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Oral abstracts Page

Geochemical anomaly mapping for base metals in the Hattfjlelldall area, Norway: same data, different tricks

Pedro Acosta-Góngora, Malin Andersson, Ying Wang , Terje Bjerkgård , Marie-Andree Dumais, Aziz Nasuti , Ana Carolina Rodrigues-Miranda, Vikas Chand Baranwal

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The Hattfjelldal area in the Nordland County, Norway, is regarded as prospective for the occurrence of Cu-Zn-Pb volcanogenic massive sulfide deposits (VMS). However, significant large-scale mineralization has yet to be found. This study re-evaluates a soil survey carried out in Hattfjelldal by combining compositional balance, concentration-area fractal (C-A) and exploratory data (EDA) analyses to target prospective areas for base metal mineralization.

Initially, compositional balance analysis was carried out to identify element associations relevant to sulfide-hosted base metal mineralization. Four balances, targeting Cu, Ag-Mo-S, Sb-Bi-Pb and Fe-Zn, were constructed and interpreted as vectors representing distinct types of mineralization. Anomalous areas for each mineralization type were then filtered using C-A and EDA. For the Cu, Fe-Zn and Ag-Mo-S balances, the C-A approach highlighted smaller anomalous areas (5%, 5% and 8% of the area of study) relative to those indicated by EDA (10%, 10%, 11%). For the Sb-Bi-Pb balance, both approaches achieved equivalent results (5%). In general, both EDA and C-A, largely signaled overlapping anomalous areas.

Our results also show that base metal anomalies (even of the same type) are not constrained to a particular lithological unit but can be hosted in several types (e.g., mica-, graphite and carbonate-rich metasedimentary rocks, and felsic and mafic volcanics). This may further indicate the presence of distinct types of mineralization and/or favorable host rocks. To narrow down the most prospective areas, the EDA and C-A results were compared against airborne geophysics and structural geology maps. In both cases, several geochemical anomalies were identified along the trace of thrust faults and/or within areas of high conductivity. Notably, approximately 65% of Cu and Ag-Mo-S anomalies (EDA and C-A) were located within moderate to highly conductive zones, consistent with the presence of sulfides.

Finally, six prospective zones (A-F) are suggested as mineral exploration targets, among which the two most intriguing ones are characterized by the convergence of multiple geochemical anomaly types (two or three) and high conductivity areas with variable proximity to potential structural corridors.

Gold-bearing quartz veins and associated rocks in western Nigeria: Insights from field investigation, petrographic study, and geochemical analysis

Sodiq Alimi, University of the Free State.

This study focused on the Wawa area, a southern extension of the Zuru Schist Belt (ZSB) in Northwestern Nigeria. The ZSB is one of western Nigeria's broadest and least studied schist belts. Information about its full extent, petrological, and geochemical characteristics still needs to be improved. Preliminary field investigations have shown that the Wawa study area possibly hosts orogenic gold deposits. This study carried out field investigation, petrological study, and geochemical analysis to understand and characterize the tectonic setting and possible origin of gold mineralization in the area. In total, 40 rock samples were studied under the microscope and 72 samples were subjected to geochemical analysis, including X-ray fluorescence (for major and trace elements) and X-ray diffraction analyses. The field investigation revealed that the rocks in the area are mainly gneiss, migmatite, amphibolitic rocks, phyllites, granitoids, and intrusive rocks such as quartz veins and pegmatite veins. Gold mineralization is confined to the quartz veins in amphibolitic rocks, and micro veins of pyrite and chalcopyrite are apparent in the amphibolitic rocks as well. The petrological and mineralogical studies showed that quartz is dominant in the samples from the Wawa study area, together with feldspars, mica, and other accessory minerals. The XRF data showed that the rocks underlying the Wawa study area are highly enriched in silica; meanwhile, several trace elements exist in anomalous concentrations compared to the corresponding average elemental values in the upper continental crust and based on several other reports from western Nigeria. The underlying rocks in the study area are mostly peraluminous with few plotting as peralkaline. Gneisses in the area are orthogneisses. The amphibolitic rocks in the area show both tholeiitic and calc–alkaline affinity. The K_2O/Al_2O_3 vs Na_2O/Al_2O_3 discrimination plot suggested that gold-bearing fluids in the area are likely from igneous and sedimentary sources. Despite the new data/information contributed by this study, further geochemical studies within the ZSB are required to fully understand the evolution and origin of gold mineralization in the area.

Golden Pike: Comparing the Effectiveness of Bedrock vs Till Geochemistry as a Regional Exploration Tool

Alan Bieber, IGO

The Red Lake belt in NW Ontario has produced over 29moz of gold and is known globally for some of the highest-grade gold deposits in the world. The geomorphology of the Red Lake area, like much of the Canadian shield, is characterised by remnants from the last glacial maxima c. 20,000 years ago. As a result, a significant portion of the Red Lake area is covered by glacial sediment and modern-day lakes which impede conventional exploration techniques.

During March 2022, a sonic drilling campaign was completed by Evolution Mining over the McFinley ore body in Red Lake, Ontario, Canada. The drilling programme was part of an orientation study designed to compare the effectiveness of bedrock geochemistry against till geochemistry & gold grain analysis as tools for regional exploration in the Canadian Shield, where much of the basement rock is occluded by a veneer of transported lacustrine and glacial sediment. Holes were drilled from the frozen lake surface, through the glacial till profile, penetrating 1.5m into bedrock. Multi-element geochemistry of the fresh rock samples failed to show a reliable pathfinder signature while the till geochemistry and gold grain counts provided a robust, kilometre-scale anomaly vectoring toward the deposit’s projected intersection with the lake bottom.

A study of thallium isotopes from the Leeville Carlin-type gold deposit, Nevada, USA

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Carlin type gold deposits are commonly associated with a suite of pathfinder elements consisting of arsenic (As), mercury (Hg), antimony (Sb), and thallium (Tl). These elements typically form broad anomalies around these deposits but provide little information about proximity to, or the tenor of gold mineralisation. This study presents thallium isotope data collected from 205 samples collected from the Leeville Carlin-type gold deposit. These data exhibit a range of ε205Tl values ranging from -17.4 to +7.2. Samples exhibiting heavier ε205Tl isotope values correlate with samples with highest Au, Tl, Sb, As and Hg. Samples exhibiting the lightest ε205Tl isotope values correlate with samples with highest potassium, rubidium, and caesium. These results support that Tl isotopes in Carlin type gold deposits fractionate based on paleo-redox state as reduced monovalent Tl^{+1} or oxidized trivalent Tl^{+3}. Reduced Tl^{+1} has similar bonding behavior as potassium, and oxidized Tl^{+3} has a chalcophile behavior. Results from this study suggest that Tl isotopes can be used as an exploration tool to discriminate reduced Tl associated with distal potassic alteration from that of oxidized Tl associated with sulphide minerals proximal to mineralization.

Next Generation Technology in Undercover Exploration

Dr Nigel W. Brand [1,2], David J. Crook [3]

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As mineral exploration increasingly pushes into concealed (covered) terrains, explorers must maximise the geochemical and mineralogical information gained to understand the geological setting, terrain prospectivity and mineral potential at various scales.

Routine, low-cost geochemical techniques enable explorers to look for anomalies within the cloud of data however mineralogical techniques that, at best provide data on the dominant mineral phases (e.g. x-ray diffraction, “XRD”), are expensive, low volume (e.g. scanning electron microscope “SEM”) or qualitative (e.g. short-wave infrared “SWIR”).

We present the findings of an ongoing regional evaluation study over concealed Proterozoic lithologies known to host magmatic nickel sulphides with potential to host other base-metal, gold and rare earth elements (“REE”) systems within the Fraser Range, Western Australia.

The data has been acquired by Micro-XRF mapping technology which can accurately quantify the chemical compositions, and through post-processing, identify and quantify mineralogy of the same geological sample. High-quality, quantitative analyses were undertaken of “end of hole” air core drill samples representing the freshest example of the rock being drilled.

This paper demonstrates the application of next generation technology in undercover exploration and highlights the importance of detecting routine, high-volume, low-cost, quality “trace” mineralogy to identify a suite of “indicator” minerals with the potential to vector towards and detect economic mineral systems.

This pilot study forms part of a much larger regional program undertaken by Mount Ridley Mines Limited to understanding the basement geology and mineral prospectively using a non-destructive micro-XRF technique to quantify mineralogy and chemistry and provide textural and petrography information that is “fit for purpose” for mineral exploration.

The MinEx Co-operative Research Centre National Drilling Initiative – novel methods and applied geochemistry

Dr Anthony Budd

Geoscience Australia and MinEx CRC

MinEx CRC is the world's largest mineral exploration research collaboration, bringing together industry, government and research organisations. The National Drilling Initiative (NDI) is a part of the CRC that brings together government and university geoscience departments from across Australia in the common goal of improving understanding of Australia’s mineral resources.

The Earth resources sector is a vital part of Australia’s economy, and our future wellbeing demands a continuing pipeline of discovery. The NDI precompetitive stratigraphic drilling campaigns have been conducted in the frontier regions of East Tennant (NT), South Nicholson (NT), Delamerian Orogen (SA and NSW), Paterson (WA) and Eucla (WA), with others to come. Each campaign has provided new rock chip and core samples from key regolith and basement units, some of which have never previously been sampled. New technology developed by NDI researchers and applied to the drilling campaign areas includes the following:

- Regolith characterisation has been made easier by new software that produce pseudologs through multivariate analysis of rapid field-acquired geochemical, hyperspectral and petrophysical data. While developed specifically to aid identification of boundaries in regolith, the method also can be applied to basement stratigraphy.
- New dating methods allow rapid characterisation of stratigraphic, tectonic and alteration events. Microanalytical techniques using laser ablation same-mass isotopes allow a much wider range of minerals to be analysed in their petrogenetic/lithologic/paragenetic contexts – especially important as we study new styles of critical mineral deposits. Diffusion modelling of high precision Ar-Ar plateau spectra allows an extensive thermal history to be revealed from tiny amounts of material.
- New software is being developed to maximise the information gained from chemical and isotopic micro-mapping of samples. This allows better predictions of the mineral potential of a region from the study of just a few uneconomic mineral occurrences, which are often found before major deposits are.

The collaboration between MinEx CRC researchers and geological surveys has proven very powerful in both trialling new analytical methods, but also to provide a much more rapid, informed geological framework in frontier covered terranes than has previously been possible. Web portals with analytical tools facilitate data delivery to explorers more promptly after drilling, allowing faster investment decision making, which is necessary to keep investment in Australia to support the transition to a low carbon economy.

Building an integrated geochemistry interpretation app for the Paterson Province

Harrison Button

Geodata Scientist, Rio Tinto Exploration

Rio Tinto Exploration (RTX) discovered the Winu Cu-Au deposit in 2017. From that time forwards, collection of a consistent assay suite through a sustained exploration effort has resulted in a large, ‘ML ready’, drilling dataset across the Paterson province. To better leverage this asset, an application has been created that allows geoscientists to automatically have new samples classified by lithology and ‘distance to Winu’ and can work out which other samples are geochemically similar to selected drilling intervals. This helps with stratigraphic modelling and near-miss identification, without the user having to operate myriad technical software and manually collate data from different sources.

The application was developed with assistance of an external consulting group, and then brought in house by the internal data science team. The data pipeline has been automated so little human intervention is required to update the application as new drilling results come in. Data engineering efforts have improved application performance over me.

RTX now has unparalleled understanding of intersected geology in the Paterson, and the tools to rapidly apply that knowledge. RTX can assist partners to get more from their own projects. In addition, suggestions on alternative approaches and application design would be welcome from the broader data science community.

“If you had all this data and geoscience understanding, what would you do with it?”

Entwined in the pines – results of some regional biogeochemical mapping studies

David R. Cohen, Joseph A. Schifano and Neil F. Rutherford

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The use of plants as a sampling media in exploration and environmental geochemical studies goes back to the early part of the 20th Century. The application in regional geochemical mapping programs was, however, a later development. Colin Dunn was a pioneer in the use of tree organs in regional surveys, and completed a number of such studies in Central and Eastern Canada, and elsewhere. Plant biogeochemistry, however, remains a rarity. This is probably a function of concerns over the species-specific geochemical response to the composition of the underlying regolith, groundwater and other site characteristics, as well as potential seasonal variability.

Recent studies conducted in Cyprus and the Cobar Basin of New South Wales indicate both potential of biogeochemistry in detecting variations in lithology and the effects of mineralisation or contamination. There are particularly strong responses in the needles of conifers to variations in a suite of elements that are typically elevated in ultramafic rocks and associated styles of mineralisation, including Ni, Co and Mg. Mineral deposits associated with felsic units and structurally-controlled polymetallic deposits in the Cobar Basin commonly display highly elevated concentrations of Au, Pb, W and other elements in pine needles.

The use of in-situ portable XRF as the primary analytical method for selected elements offers the chance of conducting large-scale surveys rapidly and cheaply, depending on species availability.

Geochemical and Structural Architecture of the Andover Pegmatites: A Revised Temporal and Spatial Model for Pegmatite Genesis in the Northwest Pilbara

Dr Joshua Combs, Mr Richard Cubitt

Since discovery of the spodumene-bearing pegmatites hosted in the Andover Intrusion ~5km SE of Roebourne, Azure Minerals has compiled a world-class geochemical, structural, geological (lithological, mineralogical, textural) and spectral dataset. Using a holistic geological approach, the company has accelerated the discovery and delineation of one of the most economically significant discoveries of the 21st Century.

Whole rock geochemical analysis from drillcore and rock chip sampling have allowed for detailed lithogeochemical characterisation of the pegmatite system at Andover. The chemical dataset provides key temporal and spatial insights into the lithium ore-forming system, hinting at the unique origins of the Tier 1 deposit.

The combination of geochemical, structural, lithological, mineralogical, textural evidence point towards an anatectic origin for the Andover pegmatites (Stewart 1978, Koopmans et al. 2023). The lithium-enriched pegmatitic melt was structurally emplaced at shallower crustal levels within the Andover Mafic-Ultramafic complex. The pegmatite underwent a high degree of fractionation within the structural network during emplacement, observed as systematic variations in whole rock geochemistry within the pegmatite swarm. This open system behaviour facilitates a more extreme degree of fractionation to a pure spodumene-quartz melt, and in much higher volumes than might be plausible with closed system fractionation within a granite pluton.

This model has far-reaching implications for the way explorers search for lithium-bearing pegmatites in the northwest Pilbara and globally.

References:

A heavy mineral map of Australia

Adj Prof Patrice de Caritat, Curtin University, Geoscience Australia, Dr Alexander T. Walker, Curtin University, Prof Brent I. A. McInnes, Curtin University, Dr Evgeniy Bastrakov, Geoscience Australia, Mr Philip Main, Geoscience Australia

Heavy minerals (HMs), i.e. those with specific gravity >2.9 g/cm^3, have been used successfully around the world in energy and mineral exploration. In Australia, however, no public-domain database or maps of the background HM assemblages or distributions exist. Here, we describe a project that delivered the world's first precompetitive continental-scale HM dataset and maps. We applied automated mineralogical identification and quantification of the HMs contained in floodplain sediments from large catchments covering most of Australia. We achieved this by leveraging the archived sample collection from the National Geochemical Survey of Australia (NGSA). The elemental and isotopic composition of those sediments previously has been shown to reflect the dominant rock types in the upstream catchment(s). Thus, the generally resistant HMs were hypothesised to largely preserve the mineralogical fingerprint of their host protoliths through the weathering–transport– deposition cycle. Underpinning this vision was a pilot project, based on 10 samples from the NGSA sample archive, which allowed development of a fit-for-purpose methodology and demonstrated the feasibility of a larger, national-scale project. The project focused on the 75-425 µm fraction of the NGSA's 'bottom outlet sediment' (BOS) samples (taken on average from a depth of 60-80 cm) to minimise both anthropogenic and aeolian influences.

Two tranches of the HM dataset, one from southeastern Australia, the other from northern Queensland and the Northern Territory, were released in 2022 as data became available. Since those partial releases, the complete national-scale HM dataset, report, and atlas were made public in late 2023. They consist of a staggering >140 million mineral observations from all 1315 NGSA samples, identifying >160 mineral species. In order to effectively deal with such 'big data', we created a bespoke, cloud-based mineral network analysis (MNA) tool to visualize, discover and investigate relationships between HMs as well as between them and geological settings or mineral deposits. We envisage that the Heavy Mineral Map of Australia (HMMA) and MNA tool will contribute significantly to mineral prospectivity analysis and modelling, particularly for technology critical elements and their host minerals. Industry uptake of the HMMA dataset since the release suggests usefulness and timeliness of this precompetitive asset.

Diagenesis of groundwater calcrete and paleochannel sediments: Implications for the genesis of channel and playa uranium deposits

Drummond, J. B. R., Pufahl, P. K., James, N. P., Bowell, R. R., Wilde, A., Layton-Matthews, D., Kyser, T. K. †

Channel and playa uranium deposits are a sub-type of surficial uranium deposits that form in Tertiary to Recent groundwater calcrete and associated dolomitic, clay-rich, paleochannel, and playa sediments. The primary ore mineral is the potassium-uranyl-vanadate, carnotite ($K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3H_2O$). Despite the economic potential of channel and playa deposits, there is a dearth of contemporary research focused on understanding their genesis. As a result, there remains significant uncertainty about how these deposits form.

Significant findings include 1) a key mineral assemblage of authigenic Mg-clays and sedimentary dolomite with carnotite in both groundwater calcrete and associated clastic sediments that post-dates calcrete formation; 2) authigenic Mg-clays are an essential nucleation substrate for both sedimentary dolomite and carnotite; 3) comparison with other channel and playa uranium deposits in Western Australia and Africa reveals that this Mg-clay-carbonate association is common in channel and playa uranium deposits across the globe.

Carnotite precipitation is interpreted to be facilitated by evaporation-driven sedimentary dolomite precipitation, which establishes a positive feedback loop that dissociates uranyl-carbonate complexes, increasing carnotite saturation in pore water. Magnesium clays are interpreted to have a tandem role in this process, serving as an essential nucleation substrate for both sedimentary dolomite and carnotite. Magnesium clay-mediated dolomite nucleation also provides new insight into the dolomite problem. This long-standing issue arises from the disparity between the abundance of dolostone in the rock record and the inability to precipitate low-temperature dolomite under laboratory conditions. Recognizing sedimentary dolomite in channel and playa uranium deposits is important because it preserves a primary isotopic composition of near-surface aquifers.

Integrating these findings with previously published data into a mineral systems framework identifies seven factors that are required to form economic carnotite deposits: 1) sources of uranium and vanadium; 2) low hydraulic gradient; 3) high precipitation deficit; 4) shallow, unconfined, high permeability aquifers; 5) focusing of U-bearing groundwater into the zone of evaporation; 6) evaporation to drive the physico-chemical processes mediating carnotite precipitation; and 7) time.

Panton Sill: more dynamic than one long lived magmatic event.

Barbara Duggan, Future Metals Limited

The Panton Sill, which hosts Australia's largest PGM deposit in the East Kimberley, is historically considered to be an isolated intrusion. A recent deep drill hole and multi element analysis has confirmed the dynamic nature of the mafic-ultramafic intrusion, in particular, the presence of separate intrusive phases. The most significant being the discovery of a sulphide rich magma being emplaced first, followed by a platinum group mineral phase which hosts the economic PGM and chromitite mineralisation.

The initial magma has a strong Ni-Cu-S association that is confirmed in thin section by the presence of fine-grained magmatic chalcopyrite, pyrrhotite and pentlandite. An olivine oikocryst marker horizon, within the initial magma, is defined by a higher MgO content, a higher 2:1 ratio of Ni:Cu and an absence of Pt and Pd compared to the rest of the unit. This marker horizon is observed near the upper contact of this ultramafic which is overall up to 200m thick on the northern contact of the Panton Sill.

Following the emplacement of the initial intrusive ultramafic, a period of hiatus followed, which is defined by a zone of mixing up to 50m thick. The next intrusive ultramafic is characterised by a higher MgO content, an enrichment in Pt and Pd but a depletion in sulphur. This is distinctly different when compared to the initial intrusive that comprises the basal contact of the Panton Sill. The economic chromitite horizon and associated PGM's within this intrusive, are emplaced near the upper contact of the ultramafic that is up to 250m thick.

The identification of two distinct phases of magma, one sulphide rich and the other PGM rich, suggests further potential for fertility within the Panton Complex. These recent advances by the use of multi-element data have identified different intrusive phases as well as variation within the units. These variations, particularly in the basal ultramafic, suggest potential for magmatic sulphide exploration which has been previously overlooked.

Mapping the geochemical landscape over the Borden Lake Gold Deposit, Kapuskasing Structural Zone, northeastern Ontario, Canada

Richard Dyer, Sediment and Soil Geochemical Services

A multimedia geochemical survey was conducted to characterize the geochemical landscape surrounding the Borden Lake gold deposit prior to the development of the mine, which began production in 2019. Stream sediment, lake sediment, lake water and till were collected and analyzed for a comprehensive suite of geochemical parameters. Relative organic-inorganic content and landscape variations, including stream catchment/lake morphology were found to be significant sources of variability to consider when interpreting the geochemical data. Gold and Mo anomalies were detected in the down-ice direction up to 3 km from the deposit in both till and lake sediment. The patterns of molybdenum anomalies in all sampled media are corroborated by lithogeochemical data and visual observations of Mo within the Borden deposit mineralized envelope. Although the model for the Borden Lake Gold deposit suggests it was part of a syn-volcanic seafloor hydrothermal system that was remobilized during metamorphism as an orogenic gold deposit, the presence of Mo in the mineralized envelope and the Au-Cu-Mo signal detected in surficial media, suggests potential for an original Cu-porphyry system, which has recently been postulated for the Côté Gold Au(-Cu) deposit located in the Swayze greenstone belt, approximately 100 km to the southeast of Borden Lake.

Peat geochemistry transects over the Triple-J gold zone, McFaulds Lake (“Ring of Fire”) Area, Northern Ontario, Canada

Richard Dyer, Sediment and Soil Geochemical Services

Peat sampling transects across a known gold zone within the Ring of Fire (RoF) area were completed to test the viability of conventional peat geochemistry as an exploration technique in the thick peat landscapes of the RoF. The landscape of the region is complex, with extensive peatlands and glacial deposits overlying bedrock.

The initial sampling transect was widely spaced across the Muketei greenstone belt; subsequently several detailed transects were completed across Wyloo Metals (formerly Noront/Ring of Fire Metals) Triple-J gold zone. The peat samples were collected from at least 20 cm above the inorganic substrate. For comparison, samples of Black Spruce bark and inorganic substrate (clay till or glaciolacustrine clay) were also collected. In-situ moisture and pH measurements were obtained using a solid-state pH meter. The peat samples underwent conventional sample preparation (air drying and sieving at -50 mesh) followed by aqua-regia digest (ARD) ICP–MS and Enzyme Leach (EL) extraction ICP-MS. The inorganic substrate and bark samples underwent MMI® analysis.

The pH data show a drop over the Triple-J zone, inferring the possible influence of an acidic “cap” perhaps related to a redox chimney. Collectively, all the peat geochemistry results contributed to a suite of metals including Au, Bi, Mo, W and Zn that are spatially related to the Triple-J gold zone. These patterns include apical peaks, rabbit ears or edge anomalies. The weak leach (EL) peat geochemistry achieved the strongest signal to noise (S/N) ratio and breadth of metal suite, including the best Au response of all sampled media, compared to the results from clay substrate and tree bark.

Redox gradient transport is the most likely theory to explain the metal anomalies above the Triple-J zone. It is suggested that the high water table typical of RoF landscapes has resulted in a “redox front” (metal accretion zone) development within the overlying peat, possibly enhanced by the metal binding capacity of organics and consistent peat textures, which have contributed to produce a better S/N ratio compared to the variably textured inorganic substrates, that are typically below the water table in the RoF area.

Finding copper-gold deposits under cover: insights from silcrete geochemistry at Winu, Western Australia

Dr. Stephanie Greene, Supervisor Resource Geologist at Rio Tinto Copper – Winu, Dr. Michael Whitbread, Principal Geoscientist at Rio Tinto Exploration – AAR

A key challenge in the modern exploration environment is identifying prospective terranes under post-mineralisation sedimentary cover. The Winu deposit in the Paterson region of Western Australia's Canning Basin is a structurally-controlled Cu-Au deposit which occurs under ~70 m of Phanerozoic cover. Extensive drilling in the Winu area reveals that a certain horizon within the cover sequence overlying Winu has distinct geochemical signatures from those that occur away from the deposit. This horizon, a harder zone beneath the sand typically cemented by silica, has been variably logged as silcrete, ferricrete, or a mottled and siliceous zone. There is a strong spatial correlation between higher Nb/Al ratios in this silcrete horizon and the occurrence of leached cap in the Winu area. Applying this geochemical test to similar horizons from drillholes across the Paterson region suggests that similar composition silcrete/ferricrete are noted in other areas, including those with known mineralisation, but the genetic relationship to mineralisation is still conjectural. At least some supergene processes are therefore likely to have occurred after the deposition of the Phanerozoic cover sequence in the Paterson region, leaving geochemical signatures in the cover which may be predictive of supergene enrichment of Cu-Au deposits at depth.

Keynote: Fluid and Metal Sources in Archean Orogenic Gold Systems

Dr Scott Halley, Mineral Mapping Pty Ltd

Archean greenstone-hosted gold deposits are chemically and mineralogically zoned when observed at the scale of a gold camp. The pathfinder element patterns resemble modern porphyry-epithermal districts. The major element patterns are consistent with a mineralogical zoning from albite-K feldspar to albite+ potassic white mica to potassic white mica to muscovite-paragonite mixtures. The feldspar-rich assemblages commonly occur with hydrothermal biotite and are commonly adjacent to hornblende porphyry intrusions. The white mica bearing rocks, especially muscovite-paragonite commonly occur just at or below unconformities, where epiclastic rocks overlie the greenstone volcanic sequences. The white micas typically occur with chlorite and carbonates. The feldspar-bearing assemblages are typically anomalous in Mo-Bi-Te. The muscovitic assemblages are most anomalous in arsenic. The paragonitic rocks are most anomalous in antimony, cesium and lithium. The paragonitic rocks have pathfinder signatures that are characteristic of very low temperature hydrothermal environments such as the upper 1km of modern active geothermal systems. Where these rocks have been metamorphosed, they retain the same major element compositions, i.e. albite-muscovite-paragonite geometries on alteration geochemistry plots, and they retain the same low temperature pathfinder signatures, but they alter their mineral assemblages. For example, amphibolite-grade rocks end up with biotite-actinolite-calcic plagioclase but still have the same bulk chemistry as muscovite-paragonite-chlorite.

The accepted wisdom in ore-deposit models is that orogenic fluids are derived from greenstones as they undergo a transition from greenschist to amphibolite grade metamorphic facies, and the metal budgets in these systems are derived by extraction of metals and sulfur from large volumes of greenstones. However, the data patterns reveal that most orogenic vein arrays are formed within volumes of rock that had undergone earlier hydrothermal alteration. This suggests that the metals and sulfur were locally derived from within previously altered rock and travelled on a scale of perhaps tens to hundreds of meters. Fluid was generated by converting low temperature phyllosilicates to higher temperature assemblages. The highest volume of fluid would have been generated from smectite-bearing rocks, hence the association with low temperature pathfinders.

Differentiating detrital from chemically mobile element signatures by combining clay fraction soil geochemistry and spectral mineral proxies

Anicia Henne, Ryan R. P. Noble, Dave Craw, Ian C. Lau, David Cole

CSIRO Mineral Resources, Kensington, Western Australia

Here we combine multi-element geochemistry and spectral mineralogy of the ultrafine fraction of soil samples and interpret the results in machine-learned landscape context to separate chemically mobile from detrital geochemical signals. Soil surveys are often the first pass physical prospectivity method employed in greenfields exploration. In areas of cover, the ability to separate chemically mobile from detrital signals of target and pathfinder elements is crucial for exploration success. This is especially true in Australia, where approximately 80 % of the surface is covered in transported regolith (surface cover materials that develop via erosion, transportation, and sedimentation processes). Additional soil properties such as mineralogy and pH can give crucial additional information to successfully interpret geochemical results. However, these soil properties are traditionally not routinely analysed, and costs can be prohibitive. A recently developed soil analytical method (UltraFine+®) combines multi-element geochemistry, visible near-infrared reflectance spectroscopy on the ultrafine soil fraction, as well as pH, at cost-effective prices for routine greenfields exploration. Over 20,000 ultrafine soil samples across two sites in the Gascoyne Province and the Yilgarn Craton were analysed for 50 elements, spectral mineralogy proxies and pH. While the lithology in both settings shows similarities (e.g., highly felsic, differentiated, low Ca, Mg and Fe granites), they have undergone vastly different weathering histories. By interpreting the geochemical analyses and mineralogy proxies in the context of data-driven landscape models, we can distinguish exploration-relevant signatures, such as detrital Cu signals in smectite-rich alluvial channels and chemically mobile Au associated with relict primary versus detrital signatures in weathered secondary mineralogies.

Finding beauty in the old and imperfect: extracting value from historic geochemical datasets and pXRF in the Red Lake gold complex, Ontario, Canada

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Some of the highest impact improvements to ore deposit knowledge and exploration models can be realised by maximising the value from pre-existing, large but unloved geochemical datasets, however variable and flawed they are. Likewise, under-utilised portable analytical technologies (e.g. pXRF) have the potential to rapidly provide fit-for-purpose data in applications beyond the target metal analyses they are typically used for, both in exploration and ore characterisation applications.

Good examples of the aforementioned opportunities come from the Red Lake gold complex, Canada. Here, a pre-existing, very large multi-element geochemical dataset has been used to better map lithological units and inform 3D geological modelling for resource estimation and near-mine exploration targeting. Despite limitations due to significant analytical issues and a diversity of analytical techniques and elemental suites, the most stratigraphically important rock units can be discriminated using this dataset, including different geochemical suites of visually similar basalts and of felsic igneous rocks. The improved stratigraphic resolution also enables better reconstruction of mineralisation-related litho-structural architecture and better prediction of trap sites for improved near-mine targeting. Additionally, most stratigraphically important rock units at Red Lake can be more effectively discriminated using pXRF analysis of drill core during logging, avoiding long turnaround times for traditional assay laboratory analysis.

Geochemical and mineralogical signatures of the Rocklands Cu-Au-(Co) deposit, Northwest Queensland, Australia

Dr Rhiannon Jones, Dr Elena Belousova, Courteney Dhnaram, Dr Vladimir Lisitsin, Dr Alkis Kontonikas-Charos, Dr Al-Tamini Tapu and Dr Benjamin Hines

The Rocklands Cu-Au-(Co) deposit is one of numerous mineralogically and geochemically diverse IOCG deposits in the Mount Isa Province of Northwest Queensland, Australia. Rocklands consists of two major, structurally controlled ore bodies; Las Minerale and Rocklands South, hosted within Proterozoic metasedimentary and volcanic rocks. The deposit contains a supergene enrichment blanket and hypogene mineralisation with dominantly sodic and calcic-ferric alteration.

The Geological Survey of Queensland (GSQ) characterised five drillholes from Rocklands South and Las Minerale using a range of hyperspectral, geochemical, and microanalytical techniques. Continuous hyperspectral and XRF core scanning with systematic whole rock multi-element geochemistry provided an effective method to classify alteration and lithology variations throughout the deposit. Selective samples were analysed using Bruker Tornado µXRF imaging and SEM-TIMA to resolve detailed paragenetic relationships and fine-scale mineral associations. Based on Tornado and SEM-TIMA imaging, multiple samples of sulfides and Fe oxides were selected for Fe and Cu isotope analyses, as part of a systematic GSQ program of geochemical and isotopic fingerprinting of IOCG deposits in the Cloncurry district.

Hyperspectral and microanalytical analyses revealed the occurrence of distinct alteration zones of dominant albite, actinolite, carbonate and, locally, K-feldspar. Comparison between whole rock multi-element geochemistry data and microanalytical analysis of selective samples highlighted a decoupling between the association of Cu and Co. Detailed SEM-TIMA analysis enabled us to investigate the distribution of Cu and Co and to recognise the occurrences of Cu and Co-bearing mineral phases. Cobalt-bearing phases included carrollite, linnaeite, and pyrite (in the lattice and within Co mineral inclusions), which were typically associated with chalcocite, bornite, and chalcopyrite.

The detailed characterisation of the Rocklands Cu-Au-(Co) deposit provides new insights into the nature of Co and Cu mineralisation and offers a framework for enhancing the understanding of mineralogical and geochemical signatures and the critical element deportment within IOCG deposits of the Mount Isa Province.

Mapping mineralogical footprints to constrain the geochemical modelling of the Nifty sediment-hosted copper deposits

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Mineral exploration under cover relies on understanding ore-forming processes and their mappable proxies using a variety of geoscientific datasets. Mapping mineral system footprints, including alteration minerals and geochemical gradients and anomalism, is a standard method of vectoring towards an ore body. However, alteration in sediment-hosted deposits is subtle and challenging to identify during drill core logging or from whole-rock geochemical data. The scarcity of knowledge regarding broader changes in mineralogy, geochemical characteristics and petrophysical response, each reflecting fluid-rock interaction, in these deposits significantly affects exploration success. The Nifty deposit, which is the focus of this study, is a sediment-hosted copper deposit located undercover within the Paterson Orogen of NW Australia.

This study aims to map the mineral assemblages at Nifty, including zonation in mineral abundance and composition to identify indicator minerals for sediment-hosted copper deposits, with subsequent application in geochemical modelling. In doing so, we address several questions: (1) Which minerals are associated with Cu mineralisation? (2) How do mineralogy and mineral composition change from the proximal to distal alteration footprint of the deposit to the barren host rocks? (3) Which mineral assemblages can be mapped on camp and regional scales using hyperspectral data? (4) How can we use this knowledge and data in geochemical modelling to assist targeting? To achieve these goals, silicate and sulfide minerals from the mineralising system and unaltered country rocks were characterised at the drill core scale using hyperspectral scanning (HyLogger3) and through micro-analytical studies, including micro-XRF mapping and SEM-based mineral mapping (TIMA).

Using hyperspectral data from drill cores, we identify zonation in alteration minerals associated with Cu mineralisation and associated hydrothermal fluids across a traverse from unaltered country rock to distal and proximal alteration zones. Mineralogy inferred from hyperspectral data was verified and further investigated through optical microscopy, scanning electron microscopy EDS and TIMA analysis to explore the subtle variations in the chemical composition of minerals. The results were used to constrain the geochemical-mineralogical modelling in understanding the mineralisation processes.

Tracking distal footprints and alteration signatures of Fe-oxide Cu-Au systems: A case study of the Ernest Henry camp, Cloncurry District, Queensland

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Vectoring towards ore deposits using a combination of geochemistry and mineralogy has successfully been applied in exploration for diamonds and porphyry deposits. However, in many instances, studies taking this approach are restricted to limited availability of samples and/or analytical techniques, as well as only targeting individual indicator minerals. Furthermore, alteration footprints of these deposits (i.e. porphyries) are typically < 2km. Conversely, IOCG systems are typified by very large alteration halos (> 5km) that are characterised by a complex combination of regional scale Na-(Ca) alteration and multiple local stages of alteration, including Na-Ca, Ca-Fe, K-Fe, and/or hydrolytic. The Cloncurry district, Queensland, contains numerous economically important IOCG deposits, of which the Ernest Henry deposit is the largest and most well-studied. Here we apply our integrated GSQ analytical workflow to track changes in geochemical and mineralogical footprints of large IOCG systems, using the Ernest Henry camp (including the E1 deposit) as a case study.

The Ernest Henry Fe-oxide-Cu-Au deposit and E1 deposit are hosted within Proterozoic metavolcanic and metasedimentary rocks of the eastern Mount Isa Province. A challenge of navigating alteration footprints in the Ernest Henry camp is the presence of multiple generations of key alteration phases occurring at regional (Na-Ca, albite-actinolite-titanite-carbonate) and pre-ore (K-feldspar-biotite-magnetite-titanite) stages, as well as at syn- (Magnetite-chalcopyrite) and post-ore (carbonate-fluorite-barite) mineral assemblages. We selected over 200 samples from drillholes within and spanning 3-4 km outside the Ernest Henry and E1 deposits to determine how geochemical and mineralogical footprints change with distance to ore. Using a combination of analytical techniques (Bulk geochemistry, HyLogger, µXRF mapping, SEM-TIMA, EPMA and LA-ICP-MS) to characterise our samples and effectively target suitable phases, we build on existing works by taking a holistic mineral chemistry approach by analysing multiple generations of actinolite, biotite, chlorite, apatite, titanite, garnet, feldspars and carbonates to map integrated mineral system footprints in trace element and stable isotope geochemistry (Cu, Fe, Ti, V, O, S, Ca, C) that could be used for vectoring towards ore in similar terranes.

Characterization of metal-bearing nanoparticles observed in loess-covered terrain: Implications for prospecting

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The recent depletion of mineral resources near the Earth's surface has led to a shift in mineral exploration toward concealed deposits in covered terrain. Consequently, significant attention has been directed toward metal-bearing nanoparticles in the soil above such deposits to gain insights into the composition of concealed ore bodies.

The characteristics of metal-bearing nanoparticles in ore samples of the Zhonghedi Ag-Pb-Zn polymetallic deposit and their overlying loess were systematically analyzed using transmission electron microscopy. Numerous nanoparticles containing Ag, Au, Cu, Pb, Zn, Fe, Mo, and other metallic elements were observed in the loess overlying the deposits as well as the ore samples. These nanoparticles exhibit a well-defined crystal shape, suggesting their primary particle nature. Moreover, the nanoparticles in the loess and ore samples share similarities in element distribution, size, and type, demonstrating their homologous nature. However, ore-related metal-bearing nanoparticles were not detected in samples collected from the background areas. Most metal-bearing nanoparticles in loess, excluding native particles, were oxides and sulfates, which may be attributed to oxidation of the native metal particles near the surface where oxygen fugacity increases. The elemental mapping of the nanoparticles showed that the ore-forming elements had the same distribution patterns and element assemblages to the ore material. These results indicate that metal-bearing nanoparticles in the loess have likely relationships with concealed ore bodies. Accordingly, the metal-bearing nanoparticles in the loess can provide information about concealed ore deposits, explain surface geochemical anomalies, and improve prospecting accuracy as a vector to mineralization.

Routinely finding nanoparticles in transported cover remains a challenge. However, this study shows it is viable and marks substantial progress in our knowledge and comprehension of metal-bearing nanoparticles in loess-covered terrain. Evidence of their presence and association with concealed ore bodies contributes significantly to our understanding of mineral exploration processes and offers new avenues for future research and practical applications.

Isotope mapping in mineral exploration: modern and Archean Perspectives

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Over the past decade, isotope mapping has emerged as a powerful tool in mineral exploration, revolutionizing our understanding of lithospheric architecture, metallogenic fertility, and ore genesis. Using the two-stage depleted mantle model age (TDM^2) or crustal residence time (TCR) of felsic igneous rocks, Sm-Nd and Lu-Hf isotope maps help understand variations in crustal source compositions in space and time. They aid in identifying and mapping crustal boundaries in modern orogens and Archean cratons.

In the Tethyan and Central Asian Orogenic Belts, isotope mapping revealed crustal architectural controls on critical metal ore systems. Porphyry Cu ± Mo ± Au deposits are confined to juvenile crustal domains (low TDM^2 and TCR), supporting the importance of mantle-derived magmas in generating porphyry Cu systems. By contrast, other metal deposits, such as granite-related W-Sn-Nb-Ta and REE deposits, are associated with ancient crustal domains (high TDM^2 and TCR), where multiple stages of crustal reworking have resulted in the release of these metals into crust-derived magmas. The U and Ag-Pb-Zn deposits occur predominantly in ancient crustal domains and at their margins in those orogens.

In the Archean Yilgarn craton, isotope mapping reveals fundamental lithospheric architecture separating isotopically distinct domains that have different metal endowment. For example, the Ida Fault, corresponds with one of the world’s most notable isotope gradients between the more ancient Youanmi Terrane and the more juvenile Eastern Goldfields Superterrane. This trans-lithospheric fault is interpreted as the margin of an intracontinental rift formed at c. 2.7 Ga. Many Tier 1 nickel, gold and lithium deposits developed in the hangingwall of this translithospheric fault zone. Isotope maps also identify more juvenile domains including the Cue Rift, which have higher Ni-Cu-PGE and Au endowment related to greater mantle input. Moreover, the integrated geochemical and isotope mapping has revealed an early ENE-trending basement architecture, which potentially controlled many lithium pegmatite deposits including Greenbushes in the Yilgarn craton.

The Geological Survey of Western Australia regularly releases isotope data including Sm-

Nd, Lu-Hf, and O isotope maps, providing an unprecedented opportunity for enhancing exploration targeting. Integration of isotope data with geological, geochemical and geophysical datasets can significantly reduce exploration risk.

Blue-sky ~~mining~~ mineral exploration; the figuratively changing landscape of exploration through cover

Ryan Noble (and many colleagues)

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The “blue-sky” idiom has two nearly opposing meanings, 1) to have unrealistic, impractical ideas or 2) to think creatively outside the box and, importantly, to generate innovative ideas. When it comes to mineral exploration through cover, collectively we’ve managed to apply new approaches from both meanings. This presentation will cover some examples of both, with a focus on the more innovative ideas over the past decades that I have been biased by and fortunate to be exposed to. Pioneering geochemists and geologists such as the late Roy Woodall made substantial discoveries in rapid succession, by applying open thinking and what we would now consider basic geochemical analyses but were novel and forward thinking at the time. The analytical progress in exploration has continued at a fast pace, but perhaps our open, interdisciplinary thinking has not continued at the same rate when it comes to applying new approaches and more interdisciplinary thinking. A lot of opportunities exist in covered terrains, with vast resources of precompetitive data and historic samples, as well as novel tools that have opened new search areas. The age of AI, big data, remote sensing and more bears the potential to make new discoveries. How do we harness these ideas, skills and data into standard everyday exploration approaches? Changes in sample media, partial extractions, particle size analysis and the introduction of different analytical data types are examples of improved geochemical approaches. Historically, some of the larger, multi-year research efforts (e.g., AMIRA, CRC LEME) have been a key part of building this knowledge and future exploration requires similar efforts guided and driven by scientific research. Some of these efforts are already on the way, such as the addition of machine learning to improve our surface and subsurface mapping which could fundamentally improve the landscape (figuratively and literally) making exploration through cover more amenable. To put this another way, the future horizon looks to have, hopefully, bluer skies for mining and exploration.

Porphyry Cu-Au Discovery, Guintar-Niverengo, Colombia, Using A Single Analytical Method On All Sample Types

Nicholas Oliver

HCOVGlobal

We present here the results of a systematic geochemical approach, fused with geology and geophysics, to successfully identify a new porphyry Cu-Au system in the fertile Cauca Belt of Colombia. The Guintar-Niverengo project sits in the Cauca Belt near to several very large yet-to-be-developed porphyry Au and Cu resources including La Colosa and Quebradona.

Most of the difficulty with progressing geochemical studies into the modern AI age of exploration relates to the raw data collection procedures and quality of the generated laboratory data, not the sophistication of the processing and interpretation software. In turn, the latest geochemical software is so powerful it makes sub-standard geochemical data an embarrassment. This has been exacerbated by a traditional separation of analytical methods depending on the sample materials, eg aqua-regia for soils, ICP-AES for regional grab samples, ICP-MS for orebody-proximal drilling, and more recently portable XRF etc. for rapid resource definition drillouts. Commercial laboratories do not provide very useful public advice on decision making within their analytical menus, so many exploration companies use poorly perceived budget constraints to decide on a semi-random analytical smorgasbord.

We used 4-acid digest ICPMS from a single laboratory on every sample (soil, grab, core) gathered from a mountainous tropical terrain with thick soils and moderate to dense rainforest. This allowed recognition and separation of the specific effects of weathering and soils on previous distributions of protoliths, metals and alteration. The soils-related depletion of Ca, S and Na in particular required care when considering several porphyry-epithermal targeting indicators. Using ioGAS, we were able to establish which metals, alteration signals and weathering-modified signals could be used to establish protoliths, alteration zones and the original temperature-dependent hydrothermal metal zonations, irrespective of the sample type. This led to a successful set of porphyry Cu-Au drilling intercepts, with ongoing potential to expand that resource. The novelty is geochemical analytical consistency irrespective of sample type!

Reinterpretation of the multistage mineralization events at the sediment-hosted Nifty Copper deposit, Western Australia

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The sediment-hosted Nifty copper deposit was discovered in 1980 and mining commenced in 1993. Four peer-reviewed publications have addressed the nature of the primary mineralization, but only one has framed key findings around a paragenesis. Our reinterpretation of Nifty is based on detailed paragenetic studies combined with large geochemical datasets.

Our work shows that low temperature, carbonate-replacement style Zn-Pb-Cu mineralisation associated with dolomite ± siderite ± phengite alteration was deposited between 810Ma to 780Ma. LA-ICPMS data from pyrite, sphalerite and chalcopyrite associated with this event is elevated in Ag, As, In, Mn, Tl, Pb, Cd, Sb. Following this, low-grade, stratiform chalcopyrite mineralisation formed. We know least about this event, but it is associated with ankerite, dolomite, and phengite alteration and does not share whole-rock geochemical affinities with the earlier Zn-Pb-Cu event or the paragenetically later high-grade Cu event. Bismuth, As, In, Tl and Ga were introduced during this mineralisation event.

The main copper event is vein and breccia style chalcopyrite mineralisation. Mineralisation is associated with quartz/silica, phengite, chlorite, biotite, siderite and trace albite, and appears to have formed over a protracted period of time. Re-Os ages from pyrite and U-Pb ages from monazite associated with this event extend from 697Ma to 648Ma. A Rb-Sr age of 619±14Ma comes from a chalcopyrite-biotite vein. Deformed and en-echelon veins, decrepitated fluid inclusions and brecciated Cu mineralisation indicate that most of this mineralisation formed during deformation. Sphalerite and chlorite geothermometry shows that the quartz-chalcopyrite veins and breccias formed between 285°C to 320°C. Copper was introduced with Sn, As, Bi, In, Sb, Ga, Co, Au and Ag. LA-ICPMS data from vein pyrite and chalcopyrite is elevated in Sn, Co, In, Bi, Ga, Sb. Our work shows that Nifty did not form during one event, but had a protracted and complicated history.

Geochemical and geological features related to gold mineralization within the epithermal high sulphidation Antonio deposit, Yanacocha district, Peru

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Antonio is an epithermal high sulphidation deposit in the world-class multimillion ounce gold producing Yanacocha district, located within the northern Andes of South America.

To compliment decades of near-surface exploration in the district, attention has pivoted to identify opportunities to apply new technologies to advance orebody knowledge and accelerate underground gold discoveries to extend mine life of the operations. Current resources in Antonio deposit exceed 1 Moz Au averaging 5.6g/t Au. This resource is blind, occurring under non-prospective lithological units and only exhibits a cryptic hydrothermal alteration at surface. Gold mineralisation is hosted within a Miocene andesitic to dacitic volcanic stratigraphy and is associated with a hydrothermal alteration mineral assemblage that includes sulfide-rich pervasive silica, massive to vuggy silica, and an alunite core that grades vertically and progressively to silica clay and propylitic halos towards surface. Economic gold mineralization is both lithologically and structurally controlled within a 1km long and 50m wide tabular body along a preferable NW-SE trend that gently dips. This work integrates systematically collected surface and downhole data using complete characterization multielement geochemistry with geological field mapping, core logging and hyperspectral core scanning across a representative cross section through the Antonio deposit to improve lithological, alteration and the mineralisation paragenesis understanding that can be used as a vector towards economic gold mineralisation and applied as a tool for future exploration at depth in the district.

Snow geochemistry as an environmentally friendly mineral exploration tool – Examples from Finland

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Snow is one of the most promising, new sample materials that can be used in mineral exploration. The exogenic geochemical signal of elements and hydrocarbons formed into the snow can be used in analysis of the elemental composition and tracing the potential mineralization in the underlying bedrock. The method is based on the so-called Mobile Metal Ion (MMI) theory, where metal ions and certain hydrocarbon released from the mineralisation in bedrock migrate through the surficial part of the bedrock and transported cover to be accumulated into the surficial soil horizons or disappears in the air. Even in winter, the movement continues, but the carbon dioxide and water vapour as well as various volatile hydrocarbons, and ions accumulate in the bottom layers of snow cover (in the areas where snow cover exists), where they adhere and bind to the snow crystals.

The lower part of the snow cover serves as the best ion binding layer, as the formation time of geochemical signal is the longest, and the upper layers of snow protect against atmospheric contamination during the winter. In addition, the lowest layer is in contact with the ground and is affected by gases and heat from the underlying soil and bedrock. In the northern regions, snow covers the ground surface for several months in a year, so the method is usable in moderately large areas of the Northern Hemisphere and mountainous areas. Snowfall and snow properties are regionally constant, which provides a good basis for extensive and comparable geochemical exploration. Snow cover provides easy access to all kinds of terrains during wintertime and snow sampling can be done without leaving any traces to the ground and environment. There are several examples in Finland how the snow geochemistry has been used as an effective exploration tool for different types of mineralization. The strongest contrast is found in mineralization where sulfide minerals are present, such as in orogenic gold deposits and hydrothermally altered, vein-type and/or VMS-type deposit Cu-Co-Ni occurrences. However, good anomaly patterns have also been found in the case of IOCG and phosphate deposits. Experiments prove that snow geochemistry is not only working for tracing surficial or suboutcropping mineralization but also for deep-seated ore deposits.

The project has got funding from the K.H. Renlund’s Foundation.

Developing new indicator minerals for the exploration of nickel sulfide deposits

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The exploration and discovery rate of magmatic Ni-Cu sulfide deposits needs to increase to meet the global demand for renewable technologies. To aid in this endeavour, we have developed a method using trace element signatures in common minerals to assess the prospectivity of exploration regions. We have examined the trace element content of spinel (chromite-magnetite), olivine, pyroxene, apatite, ilmenite, and plagioclase and how these signatures vary between mineralised and unmineralised intrusions and komatiites. We have created a large and robust mineral chemistry database from 1,160 samples collected from 12 case study areas in Western and South Australia. We have supplemented these with samples from world-class ore deposits globally. The dataset contains over 11,000 individual mineral analyses and was interpreted using machine learning models to predict the likelihood of an individual mineral analysis being associated with magmatic sulfide mineralisation. Spinel analyses were the most numerous in this study, and this large dataset allows for confident predictions of grain compositions from mineralised versus non-mineralised intrusions or flows (77% accuracy). Based on model introspection, the critical elements used to make these predictions included Co, Ga, V, Ni, and Cr. Further, trace element analysis of spinel shows the potential to indicate both prospectivity and sulfide volume which could vector toward more extensive and economic deposits. We show evidence that weathering and regolith formation have little effect on the trace element composition of spinel, making it an ideal resistant indicator mineral for exploration. Other minerals, such as olivine, plagioclase, and pyroxene do not survive within the weathering profile. However, these minerals still show potential for use as in-situ indicator minerals. For example, pyroxene can be examined for trace element (Cr-Ti) variation within grains to understand if an intrusion has the potential to be a magma conduit. Although not a direct indicator of sulfide presence, conduit intrusions have a high throughput of silicate magma, which can create a metal-rich sulfide (if sulfide saturation has occurred). Our research shows that indicator minerals can be a valuable addition to the exploration toolkit, enhancing exploration globally.

Certified Reference Material Accepted Values and Tolerances: Some Idle Thoughts and an Idea or Two

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Certified reference materials (CRMs) are used to assess the accuracy and precision of element concentrations determined by geochemical laboratories. CRM accepted values (means) and tolerances (standard deviations) are derived via round-robin analysis of randomly selected sub-samples at multiple geochemical laboratories using ostensibly common analytical procedures. Unfortunately, CRM sub-sampling, digestion, and analysis procedures vary, as many laboratories implement custom calibrations and tweaks that they view as beneficial and industry-competitive, significantly degrading CRM round-robin result conformity.

Statistical evaluations of these results illustrate that between-laboratory variances are commonly far larger than within-laboratory variances. The procedural differences employed by laboratories likely invalidate the use of the variances as tolerances and bias the accepted values. CRM round-robin variances also tend to be larger than CRM variances in normal geochemical analysis because they are derived from several laboratories (not just the one used for the geochemical survey). This causes CRM results to pass QAQC 'fit for purpose' thresholds far more frequently than expected, preventing geoscientists from recognizing analyses with unacceptable errors.

To ensure that CRM analyses produce appropriate accepted values and tolerances, outlying analyses and laboratories are excised from consideration. Unfortunately, the outlier recognition methods used to date have not been effective in adequately removing the inter-laboratory variation. Moreover, although outliers are identified, no corresponding analytical cause is generally recognized to justify elimination of these data from consideration, invalidating their excision.

An agglomerative dendrogram clustering approach to quantify inter-laboratory variation is presented herein. This method uses the Mann Whitney U test statistical probability as its distance measure, determining its own threshold to terminate clustering. Results are, to date, disappointing.

Clearly, current procedures for producing CRM accepted values and tolerances IS NOT WORKING. Improving CRM round-robin data quality is likely going to require the formation of a panel of stakeholders (geochemists, CRM producers, analytical laboratories, geologists, regulators, etc.) charged with identifying best practice CRM accepted value and tolerance production methods to allow their confident use in the mining and environmental industries.

Characterization and Spectral Zoning of the Transition from Epithermal Systems to Porphyry in the Peruvian Andes.

MSC. Johnny Vargas Miranda, Newmont Mining

In the Peruvian Andes, on the Andean Cycle, the emplacement of porphyry Cu-Au-Mo Illari (79-78 Ma), discovery from Newmont in Northern Peru's Cretaceous magmatic arc. In the Inca I phase, were emplaced the Cu-Mo porphyry Cerro Verde (58 Ma), Toquepala (56 Ma), Quellaveco (54 Ma), Cuajone (53 Ma) in the Lower Pleocene to Eocene.

In the Abancay deflection, Upper Eocene-Oligocene skarn-related porphyries such as Las Bambas (36 Ma), Cotabambas (36 Ma), Antapacay (35 Ma), Haquira (34Ma), Tintaya (33 Ma), and Los Chancas (32 Ma).

The Huamachuco-Huancabamba belt host the La Arena porphyry (Alizar - 25.85 Ma) associated with high-sulfidation epithermal gold, Calaorco (25.8 Ma) and Vanessa (25.7 Ma) linked to the Inca III and IV phases. The Lower Miocene porphyry Chipispaya in the south (23 Ma), in the north Galeno/Michiquillay (20 Ma), La Granja (17 Ma), Perol (15.8 Ma), Magistral (15Ma), Cerro corona (14Ma) and Kupfertal (10.7 Ma), showing vertical transition to San Jose high-sulfidation system (10.7 Ma). High Sulfidation systems such as Lagunas Norte (17Ma), Pierina (14.5 Ma), Tantahuatay (12.4 Ma) and Yanacocha (11.5 – 8.5 Ma). In the Southern Peru, low to intermediate sulfidation Au-Ag systems include Orcopampa (17 Ma), Selene (14 Ma), Caylloma (11.8 Ma), and Arcata (5.4 Ma). Younger systems: Corihuarmi, Arasi, and Aruntani (4.6 Ma) from Upper Miocene-Pliocene.

The link between porphyry and epithermal deposits, high-and intermediate-sulfidation, is well-documented (Sillitoe, 1973, 2010; Hedenquist et al., 1998, 2022). Degassing intrusions form potassic alteration: K-feldspar - Biotite, in porphyry systems and lithocaps of advanced argillic alteration, with residual quartz and Alunite, Kaolinite/Dickite, Pyrophyllite, Diaspore, Topaz and Zunyite. Leaching and quartz residual formation start below ~220°C (Hemley et al., 1969; Stoffregen, 1987; Hedenquist, 2022). Lower salinity liquid leads to chlorite and white mica/ sericite in hydrothermal alteration, while epidote forms in propylitic and kaolinite-smectite in argillic/intermediate argillic.

Spectral tools operate within the electromagnetic spectrum. Portables PIMA, ASD, TerraSpec, Halo, specTERRA and ArcoPIX, since the 1990s, in VIS-NIR-SWIR. Desktop tools, Hyglogger, Geological AI, BoxScan + XRF, CoreScan, now integrate MIR-LWIR, like Core – TheiaX and TerraCORE, with variety in spectral resolution. Using Halo, TerraSpec, and specTERRA, we obtain spectrums of epithermal and porphyry alteration minerals and defined with Newmont's method, aiSIRIS / aiSWIFT.

In Kupfertal (10.7 Ma), a transition occurs from the San Jose High Sulfidation (10.7 Ma). Patchy texture with Quartz-Pyrophyllite-Alunite and Quartz-Pyrophyllite-Zunyite changes to Wormy texture and "A"-type quartz veins with White Mica, characteristic of porphyry system; potassium alunite from shallower depths may combine with pyrophyllite from higher temperatures.

At Tantahuatay, alunite dated at 12.4 Ma. Associations include quartz-alunite, quartz-pyrophyllite, and quartz-pyrophyllite-alunite, of advanced argillic alteration. Patchy texture with pyrophyllite and alunite; absorption patterns reveal only K _Alunite. At Corihuarmi, Vuggy Silica alterations, Quartz-Alunite, Quartz-Clays, bordered by Argillic and Propylitic alterations. At Diana, Patchy texture of potassium alunite and quartz. Spectral geology is crucial in systems lacking "Patchy" or "Wormy" textures, utilizing VIS-NIR-SWIR reflectance spectroscopy.

Hydrothermal alteration mineral systems analyzed using TerraSpec spectra identify the minerals found in both epithermal and porphyry environments. The vertical distribution of minerals, ranging from low to high temperature and pH, along with their associations, offers insights into the hydrothermal system's history. Considering erosion and structural conditions, we can determine the type of alteration, its position, and the degree of preservation of the hydrothermal system, covering from epithermal to porphyry environments.

Theme: Exploration

Can the National Geochemical Survey and Heavy Mineral Map revitalise major greenfields discoveries? A case study of the Darling Headwaters says Yes!

John Anderson

One of the excuses for the paucity of greenfields minerals discovery in Australia is “The Cover”. As most of the known deposits are on drainage divides, there is no doubt Industry is poor at exploring through any sort of cover. It is time to close that gap with good management and geoscience.

The co-located catchment drainage samples for the 2011 NGSA and 2023 HMMA pre-competitive datasets provide a matrix of target vectors to take on the next level of exploration challenge and opportunity in thinly-covered regions. Early partial release of the HMMA data enabled a case study of the southern margin of the Eromanga Basin.

The mineral and hardness variables for the new HMMA data are integrated with the preceding nine variables of the NGSA data. Geochemical and mineral pathfinder suites are selected to provide proximity measures for different deposit classes. For example, combined gahnite and rhodonite provide initial measures of BHT proximity. Although cassiterite is a direct HM member of tin systems, it is also potentially a distal indicator due to its hardness and ability to migrate across catchments. The concept of Pathfinder Dispersion Fields is developed comprising multiple contiguous catchments with outlet samples containing HM representing a single deposit class. This enables vectoring back to near-, proximal- or distal- source areas. Multiple overlapping PDFs can be untangled by using HM members that are exclusive to each deposit class.

Sulphides are well-represented, requiring local preservation near subcropping basement highs. Nationally high pentlandite, chalcopyrite, sphalerite, galena, cassiterite and scheelite observations in the Darling Headwaters imply special preservation conditions and near copper nickel and tin tungsten mineral systems.

The anomalism of the Darling Headwaters is explained by the strongly convergent pattern of the young catchment system. Divergent catchments draining the divides at Broken Hill and Mount Isa to distant outlets have more erratic and subtle HM signatures that are still valuable information. The national NGSA/HMMA data potentially maps new tectonic & metallogenic provinces. Examples will be discussed.

Innovative geochemical vectoring within a new tectono-stratigraphic framework disrupts iron oxide copper gold exploration in South Australia

John Anderson

A common tectonic setting, magmato-hydrothermal signatures and stratigraphic correlations are proposed for the coeval yet diverse mineral deposits of the 1590Ma Olympic Metallogenic Event. Haematitic IOCG deposits, headed by Olympic Dam, and the Paris-Nankivel epithermal-porphyry system are on either side of an interpreted mega-caldera infilled by Gawler Range Volcanics. The OME was triggered by caldera collapse between the precisely dated Lower and Upper GRV. Both deposit styles are fluorine-enriched. At Paris silver deposit, rhyolite dykes have low Zr/Hf signatures characteristic of major hydrothermal systems. The dykes are intermingled with the mineralised epithermal breccia producing a mixing trend of zirconium depletion. The Zircon Alteration Index (40 - Zr/Hf) is proposed as a simple wholerock alteration measure independent of inherited zircon signatures in diverse host rocks.

Public data for the Emmie Bluff/Oak Dam camp is re-interpreted to show a sequence of sandstone, mafic ironstone and red shale is altered and collapsed into the HIOCG breccia pipes. The sequence is correlated with the Lower Pandurra Formation previously considered younger cover to the eroded tops of the HIOCG deposits. The pipes are now interpreted to form hydrothermal mounds at the palaeosurface subsequently covered by a haematitic siltstone correlated in this study with the Upper GRV. The enigmas of clastic sediment inclusions within Olympic Dam and therefore a missing "Olympic" Basin are now resolved. The HIOCG deposits are confined to 1590Ma depo-centres of Lower Pandurra proposed for redefinition as the Emmie Formation. The younger and more extensive cover of 1500Ma Upper Pandurra forms the true Cariewerloo Basin as defined in the Pandurra area.

Tested within the new 4D framework of the tectono-stratigraphic model, ZAI is confirmed as a valid vectoring tool that requires less drilling. ZAI in the Red Shale peak OME marker provides a regional pathfinder enabling early selection of target areas. Increasing ZAI directs drilling towards the prospective sedimentary facies and mineralogical alteration on the aprons to the HIOCG pipes. HIOCG target areas revitalised by re-assessment of historic drillholes will be discussed.

A regolith mineralogy map of South Australia

Adj Prof Patrice de Caritat, Curtin University, Geoscience Australia, Dr Anna Petts, Geological Survey of South Australia

Bulk quantitative mineralogy of regolith is a useful indicator of lithological precursor (protolith), degree of weathering, and soil properties affecting various potential landuse decisions. To date, no empirical national-scale maps of regolith mineralogy are available in Australia. Satellite-derived mineralogical proxy products exist, however, they require on-the-ground validation. Catchment outlet sediments collected over 80% of the continent as part of the National Geochemical Survey of Australia (NGSA) afford a unique opportunity to rapidly and cost-effectively determine regolith mineralogy using the archived sample material. Combining regional datasets of surface mineralogy and geochemistry can be crucial for deciphering and understanding regolith processes.

Here, we report on X-ray diffraction (XRD) mineralogical data and metadata obtained on a subset of 170 NGSA ‘top outlet sediment’ (TOS) samples, collected from a depth of 0 to 10 cm, covering most of South Australia (SA). Mineral identification was carried out on both bulk and clay (<2 μm grain-size) fractions using EVA®, whilst quantification was determined using Siroquant®. Resulting mineral abundances are reported with a Chi-squared goodness-of-fit between the actual diffractogram and a modelled diffractogram for each sample, as well as an estimated standard error (esd) measurement of uncertainty for each mineral phase quantified. Sensitivity down to 0.1 weight percent (wt%) was achieved, with any mineral detection below that threshold reported as ‘trace.’ Data quality was deemed fit-for-purpose for regional regolith mineralogy mapping.

Around 30 mineral phases were identified in the SA regolith, in order of decreasing commonality: quartz (identified in all 170 samples), kaolinite, K-feldspar (165), micas (group), plagioclase, smectite/illite-smectite (135), anatase, mixed layer illite-smectite, calcite (97), hematite, chlorite (group) (58), amphibole, rutile (28), halite, gypsum (20), goethite, aragonite (16), zeolite (group), jarosite (8), pyrite, smectite, talc, ankerite (7), dolomite, alunite (3), bassanite (a partially hydrated calcium sulfate), nosean (a sulfate bearing feldspathoid), palygorskite or illite-smectite/vermiculite, and vermiculite (2). Poorly diffracting material was also quantified and reported as ‘amorphous’ (identified in 169 samples).

Mineral abundance patterns in the SA dataset suggest a strong link to geology, including proximity to fresh bedrock, weathering during sediment transport, and robust relationships between mineralogy and geochemistry. Examples of this will be shown.

A regolith strontium isoscape of Australia

Adj Prof Patrice de Caritat, Curtin University, Geoscience Australia, Prof Anthony Dosseto, University of Wollongong, Dr Florian Dux, University of Wollongong

Strontium isotopes (^{87}Sr/^{86}Sr) are useful to trace processes in the Earth sciences as well as in forensic, archaeological, palaeontological, and ecological sciences. As very few large-scale regional Sr isoscapes exist in Australia, we have identified an opportunity to determine ^{87}Sr/^{86}Sr ratios on archived floodplain sediment samples from the low-density National Geochemical Survey of Australia (NGSA). Over the last few years, we have analysed 545 ‘bottom outlet sediment’ (BOS) samples from NGSA sites over three regions, each approximately 1 million km^2 in size: inland southeastern, northern, and southwestern Australia. The BOS samples were collected on average from 60 to 80 cm deep, thus minimising recent anthropogenic effects (e.g., fertiliser application, changes in sediment transport/deposition in response to landuse change). Coarse BOS samples (sieved <2 mm) were air-dried, sieved, milled, and fully digested (hydrofluoric acid + nitric acid followed by aqua regia) to release total Sr. The Sr was then separated by chromatography, and the ratio was determined by multicollector Inductively Coupled Plasma-Mass Spectrometry. Accuracy, analytical precision, intra-sample variation and in-field variation were found to be fit-for-purpose for creating large regional-and national-scale isoscapes.

A smaller number of coarse ‘top outlet sediment’ (TOS) samples (0-10 cm depth) were prepared and analysed the same way, some from sites were BOS samples were also selected. A very strong linear correlation was found between TOS and BOS ^{87}Sr/^{86}Sr values (r^2 = 0.97). Thus, in total, 576 measured or regressed BOS coarse ^{87}Sr/^{86}Sr ratios were determined and mapped. This sample selection and preparation strategy (depth, grainsize, and digestion) maximises the likelihood that the Sr isotope results obtained reflect geogenic, upper crustal characteristics. The results demonstrate a wide range of Sr isotopic values (0.7048 to 1.0909; median 0.7377) over the three survey areas, reflecting a large diversity of source rock lithologies, geological processes, and bedrock ages. The spatial distribution of ^{87}Sr/^{86}Sr shows coherent (multi-point anomalies and smooth gradients), large-scale (>100 km) patterns that appear broadly consistent with surface geology, regolith/soil type, and/or nearby outcropping bedrock. We conclude that the ^{87}Sr/^{86}Sr systematics of NGSA sediments are a suitable proxy for catchment-averaged upper crustal composition.

Using Drill Sample Multi-Element Analyses as a Proxy for Pyrite Mineral Chemistry in Mineral Exploration & Orebody Characterisation

Simon Griffiths & Aidan Kitchner

Pyrite is a common mineral in many types of metalliferous ore deposits and forms under diagenetic, hydrothermal, magmatic and metamorphic conditions. This genesis can be determined using pyrite chemistry from in situ laser ablation inductively coupled mass spectrometry (LA-ICP-MS) analysis of individual crystals. Such studies are important in improving the ore body knowledge at various deposit types. Studies using pyrite chemistry data have defined formation conditions from trace element chemistry of biogenic, authigenic and hydrothermal pyrite phases.

Reiger et al (2023) demonstrate pyrite chemistry from the Teena deposit, a clastic dominant massive sulphide Zn deposit in the McArthur Basin, Australia, exhibits trace element affiliation for end members of pyrite species. Hydrothermal pyrite is associated with As, Pb, Tl, Zn enrichment, whereas diagenetic pyrite is enriched in Co, Mo, Ni, V comparably. These variations are used to determine the hydrothermal influence on sulphide abundance and produce target horizons for mineralisation. This data use a Li borate fusion digestion, and spot analysis (10µm) on different paragenetic pyrite stages. However, instrument availability, which in turn affects analytical cost and turn-around time, is prohibitive to wide-scale implementation of mineral chemistry systematically throughout an exploration project. As such, Best Practice drill sample analyses are performed using a multi-acid digest and multi-element determinations of a pulverised, homogenised sample aliquot.

In this paper we use 4-acid, multi-element exploration data from drill core to ascertain which samples contain pyrite and other sulphides. The iron-sulphur ratio (Fe:S) outlines samples likely containing significant quantities of pyrite and sulphides. These sulphide rich samples are then assessed using multivariate analysis, specifically by applying a PCA (principal component analysis) statistical tool. The tool is applied specifically to samples previously determined to contain pyrite, using trace elements documented to potentially be present in pyrite.

We show that diagenetic and hydrothermal pyrite stages are distinguishable using trace element vectors from industry-standard drill core sampling data, thereby enhancing alteration modelling, geochemical targeting and geomet characterisation of projects. These interpretation and modelling workflow can be applied to exploration projects and mining operations at any pipeline stage.

Multi-Element Analyses in the Determination of Chemostratigraphic Facies with RedOx Sensitive Trace Elements (ROSTEs) as an Exploration Tool for Carbonate Hosted Mineral Deposits.

Simon Griffiths & Aidan Kitchner

Chemostratigraphy has long been used to differentiate between facies changes in marine sedimentary successions, especially in the field of hydrocarbon exploration. RedOx Sensitive Trace Elements (ROSTEs), or the so-called organometallic elements, have been shown to vary over geological time, reflecting changing redox conditions at the seawater-sediment interface. These trace elements exhibit enrichment in sediments containing organic and/or sulphidic material, deposited under anoxic or euxinic conditions. Such conditions reflect the sedimentary basin environment during deposition and Enrichment Factors have been shown to be applicable to marine sediments deposited throughout the past approx. 800Ma.

Chemical changes through the stratigraphic column at a project are characteristic of individual facies which can be considered Units of the same Formation. Often these units do not display clear textural or mineralogical differences and remain undifferentiated during core logging. Changes in water column depth and oxidation state during deposition, reflected in the variable Enrichment Factors and covariance between ROSTEs, determine the future reactivity of marine sediments involved in epigenetic hydrothermal fluid-rock interactions. Modelling of such features, which are strong controls on mineralisation, can shorten the time to discovery and add value through more detailed geometallurgical models for both ore and waste material.

Organometallic elements can also be used as proxies to map relative Total Organic Carbon (TOC), an indicator for reduced sediments. ROSTEs, which include V, Mo, Ni, Zn, Cu, Cd, Y, Cr, often conform to two groups: elements enriched in samples with elevated TOC (Mo, U, V, Zn) and elements with low Enrichment Factors in samples with high TOC (Cu, Cr, Co, Ni). Using a multivariate approach to assess how these elements and Enrichment Factors covary with one another, we show interdependence with Degree of Sulphidation. In turn, a robust interpretation of oxidation state during deposition of sedimentary facies can was generated. This effective tool for identifying reduced sediment (reactive) horizons has been applied to several carbonate hosted ore deposits, including Carlin Type Deposits and Carbonate Replacement Deposits.

Preliminary characterisation of greisen-hosted Li mineralisation in eastern Tasmania

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Lithium is increasing in demand and becoming a major exploration target, since it is an essential metal to rechargeable battery and green manufacturing as transitioning into a low-carbon emission economy. Large granite batholiths of Eastern Tasmanian terrane (400–375 Ma) were formed in a N-trending belt parallel to the active continental margin of eastern Australia. These granitoids have pre-, syn- and post-collisional timings relative to the Tabberraberan Orogeny (~390 Ma). The post-collisional eastern Tasmanian granitoids produced Sn-W, base metal and intrusion-related gold deposits that are hosted in the granitoids and surrounding Siluro-Devonian turbidites. Recent exploration activities reported up to 1.14 wt.% lithium grade ores (Li_2O) associated with greisen alteration in eastern Tasmania at areas such as the Dead Pig and Guinea Pig prospects. These mica-rich greisens are related to leucogranitic intrusions (~375 Ma) emplaced in an extensional setting, characterised by high SiO_2 and Rb/Sr contents, relatively low Fe_2O_3/FeO, and enriched F values (>100 ppm). In altered Tasmanian granites, Li contents (up to 1,400 ppm) increase consistently with SiO_2 contents (> 75 wt.%) and positively correlate with high Rb and Cs concentrations, implying that prolonged degree of fractionation can promote Li enrichment in the granitic magmas. Field and microscopic observations reveal that the main Li-bearing mineral in the greisens is zinnwaldite and associated with an alteration assemblage consisting of topaz ± fluorite + albite + K-feldspar + quartz. Euhedral, coarse-grained (0.2 mm–2 cm) zinnwaldite, fluorite and topaz are interstitial to quartz, K-feldspar and albite and have been overprinted by kaolinite ± dickite alteration. LA-ICP-MS analyses show that the zinnwaldite has an average of 1.32 wt.% Li, 1.21 wt.% Fe, 7,400 ppm Mn, 6,900 ppm Rb, 640 ppm Zn, 280 ppm Cs, 100 ppm Nb, 80 ppm Sn and 40 ppm Be. The zinnwaldite is characterised by extremely high Rb/Sr, constant K/Rb, and low Nb/Ta ratios. The textural and chemical characteristics are consistent with the Tasmanian zinnwaldite precipitating from highly evolved fluids derived from leucogranites. This work can help to assess the potential of greisen-hosted Li mineralisation and provide insights for exploration in Tasmania and elsewhere.

Near-mine targeting via lithochemical discriminators - a case study at Olympic Dam, South Australia

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Understanding the prospective economic domains within the footprint of a deposit, and drill-testing them, remains imperative for informing mine planning and achieving production goals. While simply exploring through extrapolated continuity of mineralisation can render exploration success, this does not leverage other geological factors and lead to unrealised exploration success. In large hydrothermal systems, mineralisation- and alteration-relationships can be captured compositionally in multi-element assays. These can provide a means to guide drilling and identify potential mineralisation via favourable compositional variations. These offer an alternative exploration model beyond simply the lack or presence of the sought-after economic elements, thus making better use of the full assayed elemental suite. This case study uses the world-class Olympic Dam IOCG deposit to present a data-driven approach to vector toward potential copper mineralisation.

Distance to the 1 wt% Cu-shell (created 10 m drilling composites) was used to categorise samples by proximity to the copper mineralisation. Using normative mineralogy calculations, concentrations of Cu-sulfide related elements (Cu-Fe-S), including Au-Ag-U, were removed from individual assays to augment other key mineralisation- and alteration-related elements. Exploratory Data Analysis (EDA) was undertaken using Principal Component Analysis (PCA) on Centre-log ratio (CLR) transformed assays to define coherent groupings associated with proximity to known mineralisation.

Preliminary findings show typical elemental associations between minor- and trace-elements common to IOCG systems in South Australia, displaying strong covariances among mineralisation-related elements Ca-S-Cu-Ba-Ce-La-Fe-P-As-U-Mo. A sub-composition of the same data, by removing equivalent Cu-S-Fe-concentrations from normative sulfides and U-Au- Ag , is able to preserve similar groupings between the range of studied elements. These compositional criteria may assist in generating potential mineralisation targets in under explored domains for further geological review, where amenable alteration relationships are present. By leveraging the full suite of elements, and supported by a sound understanding of deposit alteration, geologists can provide a strong alternative view of exploration potential within their own deposit, which can ultimately add value to their business.

Hyperspectral-geochemistry integration as a tool for gold exploration in deeply weathered terrains

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Mineral exploration in regolith-dominated terrains is challenging. Due to missing surface expression, mineral exploration undercover relies on gaining an understanding of ore-forming processes and characterizing alteration regimes to decipher suitable vectors toward ore deposits. Visible-near, shortwave, and thermal infrared reflectance spectral analyses acquired from drillholes is a cost-effective technique to identify and characterise mineral assemblages in regolith to better understand mineral systems, weathering processes and distinguish hydrothermal alteration footprints in the regolith. The presented work focuses on characterizing gold mineralisation in acidic-intermediate volcanic and volcaniclastic rocks and the overlying weathering profiles to understand metal dispersion mechanisms. Hyperspectral and geochemical analyses were integrated with geological observations to determine mineralogical vectors toward mineralisation within regolith. Intense weathering produced a thick (up to 100 m) weathering profile dominated by a leached zone of kaolinitic-micaceous saprolite. The presence of the leached zone and the overlying transported cover obscures the geochemical signature of the gold mineralisation near surface. The mineralogical and geochemical compositions of gold mineralisation were determined using HyLogger, X-ray diffraction, bulk geochemical analyses, TESCAN Integrated Mineral Analyzer and laser ablation ICP-MS. Gold is associated with multiple generations of pyrites and Cu-Bi-As-Ag-Se-Ni-Pb-Zn sulfides and sulfosalts that exhibit various textures and element zoning. Gold and associated sulfides were formed in response to hydrothermal alteration and metamorphic recrystallisation. Weathering of gold and sulfides produced a blanket of supergene mineralisation near the weathering front that consists of colloform and framboidal pyrite, pure microcrystalline Au, chalcocite, bornite, malachite, and alunite. Hyperspectral data from saprock-bedrock identified compositional and abundance trends in chlorite and white mica. The mineralogy identified varied from Na- and Al-rich white mica (paragonite) and Fe-chlorite (chamosite) in proximal areas to K-rich and Al-poor white mica (muscovite) and Mg-chlorite (clinochlore) distal to the mineralisation. The leached zone is dominated by white micas with traces of chlorite and preserves the same compositional variation trends of the saprock-bedrock. Therefore, the survival of white micas in regolith can be used to map the hydrothermal alteration patterns at shallow depths even though the gold mineralisation is leached by weathering.

Utilising CoDA based techniques for till and surficial geochemical data in mineral exploration for critical raw materials

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Compositional data, such as geochemical data are the data that can be summed up to a fixed constant. There are two main till geochemical datasets available in Finland with different sampling densities. The targeting till geochemical data set is having sampling density of 6-12 samples per km^2 where the sampling density of regional till geochemical data is one sample per 4 km^2. A subset of data from the central Lapland in Finland has been considered. Quantile-quantile plots, principal component analysis (PCA) biplots and heatmaps were used to explore and analyse the different data sets and elemental association between different analysed elements. The distribution of elemental concentrations varies strongly between map sheets in targeting till data as well as they vary between targeting and regional till data sets despite compositional transformation. Thus, it was decided to analyse the map sheets (1:100 000 scale) separately. PCA biplots related to an area which contains two Ni-Cu-PGE deposits (Sakatti and Kevitsa), representing all data sets separately illustrate elements in distinguishable 2 elemental groups of Ti, Al, V and Cr, Ni, Mg which positively correlates with each other.

Another approach in surficial geochemistry is to test how the weak leach geochemical methods of upper soil as well as biogeochemistry are working in tracing the critical metal sources related to ultramafic rocks in different soil types and land use areas in Europe. The target areas locate in Czech Republic, Finland, Poland and Portugal. Upper soil analyses show a significant response to many elements with known mineralized bedrock targets observed in the suboutcrops and drill core data. An elemental distribution is also reflecting the lithological variations of rock units in the bedrock. In addition to the weak leach geochemical data, there is also good or moderate correlation for several elements between the biogeochemical data and underlying bedrock. However, there are significant differences between the plant species and parts which need future studies. This research proves that surficial geochemical methods in different terrain types are an effective, environmentally friendly geochemical exploration technique for critical raw materials.

This research is a part of the EU funded SEMACRET project.

Understanding geochemical interfaces in the Georgina Basin: Applications for mineral exploration

I. Schroder, D. Champion, P. de Caritat, D. Huston

In-situ near-surface geological boundaries and redox transition zones are valuable geochemical interfaces for trapping and concentrating elements that can be indicators for deeper or distal mineralisation. As a result, they can be a more cost-effective and geochemically sensitive sampling target than in-situ alteration or mineralisation, yet this is often overlooked in traditional exploration and drilling campaigns. However, the geochemical processes that transport or trap these elements can differ markedly depending on many factors including lithology, weathering regime and hydrogeology. Thus, building an understanding of the local geochemical interface(s) and their provenance is needed when entering a new geological province (or basin), to best enable their use as a tool for mineral exploration.

As part of Geoscience Australia's Exploring for the Future Program, our investigation focuses on the Georgina Basin. Using new whole-rock and isotope geochemistry from 9 drillholes in the central Northern Territory, we demonstrate an improved understanding of the processes affecting geochemical migration in this region. Our findings provide insights into Georgina Basin's sediment-hosted Zn-Pb and phosphate potential, while also having relevance for new clay-hosted rare-earth element (REE) prospectivity.

Portable XRF data of these drillholes provided the first indication of geochemically enriched interfaces in the Georgina Basin, with elevated Pb, Zn, Cu, P and REEs observed at consistent depths between drillholes. Follow-up whole-rock geochemistry (76 samples) and isotopes (Pb and Sr, 17 samples) is presented here, which targeted transects through these interfaces, as well as background lithostratigraphy.

Looking into the elemental and mineral associations across these interfaces, clear redox transitions are evident at two depths in the basin. The shallower geochemical interface (~5-20 m depth) is interpreted as a surface weathering profile, while the deeper interface, coined the water-intercept zone (~40-70 m depth), is found near the water-table of the regional aquifer. Supported by geochemistry, we discuss the mechanisms that have formed the water-intercept zone, covering the provenance, migration and trapping of geochemical signals. Finally, we showcase how the water-intercept zone can be practically used for mineral exploration, by integrating with the groundwater chemistry to validate and map radiogenic Pb isotope anomalies representative of the basin's sediment-hosted Zn-Pb mineralisation.

Blank Analyses in Geochemical Quality Control: How to Get Something from Nothing

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QAQC samples that can be used to determine if geochemical analyses are 'fit for purpose' include: (*i*) reference materials, (*ii*) field, preparation, digestion, and analytical replicates, and (*iii*) blanks. These samples assess the essential measures of data quality (accuracy/precision), detect contamination, and identify other sampling/analysis problems. Researchers have developed sophisticated numerical procedures to assess accuracy and precision (*e.g*. Thompson & Howarth error plots for duplicates, and Shewhart control charts for reference materials), but blanks are commonly only examined to identify whether contamination is present. Fortunately, blank analyses have other high-value purposes, particularly if element concentrations are provided by the laboratory in un-truncated/un-rounded (raw) form (*most will*).

Element concentrations calibrated from analytical responses presume that analytical blanks have a zero concentration. Using raw geochemical results, statistical tests can be used to rigorously assess this hypothesis. When rejected, the mean of a non-zero analytical blank serves as a background correction factor that can be subtracted from the concentrations to eliminate analytical bias.

Raw laboratory blank analyses can also be used to assess whether an analytical batch has been reported with an appropriate detection limit, defined as the concentration where analytical error is 50 % (equal to two standard deviations of the blank analyses). Furthermore at this detection limit, the magnitude of the reporting interval that introduces an acceptable amount of round-off error (5 or 10 %) is also calculable. This allows geoscientists to truncate and round laboratory-supplied raw element concentrations in a manner that reports these data with the highest statistically justifiable resolution, a feature not necessarily achieved using the routine laboratory truncated/rounded concentration data.

Even using the lab-truncated/rounded results, geoscientists can statistically test whether the number of blank analyses exceeding the detection limit is statistically expected, a procedure that effectively flags batches where inappropriate detection limits have been used by the laboratory, or where outlying (contaminated) concentrations may be present. Clearly, important data quality information can be obtained from blank analyses, provided they and their associated data, are supplied in raw form by the analytical laboratory (*i.e.*, ***you can get something from nothing!***).

Deploying a LIBS and XRF in the field for early-stage lithium exploration

Steven Tambanis

Realtime Pty Ltd was formed in 2023 to establish a field-based LIBS capability for lithium exploration. Geologists Mark Saxon, Mike Hudson and myself purchased a Sciaps Z-903 LIBS primarily to conduct our own first-pass evaluation of lithium prospects. Real-time analysis of light elements, in particular lithium, was a highly attractive concept as I had worked in a lithium mine and saw the difficulty identifying lithium mineralisation when exploring. We bought a pXRF at the same time so you could say we pretty much maxed-out investment into portable spectrometry… most of it into a cutting edge technology of which we knew nothing. What could possibly go wrong? Anyway, it's been an interesting deep dive into LIBS - from an exploration geologist's perspective. What we assumed was a point-and-shoot device… taught us to never assume. We quickly learned what our boundaries were, re-learned all things about sample preparation, sampling theory… and practice, instrument calibration, statistics and assaying protocols. We squeezed a lot into an eight month period and along the way developed some useful learnings about implementing LIBS into the field. Real time analysis enables better decision making to be made during a field programme, rather than waiting 4-8 weeks for laboratory assays to be returned. This empowers your field exploration team to optimise programmes on-the-fly, saving time and resources

The LIBS is a highly sensitive instrument with the ability to accurately report low tenor lithium in soils down to 20mm Lithium… through to high grade spodumene. Sample preparation is mandatory and with a handful of laboratory assays for orientation, you can get quantitative lithium assays. You also need to write custom calibrations for your LIBS. We can generate accurate lithium soil grids in real time together with LCT metal ratios. We love the LIBS for lithium but when it comes to heavier LCT elements and ratios like K/Rb, a pXRF is superior due to its larger beam size and simpler sample preparation. In our opinion, you need both a LIBS and a pXRF in the field. The LIBS is used primarily for lithium analysis.

We developed a novel method of presenting samples to LIBS that does not require pressed pellets. It's rapid to deploy in the field and appears to be as good as pressed pellets. Because we could not find anyone in Australia to make and provide pressed pellets, we purchased a hydraulic pellet press and developed our own capability.

We make our own binder-free pressed pellet reference materials for instrument calibration, including CRMs and our own samples. We also custom-pelletise sample material on order.

If LIBS and XRF are of potential interest to your hard rock lithium exploration programmes, please contact Mark Saxon, Michael Hudson or myself to discuss. You can contact us through LinkedIn, or info@libsxrf.com. www.libsxrf.com

Clay-Hosted Rare Earth Element mineral deposit formation and exploration in Southwestern Western Australia.

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Due to rapid technological advances in recent decades, Rare Earth Elements (REE) are critical metals of global importance. OD6 Metals exploration Splinter Rock tenement packages located ~100 km NE of Esperance, Western Australia, are prospective for clay-hosted REE. A comprehensive understanding of the mechanical and hydromorphic dispersion of REE in these deposits is essential for effective geochemical exploration.

Regolith profiles analysed from the region ranged in thickness from 1 to 111 m, with thicker (> 20 m) clay hosting REE units found between outcropping granites. Idealised logs show a profile comprised of an upper 1-3 m calcrete unit below which a medium-grained sandy horizon approx. 10 m is present. The underlying 10-20 m comprises smectitic clay. A black organic-rich clay layer may be below these clays (1-15 m thick). Below this, more homogeneous kaolinitic light grey clays are common. Total rare earth oxides and yttrium (TREOY) concentrations are highest in the lower portion of the profile (up to 6600 ppm TREOY, with concentrations commonly close to 1500 ppm).

The degree to which regolith is transported is often challenging to determine due to the similar mineralogical composition of both in-situ and transported material e.g. clays and iron oxides. In this deposit, increases in potassium concentrations related to the presence of unweathered feldspars and changes in kaolinite crystallinity mark the boundary between transported and in-situ regolith. This boundary is further emphasised by changes in conductivity observed in airborne electromagnetic surveys, with consistent horizons mapped over 10s of km. TREOY concentrations are highest in the in-situ regolith close to the boundary with transported clays and are hosted within phosphate minerals.

The region's landscape history shows that granite was variably exposed before the Eocene. The associated REE enrichment in the in-situ regolith most likely occurred during this period, before transgressions in the Eocene resulted in deltaic conditions leading to the deposition of black clays overlying the in-situ regolith.