimberlite, Northwest Territories, shows a clear geochemical response in Mg, Ni, Cr and Nb at low level concentrations. A distinct group of hydrocarbons, in particular the light alkanes and light benzenes show anomalous responses which are highly correlated with the kimberlite indicator trace element concentrations. Genomic sequencing of the samples has established distinct microbial populations within the same sample suite linking trace element chemistry, hydrocarbon chemistry and microbial action together.

This paper will discuss the causative links between the 3 components.

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2260 - KEYNOTE: Hydrocarbon and metal anomalies over petroleum and metal deposits

David Seneshen

Geochemical Insight has collected various sample media (e.g. soil gas, soils, vegetation or groundwater) over petroleum and metal deposits for both organic and inorganic analyses. This talk will present the findings of geochemical surveys where various sample media were analyzed for hydrocarbons in the C1 to C24 range and major and trace elements. Where possible, it is important to use forensic geochemical tools (e.g. hydrocarbon ratios, carbon and deuterium isotopes, major and trace element composition of surface soils, vegetation, and groundwater) to link surface anomalies with underlying petroleum and metal deposits.

Linking surface anomalies with underlying deposits can be challenging, but it is important to the outcome of any exploration program. Case studies from geochemical exploration surveys conducted in the Williston Basin (Roncott oil field), Michigan Basin (Albion-Scipio oil field), Green River Basin (Jonah tight gas field), Great Basin (Grant Canyon oil field) and the Entrada Sandstone hosted Harley Dome helium field in eastern Utah. The Michigan Basin geochemical survey in combination with a 3D seismic survey helped with the discovery of additional oil reserves. Oil seeps over the field were compositionally identical to produced oil from the 4,000-foot deep Trenton dolomite reservoir. Geochemical surveys conducted in the Williston and Green River Basins demonstrated their effectiveness for defining potential “sweet spots” (structural traps and overpressure) in the Bakken shale and Lance sandstone reservoirs, respectively. Trace element anomalies (e.g. lithium) in soils over the Grant Canyon Oil Field were directly linked with leaking oil-field sodium bicarbonate waters.

The results of a geochemical orientation survey over the Lance uranium deposit in southeast Wyoming will also be presented. In this case, ethane, helium and radon concentrations are anomalous over the surface projection of mineralization. The light hydrocarbon seepage may be the reductant for pitchblende precipitation in the roll-front mineralization.

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2462 - Imaging buried kimberlite and sulfide bodies in northwestern Quebec using hydrocarbons and soil geochemistry

Jamil Sader - *Bureau Veritas Minerals*

AGI Sorbers samplers (known as Gore sorbers at the time of this study) were installed along transects at the Honerat Kimbelite and a small Pb-Zn sulphide showing, both in the Temiskaming region of the province of Quebec, Canada. The purpose of these samplers is to adsorb volatile compounds (light sulphur species to organics with 20 carbon atoms) that are known to form during oxidation of a mineral deposit, its contact zone, or an associated redox systems operating in the shallow subsurface. Surface media samples were also collected at each AGI Sorber location for determination of trace element geochemistry. The samplers that were installed over the kimberlite have a depleted signature for C3 to C7 compounds. This negative anomaly is also observed for individual compounds such as 2-methyl butane. Likewise, kimberlite pathfinder elements including Ni, Co, K and REEs in C-horizon soils (the horizon samplers where installed in) are also depleted over the kimberlite. It is unclear if the concomitant negative hydrocarbon and geochemical anomalies are related to the same geochemical processes or whether the processes are independent of each other. However, it is important to note that soils with the negative anomalies are significantly more reduced compared with those outside the footprint (ORP values up to 100 mV lower). Comparatively, there is a positive anomaly for the C3 to C7 hydrocarbons and dimethyldysulfide over the buried sulphide showing, but a negative anomaly for the C12 to C20 hydrocarbons. These anomalies are closely associated with elevated concentrations of sulphide pathfinder elements including Zn, Pb, Cu, Fe, and S in peat soils. The results of the hydrocarbon surveys at both the Honerat Kimberlite and the sulphide showing, and their close association with more traditional soil geochemistry suggests that hydrocarbon and sulphur species can delineate buried ore deposits, but specific signatures can vary.

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2159 - Subtle geochemical signatures – frontiers in partial extraction and passive soil gas analyses

Ryan Noble - *CSIRO*
David Seneshen - *Consultant*
Ravi Anand - *CSIRO*
Melvyn Lintern - *CSIRO*
Brian Townley - *University of Chile*
Tenten Pinchand - *CSIRO*

Traditional, near surface geochemical techniques have been effective in mineral discovery, but to explore through deeper transported cover (>10m), improved methods are required. As mineral exploration transitions into deeper covered terrains, geochemical signatures of buried mineralisation are diluted and the ability to successfully discern subtle geochemical signatures is essential. Water partial extractions of soil samples and passive soil gas were tested at a number of sites for the ability to recognise mineralisation through cover. The sites included are the Jaguar and Bentley base metal VMS deposits and the North Miitel Ni deposit in Western Australia as well as the Inca de Oro Cu deposit in Chile. A series of laboratory experiments (ore weathering cells) and field tests (pits and orientation traverses) were conducted with varying analytical methods to confirm the field observations with respect to soil hydrocarbon and gaseous element migration through overburden. At the “geochemically-blind” North Miitel deposit, we compared soil-gas hydrocarbons and water extracted elements from soil (10-20 cm depth) with both proving successful. The water-extractable concentrations of Ni, Co, Mo, Sb, and Sn identified mineralisation (Minimum Hypergeometric Probability or MHP <1%, type II error). The hydrocarbons, 2-methylbutane, pentane and 1-pentene were also successful (MHP <1%) using the Amplified Geochemical Imaging (AGI) passive soil-gas collectors. Of the techniques used, the water extraction and the passive soil-gas data were superior to the stronger partial extractions using hydroxylamine hydrochloride and aqua regia that did not identify the mineralised zone (MHP>>1%). The other site and laboratory experiments show varying success regarding gaseous migration of metals. Integrating an understanding of migration mechanisms with the evolution of target and pathfinder compounds related to deposit types will improve future exploration. Extending into much deeper cover (>20 m), the viability of passive soil-gas methods may become more relevant and warrant further study for mineral exploration.

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1346 - Organic geochemistry: a pathfinder in copper porphyry exploration

Pearce Michael Luck - *MDRU*
Rachel Chouinard - *MDRU*
Shane Rich - *MDRU*
Peter Winterburn - *MDRU*

Discovering new deposits in covered terrain poses a significant challenge for modern geologists. Traditionally, commodity and pathfinder elements in soils were used to corroborate geophysical evidence and improve drilling outcomes. In areas with thick till sequences, geochemical signals derived from ore or gangue minerals may be complex and dispersed by ice transport. Organic compounds are a promising and under-researched pathfinder group for non-petroleum based mineral exploration. Hydrocarbon concentrations in soil change in the presence of mineralisation and have the potential to identify targets beneath overburden.

Hydrocarbon anomalies in soil are believed to form over mineral deposits as by-products of microbial metabolism and death phase cell rupture. Microbial processes such as the oxidation of sulfide and iron and reduction of sulphate are key components of supergene weathering. Such processes produce organic compounds as by-products. These are commonly observed on mine sites as biofilms comprising microorganisms and organic extracellular polymeric substances. Redox gradients generated at the interfaces between ore, host rock, till, water and air for a variety of metalliferous and non-metalliferous deposit types are conducive to chemotrophic microbial activity and preservation of dispersed hydrocarbon signals in soils.

In this study, organic compounds in soil samples successfully identified copper porphyry occurrences though glacial till. Straight chained alkane hydrocarbon concentrations were elevated above and adjacent to mineralised subcrop. Observed hydrocarbon signals in soils are related to mineralisation, major structures and surficial geology. Integration of geological, geochemical and environmental characteristics, including macro and microbiology has improved interpretation of multi-compound organic signals. Data analysis aims to discriminate areas with elevated hydrocarbon abundances generated by barren geology or geomorphic changes from those of economic interest.

Minerals
MIN55: Analytical Technology in the Search for Minerals: Space to the Lab to the Field (AAG: 28th IAGS)

Paper ID

Paper Title

1691

KEYNOTE: 2008-2018 – The Portable XRF Decade (./pdfs/rfg1691.pdf)
Aaron Baensch

2090

Portable instruments and field services: protocols to achieve fit-for-purpose quality data (./pdfs/rfg2090.pdf)
Hugh de Souza, Alexander Seyfarth, Russ Calow, Peta Hughes

1609

Low Level Field Analysis of Gold Using PXRF (./pdfs/rfg1609.pdf)
Melvyn Lintern, Simon Bolster

1702

Application of pXRF to environmental investigations and geochemical baseline of abandoned mines (./pdfs/rfg1702.pdf)
Bruno Lemiere, Valerie Laperche

1524

Hand held Laser Induced Breakdown Spectroscopy [LIBS]: A new tool for field geochemistry and mineralogy (./pdfs/rfg1524.pdf)
Andrew Somers

2469

Soil Clay Fraction Geochemistry for Surficial Exploration: a case study from the Tethyan Belt (./pdfs/rfg2469.pdf)
Jamil Sader, Chris Benn, Nikolay Zhivkov, Tsvetana Jeleva, Roger Anderson

1347

Mineralogical reaction modelling of partial extractions in geochemical samples (./pdfs/rfg1347.pdf)
Ryan Shaw, Peter Winterburn

2083

Exploring for laterally transported copper through gravels cover using radon detectors (./pdfs/rfg2083.pdf)
Thomas Bissig, Peter Winterburn

2101

ARTPhot: Automated routine for grain counting using a digital microscope and a neural network (./pdfs/rfg2101.pdf)
Alexandre Néron, Réjean Girard, Paul Bédard

1691 - KEYNOTE: 2008-2018 – The Portable XRF Decade

Aaron Baensch - *Olympus*

The last decade (2008-2018) has seen an unprecedented acceleration in the innovation and adoption of Hand-Held and Portable X-ray Fluorescence (pXRF) analysers within the mineral exploration and mining industries. A futuristic device that was once heavily criticized, has now become an industry standard tool and continues to evolve at an increasingly rapid pace, in line with the high performance and field ruggedization expectations demanded by the modern geoscientist. This talk will aim to summarize the key advancements and achievements both in pXRF technology, as well as application development. Key highlights will include:

Technological Innovation (Hardware/Software):

- Move from active sources to tubes

- Evolution of form factor – computing power & ruggedization

- The innovation to Silicon Drift Detectors (SDD's) from Silicon Pin (Si-PIN) detectors

- New generation High Count Rate (HCR) Digital Pulse Processing (DPP) that has sped up and de-bottlenecked performance

- The continual drive towards lower LOD's and expansion of the element suite (light elements & REE's)

- The uptake and innovation in field based sample preparation equipment

- Real-time QA/QC, data management, visualisation and the move to cloud-based data delivery

Application Development & Highlights

- The change in culture and adoption of best practice guidelines (off the back of CAMIRO pXRF project…etc.)

- Key organisations, researchers and companies that are leading the pack in best practice application of pXRF (CAMIRO, DET CRC, CSIRO, MDRU, Reflex…etc.)

- Chemo-stratigraphy

- Gold pathfinders & alteration vectoring

- REE & Battery Metals

- GeoMet applications

- Key Journal Volumes, Papers & Publications

- JORC / 43-101 considerations

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2090 - Portable instruments and field services: protocols to achieve fit-for-purpose quality data

Hugh A de Souza - *SGS Minerals*
Alexander Seyfarth - *SGS Minerals USA*
Russ Calow - *SGS Minerals*
Peta Hughes - *SGS Minerals*

There has been an explosion of portable analytical tools in the past decade inspired by the development of miniaturised and rugged analytical tools on the Mars Rover and enabled by smart chips and microelectronics. Those available currently include XRF, LIBS, microXRF for elemental analysis and near infra-red (pNIR & pFTIR), XRD, and uRaman for mineralogical analysis. They offer data in real time that can speed up and improve decision making whether it be in a grass roots exploration program or at a mine site as sensors for process control. Specific combinations can be optimised for specific types of ores. For example, LIBS and pXRD are necessary for lithium ores as pXRF does not measure lithium and key lithium minerals may not be recognised by current pNIR systems.

While there is no doubt that the rise of portable instrumentation constitutes a significant innovation in analytical technology, it is clear too that proper sample preparation, instrument calibration and operational protocols are still key to getting reliable results just as they do in laboratory settings. Over the last 60 years of instrumental analysis, labs have accumulated a large repertoire of procedures for quality analysis that can be adapted for use with portable instruments. Of these, proper sample preparation may be the most difficult to achieve in the field. While hand held technologies enable in-situ analysis, variability in the sample presented can lead to significant bias in the results. Elimination of this bias can be achieved through standardised protocols in mobile sample preparation units.

Who does it is as important as how it is done and trained analysts are critical to oversee the deployment of Field Services as they have experience in controlling sophisticated analytical systems and operations in order to deliver defendable, fit-for-purpose quality data.

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1609 - Low Level Field Analysis of Gold Using PXRF

Melvyn Lintern - *CSIRO*
Simon Bolster - *PPPB*

An inability to have cost effective ppb level gold determinations completed at remote locations holds up gold discovery and leads to stop-start exploration programs. Exploration is often about a working hypothesis and setting about testing these hypothesise. Gold exploration is for some, a bit like a game of battleships. Money, personnel and equipment are directed in one area, samples collected and dispatched and the team often waits until assays are received before undertaking further work. Waiting for assays and advancing exploration comes at a considerable cost in terms of time, which translates to real financial costs to any exploration mining company or investor.

After some industry resistance and hesitation the use of Portable X-Ray Fluorescence (pXRF) by explorers and miners is now widespread particularly in base metal exploration and for determining the presence of gold pathfinder elements such as arsenic. Conventional pXRF gold determinations whilst possible, are generally at detection limits well above the range required by most explorers.

Identifying that using the pXRF for gold explorers could be a game changer for the industry, CSIRO set about inventing a way to do this. The result has been the invention of detectORE TM which provides gold determinations from a field camp within 24 hours to sub 10 ppb Au levels using conventional pXRF. This for the first time opens up the possibility to do continuous gold exploration in the remotest locations cost effectively.

The presentation will describe the test work completed to date, some initial field trials plus plans ahead to take this game changing technology out to industry globally

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1702 - Application of pXRF to environmental investigations and geochemical baseline of abandoned mines

Bruno LEMIERE - *BRGM*
Valerie LAPERCHE - *BRGM*

We developed a method based on field measurements by portable XRF to distinguish anthropogenic anomalies resulting from mining activities, and other anthropogenic anomalies, from geogenic anomalies. It is derived from the traditional exploration strategy, based on soil and stream sediment. Instead of starting from a large and weak anomaly and focusing towards a target orebody, we start from a known mine and we observe its outwards decreasing anomaly, which includes the natural geochemical anomaly and the anthropogenic impacts. This method was applied to determine the environmental legacy of abandoned metal mines in France.

Most of the differences in geochemical baselines are due to the dissimilarities in basic geology. Metals and metalloids in soils are derived from the soil parent material (lithogenic source) and from various anthropogenic sources. Transport mechanisms comprise waste erosion, airborne particles, soil creep, solifluction and surface water transport. Flood plain deposition of contaminated stream sediment and mine waste was observed and identified as one of the most extensive anomalies of anthropogenic origin.

Natural and anthropogenic anomalies can be distinguished on the basis of elemental signatures, speciation and grain size patterns. Soil anomalies need to be related with background element ranges determined for each lithofacies. Large extension anomalies are usually geogenic or related with large mines. Determination of geochemical signatures of mineralisation and of mining waste allows recognition of these signatures in soil. Anthropogenic elemental anomalies are observed in stream sediments much further away than in soils, except in flood plains.

Environmental geochemical baselines taking into account lithofacies are needed to assess the present state of the surface environment and distinguish the “natural part” from the “anthropogenic part” (mine, smelter…), to follow the extent and impact of a contamination, and to define remediation objectives.

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1524 - Hand held Laser Induced Breakdown Spectroscopy [LIBS]: A new tool for field geochemistry and mineralogy

Andrew Somers - *SciAps Inc.*

Laser Induced Breakdown Spectroscopy or LIBS is a form of atomic emission spectroscopy that can rapidly provide spectral data showing elemental peaks for a comprehensive suite of elements. This technique has been applied to geological samples in a range of settings including laboratories, mineral processing plants and even on the Mars Science Laboratory Curiosity Rover. The advent of commercially available hand-held LIBS capable of producing high resolution spectra over wide wavelength ranges has allowed in-field qualitative and quantitative analysis of geological samples. LIBS allows in-field analysis for many elements such as Li, Be, B, C, Na that are not possible using conventional techniques such as pXRF. Quantitative chemical analysis is possible using empirical calibration approaches. The LIBS spectra can also be used as a geochemical fingerprint which is quite distinctive for each sample and statistical techniques such as principal component analysis [PCA] can be used to identify differences between different spectra and partial least squares discriminant analysis [PLSDA] can be used to classify the different materials. LIBS is highly spatially resolved allowing the analysis of specific parts of a sample such as individual minerals within a geological sample. With the use of rastering samples can also be mapped and the chemistry and mineralogy of several components of a geological sample can be investigated in a single acquisition. This study includes specific examples of these capabilities using a commercially available hand-held LIBS analyser.

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2469 - Soil Clay Fraction Geochemistry for Surficial Exploration: a case study from the Tethyan Belt

Jamil Sader - *Bureau Veritas Minerals*
Chris Benn - *Consultant*
Nikolay Zhivkov - *Dundee Precious Metals*
Tsvetana Jeleva - *Dundee Precious Metals*
Roger Anderson - *Bureau Veritas Minerals*

A field and lab orientation study was undertaken in order to determine if analysis of the soil clay fraction (<2 µm) would provide a better geochemical response compared with the standard <180 µm fraction. The survey involved the collection of soil samples along one transect over zones of mineralization (hosted by Miocene sedimentary rocks) and barren zones (sediments and basement metamorphic amphibolite rocks). One split of the soil sample was sieved to <180 µm, followed by a 30 g aqua regia/ICP-MS analysis. From a second split, the clay-sized fraction (<2 µm) was retained and analyzed by the same aqua regia/ICP-MS, but only a 0.5 g sample size digested. Based on Au and Ag concentrations, both methods were successful at defining the mineralized zones. However, the <2 µm fraction has significantly better anomaly to background contrast ratios for Au and Ag (37% and 16%, respectively) compared to the < 180 µm fraction. This signal enhancement for the <2 µm fraction can be attributed to removal of dilution effects, which may exist with larger grain size fractions. The clay fraction also showed superior analytical reproducibility and consistency, especially for Au and Ag. The RSD for these elements is up to 12% lower and is likely due to the removal of Au and Ag grains that can produce nugget effects in the larger <180 µm fraction. Several other elements including Cu, and Zn demonstrate higher concentrations in the <2 µm fraction. They could be explained by an increase in the adsorption surface area per analyzed weight (i.e., smaller grainsize translates to greater surface areas), and ion adsorption onto oxide coatings on grains. In addition to better identification of geochemical targets, the clay mineralogy of the <2 µm fraction clearly defines alteration mineralogy associated with mineralization.

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1347 - Mineralogical reaction modelling of partial extractions in geochemical samples

Ryan Shaw - *MDRU - Mineral Deposit Research Unit*
Peter Winterburn - *MDRU - Mineral Deposit Research Unit*

Geochemical exploration using partial extractions, targeting specific phases in soil samples for analysis, allows for detection of nuanced signals from mineralization under exotic cover. These deposits make up a large portion of mineral resources in areas that have experienced recent glaciation, such as Canada or are buried under ancient arid gravels such as in Chile. Interpretation of extraction data is challenging due to the uncertainty of targeted phases under various extraction conditions. To better constrain the effects of these extractions, multi-staged mineralogical and chemical analysis of the samples and the processes themselves are required.

Samples collected from kimberlites in the Northwest Territories, Canada and copper-porphyry deposits from BC and the Atacama Desert, Chile present an opportunity to observe the effects of partial extraction geochemistry across multiple deposit types and exotic cover materials. Sequential extraction analysis on selected samples indicated that additional phases besides the targeted phases are being attacked. Mineralogical and chemical characterization of these anomalous samples, as well as fraction separates and mono-mineral samples have been completed using XRD, LA-ICP-MS, synchrotron XANES, and SEM methods to generate trace metal deportment models. These samples have been subjected to a variety of commercial partial extraction techniques followed by re-characterisation post extraction to determine the phases removed, new phases created and the re-distribution of the chemistry. Experimental set up during these leaches allowed for continuous pH, Eh and chemistry changes to be monitored during the extraction. The evolution of these parameters creates conditions that influence sorption and mineral precipitation within the sample. The leachate was analyzed using ICP-MS allowing for a chemical mass balance and the creation of reaction models for the extractions.

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2083 - Exploring for laterally transported copper through gravels cover using radon detectors

Thomas Bissig - *Goldcorp Inc*
Peter Winterburn - *University of British Columbia*

Copper is readily leached from acid generating sulfide ore during weathering and oxidation and can be transported laterally for up to 6-8 km until the solutions are neutralized (or reduced) enough to precipitate Cu. This lateral dispersion process can generate Cu anomalies within or below gravel units and potentially forms economically exploitable exotic Cu deposits. Detection of oxidized copper mineral species under gravel cover by traditional geochemical or geophysical means is challenging. However, since Uranium can be transported, together with Cu, in oxidized and acidic meteoric fluids, Rn gas may be used as a proxy to explore for elevated U and by inference Cu in gravels. To test this hypothesis, a total of 128 Rn testing devices were deployed for ~10 days in the soils above and adjacent to the Picarón exotic Cu prospect and at Huinquintipa exotic Cu deposit, Chile. An additional 12 devices were deployed in a control survey over barren ground. The Rn testing devices (Accustar AT-100) record alpha decay from Rn as fission tracks on cellulose film.

At both test sites Rn detectors placed above or near known exotic mineralization yielded between 3300 and 8000 Bq/m3. Devices placed away from mineralization or where exotic Cu is mined out, yielded 333 to 2250 Bq/m3, the lowest value coming from a device placed above low-grade primary mineralization upstream from Picarón. Limited analyses from exotic Cu mantos at Huinquintipa yielded 5 to 21 ppm U, roughly one order of magnitude above crustal abundance of U whereas at Picarón no appropriate material was available to directly determine the U content of gravels with elevated Cu. Selective leach geochemistry on soils taken ~35 m above Picarón mineralization failed to detect elevated Cu. Thus, Rn testing devices are a potential low-cost exploration tool for areas where traditional means fail.

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2101 - ARTPhot: Automated routine for grain counting using a digital microscope and a neural network

Alexandre Néron - *IOS Services Géoscientifiques inc.*
Réjean Girard - *IOS Services Goescientifiques inc.*
Paul Bédard - *UQAC*

Gold grain counting in tills is a well establish method for gold exploration in glaciated terrain. One of the drawbacks with this method is the bias caused by the lack of constancy induced by the visual sorting of the grains. Although automated sorting can be achieved with the use of SEM such as ARTGold®, productivity is limited. To improve efficiency, SEM scanning has been replaced by automated optical sorting based on a digital motorized microscope (in this case, a AXIO Zoom.V16 coupled with the Axiocam 506 color camera from Zeiss). A gold recognition algorithm is divided into two steps. First, gold having a characteristic spectrum in visible light, a simple subtraction of the channel from the blue channel highlights potential gold grains, though this maintains a large amount of false positives. Then, a second algorithm is needed to eliminate most false positives. The discriminator uses a deep convolutional neural network inspired by Google's Inception V.4 model, trained to recognize gold grains. The architecture of the model is built in such a way as to ensure no gold grain is misclassified, avoiding false negatives and therefore accepting a certain proportion of false positives. This way, 90% of the gold grains are correctly identified, a proportion far exceeding the success rate of the human eye. Most of the undetected gold grains, confirmed by SEM, are too small (< 20 µm) to be identified by eye compared to the optical resolution of the system. Finally, the routine is in interoperability with the SEM. Stage coordinates of the grains are transferred with the sample shuttle, and final checks are made with EDS analysis and high magnification imaging.

Minerals
MIN58: Geometallurgy

Paper ID

Paper Title

1198

KEYNOTE: Geological contributions to geometallurgy (./pdfs/rfg1198.pdf)
Julie Hunt, Ron Berry

2150

The Determination of Mineralogy of Lithium in a Pegmatite deposit for Geometallurgical Purposes, Separation Rapids Lithium Deposit, Northwestern Ontario (./pdfs/rfg2150.pdf)
William Mercer, Volker Moeller, J. Chris Pedersen

1979

Geochemistry of Hydrothermal Alteration Associations in Porphyry Copper Deposits: Applications to Geometallurgical Modeling (./pdfs/rfg1979.pdf)
Brian Townley, Rodrigo Luca, Luis Lopez, Marcia Muñoz, Pamela Castillo

1203

Modelling mineralogy from whole rock assay data – a case study from Productora Cu-Au-Mo deposit, Chile (./pdfs/rfg1203.pdf)
Angela Escolme, Ron Berry, Julie Hunt, Scott Halley, Warren Potma

1193

Geochemical Input for Geomet Applications (./pdfs/rfg1193.pdf)
Pim van Geffen

1714

Integration of VNIR-SWIR hyperspectral core scanning in predictive geometallurgical modelling (./pdfs/rfg1714.pdf)
Laura Tusa, Louis Andreani, Sabine Gilbricht, Paul Ivascanu, Richard Gloaguen, Jens Gutzmer

1853

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1198 - KEYNOTE: Geological contributions to geometallurgy

Julie Hunt - *MDRU (Mineral Deposit Research Unit)*
Ron Berry - *UTAS*

Geometallurgy is a team-based, cross-disciplinary approach that documents variability within an orebody and quantifies the impact of geology and mineralogy on the mining value chain. This chain includes comminution, metallurgical response, recovery and refining processes as well as waste and tailings disposal, acid rock drainage, energy usage and CO2 generation plus social license to operate. Geometallurgical data need to be quantitative and spatially constrained in order to be used in predictive and spatial modelling, and mine planning. They also need to obtainable relatively inexpensively in order to be abundant enough to provide statistically valid sample distributions for modelling. The data produced are of most use if they can be easily transferred in a useable form between different departments along the mining value chain, thus avoiding duplication. The aim is to have 3D models that show the grade of valuable commodities AND other properties that may influence mining and processing, i.e. the impacts of rock properties on all cost centers along the mining value chain are taken into account.

The properties of minerals making up the rock mass, how the minerals are bound together and many other aspects of rock texture affect the whole mining value chain and in this presentation we examine rock properties (e.g. strength, composition, mineralogy, texture) significant in geometallurgy and provide examples of test methods available to measure or predict these properties.

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2150 - The Determination of Mineralogy of Lithium in a Pegmatite deposit for Geometallurgical Purposes, Separation Rapids Lithium Deposit, Northwestern Ontario

William Mercer - *Avalon Advanced Materials Inc.*
Volker Moeller - *Avalon Advanced Materials Inc.*
J. Chris Pedersen - *Avalon Advanced Materials Inc.*

The Separation Rapids lithium deposit is an example of a large “complex type” lithium pegmatite deposit classed as belonging to the LCT (lithium cesium tantalum) group of pegmatites.

The main potential mineral products are the petalite, lepidolite and feldspar. Lithium is contained in three minerals in the deposit, being in petalite, lepidolite and subordinate spodumene as well as being anomalous in the muscovite present. Feldspar occurs as both potassium feldspar and albite. Petalite is used in specialty glass-ceramics but along with lepidolite, also can be processed to produce lithium chemicals used in lithium ion rechargeable batteries, for example.

Quantitative mineralogy relative to identified ore types is an obvious requirement for truly understanding the metallurgical character of the deposit and optimum methods of metallurgical processing from mineral separation by flotation through to hydrometallurgy. So a major challenge to geology is defining the mineral abundance of the deposit, not merely the resources of lithium. This mineral abundance must also incorporate various populations of mineral assemblages in order to define metallurgical ore types.

To quantify the mineral abundance numerous methods are being utilized including Qemscan®, XRD, hyperspectral, custom normative calculations and optical mineralogy. Each method has strengths and weaknesses which have been clarified in the work. A major challenge is that many analytical methods’ have an inability to analyse for lithium.

Four ore types were identified through visual core logging with three subunits having petalite as the dominant lithium mineral and one with strong presence of lepidolite. The subunits with and without lepidolite will require very different processing. The studies are enabling the refinement of the mineralogical character of these ore types, enabling a more definitive understanding of the metallurgical nature of the deposit and lead to a mineral abundance resource estimate. Results of the mineralogical analyses will be presented.

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1979 - Geochemistry of Hydrothermal Alteration Associations in Porphyry Copper Deposits: Applications to Geometallurgical Modeling

Brian Keith Townley - *University of Chile*
Rodrigo Luca - *GeoAV SA*
Luis Lopez - *GeoAV SA*
Marcia Muñoz - *Universidad Andres Bello*
Pamela Castillo - *University of Chile*

In the present study we discuss the value of multi-element geochemistry in ore modeling which has important applications to geometallurgical processes. In mine production of porphyry copper deposits much effort is placed on geological modeling which is the base for mine planning, applied for predictive mineral processing behavior, from blasting, grinding, leaching or flotation, down to waste disposal and environmental management. High confidence geological models are commonly based on geological mapping of drill core, and surface/ underground exposures, combined with mineral characterization techniques (e.g., petrography, QEMSCAN®, XRD, spectroscopy, etc.). Unfortunately these are expensive and can only be applied to limited numbers of samples thus lacking sufficient representation. In addition, geological mapping always presents a degree of uncertainty, based on qualitative and semi-quantitative estimates. The combination of information usually provides geological models that are hard to combine with geometallurgical data, much less with mineral processing predictive behavior. The advent of multi-element geochemistry, at low cost, has allowed many companies to employ such tools, yet little use is given to the data. Geochemistry reflects the mineral composition of rocks, thus allowing characterization of lithology, alteration types and intensities, and mineralization. As an example of such applications we present a generic classification based on aqua regia geochemistry, which allows for quantitative modeling at high resolution sample support of key aspects of lithology, hydrothermal alteration and mineralization, and which may be cross referenced to metallurgical test samples and by that, to geometallurgical properties of rock and modeling.

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1203 - Modelling mineralogy from whole rock assay data – a case study from Productora Cu-Au-Mo deposit, Chile

Angela Escolme - *TMVC-CODES, University of Tasmania*
Ron Berry - *TMVC-CODES, University of Tasmania*
Julie Hunt - *CODES, University of Tasmania*
Scott Halley - *Mineral Mapping Pty Ltd*
Warren Potma - *CSA Global Pty Ltd*

Mineralogy is a fundamental characteristic for a given rock mass throughout the mining value chain. Understanding the mineralogy of the bulk rock, including both the gangue and ore components, is critical when predicting processing behavior and waste characteristics. Throughout the exploration and resource development process, mineralogical data are collected mostly in a qualitative manner through visual logging. These datasets are subjective and commonly inconsistent. Current methods for quantitative estimates of bulk mineralogy (e.g. X-ray point counting using SEM-EDS based software packages, and QXRD) are expensive and often very slow.

We present two new approaches to predicting bulk mineralogy using commonly available 33-element geochemical assay data. Firstly, we demonstrate qualitative estimation from assay using geochemical discrimination plots and validate this approach using quantitative XRD data. Secondly, we demonstrate quantitative estimation by calculated mineralogy. These approaches are presented using the Productora Cu-Au-Mo deposit, Chile, as a case study. Productora provides an example of an early stage project where geometallurgical models of mineralogy have been used to mitigate risk and uncertainty.

Our results indicate that robust, deposit-wide, predictions of bulk mineralogy can be generated quickly and cost effectively from geochemical assay data. These methods provide semi-quantitative mineralogical data for every multi-element geochemistry sample interval across the whole deposit. The number and spatial distribution of mineralogical data points can be significantly increased, by orders of magnitude. This data is then available to construct geometallurgical models and provides truly representative, deposit wide, mineralogical variability data. In turn, this provides significant benefits for the selection of representative samples for metallurgical test work, or the siting of specific metallurgical test work holes. Quantitative estimates of mineralogy on each assay interval can also be directly incorporated into resource block models, for mine planning purposes.

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1193 - Geochemical Input for Geomet Applications

Pim van Geffen - *Vancouver Geochemistry*

Process optimization is commonly applied in mining operations, from the block model to scheduling and stockpiling, blending, crushing, milling, and metallurgical extraction. While these processes may be integrated within operations, the data used for optimization may not include all the available information for the project. High quality exploration data are often excluded or unavailable, leaving great opportunities for improvement. On the exploration side, data acquisition is generally focused on targeting, grade distribution, and resource definition, and may not include parameters that would be most useful in the modeling of downstream processing, let alone tailings disposal and site reclamation. When we step back and consider the entire life of the project from a geometallurgical perspective, we can identify such information gaps and implement ways to bridge them. Geochemical methods can provide much of the required information, such as the content of penalty and royalty elements, acid-generating and neutralizing potential, carbon and sulfur speciation, as well as proxies for ore and gangue mineralogy, clay content, and other metallurgical performance parameters. When integrated with mineralogical and petrophysical information, this allows us to model the actual value per block, rather than grade only, which would improve operational success and greatly reduce the financial risk of the project.

Water
WA14: Hydrogeochemistry: Environment and Exploration (AAG: 28th IAGS)

Paper ID

Paper Title

2418

KEYNOTE: Combining low-cost drilling and hydrogeochemistry to explore for Carlin-Type-Gold Deposits (CTGD's) in covered settings: A case study from the Kelly Creek Basin, Nevada (./pdfs/rfg2418.pdf)
Wade Hodges

2375

Exploring undercover using 3D geochemistry: transitioning from basin-scale to prospect-scale Au exploration using hydrogeochemistry (./pdfs/rfg2375.pdf)
James Buskard

1816

Hydrogeochemical exploration of concealed PGE-bearing ultramafic rocks: A case study from the La Cabaña area in south-central Chile (./pdfs/rfg1816.pdf)
Antonia Genot, Linda Daniele, Martin Reich, Fernando Barra, José María González-Jiménez, Javier Rivera, Christian Antileo

1723

Tellus Survey, Ireland: Regional surface water geochemistry as an exploration tool and environmental indicator (./pdfs/rfg1723.pdf)
Vincent Gallagher, Katherine Knights, Ray Scanlon, Judith Mather, Mairead Glennon, Jim Hodgson

1372

Hydrogeochemistry in Sediment-hosted Cu exploration: a case study from the Sentinel Deposit, NW Zambia. (./pdfs/rfg1372.pdf)
Amanda Stoltze, Michelle Carey, James Kidder

1208

KEYNOTE: Continental scale hydrogeochemistry: providing baselines for lithology mapping, health, agriculture and opening new areas for exploration (./pdfs/rfg1208.pdf)
Nathan Reid, David Gray, Robert Thorne

2131

Unravelling the fate of organic micropollutants in the subsurface using stable isotopes (./pdfs/rfg2131.pdf)
Daniel Hunkeler, Clara Torrento, Rani Bakkour, Aileen Melsbach, Christina Lihl, Volker Prasuhn, Martin Elsner, Thomas Hofstetter, Violaine Ponsin

1932

Hexavalent Chromium: Diffusion and Reaction in Fractured, Porous Sedimentary-Rock Aquifers (./pdfs/rfg1932.pdf)
Shuo Liang, Tom Al

1589

Investigating the Geochemistry of Selenium in the Residual from Biologically Treated Mine-Impacted Waters (./pdfs/rfg1589.pdf)
Laura Volden, Dirk Kirste, Robert Gordon, Mario Bianchin

2407

KEYNOTE: Geochemical characterization leads to a fully-integrated conceptual model of groundwater flow systems, Wood Buffalo National Park, Canada (./pdfs/rfg2407.pdf)
Judit Déri-Takács, Carl Mendoza, Ben Rostron

2207

Hydrogeological Source Determination through Data Manipulation in Saskatchewan: a Regional Analysis of the Birdbear, Duperow, Souris River, and Dawson Bay Formations (./pdfs/rfg2207.pdf)
Kristl Tipton

1775

Chemical and isotopic evidence of fragmented recharge areas and groundwater evolution in a glaciated, regional-scale carbonate groundwater system. (./pdfs/rfg1775.pdf)
Elizabeth Priebe, Shaun K. Frape, Richard E. Jackson, David L. Rudolph, Abigail K. Burt

1231

Estimating hydrologic budgets of lakes in Parkland County, Alberta (./pdfs/rfg1231.pdf)
Katherine Snihur, Julia Valentina Soares, Tingxian Zhang, Shannon Flynn, Alberto Reyes, Duane Froese, Daniel Alessi

1031

Rapid field hydrogeochemistry part I: reliability, methodology and sectors potential - lessons from southern BC 2011-2017 (./pdfs/rfg1031.pdf)
Ron Yehia, Ray Lett, Dave Heberlein

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2418 - KEYNOTE: Combining low-cost drilling and hydrogeochemistry to explore for Carlin-Type-Gold Deposits (CTGD's) in covered settings: A case study from the Kelly Creek Basin, Nevada

Wade Allan Hodges - *Nevada Exploration Inc.*

Nevada contains one of the largest concentrations of multi-million-ounce gold deposits per unit area of any place on earth and 60% of that area is covered by sand & gravel. Conventional extrapolations of range-front geology, geochemical surveys and geophysical techniques have all been stretched to their limits as evidenced by dramatic drops in discovery rates as expensive exploration programs moved into these highly prospective covered terranes over the last two decades. Lower-cost drilling methodologies as typified by RAB drilling allow the drill rig to be used more like a rock hammer by the explorationist. Covered, oxidizing mineral deposits create measurable hydrochemical footprints. Recent advancements in low-cost drilling and in analyzing groundwater directly for gold and other trace-elements unique to CTGD's combine to lower the cost of collecting and analyzing large numbers of groundwater samples and provide a cost effective approach to targeting covered CTGD 's.

Kelly Creek Basin represents a 900 km2 underexplored covered search space, with >70 Moz Au discovered in and near the ranges immediately surrounding the Basin. Conventional exploration techniques consistently identify the intervening area as highly prospective, but the area is large and completely covered by from 50 m to >300 m of post-mineral, sand & gravel that has made historical exploration programs expensive and risky. 500 bore holes across the area have generated 900 samples of groundwater that have been collected and analyzed for gold and other trace-elements. Here discrete 3D concentration gradients in groundwater show dispersion patterns anchored to highest Au-in-bedrock (>0.1 g/t) at shallow depths and vector toward specific, more deeply-buried bedrock targets. Previous conventional exploration results have been combined with powerful low-cost drilling and new hydrogeochemistry techniques in a covered terrane to provide an otherwise missing scale of information before transitioning to more expensive exploration tools to dramatically reduce risk.

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2375 - Exploring undercover using 3D geochemistry: transitioning from basin-scale to prospect-scale Au exploration using hydrogeochemistry

James Buskard - *Nevada Exploration Inc.*

There is a pressing need for innovative 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 tool to open up covered terrains to systematic exploration and to constrain covered targets for follow-up drilling.

For Au exploration, researchers agree the best hydrogeochemical pathfinder is dissolved Au itself. Despite Au's relatively low solubility, with rigorous field protocols, appropriate analytical methods, and suitable sampling density (often requiring purpose-drilled boreholes) explorers can respond directly to dissolved Au with robust parts per trillion (ppt) level analyses.

Dissolved Au distributions seen in large regional sampling programs and more focused case studies in both Australia and Nevada show high-contrast, low-frequency anomalies against relatively low background values – desirable attributes of any geochemical pathfinder. Complimented with the other benefits of hydrogeochemistry versus other geochemical exploration tools (e.g. larger footprints requiring fewer samples to detect, and groundwater can recharge from depth to reflect deeper mineralization), dissolved Au represents a powerful pathfinder well-suited for Au exploration in covered terrains.

While the focus to date in the literature, as well as within industry, has been on the use of hydrogeochemistry as a generative, basin-scale (regional) exploration tool to identify new prospects in covered settings, pathfinder concentration gradients seen at the prospect scale can still show significant and useful contrast. By increasing sampling density, including collecting multiple samples downhole, explorers can model hydrogeochemistry in 3D at the prospect scale to provide clear vectors to constrain and advance covered prospects. Compared to conventional drilling, detailed prospect-scale hydrogeochemistry sampling programs are less expensive, providing cost-effective, early-stage information to allow explorers to be more focused and selective in their use of more expensive conventional drilling tools, providing an opportunity to lower both the cost and risk of exploring in covered settings.

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1816 - Hydrogeochemical exploration of concealed PGE-bearing ultramafic rocks: A case study from the La Cabaña area in south-central Chile

Antonia Genot - *Universidad de Chile*
Linda Daniele - *Universidad de Chile*
Martin Reich - *Universidad de Chile*
Fernando Barra - *Universidad de Chile*
José María González-Jiménez - *Universidad de Granada*
Javier Rivera - *Universidad de Chile*
Christian Antileo - *Universidad de La Frontera*

Platinum group elements (PGE: Ru, Rh, Pd, Os, Ir and Pt) play a key role in technological and energy applications in modern society, however, their concentration in the upper crust is very low. PGEs are almost exclusively associated with mafic and ultramafic rocks at ppm-to-ppb levels in cratonic areas (layered mafic intrusions) or related to ophiolite complexes. This study was focused on the La Cabaña area in south-central Chile where partially to totally serpentinized, PGE-bearing peridotite bodies from a dismembered ophiolite complex are hosted within mica schists from the metamorphic basement of south-central Chile. We characterized surface and ground waters that have interacted with the PGE-bearing ultramafic rocks to establish a hydrogeochemical exploration method to detect the presence of concealed peridotite bodies. Major and trace element analyses, including PGE concentrations, were carried out on water samples from rivers, streams, wells, and springs, using a combination of analytical techniques including AAS, IC, ICP-OES and ICP-MS. Hydrogeochemical data show that waters that have interacted with peridotites can be differentiated based on their magnesium-bicarbonate nature and anomalous concentrations of chromium (0.86 to 4.27 ppb) and nickel (9.57 to 52.89 ppb). In contrast, the waters that have interacted with mica schists are of the sodium-chloride type, and do not contain anomalous concentrations of the aforementioned metals. Furthermore, our data show that the concentration of toxic elements (e.g., Cr) in these waters is negligible. Our results show that hydrogeochemical techniques can provide not only valuable information for exploration of concealed PGE-bearing rocks but also for water-quality assessment for human consumption in the area.

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1723 - Tellus Survey, Ireland: Regional surface water geochemistry as an exploration tool and environmental indicator

Vincent Gallagher - *Geological Survey Ireland*
Katherine Knights - *Geological Survey Ireland*
Ray Scanlon - *Geological Survey Ireland*
Judith Mather - *Geological Survey Ireland*
Mairead Glennon - *Geological Survey Ireland*
Jim Hodgson - *Geological Survey Ireland*

The Tellus survey is Ireland's national regional geochemical and airborne geophysical survey, carried out by Geological Survey Ireland. To date 50% of the country has been surveyed and the aim is to complete coverage of the entire country (70,000 km2) in 6–8 years. The geochemistry programme includes multielement analysis of soils, stream sediments and surface waters (first- and second-order streams) sampled at average densities of one sample per 3.5 – 4 km2. Multielement analysis of surface waters is by ICP-MS, anion analysis by ion chromatography. Quality-controlled data and element distribution maps are available free of charge on GSI's website.

Water samples are collected and processed under rigorous QA/QC procedures and this, coupled with low analytical detection limits now available, has provided a set of robust hydrogeochemical maps that have significant potential as a mineral exploration tool. Surface water chemistry is influenced by various non-geological factors, including e.g. agriculture, industry and domestic waste, but the Tellus regional hydrogeochemical maps clearly demonstrate that, for many elements, surface water chemistry carries a distinct geogenic signature. Comparison with stream sediment data indicate that surface water chemistry has comparable success in identifying both known mineral deposits and prospects. For the northern and western parts of Ireland for which data have been published to date, these include gold (As and Sb in surface water) and base metal deposits (Zn, Pb ± Cd). Moreover, water sample collection is a relatively low cost and rapid exploration technique. Future analysis of surface water samples from the Irish midlands, home to the Zn-Pb orefield, will test the possibility of using hydrogeochemistry to detect deeply buried ore deposits.

Tellus hydrogeochemistry can also help identify contaminant sources, e.g. regional controls on eutrophication, and improve radon risk modelling through greater understanding of the source and distribution of uranium in surface water.

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1372 - Hydrogeochemistry in Sediment-hosted Cu exploration: a case study from the Sentinel Deposit, NW Zambia.

Amanda M Stoltze - *Perth, Australia*
Michelle Carey - *Imdex Limited*
James Kidder - *Department of Geological Sciences, Queen's University*

Exploration for Sediment-hosted Cu in the Central African Copper Belt (CACB) has traditionally relied on soil sampling for direct detection of mineralisation. As exploration moves into areas with substantial transported cover other techniques are required, one with proven effectiveness in other deposit styles is hydrogeochemistry. It's application in the CACB has previously been limited and as such case studies on known deposits are important to understand how local waters interact with mineralisation. Hydrogeochemistry was applied to the Sentinel Cu and Enterprise Ni Deposits before mining in order to characterise these mineralisation styles in ground water.

District scale sampling was carried out using community water sources distal to mineralisation in addition to previously drilled exploration and resource drill holes within mineralisation. Samples were collected at the end of wet and dry seasons to compare seasonal variability. The sampling method was the standard First Quantum Minerals protocol based on that of Noble et al. (2011). During sampling a range of physiochemical data were collected: Eh, pH, conductivity, TDS and temperature in order to characterise the waters.

Two distinct water types were identified in both proximal and distal locations and in both wet and dry seasons: acidic oxidising and neutral reducing. The behaviour of pathfinders in the two water types is distinctly different with metals generally found in higher concentrations in the acidic oxidising water. The elements associated with mineralisation in the two water types were found to be As, Ba, Co, Cu, Mo, Ni, Li and W. Hydrogeochemistry was found to be effective in identifying mineralisation and suggest that water sampling in areas of transported cover can be used as a tool for identifying sediment hosted mineralisation in the CACB.

Nobel, R.R.P., Gray, D.J. and Gill, A.J. 2011. Filed guide for mineral exploration using hydrogeochemical analysis. CSIRO Earth Science and Resource Engineering.

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1208 - KEYNOTE: Continental scale hydrogeochemistry: providing baselines for lithology mapping, health, agriculture and opening new areas for exploration

Nathan Reid - *CSIRO*
David Gray - *CSIRO*
Robert Thorne - *CSIRO*

Hydrogeochemistry can assist mineral exploration. With a high signal-to-noise ratio, groundwaters are a useful medium for geological sensing and mineral exploration in specific environments, and are also sensitive to faults and other geological structures. There is considerable scope for hydrogeochemistry value-adding to mineral exploration where prospective rocks are covered within basin margins.

We are encouraging uptake of the technology, through development of robust and cost-effective methodology with site studies. Field guides, notebooks, and a field sampling android application are now available. Issues such as bailing vs. pumping have been tested, as well as metrics for contamination and determination of its effects on varying elements.

CSIRO has taken all publically available groundwater databases, combined them with robust quality measures to remove all possibly spurious data and baseline issues to create a ‘seamless’ whole dataset as across the Australian continent. This dataset includes anything from single total dissolved solid (TDS) measurements up to 60+ elements per sample.

At the Terrane scale, specific indices can delineate large scale lithological groups, and major mineral camps. Such a broad-scale approach does obscure camp scale-variation but does delineate major features, such as the Agnew and Granny Smith Gold camps in the northern Yilgarn Craton. Other large systems, such as IOCG’s or Cu Porphyries may also be observable. At the Prospect scale, indicator elements (e.g., Au, Ni, Cu, Zn, W, As) are commonly valuable, with Indices developed for specific commodities (e.g., AuMin or NiS). Combined with geophysics, this may assist in selecting drilling targets.

Hydrogeochemistry, combined with a robust understanding of environmental factors, rock weathering and good quality analytical chemistry, can positively assist exploration at varying scales as well as provide baseline chemical data for human and agricultural health.

2131 - Unravelling the fate of organic micropollutants in the subsurface using stable isotopes

Daniel Hunkeler - *University of Neuchâtel - CHYN*
Clara Torrento - *UNINE*
Rani Bakkour - *EAWAG*
Aileen Melsbach - *Helmholtz Munich*
Christina Lihl - *Helmholtz Munich*
Volker Prasuhn - *Agroscope*
Martin Elsner - *Technical University Munich*
Thomas Hofstetter - *EAWAG*
Violaine Ponsin - *UNINE*

Compound-specific isotope analysis (CSIA) is a powerful method to track the fate of contaminants in the aquatic systems, so far mainly applied to legacy contaminants, such as chlorinated and petroleum hydrocarbons. We present results from a collaborative research program to extent multi-element CSIA to polar organic micropollutants, such as pesticides, pharmaceuticals and consumer care products, which are of increasing concern for human and ecosystem health. CSIA of polar organic micropollutants is demanding because they tend to occur at low concentrations, are challenging to extract from water, more difficult to transform to the IRMS measurement gas and are transformed by numerous mechanisms, whose isotope effects are not known yet.

Thanks to the successful development of large-volume (up to 40L) pre-concentration and clean-up methods, it was possible to perform CSIA at environmentally relevant concentrations (as low as 0.2 µg/L) even if matrix to analyte ratios were highly unfavorable. Using a combination of LC-IRMS, GC-IRMS combined with new derivatization methods, and GC-qMS, multi-element (C, N and Cl) CSIA became feasible for frequently detected pesticides, their metabolites and consumer care products. The methods were field-tested in a three-year lysimeter experiment and at waste water treatment plants. While pesticide/metabolite concentrations strongly fluctuated in the lysimeter study due to the highly transient hydrological conditions, CSIA data show a steady enrichment of heavy isotopes for some compounds, even if injected below the root zone. These results highlight the potential of multi-element CSIA to demonstrate transformation of polar organic micropollutants under transient environmental conditions, which is difficult to achieve with other methods.

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1932 - Hexavalent Chromium: Diffusion and Reaction in Fractured, Porous Sedimentary-Rock Aquifers

Shuo Liang - *University of Ottawa*
Tom Al - *University of Ottawa*

Hexavalent chromium (Cr(VI)) is a toxic carcinogen and it has become a common anthropogenic contaminant in groundwater. Although there are many similarities in the biogeochemical processes affecting transport and persistence of Cr(VI) in unconsolidated vs bedrock aquifers, we focus on fractured porous bedrock because little is known about how the sharp hydraulic discontinuity between the fractures and matrix affects the Cr(VI) mass distribution, reaction processes and rates. In previous work, we demonstrated that Cr(VI) is transferred from fractures to the porous matrix by diffusion, and that Cr(VI) can be immobilized in the matrix by reduction to Cr(III). The present objectives are to gain a quantitative understanding of diffusion rates for Cr(VI) in the porous matrix and the nature of reaction processes that immobilize Cr(VI).

Four sandstones were sampled; two from California, one from New Jersey and one from New Brunswick. They were chosen for variations in grain size, porosity, and redox condition. Mineralogical properties of the samples were characterized using XRD, optical and scanning-electron microscopy with the goal of identifying reactive phases such as organic matter and Fe(II)-rich minerals such as chlorite, ilmenite and pyrite. Small cores (25 mm dia × 10 mm L) were drilled from each sample and placed in through-diffusion cells to measure diffusion coefficients using tritiated-water (HTO) and CrO4- tracers. In all cases, the diffusive flux of Cr(VI) was retarded by reaction processes, and in one case, no breakthrough was observed after 64 days. Mineralogical analysis indicates that reduction of Cr(VI) to Cr(III) occurs in contact with fragments of organic carbon and Fe(II)-bearing minerals – biotite, chlorite, magnetite. Chrome-bearing Fe-oxyhydroxide is the only mineral reaction product identified.

This research demonstrates methods that could be effective for evaluating the suitability of Cr(VI)-contaminated bedrock systems for management by monitored natural attenuation.

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1589 - Investigating the Geochemistry of Selenium in the Residual from Biologically Treated Mine-Impacted Waters

Laura Volden - *Simon Fraser University*
Dirk Kirste - *Simon Fraser University*
Robert Gordon - *Simon Fraser University*
Mario Bianchin - *Wood*

Selenium has the potential to be extremely toxic in high concentrations and is of particular concern due to its propensity to bioaccumulate within food chains. Industrial activities, such as mining, have resulted in elevated levels of selenium in the wastewater and ultimately in nearby surface water bodies. Bacterially-mediated redox based methods are used to treat the wastewater. The by-product of this treatment is a solid state residual which contains selenium at concentrations in excess of 4000 mg/kg. This research aims to understand how selenium occurs within the residual, and under what conditions it may remobilize. The speciation of selenium within the residual is of particular importance, as redox state impacts the toxicity and mobility. The mobility controls on selenium in the residual were determined through a series of aqueous batch experiments that simulated a variety of redox and pH conditions using O2, Fe3+ and NO3- as oxidants. While selenium was mobilized under all simulated conditions, the highest concentrations were detected under mildly oxidizing conditions. Absorption effects were also observed, as the concentration of selenium in the aqueous phase increased initially, followed by a steady decrease. The selenium speciation of the residual were characterized in both pre- and post-experiment samples using X-ray Absorption Near Edge Structure (XANES) techniques. While the mildly oxidizing conditions created the most detectable aqueous selenium, they showed the least amount of speciation change in the solid phase. The remaining conditions (highly oxidizing and low pH), however, resulted in significant oxidation of metal selenide species to either SeS2 or Se0 (red). The goal of this research is to assess the risk posed by the residual and ultimately develop proper disposal methods that will minimize the risk to the local ecosystem and human health.

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2407 - KEYNOTE: Geochemical characterization leads to a fully-integrated conceptual model of groundwater flow systems, Wood Buffalo National Park, Canada

Judit Déri-Takács - *University of Alberta*
Carl Mendoza - *University of Alberta*
Ben Rostron - *University of Alberta*

Wood Buffalo National Park (WBNP), Canada's largest national park comprises millions of hectares of boreal forest, extensive wetlands and prairie, springs, karstic landforms, groundwater-dependent ecosystems, and unique salt flats. The Salt Plains region along the eastern edge of the WBNP exhibits highly variable Total Dissolved Solid (TDS) contents, ranging from less than 1000 mg/L to more than 300,000 mg/L, with a wide range of hydrochemical facies, from CaHCO3-type to more evolved NaCl-type waters. Stable isotopes of oxygen and hydrogen reveal that groundwaters are strongly correlated with the average isotopic composition of local precipitation. Thus, it is interpreted that groundwaters of the study area originate from meteoric water, rather than formation waters of the Alberta Basin. Analyses of possible rock-water interactions show that solutes are related to three different sources: dissolution of halite, dissolution of gypsum/anhydrite, and dissolution of carbonate minerals. It is concluded that TDS variability and hydrochemical facies reflect different scales and/or segments of flow systems. These geochemical and isotopic results yield a robust conceptual model of the groundwater flow systems present within the WBNP region.

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2207 - Hydrogeological Source Determination through Data Manipulation in Saskatchewan: a Regional Analysis of the Birdbear, Duperow, Souris River, and Dawson Bay Formations

Kristl J Tipton - *University of Saskatchewan*

Hydrogeological Source Determination through Data Manipulation in Saskatchewan: a Regional Analysis of the Birdbear, Duperow, Souris River, and Dawson Bay Formations in Saskatchewan

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Abstract:

Publically available, industry provided, and newly sampled geochemical and isotopic data are currently being combined for stratigraphies of interest within the Elk Point Basin in Saskatchewan. The creation of a comprehensive database has allowed for graphical as well as spatial analysis of water chemistry within the basin. Manipulation of this data can assess for patterns in variation and attempt to track chemical evolution at a regional scale. Patterns found can then be utilized to assess regional scale hydrogeology, recharge and discharge, and may indicate structural complications that allow leakage between aquifers. In addition to this, a better understanding of regional hydrochemistry allows for more accurate interpretations of smaller scale hydrogeology. This is valuable information for current mining infrastructure, mineral exploration and when assessing hydrocarbon migration. By combining data on water chemistry, interpreting the salinity characteristics and expressing the results in a spatial context, information on mineral precipitation, dissolution and fluid migration can be obtained.

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1775 - Chemical and isotopic evidence of fragmented recharge areas and groundwater evolution in a glaciated, regional-scale carbonate groundwater system.

Elizabeth Priebe - *Ontario Geological Survey*
Shaun K. Frape - *University of Waterloo*
Richard E. Jackson - *Geofirma Engineering Ltd.*
David L. Rudolph - *University of Waterloo*
Abigail K. Burt - *Ontario Geological Survey*

The Early Silurian carbonate bedrock formations of the Michigan basin, southern Ontario, contain significant quantities of high-quality groundwater resources and provide the sole drinking water source to many large municipalities and private residences. This investigation represents the first attempt to characterize these carbonate groundwater resources in their entirety. Although the bedrock formations are relatively flat-lying and regionally extensive, suggesting ease of characterization, the systems are complex due to the influence of glacial sediment cover on recharge and the effect of karst on groundwater residence times. Recharge timing and controls are investigated with several isotopic and geochemical indicators of recent recharge in groundwater, within the context of the sedimentary geology and sediment thickness of the study area. Spatial trends of tritium, and SF6 in groundwater, interpreted as representing recent recharge (< 50 years), corroborate with aerobic redox chemistry in the carbonate groundwater systems underlying areas of thin or permeable sediment cover. Groundwater chemical evolution beyond recharge areas is assessed with general chemistry, the redox profile and an investigation of water-rock interaction. A comparison of strontium isotope ratios (87Sr/86Sr) in bedrock and groundwater shows that long residence times are required for the isotopic signature of the rock to imprint on the groundwater. Increasing Sr to Ca ratios along the groundwater flow path are likely resulting from incongruent dissolution of dolomite and the precipitation of calcite with evolution. Sulphur isotopic composition of sulphate in groundwater shows isotopic evidence of pyrite oxidation in recharge areas, and a Silurian sulphur isotopic signature in areas of thick and low permeability sediments, well downgradient of identified recharge areas. For this investigation, isotopic and hydrochemical tools have provided many essential lines of evidence, supporting the development of a conceptual model of recharge and groundwater evolution in this complex setting with many geological controls at play.

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1231 - Estimating hydrologic budgets of lakes in Parkland County, Alberta

Katherine Nicole Snihur - *University of Alberta*
Julia Valentina Soares - *University of British Columbia*
Tingxian Zhang - *University of Alberta*
Shannon Flynn - *NewCastle University*
Alberto Reyes - *University of Alberta*
Duane Froese - *University of Alberta*
Daniel Alessi - *University of Alberta*

The Canadian prairies and boreal plain have numerous shallow ponds and lakes that sustain unique aquatic ecosystems and are critical in supporting migratory birds in North America. The annual water budget of these features varies widely with climate and position on the landscape, and is often not well understood. In this study, we investigate the water budget of lakes in the Parkland Lakes region of Alberta, located within the North Saskatchewan River Watershed. The area is home to numerous small lakes and the larger Wabamun Lake, and lies in a region where annual precipitation is roughly equivalent to evaporation. Over the past 20 years, the residents of Parkland County have observed declining water levels in many lakes in the region, and the cause is unclear. To gain insight into the major water fluxes in the region, we use a combination of inorganic geochemical analyses coupled with stable water isotopes to constrain the hydrologic budgets of lakes in the region. Our results show that reactions along the flow paths control the major element geochemistry of the groundwater, while water from the lakes generally shows unchanging stable isotope values and cation concentrations. By coupling models of stable isotope data and geochemical data using activity - activity plots, we found that groundwater is only a minor input into the lakes, indicating water fluxes in these lakes are dominated by evaporation and precipitation. The modelling also supports short water residence times, ranging from two to 12 years in the small lakes and 39 years in Wabamun Lake. We propose that the declining lake levels are the result of a shifting evaporation – precipitation balance towards a drier climate during the past two decades. This could be due to either natural climatic cycling or as a consequence of recent anthropogenic climate change.

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1031 - Rapid field hydrogeochemistry part I: reliability, methodology and sectors potential - lessons from southern BC 2011-2017

Ron Yehia - *Vancouver, British Columbia*
Ray Lett - *Self*
Dave Heberlein - *Heberlein Geoconsulting*

Variations in ground and surface water chemistry can be valuable exploration guide to concealed minerals in bedrock and overburden, and for monitoring potentially hazardous trace metals in contaminated waters. Sampling and laboratory analysis of water can be time-consuming and expensive especially when samples, collected in a remote area, need rapid transfer to a laboratory for measurement of multiple parameters. Portable systems such as bench top photometry and voltammetry can analyse water samples for numerous dissolved constituents near the sample site providing rapid results and thus avoiding sampling shipment and laboratory reporting delays. This paper describes field-based analysis of stream water samples collected by the authors during regional hydrogeochemical surveys from 2011 to 2016 in central British Columbia, Canada, with the Palintest® Photometer 8000 and the Modern Water PDV6000Ultra systems. The Photometer determines Al, Ca, Cl, Cu, F, Fe, Mg, Mn, K, Si and SO4 in water from 1 ppm to as low as 10 ppb by measuring the colour and light transmittance of a solution after the addition of metal-sensitive colour dyes. Modern Water's PDV6000Ultra measures trace elements including As, Cd, Cu and Pb by anodic stripping voltammetry (ASV) to 0.5 ppb. Precision based on the results of field duplicate water sample analyses expressed as percent relative standard deviation is better than +/20% for all elements (except Cl) by both methods. Analyses for most elements, especially Cu and As by Modern Water's PDV6000Ultra ASV system can be compared well with laboratory results on same water samples and standards. Results of stream water samples from two regions of British Columbia by field-based photometer and ASV reveal that element anomalies can be explained by known base and precious metal mineral occurrences.