KEYNOTE PRESENTATIONS

in alphabetical order

USE OF BIOTA IN MINERAL EXPLORATION IN AREAS OF TRANSPORTED COVER

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The use of biota as sample media for mineral exploration and environmental monitoring has become an accepted exploration practice in the northern hemisphere and parts of the tropics. In Australia, its use and uptake has been slow. This may be due to the unpromising results of some earlier work on the use of biota for gold exploration. At the same time, sampling of soils and other surface materials was reasonably effective in deeply weathered areas, with or without shallow transported overburden, and there was little need to further probe the potential of biota.

Exploration has changed and it now appears that future discoveries of base metal and Au resources in deeply weathered terrains will probably be under transported overburden where soil and lag sampling are likely to be ineffective. As the focus of exploration shifts to these more difficult terrains, mechanisms need to be investigated that can produce a surface signature of mineralization buried under tens of metres of cover. Only recently, work done on base metal and gold deposits in the Yilgarn Craton has shown that certain biota are not only highly effective in showing geochemical signatures of bedrock mineralization, but some also appear to 'see through' a substantial thickness of cover at sites where total, partial and selective extraction analyses of soil show no or only ambiguous signatures of the bedrock mineralization.

This paper presents findings of some studies by CRC LEME on biota that show geochemical anomalies at surface over several buried gold and base metal deposits. Four sites from the northern Yilgarn will be discussed. At these locations (I-III in the north eastern Yilgarn Craton, IV in the north western Yilgarn) transported cover ranges in thickness from 0 to 25 m and varies in age from Quaternary to Permian.

Five different plant parts (fine roots, coarse roots, bark, branch wood and phyllodes) and litter were collected from mulga. In addition, soil samples were taken 10-20 cm below surface and analysed following total, partial and selective digests to identify any potential geochemical signature of bedrock mineralization at surface. At one site, soil samples were also taken at 40 mm intervals from surface to a depth of 32 cm to identify any discrete 'metal accretion zones'. At all sites, soil samples from the rhizosphere were collected for microbial studies. Soil profiles show no or little development.

Soils were air dried, sieved to <250 µm and extracted using (i) aqua regia, (ii) 0.1 M hydroxylamine hydrochloride (Mn oxides), (iii) 0.25 M hydroxylamine hydrochloride (amorphous Fe oxides), (iv) sodium dithionite (crystalline Fe oxides), (v) enzyme leach (amorphous Mn oxides) and (vi) sodium pyrophosphate. Whereas soil data are mostly ambiguous, biota geochemistry shows strong evidence of buried mineralisation and appears to be more effective than <250 µm soil (10-20 cm) and selective/partial soil analyses.

(I) The Jaguar VHMS Cu-Zn-Ag ore body is approximately 250 m below surface, dipping steeply to the west. A stratabound primary metal halo around the deposit appears to extend to a palaeosurface which is covered by about 15 m of colluvium and alluvium. The <250 µm soil results show a single high (Cu, Pb, Zn and Cd) above the interpreted up-dip surface projection of the deposit. Selective extractions (0.1 and 0.25M hydroxylamine hydrochloride and sodium dithionite) also show single point Cu and Zn highs without Cd. Enzyme Leach produces a marginally displaced (west of the mineralisation) strong, single high in Cu, Pb, Ni, As, Ga, Br, Rb, Y and Zr. By contrast, the biogeochemical survey shows a multi-point, multi-element signature in different ashed vegetation sample media over the surface projection of the mineralisation. Zinc, in particular, is anomalous in phyllodes, bark, branch wood, roots and litter. Cadium is anomalous in branchwood, bark and roots.

Litter shows a multi-element (Zn, Cu, Pb, Cd, Ag and In) response over the surface projection of the mineralization that is particularly strong compared to other parts of the plant.

(II) At Moolart Well, Au mineralisation is hosted by a sequence of diorite, basalt, dolerite and ultramafic rocks within a north-trending shear zone. A shallow ‘lateritic’ resource contains in excess of 500,000 ounces of Au with mineralisation open at depth. Several plant parts show multi-element signatures (Au, As, Mo, Ag, Cu) that show better contrast than soil and selective extraction results. The best response to mineralisation is again in litter.

(III) Gold mineralisation at the Rumour prospect occurs in association with intense carbonate alteration over 5 km of strike along the prominent Chatterbox shear zone. Results are similar to those from Moolart Well: Au in litter shows a broad response over the mineralisation. Conventional soil total digests and selective extractions do not show an unambiguous signature.

(IV) At the Gossan Hill Cu-Zn-Au deposit, Golden Grove, a steep W-dipping horizon of thinly bedded chert and tuff, within the Golden Grove Formation, hosts the base metal mineralization. Gold, As, Bi, and Ag concentrations in litter show the mineralization beneath (no other biota sampled).

Detailed soil profile sampling at Jaguar shows that sampling depth and soil properties (especially organic matter) appear to control the metal distribution. Ore-related elements were extracted by sodium pyrophosphate and hydroxylamine hydrochloride at 0-4 cm depth and there is a significant drop in concentrations of Zn and Cu at shallow sub-surface (> 4 cm). As most soil sampling is commonly done at 5-20 cm depth, the near-surface signature will almost certainly be lost due to dilution. The generally very poor soil (10-20 cm) results, compared to biota and, in particular, litter, may be due to one or both of the following reasons. (1) The metal may not be released into soil from the litter due to slow decomposition in arid terrains coupled with the continuous loss of soil and fine litter particles by wind erosion. (2) Alternatively, or additionally, fines and metals may be rapidly flushed out by rain pre-empting adsorption into/onto Fe and Mn oxides in soil near their bedrock source.

The reasons for the accumulation of elements in litter are not yet clear. Possible explanations include the accumulation of various plant parts throughout the year, nutrient withdrawal during the senescence period immediately prior to leaf fall, preferential leaching of more mobile constituents including Ca, Mg, K and Na, dropping of metal-rich exudates from leaves, upward transfer of metals through unknown processes, or pre-concentration of metals on litter components such as charcoal over a number of years.

We have also assessed the abilities of microbes to act as biomarkers for Au and base metal deposits and the results will be discussed at the meeting.

Our data appear to support the important role that vegetation and mechanical bioturbation play in bringing metals to surface in areas with a semi-arid to arid climate and a low watertable (in the study areas, groundwater commonly occurs more than 5 m below surface). Present results on biota geochemistry may lead to a practical method for locating mineralisation under transported cover. Importantly, biological activity may provide clues as to the potential mechanisms responsible for the transport of Au and pathfinder elements through cover. This field of research is being therefore addressed by CRC LEME/CSIRO as a matter of priority.

THE ROLE OF MINERALOGY IN THE INTERPRETATION OF ENVIRONMENTAL AND EXPLORATION GEOCHEMICAL DATA

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When attempting to interpret most forms of geochemical data, three rules should always be applied: "mineralogy, mineralogy, mineralogy" (Day. 1997). Mineralogical interactions govern most forms of geochemical reactions and it is essential that an applied geochemist has an understanding of these.

Mineralogy helps to define not only the source of reactants in a geochemical reaction but, by characterizing the products, the mechanism of reaction may also be revealed. The information can be utilized to explain the geochemical distribution of a given element or suites of elements in a solid material or dispersed by hydromorphic, physical or aerial mechanisms.

This review will present current understanding of important mineralogical reactions involving the release, transport and attenuation of inorganic elements in superficial materials. This understanding will be used to explain how such reactions are important in interpreting exploration and environmental data and the importance of mineralogy in assessing limitations on analytical methods

PUNCTUATED EQUILIBRIA IN THE 30-YEAR EVOLUTION OF GEOCHEMICAL EXPLORATION UNDER COVER

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This presentation takes the audience through a retrospective journey over the past thirty years in the geochemists' quest to develop methods of exploration for mineral deposits under cover and the associated use of partial extractions applied to overlying soils in order to highlight previously labile elements. None of the potential deposit-element migration mechanisms that are suggested today, such as electrochemical dispersion, gas 'streaming' or 'fast ion migration', were discussed in early issues of the Journal of Geochemical Exploration (JGE). Partial leaches then were used in a broad sense, as for example in Peter Bradshaw's seminal paper in 1974, to differentiate hydromorphic from mechanical dispersion in his conceptual exploration models.

The journey begins in the early 1970s with the electrochemical dispersion models of Gerry Govett in Canada and Bjorn Bolviken in Norway. The term 'rabbit-ear' anomaly was coined at that time by Govett. Barry Smee, while at the Geological Survey of Canada, further developed Govett's model in glaciated terrain, showing that diffusion through relatively thick glacial sediments to surface of any cation but the highly mobile H^+ was not feasible in the necessary 8000-year time-frame. Both Govett and Smee suggested that prime indicators of underlying mineralisation were H^+ and conductivity measurements of B-horizon soil slurries; partial extractions were viewed at least by Smee as indicative only of indirect element redistribution (e.g. Fe) due to the presence of H^+. By the mid '80s, Malmqvist and Kristiansson in Sweden were developing their concept of gas migration or 'streaming' to explain upward element movement in the form of particulates or ions in 'Geogas'. Membrane collectors were placed in soils for several months and anomalies found in deposit elements; snow pack overlying mineralization was shown to be anomalous in elements such as arsenic. More direct approaches, measuring such gases as CO_2, O_2, COS and CS_2 in soil, were implemented at this time by McCarthy, Oakes, Hale and Kesler. The successes and, to a degree, the controversial theories, were published in Steve Kesler's issue of the JGE in 1990. With the establishment of the sensitive analytical technique of ICP-MS in commercial laboratories by the mid 1990s, there was a proliferation of partial extractions, championed initially by Activation Laboratories and the 'Enzyme' leach in Canada and the Mobile Metal Ion (MMI) leaches in Australia. Encouraged by reports from the Russian Rudgeophysika scientists of their success in exploration under cover using essentially partial extraction techniques, and with laboratories offering Enzyme and MMI leaches for this purpose, the mining industry embraced this approach wholeheartedly. Another special issue of the JGE, this time focussing on selective leaches, was published in 1998. Unfortunately, a lack of understanding of the processes of element migration and their complexities led to many wasted trials and barren drill-holes. Industry then supported further research to assess and expand upon the older theories of migration. Eion Cameron developed the theory of seismic pumping in arid terrain and Stew Hamilton modified previous electrochemical models to demonstrate his hypothesis of the movement of reduced species up to the water table in glaciated terrain. The work at the VMS Cross Lake deposit in Canada showed for the first time, through Pb isotopic signatures in partial leaches, that a deposit element had indeed migrated through ~ 30 m of fine-grained glacial sediments and that the anomaly was not simply a result of element redistribution at surface or of contamination. Currently, interest has been revived in gas migration and commercial methods such as SDP and SGH are available. Whether these hydrocarbons are produced at depth or in the near-surface by microbes is yet another question to be resolved. By looking back at what we have achieved, perhaps the issues to be addressed on the way forward will become crystal-clear!

FIFTY YEARS OF GEOCHEMICAL EXPLORATION IN THE WESTERN AUSTRALIAN GOLDFIELDS

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The application of geochemical prospecting methods in mineral exploration in the Western Australian Goldfields effectively commenced in the early 1960s, with gold and base metals the initial targets. Lack of analytical sensitivity for gold led to early emphasis on pathfinder elements in gold exploration. The As-Au association was documented at Kalgoorlie and Norseman and subsequently applied in exploration using fresh and weathered rock, soil, laterite, stream and playa lake sediments. The discovery of Ni at Kambalda in 1966 triggered a major surge in Goldfields exploration which attracted exploration and mining companies from around the world. Lithogeochemistry contributed substantially to early understanding of the characteristics of the previously unknown komatiite-associated nickel sulphide deposits. Geochemical programs using bedrock, soil, lag and gossan samples, with analysis by atomic absorption spectrophotometry, were widely applied.

During the 1970s, the focus of Goldfields exploration shifted to volcanic-associated massive sulphide (VMS) deposits and uranium. Although the VMS search was largely driven by the Canadian geological model, the application of laterite as an effective geochemical sampling medium was demonstrated by CSIRO investigations at Golden Grove. Hydrogeochemistry was found to be effective in reconnaissance exploration for calcrete uranium deposits of the Yeelirrie type. This stimulated efforts to develop hydrogeochemistry for other deposit types in the extensively weathered and concealed terrains of the WA Goldfields.

Gold exploration resurged in the early 1980s and has continued strongly until the present time. The development of methods capable of analysing gold to 1 ppb (background) levels, firstly by AAS and more recently ICP-MS, has revolutionised Goldfields exploration since the mid-1980s and marked the emergence of geochemistry as the primary exploration method for gold. The extent and homogeneity of anomalous dispersion patterns for Au in soil and lag over mineralisation show little evidence of the expected "nugget" effect. The close correlation of anomalous Au with pedogenic carbonate in many Goldfields soils has been exploited in a selective sampling strategy. The fine grain size of gold particles and occurrence of anomalies in transported overburden, in some cases 10s of metres thick, suggests derivation by evaporative processes and/or vegetation cycling from groundwater. Extensive hydrogeochemical anomalies for Au have been documented near mineralisation and show promise as a reconnaissance method for concealed terrain. The acceptance of hydrogeochemistry as a mainstream exploration technique has been hindered by a lack of consensus amongst geochemists on the sampling protocols for surveys, together with ineffective communication with exploration management.

The major advances over the last 40 years have been in analytical and computer technology, although the availability of GPS instrumentation and improved understanding of regolith complexity have also enhanced geochemical exploration methods in recent years. Computer technology is an indispensable aid to the interpretation and communication of the copious high-quality geochemical data now being generated by ICP-AES and -MS. Interpretation methods have progressed from the basic concepts of background, threshold and anomaly to pattern recognition, and to multi-variate statistical techniques that incorporate multi-element data into signatures indicative of target ore associations. The diversity of geochemical sampling and analytical methods applied over the past 40 years has resulted in large and complex databases. Robust statistical methods and computer visualisation techniques are now used to extract useful knowledge from such historic data, as well as new multi-media surveys.

Developments over the next decade are likely to see the emergence of hydrogeochemistry as an important technique in concealed and leached terrains. The documentation and interpretation of 3-dimensional multi-element primary dispersion patterns is also likely to be used increasingly to target blind mineralization, particularly in established mining camps. The effectiveness of GPS-controlled low density multi-media geochemical sampling combined with sensitive multi-element analysis has been convincingly demonstrated and will become a mainstream tool in regional exploration and geological mapping.

ORAL PRESENTATIONS

in alphabetical order

LOCAL SCALE VARIATION : LAG SAMPLING IN THE COBAR AREA, NSW, AUSTRALIA

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A review of regional lag sampling covering the Cobar goldfield was completed for Peak Gold Mines (Wheaton River Gold). Approximately 7,500 lag samples were contained within the dataset.

The lag data were collected on a 400m (NS) by 200m (EW) grid pattern. Various infill grids had also been completed over a number of prospects. Initial inspection of the data indicated that samples had been collected over all regolith types. This was considered to be a potential problem given that lag obtained from active drainages (transported regime) would be considered to be of poor quality. However, further inspection of the data and review using Landsat TM revealed that most of active drainages had been avoided. Some samples were collected over depositional terrain and these were considered suspect.

This interpretation of the lag data focussed on determining local scale anomalism. The approach taken with this study was to examine various "background" (i.e., unmineralised) areas in order to determine local elemental relationships. Five areas were selected – each area was selected to be geographically diverse and to encompass different types and styles of regolith.

As an initial pass, all elements were plotted to determine background correlations with Mn and Fe. These elements were selected to determine potential scavenging or quartz dilution and thus to determine whether interpretation would be assisted by ratioing the element to either Fe or Mn. In local areas, strong background correlations in the whole dataset might have obscured subtle features of anomalism. Thus, inspection of relationships was conducted on a local basis since not all areas or regolith regimes can be expected to respond in the same way.

Strong local correlations are evident in the data. Strong Fe correlation of As, Bi and Pb was noted in one area while strong Fe correlation with As, Bi and Sb was noted elsewhere. Bismuth is strongly correlated with Fe in all areas analysed while As, Pb, Sb and Mo may or may not be correlated. It is important to note that these correlations are present for some elements in some areas. The correlations vary throughout the Cobar Goldfield.

Manganese correlations are not as evident nor as distinct as the Fe correlations in the five background areas. However, they are present in some other areas that were reviewed and can be dominant.

The conclusion from this work is that local scale correlations dominate the Cobar lag data. These correlations need to be analysed and established when assessing individual prospects. With a large dataset, it is tempting to process all data as a single entity. This approach would be inappropriate for the Cobar goldfield and will not detect geochemically subtle but geologically significant anomalies.

USE OF PARTIAL/SELECTIVE EXTRACTION SOIL GEOCHEMISTRY IN FOCUSING EXPLORATION IN MATAGAMI, QUEBEC, AN ESTABLISHED VMS MINING DISTRICT

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The Matagami district of northern Quebec is host to numerous volcanogenic massive sulfide (VMS) deposits hosted by late Archean volcanic rocks of the Abitibi sub-province, part of the Superior tectonic province of Canada. Exploration in the camp has been on-going since the mid-nineteen fifties and significant discoveries have occurred on a regular basis. Although the camp has been extensively explored, new discoveries are still being made. These tend to be either deep or small with the latter targets being preferred for reasons of economics. The most recent exploration successes include the Perseverance deposit discovered in 2000 (Total measured and indicated resource of 5.12M tonnes grading 15.82% Zn and 1.24% Cu) and the new Renaissance discovery made in 2004.

The Renaissance discovery was made on the McLeod property, which is located on the south side of the camp and straddles the favorable Key Tuffite (KT) contact, where most of the deposits occur. In this area the KT dips about 60 degrees to the southwest and extends from surface down to a depth of 1,000 meters. The Renaissance discovery is located down-dip of the McLeod showing (4.21% Zn and 1.17% Cu / 7.0m), a stringer sulfide mineral occurrence which occurs near the center of the property above the KT contact at a vertical depth of approximately 150m. On the adjacent property to the west, drilling down to a depth of nearly 1,000 m has outlined a complex footwall/hangingwall alteration system on the Bracemac property with sub-economic stringer and disseminated sulfide mineralization over a large area (best intersection 6.3% Zn and 0.17% Cu / 10.4m).

The McLeod property is covered by 10 to 20 meters of transported overburden consisting of glacial tills, outwash sand and gravel and fine lacustrine sediments and capped by up to a few meters of organic-rich peat. Soils vary from podzolic (Canadian System of Soil Classification) in the center of the property near Veract Creek which drains into the Bell River to the northeast, to organic elsewhere as the drainage becomes poorer and the peat layer becomes thicker.

A partial/selective extraction soil geochemical survey was undertaken in 2004 with the objective of prioritizing the remaining untested KT contact down to a depth of 800m. The survey was done as a complement to a proposed stratigraphic drilling program with the objective of prioritizing the initial drilling in the hope of making an early discovery.

A total of 452 soil samples were collected of A0 and B-horizon material according to a standard sampling protocol based on recent work by CAMIRO-OMET and our own experience in the past few years. QAQC consisted of complete randomization of samples prior to batch assembly, regular insertion of a drift monitor and collection of field duplicates (28). Samples were submitted for Enzyme Leach^{SM} analysis (code 7-Enzyme Leach) at Actlabs in Canada. In addition a random selection of 60 humus samples were submitted for aqua regia digestion, ICP-ES analysis (code 1E2) plus infrared total carbon (code 5D-C).

Results were interpreted initially by the response ratio method to provide a baseline for subsequent comparisons and then by analysis of variance (ANOVA) to remove the deterministic effects caused by various surficial factors that can mask the sought after bedrock responses. Both methods suggest the property can be divided into two distinct domains with a dividing line corresponding approximately to the McLeod showing. The western part of the property is underlain by the Bracemac domain and is in spatial continuity and thought to be part of the Bracemac VMS mineralized system. The background for most elements is high and the variability of results also high. To the east, the McLeod domain on the other hand has much lower background and lower variability of results. The survey results suggest that drilling should focus initially on the western part of the property where results are generally higher and more variable.

The ANOVA method outlined a number of anomalous target areas, three of which are thought to be related to either VMS mineralization or to the surface expression of the sub-cropping KT horizon. Diamond drilling beneath the area of the best target (EL-1) resulted in the Renaissance discovery 14.81% Zn and 1.65% Cu over a 9.5m core length at a vertical depth of 465m (see Renaissance project at www.noranda.com). Although the soil survey was not used for targeting in this case because of time constraints and thus did not lead to the discovery, the ANOVA method underlines the power of normalization to filter out surficial effects from the weaker responses of bedrock sources on partial/selective extraction soil geochemistry.

Lessons learned from this work are that most plainly observable features in partial/selective extraction surveys are caused by surficial effects, normalization for which is essential to highlight the weaker bedrock responses and that any such survey must be randomized to ensure unbiased analytical results. Finally, field duplicates provide an assessment of the total variance associated with sampling and hence of the interpretability of the analytical results.

EXPLORATION FOR IOCG TYPE DEPOSITS USING LITHOGEOCHEMISTRY AND STABLE ISOTOPE GEOCHEMISTRY

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Introduction

Exploration for Cu and Au rich Iron Oxide-Copper Gold (IOCG) deposits in the III Region, northern Chile over the past decade has failed to identify either new IOCG districts or extensions to the La Candelaria-Punta del Cobre or Manto Verde deposits. The development of innovative and effective exploratory methods constitutes a challenge for companies targeting this type of deposit. This study is a contribution to both the recognition and integration of lithogeochemical vectors and isotopic anomalies which would assist in the exploration for IOCG lacking megascopically recognizable (i.e. cryptic) alteration haloes.

Process

Deposits in the Manto Verde area are hosted by a calc-alkaline volcano-plutonic terrain of Mesozoic age. Intermediate calc- alkaline plutonic rocks assigned to the Coastal Batholith have ages ranging from 200 to 90 Ma and become younger from west to east. Monzodiorites and diorites are the most representative intrusive lithologic types. The plutonic rocks in the Manto Verde area can be classified as I-type granitoids, members of the magnetite series. The major structural features in the area are related to the tectonic evolution of the Atacama and Chivato Fault Systems. Over 400 samples representing the spectrum of rock types and alteration were collected, examined petrographically, analyzed for chemical composition using total dissolution and for isotopic compositions using new techniques.

Results and discussion

Lithogeochemistry using PER analysis indicates that host rocks in Manto Verde area were affected by Na depletion and K enrichment. A significant introduction of Cu took place only when host rocks were completely depleted in Na. By taking into account the dominant mineral phases encountered in both volcanic and plutonic rocks, PER can be used to define an alteration coefficient to quantify the degree of hydrothermal alteration in host rocks. The alteration coefficient correlates spatially with the location of known mineralized centers in the area. $\delta^{18}O$ values of selected host-rock samples in conjunction with the alteration coefficient differentiate the mineralizing processes from regional low-temperature alteration processes. Both O and S isotopic compositions are consistent with the incursion of magmatic-derived fluids during early paragenetic stages of iron metasomatism (i.e. magnetite stage), and subsequently fluids from an evaporitic source during late paragenetic stages associated with the deposition of sulfide bearing specular hematite breccias and veins. Sulfides with high $\delta^{34}S$ values are associated with economically important deposits (i.e., Manto Verde, Cerro Negro).

Conclusions

The combination of lithogeochemistry and isotope geochemistry provides a reliable exploration tool for Andean type IOCG deposits lacking megascopically recognizable (i.e., cryptic) alteration haloes.

GEOCHEMICAL DISPERSION IN THE LATERITIC REGOLITH OF THE CHAPADA Cu-Au DEPOSIT, CENTRAL BRAZIL

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This work reports the partial results of a research program carried out in the lateritic terrain of Central Brazil aimed at investigating geochemical dispersion in the regolith of base metal deposits. This type of information is generally lacking in humid tropical areas, such as that where the Chapada deposit sits.

The Chapada deposit contains 155 Mt of ore grading 0.44% Cu and 0.35 g/t Au, and is hosted in biotite, muscovite schists and amphibolites associated with the Upper Proterozoic Mara Rosa volcano-sedimentary sequence. The deposit has been tentatively related to a porphyry system. Important elements associated with primary mineralization are Cu, Mo, Au, Pb, Sr and the principal ore mineral is chalcopyrite.

Regolith mapping in the area shows a relict regime, dominated by lateritic plateaus, and erosional regimes where soil is developed directly over saprolite on a more irregular topography. The regolith stratigraphy of the relict regime of the deposit area is dominated by a 30 m thick saprolite, overlain by a mottled zone which grades upwards into an iron crust and then into a nodular horizon containing remnant lateritic material. Above this, at the surface, there is a latosol horizon, in places impregnated with humic material,. Lateritic lag and blocks of Fe crust occur scattered at the surface on a generally flat topography.

Surface sampling included lag, crust and latosol, and pits and auger holes were used to sample the saprolite at a depth of approximately 5 m. These materials were sampled along a 1.5 km long traverse across the deposit and on regional background samples. Saprolite and laterite materials were analysed by ICP after strong acid attack, and the latosol was tested with aqua regia plus Na pyrophosphate and a proprietary extractant aimed at the loosely bonded ions on amorphous Fe oxide phases. Gold was analysed by Fire Assay and ICP.

Metals that closely follow the Fe distribution in the regolith are As, Sb, Bi, Mo, Cr and V. These are distinctly enriched in the iron crust, but are increasingly depleted upwards in the nodular and latosol zones. Copper shows similar behaviour, but is highly depleted above the crust, whereas Au is enriched in the mottled zone, similar to findings in equivalent humid tropical terrain in Africa. Despite the strong tendency for base metal leaching upwards in the regolith, the geochemical signal in the surface latosol has a sufficiently high contrast to indicate mineralization and is preferred for locally-based surveys. However, for the important metals associated with the primary mineralization (Cu, Mo, Sb, Pb, Sr), partial extractants offer no advantage over aqua regia in locating the position of the orebody. This is probably due to the residual nature of the regolith and its high metal content. Background levels of trace elements in latosol will vary according to the thickness and extent of development of the latosol horizon; latosol has a lower response when developed over Fe crust (relict) and a higher response over saprolite (erosional)

There is an indication that iron crust and lag present wider dispersion haloes. However, the iron crust is not always present, which poses a problem for sampling areas in erosional regimes. The presence of lag is more widespread and represents a more effective alternative sample media for regional surveys. Within the lag sample, lateritic fragments are richest in Cu and Au, whereas the “buckshot” or magnetic lag fractions are richest in Mo and Pb. Buckshot gravel is also rich in As, Sb and Bi, which are not related to mineralization.

LATERITIC DURICRUSTS: CROWNING GLORY OF DEEP WEATHERING PROFILES, OR EARLY PRODUCT OF LATERAL GROUNDWATER FLOW?

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Introduction

Many areas of deep weathering are characterized by ferruginous duricrusts overlying deep profiles that contain clay-rich saprolite and texturally-destructive plasmic zones. In arid regions like the Yilgarn Craton of Western Australia, there is clear evidence that substantial modification, including leaching and textural destruction, has occurred during later super-imposed arid climatic regimes. Nevertheless, the prevailing view of classical lateritic profiles is that they develop progressively over time by dominantly vertical chemical processes, and that landscape reduction occurs by progressive settling of the profiles, with the iron-rich zone migrating downward over the clay-rich underlying zones. This paper presents an alternative model in which lateral groundwater flow is the key process.

Discussion

The common preservation of delicate textures and strong geochemical signatures within the ferruginous zones of laterites (and possibly also within siliceous duricrusts in ultramafic lithologies) suggests these zones are unlikely to be developed from clay-rich saprolite that has already experienced advanced chemical leaching. It is proposed that they are more likely to have been formed on minimally weathered materials at an early stage in profile development, in close proximity to the weathering front.

A model is suggested whereby chemically reduced groundwaters, originating higher in the landscape, migrate downwards into topographic lows, where they interact with the atmosphere and oxidize. This results in deposition of iron by ferrolysis within immature colluvium and/or alluvium and/or permeable saprock. In all cases, this zone of iron deposition is interpreted to be within chemically immature materials (i.e. not previously strongly leached) and close to the prevailing weathering front above fresh rock.

It is proposed that this early iron deposition causes mantling of the rock fragments and thus helps to protect both textures and chemical signatures from further aggressive weathering. However, it also reduces permeability and introduces an aquaclude against further groundwater infiltration. Continued groundwater flow down the hydraulic gradient is then forced either to the surface above the zone of iron impregnation or below it into underlying saprock. Under the latter conditions, where reduced conditions prevail owing to lack of contact with the atmosphere, further chemical weathering and leaching can take place. This results over time in a deepening of the weathering profile and the progressive development of a thick, clay-rich saprolite beneath the early-formed lateritic cap and above the now re-located fresh rock interface.

Conclusion

The implications of this model are that lateral rather than vertical geochemical migration is the dominant cause of deep weathering profiles. Hence locally displaced geochemical anomalies should be expected. It also implies that long-term profile reduction is likely to be a result of repeated micro-events involving local erosion and local re-distribution of groundwater flow associated with a complex interplay of physical and chemical weathering events, rather than purely by progressive settling involving continual chemical re-dissolution of duricrusts and their re-precipitation down profile over clay-rich, chemically leached saprolite.

URANIUM EXPLORATION USING PB ISOTOPE ANALYSIS OF PARTIAL LEACHES

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Introduction

The west Arnhem Land region of northern Australia is richly endowed with Proterozoic unconformity-related U mineralisation, but geochemical exploration techniques have proved difficult to apply because of the vast, remote area and the cover of Tertiary to Recent sandy sediments. In addition, recent secondary U accumulations unrelated to primary mineralisation create a geochemical smoke screen that hampers target selection.

We present here a technique based on the Pb isotope analysis of stream sediments that is both sensitive and discriminating between primary and secondary sources of metals. The technique is also potentially low cost in comparison to conventional Pb isotope analysis as modern quadripole ICPMS can be utilised instead of the conventional higher cost Multi-collector ICPMS or TIMS techniques. The technique was developed jointly by CSIRO and Rutherford Mineral Resources Consultants in 1990, but has not been used or publicised because of the downturn in U exploration.

Theory

Lead isotopes are well suited to exploration for Proterozoic mineralisation because the measured ratios are very sensitive to both age and to the relative abundance of U, Th and Pb in the primary samples. Of the four isotopes measured, ^{206}Pb and ^{207}Pb derive from the decay of ^{238}U and ^{235}U, respectively, and ^{208}Pb derives from the decay of ^{232}Th. Thus the measured ratios with respect to ^{204}Pb, which has no radioactive parent and whose abundance has remained constant through geological time, increase as a function of the U/Pb and Th/Pb in the primary mineralisation. Uranium mineralisation, characterised by very high U/Pb has very high ^{206}Pb/^{204}Pb and ^{207}Pb/^{204}Pb ratios, but generally low ^{208}Pb/^{204}Pb ratios because of the low Th contents.

Whilst highly elevated ^{206}Pb/^{204}Pb ratios (^{206}Pb/^{204}Pb > 70) in particular have been used to discriminate a U-rich source in geochemical samples, values in the range about 30 – 70 could represent Pb simply derived from unmineralised country rock or a mixture of mineralised and unmineralised rock. In assessing partial leaches where labile Pb adsorbed to clays, organic compounds or within secondary Fe-Mn oxides will have multiple sources, it is very important to be able to discriminate within this ^{206}Pb/^{204}Pb range.

We have devised a simple technique which calculates the Th/U ratios of the source rocks from partial leach analyses and compares these to known range for background rocks in the Arnhem Land region. We can thus define a threshold between samples with a high probability of deriving solely from unmineralised country rock and samples that have a high probability of containing a component of Pb derived from a U-enriched source.

Results

The study included analysis of drill core, soil samples as well as stream sediments and vegetation. Of particular interest are the results for aqua regia and light acid leaches of stream sediments up to 1 km downstream from the outcrop of the Caramel deposit. Both U content and the calculated Th/U ratios of aqua regia leaches are anomalous to 500m downstream of the mineralisation. However the calculated Th/U ratio of the light acid leach is anomalous to at least 1 km downstream.

A pilot study comparing the calculated Th/U ratio of soils and vegetation above known mineralisation has shown that the vegetation closely mimics the soils data. Whilst vegetation provides no advantage in residual soils, it could be used in areas of transported cover.

LATERITE GEOCHEMICAL MAP OF THE SW YILGARN CRATON

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Geochemical mapping has been routinely undertaken in many parts of the world at sampling densities ranging from 1 per 2 km^2 to 1 per 1600 km^2 or greater, to delineate major geochemical and metallogenic provinces.

In Western Australia, the only examples of regional geochemical surveys are those by the Geological Survey of Western Australia, completed in the northern Yilgarn Craton and adjacent Proterozoic basins, and the CSIRO-AGE geochemical database and the Astro regolith database, both focussed on the Yilgarn Craton. One reason for this limited coverage is the lack of a widely available, suitable sample medium. In deeply weathered terrains, geochemical and mineralogical variations in surface materials reflect more the composition and preservation of the regolith, rather than that of the underlying bedrock.

A residual ferruginous gravel and/or duricrust, termed lateritic residuum, is common at surface on the Yilgarn Craton and reflects bedrock geochemistry. The use of such ferruginous material for mineral exploration in Western Australia (‘laterite sampling’) has been extensively researched by CSIRO, CRC LEME and other organisations, leading directly to major mineral discoveries by industry in the Yilgarn Craton (*e.g*., Boddington and Mt. Gibson), and contributing to the discovery of many others.

Although decades of laterite sampling by industry and research organizations has resulted in a large laterite database, the coverage remains patchy with large areas or prospective terrain untested. Moreover, the application of a wide range of analytical techniques and element suites makes it virtually impossible to produce a homogenous dataset.

To overcome these difficulties, laterite geochemical mapping of the Yilgarn Craton commenced in 2004 to provide industry with a uniform, regional geochemical data set that shows broad-scale geochemical trends and can be interpreted together with geological and geophysical information. The resulting geochemical map will also provide background levels for local exploration and base line data for environmental monitoring.

For the purpose of compiling the geochemical map, the Yilgarn Craton was subdivided into four arbitrary sectors along longitude 120°E and latitude 30°S, with each sector covering an area of approximately 150 000 km^2. Sampling commenced on the two western sectors, as they are the most accessible, with a large number of samples already available from existing collections. The locations of existing samples were compared to a theoretical 9 km-spaced triangular grid, and those nearest to the grid nodes were selected and re-analysed. All remaining grid nodes were then field sampled, with most sample sites moved to the nearest occurrence of lateritic residuum, generally within 3 km. Where possible, the field team samples lateritic pisoliths and/or nodules along public roads, tracks and gridlines, at sites of minimal disturbance and contamination. At each site, one reference and one analytical sample, each approximately 1 kg in weight, are collected. The analytical sample is pulverized to <75 μm and analysed for 53 elements by XRF, ICP-MS and ICP-OES. Sampling and analytical work for the southwest quadrant has now been completed and results of some 2000 analyses will be presented; sampling and analysis of the northwest quadrant is in progress.

Element concentration maps are shown for Au and selected elements outlining broad geochemical trends and signatures. The use of exploration indices and discriminant function analysis is demonstrated for identifying alkaline ultramafic rocks, *e.g*. kimberlite, and greenstone occurrences in deeply weathered residual terrain. The element concentration maps show craton-scale geochemical patterns, reflecting structural and petrogenetic provinces, and discrete rare metal anomalies in the westernmost part of the Yilgarn Craton. As most of the terrain is covered by deep residual regolith or colluvium/alluvium, the geochemical patterns, particularly those indicating the presence of mafic and/or ultramafic rock, may lead to a re-evaluation of the mineral potential of parts of the SW Yilgarn Craton.

GEOCHEMICAL SIGNATURE OF AU-MINERALISED LATE-METAMORPHIC DEFORMATION ZONES, OTAGO SCHIST, NEW ZEALAND

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Introduction

Schist-hosted mesothermal (orogenic) gold deposits are commonly dominated by quartz veins, with relatively minor host rock alteration, and mining has historically focussed on gold in quartz veins. However, mining technological advances now enables economic processing of large tonnages of low grade ore, and gold disseminated through the host rocks in these deposits is now a desirable target for exploration. This research is directed at characterizing the inter-relationships between structural evolution and geochemical alteration that accompanied disseminated gold mineralization in the Otago Schist.

Regional geology

The Mesozoic Otago Schist belt is a thoroughly recrystallised metasedimentary pile of mainly greenschist facies rocks that underwent pervasive ductile deformation during metamorphism. During Jurassic-Cretaceous uplift from metamorphic depths, deformation became focussed into relatively narrow zones (<1 km wide). Some deformation zones are well-defined shears that have hosted extensive hydrothermal activity. Two of these shear zones are known to contain gold: the Hyde-Macraes Shear Zone that hosts the Macraes mine (total resource >100 tonnes Au); and the Rise & Shine Shear Zone that has been mined historically. Both of these shear zones have been truncated by post-mineralisation regional scale normal faults.

Methods

This study involves regional mapping of structural features, and detailed analysis of interaction between structures and fluid flow at the mesoscopic and microscopic scale. We have developed a large database of whole rock X-ray fluorescence analyses of host rocks and mineralised rocks from natural outcrops, historic workings, and the active Macraes mine. Trace metal contents were obtained on selected samples by inductively-coupled plasma analysis. Mineralogical data have been obtained by electron microprobe analysis and X-ray diffraction. Carbon analyses were obtained with a Perkin-Elmer elemental analyzer, and crystallinity of carbonaceous material was determined using Fourier-transform infrared spectroscopy. Nitrogen contents and nitrogen isotopic ratios were determined by mass spectrometry.

Results and discussion

Hydrothermal processes along shear zones were dominated by structurally controlled fluid flow and mineralisation in the host schist, with relatively minor quartz vein formation, and mineralised rocks are only subtly different from unmineralised rocks. Most gold in the shear zones occurs in, or associated with, sulfide minerals (pyrite and arsenopyrite) disseminated through the host schist or along microshears. Arsenic enrichment (to 1 wt%) is the most prominent indicator of gold mineralisation. Minor enrichment of Sb, Mo and Bi is detectable at Macraes, and some U and Th enrichment has occurred in the Rise & Shine Shear Zone. Sericitic hydrothermal muscovite formed by alteration of metamorphic albite and shear-related recrystallization of muscovite. This muscovite is slightly more aluminous (1-2 wt%) than metamorphic muscovite, and later stages of mineralization at Macraes have low-K illitic hydrothermal muscovite formed as the shear zone was uplifted through the brittle-ductile transition. Macraes muscovite averages >900 ppm N, in contrast to metamorphic muscovite that averages ca. 200 ppm N. The N enrichment during mineralization resulted from addition of metamorphic fluids with essentially the same isotopic signature as the host rocks: $\delta^{15}N$ =0-6‰.

Rutile is the predominant opaque mineral in altered host rocks, and this has been formed by almost pervasive alteration of metamorphic titanite throughout the shear zone rocks. Rutile formation was essentially a strain-induced retrogressive reaction driven by grain boundary scale and microshearcontrolled late metamorphic fluid flow. Structurally controlled hydrothermal graphite at Macraes occurs in microshears and is readily observable in hand specimen (up to 3 wt%, above background <0.2 wt%). The hydrothermal graphite is well-crystallized and is distinctly different from the incipiently graphitized carbonaceous matter of sedimentary origin in the host rocks. This graphite may have been instrumental in inducing metal deposition by chemical reduction. Similar graphite enrichment has occurred associated with the Rise & Shine Shear Zone, but this post-dated gold mineralization. Graphite deposition may have resulted from mixing of a CH_4-bearing fluid with a CO_2-bearing fluid. This reaction at Macraes generated water with low δD of < -80‰ during mineralization. Graphite along microshears is commonly interconnected along the shear zones, and may cause low resistivity zones in the rock mass that are detectable geophysically.

Conclusions

Subtle hydrothermal alteration zones in metamorphic belts are potentially important exploration targets for high tonnage low grade gold deposits. In the Otago Schist, disseminated gold occurs in late metamorphic shear zones with only sporadic quartz vein mineralisation. Fluid flow occurred mainly along grain boundaries and microshears, rather than open fractures, and has resulted in near-pervasive alteration. These subtle alteration zones have distinct arsenic and carbon enrichment, and minor anomalies of other metals. Mica textures, compositions, and N contents, in mineralised rocks are distinctively different from those of host rocks, and reflect the late metamorphic structurally-controlled fluid flow responsible for the mineralization. This style of deposit is difficult to detect in weathered rocks as many of the subtle features are readily obscured by oxidation.

MAPPING REGOLITH AND ALTERATION MINERAL PHYSICOCHEMISTRY USING AIRBORNE HYPERSPECTRAL DATA

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Maps of the physical and chemical properties of minerals provide a valuable new layer of data products for the mineral exploration industry working in variably exposed terrain in Australia and similar environments. These products include measurement of the abundance of specific minerals such as kaolinite, hematite, goethite, illite and muscovite, as well as the measurement of their physical attributes like crystallinity disorder and hydration state. Such mineral maps, when placed in the context of process models for the stabilization of secondary minerals during regolith formation and hydrothermal alteration events, can be used to map transported versus *in situ* materials quickly and accurately, and to identify potential alteration haloes or "footprints" that can be used as vectors to potential mineralisation.

To demonstrate this opportunity for the minerals industry, a collaborative research project, involving MERIWA, CRC LEME, Geological Survey of Western Australia, CSIRO, Placer Dome Asia Pacific and HyVista Corporation, was established to evaluate whether airborne HyMap and satellite ASTER data could be processed to deliver a series of regolith and alteration mineral distributions for a 1:100 000 scale special map sheet (2500 km^2) centred on the Kalgoorlie-Boulder township, Western Australia. Processing the 26 HyMap flight lines demonstrated that seamless maps could be derived for regolith mineral distributions (e.g. kaolinite abundance and crystallinity, iron oxide abundance and hydration state, hematite-goethite ratio, gypsum) and alteration mineral distributions (e.g. white mica abundance and Al-end member, talc, chlorite, amphibole). Field sampling, ground spectral measurements, XRD and geochemistry have been used to validate the accuracy of these mineral information products. The map products show that:

(1) kaolinite disorder and hematite/goethite ratio are useful for regolith mapping, and in particular differentiating between erosional/residual and depositional environments, and
(2) white mica abundance and mineral chemistry are useful for identifying hydrothermal alteration haloes.

Ultimately, such mineral mapping products will become routine GIS-compatible pre-competitive geoscience data available to the mineral exploration and environmental management industry over large parts of the Earth.

AN ALTERNATIVE APPROACH TO GEOCHEMICAL LEACHING: THE PINK LEACH

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Considerable work has recently been directed towards detecting geochemical anomalies in areas of transported or deep regolith cover using selective extractions. In this study an alternative approach to traditional leaching methods is presented. Instead of using concentrated acids or buffers to control reaction conditions, conditions for each sample (mainly pH) is individually controlled, permitting samples of varying mineralogy to be maintained at the desired reaction conditions. As pH is the dominant control over ionic exchange in solution, this technique allows the conditions of the reaction to be the same for all samples tested, independent of whether they are influenced by precipitated carbonates or a rising acidic plume.

The method of control is based on the use of indicators. One indicator tested is phenol red, for which the endpoint colour at pH 7.8 gives this particular permutation its name: the pink leach. It is immediately clear from the solution colour if a sample is not reacting at the correct conditions and by recording the amount of acid or base required to bring the sample to neutrality (or the desired pH), a profile of the general soil pH conditions from which a sample was collected can be generated. The amount of acid or base required to bring a soil-water mix at equilibrium to neutrality is fundamentally different from the pH determined from a water slurry because of the potential buffering capacity of soil and carbonate. This information can be used to give an idea of the structures in the area and locate zones where geochemical cells may be active. A comparison is made between a short and an extended version of this tailored leach, demonstrating the potential for reprecipitation and adsorption.

The methods has been tested on surface soil samples collected in an area where 50m of transported regolith covers a Cu-Au porphyry system at Mandamah in central NSW. Previous partial extraction studies in the area have not clearly demonstrated where a surface geochemical anomaly exists over mineralisation. In the case of the pink leach, solutions will all react at a pH of approximately 7.8, which is roughly the average pH in background. The pink leach successfully detected a multi-element anomaly for several target elements (including Au), and is compared with a lack of strong patterns in more traditional acetate leach and hydroxylamine.HCl leaches. A spatially continuous Au, Mo and W anomaly in the pink leach data was observed in samples from a relatively acidic environment (interpreted as being the surface expression of a rising acidic plume) which occurs between two adjacent highly alkaline zones (interpreted to be areas of carbonate precipitation). This added information from the pseudo-structural interpretation makes this tailored leaching method more meaningful as it clearly shows anomalies to be coincident with the zones of pH non-neutrality.

The sample specific approach of the pink leach is demonstrated to have both the potential to detect geochemical anomalies through cover but also allows for the results of a geochemical survey to be linked to a geochemical dispersion model by revealing the presence of active geochemical cells.

AN EVALUATION OF METHODS FOR IMPUTATION OF MISSING TRACE ELEMENT DATA IN GROUNDWATERS

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Introduction

Trace elements in groundwaters can be concentrated to unacceptable levels during evaporation of saline groundwaters into waste destined for disposal. In addition, saline waters provide a host for sulfate-reducing bacteria which can also lead to build-up of toxic metals in pond sediments. Because evaporation ponds are either in place or proposed as part of the solution to Australia's groundwater salinity problems, we have been evaluating the potential for trace metal-related problems. For example, in the San Joaquin Valley, in California USA, such problems have resulted in the cessation of use of evaporation ponds due to high concentrations of Se, Mo and U in the sediments of the ponds and subsequent detrimental effects on wild fowl. In Australia, concentrations of U and Ra around salt-lakes have misled companies exploring for U into unwarranted expenditure. Groundwater data sets with the complete major cation and anion chemistry are widely available, but data on toxic trace elements such as As, Cr, F, Se, U are much rarer. The study reported here investigated the use of data imputation methods to extend the small database of samples, with multi-element analyses using the larger incomplete databases.

Methods

Two methods of imputation were evaluated in this study: self-organizing maps (SOM) and regularized expectation minimization (REM). SOM is a neural-net-like method that uses repeated learning to develop a "map" of the underlying trends in a data set. Once the map is obtained, replacements for missing values can be obtained from the best-matching map vectors for individual samples. The REM method, using an iterative regression, models between the missing data and available data, assuming an underlying Gaussian distribution in the data. Regularization assists in filtering the noise inherent in real data. SOM is also robust against noise and outliers in the data. In this study, a groundwater data set from NSW and Victoria was used. This set included U analyses that covered a wide range of U values (20% above 30 μg/L U). In addition, F analyses were included to indicate geochemical inputs from granites. Tests were made by setting a known fraction of U values as missing, and then determining the accuracy with which they could be estimated using the remaining data.

Discussion and conclusion

Results show that neither method can accurately replace missing values in groundwater data. SOM-derived replacement values tend to fall within the range of the measured values in the original data, whereas REM values can be widely scattered. For 25% of U data missing, SOM values were better by a number of measures than REM, but for 50% missing, this was reversed. We conclude that as U concentrations in groundwaters result from complex interactions involving groundwater, geology and mineralogy, the major composition of water alone is a poor indicator for U. There is no substitute for measuring U directly. The poor imputation results found in this study for U should not be taken as a impugning imputation in general. Imputation is a valuable tool for solving various data problems and SOM, through its model-free approach, is a useful addition to the array of imputation tools.

THE DISCOVERY, MAPPING AND CLASSIFICATION OF THE RAMAKOK'S KRAAL CARBONATITE, BUSHVELD AREA, SOUTH AFRICA

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The discovery of the Ramakok's kraal carbonatite complex is a result of the high density Regional Geochemical Mapping Programme of South Africa. The anomaly was identified through a stepwise multi-disciplinary strategy whereby the Ramakok's kraal anomaly was ranked as the most prospective for under-saturated complexes. The anomaly was first verified and consequently followed up.

During the follow-up programme, an additional 117 soil and 15 rock samples were collected. These samples were analysed for 23 elements (As, Ba, Co, Cr, Cu, Fe, Mn, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Sr, Ti, Th, U, V, W, Y, Zn and Zr) on a simultaneous X-ray fluorescence spectrometer. In addition, the soil samples were also analysed quantitatively for P, Ca, Ce, La, and Nd on a sequential X-ray fluorescence spectrometer. The 15 rock samples were also semi-quantitatively analysed for the most important mineral phases on a X-ray goniometer.

The follow-up results were conclusive and a carbonatite complex approximately 2-3 km in diameter was discovered. Sovite and alvikite, extracted from an excavation trench, as well as trachyte, syenite and alkali syenite float, confirmed the presence of the carbonatite complex. The geology of the complex was geochemically mapped through the application of principal component analysis and response ratios, based on litho-geochemical associations. Economic targets for commodities such as lime, calcite, dolomite, phosphate, copper, niobium and LREEs were also delineated.

The study showed conclusively that a scientifically based mapping and exploration strategy, based on high density soil data, can be successfully used to discover new under-saturated complexes.

ENVIRONMENTAL GEOCHEMISTRY AT RED MOUNTAIN, AN UNDISTURBED VOLCANOGENIC MASSIVE SULFIDE DEPOSIT IN THE BONNIFIELD DISTRICT, ALASKA RANGE, EAST-CENTRAL ALASKA

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Introduction

We are currently investigating the environmental geochemistry of a group of unmined volcanogenic massive sulfide (VMS) deposits located south of Fairbanks. The Red Mountain (Dry Creek) deposit is well exposed, relatively large, and displays a remarkable environmental footprint of natural acid generation and high metal and light rare-earth-element (LREE) contents in surface waters. This study establishes pre-mining baseline geochemical conditions of an undisturbed VMS deposit, a generally rare occurrence in North America. These conditions provide a useful natural analog for developed VMS deposits in similar climatic settings.

The 26 known VMS prospects occur within a greenschist-facies assemblage of metavolcanic and metasedimentary rocks of the Yukon-Tanana terrane. Protoliths consist of felsic and mafic volcanic rocks, subvolcanic felsic porphyries, and carbonaceous and siliciclastic sedimentary rocks, indicative of a submarine, basinal setting. The igneous rocks are Late Devonian to Early Mississippian (376 to 353 Ma) in age, compositionally bimodal, and were emplaced in an extensional setting. Mineralized rocks lie within the Mystic Creek Member (intrinsically high in LREE) of the Totatlanika Schist.

Red Mountain, actively explored through 1998, is a pyrite-rich VMS deposit containing sphalerite, galena, chalcopyrite, and local precious metals. Quartz-sericite-pyrite (QSP) alteration covers about 2.2 km^2. Secondary, natural oxidation of pyrite is largely responsible for the various red, maroon, orange, and yellow hues that give the mountain its name. A portion of the deposit has an inferred resource of 2.9 million tonnes of 4.4% Zn, 1.9% Pb, 0.2% Cu, 103 g/tonne Ag and 0.62 g/tonne Au.

Methods

Spring and stream water, stream-bed sediment (minus 80 mesh, 0.177 mm), mineral precipitate and rock samples were collected from 36 sites in 2003 and 2004. On-site measurements included pH, conductivity, alkalinity, acidity, dissolved oxygen, temperature, ferrous iron, turbidity and a flow estimate. One-litre representative water samples were collected and sub-samples included filtered (0.45 micron)-acidified (nitric) and filtered-unacidified water for cation and anion analyses, respectively.

Samples were analyzed by inductively coupled plasma (ICP) atomic emission spectroscopy, ICP mass spectrometry, hydride-generation atomic absorption or ion chromotography. Quality assurance/quality control concerns were addressed through the use of duplicates, blanks, and standards.

Results

Surface and spring water samples from sites within, upstream and downstream of the QSP alteration zone (AZ), vary widely in pH, conductivity, and chemical composition. Samples from within the AZ are overwhelmingly sulfate dominant, whereas admixtures of bicarbonate are found in samples upstream of the AZ. High concentrations of Al, Fe, SO_4^{2-} and total dissolved solids are found in water samples within and downstream of the AZ.

Water pH ranges from 2.4 to 7.8, with values above 6.4 upstream of the AZ, and generally less than 3.5 within the AZ. Downstream from the AZ, pH remains low (4.2) for a distance of about 2.5 km, but quickly rises to 7.1 upon mixing with surrounding glacial-silt-laden stream water. Conductivity values upstream of the AZ are lowest, ranging from 370 to 830 µS/cm, rise significantly (up to 4800 µS/cm) in waters within the AZ, and fall to 580 µS/cm upon mixing with surrounding streams. Conductivity values above 2500 µS/cm are common within the AZ.

Trace elements in water that exhibit the widest variation, spreading across four or more orders of magnitude, include Al, Cd, Co, Fe, Ni, Pb, Zn, LREE (La, Ce, Pr, Nd, Sm) and Y. Extremely high concentrations are found for Zn (mean, 41,000 µg/L; median, 13,000 µg/L), Mn (mean, 8,500 µg/L; median, 4,200 µg/L) and the REE (mean, 6,100 µg/L; median 3,200 µg/L). In all cases, the highest trace metal concentrations are found in low-pH springs and streams within and downstream of the AZ.

Stream sediment samples collected within and downstream of the AZ are anomalously high in Cd, Se, Zn, Pb, S, As and Mo (6 to 20 times higher than upper continental crust values), with concentrations decreasing downstream. Sediments are also enriched in Nb, Sn, Th, U, Ce and La, reflecting the felsic nature of the metavolcanic host rocks.

Ferricrete up to several metres thick actively cements alluvium within lower pH portions of the AZ. As stream pH rises, milky white to tan amorphous Al floc forms centimetre-thick gels in calm stretches several kilometres below the AZ. Efflorescent salt precipitates are common and include the following Fe-, Al-, Mg-, K- and Na- hydroxysulfate minerals (decreasing abundances): gypsum, jarosite, schwertmannite, alunogen, halotrichite, hexahydrite, kalinite, melanterite, pentahydrite, pickeringite, hydronium jarosite and natrojarosite. The oxyhydroxides ferrihydrite and goethite also are present.

Conclusions

The Red Mountain deposit is a well-constrained example of acid-generating, metal-leaching, metal-precipitation, and self-mitigation processes that occur in an undisturbed natural setting. Natural pyrite dissolution and associated secondary reactions under near-surface, oxidizing conditions are the primary causes for the acid generation and metal leaching of the felsic metavolcanic rocks at Red Mountain. High metal concentrations in water are related to active dissolution of sulfides (Fe, Zn, Pb, Cd, Co) and rock-forming minerals (Al, Mg, F^-, K, Mn, REE, Si). These elements, and the associated efflorescent salt precipitates are common products of sulfide dissolution and coincident acid-rock drainage. However, self-mitigation by influx of surrounding buffered waters generally limits downstream hydrogeochemical evidence of the deposit to within a few kilometres.

DISCRIMINATING BARREN AND PRODUCTIVE GEOPHYSICAL TARGETS USING PARTIAL DIGESTION SOIL GEOCHEMISTRY: DISCOVERY OF THE HUNT GOLD ZONE, MANITOBA, CANADA

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The Hunt Gold Zone is a shear-hosted vein-type Au deposit situated within the 100-km long Assean Lake Deformation Zone (ALDZ) in east-central Manitoba. Significant soil Au anomalies coincident with induced polarization targets led to the discovery of the main mass of the Hunt Gold Zone and approximately 200,000 ounces of gold, to date. Bedrock is mantled by 5-60 m of massive and varved glaciolacustrine clay, coarse cobble and boulder glacial outwash, till and peat in discontinuous permafrost. Mineralization comprises visible gold, and lesser pyrite, pyrrhotite, chalcopyrite, galena and sphalerite.

Soil geochemical surveys were initiated in the Assean Lake area to discriminate between multiple ground electromagnetic conductors previously identified by several phases of historical exploration. A high contrast bi-lobate soil anomaly with adjacent Zn-Cu and Au-Ag-Pd-Co responses was defined over the vertical surface projection of one blind and buried bedrock conductor. Drilling beneath the Zn-Cu anomaly intersected narrow intervals of mineralization grading 5.1% Zn, 1.6% Pb and 29g/t Ag. Mineralized drill intersections beneath the Au-Ag-Pd-Co anomaly assayed 22g/t Au and 190 g/t Ag over 1 m. Subsequent to follow-up exploration this precious metal intersection was recognized as the western terminus of the Hunt Gold Zone deposit. Two additional Au zones have since been discovered in the immediate area of the Hunt Zone and include the Blowfish Lake Zone (5.69 g/t Au over 6.2 m) and the BIF Zone (4.26 g/t Au over 1.75 m).

Eleven new Au-mineralized zones over 12 km have now been identified along the ALDZ. Historic and recent ground electromagnetic and induced polarization targets along this trend can be prioritized for diamond drill testing using partial digestion soil geochemical techniques.

ORDERED VECTOR QUANTIZATION FOR THE INTEGRATED ANALYSIS OF GEOCHEMICAL AND GEOSCIENTIFIC DATA SETS

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Introduction

Computational techniques that provide an integrated approach to data analysis and interpretation are needed to improve the efficiency and effectiveness of geochemists (and other geoscientists) as they seek to understand the relationships within and between diverse data sets, and identify trends or anomalies associated with various processes, including that of mineralization. For geoscientific studies, traditional multivariate statistical methods are commonly confused by data sets with variable relationships that are non-linear, by data distributions that are non-normal (typically with multiple populations), and by the data themselves that may contain missing values, text, and both continuous and discontinuous numeric values. However, recent advances in "Data Mining" methodologies (developed for bioinformatics, government and military-intelligence applications) can overcome many of these problematic issues.

Based on the principles of "ordered vector quantization", the Self Organizing Map (SOM) approach has the advantage that all input data samples are represented as vectors in a data-space defined by the number of observations (variables) for each sample. The SOM procedure is an exploratory data analysis technique whereby patterns and relationships within a database are internally derived in an unsupervised fashion based on measures of vector similarity (e.g., Euclidean distance and the dot product). The outputs of a SOM analysis are highly visual, which assists the analyst in understanding the data's internal relationships. CSIRO Exploration and Mining have their own implementation of SOM (SIROSOM), which has been developed specifically to analyze exploration-related data sets.

Results

Our SIROSOM approach to integrated data analysis using spatially-located samples has been evaluated using three data sets. The first study used SIROSOM to perform a combined "mineralogical-geochemical" study from a poly-metallic mine that has elevated Au values. Five Au populations were identified as a consequence of the analysis, each with its own particular sulfide/geochemical association. Two of the populations had average Au values above 16 ppm; and each of the five populations formed a coherent pattern when plotted in 3D spatial coordinates.

In the second study over a high-sulfidation Au-prospect, geochemical assay measurements were supplemented by a geologist's logged alteration descriptions in a SIROSOM analysis. In this case, the alteration descriptions were used as labels and not actually included in the SIROSOM analysis. Two distinct high-Au associations were delimited by the SIROSOM method. One Au association was related to high Ag values; the other Au association was related to only moderate Ag values. These two Au populations, when plotted spatially, form coherent spatial patterns. On a scatter plot of Au and Ag values, coloured by their SIROSOM-assigned groupings, a distinct trend could be observed that we believe indicates the "process of mineralization". This information can be used on spatial plots as a "vector-to-ore". When the alteration labels were overlain onto points on the scatter plot, there is a general trend evident from poorly mineralized propylitic samples through to highly mineralized samples exhibiting silica flooding; however, not all samples logged as "silica-flooding" were highly mineralized.

In the third study, SIROSOM was used to analyze Hylogger™ mineral reflectance "parameters" and Au assay data from drill core collected within an Archaean Au deposit. From the SIROSOM analysis, it was apparent that elevated Au assays were associated with particular AlOH wavelength absorptions in the 2205 nm region, with FeOH absorptions in the 2255 nm region and with CO_3-related absorptions at approximately 2350 nm. Scatter plots of these reflectance-derived parameters verses

Au all show a trend that again can be considered to indicate the “process” of mineralization. Three dimensional spatial plots of the samples, coloured by their SIROSOM cluster-coding, could again also provide vector-to-mineralization information.

Discussion and conclusion

In each of the studies, the SIROSOM procedure provided fundamental new knowledge to assist in the analysis and interpretation of the data sets. Because of its “ordered vector quantization” foundation, the SIROSOM procedure is a substantial improvement over traditional statistical methods in three main areas: 1) its ability to handle data from disparate sources, including different data types; 2) its ability to analyze sparse data sets with missing values; and 3) its ability to analyze and visualize non-linear relationships within a data set. Furthermore the spatial context and coherence of the SIROSOM outputs is a valuable contribution towards their understanding and analysis.

SOIL AND LAKE SEDIMENT GEOCHEMISTRY IN EXPLORATION FOR KIMBERLITE: NWT, CANADA

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Following the discovery of diamond-bearing kimberlites in the Lac de Gras area, NWT, Canada, GGL Diamond Corp embarked in 1993 on an aggressive soil and lake sediment geochemical program under the consultation of the late Dr. Stan Hoffman and the authors. Integrated with drift prospecting for diamond indicators, prospecting, geological mapping and geophysical surveys, lake sediment and till geochemistry allow rapid assessment of prospective areas.

Signature-element soil anomalies in eskers and till over and down-ice of the then unknown Doyle Lake kimberlite sill were initially discounted due to their size and the drift complexity. Discovery of the sill beneath the anomaly and the subsequent drilling campaign demonstrates that till geochemistry accurately defines the limits of the intrusion. Bolstered by this success, a separate nearby soil anomaly is being re-evaluated. Initially attributed to the Doyle Lake kimberlite sill, re-sampling for indicator minerals has produced high counts that terminate simultaneously with the soil anomaly on the shore of a small lake. Drill testing will commence following a geophysical program to pin-point the target.

Readily weathered and easily eroded, kimberlite typically forms topographic lows in the Canadian arctic. Hypothesizing that mechanical and/or chemical dispersion will eventually generate anomalous concentrations in the sedimentary column over a kimberlite body led to reconnaissance lake sediment sampling. Orientation studies of known kimberlite-bearing lakes gave rise to a discrimination graph that ratios key signature elements. Awry Lake was so defined as a highly-prospective target early in the exploration program. Follow-up investigation produced strong down-ice soil anomalies but a weak indicator mineral train. Shoreline prospecting years later discovered carbonate-healed granite breccia boulders that yielded a G9 garnet. Re-sampling of down-ice tills generated significant counts of indicator minerals including garnets and ilmenites with oxidized rims. A high-risk vertical drill-hole from an ice-supported platform into the heart of the target will be conducted this spring.

TOWARDS AN INTEGRATED MODEL FOR SUPERGENE GOLD REDISTRIBUTION IN THE YILGARN CRATON

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The variable intensity of supergene Au depletion in the upper residual regolith has implications for the effectiveness of surface calcrete sampling and shallow (< 40 m depth) exploration drilling, particularly in green-fields exploration. The ability to model and therefore predict these depletion effects will enhance the effectiveness of these sampling techniques. Research by CRC LEME / CSIRO has indicated a range of controls on supergene Au redistribution, as discussed below.

Gold redistribution generally occurs below the water-table. There is a sharp boundary, commonly at about 40 m depth, between the Au-depleted zone and the underlying enrichment. The greatest Au concentrations occur in the top 1-5 m of the enrichment zone, due to absolute hydromorphic accumulation. Below this, enrichment appears to be almost exclusively residual. There is little lateral dispersion and hence no increase in anomaly size, though the absolute concentrations in the regolith are greater than in the unweathered rock. The Au depletion front commonly occurs at the boundary of the lower saprolite with overlying clay- or upper saprolite, which is generally related to the alteration front of primary alumino-silicates to clay minerals, mostly kaolinite and Fe oxides. The chemistry of the upper-saprolite allows highly acid and oxidising groundwater conditions, whereas groundwaters in contact with the lower saprolite or saprock (below the depletion front) are more strongly buffered and remain neutral and reducing to weakly oxidizing. The Au depletion front is more weakly correlated with the Fe^{3+}/Fe^{2+} redox front.

There are major geographic differences in supergene Au redistribution, with stronger depletion in the SE Yilgarn, relative to the N. This can be related to changes in groundwater conditions, from extremely saline, acid and commonly oxidising (and therefore highly corrosive for Au) in the SE, saline and neutral in central areas, to fresh and neutral in the N. Within these regions of the Yilgarn Craton, the degree of Au mobility is affected by local geomorphological factors. Around Kalgoorlie, strong Au depletion of the upper regolith is common, except along ridges or close to drainage divides. In the Central region, there is strong depletion at the valley floors, slight to moderate depletion along valley flanks, and little depletion in the uplands. In the Northern region, strong depletion occurs only locally in the main drainage channels, or where enhanced by lithological factors (e.g., high-sulfide orebodies).

Supergene Au remobilization is also influenced by primary mineralization and lithology. Free primary Au, partly enclosed by quartz, tends to remain stable in the regolith and can be residually concentrated near the surface, with only partial depletion from the upper regolith. In contrast, Au associated with (particularly massive) sulfides is much more mobile in the regolith. Regolith over massive sulfide orebodies shows strong Au depletion and remobilization, regardless of region or depth of water-table.

The intensity of the Au-in-calcrete surface anomaly does not correlate with the size or grade of the primary mineralization. Surface or near surface carbonate sampling for Au exploration can “see through” transported cover only where the cover is less than 10 m, at best, or, more probably, less than 5 m. Thus, carbonate sampling represents a very useful first pass technique. However, results should only be interpreted in the context of the local regolith setting.

Much of this research was done within CSIRO and part-funded conducted through AMIRA sponsored projects. The Cooperative Research Centre for Landscape, Environment and Mineral Exploration (CRC LEME) also provided support.

REGIONAL BIOGEOCHEMICAL EXPLORATION IN SOUTHERN AUSTRALIA

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Introduction

Deep rooted shrubs and trees are affected by the accumulation of trace elements in the substrate beneath them. These can be used successfully as tracers in mineral prospecting and for analysis of environmental degradation in many areas. Regolith carbonates (calcrete), especially in regions with transported cover, have a wide distribution in southern Australia and this introduces some difficulties for mineral exploration. Indeed, the most obvious advantage of geobotany and biogeochemistry is in regions where there is no surface expression of mineralization and where mineralization at depth is masked by a geochemical barrier such as calcrete. In southern Australia, from New South Wales to Western Australia, there are mallee shrublands, which occur on a range of calcareous soils. Mallee eucalypt root systems reach depths of 28 m and are extremely efficient at extracting soil-water. Most of the previous studies in these calcrete terranes have been focused on or confined to a limited area or specific mineral deposit. This is the first time that a regional biogeochemical survey over an extensive area within Australia has been undertaken. Only with such a study can we assess the influence of local vs. regional factors on the biogeochemical behaviour of vegetation.

Methods

Three hundred and twenty plant samples, including leaves, twigs and bark of mallee eucalypts and 116 soil samples from 94 key sites across southern Australia were analyzed by INAA. Analytical results for As, Au, Ba, Br, Ca, Ce, Co, Cr, Cs, Eu, Fe, Hf, K, La, Na, Rb, Sc, Se, Sm, Th, and Zn are presented here. The sampling sites were not selected on the basis of a statistical grid, but rather were chosen by making the best use of existing knowledge (topography, earlier calcrete studies, geology, vegetation maps and soil maps). Plant samples weighing 200 g or more of each tissue type were collected in standard cloth sample bags at each site to keep them fresh before washing. The outer bark was collected, and is more informative than inner bark as it commonly holds higher trace element concentrations. Soils were collected from 10–20 cm depth to avoid more recent transported material.

Results

The nature of the underlying substrate (regolith or bedrock) is found to have a considerable influence on the elemental composition of the plant organs. The biological absorption coefficient (BAC), which is one of the biogeochemical parameters used in mineral exploration, was produced to characterize the absorption of chemical elements by plants from their substrate. A group of elements show ratios >0.1 for all organs; K is the first element in this group. It is most in leaves (0.935) and lowest in bark (0.225). Further elements in this group are Ca and Zn in leaves, and Zn in bark and twigs. The next group of elements displays ratios >0.01 in all plant organs (As, Au, Ba, Ce, Co (except in twigs), Cr (except in leaves), Cs, Eu, Rb and Sm). Most trace elements are characterised by comparable ratios for all plant parts. This may be because that their uptake is strongly regulated to achieve an optimal level by plant internal processes. Pedo- and biogeochemical patterns based on results of exploratory data analysis (EDA) techniques and robust-class selection were applied to the analysis of data. Regional biogeochemical maps of As, Au, Cr, Te and Zn show an association of these elements coincident with known base-metal sulfide mineralization, and delineate anomalous sites where no mineralization is reported. Arsenic also shows a close spatial correlation with Au in soil and vegetation. An explanation may be found in the geochemical behaviour of arsenic as a pathfinder for gold deposits. This association also accords with correlation analysis results of soil and biogeochemical data sets. There is a particular spatial distribution for Zn anomalies in both soil and plants. The soil and biogeochemistry map for this element indicates that zinc has been enhanced in soil and biosamples near and over a Pb-Zn mineral prospect. The great conformity of all biosample anomalies may reflect the ability of this approach to regional mineral prospecting in southern Australia.

Conclusion

In this study it has been demonstrated that, by using the biogeochemical exploration technique, it is possible to distinguish the several major bedrock types and regional mineralized areas. The application of EDA techniques proved to be effective in analysing the soil and biogeochemistry data set for single elements in an area where the variability of data might be expected to be affected by lithological, analytical, sampling, climatic, and physiographical factors. We proved the applicability of biogeochemistry for reconnaissance geochemical investigations in this semi-arid area where there is no developed stream networks and a pedogenic carbonate (calcrete) geochemical barrier exits. Also, we demonstrate the usefulness of utilizing mallee eucalyptus for this study in southern Australia where the mallee habitat is widespread and the plant has deep root systems.

REVEALING THE STRUCTURE OF GOLD OCCURRING AS NUGGETS

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Gold nuggets have long captured the imagination of exploration geologists, prospectors and the general public. Western Australia, and particularly the Eastern Goldfields, is one of the principal locations in the world where nuggets are relatively abundant. However, as time passes, they are becoming more difficult to find and their commercial significance has increased accordingly. Nevertheless, despite this widespread interest, the origin of gold nuggets is controversial and their geological significance is uncertain. In particular, it is uncertain whether some or all nuggets are partially or wholly "primary", that is, formed during the emplacement or metamorphic alteration of the ore, or whether a proportion are "secondary", formed at the earth surface during weathering.

The term 'nugget' is poorly defined as "a large lump of placer gold" (AGI Glossary). In Western Australia, the term is applied to masses of gold from a few millimetres to tens of centimetres in size. Few, if any, are found in placer deposits and, as such, have a rather different origin from that implied by this definition.

In Western Australia, most gold nuggets have been found at or near the soil surface. Others have been found deeper within the regolith and at the weathering front. Smaller nuggets, in particular, may be intimately associated with, and even appear to enclose, soil materials and weathered rock. Even large nuggets are reported to have surface features and/or gross morphologies that suggest chemical reworking in the regolith. In addition, large masses of gold have occasionally been found at considerable depth, in completely unweathered, primary environments.

Gold is a noble metal, implying that it is inert under most ambient, earth-surface conditions and commonly considered chemically immobile in the weathering environment. Consequently, gold nuggets, especially those found in placers, have generally been regarded as primary in origin. Nuggets in placers are considered to have been physically eroded from the original ore, and subsequently transported and deposited under fluvial conditions, whereas those in deep regolith have accumulated by residual concentration during weathering. However, for over 100 years, Australian geologists and chemists have recognized that gold can be chemically mobile under some weathering conditions, and could, therefore, form "secondary" nuggets in zones of supergene enrichment. The occurrence of crystals, crystal aggregates and grains of secondary gold is well documented and in most cases these are Ag-poor (i.e., of high fineness). In comparison, primary gold commonly contains 5-15% Ag, with over 50% in some deposits. Depletion of silver along the margins of primary gold grains in placer and residual regolith environments has been widely reported and it is possible that some 'secondary' grains have been formed in situ by the completion of this process.

Recently, it has been shown that bacteria can be involved in the dissolution and re-precipitation of gold and it has been suggested they could help accumulate gold in the surficial environment to the point of producing a nugget. However, it appears that most nuggets have Ag contents similar to primary gold, so that secondary processes (whether chemical or biogenic) must be able to precipitate Ag at the same time as Au.

We have examined the structure and composition of a suite of gold nuggets from Western Australia to ascertain their internal and external morphologies, variations in Ag content and other features in order to determine characteristics that may indicate their genesis and their stability in the weathering environment. The outcomes of the study will add to our understanding of the mobility of gold in the weathering environment and the formation of supergene gold deposits, and assist with interpretation of geochemical exploration data.

RIVER RED GUMS AS AN IMPORTANT BIOGEOCHEMICAL SAMPLING MEDIA FOR MINERAL EXPLORERS AND ENVIRONMENTAL CHEMISTS

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River red gums (*Eucalyptus camaldulensis*) are one of the most widely distributed tree species within Australia and in particular the Curnamona Craton and adjacent regions, where they mostly occur along riparian zones of major drainage channel and alluvial outwash plains. Their prevalence in regolith-dominated terrains, in particular the basin margins flanking highly prospective bedrock-dominated uplands provides mineral explorers with another means of sampling that can be employed along with traditional methods such as stream sediments, groundwater, soils, or else drilling to the underlying bedrock.

River red gums are typically gnarled trees with a spreading evergreen canopy that extends from ground level up to heights between 15-30 m. There are two main taxonomic variations within the river red gums species: *E. camaldulensis* Dehnh. var *obtusa* Blakely; and, *E. camaldulensis* Dehnh. var *camaldulensis.* Flowering periods for the latter are variable in arid to semi-arid regions due to variable water availability. Generally, flowering takes place in late spring and summer, producing numerous creamy white flowers followed by fruiting. River red gums mostly form belts or stands with minimal woody understorey along the fringes and within watercourses throughout much of arid and semi-arid Australia. Regolith lithologies hosting river red gums include alluvial sediments ranging from poorly-sorted gravels, to well-sorted, fine-grained sands, to organic-rich silts and fine sands. Landform assemblages include alluvial channels, swamps and depositional plains.

Analytical results revealed that Sb, Cs, Hf, Ir, Se, Ta, In, Te, TI, Th, V, U, Zr, Be, Bi, Mo, Eu, Yb, and Ga were below detection limits for all sampling media at all locations. Although Pb contents were below detection limit in most of the samples from this study, leaf assays from near the Pinnacles Mine have over 300 ppm Pb. Recent excavation near the tree with the highest Pb content at the Pinnacles revealed a continuation of mineralisation, otherwise concealed beneath 2.5 m of stream sediments. Many of the other elements showed some detectable chemical heterogeneity between river red gum organs. The Au contents in the major organs are extremely variable both within individual trees and between sample sites. It is encouraging that two of the sites closely associated with Au mineralisation (Tibooburra and Williams Creek) had detectable Au contents in the trees. The detectable Au content at Teilta also offers some encouragement for further exploration in that area. Au contents tended to be higher in twigs than in leaves, but the high variability of results suggest that obtaining representative results is a major challenge for interpretations associated with this element. The As contents tend to be higher in the leaves and also at the more Au-rich sites (Tibooburra, Teilta and Williams Creek). The Zn contents appear to be less variable than some of the other elements and are generally highest in twigs at all sites except Tibooburra where they are highest in leaves. The Cu contents are also generally higher in twigs than leaves at all sites except Tibooburra, however the Cu content in twigs is slightly more variable than in the leaves. River red gum biogeochemistry displays slight to intermediate temporal variation that corresponds to periods of growth development between the seasons. This is significant in defining optimal sampling periods for some elements of economical interest such as Au, although for most elements the variation here was slight enough to allow for sampling at any time of year.

A characteristic of river red gums is the rapid development of an extensive and deep taproot system. The dense surface root system of a mature river red gum has been shown to extend at least 20 m in the horizontal direction and greater than 10 m vertically. Field observations from western NSW suggest that even these figures are conservative. River red gums can therefore have a biogeochemical sampling area of >4000 m^3 , with potential for element uptake via their roots from: the adjacent stream sediments; the shallow ground water aquifers within the alluvial sediments and buried bedrock or saprolite.

In conclusion, many of the characteristics of river red gums are consistent with the criteria required of a biogeochemical sampling media such as:

- an easy to identify plant species;
- a locally dominant and widespread distribution;
- a tendency to colonise areas dominated by regolith (where bedrock related information is less readily available);
- an extensive root system that may penetrate transported cover and possibly also provide a homogenised expression of heterogeneous transported cover;
- an ability to retain many plant organs throughout the year; and,
- large, smooth and waxy leaves that may tend to shed detrital surface contaminants.

THE SUCCESS RATES FOR VARIOUS SOIL ANALYTICAL METHODS AROUND A MINING CAMP IN WESTERN AUSTRALIA

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Major soil geochemistry exploration surveys at a mining camp in the Yilgarn Craton of Western Australia have generated 27,360 data values within an area of 600 sq km using six different sampling and/or analytical methods. These are: (i) aqua regia digest and AAS finish using a graphite tube analyser (GTA); (ii) three bulk cyanide leach (BCL) methods with variable cyanide solution concentrations done at different laboratories; (iii) a MagLag sampling method with concentrated HCL digest; and (iv) the MMI Technology® M Extraction. The methods have variable lower detection limits, and cover 28 sites shown by extensive drilling to be either barren or mineralised within the lower saprolite or bedrock. The area is typical of the deeply weathered Yilgarn terrane; exposure is very poor and all the known mineralised sites are covered by either deeply weathered Cainozoic sedimentary rocks and sediments, or by Archaean pallid clays and saprolite.

The relative merits of these methods were evaluated by counting their successes and failures at both mineralised and barren sites, so defined by drilling to bedrock at sufficient density to fully test for the presence of mineralisation at each site. Failures are (i) false anomalies that led to unnecessary drilling in a barren area, and (ii) lack of anomalism over known mineralisation. A perfect success rate of 100% will result in the optimum application of exploration drilling expenditures. The data were levelled by (i) flagging each sample value by regolith type (regolith domaining); (ii) calculating background values for each regolith type; and (iii) by re-calculating the sample values in each regolith domain to "Times Background" responses. The four regolith types are ferricrete, eluvium, colluvium and alluvium.

Method	Aqua Regia + AAS/GTA	BMA Lab BCL 1%CN	XRA Lab BCL ?%CN	GNS Lab BCL 0.1%CN	MagLag Conc.HCL	MMI M Extraction
Detection Limit	1 to 3 ppb	0.1 ppb	0.1 ppb	0.1 ppb	0.5 ppb	0.1 ppb
PASS at Barren Sites (Sterilises ground correctly)	1 / 25	1 / 14	0 / 9	2 / 13	0 / 3	6 / 6
FAIL at Barren Sites (False anomalies)	24 / 25	13 / 14	9 / 9	11 / 13	3 / 3	0 / 6
PASS at Mineralised Sites (Discovery success)	2 / 2	1 / 1	1 / 2	2 / 6	3 / 4	5 / 5
FAIL at Mineralised Sites (Discovery failure)	0 / 2	0 / 1	1 / 2	4 / 6	1 / 4	0 / 5
OVERALL SUCCESS RATE	3 / 27	2 / 15	1 / 11	4 / 19	3 / 7	11 / 11
	11%	**13%**	**9%**	**21%**	**43%**	**100%**

All of the methods, except for MMI, generate a large proportion of false anomalies, a reflection of their aggressive digests relative to the M Extraction, and the consequent nugget effect. Those methods do not sterilise ground efficiently and have led to significant unnecessary drilling expenditure.

The combined results for the three BCL methods failed to define five of nine mineralised sites, at all of which the data is above detection and within background. Two of these fails are due to the deep weathering and leaching, which post-date anomaly formation during the earlier iron-enrichment (ferricrete-forming) event. One fail is a reflection of subsequent colluvial cover derived from adjacent granite, that has buried any potential anomaly-hosting regolith. The reasons for the other two fails are not clear. The MagLag failed at one of four mineralised sites, at which all the analytical values were less than the detection limit. This is probably because of the destruction of magnetite and maghemite to clays, caused by the intense leaching in the regolith at that location. Such regolith is abundant in the Yilgarn and a larger sampling program would probably diminish the overall success rate by revealing further failures of this type for the MagLag method.

The MMI was able to achieve measurable natural background values in all types of regolith and was the most successful method at all the sites at which it was used.

ENVIRONMENTAL AND EXPLORATION GEOCHEMISTRY OF MASSIVE SULFIDE DEPOSITS IN ARCTIC CLIMATES: DISTINGUISHING NATURAL VERSUS ANTHROPOGENIC SOURCES

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Introduction

Northwestern Alaska contains enormous amounts of metals in sediment-hosted Zn-Pb-Ag massive sulfide deposits. Natural weathering of these deposits has dispersed metals over a wide area. Local anthropogenic sources also contribute metals to the environment. Galena- and sphalerite-bearing ore concentrates are produced at the Red Dog mine, the only operating mine in the region. The concentrates are transported along a haul road from the mine to a port storage facility. Transportation and storage of the concentrate has inadvertently resulted in dispersal of dust from the concentrates along the haul road and port facility. Geochemistry of surficial samples (soils, alluvium, and colluvium), together with their mineralogic character (including mineral species and the morphology of grains), distinguishes natural soils from soils containing ore concentrate dust.

Environment

The arctic climate of northern Alaska is semi-arid with temperatures averaging 11°C (July) and -22°C (February). Mean annual precipitation is 25.7 cm and snowfall averages 145 cm. The area is underlain by continuous permafrost and therefore, most of the surface features are the result of freezing and thawing processes such as frost action, soil creep, and other cryogenic processes.

Methods

Surficial samples were collected in areas of known massive sulfide deposits as well as adjacent to the haul road and port facility. Multi-element geochemical data were obtained using INAA and ICP-AES methods. The mineralogy and morphology of grains were determined by X-ray diffraction (XRD) and the scanning electron microscope (SEM).

Discussion

Soils overlying buried massive sulfide deposits have patterns of increasing metal contents with depth and proximity to the metal-bearing source. Elements that most clearly show this pattern include Fe, Pb, and Sb. From near-surface to about 40-cm depth, iron increases from 2.2% to 4.3%, lead from 849 ppm to 13,800 ppm, and antimony from 6.8 ppm to 112 ppm. The acidity produced by natural weathering of the deposits mobilizes some elements such as Ca, but not others such as Se and Mo. Consequently, high Mo (30 ppm) and Se (17 ppm) and low Ca (<0.1%) contents characterize surficial materials near natural deposits. Other diagnostic elements of soils near the sulfide deposits include Ag (0.5-2.6 ppm), P (0.1-0.3%), and V (170-406 ppm). Acidic conditions also yield high Pb/Zn ratios (10-100) because sphalerite is chemically weathered and zinc is preferentially mobilized and removed. In natural soils, secondary jarosite, plumbojarosite, and anglesite are developed. Remnant galena is etched and rounded due to a long history of chemical and mechanical weathering. This galena has high concentrations of impurities (Al, K, and Si) owing to the presence of intergrown secondary mineral phases such as jarosite.

The variations in metal contents and mineralogy of natural soils contrast distinctly with those containing mining-produced fugitive concentrate dust. Dust is localized at the surface, and therefore metal concentrations are high within the upper 10 cm of soil profiles. However, concentrations sharply decrease downward. At 28-35 cm depth, Pb, Zn, Ag and Sb are at least 2 orders of magnitude lower compared to surface concentrations. Samples with ore concentrate dust are not acidic because acid-producing minerals like pyrite are minor or absent and oxidation has not occurred. Therefore, elements that are typically highly mobile in acidic conditions (e.g., Zn) are not as easily removed. Evidence for the immobility of Zn in concentrate-bearing sites is the consistent Pb/Zn ratios of about 0.2 throughout soil profiles. Galena grains from these profiles show perfect cubic cleavage (i.e., not rounded), are not rounded, are unetched and have no detectable concentrations of Al, K or Si. Secondary minerals such as jarosite and anglesite are not present in ore concentrate dust-bearing soils.

Conclusion

The geochemistry and mineralogy of surficial materials near massive sulfide deposits suggest that chemical weathering is an important process in the arctic environment. The complicated natural processes that disperse metals to the environment produce several distinct characteristics of the resulting metal-bearing materials. Assessment of metal-rich surface materials using the methods discussed here can reliably indicate if the metals are from natural or anthropogenic sources. Furthermore, the suite of elements that characterize the deposits (Ag, Fe, Mo, Pb, Sb, Se, Tl, V, and Zn) may be used as exploration guides to sediment-hosted zinc deposits in the arctic environment.

ECOLOGICAL AND BIOGEOCHEMICAL MAPPING OF MERCURY IN LAKE BAIKAL

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In 1994, the North Baikal expedition of Buryatgeology, the State Industrial Geological Organisation, found that the waters of Lake Baikal were very significantly polluted with mercury. Concentrations of 5-63 mkg/L (µg/L) Hg exceed the limit of permissible concentration (LPC) for drinking waters (0.5 mkg/L (µg/L)) by factors of 10 to 126. These data were not unexpected, because even in the 1950s and 1960s, data from the Buryat sanitation-epidemiological station recorded that some fish from Lake Baikal exceeded the LPC. However, the data were fragmentary and obtained by analytical procedures with a detection limit close to LPC. Conflicting data were also given by analysis of Baikal water, with maximum Hg concentrations of 0.5 LPC. Lake Baikal is situated in a zone of contemporary rifting, with active tectonic movements and numerous earthquakes, some catastrophic. Because of this, Hg pollution of the lake would be expected to be very variable in place and time. Monitoring is therefore critical.

Mercury pollution of Lake Baikal has been found to occur 0.5 to 1.5-2.0 km from shore, at depths of 1.5 to 6.0 m, affecting a significant volume of water. Drinking water from groundwater sources has also been found to be polluted. Water from seven of nine boreholes from the settlement of Severobaikal'sk exceed the LPC by factors of 5 to 14, and at the settlement of Nizhneangarsk, water from seven of eleven boreholes exceed LPC by factors of 5 to 52. In addition, concentrations of Cd here exceed background by a factor of 55, Tl up to 16 times and Se up to 1.4 times. It may be significant that these toxic elements potentially migrate as gases. The highest concentrations of Hg, up to 100-700 mkg/L (µg/L), were found in the filtrates of snow water. These exceeded LPC by 200-1400 times, and may give short-time maxima of Hg concentrations in rivers during spring floods. High concentration of Hg, which exceed the LPC for drinking waters by 2-20 times, have even been found in rainwater.

Natural Hg pollution of waters is sometimes complex, accompanied by Cd, Tl, As, Se and other toxic elements, and may be heterogeneous in space and variable in time.

CARBON ISOTOPIC EVIDENCE FOR MICROBIAL INFLUENCE IN EXOTIC-TYPE COPPER ORE DEPOSITS: IMPLICATIONS FOR EXPLORATION WHERE MICROBES ARE INVOLVED

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Introduction

Microbial metabolism has been documented in a wide range of surficial environments, including those of acid mine drainage and chalcocite blankets of porphyry copper deposits, consistent with supergene enrichment processes being facilitated by organisms. In rare cases, the organisms have been imaged but, in others, microbial activity is preserved only by aberrantly low $\delta^{13}C$ values generated through the oxidation of bacteria. Exotic-type copper deposits at Mina Sur and Huinquintipa in northern Chile represent environments conducive to some microbes because they are in the near surface environment, contain nutrients such as phosphate, nitrate and sulfate, and have elevated concentrations of toxic metals that discourage some bacteria but promote others. These bacteria may not only participate in formation of the ore, but post-ore species would mobilize some components out of the ore and into surrounding environment. Using selective extraction of CO_2 via crushing, pyrolysis, reaction with NaOCl or reaction with EDTA from both ore and soil samples, $\delta^{13}C$ values were used to determine the influence from microbes and whether carbon isotopes can be used to indicate exotic-type mineralization.

Results and discussion

There are three principal reservoirs of carbon in exotic-type deposits and overlying soils in northern Chile, namely carbonate derived from atmospheric CO_2, carbonate resulting from respiration of plants and bacteria and isotopically distinct carbon from methanogenic bacteria. The first two reservoirs are ubiquitous in soils throughout the area, but the latter reservoir is restricted only to exotic-type ores and the overlying soils and is released by reaction with EDTA. Ores from Huinquintipa have anaerobic bacterially generated carbon that is isotopically distinct from CO_2 adsorbed on grain surfaces or released from fluid inclusions. The anaerobically produced carbon resides in Cu carbonates and phosphates in the ores, but SEM images of the surfaces of chrysocolla botryoids reveal clusters of ovoid depressions underlain by a fibrous mat that are probably products of late reabsorption or dissolution. Thus, although no visible evidence for microbes remains in the ores, evidence for microbial activity is preserved by the aberrantly low $\delta^{13}C$ values generated through the oxidation of bacteria and released via reaction with EDTA.

Conclusions

Selective extraction of CO_2 from exotic-type ores and soils around the deposits reveal the occurrence of exceptionally low $\delta^{13}C$ values in the ores and only in soils directly over the ores or in feeder channels. Moreover, because such carbon is released only through EDTA dissolution of ore samples, microbial metabolism may have contributed directly to Cu silicate precipitation. The spatial relation of the ore with low $\delta^{13}C$ values indicates that microbial activity can mobilize components from ore zones and this activity can be revealed by carbon isotopic compositions.

SUPERGENE GOLD ENRICHMENT IN A REDUCED PALAEOCHANNEL, SUNRISE DAM DEPOSIT, LAVERTON, WESTERN AUSTRALIA: IMPLICATIONS FOR EXPLORATION AND MINING

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Introduction

Sunrise Dam is a world-class gold deposit located on the margin of Lake Carey, a playa near Laverton, Western Australia. The present-day, flat land surface covers a complex sub-surface regolith that is semi-saturated by hyper-saline groundwater. Coarse-grained, high-grade primary mineralization subcrops in weathered Archaean sedimentary and volcanic rocks at 25 m depth. A multiphase, buried Eocene palaeo-drainage system crosscuts, and truncates, the mineralized zones down to 80 m depth. Bacteria-induced and mediated organo-reduction processes in poorly drained parts of the channel-fill have caused the chemical reworking and redox-controlled supergene enrichment of gold in the regolith cover.

Discussion

The channel-fill comprises quartz-rich gravels and conglomerates, sand, and organic-rich silts (5-15 m thick); overlain by grey sandy-clay containing weathered rock and carbonaceous fragments, interbedded with lateritic gravel and sand lenses (20-60 m thick). Organo-reduction processes in low-water flux zones have caused distinctive purplish-red hematitic staining and mega-mottling, together with the local degradation of iron oxide-rich and siliceous units, and the formation of grey clays in the channel-fill and in saprolite abutting the palaeochannel. Strong reduction in the basal sediments is characterized by the precipitation of supergene sulphide minerals, particularly fine-grained framboidal pyrite and marcasite. Fresh goethitic staining marks active acidic redox fronts surrounding the reduced zones.

Low-fineness, micron-sized refractory gold grains are encapsulated in alunite at grades of up to 5 g/t Au within reduced grey clay above the secondary sulphide zone. Elsewhere, gold is depleted from the reduced channel-fill and enriched just above the top redox front, at up to 20 g/t Au, in a sub-horizontal zone perched at 18-25 m depth in the palaeochannel-fill, independent of sedimentary horizon and locally intersecting the adjacent mineralised weathered bedrock; gold is also enriched just beneath the bottom redox front at the base of the palaeochannel, as high-grade bonanza deposits, in excess of 1000g/t Au, that extend into the underlying residual regolith about the unconformity. Some apparent detrital gold grains are preserved within the redox enrichment zones, but most grains show evidence of multi-phase accumulation and electro-refinement to high-fineness, anhedral and crystalline forms indicative of a chemogenic origin for the gold.

Conclusion

The formation of coherent redox-controlled supergene gold enrichment zones in reduced transported cover provides laterally extensive near-surface regional exploration targets for buried primary deposits. From mining and metallurgical viewpoints, the supergene ores provide early returns due to free digging and ease of gold extraction.

MINERAL HOSTS FOR GOLD AND TRACE METALS IN REGOLITH

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Introduction

Geochemical dispersion of gold, base metals and their geochemical tracers is dependent on the retention in the mineralogical phases in the regolith. The element-mineral associations have been investigated in the in situ regolith developed on mineralised rocks at the Boddington Cu-Au deposit, Mt Percy Au deposit and Scuddles massive Cu-Zn sulphide deposit, all situated in the Archaean Yilgarn Block, Western Australia. The residence of gold and trace elements has been determined by in situ Laser Ablation ICP-MS and electron microprobe analyses. A method to interpret the LA-ICP-MS data obtained from mainly heterogeneous microcrystalline material has been developed during this study.

Settings and mineralisation

The Boddington Au deposit is located in the Saddleback Greenstone Belt. The porphyry-style Cu-Mo-Au-Bi-W mineralisation is hosted in felsic to intermediate volcanics. The Mount Percy Au deposit is situated in the Kalgoorlie goldfields in the Norseman-Wiluna Greenstone Belt. Gold mineralisation is hosted by porphyries and contact fuschite-carbonate alteration zones. The Scuddles Cu-Zn deposit is in the Golden Grove district, Murchison province. The mineralised horizon occurs in a sequence dominated by felsic and intermediate volcaniclastic sediments and lavas, and comprises an upper layer of massive Zn-Fe sulphides grading downwards to a pyritic zone.

Regolith mineralogy

At Boddington, the saprock and kaolinite rich-saprolite contain chlorite-vermiculite, biotite-vermiculite and vermiculite. The top part of the regolith comprises a partially ferruginised clay zone, a bauxitic layer and a fragmental and nodular duricrust. Gold abundance increases from the saprolite to the bauxitic zone where it peaks with a maximum value of 9000 ppb; Cu, Mn, and Zn are concentrated in the lower saprolite.

At Mt Percy, the lower saprolite and upper saprolite contain abundant sulphide relics replaced by goethite and hematite. Kaolinite is locally replaced by alunite in the upper saprolite. Cutans consisting of microcrystalline kaolinite, goethite and hematite are abundant in the strongly ferruginised mottled and plasmic clay zone above. Gold is concentrated in the lateritic duricrust and in the alunite-rich zone in the clay saprolite.

At Scuddles, the saprolite developed above the mineralisation contains abundant chlorite and hematite-goethite pseudomorphs after sulphide. In the hanging wall, chlorite is weathered into corrensite, and nodules of Mn-oxides (coronadite and lithiphorite) are abundant. Copper, Zn, and Pb are concentrated in the hanging wall. Bismuth, Mo, Sb and In are concentrated in the near surface horizons over the mineralisation.

Results

Boddington: in the saprolite, Au (up to 270 ppb), Cu (up to 4%), Bi (up to 340 ppm), W (up to 100 ppm), Mo (up to 200 ppm) and As (up to 0.5%), are preferentially trapped in goethite formed from the weathering of vermiculite and in goethite-hematite pseudomorphs. Vermiculite also incorporates Cu (1.3% CuO). In the duricrust, Au (up to1000 ppb) occurs in goethite in the matrix, cutan and core of the nodules. Copper (130 ppm), As (120 ppm), and Mo (106 ppm) are concentrated in the cutan goethite. Kaolinite and gibbsite do not scavenge trace elements related to the mineralisation. The W, Ta and Bi enrichment observed in the duricrust is partly caused by residual accumulation of anatase.

Mt Percy: gold (up to 400 ppb) is concentrated in cutans in the mottled and plasmic clays, presumably as cryptocrystalline particles. Goethite-rich cutans strongly scavenge Sb (up to 900 ppm), As (0.1%), Mo (up to 430 ppm) and Cu (up to 740 ppm). Tungsten and Sb are also residual in rutile, and some Cu is incorporated in alunite in the clay saprolite.

Scuddles: in the lower saprolite of the hanging wall, Cu (up to 0.33%) and Zn (up to 0.33%) are preferentially trapped in vermiculitic layers of corrensite. Lead and Mn are concentrated in coronadite and lithiophorite. Over mineralisation, Sb (up to 440 ppm) and Mo (up to 220 ppm) are concentrated in goethite in the reddish mottles of the upper saprolite whereas Bi is enriched in the bleached kaolinitic material where it occurs as Pb-Bi micrograins. Antimony, Mo and Bi are also hosted in rutile uniformly distributed in the horizon. The depletion of Cu and Zn in the upper saprolite can be explained by the scarcity of potential hosts such as vermiculite. Kaolinite does not incorporate or adsorb base metals under the prevailing weathering conditions.

Conclusions

The trace element dispersion is strongly controlled by the occurrence of one or several suitable receptors in the regolith. Vermiculites, smectites and corrensites are crucial for trace element retention. Goethite traps gold, base metals and pathfinder elements (Sb, W, Bi and Mo). Kaolinite and gibbsite dilute geochemical anomalies, and the relative accumulation of residual rutile and anatase inflates W, Bi, Sb and Mo anomalies in bulk analyses.

GEOHEALTH IMPLICATIONS OF THE RIVERINA GEOCHEMICAL SURVEY

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Introduction

Geological factors can impact the health of plants, animals and humans (geohealth), e.g., Se deficiency in China and As poisoning from groundwater in Bangladesh. Excess or deficiency of many (if not all) elements in living organisms can adversely impact their health.

Low-density geochemical baseline surveys have been conducted in many countries - but not Australia - for applications in resource evaluation, land use management and geohealth. The Riverina geochemical survey (see Caritat *et al.*, this volume) is one of very few of this kind of studies in Australia to date. It aims to provide essential information on the natural concentrations, sources and sinks of chemical elements and compounds in the near-surface environment. The objective of this paper is to discuss, in a geohealth context, the deficiencies and excesses of elements within the Riverina dataset.

Methods

Surface (TOP) and ~60-90 cm deep (BOT) samples of overbank sediments were collected at 142 sites over a 123,000 km^2-area in the Riverina region. This sampling medium is able to represent large catchment areas with just one or a few samples. Major and trace element compositions were determined in <180 µm fractions and in selective extracts.

Results and discussion

Several trace elements were found to be deficient or in excess relative to national and international guidelines for maximum allowable concentrations (MACs) in agricultural soils, for soil remediation or biosolids application. The geochemical survey of the Riverina region shows that As, Ba, Br, Cd, Cr, Cu, F, Ga, Ni, Sb, U and V concentrations in overbank sediments are locally elevated above these guidelines. Conversely, Co, Cu and Mo are found to be potentially deficient in parts of the region.

Over half of the samples collected contain more than 50 mg/kg Cr, which is the Western Australian Ecological Investigation Limit (WAEIL). Concentrations of Cr (BOT) increase smoothly towards the south, with sites from the south-central part of the area among the most elevated (exceeding the 100 mg/kg guideline value for both the German Maximum Tolerable Level in agricultural soils and the MAC for application of biosolids to agricultural land in Australia). The catchments that contain these samples drain directly from a ridge of Cambrian mafic volcanics, which is a likely source of the elevated Cr. Another possible source is the Quaternary tholeiitic basalts located just south of the Riverina region. While high Cr levels can be related to increased incidences of lung cancer, skin irritations and kidney and circulatory problems, even the maximum total value in the Riverina is unlikely to yield excessive available Cr because only a small proportion of total Cr is likely to be bioavailable. Heavy mineral fractions separated from a dozen samples contain chromite, ilmenite and other spinels, which are likely hosts for Cr.

Molybdenum is an element that is potentially deficient in the Riverina. Molybdenum deficiencies have not been reported in humans, but Mo is an essential nutrient to many crops. The world average concentration of Mo in soil ranges from 0.2-5 mg/kg and levels between 0.1-0.3 mg/kg are expected to produce Mo deficiencies. The median value in the study area (TOP and BOT together) is only 0.8 mg/kg, with 37 samples having Mo concentrations of 0.6 mg/kg or below. Low Mo concentrations in the Riverina occur mostly in the north and are more common in the TOP samples. Molybdenum has lower bioavailability in acid soils, therefore those in the southeast are more likely to be lead to deficiencies in crops even though soils here do not have the lowest total Mo concentrations. This corresponds to observations by farmers that soils in the tablelands to the south of the region need Mo fertilizer applications to boost plant growth.

Conclusions

The fine balance between excesses and deficiencies of trace elements in soil is essential for healthy growth of crops, plants in general and animals. In the Riverina, As, Ba, Br, Cd, Cr, Cu, F, Ga, Ni, Sb, U and V are locally found to be in excess compared to national and international guidelines while Co, Cu and Mo are potentially deficient.

As Australian guidelines are available only for a limited number of elements, external guidelines have been used as a substitute. Likewise, WAEIL data were used as no MACs are available for eastern Australia. Australian guidelines need to be developed for all elements and it would be useful that they report bioavailability limits in addition to total concentrations. Additionally, geochemical surveys need to be carried out for all major agricultural regions to ensure that health risks are identified.

MINERAL EXPLORATION TARGETS IN BRITISH COLUMBIA, CANADA, IDENTIFIED FROM REGIONAL STREAM GEOCHEMICAL SURVEYS

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Introduction

Canada's National Geochemical Reconnaissance (NGR) program, started in 1974 by the Geological Survey of Canada, produces high quality baseline geochemical data and identifies areas of high mineral potential. In British Columbia, this program, known as the regional geochemical survey (RGS), has generated geochemical data from the multi-element analysis of over 52,000 drainage sediment and water samples. Approximately 700,000 square kilometres of British Columbia have been covered at an average sample density of one sample per 13 square kilometres. Sampling and analysis is carried out to the original Geological Survey of Canada standards. To date the minus 80-mesh (<0.177 mm) fraction of the stream sediment has been used because it has proven to be an effective and cost-efficient regional exploration technique. In 2004, an orientation survey was carried out around the Eskay Creek gold mine in northwestern British Columbia to characterize the heavy mineral concentrate dispersal train associated with the gold mineralization. The Eskay Creek mine is a sub aqueous hot spring deposit with an estimated 2.94 millions tonnes of ore grading 43.25 g/t gold. The ore horizon, comprising massive and disseminated pyrite, stibnite, tetrahedrite, realgar, cinnabar and arsenopyrite, occurs in a Jurassic mudstone that has elevated cobalt, arsenic, antimony, and silver and mercury contents.

Methods

Bulk sediment samples, conventional silt and water samples were collected from 34 stream sites along a 2,500 square kilometre belt extending north and south of the Eskay Creek mine. The bulk samples were collected at the head of mid-channel bars and wet-sieved on site, through a 12-mesh (1.68 mm) stainless steel sieve, to recover 10 to 15 kilograms of the minus 12-mesh sediment material. Laboratory tabling and heavy liquid separation produced several different size and density fractions from each sample. The number of gold grains in the table concentrates was estimated visually. The minus 80-mesh (< 0.177 mm) size fraction of conventional silt samples and the heavy mineral concentrates were analyzed for trace elements by instrumental neutron activation, aqua regia digestion-plasma mass spectrometry and by specific techniques

Results

Geochemical data collected during a 1986 NGR regional survey reveal gold, arsenic and mercury sediment anomalies close to the Eskay Creek mine. A bulk sediment heavy mineral concentrate from a stream just east of the mine contains 413 gold grains and two other streams within 10 kilometres southwest of the mine have respectively 70 and 36 gold grain counts. Ten kilometres northwest of the mine, two streams drain the Iskut-Palmiere prospect located on a low ridge. Bulk sediment from these streams has up to 177 gold grains, but only background gold and trace element levels were detected in conventional silt samples from the same area.

Conclusions

In British Columbia, the NGR program traditionally uses conventional stream sediment geochemistry to identify areas of high mineral potential. However, heavy mineral concentrates can complement silt sampling to better define exploration targets. For example, the area around the Eskay Creek gold mine in northwestern British Columbia is outlined by gold anomalies in both heavy mineral concentrate and stream sediment samples. A mineral prospect northwest of the mine, however, is only revealed by anomalous gold in the heavy mineral concentrates.

THE DUAL ROLE OF VEGETATION IN ANOMALY FORMATION AT BARNS GOLD PROSPECT, EYRE PENINSULA, SOUTH AUSTRALIA

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Introduction

Mineral exploration using biogeochemistry is well documented. Plants have been used successfully to identify mineralization in North America, Russia and elsewhere. There are fewer Australian examples, partially because sampling of soils and other surficial media is commonly successful. However, as Australian exploration companies move away from traditional areas of outcrop or shallow cover, biogeochemistry may gain importance if it is able to penetrate deep cover without the need to drill. The Barns Gold Prospect, a Au-in-calcrete discovery in the northern Eyre Peninsula, South Australia, provides an example where vegetation (i) was anomalous in metals and might be sampled directly to 'see through' transported overburden and (ii) may have led, indirectly, to the formation of a Au anomaly in calcrete within the dune.

Site description

The Barns Gold Prospect is overlain by aeolian quartz sand at least 1 m thick. The cover thickens over part of the prospect to 8 m, due to the presence of a longitudinal sand dune, which provides an opportunity to study Au distribution and process in a relatively simple and recent regolith setting. Near the surface of the dune, there is an accumulation of organic material, underlain by near-white quartz sand. Below this, the colour of the profile changes to an orange-brown, due to clay coatings. The base of the dune consists of cemented calcareous clay that grades into a siliceous bleached saprolite derived from granodiorite. Mineralization is associated with quartz veins. The dune is well-vegetated, with *Melaleuca* and *Eucalyptus* up to 5 m high.

Methods and results

The study comprised two parts. Firstly, *Melaleuca* and *Eucalyptus* were sampled at about (i) 200 m intervals on a 5 km long traverse partly bordering the longitudinal dune and (ii) 25 m intervals perpendicular to, and transecting, the dune and mineralization on a much shorter 125 m traverse. Both traverses cross buried mineralization in weathered bedrock 35 m below the interface between the dune and leached saprolite. Gold concentrations in *Melaleuca* reached a maximum of 1.3 ppb, but only 0.2 ppb above mineralization in a combined sample of leaves, small branches and fruiting bodies; Au concentrations in *Eucalyptus* reached a maximum of 0.6 ppb, but only 0.3 ppb above the known extent of mineralization. *Eucalyptus* roots sampled from deep within the sand dune (see below) over mineralization, which had penetrated the saprolite, had a concentration of 1.2 ppb Au. Pathfinder (Ag, Bi and Pb) and other elements not known to be associated with the deposit (Co, Sb, W and Ta) were anomalous in vegetation growing over the buried mineralization. *Eucalyptus* is superior to *Melaleuca* as it tends to produce stronger anomalies in more elements, particularly pathfinders e.g. Ag, Sb, Pb and Bi. This is probably due to the presence of the deep tap roots that are able to source elements in the saprolith.

For the second part of the study, a slot was excavated in the southern face of the dune adjacent to the short biogeochemical transect. Regolith samples were analysed for geochemistry and luminescence dating. Gold concentrations in the sand dune ranged from below detection (0.1 ppb) to 9.2 ppb (mean of 0.5 ppb from 60 analyses). The highest Au concentration occurs in calcareous accumulations around a root channel at least 5 m above the residual regolith and 2.3 m below the surface of the dune. Laser ablation ICPMS transects of the calcareous sand indicate that the Au is unevenly distributed. The dune age was determined to be 27,000 years and hence the anomaly could be as old as this or as young as a currently growing tree. Calculations indicate that Au anomalies in calcrete can easily form as a result of vegetative processes during these time-frames.

Discussion

The simplicity of the dune regolith profile at Barns makes it a useful site for investigation of processes involved with geochemical anomaly formation. The role of vegetation in creating anomalies at Barns is indicated to be two fold. Firstly, plant roots are directly accessing elements (including those associated with mineralization) within the saprolith and bringing them to the surface forming an anomaly in plant parts. Secondly, metals are translocated down the porous sandy profile by meteoric water and illuviation. Evaporation is intense at the surface and generally decreases with depth but further concentration (and precipitation) takes places in root zones due to transpiration. The alkaline earth metals and translocated Au complex(es) precipitate together to form a second anomaly in the calcrete.

GEOCHEMICAL EXPLORATION IN AN AREA WITH ARTISANAL GOLD MINING IN PERU

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The artisanal gold mining in the Ayacucho Department (Peru) produces intensive pollution in the surrounding environment by mercury emissions. Large quantities of mercury-rich wastes from operations related to ore extraction and processing are disposed on land, where they are an important source of pollution. Artisanal gold mining uses the mercury-based amalgamation process, with negative consequences for the environment and human health. The mercury released into the air in the form of vapour or lost in the rivers and soils is a dangerous pollutant.

Significant data from a preliminary geochemical exploration campaign have been used for the environmental assessment of pollution associated to the artisanal gold mining in the area. On the basis of representative samples of soils from inhabited areas, in agricultural soils, and in wastes from the ore-processing operations stored in ponds in the catchment of the Acari River, geochemical anomalies have been inferred. The soil samples have total mercury contents ranging from 15.3 mg.kg^{-1} to 44.2 mg.kg^{-1}. Agricultural soils all have total mercury contents of less than 2 mg.kg^{-1}. The total mercury content of wastes from ore processing works, collected on two storage ponds, is between 139 mg.kg^{-1} and 189 mg.kg^{-1}.

As a result of the analyses of mercury contents, some action plans must be take in to consideration in these areas to avoid the pollution associated to the use of mercury in artisanal gold mining. As a first step, mercury anomalies in areas with different land use must be evaluated and a risk assessment undertaken.

ON THE SPECTRAL REFLECTANCE CHARACTERISTICS OF ZINC PHOSPHATE MINERALS AND A NOVEL APPLICATION OF U-TH/HE THERMOCHRONOMETRY TO CONSTRAIN THE AGE OF NON-SULFIDE MINERALISATION AT SKORPION, NAMIBIA

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Introduction

Non-sulfide zinc deposits such as Skorpion in Namibia are a significant class of base metal mineralisation, whose relevance has been recently reconsidered in the light of their potential for low cost production of metal at the mine gate. The surface expression of non-sulfide zinc deposits of this type, however, is unlikely to be iron-rich gossans but rather non descript rocks such as weathered arkose or carbonate containing difficult-to-recognise admixtures of zinc or lead-rich clay, phosphate, oxide, sulfate and arsenate. Such mineral assemblages are genetically linked to the commonly poorly understood or constrained weathering and climatic histories of the terrain in which they occur. Accordingly, we have investigated the spectral reflectance characteristics of Zn phosphate minerals from several locations, with a view to developing a potential exploration tool utilizing airborne techniques such as Hymap, and to assist mapping at mine scale. We have also performed a novel (U-Th)/He thermochronometry approach to age dating using the zinc phosphate mineral, tarbuttite, in order to tentatively constrain the timing of mineralization at Skorpion.

Methods

Zinc phosphate spectral reflectance characteristics were measured using Analytical Spectral Devices Inc.'s (ASD) Fieldspec Pro Spectrometer on coarse-grained crystalline hand specimens from Skorpion (Namibia), Broken Hill (Zambia) and Reaphook Hill (South Australia). The raw spectra were imported into the software, The Spectral Geologist (TSG^{TM}), developed by CSIRO Exploration and Mining, for displaying, analysing and interpreting hyperspectral field and laboratory measurements. Age dating was performed by (U-Th)/He thermochronometry, along similar lines as those established for the well known apatite thermochronometer, on coarsely crystalline tarbuttite, associated with high-grade mineralisation from the upper part of the orebody at Skorpion. The >200 μm diameter shards analysed were sub-sampled from a 1 cm diameter tarbuttite crystal so no correction for alpha ejection was made. The samples were loaded into platinum capsules for helium extraction and analysis under vacuum using a Nd:YAG laser and quadrapole mass spectrometer. Uranium and thorium were analysed by isotope dilution ICP-MS after crystal dissolution in boiling HNO_3.

Results

Zinc phosphates have well developed absorption features in the visible to near infra red (VNIR) and short wavelength infra red (SWIR) regions of the electromagnetic spectrum. Tarbuttite ($Zn_2(PO_4)(OH)$) is the best example of this group with inferred PO_4^{2-} absorption features at variable wavelengths between 1200 nm and 2300 nm, that are identical to absorption features measured in hopeite ($Zn_3(PO_4)_2.4(H_2O)$) and to a lesser extent in scholzite ($Ca,Zn_2(PO_4)_2.2(H_2O)$). The ages obtained from nine determinations of the tarbuttite from Skorpion ranged from 42-90 Ma with a weighted mean of 54.4 ± 1.9 Ma.

Conclusions

The spectral reflectance characteristics of Zn phosphate minerals, and tarbuttite in particular, are encouraging for mineral explorers and miners who wish to engage spectral reflectance techniques from regional prospecting to mine scale mapping, and possibly complementing down-hole spectrometric nuclear logging for grade and quality control. Bench-scale measurements are continuing in order to ascertain if the spectral reflectance characteristics can be differentiated in more complex mixtures of non sulfide Pb and Zn minerals. Tarbuttite is suitable for dating by U-Th/He thermochronometry. Its measured age better constrains the time interval hypothesised thus far for supergene mineralisation at Skorpion, as it relates to repeated erosion and paleoweathering episodes of the "African surface" following the post-Gondwana rifting. It is possible that the bulk of the Skorpion orebody formed during the hot and humid weathering conditions during late Cretaceous. The formation of phosphate minerals, including tarbuttite, might reflect the end of this phase, before onset of the new arid climate marked by the (?Cenozoic) silcrete and calcrete deposition at the top of the deposit.

CONTINUOUS LEACH INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY: APPLICATIONS FOR EXPLORATION AND ENVIRONMENTAL GEOCHEMISTRY

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Introduction

Continuous Leach (CL)-ICP-MS is a new analytical technique developed to address some of the shortcomings of conventional geochemical procedures. The low sensitivity of bulk leach techniques associated with matrix dilution effects are improved while simultaneously overcoming the uncertainties associated with interpreting selective extraction data. CL-ICP-MS provides information on the specific geochemical sites and mineral phases from which elements are being released using real-time data generated by continually analyzing progressively reactive solutions varying from water to 30% nitric acid as they are pumped through a sample directly into a high resolution ICP-MS. Mineral breakdown reactions can be monitored from the major elements released, thereby eliminating the uncertainties related to reagent specificity commonly encountered in selective extraction procedures. By comparing major and minor element release patterns, trace elements can then be reliably assigned to host phases.

Results and discussion

Results from single mineral phases, mixtures of mineral phases and natural ore samples indicate that the release of elements from specific minerals is not obscured when determined in complex samples. SEM examination of continuous leach reaction products have been used to verify which phases react and these support the CL-ICP-MS data interpretations. Results for natural soil samples found prospective for Irish-type Pb-Zn deposits by conventional techniques indicate that false mobile element anomalies can be identified using CL-ICP-MS and underscore the importance of understanding where trace elements reside in samples used for environmental studies or mineral exploration. Accurate determination of Pb isotopes is achieved by analyzing a limited suite of elements allowing counting times for Pb isotopes to be increased over multi-element CL-ICP-MS methods and more accurate Pb isotope ratios to be generated. Comparison of major element release patterns to variations in Pb isotope ratios indicate that host phases can be identified for isotopically distinct Pb reservoirs within geological samples. Multi-element data indicate that the U, Th and total Pb content of these reservoirs can be utilized to gain insight into the mechanisms producing distinct isotopic signatures in particular phases.

Conclusions

CL-ICP-MS can provide information on specific phases and mineralogical sites from which trace elements are being released. Concentration profiles are obtained from samples while continuously monitoring analyte signals by high resolution ICPMS. Compared to batch extraction procedures normally used, the approach involves minimal sample preparation, reduces contamination because the leaching is performed in a closed system and allows correlation of reactions rates for major and trace elements. However, analysis time is long and the spectra obtained can be complex. Continuous on-line monitoring also allows a greater resolution of the various phases reacting with a given reagent. It can therefore be used to design effective leaching strategies and to trace isotopic compositions, particularly Pb isotope ratios.

GOLD GEOCHEMISTRY OF THE SUMAYAR VALLEY, NORTHERN AREAS OF PAKISTAN

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The Sumayar valley (36º 08’ to 36º 19’ N, 74º 37’ to 74º 45’ E) is located in south central Karakoram Range close to the suture that thrusts the Karakoram plate on to the Kohistan Island arc. Bedrock in the valley comprises medium to high grade metamorphic terrigenous sediments intruded by Tertiary Sumayar tourmaline granite. The valley faces extreme gradients (altitude ranging from <2,000m to >7,000m) and weather conditions. The upper part of the valley is occupied permanently by the Silkiang glacier, which sheds a range of glacial sediments that are deposited downstream of the glacier.

Stream sediments were collected from 12 pairs of sites representing high and low energy hydraulic environments. In addition, samples were also collected from adjacent talus fans, glacial deposits, avalanche and lacustrine deposits. Thirty three elements were analyzed by XRF and INAA as coarse (125-180 μm), fine (<125 μm) and pan concentrates for each site. However, this paper highlights the occurrence of gold in the samples with the objective to establish parameters for further investigation and its possible source rock(s).

Gold concentrations range from 1 to 3,050 ppb in the coarse fraction, 1 to 4,800 ppb in the fine fraction and 54 to 33,400 ppb in the pan concentrates of the stream sediment samples. The highest concentration of gold recorded in talus fans is 44 ppb, in moraine 114 ppb, in avalanche 52 ppb and a surface hard rock sample contains 38 ppb. At least one stream sediment sample has yielded 3 pieces, 2 specks and 70 colours of visible gold.

Data have been interpreted by employing EDA and other statistical techniques. Results have been concluded with the help of spatial distribution diagrams of anomalous samples comparing with surface geology. In conjunction with all these, Factor analysis are suggestive that gold in association with actinide and rare earth group of elements is likely to be related with tourmaline-granite (Factor-2) as epigenetic. Here, gold is significantly related to tin and uranium. There appears to be elemental gold in the metamorphic rocks (Factor-8), with some possible relationship with ultrabasic rocks. For further geochemical exploration programs, fine fractions of low energy and pan concentrate of high energy stream sediments seem to be the best sampling media for gold and base metals in the Karakoram Range conditions.

RARE EARTHS AND PARTIAL DIGESTIONS – DIAGNOSTIC SIGNALS FROM BELOW

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Rare earth elements appear commonly and strongly in partial digestions from a wide range of “unexpected” mineral deposit styles and geological assemblages – komatiitic nickel sulphides, vein-type Au deposits, and kimberlites, for example. Rare earths are commonly thought of as being associated with felsic and granitic rocks and carbonatite mineralization. Investigations of several komatiite-type NiS deposits from Western Australia (e.g., Nepean, Miitel North) show high concentrations of Ce and Nd from MMI-M digestions of soils in close proximity to sulphide ore, even when felsic rock types are absent or laterally displaced. Comparison with previous fresh-rock geochemical and geological models suggests that, in these cases, the rare earths are probably derived from, and are diagnostic of, felsic plumes incorporated into the basal part of the massive sulphides. As such, the rare earths from partial digestions of soils over ultramafic rocks can be a very useful vector to ore.

Similar observations have been made on a limited number of vein-type gold deposits. Partial (MMI-M) digestions commonly show high values for rare earths coincident with the high Au and Ag signals from soils above the mineralized part of the vein system. Again, comparison with previous hard rock geochemistry shows that rare earths are often present in the mineralized parts of vein systems, and are probably indicative of precipitation of specific (and possibly diagnostic) minerals from the mineralizing fluids.

It appears that rare earth elements have a geochemistry that is conducive to excellent vertical migration (and spatial discrimination), and which is also compatible with weak extraction and ICPMS analysis. Accordingly they may play a role in elucidating vertical migration mechanisms as well as providing useful exploration information for a wider range of mineral deposit types than has previously been recognized.

HARDPANS AND BASE OF HARDPAN GEOCHEMICAL SURVEYS

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In the late 1980s and early 1990s, base-of-hardpan (BOH) sampling was developed as one of the routine and more successful geochemical survey techniques for gold exploration in the Murchison district of Western Australia. Hardpan is a widespread regolith unit and is typical of the more arid northern half of the Archaean Yilgarn Shield. Characteristically, the hardpans are red brown laminated and lithified (silicified) units typically 2-3 m thick and usually concealed by a veneer <1 m thick of recent colluvium and/or alluvium. Hardpan has formed over an extended period of geological time, probably since the late Tertiary – early Quaternary, and has developed over a wide variety of substrates – truncated and intact lateritic profiles and older transported alluvium and colluvium. Where developed over truncated and intact lateritic profiles, hardpan contains varying levels of gold, base metals and trace elements that reflect the distribution of these elements in the unleached bedrock, saprolite or enriched ironstones and duricrusts of the laterite profile. Although research on the mechanisms of concentration of gold and base metals into the hardpan is by no means completed, it is almost certainly due to a combination of biological and physical (hydromorphic) processes. For geochemical exploration, hardpan is best considered and treated as a fossil soil.

Vacuum drill sampling on a 50x200 m grid spacing of the basal 0.3-0.5 m of the hardpan profile, with analyses of samples for gold, base metals and trace elements on a single aqua regia digest by AAS methods, were the essence of Newcrest's BOH technique. BOH surveys are a very cost and time effective approach to the evaluation of broad geological/geophysical gold exploration targets beneath the margins of extensive colluvium/alluvial plans which flank islands of Archaean greenstone outcrop in the arid parts of the Yilgarn Shield. BOH surveys are 3-5 times less costly and take a third to half less time than the traditional RAB drill hole, saprolite sampling programs. For budgeting purposes, allow about \$4,000-\$5,000/km^2 for BOH surveys on 50x200m spacing.

Gold and base metal anomalies in hardpan are dominantly hydromorphic features, but the patterns are usually sharply defined, with little or no lateral displacement of peak values from the bedrock sources, compared to gold in pedogenic carbonate soils. With infill drill hole sampling at 50x100 m, BOH anomalies become direct targets for follow-up RAB and RC drilling.

Gold 'anomalies' are typically contourable at around 20-25 ppb Au. In the Murchison area, peak values are in the range 75-125 ppb Au – depending on the specific lateritic substrate, generally define first order targets for RAB/RC drilling.

Multi-element BOH data offers significant advantages over gold-only data, with relatively small add-on costs for gold targets with multi-element signatures and for mapping prospective structures alteration and bedrock lithology. BOH geochemical surveys are also suitable for base metal exploration (Cu-Pb-Zn and Cu-Ni) in the northern Yilgarn.

The Murchison BOH survey method has been shown to work for hardpans developed over intact or partially stripped lateritic profiles throughout the northern Yilgarn. There is very little data from CSIRO and company research at present to consider whether BOH surveys can be extended to areas where the substrate is transported material. The discovery of anomalous gold in calcareous red clay soils developed over thin (up to 15 m) alluvium-covered saprolite gold deposits in the eastern Goldfields (e.g., Panglo), suggest this may be a distinct possibility where the transported cover beneath the hardpan is thin.

LOCATING ORE UNDERCOVER USING A BACTERIAL LEACH AND OTHER GEOCHEMICAL TECHNIQUES

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The 21st century provides new challenges to mining industries as new, economic mineral deposits are becoming more difficult to locate. Exploration for major ore bodies is progressing under various depths and types of cover. Under these difficult exploration areas, geochemical investigation can play an important role in the success of exploration, particularly in regions of transported overburden and poor geophysical response.

Partial chemical extraction techniques are commonly employed as geochemical exploration tools. Partial extractions used in other studies have had some ability to locate buried mineralisation in specific environments and can provide a rapid, cost effective method for exploration under regolith cover. Bacterial Leach, a partial extraction using bacteria, has the potential to greatly magnify the geochemical signature imparted on the sample by the underlying mineralisation. The bacteria cause dissolution of ultra-thin surface layers of mineral particles, so the geochemical signature is not diluted in the sample matrix. The objective of the study is to understand the efficacy of Bacterial Leach and other common geochemical techniques to identify buried mineralisation. Two very different prospects are investigated: Wildwood, Au mineralisation in north western Victoria and Ni mineralisation at Honeymoon Well, in central Western Australia.

The Wildwood Au prospect is located 250 km northwest of Melbourne on the boundary of the Ballarat Trough and Murray Basin. Recent efforts have been made to explore the region where potentially repeating gold bearing units occur under varied thicknesses of regolith. Regolith cover overlying the mineralised zone is 25-75m thick. At this location, alluvial sediments of the Murray Basin overlie basalt, volcanogenic sediments and psammopelitic rocks. The regolith thickness increases to the north.

The Honeymoon Well Ni prospect is located 45 km south of Wiluna in the Agnew-Wiluna greenstone belt. Disseminated and massive sulphide deposits are hosted in the ultramafic sequences of diverse metamorphosed komatiite lithologies. The regolith in the study site is 15-40 m depth of mixed transported material.

Soils were sampled along traverses across areas overlying known mineralisation. Samples at Honeymoon Well were taken at the surface and 30-40 cm below the surface, while samples from Wildwood were taken at the argillic horizon, 30-85cm below the surface. Samples were subjected to Bacterial Leach analysis, and the results combined in geochemical element suites to predict the underlying mineralisation. Combining potentially anomalous elements suppresses the background and increases expression, thus enabling recognition of an anomaly where it may have been overlooked in investigations using single elements only. Element combinations are typically necessary, given the bacterial mechanisms for non-preferential, incomplete, partial digestion. Element indices in this study used combinations of the following: As, Bi, Cu, Ga, Ge, Ni, Sb, Se, Te, Ti, V and W.

Empirical assessments of anomaly expression for the geochemical techniques were conducted using hypergeometric statistics, allowing a quantitative comparison of conventional and new exploration techniques. Bacterial Leach significantly predicted mineralisation ($P(x)<3\%$) on 2 of the 5 assessed traverses at Wildwood, but none of the 3 traverses at Honeymoon Well were successfully predicted. The results indicate that Bacterial Leach is providing some beneficial results, but is not consistently identifying the mineralisation under cover. The Bacterial Leach geochemical indices respond similarly over all traverses. This trend is expected: certain elements are used in all derived groupings, but one combination provided the best results in the form of higher contrast anomalies and fewer false positives. Other geochemical techniques were not successful in detecting mineralised zones undercover; however, some techniques still need to be applied to the Honeymoon Well samples. No single element anomalies were evident at Wildwood, but some inconsistent single element anomalies were found at Honeymoon Well. Concentrations in surface materials were much lower than those collected at depth at Honeymoon Well location, which could be significant in future soil sampling exploration in the area.

Further investigation of the soils was undertaken to compare the results of these chemical extractions with those of the Bacterial Leach. Comparing the responses for elements based on the various leach treatments by correlation and principle component statistical analysis indicated that Bacterial Leach was most similar to the weak hydroxylamine hydrochloride leach. The hydroxylamine hydrochloride specifically targets amorphous Mn-oxide phases and implies that Bacterial Leach may be slightly selective towards the same phase.

The results of this study have allowed for identification of possible areas of buried mineralisation using Bacterial Leach that were not apparent through other chemical extractions in Victoria. However, the success is inconsistent and was not apparent in the different climate of Honeymoon Well. Whether Bacterial Leach has superior qualities as an individual, ‘stand alone’ technique is yet to be determined. Regardless of this fact, Bacterial Leach and other partial or selective extractions are likely to be beneficial tools in future geochemical exploration in areas of regolith cover.

HYDROGEOCHEMICAL EXPLORATION FOR GOLD IN THE WESTERN AUSTRALIAN WHEATBELT

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Introduction

The hydrogeochemistry of 139 groundwaters in an area of the Western Australian wheatbelt has been examined as part of a regional Au exploration program. The study area has a semi-arid climate, and is covered by a regolith profile up to 10 m deep. Known Cu-Au mineralization, identified by laterite sampling, formed the central part of the study area at two locations approximately 4.5 km apart. Groundwater sampling was conducted on either side of these mineralized zones over a total strike length of 110 km that was coincident with a geological/magnetic structure. Where possible, sample density was 1 sample per 1.5 km around this area, and a density of 1 per 3.0 km was sought for the remaining area. The purpose of the study was to use hydrogeochemistry to complement traditional geochemical and geophysical exploration techniques such as stream sediment sampling, soil augering and airborne magnetics. A particular focus of this study involved various pre-treatment/pre-concentration methods being trialed on samples prior to Au analysis.

Methods

Groundwater samples were collected mainly from stock bores or piezometers. Many bores were equipped with windmills or submersible pumps and could be sampled directly. Groundwaters from piezometers and non-equipped bores were sampled with a flow through tube sampler. Field filtration and preservation techniques were applied to various sub-samples for a suite of metal and anion analyses. Up to three groundwater samples were collected at each site specifically for Au determination. In each case, Au determination was based on the pre-concentration of Au from 1 L of groundwater onto 1 g of activated carbon. To examine the effectiveness and necessity of special sample treatment, one sample was filtered and acidified, another was collected unfiltered and treated with NaCl, whilst a third sample was collected unfiltered and treated with KCN. The carbon was recovered and analyzed for Au and some other elements including W and Cu, since these elements were considered to be potential pathfinders for the style of mineralization being targeted. Ashing and digestion of the carbon, followed by ICP-MS analysis, was used in this study due to the current absence of NAA in Australia.

Results

Groundwaters in the region are mainly of the Na-Cl type, circum-neutral (pH 5.3-8.5, mean 6.5) and exhibit relatively low salinity (TDS 100-17,900 mg/L, mean 3500 mg/L). A full suite of major and trace elements were determined in the groundwater samples. Appreciable levels of W (up to 530 µg/L) were found from direct determinations and pre-concentrated on the carbon, forming a coherent anomaly. Gold distribution appeared to be more sporadic; but a number of anomalous zones were identified. Unfiltered groundwaters treated with KCN gave the best response for Au in this study; however, issues relating to sample consistency must be recognized. Analysis of the carbon proved challenging, with laboratory batch effects likely for some samples.

Conclusion

Hydrogeochemistry has demonstrated its applicability in regional exploration programs, assisting in the exploration through cover and highlighting priority areas for follow-up investigation. More research is needed on the analysis of carbon to provide cost-effective alternatives to NAA for Au analyses in water samples. The analysis method for Au on carbon considered in this study is not ideal due to the number of steps required to prepare the carbon for analysis, the potential for contamination and analyte loss.

CONTAMINATION OF PEAT AND MOSS SAMPLES 150 KM FROM THE FLIN FLON CU-ZN SMELTER, CANADA: IMPLICATIONS FOR EXPLORATION

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Introduction

Copper-Zn massive sulphide deposits occur up to 150 km ESE of Flin Flon, Manitoba, Canada. These deposits have distinct geophysical characteristics owing to mineralization comprising pyrrhotite, sphalerite, chalcopyrite and pyrite, but they lie below up to 100 m of Phanerozoic sediment and cannot be differentiated from other geophysical conductors in the area that contain only Fe sulphides. Overlying the Phanerozoic sediment, there is up to 2 m of peat and sphagnum moss, sample media that can accumulate and sequester elements of interest should the elements be migrating from their source in a positively charged state. Therefore, peat and moss were collected along traverses over mineralization to determine if geochemistry could be used to distinguish geophysical anomalies containing Cu-Zn massive sulphide deposits from Fe-only sulphide deposits.

Results and discussion

Moss collected in 2003 had anomalous base metal concentrations at multiple points along the sampled traverses and was initially considered a suitable media despite the presence of the odd false positive anomaly at sample stations not known to be associated with mineralization. Peat samples, collected at various depths along the same traverses in 2001, 2002 and 2003, were also anomalous above mineralization, but for a much wider range of elements, including major, chalcophile, high field strength and rare-earth elements. A correlation between Loss on Ignition values and geochemical anomalies quickly shifted attention to the possibility of contamination by wind or water transportation and it was subsequently revealed that many elements share a strong correlation with Al, the principal element in clays and many silicates. In the moss samples, Al concentrations correlate strongly with 33 other elements including both immobile high field strength elements and mobile transient and chalcophile elements. In shallow peat samples (<25 cm), Al correlates closely with 23 immobile and mobile elements, but in deep peat, (>40cm) Al only correlates with 11 immobile elements and there is a notable suppression of chalcophile elements. The trend from a wide range of elements in the moss to a limited number of relatively immobile elements in the deep peat suggests that the most mobile elements are being leached from the system during progressive burial.

Samples of the moss and peat used were examined using SEM coupled with EDAX. Small (< 6 micron) particles of K-feldspar, albite, quartz, amphibole, calcite, Cu/Zn sulphate/sulphide and Cu(+Zn) metal were observed in all of the moss samples, totalling 0.1% by volume. Most particles were found as free, separate particles, but at least one Cu-Zn particle suggests that moss was growing around the particle, consistent with deposition during growth of the moss. In contrast to the moss samples, no Cu-Zn sulphate/sulphide/metal particles were found in the peat samples, but the abundance of silicate particles was up to 2% of the total sample. The presence of these particles is physical evidence that aerosol and water deposition from anthropogenic activities and natural processes can affect the trace element geochemistry of surficial samples. The Flin Flon smelter complex, 150 km NW of the deposits, is the most obvious point source pollutant for base metals in the area, but particles derived from dried tailings, exposed ore residue dumps, forest fire debris and water run off during the spring thaw cannot be underestimated and is considered likely.

APPLICATION OF LITHOGEOCHEMISTRY TO GOLD EXPLORATION AT GOLD FIELDS ST IVES, WESTERN AUSTRALIA

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Lithogeochemistry is being applied to gold exploration programs at St Ives, Kambalda. Within 6 months of initiation, multi element analysis of first fresh Archaean rock from drill holes has realised considerable benefits including: a) effective identification of lithology and stratigraphy leading to stronger geological interpretations; b) chemical characterisation of alteration and pathfinder signatures in existing St Ives deposits; c) the ability to quantitatively compare and rank exploration prospects on alteration and pathfinder features; d) significant reduction of exploration target areas resulting in more cost effective, follow up drilling; and e) generation of conceptual exploration targets through integration with geological and geophysical datasets in GOCAD and application of geochemical concepts from ongoing Predictive Mineral Discovery CRC programs.

The St Ives deposits have collectively produced 7.1 million ounces of gold since 1980. They are structurally complex and occur within all rock units of the local Archaean stratigraphy which comprises (from oldest to youngest): Lunnon Basalt; Kambalda Komatiite; Devon Consols Basalt; Kapai Slate; Paringa Basalt; Black Flag Beds; and Merougil Creek Beds. Paringa Basalt and Black Flag Beds were intruded by differentiated mafic sills of Defiance Dolerite and Condenser/Junction Dolerite respectively. The Condenser/Junction Dolerite is considered the stratigraphic and chemical equivalent of the Golden Mile Dolerite. Numerous felsic, intermediate and mafic intrusions of occur throughout the St Ives stratigraphy.

Sampling of fresh rock for multi element analysis at St Ives is undertaken in all ongoing exploration drilling. Supplementary sampling of archived drill hole pulp samples has also been implemented. The aim is to achieve full coverage of the St Ives leases with multi element data at sample spacings of 250 to 500 m. Samples are analysed by ICP-MS/OES for 36 elements (Ag, As, Ba, Bi, Ce, Cs, Hf, La, Li, Mo, Nb, Pb, Rb, Sb, Ta, Te, Th, W, Zr, Al, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, S, Sc, Sr, Ti, V, Zn). Multi-element results undergo two stages of assessment: a) utilisation of trace elements to characterise lithological and stratigraphic domains, and b) utilisation of major and pathfinder elements to characterise samples that are altered or enriched above background levels.

Bi-plots of Th:Sc, Th:Ti and Th:Cr are used to constrain rock type and stratigraphy. Distinct groupings and positive trends are apparent, which enable clear differentiation of Kambalda Komatiite, Devon Consols Basalt and Paringa Basalt. Condenser/Junction Dolerite can be differentiated from other mafic units except Lunnon Basalt. Spatial comparison with adjacent samples discriminates between Lunnon Basalt (the lowermost stratigraphy overlain by ultramafic rocks) and Condenser/Junction Dolerite (hosted in the Black Flag Beds in the upper stratigraphy). Fractionated dolerite sills are highly prospective host rocks for gold mineralisation in the St Ives field. In all cases the fractionated portion of dolerite sills are readily identified by a Ti content >7000 ppm. Epiclastic and volcaniclastic rocks of the Black Flag Beds have compositions geochemically indistinguishable from felsic and intermediate intrusive rocks. Further work is being undertaken to establish identifiable geochemical signatures for the sedimentary rock units and felsic and intermediate intrusions.

Unaltered and altered ultramafic, mafic, felsic and intermediate rocks have been assessed using alteration indices. In particular, the ratios of Na/Al and K/Al are used to define areas of sodic, sericitic and strong potassic alteration. The distribution of potassic and sodic altered samples favourably correlates with the distribution of observed biotite and albite alteration and known gold mineralisation.

Pathfinder element signatures (As, Bi, Sb, Te, W, Mo) are highly variable. At the Victory gold deposit, Mo and W anomalies (up to 64 ppm and 50 ppm respectively) correlate with the distribution of potassic and sodic alteration. Bismuth (<9 ppm) and Sb (<5 ppm) anomalies occur in the Greater Revenge Area. The major structures at St Ives have differing pathfinder geochemical signatures (typically either W, Bi, As or Sb dominant), which are interpreted to represent pathways for different fluids present during gold mineralisation.

Multi-element results at St Ives have been effective in identifying empirical exploration targets and provide a means of quantitative comparison between targets. However, conceptual targets are also generated, founded on the improved understanding of geochemical processes in Archaean gold deposits that is emerging from the pmdCRC program. The St Ives multi element results are being incorporated into a 3D camp-scale GOCAD model, enabling integration of geochemical, geological and geophysical information. GOCAD models are utilised to visualise and interrogate the timing and distribution of features important for gold mineralisation at St Ives, and to generate conceptual exploration targets.

TARGETING GOLD MINERALISATION BELOW LAKE WAY, NEAR WILUNA: A POTENTIAL GEOCHEMICAL METHOD FOR EXPLORING THE EXTENSIVE SALT PLAYA SYSTEMS OF WESTERN AUSTRALIA

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Introduction

Salt lake geochemical sampling has been used to define Archaean gold and nickel mineralisation at Lake Lefroy, near Kambalda, in the southern portion of the Eastern Goldfields of WA but, to date has not been trialed in the northern part of the goldfields. The present study has confirmed the efficacy of shallow auger sampling using a specially designed light weight hydraulic auger drill rig towed by a dual axle quad bike to test known mineralisation beneath Lake Way, approximately 20 km south-southeast of the Wiluna gold operations. The Williamson gold deposit occurs below Lake Way and was originally discovered using a large, track mounted air core drilling rig targeting magnetic anomalies. Although successful, this method has proved to be expensive and the drilling rig cannot be mobilised quickly.

The Williamson Lode represents epigenetic gold mineralisation associated with quartz – sulphide veining occurring within a north–south trending monzogranite slither exhibiting faulted contacts with high magnesium and tholeiitic basalts, and doleritic intrusive sills, typical of the Archaean stratigraphy in the Wiluna region. The mineralisation has a strike length of 800 m and is considered to be open along strike. The deposit has been drilled to a depth of 125 m with typical transitional (lower saprolitic) zone RC drill intercepts of 23 m @ 5.17 g/t and 17 m @ 2.29 g/t Au contributing to a resource of 3.23 Mt @ 2.3 g/t Au. The deposit has been obscured by lake sediments, with strong weathering being to 75 m depth within the sheared mineralised zone.

Methods

Two orientation auger traverses were completed over the Williamson deposit at 50m holes spacing. Bedrock mineralisation was found to be reflected in the transported gravelly clay horizon immediately above the deposit with maximum results of 13 ppb Au and 213 ppb against a background of 3 ppb Au. Reconnaissance auger geochemical sampling was subsequently conducted over the salt lake on traverses up to 400 to 800 m apart, with auger holes at 25 to 50 m intervals. The auger traverses have been designed to test potential extensions to mineralisation as well as anomalies resulting from a detailed Sub Audio Magnetic survey conducted over the lake. The auger holes have penetrated lake clays (typically 1 to 3 m deep) overlying a “transported” gravelly horizon containing fine granular pisolitic and minor lithic (i.e., quartz) clasts (from 2 to 6 m) underlain by upper saprolitic clays representing strongly weathered bedrock. The lake/saprolitic clays effectively cling to the auger flights facilitating regolith logging and geochemical sampling. The clayey samples were sun dried prior to dispatching to Genalysis laboratories in Perth for Au, Ag, Pt, Pd, As, Sb, Te, Mo, W, Cu, Ni, V, Fe, Mg and U analysis after using an aqua regia digest and ICP – MS/OES techniques. A limited number of samples were also analysed for “oxidation suite” elements by Actlab laboratories using a partial “Enzyme Leach” digest.

Results

The lake stratigraphy is variable with a tendency for slightly shallower depths (4 to 6 m) over the Williamson deposit and the development of deeper channels (up to 12 m) to the east and southeast of the lode. However, there appears to be little correlation between the deeper channels and anomalous Au values (>6 ppb Au) that have been reflected in the pisolite–rich gravelly horizon overlying anomalous saprolite. In some cases, Au values are enhanced in the pisolite horizon (up to 112 ppb Au) relative to the saprolitic clays (40 ppb Au). A series of box and whisker plots comparing depth with the pathfinder elements – As, Mo, W, Te and Sb, as well as Ni, Mg and U generally show enrichment within the ferruginous gravelly horizon and reflect trace element dispersions expected within a typical lateritic profile. PGE and U are also enriched at shallower levels in the salt lake stratigraphy.

Conclusions

The auger geochemical programme has been successful in defining gold mineralisation occurring below Lake Way, a salt playa in the northern goldfields of WA. The survey has shown that in a relatively shallow salt lake (i.e. <12 m deep), ferruginous horizons can occur at shallow levels (i.e. 3 to 6 m) and provide a natural sink for secondary Au and pathfinder elements that have been mobile at some stage during the development of the salt lake. The preliminary data confirm that standard geochemical methods can target Au mineralisation in a geochemically hostile environment and may have implications for exploring the extensive salt playa systems in the Eastern Goldfields.

USE OF DIFFERENT FRACTIONS AND HEAVY MINERALS OF TILL FOR ORE EXPLORATION IN RIBBED MORAINE AREAS IN SOUTHERN FINNISH LAPLAND

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The use of different fractions and heavy mineral concentrates of till in ore exploration was examined in the Peräpohja Schist Belt in southern Finnish Lapland. The study area is situated in the central region of the latest Scandinavian glaciation with 3-7 m thick till sheet lying on the Archaean granites and Palaeoproterozoic sedimentary and volcanic rocks. Typical glaciogenic formations of the area are ribbed moraines consisting of till ridges perpendicular to the general glacial flow direction. The ridges are spaced 100 to 300 m apart. They are composed of two or more till units and their surface is covered with boulders.

To estimate dispersion of Au, Cu, Co and Zn in till of the ribbed moraines, different fractions (<0.06, 0.5-2 and >2 mm) and heavy mineral concentrates of till were separated and analysed. Test pits, test trenches and percussion drill holes were used to collect till samples. Samples were partially extracted (aqua regia) and then analysed using ICP-AES or GFAAS methods in the geolaboratory of the Geological Survey of Finland (GTK). Some older analyses (GFAAS) from detailed systematic till sampling were also used. The distribution of elements was examined both horizontally and vertically.

The surficial parts of ribbed moraine ridges seem to be most useful for sampling in ore exploration because they contain a lot of local bedrock material. For example, in one case, close to a Au-Cu occurrence, anomalous Cu and Au contents occur particularly in the coarsest till fraction and as well-preserved pyrite grains in the uppermost till unit. The shape of the Au anomalies and its pathfinder elements are clear-cut in the distal side of mineralization. If the surface area of the sub-outcrop of the mineralization is wide, the metal anomalies in upper till are large and the metal contents are also elevated in lower till units. A very short glacial transport distance is also seen in the composition of surficial boulders. Pebbles and boulders in the uppermost sandy or gravelly till unit and at the surface indicate glacial transport of a very short distance, mostly only tens to some hundreds of metres.

RUTILE COMPOSITIONS AT THE BIG BELL AU DEPOSIT AS A GUIDE FOR EXPLORATION

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Introduction

Rutile is an accessory mineral intimately associated with mineralization, especially in porphyry-related Cu-Au deposits, where its abundance, grain size and chemical composition appear to be related to the intensity of hydrothermal alteration/mineralization. Studies of other types of deposits have also shown that features of rutile grains can be related to alteration/mineralization events. For example, V+ W+ Sb-rich rutile outlines the ore zone at the Hemlo Au deposit in Canada. That deposit (>80 M tonnes at 7.7 g/t Au) is distinguished from most other Archaean Au deposits of Canada and Western Australia by its greater tonnage and by the strong association of Mo, V, As, Sb, Hg, Tl and Ba with the Au. However, the Big Bell Au deposit, in the Murchison Province, 560km NNE of Perth, has suffered high grade metamorphism and has a Au-Sb-Mo association.

Results

This study documents the compositions of 277 grains of rutile from 24 samples from the Big Bell Au deposit and nearby smaller deposits. Results show that rutile associated with ore at Big Bell, and for up to 200 m into the wall rocks, are V+W+Sb-rich - a characteristic of rutile which has previously only ever been documented at the Hemlo Au deposit. Rutile at the nearby deposits of Fender and Indicator also share this Big Bell-type signature, but rutile from North Fender contains Nb±Ta with W and Fe, refecting formation from a quite different fluid and implying a different period of formation. Furthermore, the presence of the different types of rutile in regolith samples in the Big Bell region, indicates that it is possible to discriminate between the V+W+Sb-rich and Nb±Ta- rich alteration in rutile using regolith samples.

Conclusions

Rutiles in the Big Bell Au deposit and for up to 200 m into the wall rocks have a characteristic V+W+Sb-rich signature - a feature that has previously only ever been documented at the Hemlo Au deposit. The presence of this signature in several nearby deposits enhances their significance, especially because rutile in the less significant mineralization at North Fender has a different (Nb±Ta-rich) signature. These differences can be seen using regolith materials.

TRANSFORMATION OF TRANSPORTED KAOLIN AND ITS EFFECT ON THE KAOLINITE CRYSTALLINTY INDEX

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Introduction

Transported overburden is common in the Yilgarn Craton. A reliable procedure to distinguish transported material from the residuum is essential for the interpretation of geochemical data. Transported and residual materials are commonly distinguished on the basis of the kaolinite crystallinity index (KCI) derived from the reflected infrared spectrum of the material. The method generally provides a well-defined boundary between shallow sediments and saprolite, but is less effective in defining the unconformity between deep channel sediments and saprolite. This study investigates two contrasting settings and explains why the KCI fails to provide a well-defined unconformity in the case of deep channel sediments.

Study site and methods

The main site for this study, the Whirling Dervish Au deposit, is located in a low-relief area adjacent to Lake Rebecca, 120 km NE of Kalgoorlie. The area gently slopes to the NE and is bounded by erosional scarps to the S and SE. It offers two contrasting settings, i.e. shallow (<16 m) sediments over saprolite and deep channel (up to 23 m) sediments over saprolite, in close proximity.

Seven vertical aircore holes were drilled to blade refusal along a 400 m long NE traverse across the centre of the deposit. Drill spoil samples (approximately 2 kg) were dried, and analysed using a portable spectroscopic instrument with a wave length range from 300 to 2500 nm. Transported and residual materials were identified on the basis of a visual inspection and the KCI. Geochemical analysis, X-ray diffraction (XRD), transmission electron microscopy (TEM) and particle size analysis (PSA) using laser diffraction were completed for selected samples.

Results and discussion

The regolith in the Whirling Dervish area consists of three main units: a 1-4 m thick calcareous and ferruginous hardpanized colluvium, red clayey alluvium and saprolite. The alluvium mainly consists of red clays with lenses of magnetic nodules that provide a good colour and spectral contrast against the underlying light-coloured kaolinitic saprolite. At the SW end of the traverse, the unconformity between the transported and the residual materials is clearly marked by an abrupt change in colour and increase in the KCI for the residual material. At the NE end of the traverse, a similar colour change from red to white is not accompanied by an abrupt increase in the KCI. Below the colour change, the material lacks saprolitic fabric and the KCI increases gradually over several metres until it reaches levels typical of saprolite. This transitional zone between red clays and unambiguous saprolite is difficult to classify on the basis of both macroscopic observations and the KCI, and therefore was investigated further.

The particle size distribution of the red clay showed three modes of particle sizes in the <10 µm fraction, and included a significant proportion of very fine clay (<0.2 µm). The particle size distribution of the transitional zone was largely similar to that of red clay. The fine fraction was absent in the saprolite, which was mostly >1 µm.

TEM investigations showed that the kaolinite in the red clay consists of very fine (<0.2 µm), euhedral crystals with well-developed faces. The crystals were very thin, as demonstrated by poor contrast against the carbon film background. The basal XRD reflections were very broad, and thus consistent with the very thin nature of the kaolinite crystals.

X-ray diffraction of the transitional zone showed that kaolinite crystals were thicker and more crystalline with depth. Consistent with the XRD, TEM revealed that both very fine kaolinite, similar to that of the red clay, and coarse kaolinite (>1 µm), considered to be neoformed, were present in the transitional zone.

Saprolite samples were devoid of very fine kaolinite, and were dominated by thicker and larger kaolinite crystals, some of which appeared to be pseudomorphs after mica.

Conclusions

TEM, PSA and XRD analyses suggests the deep sediments have been subject to a transformation process at their base. The process consists of destruction of iron-rich kaolinite and formation of more well-crystalline kaolinite, resulting in a gradual increase in the KCI with depth. Iron in the affected sediments, both free and structural, is also mobilized and removed, leading to simultaneous bleaching. The vertical extent of the process is probably controlled by the groundwater table. Shallow sediments above the groundwater table are unaffected by the transformation and thus their colour and distinctive low KCI, compared to the underlying saprolite, is preserved.

The study demonstrates that deep sediments cannot be logged solely on the basis of colour and a KCI cut-off needs to be determined in view of the fact that KCI may increase at the base.

INLAND ACID SULFATE SOILS – A NEW GEOCHEMICAL SAMPLING MEDIUM: A REGIONAL ORIENTATION STUDY FROM THE MOUNT LOFTY RANGES, SOUTH AUSTRALIA

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Inland acid sulfate soils (ASS) from creeks, dams, seeps, springs and wetlands were sampled in an area 25 x 40 km in the eastern Mount Lofty Ranges, between Mount Torrens in the north and Strathalbyn in the south. Inland ASS are common in landscapes with relief and can occur in seeps or springs (on mid to upper slopes of valleys) or in creeks and wetlands, typically in narrow valleys, where Fe- and S-rich precipitates accumulate from rising ground and surface waters (bearing sulfate and Fe^{2+} ions). The solutions are able to scavenge anomalous concentrations of elements such as Cu, Pb, Zn, from mineralized zones in bedrock. These ASS contain sulfidic materials (Fe and other sulfides; pH >4), which may form continuous layers (up to 30 cm thick), or consist of a series of discontinuous layers, normally below water level, under reducing conditions. Sulfidic materials may contain two types of iron sulfide: pyrite and Fe monosulfides (such as greigite or mackinawite). The matrix to the sulfides is dominantly quartz, with variable minor amounts of mica, plagioclase, potash feldspar, calcite and kaolinite. In drained or disturbed ASS, several rare to accessory phases such as gypsum, halite, jarosites, ferrihydrite and/or schwertmannite and Fe oxides occur in sulfuric horizons (pH <4). However, in the vicinity of mineralized zones in bedrock, sulfidic materials may also contain Cu, Pb and Zn sulfides, native gold, barite and Mn oxides (containing minor Co, Zn and I). These minerals tend to be intimately associated with, and incorporated in, organic matter. In particular, Zn and Pb sulfides tend to occur in very fine (<1 µm diameter) spherical grains precipitated via bio-mineralization processes. The composition of the Zn sulfide in sulfidic material is relatively Fe-poor, in contrast to the relatively Fe-rich sphalerite from the nearby primary mineralized zones. Inland ASS proximal to mineralized zones in bedrock are anomalous in a range of elements, including Ag, As, Au, Bi, Cd, Co, Cu, Hg, In, Ni, Mo, Pb, Sb, Se, Tl and Zn, for example, at Wheal Ellen, Glenalbyn, the Mt Torrens and Monarto prospects, and in the Kanmantoo area. Several anomalies also occur in locations not associated with known mineralization. Inland ASS have the potential to give, or at least enhance, surface expressions of otherwise buried and blind mineral deposits.

UNIVARIATE DATA PRESENTATION: THE CONTOURING CONUNDRUM AND PHILOSOPHICAL ARGUMENTS REGARDING THE CONTOURING OF GEOCHEMICAL DATA

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The presentation of univariate geochemical data on maps has long generated controversy, largely because of three factors:

(i) the sample locations may define an irregular geometry,
(ii) the frequency distribution of the data may not 'reveal' geochemically distinct populations with spatial coherence, and
(iii) the data may lack sufficient 'regionalization' (smoothness) in the data surface to be contoured.

Each of these factors introduces complications to contour plots that can make interpretation difficult, and arguments against contouring of data generally cite at least one of these factors.

When samples do not occur at regular intervals on a grid, contouring algorithms may not place contour lines at locations that are entirely consistent with the underlying data. Furthermore, fictitious contour patterns can occur at the sides of the map or in areas with low sample density because of irregular or sparse data. Fortunately, many of these problems have been solved by advanced contouring algorithms that do not try to contour in areas absent of data, and ensure that contours are consistent with the raw data used to derive the grid to be contoured.

The second cause of complaint regarding contouring relates to the underlying frequency distribution of the data to be contoured. Extant geochemical patterns may not be recognizable, because samples defining these patterns may not exhibit sufficient geochemical contrast. This problem can be tackled by transforming the data into a form that allows recognition of the underlying differences in the data. This is essentially equivalent to changing the contour intervals used on the contour plot.

Unfortunately, the selection of most data transformation functions are undertaken in a haphazard manner that attempts to 'create' the most interpretable patterns. As a result, the transformation function selected is identified in a non-scientific manner (via circular reasoning) as the best transformation, because it results in the most interpretable contour plot (*i.e.*, the end justifies the means). This is not an appropriate objective reason for transforming geochemical data. Other motivations for use of a transformation exist, and include achieving: (1) normality, (2) constant measurement error (homoscedasticity), (3) additivity, and (4) maximum geochemical contrast, as a result of the transformation. All of these attributes represent optimal features that are independent of the interpretability of the resulting contour plot, and thus represent appropriate reasons for transforming data. Once transformed, contour plots may reveal new information in the data not originally obvious in its original form.

The third reason that contouring geochemical concentration data is controversial is that the data to be contoured may not exhibit a 'regionalized' pattern, or smoothness, at a large enough scale to be discernable in the samples under investigation. Geochemical concentration data is uniquely different from most other quantitative geological data (*e.g.*, geophysical data) because, in geochemistry, there is no underlying *a priori* guarantee that the data will exhibit a smooth trend. In geophysical data, the various applicable field theories require the magnitudes of the data to be spatially correlated, and thus to exhibit smooth trends and be 'contourable'. However, the all too common 'salt and pepper' patterns observed on contour plots of geochemical data illustrate that geochemical data are fundamentally different.

This difference can be understood by considering two regions:

1) the region of sample integration (RSI; the size of the area or volume sampled by a measurement), and

2) the region of sample assignment (RSA; basically the area or volume extending from a sample to half the distance to all adjacent samples; the inverse of the sampling density).

When the RSI is larger than the RSA, adjacent samples will likely be in part measuring some of the same features because their RSI's will overlap. As a result, there will be a correlation between these adjacent responses, causing a smoothness, or regionalization, in the data and making it highly suitable for contouring. This phenomenon is the norm in geophysical data.

Unfortunately, geochemical data does not satisfy this property, and the RSI (the actual volume of the geochemical sample collected) is generally smaller than the RSA. As a result, there is no *a priori* guarantee that adjacent geochemical samples will be correlated, and thus no guarantee that regionalization exists. Consequently, contouring of geochemical data may not be warranted theoretically, and an alternative justification must be identified.

An alternative way to justify contouring geochemical data involves empirically demonstrating that it is regionalized. This can be undertaken in two ways: (1) by using a bubble plot to initially plot the data, where the data are plotted at their sample locations as circles whose diameters are proportional to concentration, or (2) by using a semi-variogram, where the variance between pairs of samples at a range of distances are compared. If a spatial smoothness to the bubble sizes can be observed on such a bubble plot, or if small distances exhibit lower variances than larger distances, empirical justification for contouring exists, and subsequent contouring can be employed. An alternative way to justify contouring geochemical data is to employ some form of 'nearest neighbour' smoothing algorithm. This will ensure that adjacent samples are functions of some common information, and thus create regionalized data. Unfortunately, this approach is fraught with problems, because random data that have been 'nearest neighbour' smoothed can develop trends that do not exist as a result of this operation.

GEOCHEMICAL AND MINERALOGICAL SIGNATURE OF KIMBERLITE DYKES IN TILL AND STREAM SEDIMENT DATA FROM SOUTHERN WEST GREENLAND

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Introduction

Exploration for kimberlite-hosted diamonds has been going on in Greenland for more than 30 years with varying intensity. In the Archaean craton of southern West Greenland, several dyke swarms of ultramafic lamprophyre (UML) and kimberlite were recognised early in the exploration history, but not until recently have diamonds been identified in any significant numbers. At present, diamonds are known from more than 20 localities within 0.6 to 0.55 Ga old UML dykes. An abundance of till and stream sediment data kimberlite indicator minerals (KIM) and trace elements have been acquired by exploration companies, but have been difficult to interpret.

Methods

Chemical (500 g samples, fine fraction, total composition) and mineralogical (20 kg samples processed for kimberlite indicator minerals, KIM) data have been acquired for samples of till and stream sediment collected at about 160 sites at variable distance from known UML and kimberlite occurrences, with the objective of identifying pathfinder elements and minerals and studying their dispersion.

Results

Mantle-derived minerals occur in large numbers in samples collected close to dykes, but dispersion range is short. Most grains are recovered from the 0.25-0.5 mm fraction. Company data are largely reproduced, but there are exceptions. KIMs in till are chemically similar to KIMs in nearby dykes. Niobium, where positively correlated with Mn, Mg, Co, Cr, U and LREE, is a powerful pathfinder element for UML and kimberlite; Nb is also correlated with the KIM content of till. In addition, till chemistry reflects regional differences in UML character.

Conclusions

The large number of KIMs in the overburden of southern West Greenland are of local origin, derived from abundant boulders and near-surface dykes and sills of UML rather than glacially transported from a distant source. Boulders, however, may have travelled variably. Kimberlites as well as carbonate-phlogopite-rich UMLs carry diamonds, and indicator minerals from the diamond stability field.

DEEP PENETRATING GEOCHEMISTRY, FROM SOURCE TO SURFACE: EXPERIMENTAL AND FIELD RESULTS

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The understanding of deep penetrating geochemistry has observed much research in recent years, yet the basic concepts behind theory date back for at least some 30 years. The most widely studied techniques for detection of undercover ore deposits are mainly associated with partial extraction analytical procedures applied to *in situ* soil samples. Empirical results over known ore deposits have demonstrated the applicability of such techniques in exploration, yet difficulties in interpretation do not provide a straightforward answer. False anomalies are common, calling for different process interpretations in order to explain on a case to case situation. Such problems have long hindered the broad use of surface geochemistry in covered areas.

Recent publications have dealt with many possibilities that explain metal cation migration to surface, mostly from a theoretical or empirical point of view. Depending on authors and location, some favour one over another, such as seismic pumping of groundwater and brines to surface along fractures and faults, among many. There is no doubt that world wide research efforts have us much closer to a clear understanding of the processes behind the theory, an effort in which we join with some new evidence and applications.

Experimental studies have followed the evolution of oxidation and bio-leaching of primary ore from the El Teniente porphyry copper deposit, providing an understanding from the initial activation of the system at the source of a geochemical signal. Oxidation and bacterial processes have been monitored, and proof of metal cation liberation and hydrocarbon gases is provided. Redox evolution and mineral changes are also observed. Testing of metal and hydrocarbon gas migration processes to surface has also been studied, empirical evidence clearly indicating the importance of gaseous transport of metals. Different types of overburden and depth have been experimentally tested.

Real-time generation of detectable surface geochemical signatures have been tested by use of artificial inserted adsorbent collectors. Results, both experimental and in field, have demonstrated the applicability of such collectors in the detection of undercover ore mineralization subject to chemical and bio-chemical degradation processes. Results also suggest that undercover deposits will only generate a surface signal when under present degradation processes, bacterial activity playing a vital role.

On-going research has provided better understanding of the processes involved in the generation of surface geochemical and bio-geochemical signatures of undercover deposits, from source to surface.

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LITHOGEOCHEMISTRY OF THE COLLAHUASI PORPHYRY CU-MO AND EPITHERMAL CU-AG (-AU) CLUSTER, NORTHERN CHILE: PEARCE ELEMENT RATIO AND STABLE ISOTOPE VECTORS TO ORE

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Introduction and process

Alteration halos have been the focus in exploration for economic ore deposits because they constitute larger targets than the deposits themselves. This is particularly true for porphyry copper deposits, in which these halos are known to extend for several kilometres. To examine the nature, extent and intensity of alteration associated with PCDs, lithogeochemistry and stable isotope geochemistry were integrated as vectors to mineralization at the Cu-Mo and epithermal Cu-Ag (-Au) cluster of the Collahuasi district in northern Chile. Pearce Element Ratio (PER) analysis eliminates non-hydrothermal sources of variation, thus permitting the definition of material transfers related strictly to hydrothermal alteration. Stable isotopes provide insights into the source and nature of the evolving fluids that produce the alteration and the ore.

Results and discussion

The identification of elements whose molar concentration has remained unchanged during mass transfer processes ("conserved" elements) is a prerequisite for mass balance calculations using PER analysis. Plots of immobile elements show that for felsic lithological units (rhyolites, dacites and pre and syn-ore porphyries), Zr and Ti are "conserved" elements. For the andesites on the other hand, Zr is the most "conserved" element. The scarcity of zircon or other minerals that would control the distribution of Zr in these rocks supports the latter.

Separate PER plots were created for both lithological groups. These plots discriminate between fresh samples and those that have been altered to different extents. Furthermore, alteration indexes that quantify the degree of hydrolytic alteration for each lithological group indicate that the host rocks had K enrichment during potassic alteration, followed by K, Ca and Na depletion due to overprinting during sericitic and later argillic alteration. PER plots record no mass transfer during propylitic alteration, consistent with propylitic alteration being isochemical for the major elements. Rocks portraying alteration assemblages that cannot be discriminated with PER plots have distinct oxygen and hydrogen isotopic compositions. The oxygen isotopic composition of rocks portraying different alteration assemblages is distinct as a result of the difference in the source of the fluids and different temperatures.

Conclusions

PER alteration indexes in conjunction with stable isotope geochemistry not only quantify the degree of alteration, but also discriminate between alteration events in which the nature of the fluids is different. The method is a reliable and cost effective exploration tool for porphyry and epithermal deposits, both at district and deposit scales.

CHROMITE AND TOURMALINE CHEMICAL COMPOSITION AS A GUIDE TO MINERAL EXPLORATION

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Introduction

The chemical composition of minerals such as chromite and tourmaline could represent potential tools to mineral exploration. The aim of the presentation is to discuss the relationships that emerge between mineral composition and geological setting (lithology, metamorphic facies, age, ore deposit *versus* barren context, ore deposit types) by using a large database of chromite and tourmaline compositions.

Methods: The chromite database contains about 26,000 chemical analyses of the chromite group minerals. The database was sub-divided according to host lithology, metamorphic grade and association of chromite with mineralized or barren metallogenic context. The lithological groups are ophiolites, oceanic and Alpine–type peridotites; layered mafic complexes; Alaska-type ultramafic complexes; tholeitiic basalts and boninites; kimberlites; komatiites; and mantle xenoliths. The metamorphosed lithology groups have been divided as a function of the metamorphic grade: greenschist, amphibolite and granulite/eclogite facies. The lithological groups have been divided also into mineralized and barren. Barren refers to the fact that the lithological group is not associated with ore deposits or occurrences. Mineralized means that lithology is spatially or genetically associated with ore deposits or occurrences, without distinction of the mineralization type (chromite, nickel, gold, PGE or diamond deposits).

The tourmaline database contains about 2,000 chemical analyses. Most analyzed tourmaline-group minerals are associated with ore deposits or occurrences. The database was sub-divided as a function of metamorphic facies, age, ore deposit type (orogenic gold, VMS or SMS, iron formations, porphyry and skarn, epithermal, and pegmatitic) and metallogenic model.

Discussion

Several characteristics of the chemical compositions of chromites that can be used as exploration tools have been identified: presence or absence of oxide substitution in the chromite Y site; relative replacement percentage of Fe^{2+} by Mg^{2+} in the X site; variation of absolute or relative oxide content; presence or absence of other minerals (magnetite, gahnite, spinel, magnesiochromite). The main positive criteria, by lithological group, which eventually can discriminate between chromites of the mineralized *versus* barren zones include: low Fe_2O_3 content and chemical composition close to stoichiometric composition (kimberlites); low MgO (< 5%) and lack of FeO substitution by MgO (komatiites); presence of magnesio-chromite, chromite substitution by other Al-rich minerals (spinel, gahnite, hercynite) and lack of Cr_2O_3 substitution by Fe_2O_3 (ophiolites); Cr_2O_3 partial substitution by Fe_2O_3 and (sum X /32.1) ratios between 0.80 and 0.95 (layered mafic complexes); high MgO content (Alaska-type ultramafic complexes). The negative criteria are: Cr_2O_3 gradual replacement by Fe_2O_3 and presence of magnetite borders (kimberlites); high MgO content (> 5%) and FeO substitution by MgO (komatiites); Cr_2O_3 substitution by Fe_2O_3 (ophiolites); Cr_2O_3 partial substitution by Al_2O_3, chromite substitution by other minerals such as spinel, gahnite and hercynite and (sum X/32.1) ratios between 0.90 and 1.05 (layered mafic complexes); low MgO content (Alaska-type ultramafic complexes).

Several characteristics of the chemical and structural compositions of tourmaline can be used to define discriminant criteria between ore deposits and barren lithologies, or between different ore types. Useful criteria are: Ca-poor composition of tourmaline associated with orogenic gold deposits and iron formations; higher Fe+Mg contents in porphyry and skarn by comparison with epithermal deposits; Al contents of tourmaline show: porphyry and skarns < orogenic gold, VMS, iron formations and epithermal < pegmatites.

The chemical characteristics of tourmaline that cannot be used to discriminate between ore and barren zones are: alkaline metal ratios, the Fe# and cationic ratios; Fe+Mg and Si contents do not distinguish between orogenic gold, SMV and iron formations; Fe and Mg cations show very high variability in orogenic gold and VMS deposits; there is no evident relationship between tourmaline composition and deposition age.

Conclusion

Chromite and tourmaline chemical compositions represent a potential exploration guide for discovery of ore deposits and occurrences hosted by various lithological and tectonic settings.

TESTING OF LIQUID GEOGAS COLLECTORS IN CHINA

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Introduction

Studies of geogas surveys have been carried out in China for over 15 years, (Tong et al., 1990, 1991, 1992, 1997, 1998, 1999, 2002; Wang et al., 1995, 1997, 1999; Xie et al., 1999; Ren et al., 1995; Liu et al., 1995, 1997, 2003; Wu et al., 1995, 1996). However, it is difficult to control the blanks of the collectors, which commonly makes people doubt whether the geogas phenomenon does exist in nature because, from our observation, the concentrations of elements (metal and non-metal) from geogas sampling are extremely low (mostly lower than 1ng/L). Therefore, low and stable blanks are key factors for the election of collectors for geogas testing. Solid collectors, such as polystyrene, polyurethane foam and activated carbon were tested in China before 1999, but they all contain high and changeable trace elements contents that are difficult to remove physically or chemically. It is easy to control the blanks of liquid solvent and analyze them by ICP/MS, and these have been studied as collectors of geogas since 1999.

Methods

To lower the blank of collectors, the water (milliQ water) and all solvent should be purified by a special device, and put into sample bottles at a dust free environment. The sampling device collecting geogas in the field is quite similar as described by Wang et al. (1997) and the only difference is in the collectors (liquid). The blank and sampled collectors were directly analysed for Au, Ag, As, Ba, Be, Bi, Cd, Ce, Co, Cs, Cu, Dy, Er, Eu, Ga, Ga, Gd, Ho, K, La, Li, Lu, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Sb, Sc, Sm, Sr, Ta, Th, Tl, Tm, U, W, Y, Yb, Zn by ICP/MS in IGGE and the National Center of Geological Analysis.

Results and discussion

After several years testing on gold, nickel and polymetallic deposits, the results show:

(1). Several solvents, including water, HNO_3, HCl and aqua regia have been tested and different media have different ability to absorb each element. Overall, HNO_3 and aqua regia are good collectors of geogas.

(2). Recent results in overburden show that, for elements associated with mineralization, the ratios of the blank to samples are > 1.5 in barren areas and >5 over mineralized areas. The great difference between blank and sampled collectors indicates that geogas (gaseous metals and non metals in soil gas) is a natural phenomenon, although we have little knowledge of it.

(3). No correlation was found between the elemental anomalies in geogas and that in the soil from same location. This suggests that the elements in geogas may be derived from buried deposits.

(4). Pilot surveys of geogas in Qinghai and Hebei using HNO_3 as a collector have resulted in discovery of new base and gold orebodies in a thickly covered area.

(5). Like any gas survey, results obtained from the same site at different times are sometimes poorly reproducible and systematic errors are observed from subgroups. Therefore, special data processing methods should be used to contour the data for a large area.

Conclusion

There is strong evidence to show that the geogas is a natural phenomenon, but we have little knowledge of it. Liquid collectors proved to be very effective at absorbing elements in geogas and have great potential for use as an exploration method for concealed deposits. It is predicted that some theoretical answers will be found in the near future, following this breakthrough in collectors.

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WIDE-SPACED SAMPLING FOR DELINEATION OF GEOCHEMICAL PROVINCES IN DESERT TERRAINS, NORTHWESTERN CHINA

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Desert terrains are widely distributed in north-western and northern China, and form large unexplored or under-explored areas totalling approximately 2 million km^2 . Sampling of lag materials (coarse fractions of regolith) has been used for regional geochemical surveys in the past. This sampling method proved to be successful in mountainous and hilly regions, but it failed in plains, valleys and basin areas.

Studies have been conducted since 1999 that aimed at understanding the environment and geochemical dispersion processes, in order to find a cost-effective, wide-spaced sampling method for delineation of geochemical provinces. The studies showed that many elements related to mineral deposits are concentrated in the fine fractions (−120 mesh) of the weakly cemented horizon in the upper part of the vertical profile. Wide-spaced sampling was carried out in an area of approximately 150 000 km^2, at a density of one sample per 100 km^2. Samples were collected from the weakly cemented horizon at a depth of 20-30cm and sieved to −120 mesh in the field. The sieved samples were ground to 200 mesh. Thirty elements were determined by ICP-MS, GF-AAS and AFS. A geochemical atlas and interpreted geochemical maps were generated using GIS.

Geochemical provinces of copper, gold and uranium have been delineated. Five gold provinces, with threshold values of more than 2 ppb, have been delineated in the whole region. Three are consistent with known large gold deposits and the other two are promising for new large gold deposits from preliminary follow-up surveys. Seven copper provinces have been delineated; three are consistent with thermal copper deposits, porphyry copper deposits and copper-nickel deposits respectively. Two provinces of uranium associated with molybdenum were delineated in the basin. One of them contains a known large sandstone-type uranium deposit, and a new large uranium deposit was discovered by follow-up drilling program in another provinces.

ASSESSING THE FERTILITY OF PLUTONS IN SPECIALISED GRANITOIDS USING LITHOGEOCHEMISTRY: CONSTRAINTS ON THE CONTRIBUTIONS OF ASSIMILATION AND FRACTIONAL CRYSTALLATION PROCESSES IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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The South Mountain Batholith (SMB) is a Devonian (~370Ma), composite peraluminous granitoid intruding Cambro-Ordovician Meguma Group metasediments in southwestern Nova Scotia. The batholith ranges in composition from biotite granodiorite through to muscovite leucogranite. It has also been divided into earlier Stage 1 and later Stage 2 plutons, although all were emplaced within a geologically narrow timeframe. Stage 2 plutons commonly appear to be chemically 'more evolved' and intrude Stage 1 plutons.

The batholith has potential for Sn-, W- and U-bearing mineral deposits (amongst other commodities), with mineralisation commonly found in greisen, vein, breccia and pegmatite showings. Mineralisation is spatially associated with the more evolved granitoids, making their identification of critical importance to mineral exploration. The principal cause of element enrichment in specialised granitoids such as the SMB has commonly been assumed to be fractional crystallisation. However, lithogeochemical and mineralogical evidence suggests that assimilation processes have also been important in the chemical evolution of parts of the batholith, and may have produced plutons that are mineralogically and chemically similar to granitic bodies that acquired their evolved compositions through fractional crystallization. As a result, the economic potential of the SMB is likely a function of five factors:

(i) the initial metal endowments contributed to the parental magma from the source rock,
(ii) the fractionation processes that operated to enhance metal contents during emplacement and subsequent cooling of the SMB,
(iii) the metal endowments of the host Meguma Group sedimentary rocks,
(iv) the nature and extent of assimilation of this country rock during emplacement and cooling of the SMB, and
(v) subsequent hydrothermal alteration that redistributed metals within or adjacent to the batholith.

Exploration companies commonly utilise lithogeochemistry to identify plutons with evolved characteristics and/or possessing anomalous metal concentrations. However, due to closure effects, the use of concentrations to classify igneous rocks is potentially laden with errors. Although closure can be avoided by using ratio formulations, there is the further complication of assimilation adding new material to the magma. This can dilute economically interesting elements and yet still result in a granitoids with 'evolved' compositions. The challenge is to develop a methodology that can aid in identification of 'fertile' plutons that have had target metals concentrated due to fractional crystallisation processes, and distinguish these that have acquired 'evolved' compositions via assimilation.

A large whole-rock lithogeochemical database of the South Mountain Batholith compiled by the Nova Scotia Department of Natural Resources has been supplemented with data of similar quality collected by Acadia University students (>650 XRF analyses). The analysed suite contains major and trace elements, including many relatively incompatible and potentially immobile elements such as Zr, Ta, Nb, Hf and Ti.

Conserved element and molar element ratio analysis procedures have been applied to the lithogeochemical database and used to determine the nature and extent of fractional crystallization and assimilation processes responsible for producing the evolved character of each pluton in the SMB. This, coupled with an assessment of how the concentrations of elements of economic interest changed as a result of these processes, potentially allows discrimination of truly 'fertile' plutons from those that only appear 'more evolved' via assimilation. Thus, highly prospective areas within the SMB worthy of further exploration interest could well be identified.

SDP SOIL-GAS GEOCHEMISTRY AT CROSS LAKE, ONTARIO

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A study was undertaken to assess the effectiveness of the Soil Desorption Pyrolysis (SDP) method at Cross Lake, Ontario. Mineralization at Cross Lake consists of massive-sulfide style copper and zinc lenses in a sequence of steeply dipping volcanics, covered by 15 to 30 meters of glaciolacustrine clay and silt. A total of 119 samples were taken along a traverse with good geological control from field mapping and boreholes (line 6 of Hamilton et al, 2004). The samples were in the form of three closely spaced lines, with three samples taken in close proximity at each northing along the traverse. Approximately 1 kg of B-horizon soil was collected at each site. Two of the lines were submitted to the laboratory, with coordinates relative to the known geology and mineralization, to serve as a training dataset. The third line of samples was randomized and submitted as blind test samples. Sample preparation consisted of a Stokes' Law clay separation by suspension in water and centrifuging to isolate the size fraction 0.2 μm to 2 μm. Analysis was by flash pyrolysis at 450˚C into a quadrupole mass spectrometer, with simultaneous determination of a wide suite of inorganic gases, sulphur gases and hydrocarbons.

The resulting data are inherently noisy, with quite high variability between points a few meters apart. While some individual compounds (e.g. CS_2, CH_3Br), appear to correlate well spatially with the subcropping zinc and copper sulfide mineralization at Cross Lake, more robust and transportable results can be obtained by using a fingerprinting approach. The distribution of samples above known subcropping mineralization on the first two lines was used to construct a calibration template, the results of which were then applied to the third group of blind samples. The template consists of the sum of compound ratios of the form $(A*B)/(C*D)$, each normalized by division by the appropriate background value. Ratios in the template are selected by a semi-automated process based on designated "mineralized" and "not mineralized" samples in the training dataset. The training set contained 42 "mineralized" and 36 "not mineralized" (background) samples. The level of template anomalism is very sensitive to the choice of samples used to define the background. For a large survey grid (e.g. as used for a porphyry copper target), it is possible to use the median of the whole population. For a single line, typical of testing a geophysical target that may be a VMS deposit or a kimberlite, it may be more appropriate to define the points at each end of the traverse as background. Otherwise, a high proportion of mineralized points are included in the background calculation, leading to higher noise and lower contrast anomalies. The results of both methods are presented.

Using the median of the whole population as background, the Cross Lake template is able to distinguish mineralized from background samples in the test dataset, with an average contrast value of 2.5. However, the data are noisy and the mineralized and background data are only distinguishable at the 80% confidence level. When the background is defined using the samples more than 250 m from known mineralization, the noise decreases dramatically, with a contrast of 3.07 between mineralization and background, and the two groups are distinguishable at the 99% confidence level. Two further templates were used to process the Cross Lake data: one derived from the Caber and Perseverance VMS deposits in the Matagami district, and the other from the Chance deposit in the Timmins district. The Matagami template clearly responds to the mineralization at Cross Lake, defining a clear anomaly over the subcropping mineralization. Using the median of all the samples as background results in high noise levels; however, if the outer ends of the traverse are used as background, the Matagami template can distinguish the mineralized from the background samples at the 95% confidence level. The template from Chance performs even better, achieving a 90% confidence level if the median background is used, and better than 99% if background is defined as the ends of the traverse.

We conclude that the effectiveness of SDP in distinguishing buried VMS systems through transported overburden has been demonstrated at Cross Lake, using a fingerprinting “template” approach. The template may be derived either from an orientation survey in the immediate area, or from another area with similar bedrock geology and overburden. When the location of the target to be tested is known (normally the case for VMS targets in the Abitibi), the confidence limits of the measurement may be improved significantly by using the samples located at the ends of the traverse to define the local background values. Work is continuing to generalize these results to other Canadian VMS deposits.

GEOCHEMISTRY AND STABLE ISOTOPES OF THE QUARTZ-ADULARIA-TYPE GOLD-SILVER MINERALIZATION, BERGAMA-IZMIR, TURKEY

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The Ovacik epithermal gold-silver deposit is located in the west Anatolian extensional province, adjacent to the ENE-trending Bergama graben, 100 km north of the city of Izmir, western Turkey. This province hosts several other epithermal deposits, such as the quartz-adularia-type Efemçukuru (3.1 Mt at 14.6 g/t Au) and Küçükdere(1.4 Mt at 6.4 g/t Au) and porphyry-related high sulfidation Kisladag (276 Mt/1.2 g/t Au). Gold and silver of economic grades at the Ovacik deposit (4.19Mt @ 7.6g/t Au) occur in epithermal quartz veins and display typical low-temperature epithermal textures, including crustiform banding, quartz pseudomorphs after bladed calcite, and multiphase hydrothermal breccias. Alteration minerals are dominated by smectite, mixed layer illite/smectite, quartz, adularia, calcite and pyrite with kaolinite overprint to a depth of 200 m. The total sulfide content is low (less than 2%) and is dominated by pyrite with traces of chalcopyrite, arsenopyrite, acanthite, argentite, tetrahedrite/freibergite, pyrargyrite, stibnite, galena, chalcocite, bornite, covellite and sphalerite, occurring mainly within the breccia clasts. The arsenopyrite and pyrite tend to be concentrated within certain bands, accentuating the banding in the breccia clasts with a dark coloration. Fluid inclusion studies reveal that main-stage quartz with liquid-rich inclusions with an average T_h of 200^0C and Tm of ice from -0.4 to -1.2^0C (salinity<2 wt. percent NaCl equivalent) are dominant.

Geochemical variations in altered wall rocks are generally characterized by two-fold enrichments in K, Rb, Cs and 25 to 93 percent depletions in Sr, Ca, Mg and Na, and more so (96 to 99 percent) in the quartz-adularia vein zone. Lanthanum, Ce, Pr, Hf, Zr, Sm, Eu, Gd, Tb and Ho also exhibit up to 50 percent depletions in the wall rock and even more (up to 90 percent for La and Nd) in the vein structure. The wall rock enrichments in Au, Ag, As, Hg and Sc are by factors of 60, 150, 88, 8 and 3, respectively. The ranges of REE in both the altered volcanic rocks and quartz-adularia veins are wide and reflect significant mobilization and fractionation during alteration and mineralization. Low Rb/Sr ratios and corresponding low K values within kaolinite-altered areas are due to acid (high H^+) leaching of K in volcanic rocks, whereas higher Rb/Sr ratios in adularia-illite-altered areas are closely related to the presence of these K-rich alteration minerals. Large variation in Rb/Sr ratios is due to changes in the concentration of both elements and follows the K addition and Ca leaching typical of wall-rock alteration of igneous rocks in shallow hydrothermal systems. Positive correlation coefficients of Au with Ag, Pb, Zn, Cd, Cu and Sb in epithermal quartz veins are strong, all greater than 0.51. Silver and Sb are remarkably enriched at higher levels of the deposit. No correlation occurs between Au-As and Ag-As, indicating that they may be related to different mineralizing events and thereby possible introduction of Au, Ag and Sb in different phases of mineralization.

Quartz and pyrite minerals in gold-silver-bearing veins have $\delta^{18}O$ values ranging from +9.5 to +15.7‰ and δD values ranging from -89 to -125‰. Quartz data indicated that ore-forming hydrothermal fluids at Ovacik had $\delta^{18}O_{H2O}$ values ranging from -2.9 to 3.5‰ (average: -0.6‰), ^{18}O enriched compared with present-day meteoric and hydrothermal meteoric water (-5.4‰ from water wells and -6.8‰ from hot springs). $\delta^{18}O$, $\delta^{18}O_{H2O}$ and δD values (from quartz) suggest that mineralizing solutions were a mixture of magmatic and meteoric waters. $\delta^{18}O$ values in the Ovacik deposit have been remarkably shifted (from-5.4‰ to -0.6‰) to more ^{18}O-rich compositions by water/rock interactions or probably by fluids from a magmatic source. The $\delta^{34}S_{pyrite}$ data range from -2.1 to 3.3‰ ($\bar{x}$ =1.2) and $\delta^{34}S_{H2S}$ range from -3.0 to 3.0‰ ($\bar{x}$ =0.4). These $\delta^{34}S_{pyrite}$ and $\delta^{34}S_{H2S}$ values are consistent with a magmatic source for S. Narrow ranges of $\delta^{34}S_{pyrite}$ and calculated $\delta^{34}S_{H2S}$ values for fluid may suggest that $\delta^{34}S_{H2S}$ fractionation stayed relatively stable during evolution of the hydrothermal system.

POSTER PRESENTATIONS

in alphabetical order

A SIMPLE MODEL FOR RARE METAL PROSPECTING

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Introduction

Despite the long history of rare metals prospecting, the problem of identification of barren- or ore-bearing granites still remain unsolved. Why do some granitic intrusions host large economic deposits of Ta, Nb and W and the others not? Usually, to answer this question, geochemists use empirical approaches based on routine data processing. In this way, using different statistical methods, the most important empirical multi-element geochemical indicators that can discriminate ore-bearing from barren granites are found. Another classical approach is to use geological, geochemical and petrological data, coupled with theoretical and experimental knowledge, to solve the problem.

In our presentation, we show the results deduced from comparing available experimental data of ore-mineral solubilities in magmatic melts to compositions of granites from different rare-metal provinces. It was assumed that i), during the differentiation of magma, the early crystallization of accessory ore minerals facilitates the dispersion of ore elements and prevents their enrichment in the residual melts and ii), the solubility is controlled primarily by melt composition. In this way, using the database and employing the results of experimental investigations, we hope to find geochemical criteria to identify potential ore-bearing granites.

Methods

A database of granite compositions was used for calculations. Currently, it contains 1200 entries and covers igneous acidic rocks from the main rare-metal provinces over the world. The composition of fine grained rock facies from evolved granite complexes, such as rhyolites, microgranites, ongonites and aplites, was preferred because of their close correspondence to the original magmatic melt composition. Evaluation of the solubility of tantalite-columbite group minerals in evolved granitic melts was assessed, using the available experimental data (Linnen & Keppler, 1997; Keppler, 1993; Linnen, 1998) and the rock compositions from the database.

Results and discussion

All available data were split into two principal groups on the binary graph ASI (Al/Na+K+2Mn) vs logNb+logMn or vs logNb+Log(Ta)+logMn. An empirical boundary between these groups coincides with the solubility trend of columbite at temperatures close to 600°C. Taking into account additional components such as Li, Rb and F does not improve the discrimination between observed subgroups. Rocks situated on the discriminate diagram below the line of columbite-tantalite saturation level are mainly of non-mineralised leucocratic, biotite granites (from Eibenstock, W.Erzgebirge; Phuket, Thailand; Shumilovsky pluton, C. Transbaikalia) as well as some rhyolites from the Macusani, Morococala fields, Bolivia; Twin Peaks, N. America; Teplice, E. Erzgebirge. Rocks above the saturation line include rare-metal granites associated with economically important mineralization of Nb (Ta), W and rare alkaline earths (Sherlova Gora, Shumilovsky, Orlovsky plutons in Transbaikalia; Phuket in Thailand; and Mangabeira, Brazil), along with topaz-rhyolites and ongonites from different regions (Spor Mountains, Tomas Range in N. America; Ongon-Khaierhan in Mongolia; and Ary-Bulak in Transbaikalia). Thereby, using a rather simple relationship between ore mineral solubility and melt composition, we can discriminate ore-bearing from barren granites ones.

Conclusion

The results confirm the leading role of magmatic processes in rare metal accumulation during magmatic melt differentiation. Further combined experimental and empirical evaluation of the ore accessory mineral solubility in evolved granitic melts will allow us to identify the most important parameters crucial for the extreme concentration of another rare metals in magmatic melts. Eventually, they will help to create reasonable criteria for exploration and prospecting of economically important rare metal deposits.

DISCRIMINATING COARSE GOLD : FINE FRACTION STREAM SEDIMENT SAMPLING IN THE SOFALA AREA, CENTRAL NEW SOUTH WALES, AUSTRALIA

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Alluvial gold was discovered in the Sofala-Wattle Flat area of central NSW, Australia in the 1850s. Extensive gold mining activity has taken place in the area since then. It was thought that this would have located most of the significant coarse gold sources shedding into the current stream systems. Alluvial terraces are also present in the district which may contaminate or confuse possible gold signals from hard rock sources in stream sampling. Pathfinder element signatures e.g. As and other chalcophile elements, would probably enable the non-alluvial signatures to be discriminated and it was initially considered that a multi-element analytical suite without gold be trialled. However, it is possible that non-gold bearing mineralisation may also contain a pathfinder signature.

Experience from other areas in NSW, in particular Oberon to the south of Sofala, demonstrated that bulk cyanide leach (BCL) sampling was very sensitive – perhaps too sensitive. It was considered that conventional BCL sampling may be misleading. All occurrences of gold, major or minor, would be detected. Given the presence of significant volumes of alluvial gold in the Sofala area, it was considered necessary to trial a non bulk BCL technique.

A series of conditional simulations was run to determine the optimum sample that would detect fine gold but would be unlikely to detect coarse gold. A small (25g), -120 mesh sample with selective duplication was recommended to screen coarse grained gold anomalism.

Regional geological mapping had delineated an area that was considered prospective, so a program of stream sampling covering this area was undertaken. Samples returning anomalous Au (>10ppb) were duplicated. If the original and duplicate samples returned reproducible results, the sample site was assigned a high priority. It was found that most of the reproducible samples clustered in one area – Spring Gully.

Follow up soil sampling over the Spring Gully stream anomaly defined a 1200m long, 50-250m wide anomaly with >100ppb Au. Initial drill testing of this soil anomaly intersected significant gold mineralisation (48m @ 1.52ppm Au). Further drilling delineated an indicated resource of 3.55Mt @ 1.01g/t Au.

The results of this stream sampling program led to the immediate identification and, ultimately, the successful delineation of the sub-economic Spring Gully gold deposit near Wattle Flat.

INTERACTIVE GEOCHEMICAL DATA INTERPRETATION

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Multi-element analysis of geochemical samples is now common practice in mineral exploration. Voluminous data are being generated and not being fully utilised by project geoscientists to optimise targeting opportunities.

Traditional anomaly definition of geochemical data has tended to focus on the highest numbers in selected target elements. This is often poorly justified. In many circumstances, the highest numbers may not be the most significant, given the geological and richer geochemical context being provided by the other elements.

Sophisticated statistical manipulation of geochemical data may not necessarily improve anomaly definition in complex geological terrains. Geological variability is commonly much greater than that represented on even the most detailed geological maps. Thus, combining “misleading” geological information with statistical data manipulation could lead to spurious anomaly definition.

Interactive Geochemical Data Interpretation enables geological variability to be identified before data manipulation or interpretation is completed. The focus is the geology, not the statistical character of the data.

Interactive Geochemical Data Interpretation is a more informative technique of viewing and visualising geochemical data. This style of targeting focuses on placing all of the geochemical data into a richer geological context; the interpretation is geologically robust and is discovering new ore in old data.

GEOCHEMISTRY OF THE SASARE- EAGLE EYE PROJECT AND THE DISCOVERY OF IRON OXIDE COPPER GOLD DEPOSITS IN ZAMBIA

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Exploration at the Sasare licence in eastern Zambia has led to the discovery of the Eagle Eye Iron Oxide Copper-Gold deposit. The geology is dominated by a north-east striking sequence of supracrustal rocks interpreted to be part of the Muva Supergroup, which have been subjected to several stages of tectonic activity as well intrusion of syn- to late granitoids. The Project straddles the Chinkombe portion of the Mwembeshi Dislocation Zone (MDZ), an inter-cratonic shear zone that trends east-northeast for more than 700 km.

Stream sediment geochemistry and soil sampling have generated a copper anomaly (maximum ~1,122ppm) over a 15 km strike length and 2 km width. The anomaly is associated with albite-quartz-hematite breccias, magnetite skarns and a large sodic alteration zone. The dominant host rocks are mafic metavolcanics with intercalated felsic volcanics, to the north of which lies post-tectonic porphyritic granite. The main copper soil response is coincident with a magnetic anomaly defined by ground geophysics, which is reported to relate directly to magnetite-bearing skarns within the volcanics. The gold results were found to be generally low and erratic.

Drilling has demonstrated the potential for economic mineralization, with drill intersections that have included 60 m at 0.75% Cu, 21 m at 1% Cu, 6 m at 5% Cu and 33 m at 0.5% Cu. The mineralization is hosted in volcanic units of intermediate composition and occurs in multiple forms as quartz veins, as magnetite-skarns, and as hematite-quartz breccias. Regional scale intense sodic and calc-silicate alteration, accompanied by iron oxide and potassic alteration, occurs proximal to the mineralization. Geochemical anomalies associated with Cu-Au mineralization include: F, Ti, Zn, Ba, Pb, U and REE as well as Cu and Au.

The Eagle Eye mineralization show significant similarities to Iron Oxide Copper-Gold mineralization described from the Salabo belt in Brazil and Ernest Henry in Australia. Based on host rock geology, tectonic setting, structure and associated geochemistry it is likely that similar deposits exist elsewhere along the MDZ.

MAMMOTH ST ANTHONY DEPOSIT: AN EXAMPLE OF COMPLEX POLYMETALLIC EPITHERMAL MINERALIZATION IN ARIZONA

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The Mammoth St. Anthony mining district is located approximately 90 km northeast of Tucson in Pinal County, Arizona. The approximate total production from 1881 to 1947 consisted of 1, 714,012 t (metric tonnes) of ore, which yielded 12.3 t Au, 30.6 t Ag, 12,890 t Cu, 27,893 t Pb, 18,017 t Zn, 2,356 t MoO_3, and 948 t V_2O_5. Historic resource evaluation has estimated approximately 4 million tonnes at 2 g/t Au, containing approximately 8 million grams (260,000 ounces) of gold remain in place.

Mineralization consists of gold-bearing, epithermal quartz veins hosted by andesite-dacite-rhyolite lavas and tuffs of Early Miocene age that overlie Precambrian granite. Normal faults with a later, variable to east-west, strike slip component controlled development of epithermal quartz veins. The Mammoth and Collins veins were deeply oxidized before being faulted, as the upper oxidized portions contain the Au-Ag-vanadinite-wulfenite ores (with mottramite and descloizite) and the lower unoxidized portions in the Collins vein contain the Cu-Pb-Ag-Zn sulfide ores.

Gold mineralization displays typical low temperature, epithermal textures, including crustiform banding, quartz pseudomorphs after bladed calcite, and multi-phase hydrothermal breccias. Veins outcrop over a strike length of 700 m, with surface widths up to 40m. Mineralized areas extend down dip for at least 150 m. Gold occurs mainly in amethyst-bearing vein material that is late in the paragenesis. The amethyst cements clasts of country rock and breccia fragments. Alteration of the wallrock associated with the mineralization consists of quartz, adularia, albite, illite/chlorite, illite/smectite, illite and chlorite. Sulfides are relatively rare in the gold-bearing zone, although trace amounts of pyrite, chalcocite and galena have been observed.

The anomalous polymetallic mineralization occurs as more discrete vein sets in vuggy quartz and quartz-calcite veins. The mineralization is dominated by an oxide assemblage. Hydrothermal alteration has a strong zone of silicification associated with mineralized zones that grades out into argillic zones. The base metal sulfide zone at the base of the deposit consists of colloform and banded pyrite-sphalerite-galena with accessory chalcopyrite, molybdenite, tetrahedrite and acanthite. Electrum has been observed as a rare phase in this assemblage.

The mineralizing fluids show variation in temperature from $<100^\circ$C near surface through 100-150°C in the anomalous metals assemblage to 200-300°C in the sulfide zone. Salinities vary from 7-15 wt % NaCl equivalents.

The trace element signature of the mineralization is complex and includes, in addition to Au, anomalous Ag, Cu, Pb, Zn, F, Mo, W, As and Sb. High Au-Ag concentrations are associated with near surface quartz veins with low As-Sb contents. Low Au-Ag zones are associated with alteration zones that have higher As-Sb contents and lower Cu, Mo and Zn.

Similar deposits in southern Arizona, California and Mexico occur where Oligocene to Miocene volcano-plutonic rocks are dissected by major north-northwest trending grabens with associated, east-west oriented, normal to sinistral strike slip faults. Primary targets should focus on volcanic rocks displaying strong argillic and adularia alteration and silicification, accompanied by breccias and epithermal, amethyst-bearing quartz veins. On a district-wide scale, anomalous Cu, Mo, F, Pb and Zn define Au-Ag bearing zones, whereas a chalcophile corridor or zone of anomalous As and/or Sb defines the wider alteration zones.

GEOCHEMICAL BASELINE IN NORTHERN NEVADA: DETERMINING BACKGROUND CONDITIONS

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For many reclamation and environmental projects, a critical aspect in determining remediation goals is to assess potential impacts against “background conditions”. Very often, because of poor baseline evaluation or pre-existing disturbance, background is difficult to establish and the default conditions applied are far more stringent that the natural baseline environment.

The Carlin gold deposits in Northern Nevada are a good example of this problem, where a series of approximately north-south trending mineralized belts exist. The belts host anomalous concentrations of metals and metalloids, principally arsenic, antimony, mercury, selenium and thallium, as well as other elements such as fluoride.

Remediation in these chalcophile corridors should take into account the naturally elevated background concentrations of these elements in rocks, soils and water in any impact assessment. In addition because of the recent geology and hydrogeology of the area, background groundwater commonly contains elevated nitrate related to organic breakdown in palaeo-river channels and soils as well as formation of buried nitre flats.

This presentation gives groundwater, soil and bedrock geochemistry for the Getchell, Battle Mountain, Cortez and Carlin-Bald Mountain belts and determines the extent of the chalcophile corridors and element distribution patterns therein.

CENTRE FORREST, ULARRING ROCK PROJECT, WA WHEATBELT - A GREENFIELDS CU-AU DISCOVERY BY CONVENTIONAL FOLLOW-UP OF OPEN FILE GEOCHEMICAL DATA

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Introduction

Centre Forrest is an unusual Cu-Au (-W-Bi Te) mineralized system in Archaean granulites and gneisses, discovered in 2000 by Sipa Resources Limited some 100 km north-east of Perth within the "wheatbelt", a region of broadacre farm land. A remnant of lateritic duricrust contains up to 2.0 g/t Au directly over the mineralized zone. This has yielded reverse circulation drill intersections of up to 32 m (true width) of 0.7 g/t Au and 0.2% Cu in hypogene mineralization along a possible shear zone on a west-dipping contact between granites and magic granulites. Mineralization is interpreted to be syn- peak metamorphism, given the close association of Bi and gold with the assemblage quartz-garnet-biotite-cordierite-pyrrhotite-chalcopyrite ± gedrite ± orthopyroxene. There appears to be only minor supergene enrichment of both Au and Cu in both saprolite and duricrust.

Discussion

The discovery was straightforward, resulting from field checking of an isolated, twenty years old, "open-file" sample containing 16 ppb gold with 890 ppm copper in a sample of lateritic pisoliths collected as part of the "CSIRO-AGE" laterite sampling program. This was one of ten priority areas chosen for examination on the basis of statistical analysis of the open file regional database. First-pass reconnaissance yielded up to 131 ppb Au and 646 ppm Cu (with anomalous W and Bi) in the area of what is now the Centre Forrest Prospect. Subsequently, a similar mineralized occurrence was "re-discovered" at Southern Brook, some 4km to the south-east, where a previous company had explored for base metals in the period 1982-85. Both prospects are now encompassed by a 1000 km^2 tenement package comprising the Ularring Rock Joint Venture between Sipa and Placer Dome Asia Pacific.

Conclusion

While not yet shown to be economic, the Centre Forrest discovery underlines the potential of the Western Gneiss Terrain to host significant undiscovered mineralization in spite of more than one hundred years of settlement, extensive cultivation and sporadic mineral exploration. Centre Forrest is an elevated and isolated lateritic knoll within dominantly sandy profiles, and probably would have remained undiscovered had this not been the case. Careful ranking and field evaluation of anomalies in publicly-accessible "open-file" data led directly to the discovery outcrop. The challenge now remains one of locating more significant mineralization in the surrounding areas, where laterite profiles have been partially stripped or are concealed under sandy soils.

ON-LINE ACCESS FOR REAL-TIME AUDITS OF LABORATORY PROCESSES

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Introduction

Industry regulators now specify that the competent/qualified person be responsible for satisfying himself or herself as to the quality of work done by all parties associated with a project. This includes the work of the laboratory. All laboratory processes, through sample preparation, analysis and data reporting, must be managed and checked. This greater level of required scrutiny necessitates a higher degree of interaction with the analytical laboratory.

Site audits give only a snapshot of what is occurring at a facility. However, complete audit trails present the chain of custody and records for every action on a sample. This level of record keeping has been a long-standing requirement for the pharmaceutical and environmental industries. It is now available for minerals and mineral exploration laboratory work.

Results and discussion

Through new technology, ALS Chemex now provides a deeper and more complete view into the laboratory. With a click of a mouse, it is possible to answer the “where is my sample?”, “what is happening to it?” and “who is doing this activity?” in real-time. The application involves detailed capture of all internal laboratory processes and then provides Web access to clients of these records for their samples. In addition, all laboratory control charts and standards data are on-line. The detailed nature of the records, coupled with the on-line web access, means the laboratory can be ‘audited’ at any time. As well, the immediate, real-time access to information gives the assurance that the representation is accurate and unfiltered.

Conclusion

This new technology gives instant access to the deeper and more detailed information regarding the laboratory processes now required by regulators. Just as critically, the access to these real-time and historical records is quick, easy and available at any time, night or day, through the World Wide Web.

REAL TIME GEOCHEMICAL ANSWERS IN THE FIELD

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Geochemists now have analytical instruments capable of mapping both chemistry and mineralogy in the field. The chemistry of essentially all media for many to most elements of interest can be determined in the field using portable x-ray fluorescence instruments. Answers to what and where to sample as well as number of samples can be determined in the field. Samples can be screened in the field and those samples that display key aspects of the geochemical signature of the target mineralization can be submitted for detailed laboratory analysis. Specialty laboratory procedures can be focused on areas of interest rather than the entire property. Site geochemical characteristics that are not usual, or cannot be easily sampled by conventional sampling practices can be investigated. Multiple sampling events are usually not necessary because a more complete understanding of the geochemistry of the property can be obtained on the first visit.

Rock and sediment surfaces can have significant geochemical signatures from desert varnish, groundwater, vapor transport, etc. that can provide either enlightening or misleading property geochemistry. In this paper, a comparison of the exposed surface versus the fresh surface illustrates a technique to separate a desert varnish geochemical signature from a rock generated signature. Examples of evaluating the geochemical signature of not only soil samples but also forest mull and different onsite trees illustrates how a much broader suite of potential media are available using a portable x-ray fluorescence instrument. Western white pine, Douglas fir, cedar and cottonwood tree signatures are compared with forest litter and soils geochemical signatures in the Coeur d'Alene District in Idaho for use in exploring for lead-zinc-silver mineralization.

DIFFERENTIAL EFFECTS OF SELECTIVE GEOCHEMICAL EXTRACTIONS WITHIN PLUMBOJAROSITE

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Selective extractions are commonly used in both environmental and exploration geochemistry to dissolve specific mineral phases or mobilise certain forms of metals, with the results used to predict features such as transport mechanisms for metals in surficial environments or the bio-availability of metals in soils and sediments. A major hindrance to the interpretation of selective extraction metal data and the evaluation of the efficiency (selectivity) of such extractions has been the lack of quantitative data relating to variations in sample mineralogy during such extractions. This is especially the case for techniques used to differentiate Fe oxide phases of varying degrees of crystallinity. This study provides a preliminary evaluation of the application of proton induced X-ray emission (PIXE) miniprobe for detailed mineral surface geochemical mapping to such mineralogical problems.

In this study, major and trace elements within the upper 50 μm of a plumbojarosite grain and surrounding hematite matrix in gossans from the Mt Bulga Cu-Pb-Zn deposit were mapped using PIXE and SEM. The sample was subsequently leached in 0.25 M hydroxylamine.HCl and then 10% HCl, with the same region of the block remapped using the PIXE after each leach. A number of elements displayed detectable concentrations within either mineral phases, including Fe, Pb, As, S, Cu and K. A comparison of element patterns, after successive leaches, indicates the rate of metal dissolution relative to Fe varies between elements and locations within the mineral grains. Relative to Fe, a weak hydroxylamine-HCl leach produced a weak enrichment of Pb but depletion of As in the plumbojarosite, whereas a subsequent dilute HCl leach (CHX) resulted in a strong enrichment of Pb and depletion of As, relative to Fe. Based on the extractions, the plumbojarosite may be subdivided into distinct domanis - the first with Fe:Pb ratios ~1 following both the CHX and HCl leaches and and the second with a ratio ~2 after CHX and 2.75 after HCl.

The results indicate variation in the relative rates of dissolution of different metals from two mineral phases – hematite and plumbojarosite – but may also indicate slight variations in mineral chemistry may have significant influence on metal dissolution rates.

SOIL AND BIOGEOCHMICAL SIGNATURES OF THE ARIPUANÃ BASE METAL DEPOSIT – MATO GROSSO, BRAZIL

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Introduction

A geochemical survey was undertaken along two traverses at Anglo Brazil's Aripuanã Zn-Pb-(Cu-Au-Ag) prospect in the Mato Grosso province of Brazil. Humic soil (A-horizon) and a more clay-rich and reddish soil (B-horizon) of the colluvium, and saprolite were collected along Traverse 1 that intersects an approximately 130 m long gossan near the top of a ridge. A and B soil horizons were sampled along a shorter traverse (Traverse 2) in dominantly depositional terrain along strike of the mineralization. Traverse 2 passes over 10-20 m wide base metal mineralization that is concealed by approximately 5-10 m of transported cover. Mull and bark samples were collected along Traverse 1, and mull samples from along Traverse 2. The mull comprised a thin (<50 mm) layer of decomposing leaves and fine roots with varying amounts of embedded soil particles.

Methods

The <75 µm and <250 µm fractions of A and B horizon soil samples were analyzed, along with saprolite samples, for 68 elements following multi acid, aqua regia or fusion digests. Mull and imbauba tree (*Moraceae* family, genus *Cecropia*) bark samples were prepared by two different methods: one portion of each samples was dried, ground and digested in aqua regia, a second portion was ashed (controlled ignition) and then digested in aqua regia; all solutions were analyzed by ICP-MS.

Results

Base metal target element concentrations along both soil traverses are, on average, two times greater in the <75 µm fraction than in the <250 µm fraction. However, the contrast (anomaly to background ratio) in the <250 µm fraction along Traverse 1 is one to two times greater than in the <75 µm fraction. Along Traverse 2, the contrast is similar in both size fractions. High contrast in the coarse fraction along Traverse 1 may be due to coarse gossan detritus, derived from the large gossan uphill. This suggests that fine-grained samples are preferable for regional exploration, whereas coarser material is more suitable at prospect scale due to the widespread occurrence of outcropping gossan.

A-horizon humic soil samples show the greatest contrast of all sample media. Mull samples (ashed) have similar contrasts to those in B-horizon samples and provide adequate information for delineation of the gossan zones along both traverses. Bark samples have very high Pb, Mo and W concentrations over the gossanous zones. However, Zn concentrations do not show corresponding enrichment.

The element suite based on contrasts (>10), that best identify the base metal – precious metal bedrock mineralization at Aripuanã are, in the order of decreasing contrasts, for A-horizon soil: Cd, Zn, Pb, In, Sb, Co, Mn, Mo, Se, Au, As and Cu; for ashed mull: Pb, Co, Sb, In, Se, Cd, Mo, V, Au, U, As and Zn; and for ashed bark: Pb, Mo and W.

Conclusion

The studies have shown that, although the geochemical response of the base metal mineralization is strongest in the A-horizon soil, mull samples clearly define the surface expression of the mineralization and are a viable alternative to soil samples due to easier collection in tropical rainforest.

DISTRIBUTION AND ORIGIN OF REGOLITH CARBONATES IN SOUTHERN AUSTRALIA

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Identifying the source of the Ca is important in assisting our understanding of the recently recognised association of regolith carbonates (especially when in an indurated form, commonly called calcrete) with Au and their use as an exploration sampling medium. With mineral exploration extending into areas of deeply weathered profiles where direct observation of the underlying bedrock is limited to expensive drill cores and very limited outcrops, the development of other methods, such as regolith geochemistry (including the distribution and chemistry of calcrete), to predict the underlying geology is necessary. Gold in calcrete anomalies as an exploration tool have been equivocal. False anomalies are common and, in some cases, anomalies are so numerous that costs for confirmatory drilling are exorbitant. Continued use of this sampling medium requires a better understanding of the relationship between regolith carbonates and Au. In particular, it would be useful to develop a method of ranking calcrete Au anomalies with respect to the likelihood that they overlie a Au source.

The research presented here investigates the formation and origin of regolith carbonates in southern Australia with particular reference to underlying Au mineralisation. It is expected that a more thorough understanding of regolith carbonate formation will provide vital clues into the Au-regolith carbonate association. Implicit in this idea is the assumption that ions related to mineralisation must travel from bedrock to the surface, and be trapped within the carbonate. Strontium isotope analysis of regolith/pedological carbonates from southern Australia indicates that the primary component, Ca, is almost entirely derived from an external marine source, with aeolian dust and/or rainfall the most likely transportation process. The extensive distribution of regolith carbonates, from the southern Australian coast to over 450 km inland is indicative of a very large source area and/or a process that has been ongoing for an extended period of time. The proposed Ca source is the sedimentary carbonates located along the southern Australia continental shelf that were exposed during the last glacial maximum. Given that Ca has an exogenic origin in the pedological system, the association of calcrete with Au and any underlying Au mineralisation must therefore be due to physical, chemical or biological processes that have occurred since or during the formation of the regolith carbonate profile i.e. during pedogenesis.

A detailed mineralogical, morphological and geochemical analysis has been completed on two regolith carbonate profiles that overlie known Au mineralization in the southern Curnamona region, South Australia. Comparisons have been made with the underlying bedrock and mass balance equations have been employed to determine elements that have been transported into or out of the system. The content and disposition of Au in the carbonates was investigated by several electron optical methods, namely field emission scanning electron microscopy, electron microprobe analysis and transmission electron microscopy.

IN SITU ARSENIC REMOVAL USING REDOX CONDITION ALTERATION: EXPERIMENTS AND MODELLING

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Introduction

In recent years, the presence of dissolved arsenic in contaminated groundwater from both natural and anthropogenic sources has emerged as a major concern on a global scale. Arsenic is a ubiquitous element present in various compounds through out the earth's crust. Natural geochemical contamination through soil leaching is the primary contribution of dissolved arsenic in groundwater around the world.

Adsorption/co-precipitation with iron oxyhydroxides is the most commonly adopted method for arsenic removal from contaminated water because the method is both effective and cheap compared with other methods. The main idea of the *in situ* treatment method of groundwater is to transfer the physical, chemical and biological processes of conventional above ground treatment plants into the aquifer. The aquifer carries the function of natural subterranean reactor where oxidation and filtration processes for the removal of arsenic and other constituents take place. The injection of oxygen-enriched water displaces the original groundwater containing iron, arsenic and other water constituents. Thus, an oxidation zone is built up in the aquifer where Fe(II) will be converted to Fe(III) compounds, which largely precipitate on the soil. During the following production phase, flow is reversed and groundwater flows through the oxidation zone towards the well. Consequently, Fe(II) and As (III) are adsorbed to the soil grains, which are partially coated by previously deposited oxidation products e.g. Fe(III). Through the next injection period, the adsorbed Fe(II) is oxidized to ferric hydroxides by the oxygen transported with the injected water.

In this paper, we deal specifically with the first stage of the remediation process where the oxygenated water is first introduced in the well vicinity and the adsorbed Fe(II) compounds is oxidized.

Methods

Due to the lack of a technology to detect the oxidation of adsorbed iron compounds in porous media, a visualization technique was suggested to make use of the different colour for ferric and ferrous compounds. The green rust precipitates were used as the representative of the adsorbed ferrous iron compounds at the field. A visualization Perspex cell with dimensions of 20x10x0.8 cm filled with glass beads saturated with green rust solution was put in a glove box under oxygen free condition and oxygen rich water was injected. The change from the green rust colour to the orange colour of lepidocrocite, and the changes in oxygen and pH were recorded and analysed. The experimental data were compared with the predictions of a developed theoretical model.

Results and discussion

Comparison of the experimental result with that predicted by the theoretically developed model shows an acceptable agreement. Although the discrepancies between the experimental and theoretical results originated from neglecting some phenomena during the development of the model due to the complexity of the studied system.

Conclusions

- Conventional column experiments where only effluent concentrations are measured are not able to determine the relevant mechanism and thus the relevant transport and reaction coefficients of interest for arsenic remediation.
- Visualization techniques makes it possible to determine the in-situ Fe(II) profiles.
- Transport and reaction parameters for the Fe(II) in porous medium under different conditions were calculated.

USING GROUNDWATER TO VECTOR TOWARDS MINERALISATION UNDER COVER: THE CURNAMONA PROVINCE

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Introduction

The Curnamona Province is endowed with the supergiant Pb-Zn-Ag Broken Hill ore body and numerous minor mineral deposits (Pb-Zn-Ag, Cu-Au, Sn, W, U, etc.). These mostly occur within the limited outcrop of the Proterozoic Willyama Supergroup. However, the vast majority of this Province is concealed by transported regolith, hampering the success of exploration based on conventional strategies.

Groundwater is a geochemical sampling medium that moves through the subsurface, is easily collected and can be analysed with great accuracy and sensitivity. It may have come in contact with mineralisation and retained a chemical 'memory' or fingerprint of such an encounter. Can one detect such fingerprints in groundwater collected from existing pastoral and exploration bores? Can they be used to target exploratory drilling in areas of transported cover? These are some of the questions our study in the Curnamona Province attempts to answer.

Methods

We have collected about 350 groundwater samples to test whether this medium could be helpful in the search for hidden mineral deposits in the Broken Hill region. We determined the major, minor and trace element concentrations of the groundwaters (by ion chromatography, inductively coupled plasma-atomic emission spectrometry, inductively coupled plasma-mass spectrometry, ion specific electrode, photospectrometry and titration) as well as the isotopic compositions of H, O (of H_2O and SO_4^{2-}), C, Cl^-, S, Sr and Pb (by mass spectrometry after various preparation methods). We also analysed several rain and surface water samples to better constrain the starting point of the evolution of the groundwater.

Results and discussion

The groundwaters have undergone a range of processes; their present-day composition is the end product of a complex and, in many instances, long evolution. Using hydrogeochemical principles and modelling, we have been able to identify and, in some cases, quantify these processes. Thus, we recognise that a number of the groundwaters have a sulfur excess (S_{XS}), i.e., an amount of S greater than that ascribed to increases due to evaporation or to mixing. Many of these samples have a low $\delta^{34}S$ composition, which possibly results from oxidation of sulfides with a Broken Hill type $\delta^{34}S$ signature (average ~0 ‰ V-CDT). Further, the $\delta^{18}O$ composition of the SO_4^{2-} helps determine whether sulfide oxidation occurred near the groundwater table or in deeper settings. Strontium isotopes identify the broad types of bedrock with which the groundwater has been interacting, from less radiogenic Adelaidean rocks (and minerals) in the west to highly radiogenic Willyama Supergroup in the east (groundwater $^{87}Sr/^{86}Sr$ ratio up to 0.737). The groundwaters have $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios comparable to, or intermediate between, various mineralisation types recognised in the area (e.g., Broken Hill, Rupee, or Thackaringa types).

The oxidation of sulfide mineralisation will result in increased concentrations of Cu, Pb and Zn (and other trace elements) in solution in the groundwater. To predict the behaviour of these trace metals during transport along a flowpath, we have generated a 1-D reactive transport model. The basic initial assumptions of the model are:

- the transporting fluid is a typical groundwater equilibrated with galena, chalcopyrite and sphalerite, with no secondary mineral precipitation, allowing for a maximum metal content in the groundwater,
- the flow path has ion exchange sites and adsorption sites, which are initially equilibrated with the unreacted groundwater, and
- flow and transport occur at 1 m/yr for 4,000 years.

The results show that elevated Cu and Zn concentrations extend to ~150 m away from mineralisation (down the flowpath), while Pb values are already attenuated within ~50 m of mineralisation. Perhaps the most important outcome of this exercise is to illustrate that trace metals do not travel far in such groundwater systems, and that Zn and Cu have a higher mobility than Pb. Thus, we can not expect high dissolved metal contents at any great distance from mineralisation. However, other groundwater constituents (such as SO_4^{2-}) may present a much larger footprint of a buried deposit.

Of the 23 real groundwater samples taken in the vicinity of known mineralisation in the southern Barrier Ranges (Broken Hill Domain), 16 (70%) yield positive indicators, that is:

- positive S_{XS},
- low $\delta^{34}S$, and
- elevated Zn and/or Cu concentrations.

This study also highlights several other locations under sedimentary cover in the Curnamona Province where our vectors suggest interaction with mineralisation.

Conclusions

Hydrogeochemistry is a very useful tool in the search for mineralisation under cover, particularly at the regional scale for area selection or target ranking, and should be part of any multi-disciplinary mineral exploration campaign.

LOW-DENSITY GEOCHEMICAL SURVEY OF THE RIVERINA REGION, SOUTHEASTERN AUSTRALIA: RESULTS AND APPLICATIONS

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Introduction

Baseline geochemical surveys provide invaluable information about the natural concentrations of chemical elements at the Earth's surface from which we grow livestock and crops, and extract water, raw materials and mineral wealth. These natural concentrations vary spatially due to geological, climatic, biological and other processes.

It is important to know the natural concentrations and distributions of elements so that:

- baselines can be established against which future changes can be measured,
- appropriate and responsible land-use policies can be adopted,
- localised contamination can be identified and better remediated, and
- new mineral potential can be identified.

In Australia, regolith, the blanket of soils, sediments and weathered rocks covering fresh bedrock, is an ubiquitous component of the landscape. It is the foundation upon which a multi-million dollar agricultural industry is based, it hosts our precious groundwater resources, and contains or covers ore bodies vital for our economy and development. Yet Australia is one of the last developed nations not to have nationwide baseline geochemical information at the disposal of decision makers.

As a pilot project, the geochemical survey of the Riverina region in southern New South Wales and northern Victoria was undertaken collaboratively between CRC LEME and Geoscience Australia. This region at the centre of the Murray-Darling basin was chosen because of its paramount importance from agricultural, societal and resource standpoints.

Methods

Overbank sediment samples were collected at 142 sites within the 123,000 km^2 survey area, giving an average sampling density of 1/866 km^2. The sites were selected to be near the outlets or spill points of large catchments. Theoretical sample sites were located by conducting a hydrological analysis to determine the lowest point in each river catchment. These sample sites were then carefully adjusted using drainage and road coverages, and field considerations such as land accessibility, landscape position and possible anthropogenic interferences at the site. At each site, a near-surface sample (TOP: 0-10 cm) and a bottom sample (BOT: ~10 cm interval between ~60-90 cm) were taken. In the field, the sediment samples were subjected to a detailed description and pH, texture and moist and dry Munsell colours were determined. In the laboratory, pH 1:5 (soil:water), EC 1:5, moisture content and laser particle size distribution were determined. Sediment splits were dried and sieved to <180 μm, then analysed by x-ray fluorescence, inductively coupled plasma mass spectrometry and instrumental neutron activation. Sequential extractions were also performed. Altogether, the concentrations of 62 elements were determined, and maps and diagrams prepared showing the spatial and statistical distributions in the TOP and BOT samples and of the TOP/BOT ratios.

Results and discussion

Knowing the concentrations and distribution patterns of chemical elements in the Riverina region can be applied, for instance:

- to detect any local contamination or salinity stress,
- to select areas (un)suitable for particular land uses,
- to draw attention to potential geohealth risks (see contribution by Lech *et al.*, this volume), and
- to select areas for mineral exploration.

Sampling an upper and a lower level at each site allows for a more detailed understanding of the potential sources of chemical elements in the environment, with the TOP sample being more prone to influence by human factors (e.g., fertilizers), and BOT sample reflecting a more geogenic influence, being well below the tilling depth.

Most elements have a higher median concentration in the BOT than TOP sample. For Ag, Pb, Sb, S, Y and most REEs, the median concentrations are similar at both depths. Median Br, Hf, LOI (organic matter), Mn, P, Si and Zr concentrations, however, are higher in the TOP sample.

The survey shows obvious patterns of Ca or Cl distributions in the upper soil horizons, which have implications for agricultural (soil pH) and salinity management applications.

Arsenic and Sb are two well-known pathfinder elements for gold mineralisation. The Victorian goldfields are located just to the south of the study area, and the As and Sb distribution maps clearly show a progressive decrease from the southern edge of the area towards the north. This is particularly clear in the BOT samples. We interpret this to be a representation of mechanical dispersion trains from the source regions to the south and perhaps below Murray Basin sediments.

Conclusions

The Riverina geochemical survey delivers a cost-effective, internally consistent and quality controlled data layer on the inorganic chemical composition of the near-surface regolith in the heart of a prime agricultural region of Australia. This data layer will be made available to decision makers, catchment management authorities, farmers, mineral explorers and other stakeholders. It has the potential to guide activities and decisions in a multitude of applications related to land use and resource management.

MORPHOLOGY AND COMPOSITION OF PALAEOCHANNEL GOLD, SUNRISE DAM GOLD MINE, WESTERN AUSTRALIA.

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Introduction

Although the physical and chemical mobility of supergene gold from regolith profiles in Western Australia is well known, morphological and compositional characteristics of gold from palaeochannels in the regolith are less well documented. This study investigates gold particles from the base of an Eocene (58-37 Ma) palaeochannel at the Sunrise Dam Gold Mine (SDGM), located 55 km south of Laverton in the northeastern goldfields, Yilgarn Craton, Western Australia. The deeply incised palaeochannel at SDGM is broadly similar in trend to the predominant orientation of the local structural architecture.

Methods

Gold particles studied are from panned concentrate collected from very poorly-sorted muddy sandy basal quartzose gravels, containing significant sub-angular BIF clasts, at 80-85 m depth in an oxidised distal portion of the Sunrise palaeochannel. Detailed textural and geochemical associations are observed using scanning electron and backscatter analysis of polished sections, coupled with line-scanning across particles at two micron intervals, constrained by qualitative electron microprobe (WDS) analysis.

Discussion

The majority of gold particles are stubby and hackly in appearance, ranging in size from 20 µm to 2 mm, and are variously equant through to elongate and complex in shape. Surface textures are generally free of deformation commonly associated with significant fluvial transportation within a placer environment (i.e. scratch and impact marks, physical deformation of protrusions, flattening and/or refolding, thickened particle rims). Similarly, striations and crystallographic features such as lattice intergrowths are not observed on external surfaces. Euhedral gold crystals, intergrown quartz/gold, and platy rounded gold particles were not observed. Although corroded in appearance, particle surfaces on a micron scale are characterised by a variety of precipitation textures (i.e. polyspheroidal and polyhedral aggregates). In section, particle outlines are anhedral and characteristically highly irregular, featuring numerous prominent embayments. Many gold particles are partially encapsulated in a Fe-rich clay matrix (± detrital? quartz).

Compositionally the gold occurs as a binary Au-Ag alloy with trace Cu in rare samples. Silver content ranges from 0 to 12 wt.%, with most gold having between 3.5-4.5 wt.% Ag. Based on Ag content, at least four populations of gold are identified, those having no detectable Ag, and those having contents around 4 wt.% Ag, 7 wt.% Ag and 12 wt.% Ag. Most of the gold particles are homogeneous in composition, although heterogeneous particles are relatively common and characterised by a second gold phase that is either high-fineness gold (>990) or pure gold. Silver-depleted gold is observed as well-defined discrete portions both within gold particles and on particle margins. Silver-depleted particle ‘rims’ were not observed.

Conclusion

Based on textural and compositional observations, it is clear that gold sampled in the palaeochannel is not of detrital (alluvial) origin, despite being collected from a fluvial environment. In addition, preliminarily analysis is not consistent with deriving the bulk of the gold from the underlying primary orebodies that make up the Sunrise Deposit (i.e. as colluvial/eluvial gold derived from a primary source). Thus, it is speculated that most of the gold at the base of the palaeochannel is of supergene origin and chemically precipitated within the basal sediment. The ultimate source of the gold is most probably derived from transported or residual mineralisation within the Sunrise Deposit, and/or dissolution of pre-existing detrital gold within the palaeochannel.

THE ROLE OF SOIL GEOCHEMISTRY IN SUCCESSFULLY PRIORITIZING DEEPLY BURIED Cu-Mo PORPHYRY GEOPHYSICAL DRILL TARGETS, BUTTE DISTRICT, MONTANA, USA

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The 10.3 square mile Ruby property of the O.T. Mining Corporation is located in south western Montana, 13 miles north east of the “Richest Hill on Earth” at Butte, where base and precious metal mining has been ongoing since 1864. Targets on the property include epithermal Au and Ag and bulk mineable intrusion-hosted Cu-Mo-Au mineralization. High priority areas on the Ruby property have been identified during helicopter-borne magnetic and electromagnetic surveys and geological mapping. Airborne targets were assessed using deep-looking ground geophysical (I.P. and M.T.) surveys and deep-penetrating soil geochemical surveys.

Diamond drill testing of ground I.P. anomalies on the Ruby property without significant soil geochemical signatures has intersected clay-rich and silicified rocks in alteration zones devoid of base and precious metal mineralization. Only in areas of significant soil geochemical response have drill results defined mineralized zones of merit.

Soil geochemical surveys in the North Anomaly target area of the Ruby property documented a 400 x 400 foot Cu-Co-Zn anomaly. A vertical drill hole collared to test the source of this anomaly intersected 587 feet of barren felsic to intermediate pyroclastic volcanic rocks. Between 665 and 1916 feet in the hole an altered and mineralized quartz-feldspar-phyric igneous intrusion was intersected. Mineralization comprises disseminated, vein and replacement masses of chalcopyrite, pyrite and lesser molybdenite. Alteration is typified by pervasive fronts and veins of potassic alteration superseded and overprinted by phyllic alteration.

The total thickness of the mineralized intersection to date is 1251 feet. The hole was halted at a depth of 1916 feet within strongly altered and mineralized intrusion to comply with U.S. Forest service winter drilling regulations. The vertical extent of the mineralized intersection will be established in early 2005 by re-entering the hole and continuing the drill program.

DATA DETERMINED ZONATION AROUND MINERALISATION

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The first hole, or subsequent early holes, in an exploration-drilling program may fail to intercept ore even if it is present nearby. It may be weakly mineralized or altered. Observations in such holes are critical to a better targeting of subsequent holes and are vital for ensuring discovery or bringing inevitable discoveries forward in time, a significant factor in minimizing risk in early stage resource delineation. Improvements in detecting and characterizing the alteration and metal haloes, present around many ore bodies, can assist.

The concept of zonation is repeatedly referred to in ore body description and ore genesis papers, though usually without specific exposition of the methodology or assumptions. In this paper, a conceptual model of zonation around mineralisation is illustrated with synthetic data, the mathematical solution is developed and applied then to high sulphidation gold mineralisation in Southern Peru.

The composition of an individual finite, sample is assumed to comprise a random mixture of two independent components. One component carries a signature of the mineralizing process, whose composition varies as a function of the distance along a changing fluid path. The other component is seen as reflecting the changing chemistry of host rocks, which may variously reflect chemical changes due to such processes as sedimentation or magmatic fractionation. Individually, each component varies slowly in space, but is mixed with the other by random combination within individual samples. Such a mixing process is intended to represent the often observed vein and fracture controlled mineralisation or alteration typically found peripheral to, and commonly within, many classes of hydrothermal mineral deposits.

When sample arrays are available, such as in continuous sampling down drill holes, the relatively large changes in composition due to random changes in vein of fracture density can be separated from the compositional changes due to the more slowly varying component background or target mineralizing process. It is further assumed that a transect of samples down a drill hole, or part thereof, represents a local fragment of a complete zonation pattern.

During data reduction, drill hole geochemical transects are pieced together in an order that maximizes the continuity of slowly varying background and evolving mineralisation components, at the same time resolving the random mixing process. The end result is the partitioning of sample composition into a relative position on an evolving fluid path, a relative position within a background process and a mixing proportion.

Cello Ccasa is a small classical high sulphidation deposit hosted in uniform andesitic lavas near Coracora in Southern Peru. At the time of examination, approximately 20 drill holes had intersected the mineralizing system in all known alteration facies ranging distally from weakly propylitically altered andesite through argillic, advanced argillic into domains of economic grades of silver and gold hosted in vuggy and massive silica facies considered to be most proximal to the fluid source. Approximately 20 major and minor elements were determined by four acid digest ICP OES on 2200 samples.

Application of the zonation model met with mixed success. The model was overwhelmed by the mineralized component, and a strong coherent zonation pattern due to mineralisation alone resulted. No resolution of a background process and thus no mixing proportion could be resolved. This partial failure was due to a combination of reasons. First, alteration was pervasive and intense and individual 2 m samples appeared to comprise largely of a single alteration facies and not, as assumed by the model, a random mixture of two processes. Secondly, the background host rock was of relatively uniform andesitic lava and thus the background variability was minimal. A contributing factor also was that the analyses available contained no element that strongly represented the andesite and which was conserved by the mineralizing process. It was concluded that the system was far simpler than could be accommodated by the more complex model proposed.

Most directly useful, in terms of mineral exploration, was the strong Pb anomalism in the peripheral advanced argillic alteration facies. When tested against available data from other high sulphidation deposits in Peru this appeared to be a consistent predictor of gold in the proximal silicic facies. A similar pattern occurs at Summitville in US, but not in Lepanto in the Phillipines.

ACID DRAINAGE IN THE WESTERN AUSTRALIAN WHEATBELT

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Introduction

Extensive investigations at Narembeen, in the central wheatbelt 300 km east of Perth, have demonstrated the presence of saline, highly acid groundwaters (down to pH 2) which are leaching into discharge drains. These groundwaters contain extraordinarily high Fe, Al, base metal and REE concentrations, with some of these flowing through the discharge drains and, potentially, the natural watercourses into which these ultimately drain, with potential for damage to receiving areas and their flora and fauna.

Groundwaters

With ongoing regional studies, acid groundwaters (though not necessarily as acid as in Narembeen) are increasingly encountered in groundwaters across the state and in particular in drains in the eastern and central wheatbelt. Ongoing sampling and detailed geochemical analysis of drainage waters from about 20 deep drains, approximately 100 additional bores and streams, along with mineralogical analysis of salt and sediments in the base of drains has demonstrated this to be an extensive issue, and potentially worsening. In nearly every landscape in the agricultural area, bores with acidic groundwater (< pH 4.5) were found. Groundwaters in the eastern wheatbelt tended to be most acidic. By contrast, surface waters were neutral to alkaline is most areas, especially western areas. Naturally acidic surface waters (pH < 4.5) were found in the Lochart River, a major river in the W.A. wheatbelt.

Drains

Various drainage networks have been engineered throughout the wheatbelt, in an attempt to mitigate problems of waterlogging and salinity. These drains also act as geochemical laboratories in which elements interact with oxygen, organic matter and sediments. Results indicate two broad systems. Measured pH was lowest (pH < 3.5) in the east and highest (pH > 6) in the western and central wheatbelt, with most drains above sea water salinity (3.3%). In particular, salinity, Fe, Al, Co, Cu, Zn, Pb and REE are high in low pH (< 4.5) drains. Drain flows have become more acidic (pH 3 → 2) and saline (60-80 → 100-200 mS/cm) in low flow periods. The sediments will now contain acid forming minerals in summer, in addition to the acidity supplied by groundwater in winter. Drain flows commonly migrate to alkaline receiving areas, which may neutralise the acidic flow and therefore remove many trace metals from solution, although elements such as As, Se and Cr are potentially more toxic under a higher pH and/or a reducing environment.

Management implications

Soils, groundwater geochemistry and pilot excavations should be assessed before drain construction to determine the risk of acid groundwater and high trace element concentrations. Sub-soils that contain calcrete, silcrete and red brown hardpan are at less risk of erosion, sedimentation, dissolution and related problems than the clay rich, sodic subsoils. Drains need to be kept free of sediments to sustain drainage and prevent additional acidification and geochemical reactions within the drains (making more acids). Organic material, such as dead vegetation, should be prevented from entering drains because of their hydraulic and geochemical impacts. Drain designs should prevent erosion and the transport of acids, and related organic and metal rich deposits (plus sediment) to receiving environments especially during flood events. An assessment of the impact of acid, trace element rich drain discharges on receiving environments (lake/river systems, evaporative basins) is critical.

These investigations are to be integrated into Regional Drainage Evaluation scenarios with an evaluation of options to mitigate or productively utilise acid groundwater, minerals, metals and other constituents.

PRESERVATION OF AS III AND AS V IN SURFACE AND GROUND WATERS

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The literature on preservation procedures for the stabilization of As redox species in waters is controversial. A recent paper by McCleskey et al. (2004) states that any field collection procedure that filters out microorganisms, adds a reagent that prevents dissolved Fe and Mn oxidation and precipitation, and isolates the sample from solar radiation will preserve the As III/V ratio. They go on to say that reagents such as HCl, H_2SO_4 and EDTA will prevent Fe oxidation and precipitation but warn that high concentrations of EDTA (e.g. 12.5 mM for sample containing up to 500 mg l^{-1} of Fe) are necessary for samples high in dissolved Fe content. In fact, for waters containing >0.1% Fe III, the concentrations of EDTA required to complex all the Fe becomes impractically high, approaching its solubility. The USGS recommended preservation procedure (Bednar et al., 2002) is to make the surface or ground water 1.25 mM in EDTA immediately after filtration (0.45 μm) and to use a medium of 12.5 M EDTA for Fe-rich acid mine drainage; opaque polyethylene bottles are advised to eliminate photo-reduction of Fe (with concomitant oxidation of As III to As V). The US EPA appears to supports this recommendation (Gallagher et al., 2001).

Earlier studies by the Geological Survey of Canada (GSC) (Hall et al., 1999) showed that HCl (a strength of 0.1% or 0.012M) did indeed effect an immediate change on the species distribution of As in several natural waters (e.g. release of colloidal As and a concomitant increase in As III) and that after *ca.* 20 days of storage at 22^{o}C, there was an increase in As V at the expense of As III and a decrease in total As of >10% after 50 days. These findings, demonstrating the inability of HCl to preserve the sample integrity, are supported by the investigations of Bednar et al. (2002) and Gallagher et al. (2001). Recent work at the GSC has shown that making up a calibration standard containing As III in an HCl medium can be problematic. For example, standards containing 0.5 or 5.0 μg l^{-1} of As III and As V in 0.1M HCl are not stable when the solution is diluted with H_2O by a factor of 10 (to make it compatible for analysis by anion exchange chromatography ICP-MS) and mixed by *shaking*: all the As III is converted to As V. However, if the solution is mixed by *vortexing*, whereupon less air is introduced to the solution, stability of the two As species is maintained. Thus, the EDTA option appears preferable.

A study of HCl (at 0.1M) and EDTA (at 12.5mM) preservation procedures using surface waters from tailings areas of abandoned gold mines in Nova Scotia generally showed comparable results, with a few exceptions where the reproducibility of duplicate samples was inferior by HCl. However, a similar study by the GSC using well waters collected in the West Bengal region showed that EDTA did not prevent the oxidation of As III to As V and indeed, in some waters, total As showed a significant decrease in the EDTA medium compared to the HCl- and HNO_3-preserved counterparts. These waters do not contain high amounts of Fe (< 10 mg l^{-1}); rather they are highly alkaline with most pH values >7.5 and high concentrations of Ca (80-120 mg l^{-1}) and Mg (10-40 mg l^{-1}). The poor performance of EDTA in this case is due to the instability of the Fe-EDTA complexes and preferential binding of EDTA by Ca, resulting in both oxidation of As III to As V (reflecting the redox interdependency of As and Fe) and precipitation of Fe in some waters, removing arsenate (and to a lesser degree arsenite where present) from solution also. Although a higher concentration of EDTA may have resulted in superior results, it is doubtful that it would have been adequate to complex the Fe at these high pH values.

Most of the investigations described in the literature have focused on waters of low pH, those in the environs of acid mine drainage such as Summitville. The work at the GSC has shown that the recommended preservation procedures are not appropriate for highly alkaline waters such as those encountered in the West Bengal region, where As in groundwater is a serious problem to health. This poster describes modifications to these procedures that are required to ensure the stability of As III and As V in solution from the time of collection to analysis, often a matter of weeks if not several months.

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ELECTROCHEMICAL TRANSPORT AND REDUCED CHIMNEYS OVER OXIDIZABLE GEOLOGICAL FEATURES – UNDERSTANDING THE PHYSICS

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“Reduced chimneys” have been postulated to occur over sulphide ore deposits for almost a decade. The theory of their formation proposes that a buried oxidizable feature, such as a sulphide deposit, ought to consume oxidizing agents in the overburden above it, thereby creating a reduced environment. Between the top of the reduced feature and the water-table, a vertical electrochemical gradient exists; along which reduced and oxidized mobile species migrate toward each other. Redox reactions occur between the two and, because oxidants are limited in the phreatic zone, they are preferentially consumed causing reduced species, and thereby negative charge, to propagate outward and upward. This is interrupted at the water-table, above which oxidants are abundant. A consequence of this process would be dissipation of negative charge away from the reduced feature, which would allow its continued oxidation. The net result would be an upward movement through overburden of reduced species, particularly metals such as Fe^{2+}, and the development of a reduced “chimney” in groundwater saturated overburden between the reduced bedrock feature and the water-table.

In the last 5 years, the Ontario Geological Survey has been documenting the existence of reduced chimneys, as predicted, over deeply buried reduced geological features. In addition, a reassessment of published studies and anecdotal evidence suggests reduced chimneys exist worldwide and occur over many different types of oxidizable features such as oil and gas reservoirs, porphyry sulphide deposits and kimberlites. Although the predictions fit the observations very well, there have been many unexpected and startling outcomes of the work including temperature anomalies, massive energy release and mass transport, and bizarre “bulges” in the water-table that occur at the strong redox boundaries over all features investigated. These latter features may be a previously undocumented form of electro-osmosis.

Notwithstanding the excellent correlation between prediction and observation, there is leap of logic inherent in the original geochemical model, a consequence of which is that the transport process appears to defy physics. This problem also exists in many of the previously published models by a number of authors. A new theory has been developed that resolves this issue and has unexpectedly resolved some of the apparent conflicts and mutual exclusivity of earlier models on the subject of electrochemical transport in the geological environment. Through the lens of this new theory, it appears now that most of the authors writing on the subject of electrochemical transport have been correct in their central arguments and were merely describing different part of the same problem.

“FOREST RINGS” AND THEIR IMPLICATIONS FOR OIL, GAS AND MINERAL EXPLORATION USING GEOCHEMISTRY

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“Forest rings” have been an enigma for 50 years since they were first identified in aerial photographs of northern Canada. They usually occur as large, near-perfect circles, in boreal forest, that range in diameter from 30 m to almost 2 km. They are not the product of glacial processes, but are post-depositional, nor do they result from paludification of lakes or meteorite impact. Clusters of similarly-sized rings are common and sometimes form linear trends in the direction of presumed geological structure. Similar structures occur in farm fields in southern Ontario, although the only feature they have in common with the popular “crop circles” is their shape. They do not form suddenly, but are permanent features in both forest and field.

A strong depletion of carbonate occurs in soils underlying the rim of the ring. This supports the OGS theory that the rings are centres of negative redox charge and form according to a published redox-gradient transport model, developed to account for geochemical processes over mineral deposits and other reduced features. The theory proposes that a chemically reduced source in bedrock or overburden maintains Fe in reduced form within the ring. Outward migration Fe^{2+} within a redox gradient, followed by Fe oxidation at the edge of the ring, a product of which is H^+, dissolves carbonate’ creating a physical depression in the mineral soil and a circular peaty area that is visible from the air.

Work is underway to understand the remarkable physical and chemical features associated with the rings, including temperature anomalies, water level “bulges”, apparent magnetite formation and the metal mobility mechanism itself, which at first glance appears to contradict physics. It is estimated that over 80% of the 1600 rings identified in the study area have CH_4 in overburden as the source of negative charge. One ring is known to be H_2S-sourced, and other reduced sources are possible. In addition to their potential for indicating resources of economic interest, the rings are excellent case-study areas for redox anomalies in overburden. Similar “reduced chimneys” have been reported over mineral deposits, kimberlites and oil and gas fields. Work carried out at the rings suggests that many of the geochemical phenomena documented over these features may be linked to redox-gradient transport and related secondary processes.

BRITTLE DEFORMATION AND MECHANISMS OF MINERAL PRECIPITATION: A MULTIDISCIPLINARY STUDY OF SYNKINEMATIC VEINS HOSTED IN AN EXTENSIONAL STRIKE-SLIP DUPLEX FROM THE ATACAMA FAULT SYSTEM

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Understanding the geometry, kinematics and timing of mineralized fault-vein networks can provide us with answers regarding the structural and geochemical processes that drive fluid transport and hydrothermal mineral precipitation in the crust. This, in turn, is a starting point to develop new tools that are currently a major need in the exploration industry.

The interplay between fluid transport and crustal deformation is fairly well known in theory; however, it has seldom been described in actual field examples. Some key questions regarding such interplay remain a matter of discussion: how do fluids interact with active deformation in order to precipitate certain hydrothermal minerals? Is there a relationship between the type and amount of the precipitated hydrothermal mineral association and geometry and kinematics of a certain structural site? What sort of fault-vein networks are more common in magmatic arc settings and why? Extensional strike-slip duplexes are commonly associated in space and time with fault-vein systems, documenting fluid transport and emplacement coeval with brittle deformation.

It has been widely recognized that faults have enormous capability to create efficient fluid pathways in the crust, which is otherwise relatively impermeable. This capability is essentially determined by the mechanical role of faults in generating displacements, dilation and damage zones. Consequently, faults are important structures controlling mineralization, as is demonstrated by the close spatial and temporal association between faults, veins and ore deposits. Advancements in the understanding of the interactions between faulting, permeability development, fluid flow and chemical reaction (mineral precipitation) are critical if we are to understand the processes of mineralization.

Favourable structural geometry promotes the possibility and efficiency of mixing of diverse fluid compositions. Pressure, temperature and fluid composition determine the solubility of fracture-filling minerals. For example, quartz may precipitate as a result of cooling or pressure reduction, but calcite solubility increases with cooling and decreases with CO_2 pressure. Mass transport in rocks can occur by two mechanisms: diffusion through crystal lattice, grain boundaries, or fluid films, and infiltration or advection via a moving fluid phase. Deformation can profoundly influence the driving forces for infiltrative mass transfer as well as the rate and location of chemical change. Inferences of the details of diffusive mass transfer or fluid flow through cracks and between cracks and wallrocks are hampered by the incomplete evidence provided by mineralogical, textural and geochemical patterns of vein infill and wallrock alteration. For dissolution, precipitation or alteration to occur, a gradient in the activity of solute species must be present. The gradient must normally reflect at least local disequilibrium, and may be triggered by heterogeneous deformation (e.g., cracks) or the passage of fluid from one place to another, whereby fluid is in disequilibrium with the ambient conditions (fluid pressure, temperature), or with the chemistry/mineralogy of the host rock.

We have employed a multidisciplinary approach, detailed structural mapping, study of the mineral phases, microstructural analyses by scanning electron microscopy (SEM) and cathodoluminescence (CL), fluid inclusion and stable isotope geochemistry of veins and rocks in fault zones, to establish the geochemical conditions of mineral precipitation during vein development and to document fluid-rock interaction. These studies include: (a) Detailed structural mapping on the outcrop-scale geometry and kinematics of fault and veins. Veins are mapped and classified according to their kinematic nature (fault-fill veins and extension veins). (b) Mineral pattern and geochemical profile studies across vein-wallrock transects to make an approximation of fluid and mass transfer for veining and alteration. (c) Pressure and temperature estimations by thermodynamical models based on mineral assemblage stability in veins and wallrocks, and chlorite thermometers. (d) Microstructural studies of fault-fill veins and extension veins using SEM and CL images to determine zoning aspects, which help to elucidate the precipitation history and mass-transport mechanism. (e) Fluid inclusion studies to provide independent constraints for thermodynamic parameters at the time of mineral precipitation. These analyses were carried out on minerals of known relationship with microstructural development. (f) Fluid source determinations by means of oxygen isotopic composition of quartz in veins and wall rocks.

Our results document a case in which control on the localization of ore deposition is directly related to opening of highly permeable pathways during deformation. Our methodology could help in predicting the localization of ore deposits (e.g., iron oxide-copper-gold deposits) hosted within active fault systems on the basis of the geometry and evolution of extensional strike-slip duplexes.

WATTLES, GUM TREES AND KANGAROOS: THE USE OF SOME AUSTRALIAN LANDSCAPE ICONS FOR REGIONAL-SCALE BIOGEOCHEMICAL EXPLORATION IN SEMI ARID SOUTHEASTERN AUSTRALIA

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In recent years, a range of regolith and biogeochemistry research has been undertaken in semi-arid southeastern Australia, particularly in the Curnamona Province and adjacent parts of western New South Wales and South Australia. The biogeochemistry of tree and shrub species has been a major focus of the research, although faunal biogeochemical characteristics, such as the biogeochemistry of kangaroo scats, have also been considered. The aim of the research has been to develop the application of biogeochemical sampling media for use in mineral exploration and environmental chemistry programs.

The sampling media has been tested for both regional and local-scale exploration programs. Regional sampling media typically have a widespread distribution across large areas and occur within a range of regolith-landform settings or within a widespread regolith-landform setting (e.g. major drainage channels). They also derive their biogeochemical signatures from broad areas either through amalgamation across a large area (such as extensive root systems), or from a substrate that is an amalgamation of regional chemical signatures (e.g. stream sediments). These attributes produce regional sampling media that derive biogeochemical signatures from broad areas and can be collected at widely-spaced intervals. Examples of regional sampling media characterised in this research include river red gums, *Acacia* (wattle) trees and shrubs, and macropod (red and western grey kangaroo) scats.

River red gums form riparian woodlands along many of the drainage lines in the region. Their root systems extend for many 100s of metres laterally and 10s of metres vertically, where they may interact with regolith substrates (mainly stream sediments), shallow aquifer systems and underlying bedrock. A river red gum leaf sampling survey has been conducted along Pine Creek, extending past the Pinnacles Mine, west of Broken Hill. The very high Pb content (over 300 ppm) in the leaves near the Pinnacles Mine and the exponential decrease in Pb contents towards background levels (below detection limits) downstream, are typical of the results that would be expected if this chemical signature reflects downstream dispersion within the stream sediment substrate. Recent excavations have now found a continuation of the mineralised lodes to immediately underlie the tree with exceptionally high Pb contents.

Two of the best examples of plants that derive chemical signatures from bedrock underlying shallow transported regolith are prickly wattles (*Acacia victoriae*), and mulgas (*Acacia aneura*) near Broken Hill. In these cases, the surface regolith materials typically have a poor chemical signature of the underlying bedrock, but the trees have ‘penetrated’ this shallow (< 5 m thick) regolith and contain chemical signatures indicative of the underlying bedrock. This characteristic is extremely important for mineral exploration programs based in areas with shallow transported regolith. It supports the use of these trees as sampling media ahead of using surface regolith materials and more expensive drilling and costean digging.

This region has hosted some very detailed study by ecologists, who have been trying to understand the behaviour of kangaroos better, including their grazing preferences and home-range (via radio tracking). Based on some of the results from this ecological research, sampling of scats from red and western grey kangaroos has been undertaken on an approximately 5 km sample spacing across large parts of the region. The assay results show high contents of Pb, Cd and Zn in the vicinity of major mineralisation at Broken Hill and the Pinnacles. These chemical signatures reside within the macerated vegetation fraction of the scats, but it is unclear whether the high assay results centred on Broken Hill are detecting a centre of mining and previous smelting, or if they represent a natural chemical ‘footprint’. These results show potential for being able to:

- be used as a regional chemical sampling media across large parts of Australia, to detect mineralised provinces or chemical pollution;
- reflect chemical background levels of important trace metals (e.g. at the very least the results so far show a measure for the environmental metal enrichment in the Broken Hill landscape); and,
- show that, if macropod droppings are included in surface regolith samples, they may account for some of the trace metal contents.

The results from this research have led to the development of several new and innovative biogeochemical sampling media and approaches that could be adopted in mineral exploration and environmental chemistry sampling programs, particularly based in areas with shallow transported regolith. Different biogeochemical media may be adopted for different roles including local and regional surveys, for combining otherwise heterogeneous chemical signatures with the regolith, or for penetrating transported regolith and expressing chemical signatures from the underlying bedrock.

SOIL GAS HYDROCARBONS (SGH) – PENETRATING PREDICTIVE GEOCHEMISTRY USING A FORENSIC INVESTIGATION WITH ORGANIC MINERAL SIGNATURES FOR MINERAL EXPLORATION

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Soil Gas Hydrocarbons (SGH) is a geochemical test that has successfully delineated gold, VMS and nickel deposits, and kimberlites as investigated in two CAMIRO collaborative studies. The alteration of historic C1 to C4 soil gas signals by the biosphere reduces their use in exploration. The ubiquitous nature of bacteria in near-surface environments and their ability to utilize or transform a wide range of organic compounds suggest the formation of more robust hydrocarbons. This SGH test uses B-Horizon soils as a collector of 162 heavier C5 through C17 hydrocarbons. Forensic pattern recognition has defined specific SGH signatures used as an exploration tool for buried targets.

MINERAL HOSTS FOR GOLD AND PATHFINDER ELEMENTS AT THE MOUNT GIBSON AND LANCEFIELD GOLD DEPOSITS, WESTERN AUSTRALIA

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Introduction

Exploration geochemistry in the deeply weathered terrain of Australia in areas of appreciable allochthonous cover requires a detailed understanding of anomaly formation processes and the mineralogical sites of elements at different scales. Building on previous bulk mineralogical and geochemical studies at the Mount Gibson and Lancefield gold deposits in Western Australia, we have performed detailed in situ microanalyses (electron microprobe and laser ablation inductively coupled plasma mass spectrometry) to determine the mineralogical-Au/pathfinder element associations within the regolith, more specifically, transported regolith at these sites.

Results

*Enterprise pit, Mount Gibson***.** At the Enterprise pit (300 km NNE of Perth), gold is hosted by mixed sulphide-bearing sheared meta-basalts. These are overlain by 20 m of bleached saprolite. In situ regolith is overlain by transported overburden principally consisting of two Tertiary and Quaternary sedimentary units. Slabby to pisolitic ferricrete is present in Tertiary sediments. The uppermost Quaternary sandy-clay unit is 3-4 m thick and has been subjected to calcification and silicification to produce calcrete and hardpans.

A bedrock sample contained Au (20 ppm), Ag (90 ppm), As (365 ppm), Zn (955 ppm), Cu (375 ppm) and Pb (1120 ppm). These elements are generally depleted in the saprolite, though localised concentrations associated with sub-vertical quartz veining and isolated ferruginised zones, do occur. The slabby and indurated ferricrete contains 585 ppb Au, and a white clay in-between slabby layer contains 110 ppb Au. Arsenic concentrations occur in areas of ferruginisation (20-50 ppm), even in the saprolite, and reach 85 ppm in slabby sediments. The silicified sediments and calcrete near the top of the profile yield little As but appreciable Au (130-435 ppb).

The *in situ* analyses identify areas of Au enrichment in the samples and, in most, the trend mirrors that of the bulk geochemistry, with As, Cu and Zn associated with Fe-rich areas. In the slabby ferricrete, As, Cu and Zn are present in minor hematite-rich clasts rather than in a dominant matrix of quartz, goethite, kaolinite and hematite. Alunite in the white clay between these slabby zones contains appreciable Au (1-2 ppm) together with Cu, As and Pb. In the uppermost sequence of hardpanised colluvium and calcrete, high concentrations of Au (1-10 ppm) are found in the calcareous matrix.

Lancefield gold deposit. This deposit, 8 km north of Laverton in Western Australia, is situated in a sheet flow plain. It is a mixed sulphide assemblage closely associated with chert within deformed ultramafic rocks. The saprolite is overlain by three sediments types; 1. Basal Permian fluvioglacial deposits (10-20 m thick), 2. Mega-mottled Tertiary palaeochannel clays (3-8 m thick) and 3. Quaternary colluvium and alluvium (0-2 m thick), locally hardpanised.

Bulk samples of saprolite contain Au (11-195 ppb), As (14-910 ppm), Cu (11-470 ppm) and Zn (44-450 ppm). Mottled Permian and Tertiary sediments were separated into Fe-rich and clay-rich components. Arsenic (65-900 ppm), Cu (21-130 ppm) and Zn (22-125 ppm) are enriched in the Fe-rich part of the Permian sediments. The same elements are also enriched in the Fe-rich parts of the Tertiary sediments, although not as strongly as in the Permian sediments, and depleted in hardpanised colluvium and alluvium.

In situ microanalyses of saprock and saprolite reveal that goethite after primary sulphides is enriched in As, Cu, Zn and Pb; whereas Cu is enriched in a chlorite-vermiculite interstratified mineral. Mottled Permian sediments contain anomalous As (up to 3,000 ppm), Cu (up to 630 ppm) and Pb (up to 145 ppm) in Fe oxides, with hematite preferentially hosting As and Pb, and goethite hosting Cu. Iron-oxides in the Tertiary clays are relatively depleted, as are the minerals within hardpanised colluvium and alluvium.

Summary.

Minerals precipitated from groundwaters in the upper sediments of regolith profiles could provide an interesting sample medium to search for hydromorphic dispersion from underlying, and deeply buried mineralisation. Alunite appears to be one such mineral occurring at the Enterprise pit, Mount Gibson that contains appreciable Au, Cu, Pb and As and could be more widely relevant.

At Lancefield, the dispersion of Au, As, Cu, Pb and Zn can be related to three weathering events and hydromorphic dispersion has played an important role in developing geochemical anomalies within Fe oxides in the Permian and Tertiary sediments. Careful in situ microanalyses of mineralogy and geochemistry provide a powerful approach to detect hydromorphically-dispersed element anomalies within transported overburden, particularly relevant for exploration in areas of deep cover.

NON-BARRIER BIOGEOCHEMICAL EXPLORATION FOR SILVER

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Non-barrier biogeochemical exploration (NBE) is based on sampling unusual plants or plant organs that accumulate metals at concentrations that are directly proportionally to the contents of the soil horizon from which the plant derives its nutrition. Silver appears to be the most informative ore element for biogeochemical exploration and mapping, having the largest number (1146) of plant bio-objects (i.e., parts and organs of various species of plants).

A 10 km^2 area in the southern part of the 300 km^2 Gil'bera deep-seated fault zone (GZDF) in western Siberia was explored for Ag by NBE for Buryatgeology, a state industrial geological organisation. The area had been prospected on four previous occasions, but this survey was based on a new method, the analysis of the ashed wood of rotten pine stumps (*Pinus silvestris*). During 1984-2001, Ag was determined in 28000 plant samples and more than 4000 lithogeochemical samples (soils, rocks, Ag ores and Ag-bearing zones) in the region surveyed. The survey found more than 250 local (1-8 m wide) 'supposed ore biogeochemical anomalies' (SOBA), with concentrations of 70-3000 ppm Ag (background 0.7 ppm), and thousands of anomalies exceeding local background by factors of 10-100. Trenching at 29 SOBA located Ag ore veins beneath 27 of them. The survey outlined 6 Ag-bearing stockworks, and indicated 5 others, indicating that the GZDF is a promising Ag province of national significance. Field standardization of anomalous plants containing 0.2 to 3000 ppm Ag showed that the plants obtain Ag from weathered bedrock at depths of 1.5-2.5 m or more, rather than the soil. Plant-rock coefficients and plant-ore coefficients for ores with low (10-100 ppm), moderate (100-1000 ppm) and high (1000-10000 ppm) Ag contents were determined. The maximum Ag concentrations in ashed wood of rotten pine stumps (1000-3000 ppm) corresponds to Ag-rich orebodies containing 1-6 kg/t Ag. Techniques for Non-barrier biogeochemical exploration and Non-barrier biogeochemical prospecting have been developed for landscapes of the south taiga region of western Siberia.

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ELEMENTAL DISTRIBUTIONS IN MINERALS AND SOILS BY MICROWAVE-ASSISTED CONTINUOUS LEACH ON-LINE WITH INDUCTIVELY COUPLED PLASMA TIME OF FLIGHT MASS SPECTROMETRY

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Introduction

Continuous Flow ICP-MS (CL-ICP-MS) permits the analysis of metals in real-time as they are leached with various reagents. This technique puts the sample directly in-line with the ICP-MS and permits the simultaneous analysis of trace metals and major elements, thereby allowing correlations between major elements released from specific phases to correlate with trace elements. In addition to complex spectra, CL-ICP-MS also requires analytical times in excess of 1 hour. To decrease the analytical time, heating of the sample via microwaves can be used, but increased mass scan rates of the ICP-Ms are required. ICP-Time-of-flight Mass Spectrometry (ICP-TOFMS) is designed specifically to analyze transient signals, with unrivalled scan rates. Thus, coupling of microwave heating of a sample with ICP-TOFMS may reduce the analytical time required to extract real-time leaching of samples used in exploration or environmental geochemistry.

Discussion

A novel technique to assess the distribution of elements in rocks and minerals based on successively leaching on-line with focused-microwave heating in combination with simultaneous multi-elemental detection through ICP-TOFMS allows the continuous monitoring of the release of elements by a given reagent reacting with a sample for analytical times of less than 15 minutes. Heating the micro-column to 90°C, using focused-microwave energy, significantly enhanced the release of analytes. Increasing the flow rate of reagents through the sample had an effect on the leaching profile, which was unavoidable due to the shorter contact time between the reagent and the sample. However, the simultaneous application of microwave energy, which increased the rate of dissolution, essentially compensated for the shorter residence time, yielding profiles fairly similar to those at low flow rate with a micronebulizer and ICP-HRMS. Sample throughput is increased in three ways: quasi-simultaneous detection with ICP-TOFMS, a higher flow rate and microwave heating of the reagents and micro-column of sample. Detection by ICP-TOFMS allowed the simultaneous monitoring of a greater number of elements, without increasing the analysis time or requiring the use of a micronebulizer. In contrast to the batch method, the elements are continuously removed from the system. As a result, the maximum amount of analyte that can be dissolved in a given reagent is measured in a short period of time.

Conclusions

Microwave assisted continuous leaching analysis using ICP-TOFMS has advantages over conventional batch methods, since it has shorter analysis time, it is simple to implement while providing real-time data on metal distribution and a greater resolution of the phases released by a given reagent. Detection by ICP-TOFMS also enables continuous monitoring of isotopic compositions which, in turn, allows identification of different sources of elements. The drastically shorter analysis time permits fast screening of samples, rendering this technique effective for exploration geochemistry and environmental studies.

TOWARDS AN ATLAS OF GEOCHEMICAL EXPLORATION MODELS FOR MINERAL DEPOSITS IN CANADIAN CORDILLERA

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Introduction

Geochemical exploration models (GEMs) address the challenge of interpreting large volumes of analytical and field geochemical data. Conceptual, three dimensional models clearly showing the relationships between mineralization and its geochemical response have been developed over the past thirty years from case histories in various parts of the world. These models have proved a valuable interpretational tool, but have generally been developed for specific landscapes largely independent of the type of mineralization present. GEMs can be improved by linking the geochemical signature of specific mineral deposit types (e.g., porphyry copper-molybdenum) as well as to their geochemical expression in different surficial deposits (e.g. residual, glacial sediment) and landscapes (e.g. alpine, boreal forest). While this greatly expands the number of models presented and therefore the number of reliable case histories to base these on, sufficient data are available for compilation of GEMs to be published as an atlas providing an exploration guide for different mineral deposit types in a variety of environments for the North American Cordillera. Geochemical data from the Ace property, a volcanogenic sulphide occurrence in central British Columbia, is used to demonstrate the type of Atlas model that will be used.

Methods

The Ace mineral property, located 425 kilometres northeast of Vancouver, British Columbia is in an area of moderate relief. Palaeozoic metasedimentrary and metavolcanic bedrock is covered by several metres of glacially transported sediment (till). Sulphide mineralized boulders contain up to several ounces per tonne of silver and up to 15.5 per cent lead, 0.6 per cent copper with anomalous arsenic, antimony, bismuth and selenium. Felsic volcanic bedrock with massive pyrite and pyrrhotite lenses has been exposed in trenches and by drilling. Extensive geophysical, stream sediment and soil geochemical surveys have been carried out by the property owner, Barker Minerals. The British Columbia Ministry of Energy and Mines collected 180 samples from vertical profiles in 70 pits on the property. The samples were screened into five size fractions and each fraction analysed for 37 elements including gold, copper, lead and zinc by an aqua regia digestion-inductively coupled plasma mass spectrometry.

Results

Distribution of copper, lead and zinc B soil horizon anomalies can be explained by the parent till geochemistry and hydromorphic dispersion of metals sub-parallel to the ice-flow direction. Zinc, in particular, accumulates in organic soil. Copper, lead, molybdenum, zinc and silver are most anomalous in the smallest (< 0.063 mm) size fraction of the samples. Gold values are higher in coarser size fractions (e.g. 0.5 mm – 0.25 mm) suggesting partitioning of free gold grains from sulphides and/or bedrock. Anomalous copper with elevated lead, zinc, selenium and thallium in till suggests a volcanogenic sulphide source for the metals. Glacial dispersal trains with anomalous gold are short, but anomalous copper can be detected in till for several hundred metres from an area underlain by an electromagnetic conductor. A GEM based on the geochemical data shows how the glacially displaced anomaly down-ice from the bedrock source has been modified by hydromorphic dispersion.

Conclusions

A geochemical exploration model (GEM) has been developed from soil and till geochemical data collected over the Ace property in British Columbia, Canada. The model summarizes in a very succinct and graphical way the geochemical response of the sulphide mineralization. In particular, it explains how both glaciation and the effects of hydromorphic transport influence dispersion of gold, copper and other elements. The important factors for using geochemistry correctly are far more readily understood when presented in this manner rather than in the original raw data. An atlas of these models broken down according to mineralization type would greatly assist the correct and efficient use geochemical exploration.

LITHOGEOCHEMICAL CONSTRAINTS ON THE HOST ROCK, HYDROTHERMAL ALTERATION AND WEATHERING OF THE GROUNDRUSH GOLD DEPOSIT

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A lithogeochemical study of fresh rock and weathered (regolith) material from the Groundrush gold mine, Tanami Region, Northern Territory, Australia has allowed definition of previously unrecognized lithological diversity, mineralization control and weathering behaviour.

Outcropping auriferous gold veins were discovered in 1997 via lag sampling, and 4.4 million tonnes of ore with an average Au grade of 4.4 g/t were mined from the Groundrush deposit by open pit methods between September 2001 and September 2004. Gold occurred within quartz veins and shear zones hosted by what was interpreted to be a metamorphosed and hydrothermally altered dolerite dyke intruding metasedimentary rocks (possibly Killi Killi beds) of the Lower Proterozoic Granites-Tanami inlier.

Petrographic examination of the host dolerites reveals that they have been metamorphosed, and presently consist mainly of albite, hornblende and quartz. Primary rock-forming igneous or alteration minerals and textures are not recognized.

Major oxide and trace element lithogeochemical data from drill core samples of visibly homogenous meta-dolerite beneath the ore-body indicate that a relatively geochemically homogenous diorite and a differentiated dolerite occur in the mine area, and that the former is the predominant host of gold mineralization. Diorite and dolerite samples exhibit significantly different conserved element ratios (e.g., TiO_2/Zr and P_2O_5/Zr), and the diorite exhibits higher SiO_2 and Na_2O, and lower CaO and MgO concentrations than dolerite.

Dolerite samples can be further subdivided into three sub-groups using molar Ni/Zr and (Mg + Fe)/Zr ratios. These three groups are spatially zoned, and thus are most likely to reflect different degrees of fractionation within the dolerite. Pearce element ratio (PER) diagrams indicate that the compositional variation within the dolerite can be attributed to the fractionation of pyroxene and plagioclase in sub-equal molar amounts.

Diorite and rare dolerite samples exhibit carbonate and sulphide alteration. PER diagrams plotting Ca/Zr vs CO_2/Zr and Fe/Zr vs S/Zr indicate that calcite and pyrrhotite are the minerals present. Neither Ca nor Fe appear to have been added to carbonatized or sulphidized samples, suggesting that only volatiles were added during alteration, and that the Ca and Fe were contributed to the alteration reaction via breakdown of primary igneous minerals within the diorite.

PER analysis indicates that negligible chemical variation exists in the diorite samples. What little variation does exist can be attributed to Si addition that is caused by the presence of quartz veins cutting the diorite. No K metasomatism accompanied hydrothermal alteration, but diorite samples exhibit evidence of minor Na and Ca loss. These observations suggest that the primary alteration minerals within the Groundrush deposit are likely to have consisted of chlorite, albite, pyrrhotite (or pre-metamorphic pyrite) and calcite.

In lithogeochemical samples of regolith, TiO_2/Zr ratios can also be used to recognize dolerite, diorite and basalt in a manner similar to that for the bedrock samples. PERs of mobile constituents in the regolith (e.g., Ca, Na, Mg, S, and C) diminish due to leaching toward the upper part of the regolith profile, whereas PERs of Si, Al and Fe are essentially unaffected by weathering. Sulphur and, to a lesser extent, C are depleted in the top 40m of the regolith profile, whereas Ca is depleted in the top

20m, and Na and Mg are depleted only near surface. In spite of these leaching effects, lithological classifications similar to those generated by the TiO_2/Zr ratios are generated by non-hierarchical (K-means) cluster analysis of the major element PER ratios/Zr

Pyrrhotite oxidation within the regolith profile at Groundrush is likely to have contributed significant acidity to the local groundwater via the reaction:

$$4FeS + 9O_2 + 4H_2O = 2Fe_2O_3 + \mathbf{8H^+} + 4SO_4^{2-}.$$

This acidity was probably buffered by reaction with carbonate via the reaction:

$$8CaCO_3 + \mathbf{8H^+} = 8Ca^{2+} + 8HCO_3^{-}$$

because the hydrolysis of silicate minerals was probably too slow to act as a significant buffer. The above equations indicate that the breakdown of eight moles of $CaCO_3$ are required to buffer the acidity generated by four moles of FeS. A PER diagram plotting S/Zr versus CO_2/Zr indicates that un-oxidized diorite samples have molar S/C ratios that are both greater and less than 0.5, indicating that these rocks were probably not significantly acid generating. As a result, gold grade distributions within the regolith profile suggest that only minor leaching of gold occurred, except within large quartz veins, where the absence of carbonate buffers allowed acidic conditions to predominate, and where species known to complex gold were present. These factors led to significant leaching of gold from the quartz veins.

ARSENIC MOBILIZATION FROM AN ABANDONED MINE SITE IN LEÓN PROVINCE (NORTHERN SPAIN)

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Las Viescas mine (León Province, Northern Spain) is located in the Riaño valley, which has been partially flooded for the construction of a dam for hydroelectric power production. The mine was operated by underground workings between 1940 and 1960, but since this time has been abandoned. A network of old galleries and chambers, two spoil heaps and remains of the smelting plant are the legacy of the old mining activity. The dam is situated downstream of the mine workings, and consequently mine drainage and spoil heap leachates flow to the dam. From a geological point of view, the area of the mine is included in the Cantabric Zone, in the southern slope of the Cantabrian Mountains. The orebody occurs as veins or masses in silicified limestone and as dissemination in the fractured rock, and it is composed of arsenopyrite, As-rich pyrite, marcasite, estibnite, bravoite and realgar, in a gangue of quartz and carbonate. The mine spoil heaps contain abundant presence of arsenopyrite and other sulphides, including pyrite and marcasite. The supergene geochemical processes developed in the mine wastes cause the dissolution of As and its transport to the dam and/or precipitation in soil. The area of the catchment affected by the old mine workings is 43 ha, and the water flow in the mine catchment is 241. 10^6 litres/year, which comprises 0.07 % of the total water flow to the dam. Total arsenic in the surface horizon of the soil ranges from 155 mg.kg^{-1} to 23,810 mg.kg^{-1}. The total arsenic content in surface water ranges from 33 μg.l^{-1}(upstream of the mine) to 900 μg.l^{-1} downstream the mine.

The analytical data show a geochemical anomaly at the mine site in soils and surface waters, so a non-negligible As contribution to the dam is occurring.

GASEOUS GEOCHEMICAL EXPLORATION AT THE SITE OF ABANDONED MERCURY MINES IN NORTHERN SPAIN

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Volatilisation is an important process for the release of Hg into the atmosphere from natural sources, such as mineral deposits and volcanoes, and from a great variety of anthropogenic sources, including fossil-fuel combustion, incineration, mining and smelting. In general, areas surrounding Hg deposits are naturally enriched in this metal, and the magnitude of the Hg release to the atmosphere is governed primarily by the Hg concentration in the substrate and/or in the anthropogenic source such as mine wastes and smelting operations. Elemental mercury is the dominant form, as mercury is emitted into the atmosphere and is slow to oxidise to more soluble species. Particulate form occurs too. Mercury, once emitted to the atmosphere, can be dispersed over a large geographical area. It can be directly deposited to sensitive ecosystems or remain suspended in the atmosphere, where it is subject to a very complex chemistry. In the average data compiled from the specialised bibliography, representative values of atmospheric mercury concentrations are greater than 10 $\mu g/m^3$ in mine waste storage areas (spoil heaps). In the area of study in northern Spain, which was an old Hg mining and metallurgical site, the total mercury concentrations in the atmosphere reach up to 202.7 $\mu g/m^3$ on the abandoned mining/smelting site, and up to 0.89 $\mu g/m^3$ in nearby urban areas. In the case study corresponding to a historical mine/metallurgical site, the local mercury background level in the atmosphere increases to 30 times the general background level of the area. The application of simple portable equipments was used to delimit anomalous areas in order to asses the potential risk that high atmospheric mercury concentrations represent.

GEOCHEMICAL EXPLORATION OF MINERAL DEPOSITS UNDER GLACIERS

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Introduction

It is known that chemical composition of glaciers depends on climatic factors and that glaciers are an unique depository of information concerning the change of atmospheric chemical composition. Geochemical studies of glaciers in Central Tien Shan has demonstrated the existence of local geochemical fields, the formation of which are largely independent of climate.

Results

The formation of local geochemical fields (LGCFs) in glaciers is due to presence of considerable geochemical heterogeneity and geochemical processes in underlying rocks, which cause the cryogenic migration of chemical elements and compounds in ice. Migration of substances in glaciers takes place through liquid-like films that envelop ice crystals in negative or close to 0^o temperature. LGCFs are found in various types of glaciers: valley and hanging glaciers, warm and cold ones.

The composition of a LGCF is characterized by qualitative (chemical components and compounds) and qualitative (elements concentration, parameters of geochemical fields) indices that depend on geochemical features of underlying rocks and are naturally spread through the glacier and at its surface.

The vertical manifestation of LGCFs can theoretically reach hundred of metres, although their ascertained thickness in Tien Shan is restricted by ice thickness of the observed glaciers – 134 m. As a rule, LGCFs at the glacier surface are situated above the source of anomaly that underlie the glacier, and are insignificantly displaced in the direction of glacier movement - with movement of the Tien Shan glaciers being dozens of metres a year.

The subvertical migration of chemical elements in glaciers has considerable penetrating power through ice. It can lead to the formation of anomalies in chemical elements above zones of geochemical heterogeneity in rocks (such as ore bodies and tectonic zones) and allow the exploration of mineral deposits that are covered with glaciers. A method for exploration for mineral deposits under glaciers is suggested.

Conclusion

The use of geochemical exploration in Central Tien Shan has allowed observation of the position of ore bodies under glaciers and discovering ore bodies that were covered by ice of dozens metres thick.

NUTRIENT CHARACTERISTICS OF SOILS FROM THE MARGARET RIVER WINE DISTRICT

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The climatic and geological factors believed to contribute to the location of, and the quality of wine produced in, a number of the world's great wine growing districts are well documented. Despite the fact that the nutrient requirements for vines are well known, very little work has been done to examine the role of soils, and the nutrient characteristics thereof, in these same wine-growing districts.

Margaret River is a relatively new, premium wine-growing district located in the south-western corner of Australia. It has a climate considered to be very similar to that of some of the famous wine-growing districts of Europe. The predominantly granite-gneisses of the region have undergone extensive weathering including lateritization. Soils also show the presence of coastal marine (calcium carbonate) sands, up to 5-10 km inland, due to aeolian processes.

A number of virgin roadside (i.e. unfertilized and un-contaminated) soils have been analyzed by both partial digestion analysis and total analysis to investigate their nutrient characteristics. The results of the partial digestions show that soils with moderate to high concentrations of mobile (available) forms of Ca, Mg, K and Fe correspond closely with the locations of vineyards, and with stands of largest marri trees, *Eucalyptus callophylla,* which were used initially to locate many of the vineyards. A multiplicative factor involving these four elements best shows the distribution of the most nutrient-favourable soils. Analysis for the same elements after total digestion does not show this same correspondence.

It is believed that Ca is ultimately derived (predominantly) from the marine sands, Mg and K from the weathering granites, and Fe via processes akin to lateritization. This exercise shows that low density geochemical sampling of virgin soils followed by partial extraction and analysis can provide useful regional information about soil nutrient status.

SELECTIVE LEACH GEOCHEMISTRY OF SOILS OVERLYING KIMBERLITES, NORTHEASTERN ONTARIO, CANADA

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Studies were carried out by the Geological Survey of Canada and the Ontario Geological Survey at the B30, A4 and 95-2 kimberlites in the glaciated terrain of northeastern Ontario, Canada, to evaluate the effectiveness of selective leaches for detecting soil geochemical signatures over deeply (>30 m) buried kimberlites. In this region, subcropping Jurassic kimberlites were covered by up to 60 m of glacial sediments deposited approximately 9000 years ago and soil-forming processes have been active since then. Two selective leaches, ammonium acetate pH 5 (AA5) and Mobile Metal Ions (MMI-D-commercial leach), were used along with aqua regia to detect and evaluate the geochemical signature in mineral soils over the kimberlites. Sampling was carried out using a depth-based protocol of 10 to 20 cm, regardless of mineral soil horizon, to test the suitability of the depth-based approach to glaciated terrain. The strongest geochemical responses in soil were detected over the A4 and 95-2 kimberlites, where mineral soils were most consistent and free of organic matter. Pathfinder elements for selective leaches applied to mineral soils over the three kimberlites include: elevated concentrations of Ba, Co, Mg, Mn, Ni, Pb, REE, Sr, Ti, Ca, Cu, Cd, I, Na, and U, and depletions of Al, Cr, Fe, Rb and Th. When used in conjunction with other exploration methods, a strong kimberlitic response from soil selective leaches can assist in the identification of deeply buried kimberlites in glaciated terrain.

GEOCHEMICAL EXPLORATION MODELS FOR REGOLITH-DOMINATED TERRAIN IN WESTERN NEW SOUTH WALES

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Introduction

The majority of known ore deposits in western New South Wales have been discovered at or close to the surface, in erosional landform settings. A few have been found obscured by relatively thin transported cover or in areas of deeper, partly leached *in situ* regolith, usually by using geophysical techniques. There are large tracts of highly prospective terrain with deeply weathered or transported regolith where no discoveries have been made. A key to successful exploration in these areas is the development of robust exploration models that integrate geochemical and geophysical techniques within a regolith-landscape evolution framework. This study of the Cobar-Girilambone region of western New South Wales has developed an approach to constructing such "regolith smart" geochemical exploration models.

Methods

The Cobar-Girilambone region hosts significant hydrothermal copper, gold and lead-zinc-silver mineralisation. It is mantled by a cover of highly variable thickness (up to 200 m) containing regolith units typical of large areas of western New South Wales. Regolith-landform mapping across the region was integrated with information from air core drilling traverses (247 holes) and regional geophysical data sets to establish the surface distribution of different regolith materials and the 3D regolith architecture. This information was combined with regolith dating to construct a landscape evolution model. This model provided a framework to interpret the regolith history and associated geochemical dispersion pathways related to hydromorphic and detrital transport processes.

Regolith samples (about 4300) from drill profiles and the surface were subjected to multi-element geochemical analysis using "total"digest ICP OES/MS, XRF and partial extraction techniques. Multivariate analysis of the geochemical data and element ratio techniques were used to determine the major compositional characteristics of the different regolith materials as well as to assess the level of background variation for target and pathfinder elements and establish element associations related to normal regolith-forming processes. Detailed mineral-chemical analysis was used to identify the different regolith host minerals for key trace elements. This background information was combined with data from areas of known mineralisation. Geochemical exploration models were then devised to predict appropriate sampling media, element dispersion/fixation behaviour and threshold values for different regolith types and for different landscape/palaeolandscape settings.

Results and discussion

Integration of petrographic, mineralogical and geochemical data for representative regolith profiles has established the compositional characteristics of the main regolith types. Key major element parameters are the relative proportions of Al (reflecting kaolinite), K (reflecting muscovite-sericite), Mg (reflecting chlorite and Mg-bearing clays) and the Fe content (reflecting degree of ferruginisation). Ratio element plots (e.g. Mg/Al vs K/Al) are useful for first order chemical discrimination of the different regolith materials. This characterisation can help in defining trace element variability related to different regolith histories and source rocks.

Four major regolith-generated associations of target and pathfinder elements have been identified from the background/baseline sites across the Cobar-Girilambone region:

- an "evaporitic" association of Ca-Mg±Au, in some cases with Ba-Sr, related to carbonate and sulfate accumulations in the near-surface regolith and at the base of palaeochannels and transported regolith;

- an association of Mn-Co-Zn±Ni-Cu±Au developed in redox boundary accumulations of manganese oxides/oxyhydroxides, commonly at around 20-30 m and also at the present, deeper water-table;
- an association of Fe-Cu-Zn with goethitic accumulations in the ferruginous mottled zones of the regolith;
- an association of Fe-As-Pb±Sb±Bi with hematite, particularly in ferruginous lag, palaeochannel sediments containing ferruginous lag and in hematite-rich mottles in the upper saprolite.

These regolith-controlled element associations can account for much of the background variation encountered when sampling the regolith of the region. Geochemical templates have been constructed for different regolith materials that identify trends in multi-element relationships reflecting mineralised environments as distinct form normal background regolith concentrations and variations.

The regional landscape evolution model has proved critical for linking site specific regolith geochemical profiles into a true 3D geochemical exploration model. It also highlights palaeodrainage and catchment evolution, allowing prediction and interpretation of element dispersion vectors.

Conclusion

The aim of geochemical exploration models is to advise the most appropriate strategies and procedures for geochemical exploration. To be effective in regolith-dominated terrains, these models must incorporate the relevant regolith parameters and take into account the regolith-landscape evolution and its effects on element dispersion processes and pathways. Such models are best devised by taking an holistic approach that integrates knowledge of the regolith architecture, mineralogy, geochemistry and geophysics as well as the history of landscape development.

DOWNHOLE TRACE AND MAJOR ELEMENT CHEMOSTRATIGRAPHIC PATTERNS RELATING TO IGNEOUS FRACTIONATION PROCESSES IN THE GOLDEN MILE DOLERITE, WESTERN AUSTRALIA

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The largest gold mine in Australia is the Fimiston Superpit, located in the Golden Mile Camp, Kalgoorlie, Western Australia. This mesothermal gold mine is jointly owned by Barrick Gold Corp. and Newmont Mining Corp. through Kalgoorlie Consolidated Gold Mines. The main host to mineralization is the differentiated Golden Mile dolerite, a sill up to 940 m thick. Previous research has subdivided the Golden Mile dolerite into ten units based on mineralogy, primary igneous texture and iron/titanium oxide mode and morphology. The area is structurally complex and boasts several deformational events. Zones of intense hydrothermal alteration with concurrent obliteration of primary igneous textures are common. These factors have made chemostratigraphic studies of the intrusion important for determining stratigraphic position within the sill, constraining structural reconstructions of the camp, and identifying deep exploration targets.

Distinct downhole molar element ratio geochemical patterns in both major and trace elements have constrained a set of igneous differentiation processes responsible for the mineral mode and textural diversity of the sill. (Al/2+Na/2)/Zr and (Ca/2+Fe/2+Mg/2-Al/4+Na/4)/Zr molar ratios that specifically track the addition or loss of plagioclase and pyroxene exhibit patterns that allow recognition of pyroxene cumulates in the lower units of the sill, despite the textural ambiguity created by subsequent hydrothermal alteration.

A major lithological discontinuity associated with the introduction of magnetite to the liquidus assemblage occurred at the base of Unit 6. Differences in shapes of the Ti/Zr and V/Zr downhole patterns give insight into the chemical controls that influenced the distribution of these elements in the magma chamber. Vanadium has a higher magnetite-melt partition coefficient than Ti. The steeply-decaying V/Zr downhole pattern reflects the rapid depletion of V from the magma chamber as it strongly partitioned into the fractionating magnetite. The 'box'-shaped downhole depletion pattern observed for Ti/Zr is a consequence of the coupled substitution of Ti with ferrous iron in the magnetite-ulvospinel phase.

Additionally, the downhole plots of base metals (Cu/Zr, Zn/Zr and Ni/Zr) exhibit enrichments that coincide with magnetite saturation. However, detectable concentrations of these elements are not observed in magnetite. They reside in anomalous concentrations of disseminated sulphide minerals (chalcopyrite and pyrite) in the magnetite-bearing portion of the sill. The presence of these co-occurring sulphide minerals with magnetite likely resulted from liquid immiscibility of a sulphide melt triggered by the saturation of magnetite in the magma chamber.

In summary, chemostratigraphic patterns observed in ratios tracking the material transfers of major elements and igneous minerals, and ratios responding to trace element partitioning of V, Ti, Cu, Ni and Zn into magnetite and an immiscible sulphide liquid, reveal new information about the igneous evolution of the Golden Mile dolerite. These patterns facilitate confident recognition of stratigraphic level in deep exploration drill cores, despite subsequent hydrothermal alteration effects.

PHYSICAL PROPERTIES OF SEDIMENTS DEPOSITED FROM THE WATERS OF A CLOSED COAL MINE

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Introduction

The Chikuhou coalfield, situated close to the Onga River in the Chikuhou region of the northern part of Fukuoka Prefecture, Kyushu Island, was once an important Japanese coal producer. The colliery is now closed and waters derived from the mine enter the nearby river via springs. These "spring waters" from the mine are highly coloured and locally called "red water". The mine water generally has a high electrical conductivity and contains high concentrations of dissolved iron and sulfate ions. In consequence, the water from this river is isolated and not included within the water resources of the area for agriculture and other purposes. It is only used for emergencies, such as fire fighting. In this study, we have investigated the river sediments, focusing on those deposited from red water.

Methods

In this study, samples of water and suspension were collected on many occasions. The sediments were examined for basic mineralogical and chemical composition by X-ray powder diffraction (XRD) and X-ray fluorescence (XRF). The morphology of the bacterially-precipitated Fe oxide suspension "Akamizu" has been undertaken by scanning electron microscopy and the surface areas of samples obtained by the BET method. Pore distribution curves of each pollutant in "Akamizu" were calculated by the B.J.H. method following measurement by a Thermo Quest SORPTOMATIC 1990 series instrument.

The water was analyzed by ion chromatography for cations such as NH_4^+, Na^+, K^+, Mg^{2+} and Ca^{2+} and anions such as Cl^- and SO_4^{2-}. Other measurements included the local site water temperature, electrical conductivity (EC), pH, biological oxygen demand, dissolved oxygen, Mossbauer spectroscopy, colon bacilli and total dissolved solids.

Results and discussion

We focused on two localities, Sensui and Namazuta, which have different features. Water and suspended solids were collected at each point of outflow and where the suspension occurred as "Akamizu". Waters at Namazuta have higher pH and turbidity than at Sensui, and the higher acidity at the latter results in higher Fe ion content.

XRD analysis indicates that the suspended material at Sensui contains poorly crystalline schwertmannite ($Fe_8O_8(OH)_{8-2x}(SO_4)_x$), which is dominantly colloidal, from a combination of iron hydroxides and sulfate. Feroxyhite (δ-FeO(OH)) is also present, but the crystals do not grow.

Pollutants at the two sites are recognizably different, with those at Sensui being richer in sulfate and poorer in silica, whereas those at Namazuta are richer in iron oxides. They have a pore size of about 1 nm and the surface morphology of the crystals is rougher at Sensui than at Namazuta. Because of the low degree of crystallinity, we cannot identify the precise crystal structure as of amorphous phase by XRD. However, Mossbauer spectroscopy shows that the Fe(III) elements consist of octahedra and indicates the coordination number as 6.

We consider that the oxidizing bacillus in the mine waters is more active at Sensui, because the surface of the river becomes redder downstream and generates considerable "Akamizu" pollutant. Therefore, it is thought that, over a long time period (semi-permanently), the oxidation of ferrous ions continues to exchange slowly and the value of EC may now be constant. At Namazuta, after rapid oxidation, the pollutants settle more slowly.

Conclusion

As the result of this experiment, we have found that "Akamizu" waters at Sensui and Namazuta have high concentrations of Fe^{2+}, Fe^{3+} and SO_4^{2-}. Ferrous iron is oxidized to becomes Fe^{3+}, precipitates and appears as a reddish suspension. However, where the pH is low, the solubility of Fe^{3+} is higher and is not readily precipitated. We have also found that "Akamizu" has higher concentrations of cations and anions derived from the contained mine waters that have flowed continuously into the Onga river since the mine closed.

THE 'ABC' OF REGOLITH: ATTRIBUTES, BIOTA AND THEIR (LANDSCAPE) CONTEXT

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Introduction

The best way to characterise the regolith, in a mineral exploration or natural resource management program, is to first examine the describable features of the surficial landscape, such as surface materials, vegetation, biota and the landform expression. To then find efficient, economical, and accurate methods for determining the 3D architecture of regolith-dominated landscapes is a major challenge for regolith researchers and their stakeholders. By developing a surficial surrogate for this parameter across the landscape, there is potential for these features to be related to the underlying regolith.

Mineral explorers are looking at areas of more extensive regolith thickness, as their focus shifts away from the shallow cover/bedrock-dominated terrains. For these explorers, the ability to delineate areas of different transported regolith thicknesses economically and accurately would be of great value, as would innovative geochemical sampling techniques in areas of transported overburden.

Approach to research

The association between regolith materials and landform expressions can be readily represented on regolith-landform maps. By relating multiple surficial attributes to the 3D regolith architecture, it is proposed that surface regolith attributes and landscape expression can then be used to predict the depth of regolith in other areas. A further implication of this technique is that chemical connections between the landsurface and buried materials may also be identified, including the processes that drive the formation of surface geochemical and biogeochemical anomalies.

Many attributes may be noted in regolith-landform mapping, before a regolith-landform unit is assigned to a particular location. In a similar way, a multi-variate approach is taken to address how we can characterise the subsurface regolith geology and geochemistry. Three main surficial regolith attributes shall be defined and developed, and may be closely associated with defining the "z-parameter" (depth) of the regolith or as a geochemical exploration medium:

- surface regolith materials;
- landform expression; and,
- biota (such as termites).

Fieldwork for this research project has been undertaken in 2 important mineral regions of Australia: the Tanami Desert (NT/WA), and the Curnamona Province (NSW). In both regions, mineral exploration has been hampered by the extensive regolith. In the Tanami Desert, collaboration with other researchers has allowed a cross-pollination of ideas, exemplifying the usefulness of such an approach to mineral exploration. Geochemical sampling of termite mounds, in conjunction with biogeochemical and groundwater sampling, has potential to become a very reliable and economic means for exploring in regions of significant cover. This technique will be explored further during follow-up fieldwork.

Discussion

An easily overlooked feature of Australia's vast, regolith-dominated terrains is the landscape history and/or surface attributes of any one site or mapping area. Important controls on the effectiveness of this approach will largely depend on the sedimentary and erosion history of a given site, and to some extent the complexity of the underlying regolith materials.

The surface expression of landforms allows for morphological characterisation, and their relationships to certain regolith materials therefore provides some 3D regolith information. Plants are well known to have close relationships with the underlying regolith substrate. They can develop both physical and chemical associations with subsurface regolith materials, with above-ground organs of a plant connected to the underlying regolith via plant tissues. This relationship is exploited in many biogeochemical-geobotanical studies, but also has the potential to reveal significant information about subsurface regolith materials and thicknesses.

The links between fauna and regolith thickness are less well known but have enormous potential to reveal many things about the subsurface regolith. Burrowing organisms such as termites and ants interact directly with subsurface regolith materials; therefore, their distribution, abundance and surface structures (termite mounds, for instance) could be closely related to regolith thickness if they are better understood. Biota in the regolith could possibly even be used as sampling medium in biogeochemical exploration strategies, in the future, once a framework is established. Ongoing work in the Tanami Desert is focussed on the role of termites in the regolith, and the use of termite mounds for geochemical prospecting.

Conclusion

Single techniques have been applied and tested in an attempt to estimate regolith thickness, however few have combined the expressions from different attributes. A multi-disciplinary approach is therefore proposed, where the characteristics of a range of attributes are used in combination to provide an efficient and accurate determination of the regolith thickness that may be used at both the prospect and regional scale, with possible mineral exploration uses also.

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APPLICATION OF S ISOTOPES TO DISCRIMINATE BETWEEN BARREN AND MINERALISED MASSIVE SULPHIDE DEPOSITS NEAR FLIN FLON, MANITOBA, CANADA

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Introduction

The Flin Flon Belt in northern Canada is one of the largest Paleoproterozoic VHMS districts in the world. Copper-Zn mineralisation is known all along the exposed Flin Flon Belt, but up to 20,000 km^2 of prospective Paleoproterozoic basement is buried beneath 10 to 100 m of Phanerozoic cover. The recent acquisition of airborne geophysics south of the Flin Flon Belt initiated a new era of exploration in the area and the large number of geophysical anomalies identified, required drill targets to be ranked. Owing to the short field season, many targets were drill tested once and follow up drilling was only warranted when Cu-Zn massive sulphide was intersected. Realising that currently producing mines in the Flin Flon and Snow Lake area contain both mineralised and barren massive sulphide zones, a S isotope study was undertaken to ascertain if the two contrasting styles of mineralisation could be geochemically discriminated. Specifically, could any of the drilled barren massive sulphide intersections have been a near-miss?

Process

Four mineralised and 8 barren sulphide deposits were investigated and compared with historical data. The mineralised deposits comprise pyrrhotite, pyrite, chalcopyrite, sphalerite and galena, and include the Trout Lake and Triple 7 mines and the Harmin and Talbot prospects, each containing between 3 and 61 million tons of >5% Cu-Zn ore. In contrast, the barren sulphide deposits comprise only pyrite and pyrrhotite, with maximum Cu and Zn contents over 1.3 m being 0.13 and 0.35 % respectively.

Results and discussion

Sulphide separates from the 4 mineralised deposits have $\delta^{34}S$ values that range between -1.4 and 6.4 ‰, indistinguishable from $\delta^{34}S$ values between –1.1 and 6.0 ‰ from the nearby, but historic, Osborne Lake Cu-Zn deposit. At the Trout Lake deposit, sulphides from mineralised Cu-Zn sulphide horizons have $\delta^{34}S$ values from 1.8 to 3.5 ‰, which is indistinguishable from pyrite and pyrrhotite extracted from barren massive sulphide zones (–1.4 and 6.4 ‰) that also reside within the deposit. 95% of the mineralised samples have $\delta^{34}S$ values between –1.4 and 3.3‰. In contrast, pyrite and pyrrhotite separates from the eight barren Fe sulphide deposits have $\delta^{34}S$ values between 1.8 and 10.0‰, which compares well with historic $\delta^{34}S$ values between –0.7 and 9.8‰ from thirty-six barren Fe sulphide deposits near Flin Flon and Snow Lake. Some barren sulphide $\delta^{34}S$ values overlap those from the mineralised deposits, but 69% of these $\delta^{34}S$ values are >3.3‰. Notably, this does not consider the fact that the historic data did not discriminate barren sulphide deposits from weakly mineralised showings, nor does it assume that any of the eight barren sulphide conductors could belong to a mineralised system, both attributes that would skew the data to lower values. These results imply that the barren Fe sulphide deposits can be statistically distinguished from Cu-Zn-Fe-sulphide mineralization based on S-isotopic composition alone. Application of this criteria to the database reveals that at least one drill hole currently identified as a barren Fe sulphide deposit could be re-evaluated as a potential "near-miss", based on the fact that all six samples analysed from this drill hole have $\delta^{34}S$ values between 2.1 and 3.3‰, identical to the majority of $\delta^{34}S$ values from the mineralised deposits.

GOLD AND ARSENIC UPTAKE AND SEQUESTRATION BY *EUCALYPTUS SALMONOPHLOIA*: TWO POSSIBLE PHYTOTRANSPORTATION MECHANISMS OF METALS TO THE SURFACE

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In Western Australia and the Northern Territory, anomalous gold concentrations in soils are known to occur over bedrock gold mineralization and its overlying *in situ* regolith profile. However, in areas where significant thicknesses of Au-barren, fluvially transported sediments mantle the *in situ* anomalous regolith and bedrock Au mineralization, Au anomalies still sometimes occur in surface soils. A possible mechanism that could explain how this Au was transported to the surface through the barren overburden involves uptake by tree roots at depth, translocation of gold to the leaves through the tree's vascular system, senescence (leaf drop) and subsequent decay and accumulation of Au in the soil over time.

Eucalyptus salmonophloia is a Western Australia tree that can grow deep (tap) roots to access groundwater from a deep water-table created by dry conditions, and so is a candidate tree to determine the extent to which Au can be taken up by tree roots, and translocated to the surface into leaves. As a result, 200 *E. salmonophloia* plants were grown from seed in a laboratory greenhouse for 10 months, and dosed with a range of concentrations of Au and As under controlled conditions for the last 3 months. The soil and plant Au and As concentrations were then measured after harvesting. Interference of Au and As uptake by As and Au was investigated by measuring element concentrations in plants and soils using dose experiments involving As without Au, Au without As, and Au and As together. In addition, plant organs (roots, stems and leaves) were analysed to determine whether Au or As accumulated in specific plant tissues. Microscopic plant tissue samples were examined, after suitable preparation and staining, to determine whether the metal doses induced microstructural tissue anomalies within the plants due to toxicity effects. Finally, microbial cultures of the soil and root environment (rhizosphere) were obtained to assess whether the element doses favoured specific bacteria or fungi, and to determine the extent to which the microbes controlled the uptake of Au and As.

Results indicate that Au and As were taken up by the roots of *E. salmonophloia* and reached significant concentrations in as little as 3 months. Linear relationships between element concentrations in the soils and plants indicate that these processes were largely passive, and that *E. salmonophloia* lacks mechanisms to specifically control Au and As concentrations in its tissues. Unfortunately, the bulk of the Au and As taken up by the plants remained in the roots, and did not get translocated into the leaves. Nevertheless, in spite of the relatively low concentrations, the amount of Au in the leaves is adequate to conservatively explain the development of 50 ppb Au anomalies in soil via leaf drop in as little as 200 years. Furthermore, given the significantly higher concentrations of Au in the roots, translocation of Au from deep (tap) roots (used primarily to obtain water during dry periods) into shallow adventitious roots (used primarily to obtain nutrients, and water during wet periods), followed by the subsequent death and decay of the adventitious roots, is adequate to explain the development of 50 ppb Au anomalies in soil in as little as two years. As a result, two mechanisms of phytotransportation of Au and As to the surface are recognized by this study, and both represent feasible explanations for the anomalous Au concentrations observed in surface soils developed over barren overburden. Although translocation to leaves, followed by senescence, is a well accepted process, the root translocation mechanism has not been described previously. This root translocation mechanism can be expected to produce a geochemical anomaly that is less widespread than that produced by leaf translocation and senescence. This is because the concentration of gold in soils via root accumulation would produce a geochemical anomaly immediately above underlying gold mineralization because the Au-bearing roots would remain in situ, whereas the Au-bearing leaves could be distributed substantial distances by wind after senescence, and thus could produce a widespread, and diluted geochemical anomaly.

Finally, As uptake into the roots was extreme, and average As concentrations in the roots commonly exceeded those in the soil! This suggests that *E. salmonophloia* could remove labile As from a soil, and thus may have potential as an important phytoremediation agent, provided the plant eventually translocates the As from the roots into its above-ground tissue.

DEVELOPMENT AND UTILIZATION OF A NATIONAL GEOCHEMICAL DATABASE

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Introduction

The Geologic Discipline of the U.S. Geological Survey (USGS) has had a long history of collecting and analyzing earth materials. Samples of rock, mineral, soil, sediment, water, vegetation and even animal tissue have been analyzed while researching topics in mineral deposits, petrography, mineralogy, geologic mapping, alteration, geochronology, mineral resources, energy resources, health and the environment. In the 1960s, with the advent of computers, sample information and resultant analytical data began to be saved in database files for possible future uses. As time passed and political administrations, philosophies, laboratories, analytical methods and personnel changed, this early database structure evolved into a series of incompatible geochemical databases within the USGS. Potential users needed to become familiar with the intricacies of USGS thought, projects, and methods just to find, retrieve and understand the data.

Process

The National Geochemical Database (NGDB) project began with the ambitious goal of taking the historical USGS geochemical databases. plus the inherited geochemical database from the U.S. Department. of Energy’s National Uranium Resource Evaluation (NURE) program, and combining them all into a single format. This single database was also envisioned to be compatible with new analytical data being produced in Survey laboratories. Although simple in concept, this process became increasingly complex as the different databases were merged and, once more, political administrations, philosophies, laboratories, analytical methods and personnel changed.

Discussion and conclusion

Although not yet complete and fully functional, the NGDB currently stores almost 2 million sample records and 39 million analytical determinations. A conservative estimate of the value of these data ranges from 1 to 1.5 billion US dollars. In addition to the database, the USGS has archival splits of most of the samples making up the NGDB, thus affording the opportunity for reanalysis to determine elements not originally analyzed or to determine elements by improved analytical techniques. Efforts are underway to increase, verify and correct data in the NGDB, and to make these data readily available on CDROM, DVD and through on-line access. Selected subsets of the NGDB are currently being served on-line and with no charge at http://tin.er.usgs.gov. The National Geochemical Database project also offers valuable lessons on how and how not to handle geochemical databases.

OPTIMIZING GEOCHEMICAL THRESHOLD SELECTION WHILE EVALUATING EXPLORATION TECHNIQUES USING A MINIMUM HYPERGEOMETRIC PROBABILITY METHOD

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Recently, Stanley devised a way to use hypergeometric statistics to establish a quantitative measure of performance of a geochemical exploration technique over a known mineral showing. Using this method, the effectiveness of new exploration techniques can be compared with conventional exploration approaches in an objective manner, allowing the mining industry to identify the most efficient exploration technologies to discover new mineral deposits.

The performance evaluation approach is applied to geochemical orientation surveys, and requires prior knowledge of the location of mineralization and a model for element dispersion from the primary into the secondary environment. This information allows assignment of which sample sites should be considered as ‘anomalous’ or ‘background’ in the orientation survey. This sample site classification represents the foundation against which the survey results are compared. Frequency analysis (*e.g.*, histograms or probability plots) of the orientation survey allows definition of thresholds that similarly classify samples collected from these sites as ‘anomalous’ or ‘background’. Using the total number of samples (t), the number of anomalous sites (a), the number of anomalous samples (k), and the number of anomalous samples at anomalous sites (x), hypergeometric statistics can be used to determine the probability that an identical number of anomalous samples would occur at the anomalous sites, if the location of anomalous samples were selected at random. These probabilities ($P(x)$) can be precisely determined using the formula:

$$P(x) = \binom{a}{x}\binom{t-a}{k-x} \Big/ \binom{t}{k} \times 100\% \quad .$$

A Microsoft Excel® spreadsheet that calculates these hypergeometric probabilities ($P(x)$) can be downloaded from http://ace.acadiau.ca/~cstanley/software.html.

Stanley’s original work requires that the geochemical orientation data to be evaluated exhibit high geochemical contrast, so that no uncertainty exists regarding whether a sample is from ‘anomalous’ or ‘background’ sub-populations (*i.e.*, there is un-ambiguous classification of the samples). A refinement of Stanley’s original performance evaluation approach now allows consideration of geochemical variables that do not exhibit this required high level of geochemical contrast, and so can consider cases where ‘anomalous’ and ‘background’ sub-populations exhibit significant overlap.

The refinement to this exploration performance evaluator involves determining the random hypergeometric probabilities ($P(x)$) at a range of geochemical thresholds, instead of at only one threshold. At each threshold, a different number of samples will be classified as ‘anomalous’ (k) and a different number of ‘anomalous’ samples will correspondingly occur at the ‘anomalous’ sites (x). Whereas the total number of samples (t) and number of ‘anomalous’ sites (a) are constant for any threshold, the resulting random hypergeometric probabilities will change because both k and x will vary. Using a range of thresholds to classify the geochemical orientation survey results, it can be shown that a minimum probability will exist at some threshold (or threshold range) for any dataset. At this threshold, the survey results will bear the least resemblance to what would be expected at random (because the hypergeometric probability will be minimized). As a result, one can consider the associated threshold to be optimal.

This approach thus allows geochemists to compare the effectiveness of several geochemical methods (using the minimum hypergeometric probabilities as metrics) quantitatively, while at the same time optimally determining the most appropriate threshold for each exploration method evaluated in the orientation survey. As with Stanley's original method, this approach can be applied to multiple survey lines simultaneously by summing the relevant input parameters used in the above formula (t, a, k, x) for those multiple lines and calculating the minimum probability in a collective manner. Alternatively, this approach can be applied in a multi-element context by multiplying the minimum probabilities independently determined for each element together and comparing the resulting 'global' probability of the several exploration techniques tested. Most importantly, this refinement to Stanley's original evaluation method furthermore removes the only restriction to the general evaluation of all exploration technique inherent in the hypergeometric probability approach, because high geochemical contrast is not required. Finally, because similar models for the response signatures derived from geophysical surveys exist, there is no reason why this new approach couldn't be applied to compare the results of different geophysical exploration methods.

Examples of the application of this refined exploration performance evaluation approach are presented that illustrate the nature of how a new exploration method can be evaluated. In all cases, an optimal threshold is identified in the process. Four sets of multi-element results from a soil traverse over Au mineralization near the Stawell gold mine, Victoria, testing the exploration effectiveness of several partial extractions, recently examined by Noble in his Ph.D. thesis, are evaluated and compared. The results illustrate how the different geochemical indices each have different minimum hypergeometric probabilities. As a result, this approach quantitatively identifies the partial digestion index with the most compelling (*i.e.*, the most non-random) results.

QUANTIFYING THE MAGNITUDE OF SAMPLING, PREPARATION AND ANALYTICAL ERRORS IN DRILLING PROJECTS FOR GOLD: MYTHS, MODELS AND STRATEGIES FOR MITIGATING THE 'NUGGET EFFECT'

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Collection and preparation of drill samples from gold mineralization can provide significant challenges for the geoscientist because of the coarse particulate nature of gold. Gold mineralization can commonly exhibit sampling errors as large as 50-100% and, to avoid this, geoscientists have opted to collect and prepare larger drill samples to reduce the magnitude of the 'nugget effect'. Unfortunately, the 'nugget effect' can cause sampling errors at any stage of sample collection and preparation when sub-sampling takes place. As a result, knowledge of the magnitude of error at each sub-sampling step is necessary to identify strategies to reduce overall error. Regrettably, the typical absolute and relative errors that occur during sample collection and preparation of sub-samples with finer particle sizes are not generally known for many gold deposit types.

Results from several gold drilling projects are presented that document the magnitude of sampling and preparation errors. These results are derived from large, blind duplicate quality assessment and control programs designed to measure sampling errors and ensure that they are minimized on these projects. In general, results indicate that a very large component of error is introduced through the collection of the initial sample, and that subordinate amounts of error are introduced during preparation protocols that would be considered to be appropriate for coarse gold-bearing samples. As a result, undertaking extraordinary efforts to reduce preparation errors does not result in a significant error reduction. However, the collection of larger initial samples can result in the substantial reduction of error.

Knowledge of the magnitude of measurement error at each sampling and sub-sampling stage can provide the geoscientist with the necessary information to optimize sampling on a drill project, and ensure that the company gets the best data (with the lowest errors) for the least cost.

A STEPWISE MULTI-DISCIPLINARY REGIONAL GEOCHEMICAL SOIL MAPPING AND EXPLORATION STRATEGY FOR UNDER SATURATED COMPLEXES

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Twenty seven under saturated alkaline and carbonatite complexes intruded into the Kaapvaal Craton in an area covered by the high density Regional Geochemical Mapping Programme of South Africa. A total of 122,400 soil samples were collected in the area on a density of one sample per 1 km^2. These samples were analyzed for 23 elements (As, Ba, Co, Cr, Cu, Fe, Mn, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Sr, Th, Ti, U, V, W, Y, Zn and Zr) on a simultaneous X-ray fluorescence spectrometer. The economic potential of under saturated complexes for high- technology metals, base metals, precious metals and some non-metals necessitated the development of a scientifically based mapping and exploration strategy.

In order to interpret the approximately 2.8 million data points for optimal results, a stepwise multi-disciplinary mapping and exploration strategy was devised. The strategy include four different mapping techniques (single element, discriminant factor analyses, ternary imaginary and response ratios) on two domain levels (super-domain and domain).

A target ranking and classification table was compiled incorporating all the information from the 27 known complexes. ‘New target’ scores were then plotted on the table which allowed the ranking and classification of each new target anomaly. The final ranking and classification for new anomalies were done using a comprehensive exploration tree showing all relevant information for a specific target anomaly. Consequently the strategy was tested with a follow-up of the highest ranked anomaly which led to the discovery of a new carbonatite complex, the Ramakok’s kraal complex.

The study showed conclusively that a scientifically-based mapping and exploration strategy, utilizing on high density soil data, can be used successfully to identify, rank, classify and discover new under saturated complexes.

LITHOGEOCHEMICAL EXPLORATION FOR GOLD IN ABU SARI, NORTHERN SUDAN

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Introduction

According to the agreement between Sudan and China, China Devro Gold Corporation Limited entered Sudan to explore for gold deposits in 1998. Because of the shortage of geological experts and exploration techniques and limited the exploration funds, the geological investigation and mineral resources evaluation is at a very low level. There are not even geological or detailed topographic maps available in the study area. To get a quick view of such a large unknown area, a geochemical survey is the best choice.

Geological setting

The study area is located in northern Sudan, near Egypt. The Proterozoic complex comprises mafic, intermediate and felsic metamorphic rocks. The known Abu Sari gold mineralization (gold quartz vein), which is more than 500 m long and up to 10 m wide, was mined by an English miner in early 1960s. However, no information about the gold mineralization was left after the miner died. Because it is situated in the eastern Sahara and the maximum local relief is less than 150 m. the only suitable sample media are rock chips.

Methods

Rock chip sampling was 4/km^2 (500 by 500m) over 2500 km^2. Sampling was totally guided by GPS because there is no detailed relief map. To improve representativeness and reproducibility at each site 7-8 sub-samples (each 2-4 cm in diameter) arranged in a random geometry in outcrop were collected as a composite sample. A total of 2148 samples were collected during April-March, 1998. The composite samples were jaw-crushed to <1 cm and to reduce analytical samples, four adjacent composite samples (100 g for each sub-sample) were recomposited to form a analytical sample. The new composite samples were pulverized in a ceramic disc grinder and were analyzed for Au, Ag, Cu, Pb, Zn, As, Sb, Hg, W and Mo in the IGGE Laboratory.

Results and discussion

All ten elements were mapped and over 20 gold anomalies were delineated in the area. The biggest Au anomaly, over 40 km^2, is located near the known gold mineralization at Abu Sari. However, the centre of the anomaly, in which four samples contain over 1000 ppb Au (maximum of 39590 ppb), is not the same as the mined gold-bearing quartz veins. Field examination showed that there is a new type of gold mineralization in the area. Silver, As, Sb and W anomalies also occur at Abu Sari, but are much smaller. Although the other gold anomalies are much smaller and weaker, according to geologists from the Ministry of Energy and Mining, they indicate all known mineralization and some prospects in the area. The distribution of Mo, Zn and Pb is different from Au, Ag, As, Sb and W; the anomalies largely occur in the southern part of the study area. The Cu anomalies are observed in the centre. Molybdenum, Zn, Cu and Pb may reflect lithological differences.

The Abu Sari gold anomaly was followed up by detailed geological mapping, drilled during 1999-2000, and proved to be a gold deposit.

Conclusion

The approach of rock chip surveying at a sample density of 4/km^2 and analytical density of 1/km^2 is very efficient for gold exploration in areas of outcrop such as this part of northeastern Sudan. The geochemical survey resulted in the discovery of a new type gold deposit at Abu Sari and many other gold prospects.

VARIATIONS AND DISPERSION OF ELEMENTS IN DESERT REGOLITH, NORTHWESTERN CHINA

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The desert terrains of northwestern China are mostly covered by regolith sediments, which include alluvium, residuum, windblown sand and a caliche horizon. Generally, the regolith sediments can be vertically divided into three layers: loosely windblown sand and lag gravel, a weakly cemented sandy horizon and a dense caliche-cemented horizon. Three types of mineral deposit, namely sandstone-type uranium, gold and porphyry copper, were selected to investigate the elemental variations both in vertical profiles and in size fraction of the regolith.

Gold deposits: Gold and associated Ag tend to concentrate in the weakly cemented horizon in the upper part of the profile over the gold deposit. Gold in the −160 mesh fraction of regolith samples has greatest contrast over the gold ore body.

Uranium deposits: Concentrations of U and associated V, Sb and Th increase in the top of the profile over the sandstone-type uranium deposits. Uranium and Mo in the −160 mesh fraction of regolith samples gave the best indication of a blind U deposit at a depth of 300 m.

Copper deposits: The concentrations of Cu and associated Mo are relatively high in the lower part of the profile, whereas Pb, Zn, Sb and As tend to increase both in the top and the bottom of the profile. Both the fine fraction, −120 mesh, and the coarse fraction, +20 mesh, are suitable for copper exploration.

The data show that Au and U tend to migrate to the surface and become trapped by fine materials such as clays and colloidal particles. Copper-related elements (Cu, Mo) are probably blocked by the dense caliche-cemented horizon or leached from the upper part of the profile.

THE CHARACTERISATION OF ST IVES HYDROTHERMAL GOLD DEPOSITS AND ALTERATION FOOTPRINTS USING PIMA SPECTRAL ANALYSIS

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PIMA spectral analysis has been employed to identify and characterise hydrothermal alteration footprints around Archaean gold deposits in the St Ives camp near Kambalda, Western Australia.

More than 500 top-of-fresh-rock samples were selected at a grid spacing of about 200 m across the St Ives Gold Mine leases. The geology of the area is complex and a wide variety of rock types were sampled. PIMA results were domained by rock type, and compared with gold grade in order to constrain spectral features important for exploration. Weathered rock was not sampled because the minerals associated with weathered rocks alter the position of the AlOH absorption feature and obscure the signature of gold-related alteration features. The PIMA spectra of all samples were analysed with AusSpec software, “The Spectral Geologist” (TSG).

Initial analysis of the data was complex as the data originated from many different rock types. In order to identify significant relationships that could be applied across the entire camp, small-scale trends in down-hole drill data were studied. Analysis of the down-hole data identified specific relationships with respect to zones of elevated gold. Rock type was also considered and it is important to distinguish alteration effects from lithological differences in mineral composition. Chlorite features (chlorite composition and intensity, as well as the sericite/chlorite ratio) work particularly well in mafic and ultramafic rocks and mica features (mica composition, intensity and crystallinity) were most useful in felsic and sedimentary rocks.

In mafic rocks, the FeOH absorption feature shifted to lower wavelengths from 2254 to 2245 nm close to zones of elevated gold grade, and chlorite intensity decreased from 0.3 to 0.1. This indicates a change in chlorite composition from iron-chlorite to magnesium-chlorite with increasing gold grade as well as a decrease in the intensity of chlorite alteration. An increase in the AlOH-FeOH ratio (negative to positive values) with gold grade indicates an increase in sericite alteration within zones of elevated gold. The mineralogy of the “sericite alteration” responsible for the shift in the AlOH wavelength has yet to be determined. The mica-AlOH absorption feature shifted to higher wavelengths from 2200 to 2212nm where there was an increase in gold grade, suggesting a change in the mica composition from muscovite to a more silica-rich form of mica, celadonite (commonly called phengite), with increasing gold grades. Wavelength ranges for mica and chlorite compositions from the down-hole data that showed good correlation with gold grade were identified. Thematic maps were created by applying these ranges to top-of-fresh-rock data. The data presented in the maps displayed a good spatial relationship with respect to known gold deposits.

The process of applying these small-scale down-hole trends to top-of-fresh-rock data will be used to identify and characterise large-scale alteration patterns across the St Ives area. Results from this work will also be used to identify alteration footprints in exploration programs. PIMA spectral analysis is a useful tool in exploration for new deposits.

SPEAKER PROFILES

The following profiles were provided for publication.

ARUNDELL Mark graduated from the University of Melbourne in 1985 with BSc(Hons) and completed a M Econ Geol at CODES in 1998. During ten years with RGC, he worked as a mine geologist in Tasmania, Northern Territory & New South Wales and as an exploration geologist throughout Australia. Mark joined North Ltd in 1995 as Senior Exploration Geologist with the Goonumbla/Northparkes team and, later, the Cowal Gold project. Mark relocated with North to Perth in 1999 and worked on the Yakabindie Nickel project and Fe-Ox Cu-Au projects in South Australia. Since early 2000, Mark has been working as a Consultant Geologist / Geochemist for various clients including Rio Tinto Exploration, Newcrest, North Ltd, Peak Gold Mines, PIRSA, ERA and SRK

BEAUDRY Charles, MSc, P.Geo, géo, FGAC. Graduated BSc, from University of Ottawa in 1979 followed by 2 years of uranium exploration in the Athabaska basin before returning to university for a MSc at McGill in 1983. Masters thesis subject on Archean volcanic stratigraphy and petrochemistry. Subsequently worked 12 years in the Abitibi exploring for mesothermal gold and VMS base metal deposits both as a consultant and for major mining companies. Successes included contributions in the discovery of the Bell Allard deposit in Matagami and the Tortigny deposit north of Chibougamau. In 1996 moved to Brazil to open a Noranda affiliate company and district exploration office to explore for base metals. Major focus in the Carajas leading to acquiring major land position in district. Since 2002 occupying position of Manager Geochemistry for Noranda Inc/Falconbridge Ltd in Toronto, focusing on QAQC issues, supervising geochemical surveys and developing new geochemical technologies.

BENAVIDES Jorge is currently a PhD student in the Geological Sciences and Geological Engineering Department at Queen's University. His area of interest deals with the development of new techniques to be applied in the exploration for Iron Oxide Copper Gold deposits located in subduction related, calc-alkaline terrains. Research areas include: lithogeochemistry using Pearce Element Ratio analysis and stable isotope geochemistry of various systems (O, S, C), in order to evaluate mass transfer processes associated with mineralization and the characterization of ore fluids.

BENN Chris has worked for BHP Billiton for 23 years and has been in his current position as Principle Geochemist for 5 years. Chris is currently responsible for geochemical exploration activities for the North American exploration group. At other times he has worked as a geologist/geochemist in a number of different countries on a wide range of projects for commodities that include gold, copper, lead, zinc, iron ore and titanium in a wide variety of geological environments. Chris obtained a degree in Geology in 1981 from Durham University, UK and an MSc from James Cook University, Australia in 1987. The title of his thesis at the latter was "Lithogeochemical Haloes Associated with Carbonate Hosted Pb-Zn Mineralization". Chris has been a Fellow of the Association of Exploration Geochemists for 6 years, is currently the Editor of EXPLORE and was a member of the organizing committee member for the 2001 International Geochemical Exploration Symposium in Santiago.

BETTENAY Leigh is Chief Geologist at Sipa Resources Limited, a Perth-based mining and exploration company listed on the ASX, where he is mainly involved in management and project generation. He has a PhD from the University of Western Australia and has worked throughout Australia and in several other countries as an industry consultant and on staff in several mining companies including BHP, MIM and Homestake Gold of Australia. His main interests lie in the mechanisms of geochemical dispersion and the application of geochemistry for mineral exploration and targeting.

CARR Graham joined CSIRO in 1979 on a 3-year term to research the geochemistry of mercury as part of an industry-funded AMIRA project. He has worked for CSIRO since that time undertaking collaborative research with both industry and State and Federal Geological Survey partners. In 1982, he joined the Pb isotope research team at CSIRO and has been an active researcher in that area ever since. He has led further AMIRA projects on groundwater geochemistry, metallogenesis of the Mount Isa terrain and partial leach technologies. Since 1994 he has been the Officer in Charge of the North Ryde laboratories and has coordinated mineral exploration research for CSIRO. Late last year he was "on track" to leave CSIRO, but has emerged as Deputy Chief, continuing to look after exploration research.

CORNELIUS Matthias is a geologist and exploration geochemist with CSIRO Exploration and Mining in Perth. Before joining CSIRO, Matthias worked with major and junior companies in the gold exploration industry for about 9 years. As part of CSIRO/CRC LEME, he has led several industry-sponsored projects aimed at new or improved methods for diamond exploration in the Yilgarn Craton, and base metal exploration in Western Australia and Brazil. Currently, he works on improving geochemical, biogeochemical and mineralogical techniques for gold and base metal exploration through transported cover. His other interests are the Yilgarn laterite atlas and the statistical evaluation of large geochemical data sets.

CRAW Dave is a lecturer in economic geology at the University of Otago. He has research interests in hard rock and placer gold mineralisation, and related environmental issues. One principal research theme is on fluid flow in collisional mountain belts, and how this relates to formation of schist-hosted gold deposits. Part of this research involves examination of historic, current, and prospective mine sites in hydrothermally mineralised gold deposits in the MesozoicOtago Schist belt of southern New Zealand, including the Macraes mine.

CUDAHY Thomas currently works as a Principal Research Scientist with CSIRO Exploration and Mining at the Australian Resources Research Centre in Kensington, Western Australia where he leads the Spectral Sensing Stream. This team is focused on the development of operational spectral sensing technologies, from satellite to field systems, that provide critical geocience data for improving the discovery and recovery of ore deposits at minimal environmental impact. His research interests include understanding the spectral-mineralogical characteristics of regolith and alteration systems and how this information can be measured accurately using the next generation of satellite and airborne sensors.

DALRYMPLE Iain is in the process of completing his PhD, supervised by Dr David Cohen and Mr Simon Gatehouse at the University of New South Wales. His work has primarily been in the field of the optimization of partial geochemical extractions, with the bulk of his work in areas of transported cover. He holds an undergraduate degree with a major in both geology and chemistry. Iain is the recipient of a CSIRO Exploration and Mining postgraduate stipend and he hopes that his PhD will be completed prior to the conference.

DICKSON Bruce is Director of Dickson Research Pty Ltd. Bruce Bruce obtained his MSc from Wellington University, New Zealand and received a PhD from Imperial College, London in 1973. He moved to Australia where, after a short time at ANU, he joined CSIRO to work on a variety of aspects of application of radiation measurements to mineral exploration. His work has covered aspects of uranium grade control, uranium exploration using ground waters, radioactive disequilibrium in uranium deposits and more recently, the processing and interpretation of aerial gamma-ray surveys. He is currently running his own consultancy, one aspect of which is visualizing and interpreting geochemical data.

ELSENBROEK Kobus currently works as a geoscientist in the Regional Geochemical Mapping Unit, at the Council for Geoscience in South Africa. His area of expertise is regional geochemical sampling, sample preparation and geo-analyses by using a Simultaneous Fluorescence X-ray Spectrometer. Kobus has also been involved in geochemical mapping programmes in the Kingdom of Morocco and the Kingdom of Lesotho. Kobus is also interested in the medical influence of geochemical anomalous areas on wildlife and cattle.

EPPINGER Bob is a research geologist with the Mineral Resources Program of the U.S. Geological Survey, located in Denver, Colorado. His current area of interest is natural and anthropogenic acid-rock drainage related to mineral deposits. Early in his career, he worked in exploration geochemistry and mineral resource assessment of public lands in the western USA. His current projects include study of natural acid-rock drainage from VMS and porphyry deposits in Alaska, environmental geochemistry of abandoned mines in central Idaho, and a mineral resource assessment of Afghanistan.

FEDIKOW Mark is a consulting exploration geochemist and geologist based in Winnipeg, Manitoba, Canada. His 30 years of experience in industry and government have been applied to mineral deposits geology and their geochemical expressions in primary and surficial depositional environments. He has developed, assessed and implemented a variety of innovative geochemical exploration techniques for a wide range of commodity types in property and regional scale geochemical surveys.

FRASER Stephen had experience as an exploration geologist in Saudi Arabia, Western Australia, Queensland and Indonesia before joining CSIRO. Currently, he is a Principal Research Scientist in the Division of Exploration and Mining. His research interests include spectral reflectance sensing, mineral mapping, geophysics and the acquisition, storage, and analysis of spatial data for mineral exploration purposes. He is currently involved on the development of data mining and visualization techniques for the integrated analysis of spatially-located data sets.

GLANZMAN Richard formed Glanzman Geochemical LLC to provide geochemical services to the mining industry. His geochemical experience includes environmental applications as Principal Geochemist for CH2M Hill, minerals exploration applications as Division Geochemist for Chevron Minerals, Research Geologist for the U.S. Bureau of Mines and Research Geologist for the U.S. Geological Survey. He specializes in multimedia geochemical signatures and their interrelationships to characterize property-specific mineralization anomalies leading to a minable resource.

GOLDSWORTHY Julian a “yarra yabby”, graduated as a geologist from Ballarat School of Mines (now University of Ballarat) in 1984. Since 1986 he has been an exploration geologist for Newcrest (and its predecessor Newmont Australia) working primarily on gold exploration in WA apart from a 3 year stint in South America based in Santiago, Chile. He is currently Newcrest District Geologist exploring the northern Ashburton for a down under version of Carlin goldfield.

GRAVEL John attended McGill University were he received his BSc Geology in 1979 and his MSc A Minex in 1985. He had the privilege of beginning his geochemical career as research assistant to the late Dr Stan Hoffman. After a stint as head of Applied Geochemistry Unit in the British Columbia Geological

Survey Branch, John returned to consult with Stan Hoffman in the early 90's and continued the consulting business after Stan passed away in 1994. Also at this time, John began work with Acme Analytical Laboratories Ltd. towards accrediting the lab under the ISO 9002 standards. Recently John became president of Acme Analytical Laboratories Ltd. following the retirement of Dean Toye, its founder.

GRAY David is "Exploration Through Cover" Theme Leader at CSIRO Exploration and Mining. Over the past 2 decades, he has researched chemical and mineralogical processes leading to the redistribution or ore elements in weathered profiles, particularly in the Yilgarn and Gawler Cratons in Australia.

HEMMATI Hamid R, currently is a PhD student in School of Earth and Environmental Sciences, University of Wollongong in Wollongong. His area of interest is mineral exploration especially using applied geo- and biogeochemical studies. He has been involved in teaching (as a lecturer) some courses for undergraduate students in Qazvin University in Iran and also as a consultant for some research projects before he commenced his PhD study in 2003.

HOUGH Robert is a research scientist with the regolith exploration geoscience group at CSIRO Exploration and Mining. He is applying detailed geochemical and mineralogical microanalyses to study gold and pathfinder elements in regolith.

HULME Karen, is currently a PhD student studying at the University of Adelaide within the School of Earth and Environmental Sciences. Area of interest involves the understanding of plant chemistry in regolith-dominated Australian prospective terrains, therefore providing another sampling media for mineral exploration.

JONES Michael is a founding director of Lithofire Consulting Geologists in Perth, Australia. He has extensive experience in research and exploration, including interpretation of remotely sensed data for mapping regolith materials, bedrock geology and mineral alteration. He has combined this with his skills as a structural geologist in major mapping projects for greenfields and near-mine target generation and exploration programs. His extensive field work in regolith geology and geochemistry at active mining centres in WA has led to important new ways of understanding regolith evolution, the distribution of metals in the regolith profile, and its application for exploration success.

KELLEY Karen has a masters degree from the University of Nevada in Reno and a PhD degree from the Colorado School of Mines. She has worked as a geologist at the U.S. Geological Survey since 1980. For the past decade, her research has been focused on understanding the genesis of shale-hosted zinc deposits in northern Alaska. In addition, she is involved in studies aimed at developing geoenvironmental models and the processes of metal mobility and transport.

KYSER Professor Kurt is director of the QFIR, the Queen's Facility for Isotope Research, with research interests that include isotope geochemistry, origin and chemical evolution of the earth, mass spectroscopy, evolution of fluids in basins, low-temperature geochemistry, geochronology, environmental and exploration geochemistry, and fluid-rock interactions. He has been a contributor toward understanding the processes associated with water-rock interactions and has helped developed or refine several novel analytical techniques for complex natural materials.

LE GLEUHER Maïté joined the Australian National University in 1989 and has held a series of positions in the department of Earth and Marine Sciences since. Her primary area of research expertise is regolith mineralogy. During her time with the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) she has investigated mineral hosts and traps for specific ore-related target and pathfinder elements. The project was funded by Normandy Mining Ltd. Maïté is now a visiting fellow at the Australian National University.

LETT Ray is presently geochemist for the British Columbia, Canada, Ministry of Energy and Mines, Geological Survey. He is responsible for regional geochemical surveys, analytical services and applied geochemical research projects. He became interested in exploration geochemistry through the enthusiastic teaching of the late Dr. Cliff James at Leicester University, England. Before joining the British Columbia government he worked as an exploration geochemist and consultant for Amax Exploration, BP Minerals and Barringer Research Ltd. His present interests are applying models to interpreting geochemical data and teaching.

LINTERN Melvyn has been a research scientist with CSIRO Exploration and Mining and CRC LEME for a number of years. His particular interests are in soil geochemistry (in particular calcrete) and biogeochemistry. He first discovered the gold-calcrete association and has since developed its use as sampling medium which has revolutionised exploration in southern Australia and in other parts of the world. For the last ten or so years, Mr Lintern has investigated the gold-calcrete association further in both the Yilgarn and Gawler cratons in a variety of regolith and geological settings which has led to the improvement of methodologies currently being used by the exploration industry. He currently leads projects in the Gawler Craton and is undertaking a part-time PhD at Curtin University (Western Australia) looking at factors involved in the formation of gold anomalies in calcrete.

MACFARLANE Bill received his MSc at Queen's University in 2003 on a thesis that developed continuous-leach techniques for exploration and environmental geochemistry. He is currently a

Research Associate at the Queen's Facility for Isotope Research, with research interests in exploration geochemistry. He is a liason researcher with Anglo American plc and has been part of the team responsible for enhancing break-through research methods for the discovery of undercover ore deposits.

MANN Alan, from 1973 was a Senior Research Scientist with CSIRO. In 1985 he established a company at Technology Park Bentley, Western Australia, to commercialize instrumentation which arose out of that research. His research also included elucidating chemical mechanisms for the dissolution and transport of gold (and a number of other elements) in weathering profiles. In 1993 with Russell Birrell he established a private research organization, The Geochemistry Research Centre, and commercialized the Mobile Metal Ion series of partial extractants, used in mineral exploration. More recently the research has included soil analysis systems for agriculture and soil additives for improving nutrition.

MARSHALL Alan, a"sandgroper" is a geology graduate from UWA in 1963 and Princeton in 1968. He has worked for a number of small and large international companies on the technical and management roles for mineral exploration in Australia and Canada to the mid 1980's. Since then as consultant and exploration manager and mostly in greenfields exploration in Western Australia he has specialsed in the development and application of exploration geochemistry. Teetering on the brink of retirement with well recognised computer illiteracy fortunately today's presentation is by Julian.

MCCONACHY Timothy. As Senior Principal Research Scientist and Head of Seabed Ore Systems at CSIRO Exploration and Mining, Sydney, Tim's main research interests include seafloor sulfide deposits and application to land-based exploration, and non sulphide base metal mineralisation. Tim has participated in 13 marine expeditions which have resulted in the discovery of numerous new vent fields and submarine volcanoes in the frontier regions of the Pacific Ocean, and Indonesia's archipelagic waters. Formerly Chief Geologist Australia for Rio Tinto Exploration, Tim has played a major role in a number of significant mineral discoveries in SE Asia and Australia.

NOBLE Ryan is currently finishing his PhD with the Department of Applied Geology at Curtin University and employed as a research geochemist with CSIRO Exploration and Mining in Perth. His presentation is based on some of the exploration related research from his thesis.

PIRLO Mark is an exploration and environmental geochemist in the CSIRO Division of Exploration and Mining, located in Perth Western Australia. Specialising in hydrogeochemistry, Mark works closely with David Gray, conducting research aimed at understanding hydrogeochemical processes for development and deployment as an exploration tool.

POLITO Paul has been the regional geochemist for Anglo American plc's Perth hub since January, 2005. Paul obtained his PhD in 1999 from Adelaide University where he researched the potential of soil gas geochemistry as an exploration tool for blind Archaean gold deposits in Western Australia. He then spent the next 5 years working at Queen's University, Kingston, Canada with Kurt Kyser where they investigated the geochemical evolution of the Mt Isa and McArthur Basins through stable and radiogenic isotopes, constrained models for the Nabarlek, Jabiluka, Westmoreland and Ranger uranium deposits in northern Australia, finger printed VHMS ore deposits in northern Canada using S and Pb isotopes and evaluated the potential of peat, water, till and trees to be used as sampling media for geochemical exploration for Cu-Zn deposits in Saskatchewan and Manitoba.

PRENDERGAST Kylie is presently employed as the Project Generation Geochemist with Gold Fields St Ives, Kambalda WA. Background summary: 1st class Economic Geology Honours James Cook University, Townsville Qld. 3 years as an Exploration and Mine Geologist with North Limited throughout Australia. 3.5 years PhD (James Cook University, Townsville Qld) entitled "Porphyry-related hydrothermal systems in the Ertsberg (Grasberg) district, Papua, Indonesia". 8 months with Ivanhoe Mines in Mongolia at their Oyu Tolgoi porphyry Cu-Au project.

RUGLESS Dr Craig is an economic geologist, geochemist and petrologist who has gained over 30 years of wide ranging experience in Australia and overseas, after graduating from Sydney University and obtaining a PhD from the University of New South Wales. Dr Rugless has been an AEG/AAG member since 1980. In addition to working for major companies including Australian Anglo American, Homestake Australia and Ashton Mining, Dr Rugless developed a successful exploration consultancy – Pathfinder Exploration Pty Ltd that provides ineragraphic/petrographic and contract geochemical services to the mining and exploration industry. Extensive consulting in geochemical exploration has involved numerous orientation studies in most regolith terrains in Australia and the Pacific, and particularly the deep lateritic profiles developed over the Archaean shield of Western Australia. The orientation studies have been targeted at finding the most effective partial digest techniques that can locate blind precious and base metal mineralisation. These studies lead to the development of innovative geochemical techniques including the **MAGSAM® 2000** rare earth magnetic sampler capable of sampling a magnetic lag fraction (MAGLAG) or magnetic stream sediment sample (MAGSTREAM) that can be coupled with sensitive partial digests capable of defining buried mineralisation and/or subtle geochemical trends. The Pathfinder salt lake auger has been developed to facilitate geochemical exploration in the inhospitable salt lake environment.

SARALA Pertti is working as Senior System Analyst in Geological Survey of Finland (GTK). My main job is concerning with the development of Internet Map Services in the GIS and geodatabase project of GTK. The area of special interest is glacial and Quaternary geology together with application of regolith and geochemical studies for ore exploration. At the moment, I'm finalizing my doctoral thesis with the object of getting it ready during the next autumn. The title of thesis will be something like: "Glacial deposits, dynamics and stratigraphy during the Weichselian ice age in southern Finnish Lapland; from the theories of ribbed moraine formation to practise".

SCOTT Keith is a Visiting Fellow in the Department of Earth & Marine Sciences at ANU and an Honorary Research Fellow at the CSIRO Division of Exploration and Mining. During a 35 year career with the CSIRO, he has conducted weathering studies directed toward developing better methods of geochemical exploration for base metal and Au deposits by understanding the processes involved during weathering. His research has emphasised the relationship of geochemistry to mineralogy and the control exerted by specific mineral phases on the distribution of pathfinder elements at different levels in regolith profiles.

SINGH Balbir is a Research Scientist with CRC LEME and CSIRO Exploration and Mining. His research interests are soil mineralogy, geochemistry and geobiology. Balbir uses a number of field and laboratory based techniques to characterise regolith and soil processes.

SKWARNECKI Marian is currently employed by the Geological Survey of Western Australia and has just completed regolith-landform mapping of the Kalgoorlie region. He has worked as a geologist and geochemist in both industry and research organizations on Archaean gold and nickel mineralization, and Au and base-metal mineralization in the Aruntas and the Kanmantoo. His specific interests are exploration geochemistry, hydrothermal alteration and weathering of ore bodies and their host rocks.

STANLEY Cliff is an Associate Professor of Applied Geochemistry and Economic Geology at Acadia University in Wolfville, Nova Scotia, Canada, although he is presently on sabbatical in Perth, Western Australia with the CSIRO Exploration and Mining Division. His primary research interests include hydrothermal alteration and lithogeochemistry, sampling theory and analytical quality control, and biogeochemical uptake and sequestration of heavy metals by plants. Dr. Stanley maintains and active consulting practice for the mining industry in the area of exploration geochemistry and economic geology, and previously worked for the Mineral Deposits Research Unit at UBC, conducting several economic geology and exploration geochemistry research projects there.

STEENFELT Agnete has an MSc in petrology and geochemistry from the University of Copenhagen, Denmark. In 1972, she joined the Copenhagen-based Geological Survey of Greenland (since 1995 merged with the Geological Survey of Denmark under the name of GEUS). She commenced reconnaissance scale stream sediment geochemical mapping of Greenland in the mid-1970s resulting in the publication of a geochemical atlas of some 100 000 km^2 of West and South Greenland in year 2001. Recently she has worked with exploration for gold and diamonds in Greenland. Her research interest is application of geochemical data to mineral exploration, recognition of metallogenic provinces, and identification of litho-tectonic domains.

URQUETA Esteban. Since the completion of his BSc degree at Universidad de Chile in 1996, Esteban has focused his work on mineral exploration along the Andean Range. He was in charge of the exploration geochemistry for Anglo American plc in Chile, Perú and Argentina. He has worked on the design and interpretation of geochemical surveys on both regional and district scales in order to vector towards ore mineralisation. He is currently a PhD candidate studying the geology and geochemistry of the Rosario porphyry copper deposit in the Collahuasi District in northern Chile.

VOICU Gabriel currently works as a Senior Geologist with Cambior Management Services at the Rosebel Gold Mines NV, Suriname, South America. He is also an Adjunct Professor of Economic Geology at the University of Quebec at Montreal, Canada. His area of interest includes the geochemistry of the mineralizing fluids, the study of trace elements in metallic minerals and the geochemistry and mineralogy applied to mineral exploration. His expertise was acquired in various geological environments, especially in Europe, South and North America He has been involved extensively in mining and exploration geology, teaching and research.

WANG Mingqi Dr worked as a senior geochemist and former vice-director of Geochemical Exploration Department in the Institute of Geophysical and Geochemical Exploration (IGGE) before 1999. His interests in IGGE lay on regional geochemistry, lithogeochemistry (zonation of primary halos), vapour (mercury and geogas) survey, selective leaching and its application in loess covered area. Dr. Wang left IGGE and went to China University of Geosciences, Beijing as an associate professor and the head of Geochemical Lab in 2000. Now his main focus is still in the geochemical exploration for mineral deposits, especially on deep penetrating geochemistry, but his interest was expended to environmental geochemistry of mineral deposits.

WANG Xueqiu achieved BSc in exploration geochemistry, MSc in applied geochemistry and PhD in Geoexploration technology. He is a senior geochemist, director of Applied Geochemistry Laboratory, Institute of Geophysical and Geochemical Exploration. He has 20 years experience in exploration geochemistry and geochemical mapping. He is involved in geochemical exploration for gold, base metal, and uranium deposits, particularly for concealed giant ore deposits in overburden terrains by using deep-penetrating geochemistry. His major contributions are related to the finding of ultrafine particles of gold, which lays a foundation for establishment of sampling and interpretation for low threshold of regional gold anomalies, and to development of two deep-penetrating geochemical methods: Selective Leaching of Mobile Metals and Nanoscale Metals in Earthgas. He is also involved in regional, national and global geochemical mapping activities and has given lectures and training courses of geochemical mapping and its application for Asia, Africa, and America countries. He has published more than 50 papers both in English and Chinese.

WHITBREAD Michael currently works as a consulting geochemist for ioGeochemistry on all aspects of exploration geochemistry for the base and precious metal industry. He is also working part time as a post-doctoral fellow at Acadia University, with Dr. Cliff Stanley, using lithogeochemistry to examine formational processes of the South Mountain Batholith, Nova Scotia. Michael has recently completed his PhD into lithogoechemical alteration studies on the Elura and Century Zn-Pb-Ag deposits in Australia. He has worked as a geochemical consultant for 3 years, and worked for Pasminco Exploration as an exploration geologist for 3 years prior to commencing his PhD.

WINDLE Steve is a founding director of SDP Soilgas P/L, a company developing soil-gas geochemistry for the minerals exploration market worldwide. He holds degrees from the Universities of Cambridge, Otago and Southampton, and over the last ten years has worked in various roles in the field of exploration geology in Australia, South America and Southeast Asia. He founded SDP Soilgas along with David Thiede in 2001.

YILMAZ Huseyin currently works as a Professor of Economic Geology with the Dokuz Eylul University, Faculty of Engineering, Department of Geological Engineering, Izmir, Turkey. His area of interest is the Ore-Forming Hydrothermal Systems and Related Ore Deposits as well as Geochemistry in Exploration, in particular gold-depositing systems and its exploration. He has been involved in direct exploration/consultation in and lecturing on precious and base metal deposits including both private and public sectors.

AUTHOR INDEX