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INDICE-INDEX (ABSTRACTS-RESUMENES)				
N٥	AUTHOR-AUTOR	TITLE-TITULO		
1	Al-Saleh	Origin of Manganese and base metal anomalies in Paleozoic cover rocks overlying the eastern margin of the Arabian Shield		
2	Bonham et al	Statistical analysis of hydrogeochemical data from a survey in Nova Scotia, Canada		
3	Boni et al	Environmental geochemical Atlas of Southern Sardinia		
4	Bonotto and Caprioglio	Radon in groundwaters from Guarany Aquifer, South America: Environmental and exploration implications		
5	Bowell and Freyssinet	A systematic classification of regolith gold		
6	Bowell and Parshley	Wasterock characterization and management: A case study from New Mexico		
7	Bowell et al	A Mass Balance Approach to estimate the dilution and removal of pollutants in the Lago Junin drainage, Central Highlands, Peru		
8	Britt and Gray	Three-dimensional investigations of gold dispersion and regolith at the Argo and Apollo deposits, Kambalda, Western Australia		
9	Burlinson	Fluid Inclusions for exploration - the acoustic decrepitation method		
10	Carey et al	Groundwater flow in playa lake environments: Impact on gold and pathfinder element distributions in groundwaters surrounding mesothermal gold deposits, St Ives Area, E. Goldfields, Western Australia		
11	Chastain and Fletcher	Exploration geochemistry of stream sediments and surficial deposits at Pascua- Lama		
12	Cheng et al	GeoDAS – A New GIS System for Spatial Analysis of Geochemical Data Sets for Mineral Exploration and Environmental Assessment		
13	Cheng	A new spatial analysis method for geochemical mapping and anomaly enhancement by incorporating local spatial association and singularity.		
14	Cohen et al	Factors controlling the dispersion of gold in stream at Timbarra, NSW		
15	Dawen et al	Application of the GMDS2000 System for the Delineation and Investigation of Geochemical Blocks in Southern China		
16	Dunn et al	Exploration for platinum, palladium and kimberlites in forested terrain of Canada using spruce tree tops		
17	Emelianenko et al 2	Fundamentally new geochemical method for quantitative evaluation of magnetite ore deposits		
18	Emelianenko et al	Fundamentally new geochemical method of evaluation of hypsometrical level of magnetite deposits ore zone		
19	Esterio	Water characterization in Drake mining area, NSW, Australia		
20	Fletcher and Bond	Evaluation of selective extractions in glaciated permafrost terrain at the Pb-Zn Swim deposit, Yukon Territory, Canada		
21	Fletcher and Muda	Dispersion of gold in a rain forest stream in the S. Kuli region, Sabah, Malaysia: implications for exploration		
22	Freyssinet and Bowell	Major morphological and chemical features of regolith gold		
23	Gallego et al	Geochemical exploration as a tool to optimize the biodegradation processes of petroleum hydrocarbons in soils		

24	Goldberg et al	The geochemical image of ore objects in country rock and thick cover
25	González and Calderón	Data processing for geochemical mapping- An example from Central Colombia
26	Gray	Naturally occurring Cr <sup>6+</sup> in shallow groundwaters of the Yilgarn Craton, Western Australia
27	Guangsheng et al	Delineation and investigation of some large gold geochemical blocks in Eastern China
28	Hamilton et al	Complementary soil geochemical and subsurface studies in the Abitibi Belt, Ontario: Comparison of selective leach methods for locating mineralization in overburden-covered terrain and evaluation of processes of element migration
29	Hauff et al	An overview of hyperspectral remote sensing as applied to precious metals exploration
30	Hill et al	Complementary Selective Extraction and Biogechemical Patterns at the I-10 and Dragoon Skarn/Porphyry Deposits, Cochise County, Arizona
31	Hobday and Fletcher	Dispersion of gold in Slesse Creek, British Columbia
32	Hoffman et al	SGH <sup>SM</sup> –A new soil gas hydrocarbon technique for Mineral exploration under deep cover
33	Holyland and Broadbent	Stream Sediment Source Accounting. Locating the sources and magnitudes of stream sediment anomalies.
34	Kapler and Williams	Supergene mineralogy - A valuable exploration tool for the field geologist
35	Kelley et al	The use of partial extraction geochemistry for copper exploration in Northern Chile
36	Kovalevskii 1	History, ethnography and archaeology in prospecting for precious metals
37	Kovalevskii 2	Deposits of PGE in wheathered rocks of deep-seated fault zones
38	Kovalevskii 3	Formation conditions of blanket-shaped eluvial deposits of platinoids
39	Kovalevskii 4	Biogeochemistry and exploration for mineral deposits in the USSR and Russia
40	Kovalevskii 5	Ecologic biogeochemistry of mercury in the Republic Buryatia
41	Loredo et al	Environmental geochemical exploration in the area of an old copper mine, Asturias, Spain
42	Lu et al.	Stable Isotope Variations in Alteration Haloes of Central Victorian Gold Deposits, Australia
43	McQueen et al	Gold mobility in the regolith at Cobar, N.S.W., Australia: Implications for geochemical exploration and oxide gold resources
44	Minton et al	Integrated Geochemical and Geophysical Exploration for Gold: Case History of the Serra de Jacobina Project, Central Brazil
45	Morris et al	Proterozoic mineralization identified by integrated regional geochemistry, geophysics, and bedrock mapping in Western Australia
46	Okujeni and Ackon	The Nature and Patterns of Element Dispersion in Aeolian Overburden Associated with Selected Gold Mineralization in Semi Arid Areas of Southern Africa
47	Parnow et al	Geochemical Dispersion from Tin Deposits on the Western Seward Peninsula, Alaska, USA –Environmental and Exploration Aspects
48	Parshley and Bowell	Environmental Geochemistry of Heap Leach Closure
49	Patinha et al	The selective extraction of Arsenic in selected minerals and tailing samples

50	Pauwels et al	Heavy Metals in groundwater around massive sulphide deposits : exploration and environmental aspects
51	Peters et al	Environmental site characterization using hyperspectral data: The International Smelter area and Bauer Mill, Utah
52	Pirlo and Giblin	Application of groundwater geochemistry to exploration for paleochannel roll front uranium, Frome Embayment, South Australia
53	Pontual et al	How useful is ground based hyperspectral data for the geochemist?
54	Porto et al	Supergene gold mobility at the Mount Joel Prospect, Western Australia
55	Prieto y Duitama	Environmental impact and acid drainage related to mineral exploitation: a case study in Cundinamarca Department, Colombia
56	Reis et al	Application of geostatistical methods to the recognition of geochemical anomalies in the Montemor-o-Novo area. Southern Portugal
57	Robertson	Dispersion into the Tertiary Southern Cross Formation sediments from the Scott and Cindy lodes, Pajingo, N.E. Queensland
58	Rogers	"Doughnuts" in the Desert : Success in the Application of Partial Extraction Geochemistry to Deep Cover Mineral Exploration
59	Rugless	MAGSAM <sup>®</sup> : An Effective Geochemical Exploration Tool for PGM Mineralisation
60	Sergeev and Gray	Gold redistribution in the regolith at the Twin Peaks and Monty Dam deposits, Western Australia
61	Sharma	Fluoride problem in geothermal waters of India
62	Simon and Okujeni	Lithogeochemical Vectors Associated with the Kabanga Ni-Cu Deposit in North Western Tanzania
63	Stanley and Radford	Primary dispersion haloes about the Mt. Charlotte mesothermal au-quartz vein system, Kalgoorlie, Western Australia: Implications for distal lithogeochemical exploration parameters and deposit genesis
64	Stanley et al	Primary lithogeochemical alteration haloes associated with the Cannington Broken Hill-type Ag-Pb-Zn sediment hosted massive sulphide deposit, Mt. Isa Inlier, Queensland: Implications for genesis and mineral exploration
65	Stanley	Objective assessment of new analytical geochemistry exploration methods: Distinguishing between scientifically valid approaches and 'witching sticks'
66	Steenfelt	Geochemical maps of West Greenland: signatures of environments with gold, high- technology metals and kimberlites
67	Taufen	Enhancing effectiveness and success rates in modern exploration
68	Townley et al	Gold exploration in covered areas: Gold nugget morphology and core crystallochemistry as an exploration aid
69	Townley	Fluid Inclusion Petrography and Microthermometry as an Assisting Tool in Exploration: An Example for Precious Metals Epithermal Mineralization in the Chilean Patagonia
70	Wildman et al	Partial and selective extraction studies in the Yandal Greenstone Belt, Yilgarn Craton, Western Australia
71	Williams and Gunn	Exploration for epithermal gold mineralisation in the Andes of Ecuador using enzyme leach soil analysis
72	Xueqiu et al	Wide-spaced geochemical survey in arid saline terrenes, Northwestern China
73	Zinbi et al	New discovery of gold mineralization in Bleida Mine (South of Morocco) using geochemistry tool.

INDICE-INDEX (BURLINSON-FLUID INCLUSIONS FOR EXPLORATION)			
N٥	AUTHOR-AUTOR	TITLE-TITULO	
1	Abarch	Abitibi belt, Canada	
2	Abarch	Archaen Au	
3	Abarch	Location Map – Australia	
4	Agrium	Decrepitation results of 4 samples from the Agrium mine, Ont. Canada	
5	Beaver	Au/Cu mineralised magnetite, Upper Beaver, Ontario	
6	Burbdm	An instrument for fluid inclusion decrepitometry and examples of its application	
7	Burblack	Decrepitation as an aid to microthermometry	
8	Burcot	Decrepitation studies in gold exploration. A case history from the Cotan prospect, N.T.,	
9	Burind	The recognition of variations in sample suites using fluid inclusion decrepitation - applications in mineral exploration	
10	Comp	Comparison of various magnetite & haematite types	
11	Customs	Customs requirements for samples forwarded to Australia	
12	Decbib	Bibliography of recent Decrepitation articles	
13	Decdesc	The decrepitation method - What is it and why use it?	
14	Decint	Decrepigram Interpretation Guide	
15	Decrep	Decrepitation in Exploration	
16	Decsam	Decrepitation sample specifications	
17	Feox	Fe Oxide decrepitation at Various locations	
18	Gbmz	Great Bear Magmatic Zone, North West Territories, Canada	
19	Guide	Decrepigram Features	
20	Howa87	Fluid inclusions: Their potential as an exploration tool for Archaean gold deposits	
21	Hum	Magnetite at Humboldt, Nevada, USA	
22	Igabspa	20th IGES, Santiago, Chile May 2001 Spanish abstract	
23	Igesabs	Fluid Inclusions for exploration - the acoustic decrepitation method	
24	Lyon	Lyon Fe/Cu/Au skarn, Nevada, USA.	
25	Mavjge	Comparison of decrepitation, microthermometric and compositional characteristics of fluid inclusions in barren and auriferous mesothermal quartz veins of the Cowra Creek Gold District, New South Wales, Australia.	

# The 20th International Geochemical Exploration Symposium (IGES), "Geochemistry and Exploration 2001 and Beyond", Santiago de Chile - May 6th to May 10th, 2001

26	Oral	Additional images from the oral presentation
27	Oral	Decrepigram features
28	Oral	Comparison of Getchell and Vista mines, Twinpeaks, Nevada
29	Oral	Comparison of various magnetite samples
30	Oral	Cosmo Howley mine - misidentification of "chert" host rock
31	Oral	Enterprise Au mine, Pine Creek, NT : CO <sub>2</sub> -rich fluids
32	Romeral	El Romeral, Chile and other Fe-only mines
33	Sanpos	Iron Oxide hosted Au / Cu deposits
34	Sanpos	Au/Cu mineralised magnetite, Upper Beaver, Ontario
35	Sanpos	Comparison of various magnetite & haematite types
36	Sanpos	Magnetite at Humboldt, Nevada, USA
37	Sanpos	Lyon Fe/Cu/Au skarn, Nevada, USA.
38	Sanpos	El Romeral, Chile and other Fe-only mines
39	Sanpos	Skarn and Carbonatite magnetite
40	Sanpos	Au/Cu in magnetite, Tennant Ck., N.T., Aust.
41	Skarn	Skarn and Carbonatite magnetite
42	Start	Decrepitation in Exploration
43	tennant	Au/Cu in magnetite, Tennant Ck., N.T., Aust.
44	twinck	Summary of Fluid inclusion results on samples collected at Twin Creeks mine, Nv, May 2000
45	victory	Vein quartz at Victory Au mine, Kalgoorlie

## Origin of Manganese and base metal anomalies in Paleozoic cover rocks overlying the eastern margin of the Arabian Shield

#### A. M. Al-Saleh

#### Geology Department, King Saud University, Riyadh, Saudi Arabia; alsaleh@ksu.edu.sa

Weak mineralization of Mn, Cu, Zn and other elements was reported from the Permocarboniferous Unayzah Formation that directly overlies the Arabian Shield at its eastern end. A persistent layer of lateritic paleosol separates the two units, and appears to have also some localized anomalies of a number of the elements of interest. The Unayzah is a thin unit (typically < 30 m) showing rapid lateral changes in thickness and lithology. At Sufayrat, where the highest Mn and Cu anomalies were reported, it is mainly dolomitic with rare stromatolite structures still preserved.

The bulk chemistry and SEM results confirm the lack of substantial mineralization despite the high background values for Mn and the base metals. Mn-rich rocks are found throughout the Unayzah, and usually show no corresponding enrichment in Cu or Zn except in stromatolitic layers.

No signs volcanic or hydrothermal activity are reported from the Upper Paleozoic of Arabia, and it is suggested here that seawater was the main agent in transporting and precipitating Mn and base metals in two separate phases. The first phase involved the leaching of Mn by cool and acidic fluids emanating from oxidized sulphide lenses and later precipitation in response to increasing Eh and the presence of cyanobacteria in stromatolitic mats. The second, and weaker, phase is one in which marine fluids pass through anhydrite layers thus becoming more oxidizing and capable of carrying Cu in solution to be precipitated as it encounters reducing conditions within organic-rich layers. It is unlikely that any of these mechanisms was capable of creating economically-viable deposits at the base of the Phanerozoic cover in Central Arabia.

## Statistical analysis of hydrogeochemical data from a survey in Nova Scotia, Canada

G. Bonham-Carter<sup>1</sup>, B. Daneshfar<sup>2</sup>, Q. Cheng<sup>3</sup>, G. Hall<sup>1</sup>, and P. Rogers<sup>4</sup>

<sup>1</sup>Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8; <u>gbonhamc@NRCan.gc.ca</u>
<sup>2</sup>Dept of Mineral Exploration, Tehran Polytechnic University, Tehran, Iran
<sup>3</sup>Dept of Earth & Atmospheric Sciences, York University, Toronto, Ontario M3J 1P3
<sup>4</sup>Chavin Consulting Limited, Shubenacadie, Nova Scotia B0N 2H0, Canada

A suite of 730 water samples collected in 1994 from streams in predominantly sedimentary rocks (Cambrian to Carboniferous) of central Nova Scotia were analysed by ICP-MS, hydride-ICP-MS, ICP-ES and ion chromatography for a large number of chemical variables. The purpose of the study was to evaluate the utility of hydrogeochemical surveys for mineral exploration, and to generate baseline data for environmental assessment.

A conventional principal components analysis (logarithmic transformation on most variables) shows that the main element associations reflect the influence of bedrock lithology. The dominant factor is a rare-earth signature, present across a variety of lithologic units. Samples collected over formations in the Windsor Group (Carboniferous carbonates, evaporites) are dominated by a Sr-Ba-SO<sub>4</sub>-pH-alkalinity-U-Cu association. A TOC-V-Se-Cr-Pb-Fe-Be association is particularly strong in the Pictou Group (Carboniferous sandstones, shales). A Na-Cl-Rb-K association is evident along the coast of the Bay of Fundy (proximity to seawater) and some Windsor units. The Halifax Formation (Cambrian slates) have a Mn-Ni-Co-Zn-As association. In order to get a better picture of the mineralization signatures, these general geological effects need to be suppressed.

One approach to this problem is to examine the less important principal components-often minor factors can reveal significant mineral indicators. The problem with this approach is that it is often difficult to be sure whether the effects are real, or simply data noise.

In some situations, catchment basin analysis may be a good tool for removing geological backgroundbut this requires a good DEM and a catchment basin map. In this study we use two new methods that are implemented in GeoDAS–a new GIS software tool for geochemical exploration data analysis. The first approach is a weighted PCA analysis, with weights generated from spatial data layers in the GIS. Weights such as proximity to geological units, lithologic contacts, the coastline and faults provide enhanced PCA solutions that in some instances improve the interpretation. The second approach is to filter single-element maps using the multifractal S-A method (filters based on analysis of logtransformed 2-D power spectrum), and carry out PCA on the high frequency information (making the assumption that the low frequency information is controlled mainly by geological background).

Information about GeoDAS can be obtained from: http://www.gisworld.org/geodas/

#### **Environmental geochemical Atlas of Southern Sardinia**

M. Boni<sup>1</sup>, B. De Vivo<sup>1</sup>, A. Lima<sup>1</sup>, A. Marcello<sup>2</sup>, and S. Pretti<sup>2</sup>

<sup>1</sup>Dip. Geofisica e Vulcanologia, Università di Napoli "Federico II"; <u>boni@unina.it</u> <sup>2</sup>Dip. Geoingegneria e Tecnologie AmbientaliUniversit 24à di Cagliari

The island of Sardinia has been for several centuries the most important mining district of Italy. As elsewhere around the world, one of the consequences of the mining development was a major metal pollution. The most affected areas are the southwest (Iglesiente-Sulcis) and the southeast (Sarrabus).

The geology of this part of Sardinia is largely dominated by Paleozoic lithotypes, both of sedimentary as well of igneous and metamorphic origin. Second in abundance are Tertiary and Quaternary volcanics, together with sedimentary rocks of similar ages. In the Iglesiente-Sulcis area there are the most important ore deposits of the island, some of them exploited until few years ago. These ores, hosted in the Lower Cambrian carbonates, contain sphalerite-galena>barite, with variable pyrite contents, and can be genetically ascribed partly to Sedex, and partly to MVT deposits. In the Sarrabus also distinct Ordovician-Silurian stratabound mineralizations occur. They contain antimonite, scheelite and arsenopyrite in porphyries, as well as Zn-Pb(Ag)-Cu sulfides in metasedimentary rocks. In both Iglesiente and Sarrabus, Ba, Pb, F and Ag occur in veins, associated to Variscan magmatites.

The environmental geochemical atlas of Southern Sardinia (Foglio Cagliari, scale 1:250.000), has been compiled as part of a general project comprising geochemical atlas covering the Italian territory. For the Foglio Cagliari geochemical data files, generated in the years 70's and 80's by mineral exploration projects, have been used, complemented with new representative sampling in the areas not sampled before. The atlas contain single elements (55), factor scores (factor analysis) and chemically compatible combined elements (by groups of three) distribution maps. It contains also land use risk maps for a selected number of elements.

The resulting geochemical maps reflect the type of control determining the occurrence of anomalies and/or deficiencies in specific areas of the territory, i.e. ore deposits, lithologies, and anthropogenic factors. For many single elements (e.g., Ag, As, Cd, Cu, Fe, Mn, Pb, Zn, Sb) the distribution of anomalous values reflects the ore occurrences, mostly in the Iglesiente-Sulcis but also in Sarrabus. Other element distributions reflect the lithologies. This is the case, e.g., of the Mg distribution, which assumes a marker character in the Iglesiente-Sulcis for the dolomite-rich Gonnesa Group and for elements such as Be, B, Y, La, which reflect the occurrence of Variscan calc-alkaline granites, mostly in the Sarrabus and subordinately in the Sulcis area. Other elements show anomalies that might indicate the presence of small epithermal (Au) mineralization: this is the case of As and Hg in Oligocene - Miocene andesites. The anthropogenic control is clear for Bi, Sb and Zn anomalies, as a response to the presence of a metallurgical industrial settlement (near Portovesme); for Cu anomalies in the agricultural areas, due to the use of chemicals, and for the anomalies of various metallic elements near Iglesias and in the Giba graben, as a response to the presence of mine dumping activities. The land use risk maps have allowed to individuate areas "potentially at risk" for a selected number of elements (As, Cd, Cu, Hg, Ni, Pb, Zn).

## Radon in groundwaters from Guarany Aquifer, South America: Environmental and exploration implications

#### D. M. Bonotto and L. Caprioglio

Departamento de Petrologia e Metalogenia, Instituto de Geociências e Ciências Exatas, UNESP, Av. 24-A, No. 1515 – C.P. 178 – 13506-900-Rio Claro-SP-Brazil; <u>dbonotto@rc.unesp.br</u>

Groundwater and sandstone samples were analyzed for radon in Guarany aquifer, Paraná sedimentary basin, South America. The sampling of the Guarany aquifer was performed at 53 localities from São Paulo, Mato Grosso do Sul, and Paraná States in Brazil, where 61 groundwater samples were collected from pumped tubular wells previously characterized in terms of physical, chemical, and U-isotopes analyses. Fresh samples of sandstones from lithofacies occurring at Paraná basin (Botucatu and Pirambóia Formations) were collected and subjected to Rn release in the laboratory under controlled conditions.

The groundwater samples (1 kg) were collected in glass bottles fitted with inlet and outlet stopcocks. 500-g aliquots of crushed sandstone (0.25-0.50 mm) were weighed and also placed into 1-L glass bottles fitted with inlet and outlet stopcocks. The rock specimens were immersed in a surrounding distilled water phase equilibrated with the atmosphere (CO<sub>2</sub> partial pressure about 10<sup>-3.5</sup> atm and pH = 5.8) and at room temperature (~25 °C). About 40 days after sealing, the <sup>222</sup>Rn was extracted by circulating a stream of Rn-free air through the sample container to purge the water phase of its accumulated <sup>222</sup>Rn. The technique used for quantifying <sup>222</sup>Rn was based on the emanation procedure, consisting on the 1) removal of radon from the sample, 2) transfer of radon to a scintillation flask, and 3) detection of radon by scintillation counting.

The obtained data for dissolved radon in the analyzed groundwaters ranged between 3 and 3303 pCi/L, being lognormally distributed, with a modal value of 1315 pCi/L, and a median value of 330 pCi/L. When the obtained data were compared with the limit of 300 pCi/L proposed by the Environmental Protection Agency of the United States for dissolved radon in drinking water, it was possible to verify that the limiting value was exceeded for several samples, requiring special attention for the usage of the water. Statistical tests of correlation between the dissolved radon content and other available data for the analyzed waters practically indicated significant values only for sulfate, conductivity, and dry residue, suggesting a probable occurrence of radium dissolution at the rock-water interface, with a consequent enrichment of radon in the liquid phase.

The results of the <sup>222</sup>Rn leakage experiments for sandstones of Pirambóia and Botucatu Formations allowed to estimate fractions between 0.36 and 0.84 of Rn atoms formed in the solid that escaped from the solid, which allowed to use a theoretical modeling for evaluating the Rn content in waters. So, when the average fraction corresponding to 0.63 was utilized, it was possible to generate a value of 1390 pCi/L for the <sup>222</sup>Rn in water, which is very similar to the modal value of 1315 pCi/L obtained for the groundwaters from Guarany aquifer. This interesting finding told us that the theoretical model is perfectly reliable to adjust laboratory and field data. Furthermore, the use of the same modeling for exploration purposes suggested that the studied part of the aquifer bathed strata with "normal" U mineral content, i.e. not an accumulation of U of economic importance.

## A systematic classification of regolith gold

#### **R. J. Bowell<sup>1</sup> and Ph. Freyssinet<sup>2</sup>**

<sup>1</sup>SRK Consultng, Summit House, 9 Windsor Place, Cardiff CF10 3RS, Wales; <u>Srk003@aol.com</u> <sup>2</sup>BRGM, Orleans Cedex 2, France; <u>Freyssinet@exchange.brgm.fr</u>

Gold grain morphology and chemistry are essential tools in the study of supergene deposits and provide useful information not only for academic studies, but also for exploration, mining and optimisation of ore processing. The intensive research on supergene deposits and particularly lateritic deposits in the past decade has resulted in an extensive knowledge of the main types of supergene deposits and on the nature and location of gold remobilization processes. The mechanical processes responsible for the modification of gold grains are subordinate to chemical processes. This is why most scientific studies on the behaviour of gold in weathered terrain are directed at remobilization of primary gold and at the re-precipitation of neogenic secondary gold particles.

In weathering profiles gold can be particularly mobile, at two dissolution fronts;

- (i) the ferruginous zone at the top,
- (ii) and at the oxidation front.

Independently of these two dissolution fronts, gold also be intensively remobilized in highly saline environments.

Several types of gold remobilization occur in weathering profiles depending strongly on the present-day and palaeo-climatic situations. The remobilization process of gold in savannah systems and particularly in duricrust profiles occurs under different length of time, hydrologic and physico-chemical conditions than under more humid climates. In duricrust profiles, the strong dissolution is a process that develops in the vadose zone with little re-precipitation. Secondary gold reprecipitates at the base of the duricrust or in the mottled zone where conditions are less oxidising, preferentially on Fe-oxides, probably because of a better adsorption capacity of gold on goethite than on kaolinite. Secondary gold in savannah systems is micro-sized, because of the vadose environments that do not allow large crystalline growth and favour spherical or irregular secondary shapes.

Under more humid conditions, like in latosols or stone line profiles, gold remobilization is a very active process, even in recent soils. Corrosion is often uniform on the grain surface, reflecting a more humid environment. Gold in latosols tends to concentrate either as adsorbed gold on organic matter in the humic horizons or as secondary gold in deeper horizons. As in duricrust, secondary shapes are mostly micro- sized spherules, but bigger automorphic crystals or irregular aggregates can develop, probably because the B horizon of these soils are seasonally saturated. Organic matter in humid tropics plays an important role in Au chelation through fulvate, ammonia and cyanide chelates, the latter originating from protein degradation.

In Western Australian supergene deposits, gold is strongly dissolved and re-precipitated within the saprolite due to the highly saline conditions. This process develops independently of the classical dissolution fronts of gold in active lateritic profiles. In this case, both gold corrosion and dissolution occur in water saturated environments and implies a large dispersion. Corrosion is of uniform type, secondary particles are predominant and can exceed several hundreds of microns.

The study of gold morphologies require a statistical approach to be significant, particularly to estimate to importance and nature of corrosion processes. Corrosion features of primary gold are dependent of the Au dissolution conditions like vadose or saturated environments. Secondary gold particles are usually easy to distinguish from primary grains by their shape, aspect and chemical

composition. However secondary shapes seem not to be dependent on specific weathering environments. Automorphic crystals, spherical shapes or irregular aggregates can be found in most of the different weathering profiles; except pseudo-hexagonal plates, which are characteristics of highly saline environments.

## Wasterock characterization and management: A case study from New Mexico

R. J.Bowell<sup>1</sup> and J. V.Parshley<sup>2</sup>

<sup>1</sup>SRK Consulting, Summit House, 9 Windsor Place, Cardiff CF103SR, UK; <u>Srk003@aol.com</u> <sup>2</sup>SRK Consulting, Suite 300, 5250 Neil Road Suite 300, Reno, NV 89502, USA;

jparshley@srk.com

The Copper Flat Mining Project, in Hillsboro County, New Mexico is currently being developed by Alta Gold Inc. As a part of this a comprehensive geochemical characterization of waste rock has been undertaken representing all lithogies and alteration types in the deposit area. These studies involved petrographic and mineralogical evaluation, field's estimates of reactivity (paste pH and EC) multi-element analysis, modified Sobek ABA, and NAG analysis. Kinetic tests were used to evaluate the relative rates of sulfide oxidation and consumption of buffering material.

To provide detailed evaluation of neutralization potential, a series of samples were also assessed by a modified carbonate NP method. Mineralogical and Whole Rock, data complemented all ARD testwork. It was observed that NAG tests were better indicators of acid generation than Sobek – style ABA methods.

The assessment work was used to clarify waste rock, according to acid generation potential which was:

• Transtional material, this has a strong potential for acid generation, expected to generate an acidic leachate with altered metals early in the project life.

• High Sulfide rocks, this has a moderate potential for acid generation: slow reaction and eventual discharge of acid and elevated metals after consumption of buffering agents present.

• Low Sulfide rocks that have a weak potential for acid generation: leachate water may possible turn acidic in the long term (>20 years)

• Oxide rocks, have little or no potential to generate an acid discharge and may act as a buffering material.

The classification was related to geological and field analytical parameters so that a pragmatic, reliable, method could be developed to clarify waste rock and assist in management for operations and closure.

## A Mass Balance Approach to estimate the dilution and removal of pollutants in the Lago Junin drainage, Central Highlands, Peru

R. J. Bowell<sup>1</sup>, A. Brigneti<sup>2</sup>, R. Dorey<sup>3</sup>, E. Lira<sup>2</sup>, and J. Torrealva<sup>4</sup>

<sup>1</sup>SRK Consulting, Summit House, 9 Windsor Place, Cardiff CF10 3RS, Wales; <u>Srk003@aol.com</u>

<sup>2</sup>SRK Consulting, Av.Paseo de la Republica 6243, San Antonio, Miraflores, Lima, Peru
<sup>3</sup>SRK Consulting, Suite 3000, 7175 W. Jefferson Ave., Lakewood, Colorado CO80235, USA
<sup>4</sup>SRK Consulting, Suite 115, 3275 W. Ina Road, Tucson, Arizona, AZ85741, USA

The prediction of pollutant removal within the Rio Ragra, Rio San Juan and Upamayo dam has been calculated using a mass balance approach coupled with equilibrium thermodynamic modelling. This drainage system connects the historic Cerro de Pasco mining district with the pristine Lago Junin ecosystem. At present the system shows no sign of impact from mine drainage and this study aimed to assess if any future potential existed from the precipitated sediments and tailings accumulated in the drainage system, and if so how it could be mitigated.

The Rio Ragra is an acidic (pH 1.8-2.9 su), metal-sulfate rich water along its entire course due to the impact of supernatant water escaping from old tailings impoundments and waste rock stockpiles at Mina Cerro de Pasco at the head of the river. Typical metal values include Fe up to 1000 mg/l, Mn up to 200 mg/l, Zn up to 150 mg/l, Pb up to 23 mg/l, Cu up to 10mg/l and trace levels of As, Sb, Ag, Cd and Hg. Additionally the water has high sulfate (up to 4000 mg/l), dissolved and suspended solids. The Rio San Juan shows good water quality above the confluence with the Rio Ragra with high pH (7-8 su), negligible salts and metals and low suspended (less than 112 mg/l). When the Rio Ragra merges with the Rio San Juan some dilution occurs but is not sufficient to offset the total impact. Consequently the Rio San Juan has a resultant chemistry of low pH (~ 3 su), high sulfate (460-1000 mg/l), iron (50-130 mg/l), zinc (~20 mg/l), manganese (14-60 mg/l), copper (0.8-5.9 mg/l), arsenic (0.34-1 mg/l), and cadmium (0.05-0.09 mg/l). Additionally the river has elevated suspended (up to 500 mg/l) and total (up to 1600 mg/l) solids. Further impacts occur downstream from limekilns and from drainage emanating from the Mina Colquijirca complex.

The Upamayo dam area reflects the build-up of metal-rich sediments that would be expected from the drainage quality of the Rio San Juan. Much of the metal recharge appears during high flow events in the wet season and is likely to represent flushing of metal-rich sediment particles into the dam from the Rio San Juan. Due to its connection with the Lago Junin the metal recharge occurring in the Upamayo area during the wet season is able to cause some impact in the Lago Junin water quality. No metal showed conservative behaviour down the river but mass balance calculations reflected the release and attenuation mechanisms active in the system and provide a reliable guide to predicting future trends in water quality.

## Three-dimensional investigations of gold dispersion and regolith at the Argo and Apollo deposits, Kambalda, Western Australia

#### A. F. Britt and D. J. Gray

Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME) c/- CSIRO Exploration and Mining, Private Bag 5, Wembley WA 6913, Australia; <u>d.gray@per.dem.csiro.au</u>

The Argo and Apollo Au deposits are located approximately 28 km SE of Kambalda and about 600 km E of Perth, Western Australia. The Apollo deposit is about 500 m NE of Argo. The deposits are hosted by the Condensor Dolerite, in the western limb of the St Ives Antiform, part of the Archaean Norseman-Wiluna Greenstone belt of the Yilgarn Craton. Mineralization is associated with albite alteration within two north-trending, west-dipping, mylonitic shear zones. A large palaeochannel, up to 60 m deep, occurs to the south of Apollo, with Argo outcropping on the palaeochannel's northern slope. The channel is infilled with Eocene and Miocene sediments and the entire area, now relatively flat, is overlain with more recent alluvium.

WMC Ltd, provided highly consistent regolith logging and geochemical data. Bedrock, saprock, saprolite, clay and ferruginous clay were recognised from the residual profile. The overlying sediments were split into basal gravels and sands, lower lake clays, lignite, middle lake clays, spongolite, upper lake clays and alluvium. These units can be correlated with regional stratigraphy.

The base of weathering deepens sharply along the strike of the two north-trending shears associated with Argo and Apollo and is also broadly deeper below the palaeochannel. Of the major residual units, the clay is generally thickest, but it has been truncated in the palaeochannel. The saprolite and, in places, the saprock have also been truncated, suggesting incision of the palaeochannel post-dates the major weathering. The thin ferruginous clay is mostly confined to the upland areas and the hill flanks of the pre-Eocene topography.

The Argo and Apollo deposits have patchy Au concentrations greater than 1 ppm within the bedrock and Au is enriched in the saprock, saprolite and lower residual clay. Sections through the deposits, and calculations of Au concentration within the weathering profile, indicate that Au is depleted above 275 mRL elevation (20 to 30 m below surface). The depletion appears to be of the order of 80% at Apollo and > 90% at Argo.

Within the palaeochannel sediments, the basal gravel and, to a lesser extent, the sand are strongly enriched in Au (means of 1640 ppb and 650 ppb, respectively). Above these units, Au concentrations decrease progressively through the palaeochannel sediments: lower lake clays (285 ppb), lignite (170 ppb), middle lake clays (135 ppb), spongolite, which is particularly low in Au, (30 ppb) and upper lake clays (100 ppb). Mean Au concentration of 40 ppb calculated for the alluvium is postulated to be erroneously high, due to cross-hole contamination. The greatest Au concentrations within the sediments occur where they abut the mineralised basement.

This research results from collaboration between CRC LEME and the Australian Mineral Industries Research Association Ltd. CRC LEME is established and supported by the Australian Government's Cooperative Research Centres Program.

### Fluid Inclusions for exploration - the acoustic decrepitation method

#### K. Burlinson

#### P.O. Box 37134, Winnellie, NT, 0821, Australia; kgb@synix.com.au

An instrument to record acoustic decrepitation of fluid inclusions has been developed, incorporating a standard desktop computer with additional control electronics. The instrument provides about 15 analyses per day on crushed samples so that fluid inclusion data can be obtained for use in exploration programmes at modest cost. The presence of  $CO_2$ -rich inclusions can be easily discerned and suites of samples can be compared empirically to discriminate between mineralised and barren samples. Although quartz is the most common mineral used, opaque minerals such as feldspars, iron oxides and sulphides can also be analysed using this technique.

Acoustic decrepitation of quartz samples containing CO2-rich fluid inclusions gives a distinctive

peak at low temperatures from  $150^{\circ}$  to  $300^{\circ}$ C, whereas samples lacking CO<sub>2</sub>-rich inclusions show little or no acoustic decrepitation at these temperatures. This provides an approximate but quick means of determining the CO<sub>2</sub> contents of fluid inclusions, which is particularly relevant in Au exploration. The relationship between CO<sub>2</sub>-rich fluids and gold mineralization has been well documented in many deposits including the Abitibi in Canada, the Kalgoorlie region in West Australia and the Victorian goldfields, Australia.

At the Victory mine near Kalgoorlie, Western Australia, several different generations of quartz veins are defined on the basis of orientation and some workers interpret the Au mineralization to be related specifically to the horizontal quartz vein sets. Acoustic decrepitation shows that both horizontal and vertical quartz veins within the ore zones contain  $CO_2$ -rich fluids, whereas veins remote from the known ore zones rarely contain  $CO_2$ -rich fluids, regardless of their orientations. Determination of  $CO_2$  contents by acoustic decrepitation would be a better guide to mineralization than reliance on the physical orientation of the quartz veins in this deposit.

The acoustic decrepitation method can also be used on opaque minerals, where normal microthermometric methods are inapplicable. Haematite-magnetite systems with and without Au mineralization have been studied at Tennant Creek, NT, Australia; Nevada, USA and the Abitibi Province, Canada.

At Tennant Creek, Au occurs in massive haematite-magnetite-chlorite host rocks and acoustic decrepitation shows marked variations at small scales, indicating complex inhomogeneity of fluids within single ironstone bodies which were previously thought to have been of uniform origin. Many of the haematite samples from these deposits show intense decrepitation, indicating abundant fluid inclusions. Had this haematite been derived by supergene oxidation of precursor magnetite, as has been proposed in some studies, the original inclusions in the magnetite would have been eradicated. Thus much of the haematite in these deposits must be of primary origin.

At the Upper Beaver mine in the Abitibi province, Canada, auriferous magnetite displays intense acoustic decrepitation but magnetite from nearby barren ironstones lacks decrepitation. Samples from non-auriferous magnetite and ironstones in Nevada may show decrepitation, but many are inactive. In contrast, skarn magnetite associated with low grade Au-Cu mineralization at Lyon, Nevada shows moderately intense decrepitation with major variations between samples several metres apart, similar to the variability seen in the samples from Tennant Creek.

Although there is little understanding of fluid inclusions in opaque minerals, acoustic decrepitation shows that the iron oxide systems can be quite complex and this technique can aid in discriminating between otherwise indistinguishable ironstones during exploration.

## Groundwater flow in playa lake environments: Impact on gold and pathfinder element distributions in groundwaters surrounding mesothermal gold deposits, St Ives Area, E. Goldfields, Western Australia

#### M. L. Carey<sup>1,2</sup>, D. C. M<sup>c</sup>Phail<sup>1</sup>, and P. M. Taufen<sup>3</sup>

<sup>1</sup>Monash University, Clayton Victoria Australia; <u>mcarey@mail.earth.monash.edu.au</u> <sup>2</sup>WMC Resources, Perth, Western Australia <sup>3</sup>WMC Resources, Colorado, Denver United States

The St Ives area, Eastern Goldfields, Western Australia, is located on the edge of a playa lake and is the site of numerous Archaean mesothermal gold deposits. A number of surveys have been completed to assess the applicability of hydrogeochemistry as an exploration tool in this and similar hypersaline groundwater regimes throughout the Eastern Goldfields of Western Australia.

The St Ives regional hydrogeochemistry survey is the most recent and comprehensive of these surveys, covering a large portion (~100km<sup>2</sup>) of the St Ives area with 1km by 1km spaced sampling wells. The results of the survey illustrate a large gold only anomaly located down flow of the three million ounce Junction orebody. None of the other elements commonly thought to be pathfinders for mesothermal Au mineralisation (As, Sb, Se, Bi, Mo, W, Ag, Cs, Te, Pb) gave a response. Mo, Bi, Te and W concentrations are too close to the detection limits of the technique used for the data to be reliable, however meaningful data was obtained for the remaining elements. The lack of response in these elements may be because evaporative processes are exerting a strong control on their distribution as indicated by the strong correlation between concentrations of these elements and salinity.

No gold or pathfinder response was identified over the Argo / Apollo / Diana orebodies which are all located in a small region commonly referred to as the Condenser region. The lack of groundwater anomalism is in contradiction to an earlier survey over the same area which identified a strong gold anomaly over the Condenser area. This is interpreted to be the result of different groundwater types being sampled in the two surveys.

In the St Ives area, three different groundwater types have been identified; regional groundwater, transitional waters and hypersaline brines. The basic groundwater cycle for the area sees regional groundwaters flowing from east to west towards the playa lake (Lake Lefroy). Upon reaching Lake Lefroy, the already saline regional groundwaters undergo evaporation to form hypersaline brines. Due to the brines having a higher density than the surrounding groundwaters, they tend to sink and then upon reaching the impermeable weathered / fresh rock interface, flow back under the regional groundwaters in an easterly direction. The density difference between the two groundwater types drives convective mixing forming the transitional waters in a broad zone approximately three kilometres from the edge of the lake.

The Condenser region is located at the interface between the regional groundwaters and hypersaline brines, within the zone of transitional waters. In the recent St Ives regional survey, groundwaters were sampled from the bottom of the sampling wells and as a result were either saline brines or transitional waters. These waters cannot be considered to be directly down flow from mineralisation and thus their chemistry does not reflect interaction with mineralisation. In the previous survey over the Condenser region, shallow samples were collected and were all regional groundwaters. These waters have interacted with gold mineralisation and have anomalous

groundwater gold concentrations. The results of the two surveys illustrate the importance of understanding groundwater flow regimes in planning and interpreting hydrogeochemical surveys.

# Exploration geochemistry of stream sediments and surficial deposits at Pascua-Lama

#### E. Chastain and W. K. Fletcher

Earth & Ocean Sciences, University of British Columbia; <u>fletcher@unixg.ubc.ca</u>

Pascua-Lama is a 17.1 moz Au and 560 moz Ag high sulfidation epithermal gold deposit (Barrick, 1999) in the High Andes of Argentina-Chile. Talus and alluvial fans flank deeply incised valleys and debris flows infill valley floors: glacial till is preserved locally. Surficial materials and stream sediments were sampled, sieved into several fractions, and analyzed for gold by FA-AAS and other elements by ICP-MS after total, aqua regia and a weak hydroxylamine leach. Heavy mineral concentrates (HMCs) were analyzed by NAA and SEM-EDS. Water samples were analyzed by ICP-MS.

In surficial media less mobile elements of the 'epithermal suite' (Au, Ag, As, Pb, Hg, Sb, Te, Mo and Bi) occur in anomalous concentrations in talus cones and alluvial fans close to the deposit. Conversely, more mobile elements (e.g., Cu and Zn) are depleted close to the deposit. Debris flows and glacial till have transported anomalous material up to 10 km from source. Maximum gold concentrations occur in the finer fraction of the surficial deposits. Till has the lowest anomalous concentrations for most elements, including gold, and the lowest geochemical contrast between anomalous and background values. Stream waters can be extremely acidic with very high dissolved metals.

In sediments, the highest and most consistent concentrations of gold are in the finer fractions. Fine fractions also give the most strongly anomalous gold values at distal sites. Other elements fall into two groups: 1) those similar to Au in downstream profiles including Ag, As, Hg, Sb, Bi, Pb, Te, and S; and, 2) elements (e.g., Cu) that correlate with pH, and have concentrations inversely related to dissolved metal concentrations. Elements of both groups have been identified in HMCs but concentrations of the former are generally enhanced in sediments compared to other surficial media.

Geochemical patterns at Lama-Pascua have developed by mechanical and chemical processes. Gold and elements in HMCs are enriched as light minerals are selectively removed during transport of surficial materials. Thus, till, with the greatest abundance of fines, has the lowest geochemical contrast. Conversely, sediments have the least fines and the highest concentrations of HMC elements. Mobile elements such as Cu have similar concentrations in surficial deposits and stream sediments, but are leached under extremely acidic conditions close to the deposit.

For regional surveys gold (accompanied by Ag, As, Pb, Hg, Sb and Bi) provides the strongest and most consistent anomalies in the finest fractions of stream sediment regardless of pH conditions. At distal sites with near-neutral pH values Cu and Zn anomalies are also present with the best contrast in the hydroxylamine leach. Based on sediment texture,  $\sim 2 \text{ kg} - 2 \text{ mm}$  field samples from medium or high energy sites should provide 50 g of -75µm material for determination of gold by FA-AAS plus ICP analysis. Stream pH should be measured and analysis of stream waters could be a valuable adjunct to sediment data. Follow-up to drainage anomalies would involve base-of-slope sampling of talus and alluvial fans and should consider the possible depletion of mobile metals close to a deposit.

Reference: BARRICK, 1999. Pascua property background/overview, www.barrick.com.

## GeoDAS – A New GIS System for Spatial Analysis of Geochemical Data Sets for Mineral Exploration and Environmental Assessment

Q. Cheng<sup>1</sup>, G. Bonham-Carter<sup>2</sup>, G. L. Raines<sup>3</sup>

<sup>1</sup>Department of Earth and Atmospheric Science, Department of Geography, York University, Toronto, Ont. Canada, M3J1P3 <sup>2</sup>Geological Survey of Canada, Ottawa, Ont. Canada, K1A0E8 <sup>3</sup>U.S. Geological Survey, MS 176 c/o Mackay School of Mines, UNR, Reno, NV 89557, USA

Geochemical Data Analysis System (GeoDAS) is a newly developed system for spatial analysis of geochemical data sets for mineral exploration and environmental assessment that incorporates some GIS functionality. For geoscientists it is designed with new methodologies and a highly interactive and graphical, user-friendly interface. It provides many unique features not available in commercial packages. An advanced functionality has been implemented for viewing and selecting subsets in dynamically linked map view, one or more scatterplot views with 2 or 3 variables, or a table. These three linked views goes much further than is currently available in other GIS systems such as Arcview or MapInfo and is particularly valuable for decomposing geochemical samples that are often a mixture of populations reflecting different geochemical processes into groups for separate analysis. In addition to the common data interpolation methods, such as inverse distance weighting and kriging, the system includes a new method of multifractal data interpolation that preserves high frequency information, which is lost in most conventional methods. Non-spatial statistical functionality is provided for analyzing the difference between subsets of samples including central tendency and dispersion, percentiles, t-test, F-test, and correlation coefficient etc and statistical graphics such as box plots, scatterplots, histogram, Q-Q plot, and dot maps. A key aspect to GeoDAS is the implementation of new techniques for finding breaks in populations, concentration-area (C-A) and spectrum-area (S-A) multifractal methods. These methods do not rely simply on information from a histogram (or Q-Q plot, etc), but incorporate geometric and spatial effects. The S-A method is particularly valuable for separating a geochemical map into components, such as background and anomaly. A multivariate association module includes principal components analysis (PCA) and a weighted PCA. In this approach, a weight variable is defined, such as proximity to known deposits, proximity to a granite, or the value of a geochemical variable that is used to weight the importance of individual samples. Weighted PCA enhances different aspects of the data than conventional PCA.

## A new spatial analysis method for geochemical mapping and anomaly enhancement by incorporating local spatial association and singularity.

#### **Qiuming Cheng**

York University, 4700 Keele Street, Toronto, Ontario, Canada, M3J 1P3; <u>qiuming@yorku.ca</u>

Creating a geochemical map from point sample data is often the first step for subsequent spatial analysis and interpretation. How to reserve the local variability of the geochemical map and to take them into account in spatial analysis is crucial not only for geochemical data visualisation but also for differentiation of anomalies from background. Most of the conventional techniques for geochemical mapping involving moving averaging point data such as inverse distance weighting and kriging smooth off the local variability of the geochemical data which may be required for extraction of geological structure related geochemical signals and patterns. This paper will introduce a recently developed multifractal technique for creating geochemical map with local structure information retained and for enhancing geochemical anomalies for anomalybackground separation. The method can take into account both spatial association and local singularity in data interpolation. It can not only create surface from point sample data but also retain the location variability (multifractality). The ordinary moving average including kriging can be considered the special case of the multifractal data interpolation method. It has shown that mineralization may cause the areas with anomalous and often singular geochemical values. Positive singular areas correspond to depletion and negative singular areas to enrichment of geochemical concentration values. A singularity index calculated by multifractal modelling can be used to characterize the local singularities of geochemical anomalies and it was incorporated into the moving average to adjust the neighbourhood statistics such that the estimated value is bigger or smaller than the ordinary average value depending on whether the location with negative or positive singularities corresponding to enriched or depleted concentration values, respectively. The geochemical concentration values of Cu, Pb, Zn, Ag, Li, Rb, Nb, Ti, Sn, Zr, Th, Sb, As, W and Au for 1948 lake sediment samples from the South-western Nova Scotia, Canada, were used to demonstrate the application of the method. The results were compared with those obtained by the ordinary kriging. The enhanced anomalies of As (ratios of the results obtained by the multifractal method and the ordinary kriging) clearly show the areas with mineralization or localized structures including faults and phase change zones in granites.

### Factors controlling the dispersion of gold in stream at Timbarra, NSW

D. R. Cohen<sup>1</sup>, A. C. Dunlop<sup>1</sup>, and T. Rose

School of Geology, University of New South Wales, Sydney NSW 2052, Australia <sup>1</sup>CRC-LEME Associates; <u>a.dunlop@unsw.edu.au</u>

Regional stream sediment surveys in the Timbarra Goldfields, involving the -2mm (BLEG) and -180µm fractions, have defined most known gold occurrences and a number of new targets. Poor correlation between Au contents of these two media and subdued responses in the vicinity of some Au-rich sediment sources are, however, common.

The Timbarra Goldfields are situated on an isolated remnant plateau, where sand-bedded streams have gradients  $<5^{\circ}$ . The surrounding escarpment has sand, rock bar and boulder-bedded stream with up to  $15^{\circ}$  gradients. Vegetation communities indicate higher rainfall on the eastern escarpment. Sulphide-poor, disseminated gold mineralisation occurs within small alteration zones, without significant quartz veining, in the Stanthorpe Adamellite. Prior to 1940, ~3t of gold was recovered from shallow alluvial and eluvial deposits. Reserves of ~10Mt@~1g/t, in the vicinity of these old workings, have been recently delineated by Ross Mining.

Wet-screened -180µm sediment, recovered from 15-20l bulk samples, with the screening water retained and evaporated, and -2mm active channel sediments were obtained from non-trap sites along streams draining Surface Hill (SH; western side of plateau) and James East (JE; eastern side), as well as alluvial terrace and soil samples. Splits of the -2mm fraction were subjected to active BLEG extraction. Remaining materials were wet-screened to seven size fractions, pulped, digested in aqua regia and determined for Au by carbon rod-AAS.

The organic content is highest in the -180 $\mu$ m fractions at both targets, but also elevated in the coarser fractions at SH. Estimates of organic C in different fractions, based on LOI at 425 °C, ranged from <1 to 35% and there was strong correlation between LOI and Au. A portion of the Au is extractable by Na-pyrophosphate.

The highest concentrations and largest proportion of total Au are present in the  $-63\mu$ m in JE samples (despite this fraction occupying <2% of the bulk sediments). There is very little visible gold in active stream sediment pan concentrates, but appreciable quantities in the adjacent alluvial terraces. Very high Au values are common in all fractions at SH (including BLEG) and there is visible Au in panned concentrates. Despite Au particle scarcity effects, BLEG values at JE are typically greater than the total aqua regia extractable Au (determined by "recombining" the various fractions). The reverse is true for SH. The BLEG and aqua-regia Au values are similar for both soil and alluvium samples. Water and fine suspended sediment decanted from 500g splits of bulk samples, that had been agitated for 1 hr, contained up to 15 ppb Au at JE and 6 ppb at SH. Au contents of wet-screened (in the field) -180 $\mu$ m fraction was significantly higher than the equivalent dry-screened -180 $\mu$ m (derived from split of the dried bulk samples).

These patterns suggest the transport of Au at SH is principally mechanical, with contributions from associated alluvial/eluvial sources, but dominantly hydromorphic at JE. Wet-screening contributes to the dissolution (or suspension) of fine Au. Significant amounts of Au are lost if screening water is not retained or where field sampling methods result in the loss of fines. Consideration of local environmental factors are essential in planning and interpretation of stream sediment surveys in the Timbarra and comparable regimes.

### Application of the GMDS2000 System for the Delineation and Investigation of Geochemical Blocks in Southern China

Liu Dawen<sup>1</sup>, Xie Xuejing<sup>1</sup>, Xiang Yunchuan<sup>2</sup> and Wang Quanming<sup>2</sup> 1. Institute of Geophysical & Geochemical Exploration

2. Research & Development Center, China Geological Survey

The success of geochemical mapping research in China in the past 23 years makes new ideas and new projects more readily acceptable. The geochemical block concept (Xie, 1995) is one of these. The very core of this conception is that the dimension of the geochemical blocks is a measure of metal endowment which is the prerequisite for the formation of large to giant ore deposits, and the stratagem of the conception is that rapidly assessing of the overall situation and then progressively narrowing the targets. The Procedures for the delineation and investigation of geochemical blocks are as follows: (1) calculating the threshold values of the geochemical blocks of different elements at the 80-85% cumulative frequency using the dataset of whole Southern China. (2) Delineating the outline of the geochemical blocks using the dataset of mean values of each 1:200 000 quadrangle (mean value of 1 500—1 700 original data within each 6 000—7000 km2 area). (3) Study of the internal structure of the geochemical blocks using the dataset of mean values of each 1:50 000 or 1:25 000 quadrangle; (4) calculating the total tonnage of metal in each block using the formula TOGB=S\*h\* $\gamma$ \*Vm, where S is the areal extension of the geochemical block, h is the assumed thickness of the block (500 m or 1 000m);  $\gamma$  is the average density of the block; Vm is the average value of all data within the block); (5) Constructing a family tree diagram to show the progressive build-up of metal concentration toward ore deposit formation. And (6) the results obtained are integrated with geological and geophysical information for the selection of the most promising targets for future exploration works.

The very work above can be carried out by our newly developed system GMDS2000 (Geochemical Mapping Database and Information System 2000). It's a powerful tool for exploration geochemists to organize their professional works. We have studied the geochemical blocks of Au, Ag, Cu, Pb, Zn, Sn, W, Mo, Sb, Hg, Ni, Co, Mn etc and their internal structures by this system in Southern China, and some unexpected results excite us. Just from the ratio of the number of large known deposits falling in geochemical blocks to the total number of large known deposit, -- large Au deposit >20 t) 15:19, large Ag deposit (>1000 t) 44:63, large Cu deposit (>5 million t) 34:38 and large Pb-Zn deposit (>5 million t) 19:30, --we can see that the geochemical block concept is very effective for the reassessment of the mineral resources potential and the selection of very promising areas for future exploration works.

## Exploration for platinum, palladium and kimberlites in forested terrain of Canada using spruce tree tops

C. E. Dunn<sup>1</sup>, R. Scagel<sup>2</sup>, L. Lahusen<sup>3</sup>, D. Seneshen<sup>4</sup>, E. Grunsky<sup>4</sup>, G. Hall<sup>5</sup>, and A. Rencz<sup>5</sup>

<sup>1</sup>Consultant Geochemist, Sidney, British Columbia, Canada; <u>colindunn@home.com</u> <sup>2</sup>Pacific Phytometric Consultants, Surrey, British Columbia, Canada <sup>3</sup>Uravan Minerals Inc., Calgary, Alberta, Canada <sup>4</sup>Alberta Geological Survey, Edmonton, Alberta, Canada <sup>5</sup>Geological Survey of Canada, Ottawa, Ontario, Canada

Chemical analysis of black spruce treetops collected by helicopter from around the Rottenstone PGE deposit of northern Saskatchewan has revealed notable PGE enrichments and clear trends in associated element distribution patterns. Data comprise 50,000 elemental determinations by ICP-MS on 794 treetops from an area of approximately 130 km<sup>2</sup>. Strong northwest trends to many elements suggest a structural and/or stratigraphic control to the element distributions. The Pd data indicate a 4 km by 6 km elliptical ring of anomalous concentrations centred upon Rottenstone Lake and the old Rottenstone PGE/Ni mine site. Plots of Pt, Te, Au, Fe, Th and Eu are coincident with this pattern. Plots of Be, Li and Bi indicate sub-parallel zones, displaced to the northeast, that might define either shear zones or structure. Additional elements indicate metal zoning (e.g. Re peripheral to Pd). The spruce top data provide substantiation to the concept that significant undiscovered PGE mineralization might be present in the Rottenstone area.

In the Buffalo Head Hills area of northern Alberta, kimberlite pipes penetrate thick layers of Phanerozoic sediments. A helicopter-borne survey was undertaken to collect treetops at 2 km spacing, with detailed sampling over known kimberlites, most of which have several metres of overburden cover. Analysis of top stems of white spruce from an area of about 150 km2 shows that samples from over 5 kimberlites exhibit a clear positive response in elevated concentrations of P, presumably derived from the apatite that is typically enriched in kimberlites. More surprising is a similar positive response of slight enrichment in Au, Te and Se. Several pipes have positive responses in Nb, Ag, As, V, Cr, Ni, Rb and Sr. A second area, dominated by black spruce, shows similar elemental responses to overburden-covered kimberlites.

It is concluded that treetop sampling, at a spacing of 250 m to 2 km (depending on the nature of the mineralized target) can be a rapid method of geochemically mapping areas of difficult terrain. The method can assist in identifying concealed kimberlites and provide focus in the exploration for zones of precious metal mineralization.

## Fundamentally new geochemical method for quantitative evaluation of magnetite ore deposits

#### T. I. Emelianenko<sup>1</sup>, A. P. Solovov<sup>2</sup>, and A. A. Matveev<sup>2</sup>

<sup>1</sup>JSC Magnitogorsk Iron and Steel Works (MMK) <sup>2</sup>Moskou State University

The efficiency of the application of geochemical methods of prospecting is clear and proven for deposits of different genetic types. However, at present there is no uniform, commonly adopted, prospecting method for magnetite ore deposits. In addition, there is not a zoning series for magnetite mineralizations. The complexity of magnetite deposits and the difficulty of locating them by geochemical methods explain these facts.

Geophysical methods are conventionally used for prospecting and evaluating magnetite deposits. However, overlapping anomalies often make difficult to interpret geophysical data. As a result, geophysical forecasts often exaggerate actual ore resources by tens or even hundreds times. At the same time, geological evaluation depends, a great deal, on subjectively selected parametric values. Under these circumstances the precision of a geological – geophysical evaluation can be improved using a geochemical method.

A research team at the Magnitogorsk Iron and Steel Works (MMK) has developed and patented a method for assessing magnetite deposits. The main advantage of this method over the existing techniques is that it enables to make an accurate quantitative evaluation of the erosional truncation level of a magnetite deposit and early resource forecast based on a single borehole sample, instead drilling a dozens of expensive holes in case of the conventional evaluation method.

The theoretical basis of the early quantitative geochemical single sample method is the principle of geometrical and geochemical similarity of genetically analogous objects of different sizes that is often used in prospecting for deposits of various minerals (Solovov, 1985). This principle was applied for the first time to the prospecting of magnetite ores by the researchers of MMK and the Moscow University under the supervision of Professor Solovov, the pioneer of using geochemical methods in the former Soviet Union. Based on the study of about 20 deposits of the Urals (Russia), at first time in history we got characteristic uniformity of the axial geochemical zoning of magnetite deposits of the Urals. For the first time in history we also calculated stable contrasting geochemical ratios, which allow to determinate hypsometrical level of magnetite ore zone and give a precise quantitative geochemical prognosis. The high reliability and efficiency of the geochemical criteria built into this model has allowed us to make a quantitative evaluation of 14 deposits in the Urals area based on single borehole samples. In 12 cases of 14 the results of the early quantitative geochemical forecast of resources on the basis of a few hole samples were quite close to conventional evaluations based on dozens of boreholes.

In conclusion we would like to highlight the main advantage of the new patented method that consists in the accurate quantitative assessment of ore deposits based on the data from a single ore sample. Together with the new magnetometer developed and patented by the Magnitogorsk Iron and Steel Works, this method can dramatically cut down the costs of iron ore prospecting. This method has 2 licences. Theoretical basis of quantity geochemical prognosis method and practical results are presented in the report.

## Fundamentally new geochemical method of evaluation of hypsometrical level of magnetite deposits ore zone

T. I. Emelianenko<sup>1</sup>, A. P. Solovov<sup>2</sup>, and A. A. Matveev<sup>2</sup>

<sup>1</sup>JSC Magnitogorsk Iron and Steel Works "MMK" <sup>2</sup>Moskou State University

The efficiency of the application of geochemical methods of prospecting is clear and proven for deposits of different genetic types. However, at present there is no uniform, commonly adopted, prospecting method for magnetite ore deposits. In addition, there is not a zoning series for magnetite mineralizations. The complexity of magnetite deposits and the difficulty of locating them by geochemical methods explain these facts.

A research team at the Magnitogorsk Iron and Steel Works (MMK) has developed and patented a method for assessing magnetite deposits, which main advantage over the existing methods is that it enables to make an accurate quantitative evaluation of the erosional truncation level and an early forecast of the resources by a single borehole sample instead of dozens of expensive holes in case of the conventional evaluation method.

The theoretical basis of the early quantitative geochemical single sample method is the principle of geometrical and geochemical similarity of genetically analogous objects of different sizes that is often used in prospecting for deposits of various minerals (Solovov, 1985). This principle was applied for the first time to the prospecting of magnetite ores by the researchers of MMK and the Moscow University under the supervision of Professor Solovoy, the pioneer of using geochemical methods in the former Soviet Union. Based on the study of about 20 deposits of the Urals (Russia), we established a characteristic uniformity of the axial geochemical zoning. For the first time in history we identified and patented the geochemical zoning series of marker elements of the Urals magnetite deposits that is different from the uniform zoning series of primary aureoles of hydrothermal sulfide-containing deposits established by Ovchinnikov and Grigorian in 1970. Based on the constancy of the axial geochemical zoning we have been the first to identify and patent stable contrast geochemical zoning ratios that clearly indicate the level of erosional truncation and the resources of the ore body by a single hole sample in the standard range breakdown. The accurate quantitative evaluation of the erosional truncation level of the single ore sample in the range of 0.0 - 1.0 allows to draw a reliable conclusion on the good prospects of the deposit in case of encountering the erosional truncation level of 0.0 - 0.4 in the supra-ore and upper-ore layers and on the lack of prospects for continuing prospecting in case of truncation levels of 0.6 - 1.0 in the lower-ore and sub-ore layers. The identified criteria for the evaluation of magnetite ores by erosional truncation levels is a reliable tool for determining the prospects of geochemical anomalies. Based on this, we have built the first summarized geological-geochemical model of the Urals magnetite deposits.

In conclusion we would like to highlight the main advantage of the new patented method that consists in the accurate quantitative assessment of ore deposits based on the data from a single ore sample. Together with the new magnetometer developed and patented by JSC"MMK", this method can dramatically cut down the costs of iron ore prospecting. Method has 2 licenses.

## Water characterization in Drake mining area, NSW, Australia

#### H. Esterio

Universidad de Concepción, Chile and Southern Cross University, PO Box 157 Lismore NSW 2480, Australia; <u>hester10@scu.edu.au</u>

This study is focused on the evaluation of the effect of past mining practices on the water quality of two creek junctions in the Drake mining area, NSW, Australia. Characterization of metal movement, partitioning and mass transport through mixing zones was determined.

Water samples were collected from a small open pit mine in November 1999 in 33 locations along Sawpit Creek, Lady Hampden Tributary, and Plumbago Creek. Concentrations of Al, Cr, Mn, Zn, Cd, Fe, Cu, Ni, and Pb were measured in total, filtered and colloidal phases.

Waste rock with pyrite, marcasite, chalcopyrite, sphalerite, and galena has been exposed to weathering, generating acid and releasing metals thus contributing to high trace metal concentrations. There are few minerals (e.g. calcite and ankerite) or rocks at the site that can consume acid. Alteration, mineralisation, and weathering have resulted in a deposit with a high potential for generating acid mine drainage and metal release and minimal capacity to neutralize this acid.

Analytical speciation techniques include chemical analysis of water in total and filtered samples, using a filter pore size of 0.2  $\mu$ m. Metal concentrations were determined by ICP-MS, sulfate and chloride were determined using a LACHAT QuickChem 8000. Concentrations of As, Se, and Ag are below detection limits (<0.001 ppm).

Sulfate:chloride ratios were 15:1. Most trace metals are associated with colloidal phase. Chromium was found only in Lady Hampden, in the filtered phase and mercury was found only in Sawpit Creek in the total phase. Sawpit Creek was the greatest source of Hg (100%), Cd (55%), and Zn (52%), whereas Lady Hampden was the major contributor of Mn (75%), Fe (80%), Cu (65%), Ni (92%), Pb (70%) and Cr (100%). Plumbago Creek contributed the smallest amount of trace metals and these were largely associated with weathering. Metals are transported in colloidal phase along the creeks.

The techniques developed in this study, have shown to be useful for discriminating between the contribution of different possible sources and total contaminant loading in natural waterways.

**KEYWORDS:** acid mine drainage, water speciation, assessment, metal transport

## Evaluation of selective extractions in glaciated permafrost terrain at the Pb-Zn Swim deposit, Yukon Territory, Canada

W.K. Fletcher<sup>1</sup> & J. D. Bond<sup>2</sup>

<sup>1</sup>Earth & Ocean Sciences, University of British Columbia <u>fletcher@unixg.ubc.ca</u> <sup>2</sup>Yukon Geology Program <u>jeff.bond@gov.yk.ca</u>

Swim is the smallest (4.3 million tonnes of 3.8% Pb and 4.7% Zn) of five sediment-hosted stratiform, pyritic massive sulphide Pb-Zn-Ag-Ba deposits in the Anvil Range, Yukon Territory (Jennings and Jilson, 1986). The deposit partly subcrops beneath 1 to 25 m of frozen till on the upper part of a steep north facing slope. Bond (1998) showed that a base metal anomaly in till extends down-ice from the deposit.

Samples of colluviated till, collected at 50m intervals across the deposit, were air dried and disaggregated before being sieved to minus 2 mm and split. One portion was screened to  $-212 \mu m$  for digestion with *aqua-regia*, cold 0.1 M hydroxylamine-hydrochloride in 0.01 M HNO<sub>3</sub>, and enzyme leach. The remaining -2 mm portion was submitted for determination of Cu, Pb and Zn by MMI. Lead isotope ratios were determined by TIMS.

Concentrations of Pb and Zn extracted by the four reagents span roughly four orders of magnitude with *aqua regia* extracting the most and enzyme leach the least. However, all four reagents give similar geochemical patterns with a strong Cu-Pb-Zn anomaly downslope from the deposit. With *aqua regia* the contrast for this anomaly decreases from Zn (6.5)  $\Rightarrow$  Cu (5.7)  $\Rightarrow$  Pb (3.4). Corresponding ratios for the weaker extraction are: hydroxylamine 9.0, 13.4 and 4.6; MMI 58.9, 22.5 and 9.9; and, enzyme leach 30.1, 5.3 and 3.5. Compared to this strong anomaly, concentrations of Cu, Zn and most other elements are depleted in till over the deposit. Pb is an exception with a weak anomaly in the *aqua regia* (1.3 x background), MMI (3.9), hydroxylamine (2.0) and enzyme leach (1.5) data over the deposit. Pb isotope ratios suggest that this weak Pb anomaly and the stronger downslope anomaly both result from the mixing of Pb from the deposit with background Pb.

The most likely origin of the strong downslope Cu-Pb-Zn anomaly are solifluction and mass wasting that have mechanically moved anomalous material downslope. For Zn the greater anomaly contrast with the two weakest extractions suggests that additional Zn has been contributed by hydromorphic dispersion. This is also consistent with the depletion of Zn and greater Pb:Zn ratio over the deposit. Insofar as the Pb anomaly over the deposit is apparent in the *aqua-regia* as well as the weak extractions, it most likely results from down-ice glacial dispersion from mineralization subcropping east of the traverse. Depletion of elements in till above the deposit may reflect changes in bedrock geochemistry as well as leaching of metals from the till during weathering.

Results show the complex origins of geochemical anomalies through a combination of glacial, mechanical and hydromorphic dispersion. All these should be considered in interpretation of similar anomalies and the strongest anomaly is not necessarily best for target definition. Pb isotope ratios can aid interpretation of the origin of geochemical anomalies.

## Dispersion of gold in a rain forest stream in the S. Kuli region, Sabah, Malaysia: implications for exploration

W. K. Fletcher<sup>1</sup> and J. Muda<sup>2</sup>

<sup>1</sup>Earth & Ocean Sciences, University of British Columbia, <u>fletcher@unixg.ubc.ca</u> <sup>2</sup>Geological Survey Department Malaysia, Kota Kinabalu, Sabah, Malaysia

Stream sediment surveys for gold are often characterized by many results below detection limits and sporadic, strongly anomalous values: this makes interpretation difficult. Although the situation can be improved by use of sediment finer than 100  $\mu$ m this is not always effective – particularly in regions of abundant silt-clay or where land disturbance artificially increases soil erosion.

To evaluate these problems we have investigated distribution of gold in sediments of a gold-rich tributary of the S. Kuamut, Malaysia. Headwaters of the stream rise at elevations >2000 m and descend  $\sim$ 1000 m in  $\sim$ 2 km. Between 1000 and 700 m elevation the stream is a mountain torrent with an average gradient approaching 20% and a boulder choked channel. Downstream gradients decrease to less than 3% as the stream descends to the Sungai Kuamut at  $\sim$ 400 m ASL. Gold mineralization in the headwaters is associated with bodies of diorite porphyry that have intruded and silicified mudstones and sandstones of the Tanjong Formation (Muda et al, 1996).

Field screened  $-425 \,\mu\text{m}$  sediments were collected from gravel (lower energy) and cobble (high energy) sites on bars and riffles along 8 km of the stream and its tributaries. Gold was determined on five fractions finer than  $-212 \,\mu\text{m}$  with a 30g fire-assay atomic absorption-solvent extraction procedure. Low energy sandy sediments were collected for determination of gold by BLEG.

Median gold values range from 620 to 670 ppb in the three sand fractions between 75 and 212  $\mu$ m but decreases to 250 ppb in the fine sand (53-75  $\mu$ m). However, gold values in the two coarsest fractions are extremely erratic and the anomaly is missed by nineteen out of fifty two samples (~36% failure). In the two finer sand fractions (75-106  $\mu$ m and 53-75  $\mu$ m) the failure rate falls to only seven samples (~13%). Gold values in the silt-clay (-53  $\mu$ m) fraction are lower (median 12 ppb; maximum 87 ppb) and provide less anomaly contrast. BLEG values were anomalous in only three of fourteen samples.

The high failure rate in coarse fractions results partly from poor analytical precision caused by subsampling problems. However, gold values in different size fractions tend to have coincident maxima and minima along the stream profile. This is unlikely to arise from a random sub-sampling problem and suggests a strong fluvial control on presence or absence of anomalous gold values at supposedly similar sites. Low gold values in the  $-53 \mu m$  fraction indicate that silt-clay acts as a dilutant to gold particles in the sand sized range.

Calculation of weighted average gold concentrations allows gold content of conventional minus xxmesh fractions to be approximated. Results suggest that the  $-106 \mu m$  fraction is the best choice to maintain anomaly contrast while minimizing erratic gold values. Increased inputs of silt-clay after land disturbance by logging activities could significantly lower anomaly and survey success rates.

### Major morphological and chemical features of regolith gold

#### Ph. Freyssinet<sup>1</sup> and R. Bowell<sup>2</sup>

<sup>1</sup>BRGM, BP6009, Orléans Cedex 2, France; <u>p.freysinnet@brgm.fr</u> <sup>2</sup>SRK Consulting, Summit House, 9 Windsor Place, Cardiff CF10 3RS, Wales; <u>Srk003@aol.com</u>

The morphology and chemistry of gold in regolith terrains is almost exclusively influenced by chemical processes. This paper presents a review on the processes controlling the morphology and chemistry of lateritic gold (Freyssinet and Bowell, 2001). Systematic studies on gold morphology were usually based on gold particles recovered by panning and exceeding at least 20  $\mu$ m. Morphological criteria are size, general shape, contour type, glance, type of faces, degree of etching and associated minerals.

Corrosion of primary gold is the main process occurring in weathering profiles leading to the decrease of grain size by volume reduction and fractionation of particles. The corrosion of gold particles result from an electrochemical reaction with the corroded surface as anode and the passive surface as cathode, regardless of whether the aqueous complex of the solution (chloride, organic acid, thiosulfate, etc.). Corrosion of primary particles is accompanied by preferential leaching of silver like in alluvial particles. The preferential leaching of silver is a centripetal process due to the diffusion of Ag within the alloy. Different types of corrosion of gold grains exist and may be related to the conditions of Au remobilization in weathered profiles.

*Pitting* is the most common type of corrosion in lateritic deposits in the vadose zone of the soils. Corrosion by pitting of Au-Ag alloys is characteristic of a process of aerial corrosion, generally associated with water droplets at the metal and atmosphere interface. At a more evolved stage, grains lose their primary shape and become rounded. *Uniform corrosion,* where no rough patch is seen on the particle surface develops generally in the saturated zone of weathering profiles. The grains lose their primary form and acquire a rounded aspect, but their surface is smooth and the grains preserve their shiny luster. It occurs more particularly in the saprolite, notably in the Western Australian deposits. Uniform corrosion of grains also occurs in equatorial rain forest soils where hydric conditions are close to saturation. *Inter-granular corrosion* is a process operating within cavities formed generally by dissolution of sulfide gangue minerals, where Au is dissolved as a thiosulfate complex. The corrosion develops deeply in the grain giving a spongy aspect. It occurs in saprolites, and notably at the oxidation front. Spongy forms develop also from Ag-rich grains (Ag grade > 15-20%)

Secondary gold particles may be clearly predominant over primary particles in the Western Australian supergene deposits, they are generally less common in lateritic deposits under tropical or equatorial climates, or are small (<2-3 $\mu$ m). Two main groups of secondary gold can be identifed : euhedral crystals and irregular growth forms. Neogenic *euhedral particles* generally crystallize either as octahedral crystals, or as octahedral or pseudo-hexagonal plates. Such crystal forms are common in the Western Australian where they result from crystalline growth developed from chloride complexes. *Irregular growth* forms, such wire, membranes, secondary gold cortex, "paint" gold, and irregular aggregates probably precipitated as very fine-grained crystals. In the saprolite, secondary gold cortex represent the first stages of gold neogenesis with rapid reprecipitation of gold at the contact of primary particles In Fe-duricrusts and latosols, the most common form of secondary gold is spherules generally less than 2-3  $\mu$ m. Amorphous irregular aggregates or larger size (10-1000  $\mu$ m) are very common in Western Australian deposits.

## Geochemical exploration as a tool to optimize the biodegradation processes of petroleum hydrocarbons in soils

J. L. R. Gallego<sup>1</sup>, J. Loredo<sup>1</sup>, J. Llamas<sup>2</sup>

<sup>1</sup>Departamento de Explotación y Prospección de Minas. E.T.S. de Ingenieros de Minas. Universidad de Oviedo. España; <u>iloredo@correo.uniovi.es</u> <sup>2</sup>Departamento de Ingeniería Química. E.T.S. de Ingenieros de Minas. Universidad Politécnica de Madrid. España

Bioremediation is an alternative remediation approach for contaminated sites with petroleum hydrocarbons. It involves the use of micro-organisms to convert contaminants to less harmful species. About the remediation of contaminated sites by means of biodegradative processes, these micro-organisms require the presence of nutrients, and an electron acceptor; several other conditions, i.e. temperature, pH, etc., affect the effectiveness of these processes. Petroleum hydrocarbons are biodegradable: The lighter soluble members such as benzene or toluene are generally biodegraded more rapidly and to lower residual levels than are the heavier, less soluble members, such as the polyaromatic hydrocarbons. The rate of biodegradation can be highly variable, depending on environmental conditions, including geochemical and biological characteristics of the contaminated site.

Before the use of a bioremediation technique for a particular contaminated site, it is fundamental to know relevant geochemical characteristics of the site under study and geochemical processes occurring. Then, geochemical characteristics of soils are fundamental to applied a bioremediation technology. Some properties, such as the composition of contaminants, including inorganic chemical that could interfere with the bioremediation process, and geochemistry of soil minerals to consider their sorption properties for establishing bioavailability, are very important. Another important characteristics of soils as redox status, pH, etc., must be considered.

A great amount of hazardous organic waste sites are co-contaminated with metals. In this way, some unfavourable geochemical characteristics of the contaminated site, as the presence of toxic metals as Cd, Co, Pb and Zn, can inhibit the action of hydrocarbon degraders micro-organisms, in the contaminated area. In order to investigate the effect of varying metal availability on microbial populations and then biodegradation of organics, geochemical studies are absolutely necessary.

Then, geochemical exploration can be used as a support tool to optimise the biodegradation processes and to identify any factors which could constrain these processes. For these studies a first step would be the characterisation of the organic pollutants and their distribution, by this way the use of indirect field geochemical methods allows a rapid and low cost delimitation of geochemical anomalies. Detailed geochemistry must be made in laboratory by chromatographic analysis of selected samples from polluted areas. Also, the presence and contents of heavy metals and other toxic chemical that could inhibit microbial growth must be considered. Site parameters as pH, Eh, temperature, moisture, and others have a very important role in microbial growth, and then in the bioremediation rate of the petroleum hydrocarbons. Microbiological analyses of soils may be undertaken before selecting a bioremediation approach.

Some experiences with diesel spills, where the realisation of preliminary geochemical exploration was done, including inorganic, organic and microbiological determinations and allowing the optimisation of an "in situ" bioremediation treatment for polluted soils with petroleum hydrocarbons, are presented.

## The geochemical image of ore objects in country rock and thick cover

#### S. Goldberg<sup>1</sup>, G. J. Abramson<sup>1</sup>, and V. L. Los<sup>2</sup>

<sup>1</sup>Ionex PTY LTD. Level 1, 55 York Street Sydney, NSW 2000, Australia; <u>ionex@ozemail.com.au</u> <sup>2</sup>Academy of Mineral Resources, Naursybai Batyra, 146/11, Almaty, Kazakstan

1.- Geochemical mapping in country rock reveals numerous cases of identical geochemical structures of ore areas (local and regional scales), as follows:

- Spatial conjugation of positive and negative anomalies of ore forming and associated elements. The external outline of the anomalies of ore-forming elements in 3D selects the geological space that is termed the geochemical system of the ore object. A linear dependence has been found between the size of a geochemical system and the resource of the ore deposits.
- Within these boundaries positive anomalies of ore-forming elements (the nuclear part of the system) and negative and positive anomalies of the ferrous group of elements are formed. Ore mineralization is superimposed onto the negative anomalies of the ferrous group of elements. Such polar localization of ore and associated elements, within the system, can be termed polar concentration zoning.

2.- A similar polar zoning structure, in areas of transported and residual overburden with thick cover, has been established with geochemical mapping by geoelectrical methods (MPF, TMGM, MDE, and CHIM). Within the system, there are also negative organic carbon anomalies in the soil, corresponding with the positive ore-forming anomalies.

The presence of geochemical systems in thick cover could be the reflection of deep-seated geochemical ore systems, by the superimposition, over the primary distribution of elements in the cover (soil), of mobile ore elements from deep ore objects. Alternatively, geochemical systems could be are formed in the cover as a result of post-genetic processes. Although this suggestion might appear to be something out of science fiction, there are geochemical data that support it.

The discovery of geochemical systems in cover above primary ore object, similar in structure to the system of ore objects in country rock, is the key to exploring concealed ore objects, whether on a local or regional scale.

## Data processing for geochemical mapping- An example from Central Colombia

#### L. M. González and J. I. Calderón

INGEOMINAS. Bogotá, Colombia. luzgonz@ingeomin.gov.co

The preparation of reliable geochemical maps is needed for use in mineral exploration and environmental studies, in this work, the data processing carried out for the geochemical mapping, conducted in the central area of Colombia, within plate, 5-09 (1:500000 scale) is described. This study was conceived as a pilot study, to initiate in the country, the application of modern techniques of geochemical reconnaissance at low sampling density, using multipurpose and multi-element methodologies in several types of sampling media, in this case sediments, soils and waters. For the attainment of such objectives, the methodologies proposed by the International Program of Geologic Correlation IGCP, Projects 259 and 360, briefed in the document " A Global Geochemical Database for Environmental and Resource Management" (Darnley et. al., 1995) were adapted.

The present report makes reference to the study conducted in a cell identified as N04W52 of the Global Geochemical Reference Network, which was selected like pilot cell because of the diversity of geologic, morphologic, pedologic, hidrologic and climatic characteristics. The cell of 160 x 160 km was divided in subcells of 20 x 20 km, where river basins smaller than 200 km<sup>2</sup> were selected, in each one, samples of active sediments, waters and soils were collected. Samples were analyzed by multielement techniques. Processing of the data, involved univariated and multivariated statistical methods; geoestatistical tools were also used for the preparation of dot and colour surface maps.

Before carrying out the geostatistical analysis, an exploratory analysis of the data (AED) was made. The spatial analysis was centered in establishing and characterizing the structure of spatial correlation of the variables in terms of their spatial continuity, expressed by the semivariograms, procedure known as structural analysis, for which the software GEOEAS was used. For the multivariated analysis the technique of Factor Analysis mode R was used, which allowed to explain the structure of correlation of the variables in terms of a smaller number of factors that are linear combinations of the original variables. In order to facilitate the visualization of the data, an application based on the concept of GIS was developed, using Software ArcView of ESRI. The application allows to integrate the descriptive and the geographical information, present maps for individual elements and for the association factors found in the multivariated analysis, and process them over the basic cartography and another information such as the geology.

The statistical analysis of the results and the construction of maps of contours allowed to delimit zones of anomalous concentrations of elements whose meaning is important for future studies of exploration of mineral resources and environmental monitoring.

The applied techniques were successful in the delimitation of geochemical distribution patterns, which showed significant correlation with the different geologic units present in the study area and its own characteristics. In addition, consistency was found in the results for different sampling media, specially between soils and sediments.

## Naturally occurring Cr<sup>6+</sup> in shallow groundwaters of the Yilgarn Craton, Western Australia

D. J. Grav

CSIRO

*Exploration and* Cooperative Research Centre for Landscape Evolution and Mineral Exploration, Mining, Private Bag 5, Wembley WA 6913, Australia; <u>d.grav@per.dem.csiro.au</u>

Many regions of the Yilgarn Craton and its margins dominantly contain deep regolith (20 -100 m). In these areas aguifers are unconfined and the water table is commonly 10-60 m below surface. Where these groundwaters are in contact with weathered Archaean rocks there is an unusual lack of correlation between Cr content and acidity, although a close relationship might be predicted from the normal aqueous chemistry of Cr. Groundwaters in contact with fresh and weathered ultramafic rocks (pH range 4.5 - 8.5) have high dissolved Cr concentrations (10 -430 µg/L), with no pH relationship. In contrast, waters in contact with other lithologies (pH range 3 - 8.5) have Cr concentrations below detection (< 5 µg/L). This offers a robust method for recognising ultramafic lithologies, even where they are concealed and highly weathered.

If the dissolved Cr was as Cr<sup>3+</sup>, groundwaters having Cr concentrations above detection and pH above 6 would be strongly over-saturated with respect to secondary Cr oxides. However, comparison of ICP and spectrophotometric analyses indicate that the Cr occurs as Cr<sup>6+</sup> in the form of chromate (*i.e.*,  $CrO_4^{2}$ ), which has a much higher solubility than  $Cr^{3+}$ . The high oxidation state of Cr is also suggested by its highly antipathetic relationship with Fe: *i.e.*, with few exceptions, dissolved Cr is only above detection when dissolved Fe is less than 0.5 mg/L. This is possibly due to the ability of dissolved  $Fe^{2+}$  to reduce chromate to the less soluble  $Cr^{3+}$  ion, which would precipitate. A similar antipathetic relationship is observed between dissolved Cr and Mn. However, in non-reducing (*i.e.*, Fe- and Mn-poor) groundwaters, chromate will be relatively stable and potentially mobile. However, the mechanism by which  $CrO_4^{2-}$  is released into groundwater is not known.

These naturally-occurring concentrations of dissolved Cr<sup>6+</sup> are, in many instances, well above the World Health Organisation maximum concentration allowed in drinking water of 50  $\mu$ g/L. In one area (Lawlers mining district), otherwise potable groundwaters cannot be used for human consumption due to concentrations of Cr<sup>6+</sup> up to 6 times greater than the acceptable limit.

The research was the result of collaboration between CRC LEME and the Australian minerals industry through AMIRA. CRC LEME is supported by the Australian Cooperative Research Centres Program.

## Delineation and investigation of some large gold geochemical blocks in Eastern China

Yan Guangsheng<sup>1</sup>, Lian Changyun<sup>1</sup> and Xie Xuejing<sup>2</sup>

<sup>1</sup>Research & Development Center, China Geological Survey <sup>2</sup>Institute of Geophysical & Geochemical Exploration

The newly established China Geological Survey has initiated a large research project for the reassessment of the overall mineral resources potential of Eastern China and for the selection of the most promising new exploration targets for future geochemical, geological and geophysical works based on the new geochemical block concept and methodology developed by Xie Xuejing (1995).

Stream sediment gold data drawn from China's RGNR database with detection limit of 0.2ppb were used for the study of gold geochemical blocks in Eastern China. Very large gold geochemical blocks were delineated including Jiaodong, Henan-Shanxi, Sichuan-Shanxi-Gansu, Lower Yangtze, Sichuan-Yunnan-Guizhou-Guangxi, Sichuan-yunnan, Guangdong-Guangxi-Hunan and North Hebei gold blocks. Nearly all the known large gold deposits in China are located within these geochemical blocks.

The Jiaodong and Henan-Shanxi gold geochemical blocks have been relatively well explored. Mineralization coefficients were calculated based on the ratio of known gold reserves with gold total tonnage in 1000 m thick geochemical blocks. The probable gold reserves of other gold geochemical blocks are estimated with reference of the mineralization coefficient obtained from Jiaodong and Yushan blocks. From the the calculations we could see there would be more large to giant gold deposits not yet discovered in China.

Some most promising gold exploration targets are selected, and the information are submitted to China Geological Survey for planning future mineral exploration projects.

## Complementary soil geochemical and subsurface studies in the Abitibi Belt, Ontario: Comparison of selective leach methods for locating mineralization in overburden-covered terrain and evaluation of processes of element migration

**S. Hamilton<sup>1</sup>, E. Cameron<sup>2</sup>, G. Hall<sup>3</sup>, and B. McClenaghan<sup>3</sup>** <sup>1</sup>Ontario Geological Survey, <u>stew.hamilton@ndm.gov.on.ca</u> <sup>2</sup>Eion Cameron Geochemical Inc. <sup>3</sup>Geological Survey of Canada

A joint Ontario Geological Survey – CAMIRO (Canadian Mining Industry Research Organization) study is being carried out at sites in Ontario's overburden-covered Abitibi belt to evaluate geochemical methods of discovering mineral deposits beneath this cover and to better understand processes of element migration. A variety of selective-leach data have been obtained for soils over known mineralization, along with complementary subsurface geochemical and SP data.

At the Marsh Zone site a sulphidic syenite-hosted gold deposit is overlain by an average 20 m of glacio-lacustrine clay and glacial clay-till topped by up to 2 m of saturated peat. Na-pyrophosphate and aqua regia analysis of peat samples collected at 50 cm depth show metal anomalies over mineralization. There is no apparent response in deeper peat or in the unweathered clays below the peat by Enzyme Leach, MMI or aqua regia. A number of measurement techniques have detected a column of chemically reduced peat, clay and groundwater above the mineralization. The column is marked by a pH high, flanked by weak pH lows.

At the Cross Lake site VMS-style Zn-Cu mineralization with several 10s of percent total sulphide subcrops beneath thick overburden that is largely unsaturated at surface. Mineralization is overlain on one sample line by 50 m of glacial sand, silt and minor clay units and on another by 30 m of clay. Unlike the Marsh Zone, the best response by the various leaches is in mineral soil rather than the organic media. The upper 10 cm of the B-horizon soils shows strong anomalies, particularly for Zn, by the weaker selective leaches: Enzyme Leach, MMI and ammonium acetate. The response is poor for the stronger leach, cold hydroxylamine, and for aqua regia. On both lines the anomalies are coincident with reduced columns, but unlike the Marsh Zone the surface materials are distinguished by a pH low. Sampling protocols are critical, since samples collected at depths greater than 10 cm in the B-horizon give poor results. The reasons for this depth selectivity both at Cross Lake and the Marsh Zone will be investigated during the 2001 field season.

The chemical processes involved in generating the observed anomalies must involve both a transport component and a concentration mechanism. The redox, SP and pH data at both sites show that a strong electrochemical field has developed in the relatively short time,  $\sim$ 10,000 years, since deglaciation. Electrochemical transport provides a means for transport of ions and oxidation of reduced species may account for the pH anomalies. The complexity of the processes is evident by results from the B-horizon soils on the clay-covered line at Cross Lake, where some elements form strong positive anomalies over the mineralization, whereas others show strong negative anomalies.
## An overview of hyperspectral remote sensing as applied to precious metals exploration

Ph. L. Hauff<sup>1</sup>, W. A. Peppin<sup>1</sup>, D. C. Peters<sup>2</sup>, G. A. Borstad<sup>3</sup>

<sup>1</sup> Spectral International, Inc., P.O. Box 1027, Arvada, CO 80001, USA; <u>pusa@rmi.net</u>
<sup>2</sup>Peters Geosciences, Golden, CO, USA
<sup>3</sup>G. A. Borstad Associates Ltd., Sidney, BC, Canada

Spectral remote sensing using satellite imagery has been commonly utilized tool for precious metal exploration. This technique, however, only is able to recognize anomalies, many of which can be correlated to inferred mineralization and alteration. Imaging spectrometry sensor technology, however, now has progressed to being able to produce reliable hyperspectral data sets not only for mineral information, but also flown from airborne sensors which have smaller spatial and spectral resolutions than available satellites. This presentation will introduce the topic of airborne and field-portable hyperspectral sensors, along with reflectance spectroscopy for minerals.

Hyperspectral sensors are the newest remote sensing technology. They collect a large number (usually more than 100) of contiguous bands with consistent and refined spectral resolutions (usually less than 20 nm). Examples of operational sensors include AVIRIS (Airborne Visible-Infrared Imaging Spectrometer; from JPL/NASA), SFSI (SWIR Full Spectrum Imager; from the Canadian Centre for Remote Sensing and G. A. Borstad Associates in Canada), and HYDICE (owned by the U.S: Navy). PROBE and HYMAP are other current hyperspectral sensors, but they are not contiguous through their spectral recording ranges.

The advantages and disadvantages of these high-resolution sensors are that they detect mineral species and chemical substitution within species. This presents a major problem for appropriate mineral identification and subsequent image generation. Specialized spectral libraries from a wide range of different deposit types and mineral species are essential to produce accurate, representative imagery. In addition, better and faster end member processing and calibration algorithms are a must. Mineral identification is a challenge because there are key absorption features identifiable only within wavelength regions that are not masked by atmospheric water vapor and gases. Minerals have different absorption and reflection characteristics as a function of chemical composition. The heavier elements tend to absorb more energy and reflect less, thus depressing the signals of such minerals as chlorites, amphiboles, tourmalines, biotites, and jarosites. The lighter elements, especially aluminum, will absorb and reflect with greater intensities, which allows species such as alunite, muscovite, kaolinite, and illite to dominate the spectral signatures. Therefore, it is important to understand which minerals are the most diagnostic and, even more importantly, the most detectable or non-detectable for specific applications and ground targets.

The benefits from high-spectral resolution sensors also are major because hyperspectral images can provide detailed mineral maps of deposits and prospects which literally are impossible to achieve as quickly from only ground reconnaissance mapping.

Field spectroscopic methods, using high-definition portable spectrometers, not only check the airborne imagery, but also can do rapid reconnaissance mapping of alteration minerals and provide maps of zoning which then can be used for vectoring to mineralized targets. These spectrometers also can acquire three-dimensional information for the alteration model through core logging and then plotting of mineral content relative to depth.

Examples will be presented for epithermal gold and porphyry copper systems. These include 1) the subtle and very distinctive signatures of Carlin-type disseminated gold systems along the historic Carlin Trend in Nevada, 2) low-sulfidation QAS (quartz-adularia-sericite) systems such as Virginia City, Nevada, 3) a three-dimensional look at the extremely complex high-sulfidation system at Goldfield, Nevada, and 4) imagery from selected porphyry copper deposits including the Ray Complex in Arizona, Cananea in Mexico, and Bajo de la Alumbrera in Argentina.

## Complementary Selective Extraction and Biogechemical Patterns at the I-10 and Dragoon Skarn/Porphyry Deposits, Cochise County, Arizona

G. T. Hill<sup>1</sup>, J. R. Clark<sup>2</sup>, and K. . Lovstrom<sup>3</sup>

<sup>1</sup>Enzyme Laboratories, Inc., 785 Andrew Lane, Reno, NV 89511, USA; <u>hill@actlabs.com</u> <sup>2</sup>Enzyme-ACTLABS, LLC, 7778 Lewis St., Arvada, CO 80005, USA <sup>3</sup>Consulting Geochemist, 1770 E. Ganymede Drive, Tucson, AZ 85737, USA

A geochemical study employing selective extractions on *B*-horizon soils and biogeochemistry is continuing on the buried I-10 and Dragoon copper skarns in semi-arid southern Arizona. Enzyme Leach<sup>SM</sup> (EL) and TerraSol<sup>SM</sup> (TS) data, and ashed mesquite data reveal diagnostic signatures indicative of buried ore-grade Cu mineralization and pre- and post-mineral structures. The skarnhosted oxide Cu resources at I-10 and Dragoon have been estimated at 440 million tons averaging 0.39% total Cu and 105 million tons averaging 0.26% total Cu, respectively. The I-10 deposit is covered by 80 meters of barren alluvium in the north and 200 meters in the south. At Dragoon, alluvial cover ranges in thickness from 0 to 60 m beneath the surveyed area. Four-hundred-five soil samples were collected in regular grids over I-10 and Dragoon, and over most of the ~5,500 m separating the two deposits. Eighty-nine mesquite samples were collected throughout the area.

Enzyme Leach<sup>SM</sup> disrupts amorphous oxide coatings on soil grains by dissolving the  $MnO_2$  component. TerraSol<sup>SM</sup> selectively dissolves all of the amorphous coatings and much of the limonite. As a result, trapped trace elements are released into the leach solutions. Patterns produced by EL and TS for the same element are often dissimilar, adding valuable information for the interpretation of subsurface geology. Mesquite, a phreatophyte, develops deep root systems in search of ground water, and where extant, is an effective sample media in semi-arid regions.

Because the skarns are oxidized, neither exhibits a strong oxidation halo; their signatures are more subtle than those associated with sulfide mineral bodies. Rhenium, the ninth rarest element, forms halos above the margins of the I-10 and Dragoon skarns as indicated by the EL data. Thallium and rare earth elements determined by EL form a halo in the southern part of the I-10 grid, suggesting the presence of an underlying mineralized stock. Very limited drilling has encountered porphyry-style mineralization at ~400 m. This deep body is indicated by weak Cu and Mo by EL halos. Copper and Mo form strong EL and TS halos around a shallow prospect just south of the Johnson Camp mine. Niobium by EL shows a N-S trend interpreted as a fault zone intersecting the I-10 skarn and underlying stock. Niobium by TS shows only the southern end of that trend, but also reveals apparent NE- and NW-striking trends that intersect at the point where the north end of the I-10 skarn bends to the NW. Gold, Re, and PGE by TS form halos flanking the N-S Nb high. The Nb trends appear to represent structures that guided the flow of mineralizing fluids out of the porphyry, into the overlying skarn. Mesquite Cu and Zn anomalies outline subcropping and concealed mineralization over the I-10 deposit. Dispersion is characterized to the east and southeast by Cu, Zn, and Mo anomalies.

These data suggest that a significant unexplored porphyry Cu (Mo) system and a potentially high-grade zone of structurally-controlled mineralization radiating from the inferred porphyry underlie the I-10 skarn.

### Dispersion of gold in Slesse Creek, British Columbia

#### J. Hobday and W. K. Fletcher

Earth & Ocean Sciences, University of British Columbia, Vancouver, BC, Canada fletcher@unixg.ubc.ca

Because of the high costs and logistics of reconnaissance geochemical surveys in remote regions sediments collected from larger streams must often suffice to determine presence or absence of mineralization in large drainage basins. Here we study this problem in Slesse Creek, a gold-rich river that drains north from the Mt. Baker District, Washington, USA to enter the Chilliwack River, British Columbia, ~80 km east of Vancouver. Within British Columbia Slesse Creek is a fourth order river that drains ~170 km<sup>2</sup> and occupies a deeply incised, glacial valley with small tributary streams that descend steeply from hanging valleys. The sediment load is predominantly large boulders and cobbles. Anomalous gold values are derived from the abandoned Red Mountain mine just south of the USA/Canada border.

Sediments were collected from Slesse Creek and its tributaries and from other large streams in the Chilliwack River basin. Samples were wet sieved and the -0.212 mm fraction analyzed by ICP-MS after a total decomposition. Gold was determined on the -0.075 mm fraction by FA-AAS. Abundance of magnetic grains and loss on ignition were also determined.

Concentrations of gold in tributaries from the Red Mountain mine range from 250 to 2330 ppb and are much greater than in other tributaries. Sediments from Slesse Creek immediately downstream from the anomalous tributaries have lower (18 to 160 ppb), but nevertheless anomalous gold values. Further downstream, gold values are anomalous but extremely erratic with maximum concentrations of 340 ppb and 360 ppb at 6.6 and 9 km downstream, respectively. This distribution closely resembles that of magnetic grains and heavy mineral associated elements (e.g., Fe, Cr, Ti and V) but is negatively correlated to elements, such as Na, associated with light minerals. Comparison of Slesse to its tributaries shows that: (i) magnetite and heavy minerals associated elements are much more abundant in Slesse; and, (ii) positive correlations between light and heavy mineral elements in the tributaries versus their negative relations in Slesse.

Results are interpreted as an evolution in sediment geochemistry going from the tributaries to Slesse Creek: geochemistry of the former appears to be controlled by source (i.e., geology) whereas geochemistry of sediments in Slesse Creek has been strongly modified by fluvial processes that concentrate heavy minerals. This shift from source related to processes related geochemistry invalidates the assumptions of the traditional geochemical dilution model. Gold concentrations are enhanced at a considerable distance from their source to give long anomalous dispersion trains that provide suitable targets for low density regional surveys. However, the erratic nature of the gold values complicates their interpretation. This problem can be partly overcome either by: (i) rationing gold values to abundance of ubiquitous heavy minerals, such as magnetite, or to an associated element (e.g., V); or, (ii) use of X-Y-Z source processes plots to evaluate the relative importance of proximity-to-source versus fluvial processes in determining gold values at particular sample sites.

## SGH<sup>SM</sup>–A new soil gas hydrocarbon technique for mineral exploration under deep cover

E. L. Hoffman<sup>1</sup>, D. Sutherland<sup>1</sup>, J. R. Clark<sup>2</sup>, G. Hill<sup>3</sup>, and D. Leng<sup>1</sup>

<sup>1</sup>Activation Laboratories Ltd – 1336 Sandhill Drive, Ancaster, Ontario Canada; <u>ehoffman@attglobal.net</u> <sup>2</sup>Enzyme Actlabs, LLC – 7778 Lewis St., Arvada, CO, USA 80005 <sup>3</sup>Actlabs Exploration Services – 7775 Andrew Lane, Reno, NV, USA 89511

The SGH<sup>SM</sup> technique involves collection of soil samples (typically *B* horizon) in the field and then desorbing the weakly bound heavy hydrocarbons in the C5-C17 range using a new technology developed by Actlabs over the last four years. The desorbed gases are collected and introduced into a gas chromatograph-mass spectrometer (GC-MS) where 190 heavy hydrocarbon and organometallic compounds are measured. Heavy hydrocarbons are used instead of light hydrocarbons as they are much less affected by environmental factors such as shipping and storage conditions. Detection limits at the low ppt (pg/g) levels are possible by this technology which easily allows background levels to be readily determined. Soils are used as long term integrators of the soil gas flux. Advantages to this approach are the absence of effects shown by instantaneous soil gas measurements which are affected by changes of barometric pressure, rain, biodegradation, etc. Anomalies related to blind ore deposits tend to have high peak/background ratios.

As part of a CAMIRO (Canadian Mineral Research Organization) project, a consortium of 8 companies funded a test of the technology over 9 blind mineral deposits. The deposits were chosen by their sponsors as they were deemed to not show a response to conventional geochemical techniques like aqua regia-ICP. These deposits included the Birchtree Ni, Cu deposit (Manitoba-INCO), the Montcalm Ni deposit (Ontario-Outukompu), Diana Au deposit (Australia-WMC), Spence Porphyry Copper deposit (Chile-Rio Algom), the Hanson Lake VMS deposit (Saskatchewan-CAMECO), the Dawn Lake and McArthur River Uranium deposits (Saskatchewan-CAMECO), the Poston Butte copper deposit (Arizona-BHP) and the BHP unnamed Nevada sediment-hosted gold deposit (Nevada-BHP). As part of this study the Enzyme Leach<sup>SM</sup> selective extraction and aqua regia ICP and INAA techniques were compared. The terrain associated with these deposits ranged from swampy glacial to arid desert environments. Two deposits were sampled from archived samples. Data will be shown which compares SGH<sup>SM</sup> to conventional aqua regia and to Enzyme Leach<sup>SM</sup> data. A combination of Enzyme Leach<sup>SM</sup> and SGH<sup>SM</sup> improves the confidence in anomaly selection by using techniques which are inherently showing different geochemical processes.

Samples for this project were collected by the exploration companies involved, using general instructions provided by Actlabs. Samples were analyzed and plotted by Actlabs with no apriori information on the location of the deposit or the geology of the area. After submission of plots Actlabs believed were significant, the location and general geology of the deposits were provided for refining the interpretation.

Soil gas compounds tend to fall into two main categories which include aromatic (ring) and alaphatic (straight chain) compounds. Geochemical maps for soils gas compounds tend to be very clean showing anomalies over deposits and peripheral to them. In some instances (Birchtree) the anomaly actually follows the shape of the surface projection of the deposit. Many organic compounds form patterns that closely follow the underlying geology.

Further studies are ongoing to explain and understand the processes involved in SGH<sup>™</sup> anomaly formation. These studies will include microbiologists, a soil gas geochemist, an expert of organic interaction with ore deposits and isotope geochemists. Results will be reported as confidentiality agreements allow.

## Stream Sediment Source Accounting. Locating the sources and magnitudes of stream sediment anomalies.

P. Holyland<sup>1</sup> and G. Broadbent<sup>2</sup>

<sup>1</sup>Georeality Pty Ltd., Suite 35 Lvl 8, 445 Upper Edward Street, Spring Hill, Australia 4004; <u>peter@georeality.com</u> <sup>2</sup>RioTinto Exploration, Belmont Avenue, Belmont, Western Australia 6104; <u>Graeme.Broadbent@expl.riotinto.com.au</u>

Stream sediments represent a mixture of soils from different locations with different source geochemistry. A method has been developed to unmix the stream sediments and give an estimation of where the constituent soils came from, how much sediment was contributed from each area, and the geochemical concentration in the source area.

The method commences with dividing the area into subcatchments based on a digital elevation model (DEM). The subcatchments are further divided into areas underlain by single rock types or hydrological response units (HRUs). Next a rainfall-runoff-sediment transport model is run which tracks the amount of sediment derived from each HRU. To estimate the background geochemistry for each rock type the total sediment from the HRUs of each rock type are summed and a linear equation for each stream sample point is generated. On the left hand side of the equations are the measured concentrations of an element in the stream samples. On the right hand side is the sum of the unknown concentrations for each rock type in the HRUs times the known quantity of sediment from each rock type. The right hand side of the equations can be modified to allow for non-linearities in transport due to heavy mineral winnowing or concentration effects. This set of linear equations can be solved as long as there are as many equations as unknowns.

Once the background values have been estimated, the values are substituted back into the equations and the difference between the original measured concentration and the calculated concentrations provide a measure of the anomaly.

The benefit of the technique is that it allows a quantitative measure of background and anomaly values (eg in parts per million), and field tests suggest that the method can predict concentrations in the source areas with similar accuracy to that obtained from reconnaissance soils surveys.

## Supergene mineralogy - A valuable exploration tool for the field geologist

#### J. J. Kapler and S. A. Williams

ÆSOP Enterprises, Inc., 1431 E. Bates Pky., Englewood, CO 80110, USA; jkapler@rmi.net

As exploration geologists, we spend much of our time evaluating and sampling areas with dumps and prospect pits. Usually these are very shallow workings that only began to penetrate the oxide zone, so naturally, all the primary sulfide ores are typically well-oxidized forming a variety of iron and other oxide zone minerals.

A working knowledge of supergene mineralogy is a valuable field tool providing ready information useful in prospecting, evaluating the potential of exploration targets, planning and interpreting geochemical analyses, and in the geoenvironmental analysis of mineral systems. It is important in mineral exploration to recognize in the field, not only what metals are present, but to know if they are absent, if they have been removed, or were never present. The presentation, by means of photomicroscopy through a 14X hand lens, will review those elements and minerals the explorationist should be able to recognize during routine fieldwork, and comment on their significance, oxide zone mineral paragenesis, and relevance to exploration for porphyry copper, gold, and polymetallic skarn / replacement deposits. The talk presents the oxide zone mineralogy from the Victorio District, New Mexico as a case history, and how that information was used in the field. Not all of the minerals that will be mentioned are common, but they are the ones most likely to occur at the surface, if the suite of elements needed to form them is present.

## The use of partial extraction geochemistry for copper exploration in Northern Chile

#### D. L. Kelley<sup>1</sup>, G. E. M. Hall, R. M. McEwen, L. G. Closs, M. Valdez, I. Hamilton <sup>1</sup>WMC Exploration, 8008 E. Arapahoe Ct, Suite 110, Englewood, CO 80112 USA; dave.kelley@wmc.com

The successful application of partial extraction geochemistry in northern Chile depends on a detailed understanding of the environment and the limitations of partial extraction methods. Most of northern Chile is within a region of interior drainage that has existed since at least mid-Tertiary time when many of the porphyry copper deposits were being uplifted, eroded and supergene enriched. The eroded material from the tops of porphyry copper deposits have been geochemically recycled into the complex post-mineral cover that includes alluvium, lake and playa sediments, evaporites, eolian material, ignimbrites and volcanic ash. The climate changed to hyper-arid from semi-arid in mid-Miocene time creating a surface environment that is saline and slightly alkaline. Other unique aspects of this environment include high-grade nitrate deposits with the ubiquitous minor constituent of perchlorate.

The geochemical expression of the Chimborazo deposit in northern Chile was studied in detail using the following wet chemical extraction methods: 4-acid, aqua regia, bulk cyanide leach, hot hydroxylamine hydrochloride, cold hydroxylamine hydrochloride, Enzyme Leach and de-ionized water. Chimborazo is a porphyry copper deposit with a superimposed high-sulfidation system. Only the high-sulfidation system is exposed. Limitations affecting several partial extraction methods include poor data quality, lack of pH control, re-adsorption, and the formation of colloids in the leachate. Experimentation with leach time and buffering capacity improved the robustness of some of the methods. Given the complex sample matrix and the high water-soluble fraction of Atacama soils and sediments, none of the methods tested is considered to be selective. Results show that mechanical dispersal is the dominant dispersion process although chemical dispersion does occur laterally on a regional scale and vertically on a local scale. The vertical chemical dispersion is associated with saline groundwater and is likely related to seismic pumping of metalliferous groundwater along fractures.

## History, ethnography and archaeology in prospecting for precious metals

#### A. L. Kovalevskii

#### Geological Institute, Siberian Branch of the Russian Academy of Sciences, Sakhyanova Street, 6a, Ulan-Ude, 670047, Russia; <u>koval@gin.bsc.buryatia.ru</u>

Our researchers have recently established that historic, ethnographic and archaelogic data can have great significance for modern prospecting for precious metals. We have experienced this studying Pt and Pd, and then a full complex of platinum group elements (PGE) in the Gil'bera zone of deep-seated fault (GZDF). This PGE mineralization occurs in alkaline syenites, where according to the PGO "Buryatgeology" and "Buryatgeolcom" geologists: "it should not be". Our complex studies, mainly lithobiogeochemical, have shown, that in GZDF, considered as silver-, gold-, fluorite- and asbest-bearing, the main mineralization is in fact PGE (PM). The mentioned PM form local stockwork-like mineralized zones (SMZ) up to tens meter width, with several steep inclined local mineralized zones (LMZ) 0,2-2.0 m width. PM occurs in an uncontoured zone more than 5 km wide and extends by about 20 km. The presence of more 1000 than local biogeochemical anomalies (LBA) of PGE and results of tens hypothetical ore biogeochemical anomalies (SOBA) of PGE, by trenching, the PM in GZDF has practical significance. Up to now in threnches have been revealed more than 100 LMZ and local spotlike deposits (LSD) of platinoids 1-20 m wide, including two practically interesting LSD more than 10 m wide. One of them on a site "Northern", on data of the most reliable fire-assay atomic-absorption analysis (FAAA), is represented by Pt+Pd+Rh (other platinoids here were not determined) with the total contents in an Pt economic equivalent from 40 up to 500 ppb. Second LSD more 18,5 m width with total concentration Rh+Os+Ir from 100 up to 650 ppb (Pt and Pd here by FAAA were not detected and also probable ruthenium was not determined).

Except for lithobiogeochemical data the evidence of PM practical value in GZDF are their old mining, and presence of platinum objects at the inhabitants of neighboring villages. Evidences of old mining during XIX and beginning of XX century are represented by tens thousands of old pits three quarries, several channels, three cemeteries with tens graves of old miners (probable, Chinese, Mongols and Japanese) buddist faith, overgrown horse roads, network of human tracks, numerous household subjects, etc. It is true established, that high-scale mining of PGE was conducted by the Japanese during American-Japanese intervention in 1918-1920. Our geoarcheologic and geoethnic data suggest that the old mining of Pt in this period were established along more than 200 kms of the regional Dzida-Vitim zone of deep-seated fault (DVZDF) from Orongoi up to Chorinsk. Taking into account, that PM (mainly Os, Ir and native Pt in smaller amounts) was mined in Dzida rare metal-gold-bearing region of Zakamensk administrative region of Buryatiya since the end of XIX Century (Vysozkii, 1933), it is possible to judge, that PM of DVZDF occur along more than 500 km and even more than 1200 km along-strike.

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### Deposits of PGE in wheathered rocks of deep-seated fault zones

#### A. L. Kovalevskii

Geological Institute, Siberian Branch of the Russian Academy of Sciences, Sakhyanova Street, 6a, Ulan-Ude, 670047, Russia; <u>koval@gin.bsc.buryatia.ru</u>

Platinoids (PGE) mineralization in the Gil'bera zone of deep-seated faults (GZDF) extends more than 20 km long and is situated in the southeastern edges of the Khamar-Daban range in the central part of the Dzida-Vitim zone of deep-seated faults (DVZDF) that is 1200 km long. GZDF is the most investigated model site in DVZDF. Historical, geoethnic and geoarchaeologic data suggest that DVZDF is PGE-bearing more than 500 km long from the Dzida rare metals and gold-bearing region in the west up to the Chorinsk region in the east-northeast. N.K.Vysotskii (1933) indicated discoveries of PGE minerals in gold deposits in upper waters of river Dzida during the XIX century. Osmium-iridium (Os, Ir) predominates here; native Pt was rare. It is academician V.I.Vernadskii's opinion that minerals of osmium-ruthenium group are found here. These manifestations were connected with mafic and ultramafic rocks. These rocks have not been revealed in GZDF yet. By our data, Pt predominates here. So a PGE geochemical specialization in western and central parts of DVZDF is diverse.

We are studying a new structural-formation and also various geochemical types of PGE mineralization in the southern part of the investigated GZDF [Kovalevskii, 1990-2000 in Russian; Kovalevskii, 1994-2000 in English]. These were revealed during folow-up of Pt anomalies in plants by non-barrier biogeochemical exploration (NBE) and non-barrier biogeochemical prospecting (NBP). It is explained by the fact that local mineralized zones (LMZ) of PGE 0,2-3,0 m width are blind and do not crop out. Superficially discontinuous eluvium-deluvium blanket-shaped deposits of Pt are of practical interest and were subjected to old mining in XIX – beginning XX century. They have subhorizontal position and are situated at the bottom of the weathering crust 1-5 m deep.

Installation of space disconnection of various PGE LMZ, and also LMZ of Ag and Au was unexpected for us. These LMZ are grouped in complex mineralized zones (CMZ) 3-30 m wide, mineralized stockwork-like zones (MSZ) 30-100 m in width, and the last - in mineralized stockworks (MS) 100-300 m width for Ag and 300-1000 m and more - for PGE since they have not been contoured yet. The system of LMZ, CMZ, MSZ and MS form a complicated, sometimes - rhythmic fractal structure of GZDF. The major feature of all 8 precious metals (PM) mineralization is the relation to zones of crushing, brecciation and cracking. The most interesting data on geochemical types of PGE deposits in weathering crust of GZDF were obtained on 4 sites at a distance up to 1 km from each other. 6-7 PM: Pt, Pd, Rh, Ir, Os, Au, Ag were determined in them (Ru was not determined). All of them have specific geochemistry with presence of Pt as main (on two sites) or one of the main components. On the "Western" site Pt was fixed in 42% of by SESA plant samples, Ir – in 29%, Rh – in 21%. I.e. "Western" site has Pt-Ir-Rh specialization. "Quarry" site with 43% samples with Pt and 36% with Au has Pt-Au specialization. "Southern" site with 30% samples with Au, 27% with Pt and 16% with Os has Au-Pt-Os specialization. "Lower" site was noted due to the greatest relative distribution of Rh (58% of samples). There was 42% of analyzed samples with Au, 18% – with Pt. It has Rh-Au-Pt specialization. It is interesting, that there was no one site with Pd dominance among 18 investigated, also a sensitivity on Pd is significantly more than on Pt, Ir, Os, Rh. The data suggest main PM in GZDF are Pt, Ir, Os, Rh, Ag, Au. Before exploration on PGE we have considered GZDF to be Ag-bearing. The data obtained show that it is PM-bearing, mainly Pt-bearing. Tens of own silver-ore bodies here 0,2-2 m width are rare LMZ of Ag in the extensive PGE-bearing field. Isolated Au-bearing zones (orebodies were not discovered yet) are rare LMZ of Au. Some of them are complex Au-Ag with

significant predominance Ag (Ag:Au = 2000 and 20000). We recommend our KNOW-HOW – NBE and NBP for evaluation of possible PGE-bearing territories of various ore deposits, especially in zones of deep-seated faults.

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#### Formation conditions of blanket-shaped eluvial deposits of platinoids

A. L. Kovalevskii

Geological Institute, Siberian Branch of the Russian Academy of Sciences, Sakhyanova Street, 6a, Ulan-Ude, 670047, Russia; <u>koval@gin.bsc.buryatia.ru</u>

The first blanket-shaped eluvial deposits (BED) of platinoids (PGE) in the silver-bearing Gil'bera zone of deep faults (GZDF) were unexpectedly discovered. They were situated in an extensive field of alkaline sienites and monzonites with absence of basites (Kovalevskii, 1990, 1993, 1994; Kovalevskii, etc., 1991 in Russian; Kovalevskii, 1994 in English). Recently ha been established, that BED are the most perspective morphologic and genetic type of PGE mineralization from 7 discovered. BED are believed to, have secondary hydrogenic or biohydrogenic origin (Kovalevskii, 1997, 1999, 2000 in Russian; Kovalevskii, 1997, 2000 in English). The primary source would be a poorly-investigated mineralization of hydrothermal, pneumatolytic or hydropneumatolytic origin represented by disseminated forms of PGE minerals with a grain-size less than 1 micron. So far only native Pt with a maximum grain-size up to 2-5 micron have been found. Occurrence in the weathering crust of Os-Ir has a unclear origin. In BED deposits scintillation spectral analysis (SESA) revealed various PGE minerals with various grain-sizes up to 10-30 micron. These PGE are mostly native precious metals (PM): Pt, Pd, Ir, Os, Rh, Au, Ag and rare two-element "alloys": Pt + Pd, Pt + Rh, Pd + Au, Pd + Ag, Au + Ag, Au + As, Ag + As. Probaly there are three-, four-element PM "alloys" with Ru.

A biohydrogenic model of BED PGE deposits forming in GZDF includes a combination of 5 processes. 1) Intensive contact absorption of the dispersed forms of platinoids roots of plants by the lithobiogeochemical model (Kovalevskii, 1991 in Russian; Kovalevskii, 1993 in English), including chelatic organic acids of root excretions. The participation of biogenic chelatic root excretions stipulates 10 times large intensity of absorption Pt, than Au. 2) Leaching of soluble forms of biogenic platinoids from above-ground parts of plants by rain waters acquiring an acid reaction and enriched by chelates - complex organic acids. 3) Migration of PGE leached from upper soil horizons A, B, C with these waters downwards within soils and weathering crusts, being partially absorbed by sucking roots by a hydrobiogeochemical model (Kovalevskii, 1991 in Russian). 4) Enrichment by acid biogenic chelates of rain and snow waters, passed through humic horizons, which dissolve platinoids from the horizons A, B, C and transfer them downwards. 5) Neutralizing of descending acid biogenicchelatizing waters in eluvium of alkaline syenitoids – soil horizon  $I_1$  and sedimentation of PGE from solutions, enriched by them. Long time formation of large, "shlikhs" particles by a size more 0,1 mm up to 1-5 mm. The processes of hydrogenic enrichment under-soil horizons by platinoids are long time studied in natural, humid tropical woods and in experiments (Bowles et al., 1983-1994). The dates of Bowles about significant growth of platinoids crystals and grains in secondary hydrogenic deposits explain well forming in GZDF "large" platinoids particles with the most interesting rare nuggets to 10 mm size.

Conditions of investigated blanket-shaped deposits of platinoids forming by biohydrogenic model are, at least, three: 1) the presence of primary enrichment by dispersed platinoids in the mineralized zones of alkalic rocks; 2) the presence of dense vegetation, ensuring intensive biogeochemical circulation of platinoids with acid biogenic chelates; 3) plenty of atmospheric precipitation ensuring water percolation down to eluvium of alkaline rocks, being a natural geochemical barrier for soluble platinoids in descending acid, biogenic-chelatizing waters.

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## Biogeochemistry and exploration for mineral deposits in the USSR and Russia

#### A. L. Kovalevskii

#### Geological Institute, Siberian Branch of the Russian Academy of Sciences, Sakhyanova Street, 6a, Ulan-Ude, 670047, Russia; <u>koval@gin.bsc.buryatia.ru</u>

The experimental biogeochemical investigations in various ore deposits in the USSR and Russia promote in significant degree to the development of the theoretical biogeochemistry by V.I.Vernadskii (1863-1945). Biogeochemical explorations were beginning in 1930<sup>th</sup> by N.N.Sochevanov, S.M.Tkalich and D.P.Malyuga. After the interruption during the Great Patriotic War 1941-1945 and the first after War years, in 1950-1970<sup>th</sup> experimental biogeochemical explorations were conducted in almost all main ore regions of the USSR. The main sampling bioobjects in this period were leaves and twigs of trees and shrubs and shoots of grasses.

It was established by our investigations of 1960-1970 that prospecting information of various plant bioobjects may be changed from the quantitative information in the nonbarrier (or barrierless) bioobjects to the absolute uninformativity in the background barrier bioobjects (Kovalevskii, 1960-2001, in Russian; Kovalevskii, 1968-1987, in English). We know the use of the nonbarrier bioobjects "The Nonbarrier Biogeochemical Exploration" (NBE). It was recognized officially and included in the second edition of "Instruction for Geochemical Methods of Exploration for Mineral Deposits", 1983. This instruction of the USSR Ministry of Geology was obligatory for all geologic organization of the USSR. The results of 100-150 bioobjects of Siberian plants grouping by their quantitative barrier characteristics for 23 chemical elements were published in the last years (Kovalevskii, 1984-2001 in Russian; Kovalevskii, 1984-1995 in English). About 4 million samples of the nonbarier plant bioobjects were investigated by the NBE technology in the USSR in 1970-1990<sup>th</sup>. In this years in the Buryatia by detachment of P.I.Radchenko it was revealed and contoured by NBE, using mainly trunk cork of pine (Pinus silvestris) and larch (Larix dahurica), two deposits: Chaluyta (Sr) and Zharchikha (Mo) and 9 ore occurrences. In Kazakhstan by V.P.Ivanchikov (1972-1987, in Russian), V.A.Alekseenko (1973-1989 in Russian) et al. were investigated close to 2 million biogeochemical samples (shoots of wormwoods mainly). It was revealed there 4 polymetallic deposits. In Uzbekistan was revealed many ore occurrences of gold. In the last decade we have discovered 2 Ag deposits, 9 supposed Ag deposits and numerous (hundreds) of supposed ore biogeochemical anomalies (SOBA) Ag, Au, Pt, Ir, Os, Rh, Pd and wide anomalous fields of these precious metals and Pb, Sr, Ba, TR (Kovalevskii, 1990-2000 in Russian).

In 1980<sup>th</sup> began the elaboration of the Nonbarrier Biogeochemical Prospecting (NBP) with evaluation of useful components geologic prognostic resources – a new direction in the geochemical exploration. The investigations of NBP were conducted in deposits of Be, Mo, Au, Ag, Pt (Kovalevskii, 1984-2000 in Russian; Kovalevskii, 1987-2000 in English). By NBP for veined silver-ore bodies (VSOB) we have revealed supposed ore biogeochemical anomalies 160 (SOBA) with 70-3000 ppm Ag on background 0,7 ppm in the ash of old, rotten wood of pine stumps. 11 thickenings with 5-50 ppm SOBA 100x150 – 300x400 m size were discovered. Opening of two the best SOBA thickenings by trenching 240-320 m length confirm the presence of the supposed silver-bearing stockworks and high (93%) reliability of VSOB revealing. Opening 29 SOBA by trnches 27 VSOB with concentrations of Ag from 20 to 6100 ppm were discovered. The elaborated technologies of NBE and NBP are recommended for using in other regions of the Earth.

The generalization of biogeochemical investigations data on ore deposits make it possible to receive the fundamental results in plants biogeochemistry. They are published in our monograph: "Biogeochemistry of Plants" (1991, Novosibirsk, Nauka Press). It is undoubted that this very valuable monograph, reference and teaching book is worthy for the issuing in English.

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### Ecologic biogeochemistry of mercury in the Republic Buryatia

#### A. L. Kovalevskii

#### Geological Institute, Siberian Branch of the Russian Academy of Sciences, Sakhyanova Street, 6a, Ulan-Ude, 670047, Russia; <u>koval@gin.bsc.buryatia.ru</u>

Our mercury-biogeochemical studies from 1966 to 2000 established that sources of natural, geological contamination of plants by Hg are ore-bearing geological structures and zones of tectonic faults – especially of deep mantle faults. The reason is a rather high intensity of an absorption of the Hg gaseous forms by plants. The value of plant-gas coefficient (PGC) of vapour Hg and other gaseous migrants is equal on the average 300000, when average value of plant-soil coefficient (PSC) is close to 1,0 and plant-water (PWC) – to 3000.

The example of natural biogeochemical provinces with high concentration Hg (and Cd) in plants with close to background contents in soils and soils-forming rocks is Ozernaya. It is connected, with the same name ore knot in Eravna district of Buryatia. It has remained encountered, since near lakes Gunda and Isinga in Eravna hollow we have revealed high contents of Hg and Cd in kidney and liver of sheeps exceeding their Limited Permissible Concentration (LPC). These unexpected data testify to a probable prolongation of Ozernoe ore knot on the east. Two other, mercury-biogeochemical areas, are connected with the silver-bearing Gil'bera zone of deep faults in the Ivolga district and with Monostoi anomalous biogeochemical field of Cd, Zn, Pb in the Selenga district of Buryatia. It is interesting, that Ozernoe, Gilbera and Monostoi mercurybiogeochemical areas are characterized by high concentrations of Hg and Cd in plants, i.e. are complex cadmium-mercury. The extensive territory with increased contents Hg in ash of plants was revealed by P.I. Radchenko in the average current of river Chikoi Kyakhta region and in a the southern part of Bichura region of Buryatia. It can be called the Chikoi mercury-biogeochemical province. One more such province we predict on territory of the gigantic polymetal deposit "Kholodnoe" in the Severobaikal'sk region of Buryatia. Mentioned 5 mercury-biogeochemical provinces are only still low investigated examples of such areas in the Buryatia, as here are known numerous other uncontoured anomalies of Hg in plant's ash.

Determinations of Hg in open reservoirs (waters, hydrobionts): lakes of Baikal, Gusinoe and Eravna have given contradictory data. By information of Limnologic Institute in town Irkutsk, high concentration of Hg, exceeding its LPC, in waters of Baikal are absent. By data of the special investigations by the North-Baikal ecology-geochemical detachment of the Industrial Geological Organization "Buryatgeology" the northern cup of Baikal in sector Severobaikal'sk-Nizhneangarsk have significant contamination by Hg. It contents reach 5-63 mkg/l, i.e. 10-126 LPC in coastal waters of Baikal, 10-120 LPC in waters of drinking bore holes on western coast of Baikal and 8 LPC in water-supply of town Severobaikal'sk. Maximum concentrations to 50-70 mkg/l, i.e. 100-1400 LPC were established in lower layers of show covers. This anomaly may be named the Severobaikal'sk hydromercury-biogeochemical province. After mercury contents exceeding LPC here have Cd, As, Se, Tl. So this province is complex. In lake Gusinoe, by data of the Institute of General and Experimental Biology, in some of investigated localities in hydrobionts (fishes and their forages) have been revealed high concentrations of Hg, exceeding its LPC. This speak that in waters of Baikal and other lakes of Buryatia in separated local places changing in time contamination of waters and hydrobionts by Hg, exceeding their LPC is observed. It must be underlined that in majority of such areas Hg is accompanied by Cd.

Thus to the present time in the Buryat Republic, mainly unexpected, simultaneously with geologic works, were established 5 mercury-biogeochemical and one mercury-hydrobiogeochemical areas

and provinces. Here are predicted a larger number of them. Such unexpected mercurybiogeochemical province are also established in Canada (Warren et al.; 1983). They are very probable all around the Earth and need special international investigations, especially in seismicactive regions.

## Environmental geochemical exploration in the area of an old copper mine, Asturias, Spain

#### J. Loredo, A. Alvarez-Wurtemberger, A. Ordóñez, and J. García Iglesias

Departamento de Explotación y Prospección de Minas. E.T.S. Ingenieros de Minas. Univ. Oviedo. Independencia 13. 33004 Oviedo, España: <u>jloredo@correo.uniovi.es</u>

The scope of the study is to asses a preliminary environmental impact from an historical mining and metallurgical copper site in Asturias (Spain), in order to provide relevant geochemical information for news studies if necessary. The Texeo copper mine is located 8 km from Pola de Lena (Asturias, north-western Spain), on the slope of the Aramo mountains, at a height of 600 to 1,200 m. It constitutes one of the oldest asturian mining works; prehistoric utils have been found on the site. On the modern age this mine has been intermittently exploited from 1893 to the end of the 50's, where the mining works were definitively abandoned. The ore deposit is formed by a metasomatic replacement related to fracture systems on the carboniferous limestones. The paragenesis of the ore deposit is constituted of pyrite, sphalerite, chalcopyrite, bornite, digenite, djurleite, chalcocite, skuterrudite, marcasite, cobaltite and covellite as sulphides, cuprite, goethite and heterogenite as oxides, malaquite and azurite as carbonates, and erytrine as arseniates. First mining works took place on the oxidised zone of the ore, which is well developed in the site of the mine. Later, cementation zone has been exploited until the closure of the mine in the 50's.

At the site of the old mining and metallurgical works, a two stage systematic sampling has been made in soils, using manual drilling, in an area of  $0.2 \text{ km}^2$ . On the first stage a 100 m square sampling grid was used, and in the area where geochemical anomalies were detected a second square sampling grid of 50 m side was made, covering an area of 22,500 m<sup>2</sup>. Soil pH measured "in situ" gives values comprised between 6.90 and 7.91 units. For the determination of total metal content in soil samples, a multielemental chemical analysis has been made by inductively coupled plasma (ICP). Total concentrations of heavy metals in soils are as follow: Cu from 37 to 9921 mg/kg, cobalt from 12 to 685 mg/kg, nickel from 25 to 1,040 mg/kg, lead from 23 to 1,191 mg/kg, and zinc from 55 to 1,123 mg/kg, where lower value for each element corresponds to its local geochemical background level. Total arsenic concentration ranges from 26 (local geochemical background) to 1,373 mg/kg. Superficial waters upstream and downstream of old mining and metallurgical works show pH comprised between 7.2 and 7.8 units, and conductivity between 300 and 500  $\mu$ S/cm. ICP multielemental chemical analysis of samples from superficial waters show not relevant heavy metals and arsenic concentrations.

Geochemical anomalies in soils compared to the local background levels are specially significant for arsenic and copper, and a computing based risk assessment applied to the site gives for these elements values high enough to be considered.

## Stable Isotope Variations in Alteration Haloes of Central Victorian Gold Deposits, Australia

Jijun Lu<sup>1</sup>, Dennis Arne<sup>1</sup>, Frank Bierlein<sup>2</sup>, Ian Cartwright<sup>2</sup>

<sup>1</sup>Western Australian School of Mines, Curtin University of Technology, Kalgoorlie, WA 6430, Australia; <u>J.Lu@curtin.edu.au</u> <sup>2</sup>Department of Earth Sciences, Monash University, Melbourne, VIC 3800, Australia

Central Victorian gold deposits have produced approximately 2500 tonnes of gold since 1851. The bulk of production has come from structurally-controlled deposits typically hosted by Upper Cambrian to Ordovician turbidites. Detailed mineralogical and geochemical investigations indicate that hydrothermal alteration haloes associated with these deposits are characterised by the presence of a variety of Fe-Mg carbonate minerals and sericite, as well as elevated  $CO_2$ , S, K, As and Au. Whole-rock and vein samples from the Stawell, Fosterville, Ballarat and Fiddlers Reef deposits have been analysed for  $\delta^{18}O$  in silicates,  $\delta^{18}O$  and  $\delta^{13}C$  in carbonates, and  $\delta^{34}S$  in sulphides in order to evaluate the degree of isotopic exchange between the host rocks and hydrothermal fluids.

Whole-rock silicates have a wide range of  $\delta^{18}$ O values (9-15‰) attributable to lithologic differences and wallrock alteration. High  $\delta^{18}$ O values in excess of 13‰ are limited to within 5 m of mineralised lodes at the Magdala deposit, Stawell, and are associated with quartz veining and silicification. Silicate  $\delta^{18}$ O whole rock values are depleted from 14‰ to 11‰ within ~8 m of the Guiding Star Lode at Ballarat West. There is no discernible trend in the silicate  $\delta^{18}$ O whole rock data within the alteration halo at Ballarat East and only minor variations observed at Fosterville. Although evidence for isotopic exchange between host rock silicates and the ore fluid is evident, the effects are often localised and/or subtle compared to the effects caused by lithological variations.

 $\delta^{13}$ C and  $\delta^{18}$ O values from carbonate minerals in whole-rock samples reflect the effects of wallrock alteration in all three deposits, consistent with the introduction of a CO<sub>2</sub>-bearing fluid. Low  $\delta^{13}$ C (-14‰) and  $\delta^{18}$ O (13‰) values in the contact lode at Magdala are from calcite that may be primary in origin, whereas high  $\delta^{13}$ C (+2‰) and  $\delta^{18}$ O (20‰) values in the central lode system are related to hydrothermal ankerite and siderite. Vein carbonate  $\delta^{13}$ C values at Magdala are consistent with mixing of reduced sedimentary carbon with a hydrothermal fluid containing heavier carbon. By contrast, the alteration halo at Ballarat West is characterised by an increase in  $\delta^{13}$ C (-6.5‰ to -5.5‰) within 8 m of the lode system, whereas  $\delta^{18}$ O decreases from ~24‰ to 14 ‰ over the same interval. Although whole rock samples from Fosterville show a general decrease in  $\delta^{13}$ C of ~2‰ as the ore zone is approached, the  $\delta^{18}$ O data show local increases of ~2‰. Significant variations in isotopic patterns exist between and within individual deposits, reflecting different isotopic reservoirs and degrees of isotopic exchange.

Sulphur isotope haloes have previously been recognised around central Victorian gold deposits, with values of around 0‰ associated with the gold deposits, and strongly positive or negative values in the enclosing host rock.  $\delta^{34}$ S values of sulphides associated with the lode systems at Magdala range from -13.4‰ to -11.9‰, implying a sedimentary reservoir for sulphur. A gradual increase in  $\delta^{34}$ S values occurs at least 65 m away from the central lode system, increasing to values

around +13‰ at 139 m away from the central lode system. At Ballarat and Fosterville, hydrothermal pyrite and arsenopyrite gives values near 0‰, consistent with data from previous studies in central Victoria. Diagenetic pyrite grains generally give values in excess of 9‰ at Fosterville and around 20‰ at Fiddlers Reef.  $\delta^{34}$ S values at the latter decrease to between 5‰ and 10‰ within and immediately adjacent to the reef. Laser ablation isotopic analyses indicate that diagenetic pyrite grains immediately adjacent to Fiddlers Reef have been overgrown by isotopically lighter pyrite. Sulphur isotope data therefore appear to provide the most reliable isotopic indicator of hydrothermal alteration around central Victorian gold deposits.

## Gold mobility in the regolith at Cobar, N.S.W., Australia: Implications for geochemical exploration and oxide gold resources

### K. G. McQueen<sup>1</sup>, K. M. Scott<sup>2</sup> and I. D. M. Robertson<sup>3</sup>

<sup>1</sup>CRC LEME, University of Canberra, ACT, 2601, Australia; <u>kmq@scides.canberra.edu.au</u> <sup>2</sup>CRC LEME CSIRO, PO Box 136 North Ryde, NSW, 1670, Australia <sup>3</sup>CRC LEME, CSIRO, PB 5 Wembley, WA, 6913, Australia

Gold-bearing polymetallic sulfide deposits occur in the Cobar Mining Field in western New South Wales. These deposits are structurally controlled, vein systems hosted in Early Devonian turbidites. Intense chemical weathering through the Cainozoic has produced oxidised and variably leached regolith profiles over the mineralised zones. The distribution of gold in these profiles indicates significant gold mobility during the weathering history. The composition and morphology of oxide zone gold also indicates supergene deposition of gold.

In the Cobar region there has been a complex history of landscape development through the Cainozoic characterised by variable erosional stripping, infilling of palaeolandscapes and topographic inversion. Case studies in different regolith-landform settings, with varying profile development and preservation, indicate two major types of weathering related to early warm and humid climatic conditions and later more arid conditions. Chemical mobility of gold appears to have been restricted during early, intense weathering under wet conditions. However, under late, arid conditions, gold mobility was enhanced by the development of chloride- and sulfate-bearing groundwaters. Mechanical dispersion of gold also occurred during erosion of exposed mineralised profiles.

Above background concentration of gold in regolith carbonates (calcrete) around the Cobar Mining Field provides evidence for widespread dispersion of gold in palaeo-drainage networks. It is unclear whether this gold has been dispersed in solution by laterally active groundwaters or locally recycled from detrital gold or gold-bearing host phases. A number of large surface lag anomalies with high concentrations of gold and pathfinder elements (particularly As) have also been detected. Some of these appear unrelated to any underlying mineralisation and may be explained by mechanical dispersion of gold in ferruginous lag.

Recognition of gold mobility in the Cobar environment has two important consequences:

- it can help explain gold dispersion and aid in geochemical exploration;
- it indicates the potential for supergene/oxide gold resources.

Deposition of hydromorphically dispersed gold at redox boundaries has produced displaced and false anomalies, creating confusion during geochemical exploration. These types of anomalies are typically have high Mn and Co contents. Near-surface leaching of gold in some profiles can also be misleading although associated parthfinder elements generally persist to the surface. In other profiles, gold is preserved in the upper part, but many of the pathfinder elements are leached.

Early mining in the Cobar Goldfield (1890-1930) exploited high-grade supergene-enriched oxide zone gold. There is potential for additional oxide gold resources both as lower grade remnants of the older workings, for example at the New Cobar deposit (currently being exploited), and in new discoveries, for example the McKinnons deposit (where supergene processes have produced recoverable gold from lower grade and refractory primary ore).

## Integrated Geochemical and Geophysical Exploration for Gold: Case History of the Serra de Jacobina Project, Central Brazil

T. Minton<sup>1</sup>, J. Misener<sup>2</sup>, G. Hollyer<sup>3</sup>, and L. Kelly<sup>4</sup>

<sup>1</sup>Geosoft Europe Limited, Wallingford, UK. <sup>2</sup>Paterson, Grant and Watson Limited, Toronto, Canada. <sup>3</sup>Geosoft Incorporated, Toronto, Canada; <u>Greg.Hollyer@geosoft.com</u> <sup>4</sup>Paterson, Grant and Watson SA, Santiago, Chile.

As part of a regional gold exploration study in the Serra de Jacobina area in Central Brazil, exploration geochemistry data from the Unified Geochemical Database of Brazil (UGDB), radiometric data from the Brazilian Radiometric Mapping Project (BRMP) and magnetic data from the South American Magnetic Mapping Project (SAMMP) were analyzed in detail. The objectives were to use historical data provided by CPRM and compiled by PGW to characterize gold occurrences in a specific lateritic environment, to identify potential source rocks, and to evaluate correlations between geochemical and geophysical results.

An initial review of the geochemistry results (i.e. gold values) indicated the presence of a significant source of gold as evidenced by many plotted samples showing values greater than 1 ppm. Although gold is known to occur in metaconglomerates in Central Brazil, analysis of rock type information provided for each sample indicated that anomalous values did not, in this case, consistently correlate with metaconglomerates. The conclusion was that many gold occurrences were related to erosional transport from a source location. To identify source locations, integrated geochemical and geophysical methodologies were implemented. Ternary diagrams of Fe, Mg and K (from radiometrics) were plotted and showed a distinctive signature that correlated with metaconglomerates. When viewed in map presentations, the signature outlined a dispersion pattern that, in turn, indicated the direction of erosional transport. Integrated comparison of gold and radiometric results also showed a strong correlation, indicating that placer and paleoplacer gold occurrences in this area are both associated with radioactive minerals, such as zircon and monazite, that are resistive to weathering.

As a final step, geochemistry data from the UGDB were evaluated numerically using spatial querying methods. The Serra de Jacobina study area was found to be strongly anomalous in Cr with most of the high Cr values occurring at or near outcrops of peridotite or other mafic rocks. This result indicated a good correspondence between the surface geochemistry and underlying rock type. Further work also showed a correspondence between Cr and Fe that led to an examination of magnetic results. Although a correlation between Fe and magnetics was expected, there was actually an inverse correlation showing that rocks with high Cr and Fe were non-magnetic. This result may provide a unique mapping tool for the area.

In summary, this case study shows the overall effectiveness in applying large volume geochemistry results with geophysical information for a variety of applications, including characterizing gold occurrences, tracking source rocks and identifying anomalous lithogeochemical signatures. In turn, these results may provide effective tools for identifying prospective gold exploration targets in the Serra de Jacobina area of Central Brazil.

## Proterozoic mineralization identified by integrated regional geochemistry, geophysics, and bedrock mapping in Western Australia

P. A. Morris, F. Pirajno, and S. Shevchenko

Geological Survey of Western Australia, 100 Plain Street, East Perth 6004, Western Australia; <u>p.morris@dme.wa.gov.au</u>

Successful mineral exploration in central Western Australia relies upon the integration of direct observations (e.g. detailed mapping of exposed bedrock, regolith geochemistry), and remotely-sensed data (e.g. geophysics), as extensive areas are characterized by subdued relief, and transported regolith in a zone of semi-arid climate. As suitable data are uncommon and often expensive to acquire, the Geological Survey of Western Australia (GSWA) instituted a helicopter-supported regolith geochemical and gravity data capture program, based on a 4 x 4 km sampling grid (Morris et al., 2000; Howard and Shevchenko, 1999). The successful integration of these data with detailed geological mapping at 1:100 000 scale is shown in a 50 000 km2 area, covering three 1:250 000 scale map sheets. This area comprises Archaean granite-greenstones, which are unconformably overlain by a 5 km thick sequence of Paleoproterozoic (ca 1930 - 1830 Ma; Earaheedy Group) and Mesoproterozoic sedimentary rocks (ca 1200 Ma Collier Group), the latter intruded by ca 1070 Ma dolerite sills and dikes. Known mineralization in this area comprises small lode gold deposits hosted by Archaean greenstones (e.g. < 0.25 Mt (a)  $\sim 4$  gpt) and localized MVT-type mineralization consisting of disseminated galena and sphalerite in Paleoproterozoic stromatolitic dolomites. Regolith geochemistry from the helicopter program outlines areas of greenstone and the MVT-type mineralization, as well as four previously unrecognized areas of potential mineralization (Table 1).

In two of the six areas summarized in Table 1, aeromagnetic and gravity data indicate that regolith geochemical anomalies are coincident with regional structures. Gravity data from the Weld Spring area shows that potential PGE mineralization is coincident with an exceptionally thick dolerite intrusion. In all cases, detailed mapping has confirmed any structural control indicated by geophysics, and is essential where potential mineralization has little or no geophysical expression (Mingol Camp; shear zone-hosted gold in Archaean greenstones).

Mineralization	Host rock	Locality	Regolith?	Mapping	Geophysics?
Shear zone-hosted	Archaean greenstones	Mt Eureka,	Host rock only	Yes	Host rock only
Au*		Horse Well			
MVT (Zn-Pb-Cu)*	Earaheedy Group	Sweetwater	Yes	Yes	No
		Well			
Shear zone-hosted	Earaheedy Group	Stanley Fold	Yes	Yes	Yes
gold		Belt			
Stratiform Mn	Earaheedy Group	Mingol Camp	Yes	Yes	No
Mn + argillic-	Earaheedy Group	Mt Wellesley	Yes	Yes	Yes
potassic alteration					
PGE	Dolerite	Weld Spring	Yes	Yes	Yes

Table 1 Mineralization detected by combined regolith, geophysics and mapping

\*previously known

- HOWARD, D., and SHEVCHENKO, S. 1999. Operations and processing methodology used in GSWA regional gravity surveys 1998-1999. *Western Australian Geological Survey, Record,* **2000**/6, 12 pp.
- MORRIS, P. A., McGUINNESS, S. A., SANDERS, A. J., and COKER, J. 2000. Geochemical mapping of the Stanley 1:250 000 sheet. *Western Australian Geological Survey*, 1:250 000 *Regolith Geochemical Series Explanatory Notes*, 53 pp.

## The Nature and Patterns of Element Dispersion in Aeolian Overburden Associated with Selected Gold Mineralization in Semi Arid Areas of Southern Africa

#### C. D. Okujeni and P. Ackon

Department of Earth Sciences, University of the Western Cape, Bellville 7535, RSA; cokujeni@uwc.ac.za

Over half Southern Africa is semi-arid to arid and vastly covered by regolith dominated by aeolian sand and calcrete. Most of these areas are increasingly becoming main focus of exploration for 'world class ' mineral deposits while geochemical criteria for recognition of surface expression of large ore system still remains a major obstacle in various exploration programmes.

This paper discusses results of regolith mapping and geochemistry conducted in four sites hosting gold mineralization at Silobela in Midlands, Zimbabwe, which is less arid than the Goldridge, Jerusalem and Amalia areas in South Africa. All areas under study are located within granite greenstone terrains that are vastly blanketed by aeolian sands, most of which directly overlie paleosurfaces/ bedrock and or lateritized sediments of the Kalahari Formations. Soils are generally calcerous with widespread association of pedogenic and valley calcretes with regolith in South Africa; carbonates are less developed in the Silobela area in Zimbabwe.

Dispersion of Au and associated elements were studied in vertical sections in all areas. Gold was leached using sequential techniques, with water and ammonium citrate and analyzed along with other elements by GFAAS. Other selective leach techniques using NaBr and tellurium and sodium pyrophosphate were also applied.

Surface geochemical signatures of gold and some associated elements occur in around deposits studied, some overlain by regolith/aeolian sand thickness of over 20 meters. At subsurface, gold enrichment occurs along palosurfaces in association with ferricrete and along fine grained clayed horizontal redox interface.

Results of selective leach experiments suggest the bulk of gold in regolith to be loosely adsorbed and partly occluded in Fe-Mn oxides and ferricrete and less dependent on sites of calcrete formation or patterns of Ca:Mg ratios. Best contrast in gold distribution was achieved by selective leaching of minus 45 micron fraction in soils from Silobela area, which is less arid as opposed to the use of minus 200 micron fraction in soils overlying gold deposits in South Africa.

The geochemical signatures are considered to result from an upward mass transfer of Fe rich colloidal solutions containing Au during movement seasonal ground- and capillary water and precipitated around Fe coated aeolian sand and Fe-Mn nodules.

## Geochemical Dispersion from Tin Deposits on the Western Seward Peninsula, Alaska, USA – Environmental and Exploration Aspects

C. C. Parnow1, L. G. Closs2, R. J. Goldfarb3, and K. D. Kelley3

1Knight Piesold Consulting, Ste. 500, 1050 17<sup>th</sup> St., Denver, CO 80265 USA. 2Dept. of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401 USA. 3U.S. Geological Survey, Box 25046, MS 964, Denver Federal Center, Denver, CO 80225, USA

Tin-bearing skarn, greisen, and replacement deposits are associated with ca. 80-70 Ma granites that intrude Precambrian(?) and lower Paleozoic argillites and limestones in northwestern Alaska. Sediments eroded from the deposits are transported across the arctic tundra and into Lopp Lagoon, which connects with the Chukchi and Bering Seas. Trace element dispersion patterns in stream sediments and waters were investigated to aid both assessment of mineral resource potential and to define any potential environmental risks to the local Alaskan native population, who harvest plants along the tundra and rely on fish and marine mammals for their diet.

Geochemical data collected during the National Uranium Resource Evaluation (NURE) program indicated that streams entering into Lopp Lagoon, downstream from undeveloped tin occurrences, were characterized by stream sediments with naturally high concentrations of 60-635 ppm As and 60-144 ppm Sn. Additional data collected during our work showed associated enrichments in Ag, Be, Cu, Sb, and W. Although waters downstream from the occurrences may contain 43-75 ppm dissolved sulfate and may be locally acidic (pH 4.7-6.5), trace elements in solution are consistently at very low levels. Except for a small seep below a tailings pile at the Lost River mine with 180 ppb As, all dissolved arsenic concentrations were <10 ppb.

Results from surficial geochemical mapping suggest that although solution transport of metal phases from tin-bearing occurrences is insignificant, arsenic- or tin-rich sediments may impact the local ecosystem. In addition, sediments with >70 ppm As indicate the existence of previously unrecognized tin occurrences in tributaries to lower York Creek, an area northeast of all previously recognized tin-rich hydrothermal systems.

### **Environmental Geochemistry of Heap Leach Closure**

#### J.V.Parshley<sup>1</sup> & R.J.Bowell<sup>2</sup>

<sup>1</sup>SRK Consulting, Suite 300, 5250 Neil Road Suite 300, Reno, NV 89502, USA; <u>jparshley@srk.com</u> <sup>2</sup>SRK Consulting, Summit House, 9 Windsor Place, Cardiff CF103SR, UK; <u>Srk003@aol.com</u>

The primary issues in the closure of gold heap leach pads in the Western U.S are the disposal of remaining heap solution inventory and the chemistry of the post-closure effluent from the heap. As a general rule, the chemistry of the existing inventory poses a greater concern because the quality is typically worse and requires disposal during a short timeframe.

Typically, the ores found on most gold heap leach pads are relatively non-reactive, the rare exception being those that contain sulfides. Consequently, most species are present in an oxidized form that has a limited mobility, e.g. arsenate dominates over arsenite and ferric iron over ferrous. Therefore, the quality of long-term leachate from closed heaps generally improves with time as the entrained heap solutions are drained from the heap. Once the remaining solution has been drained from the pad, the pH tends to drop rapidly to circum-neutral levels, and constituents mobile in alkaline solutions, such as arsenic, become less soluble. The drop in pH also tends accelerate the degradation of any cyanide remaining in solution.

Many of the remaining solutes can be removed from the solution through natural attenuation processes, such as adsorption onto hydrous ferric oxide (HFO) or clay surfaces, in constructed attenuation basins or designed infiltration fields. Interestingly, at many of these sites, the natural levels of many metals and metalloids in local soils are often in the range of the leachable levels in the spent ore. As a result, mass balance evaluations of solute attenuation indicate that the mass of constituents added to the environment is often insignificant when compared to the background chemistry of the native environment.

Currently the most common regulatory criteria for heap closures are numerical standards and/or demonstration of non-degradation. However, for most oxide-gold ores, the environmental toxicology of long-term heap effluent is typically benign. Because the mass of added constituents in the attenuation area is characteristically negligible, the local environments are tolerant to the release of heap leach effluent. Therefore, an ecological risk-based approach heap closure and assessment of long-term impacts is more appropriate that adherence to rigid numerical standards.

# The selective extraction of Arsenic in selected minerals and tailing samples

C. Patinha<sup>1,2</sup>, E. Ferreira da Silva<sup>1,3</sup>, and E. Cardoso Fonseca<sup>1</sup> <sup>1</sup> Geosciences Department, University of Aveiro. 3810-193 Aveiro. Portugal <sup>2</sup> PRAXIS XXI Scholarship <u>cpatinha@geo.ua.pt</u> 3 <u>eafsilva@geo.ua.pt</u>

The study described herein concerns the application of selective chemical extractions on selected arsenic minerals and tailings samples.

The four minerals (arsenopyrite, scorodite, tennantite and conichalcite) used for the kinetic study were crushed and sieved through a minus 80-mesh sieve. This fraction was then intimately mixed with two matrixes (carbonate and aluminosilicate) of well-known mineralogical composition, and of the same granulometry. The carbonate matrix contained a background of 10 ppm As and the aluminosilicate matrix a background of 40 ppm As. The weight of minerals (arsenopyrite, scorodite, tennantite and conichalcite) added to 100g of matrix used to prepare mineralised samples (doped samples), is calculated in such a way that there are about 500 ppm As in scorodite and arsenopyrite and 300 ppm As in conichalcite and tennantite.

A kinetic study of the selectivity of partial chemical extractions applied to minerals of arsenic was undertaken in order to establish a procedure (reagents, time of extraction, etc), which could be recommended for soils and tailings of the Talhadas and Preguiça old mines. It is shown that: (1) NH<sub>4</sub> acetate and hydroxylamine dissolves conichalcite partially; (2) oxalate dark dissolves scorodite, arsenopyrite and conichalcite only partially; (3)  $H_2O_2$  dissolves scorodite, tennantite and arsenopyrite only partially; (4) oxalate U.V. dissolves arsenopyrite, scorodite, tennantite and conichalcite only partially; (5) hot mixed acids dissolve residual arsenopyrite and scorodite.

Two tailing samples were collected from two mineralised districts in Portugal, one in a carbonate area (Preguiça – south Portugal) and the other in an aluminosilicate zone (Talhadas – north Portugal).

For the kinetic study in tailing samples from Preguiça and Talhadas zones, the minus 80 mesh fraction was submitted to an extraction procedure using the following reagents, in succession:  $NH_4$  acetate, hydroxylamine hydrochloride, ammonium oxalate in darkness,  $H_2O_2$ , ammonium oxalate under U.V. irradiation and finally strong acids (HCl + HNO<sub>3</sub> + HF).

The mineralogy of the two mineralised areas is different. In the aluminosilicate area (Talhadas area) the mineralization occurs as a complex sulphide ore body composed by chalcopyrite, galena, sphalerite, pyrite and arsenopyrite. In the carbonate area (Preguiça area) the mineralization occurs as polymetallic sulphides of Zn and Cu (sphalerite, chalcopyrite and pyrite). In Preguiça area, the oxidation of sulphides deposits has led to the development of a gossan (hematite, goethite and lepidocrocite iron oxides) with high values of Zn, Pb, Sb, As, Ag and Cd.

The results of the kinetic study in tailing sample from Talhadas and Preguiça areas compared to the results obtained by selective extraction in doped samples, shows:

Preguiça area – the arsenic is extracted by oxalate dark and oxalate U.V. The arsenic extractable is related to "amorphous iron" and associated with iron in goethite and lepidocrocite in tailing sample.

Talhadas area - the arsenic is extracted by oxalate dark,  $H_2O_2$  and oxalate U.V. The arsenic extractable is related, essentially, to arsenopyrite.

## Heavy Metals in groundwater around massive sulphide deposits : exploration and environmental aspects

H. Pauwels<sup>1</sup>, M. L. Tercier-Waeber<sup>2</sup>, M. Arenas<sup>3</sup>, R. Castroviejo<sup>4</sup>, Y. Deschamps<sup>1</sup>, F. Graziottin<sup>5</sup>, A. Lassin<sup>1</sup>, A. Molina<sup>3</sup>

 <sup>1</sup> BRGM, 3, av Claude Guillemin, 45060 Orléans cedex, France; <u>h.pauwels@brgm.fr</u>
<sup>2</sup> CABE, Department of Inorganic, Analytical and Applied Chemistry, University of Geneva Sciences II, 30 quai Ansermet, 1211 Geneva 4, Switzerland
<sup>3</sup> Inima S.A., Arturo Soria N°336, 6a Plant<sup>a</sup>, 28033 Madrid, Spain
<sup>4</sup> University Politecnic of Madrid, Rios Rosas n°21, 28003 Madrid, Spain

<sup>5</sup> Idronaut Srl, Via Monte Amiata 10, 20047 Brugherio (Mi), Italy

A detailed chemical study of groundwaters was carried out to elucidate the processes controlling the oxidation and dissolution of sulphide minerals at two massive sulphide deposits in the South Iberian Pyrite Belt (Spain); the worked La Zarza deposit and the unexploited 400 to 600 m depth Masa Valverde deposit. Variations in major elements mainly concern pH, Eh, SO<sub>4</sub> and Na concentrations and are related both to different hydrologies - one site is in a water recharge area, the second in a discharge area, and to human disturbance at La Zarza. Metal concentrations were determined by ICP-MS after filtration and, in some cases, voltammetric measurements of Cu, Pb, Zn, Cd and Mn were also performed with the Voltammetric In-situ Profiling (VIP) system which allows the exclusive detection of the mobile fractions of trace elements (free metal ions and small labile complexes a few nanometers in size). A comparison of the results obtained through the two methods, as well as the results of calculations performed with the EQ3NR geochemical code, indicate that groundwater at both deposits shows an important enhancement of metal solubility through complexing with organic matter and/or adsorption onto colloids and/or small particles. Under very low redox conditions, the attained metal concentrations can be as much as several orders of magnitude greater than those expected from equilibrium with respect to sulphide minerals. These results have implications from both mineral exploration and environmental points of view:

1. Mineral exploration - the total metal concentrations appear to be significantly enhanced in groundwater, even when the sulphides are unoxidized, and this increases the potential for using groundwater chemical composition as an ore-deposit exploration technique.

2. Environmental assessment - knowledge concerning the natural concentrations of specific chemical forms of metals that existed in groundwaters prior to mining operations is of particular importance for preparing realistic and technically achievable remediation plans. The relevant data can be acquired through baseline quality monitoring before exploitation commences. However, for sites already contaminated by exploitation, predictive geochemical modelling can under-estimate the metal concentrations because of a lack of thermodynamic data concerning metal adsorption on colloids or small particles.

## Environmental site characterization using hyperspectral data: The International Smelter area and Bauer Mill, Utah

D. C. Peters<sup>1</sup>, Ph. L. Hauff<sup>2</sup>, E. D. Dillenbeck<sup>3</sup>, W. A. Peppin<sup>2</sup>, E. C. Prosh<sup>2</sup>, and G. A. Borstad<sup>4</sup>

<sup>1</sup>Peters Geosciences, 169 Quaker Street, Golden, CO 80401-5543 USA; <u>petersdc@petersgeo.com</u> <sup>2</sup>Spectral International, Arvada, CO USA <sup>3</sup>Colorado School of Mines, Golden, CO USA <sup>4</sup>G. A. Borstad Associates, Sydney, BC Canada

Studies conducted under a NASA Earth Observations Commercial Applications Program (EOCAP) project on applications of hyperspectral data to mine and mill wastes have helped advance the acceptance of this remote sensing technology among the mining and environmental communities in the United States. Our work addressed mineralogical and vegetation analysis of mine and mill waste areas as a means of identifying environmentally important material differences (different wastes and background *versus* wastes) that are critical to understanding which wastes may require remediation and those that do not. Ultimately, the goal is to effectively target and guide further environmental ground studies, rather than relying on current typical practice of grid or random sampling without prior comprehensive knowledge of site characteristics.

In this presentation, we will discuss two case studies: the International Smelter area east of Tooele, Utah, and the Bauer Mill and tailings ponds north of Stockton, Utah. These two sites represent the approximate ends of the mill site reclamation spectrum. The Bauer Mill, is a completely unreclaimed site with mill foundations, assorted outbuildings, waste dumps, and large tailing ponds. The International Smelter area, consist of "reclaimed" (but not "remediated") and revegetated tailing ponds, building sites, mine dump, and slag dump. The potential impact of windblown tailings from the Bauer tailings ponds and on-site and potential downstream impacts of unremediated wastes at International were topics of interest during our investigations. Both processing facilities handled base- and precious-metal ores.

Because the Bauer site is unreclaimed, it provides the ability to assess unobscured mill wastes and their actual and potential impacts on their surroundings. Wastes have been differentiated mineralogically from the surrounding background materials and potential and actual on-site acid production and potential toxic metal releases could be established for the area. Bauer is releasing windblown tailings off site, which have been documented to contain high levels of arsenic and lead. The extents and effect of the "plume" can be difficult to impossible to detect visually on the ground, but easily can be identified through remote sensing.

In the International Smelter area, most revegetation has been effective or at least acceptable since the reclamation work was completed in 1989. However, resurgent sulfidic wastes and other unremediated wastes are damaging flora and fauna. In addition, "off-site" areas of tailings that were not addressed during reclamation need to be considered in further reclamation planning. Such wastes and their effluent have the potential to impact a downstream community during wet periods and already have impacted use of the site for pasture. Investigations also have begun on identifying, through the hyperspectral data, the extent of impacts from past smelter emissions on the nearby western flank of the Oquirrh Mountains.

The result of this project can be used by environmental and land management agencies to prioritize further site assessment and eventual remediation activities. Chemical relationships to mineralogy,

identifiable through remote sensing, can be established and support the differentiation of potential or actual problem wastes from those that do not require significant characterization and/or remediation efforts.

## Application of groundwater geochemistry to exploration for paleochannel roll front uranium, Frome Embayment, South Australia

M.C. Pirlo<sup>1</sup>, and A.M. Giblin<sup>2</sup>

<sup>1</sup>GEMOC National Key Centre, Dept. Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia; <u>mpirlo@laurel.ocs.mq.edu.au</u> <sup>2</sup>CSIRO Exploration and Mining, North Ryde, NSW 2113, Australia

Current research has examined the use of groundwater geochemistry (hydrogeochemistry) in the exploration for Tertiary paleochannel uranium targets in the Frome Embayment of South Australia. The region experiences a semi-arid climate and the uranium mineralisation typically exists in paleochannels that contain saline groundwaters. The paleochannels are concealed beneath approximately 70m of cover, with no surface indication, making for challenging exploration. Uranium exploration and production has experienced growing interest in Australia in recent times, particularly in this region. This is partly due to advancements in in-situ leach production technology being applied to paleochannel roll-front uranium mineralisation.

Thirty six groundwater samples have been collected from monitoring bores in mineralised aquifers. Samples have been analysed for a suite of major and trace elements. Equivalent major element concentration plots (Schoeller Plots) have identified a pattern similarity amongst groundwaters sourced from and directly adjacent to sediment hosted uranium mineralisation. A different pattern is observed for groundwaters in the vicinity of the nearby basement that is inferred to be the source of the uranium now in sediment hosted uranium mineralisation. A groundwater database maintained by the state government and consisting of 85 samples has been obtained for the region and Schoeller ratios calculated for each of these groundwaters. These samples exhibit similar Schoeller Plot patterns to the samples collected for this study, supporting the use of Schoeller Plots as an effective means of identifying groundwaters similar to those associated with roll-front uranium mineralisation. Dominant characteristics of Schoeller Plots from mineralised localities are the Ca:Mg ratios.

The geochemical modeling code REACT (Bethke, 1998) has been used to develop equilibrium models of the groundwater samples collected. From these, major ion activities and aqueous speciation has been predicted. Plots of major ion activities against ionic strength have been shown to be in good agreement with those reported for the region by Giblin (1987), although the strong correlation between U and  $\log (a C a^{2+} \bullet a \$ 0 \frac{2^{-}}{4})$  for groundwaters from mineralised locations is not obvious with all current samples. However the current groundwater samples plot in the same general fields of the major ion activity-activity plots for dominant carbonate minerals as did the 1987 samples. The stable equilibrium mineral assemblage predicted by the equilibrium models suggests that uranophane, dolomite and chalcocite control the aqueous U, Ca and SO<sub>4</sub> activities respectively. All samples are undersaturated with respect to gypsum. With further development, groundwater geochemistry may be an effective means of detecting economic mineralisation within the paleochannel system.

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### How useful is ground based hyperspectral data for the geochemist?

S. Pontual<sup>1</sup>, N. Merry<sup>1</sup>, and J. Bartlett<sup>2</sup>

 <sup>1</sup> Ausspec International, P.O.Box 222, Ferny Creek, Vic 3786, Australia ausspec@ausspec.aust.com
<sup>2</sup> CODES, University of Tasmania, Hobart, Tasmania, Australia

There is a growing acceptance of ground based hyperspectral analysis in the mining and exploration industries as more companies search for a technological edge and the ability to more accurately and rapidly assess project areas. In particular, the growing interest is because this technology allows large amounts of data to be rapidly collected on site and alteration mineralogy, including mineral crystallinity and mineral composition, to be quickly assessed.

This observation rings particularly true over the past few years where commercially available field spectrometers, such as the PIMA, have demonstrated their usefulness in a wide range of geological environments and at various stages of exploration programs, from grass roots reconnaissance through to drilling programs and resource evaluation. Until recently, however, the spectral data have frequently been analysed and interpreted in isolation using time consuming data analysis techniques removed from the realities of a fast moving exploration industry. This approach has largely been because of the lack of software tools that allow easy processing of large spectral data sets and integration of these data with more traditional geological data sets, in particular with geochemical data.

In general, although spectral data contain a wealth of mineral information, it is usually impractical to use this information in its raw form. A more effective approach involves the extraction of key characteristics of these data (i.e. mineralogy, mineral composition and crystallinity) as numerical values, which facilitates the integration of this "digital mineralogy" with more conventional exploration datasets. In addition to allowing detailed evaluation of mineralogy, the integration of the "digital mineralogy" data with geochemical data leads to the ability to describe not only geochemically anomalous intersections or regions but also to recognise associations between subtle changes in mineralogy (as expressed in the spectral data) and target mineralisation. Such observations are often important because understanding these mineralogical associations can lead to more accurate targeting and rapid assessment of a project area.

This paper demonstrates that the integrated analysis of sound geological observations, geochemical, spatial and spectral data can quickly lead to a greater understanding of the nature and distribution of target mineralisation. Case studies from Australia and SE Asia are presented to demonstrate this application including examples from regional and reconnaissance surveys, evaluation drilling, and geochemical exploration around known resources in deeply weathered environments.

### Supergene gold mobility at the Mount Joel Prospect, Western Australia

C. G. Porto<sup>1</sup>, D: J. Gray<sup>2</sup>, and N. B. Sergeev<sup>2</sup>

 <sup>1</sup>Federal University of Rio de Janeiro (UFRJ), Department of Geology, Igeo, Ilha do Fundão, Cidade Universitária, Rio de Janeiro, 21949-900, Brazil; <u>portoc@uol.com.br</u>
<sup>2</sup>Co-operative Research Centre for Landscape Evolution and Mineral Exploration c/o CSIRO Exploration and Mining, Private Bag 5, Wembley, Western Australia, 6913, Australia

The Mount Joel gold prospect is located 20 km NE of the Bronzewing gold mine in the Yandal greenstone belt at the northern part of the Yilgarn Craton. Mineralization has been delineated along an 8km long N-S trend, primarily hosted in sheared metabasalts where gold occurs in a sulphide-poor quartz stockwork vein system. The area is generally flat with a regolith cover up to 100 m thick.

Two distinct regolith domains are present in the area and their corresponding Au distribution patterns were established based on assay results from nearly 1000 RC holes drilled in an approximate 40 x 40 m grid pattern. Gold grade results were treated statistically and displayed using 3D visualization software, which allows incorporation of regolith stratigraphy.

In the southernmost portion of the area the regolith is dominated by Au-poor palaeochannel sediments, up to 80 m thick, that cut across the mineralized trend in a west to east direction. This is underlain by a 30m thick residual profile containing an upper Au-enriched lateritic residuum. Close to the unconformity is a pisolitic zone where lateral Au dispersion follows the palaeochannel gradient. These patterns result from Au enrichment processes during laterite formation and subsequent mechanical dispersion before or during burial by channel sediments. The lateritic residuum grades downward into a ferruginous saprolite where Au enrichment blankets or depletion zones are not identified.

In the northern parts of the Mt Joel area the transported overburden comprises less than 10 m of Aupoor alluvium. The underlying residuum is about 60 m thick and truncated to saprolite. The upper, clay rich, portions of the saprolite are strongly leached and Au depleted. However, close to the unconformity is a moderately enriched Au zone showing a more homogeneous Au distribution. This zone has the greatest proportion of soluble Au, implying a chemical enrichment process, possibly resulting from a continuous downward Au migration during lowering of the land surface. This enrichment took place very locally, closely matching primary mineralization, with very limited lateral dispersion. Present day groundwater conditions are not conducive to gold mobilization, consistent with the lack of dissolution features observed in supergene Au particles, which have crystalline shapes and high fineness. Supergene particles present in the lower portions of the saprolite probably result from local remobilization and supergene enrichment blankets are not observed.

The poor response of Au and other indicator elements in the transported material necessitates target exploration sampling at the top of the residuum, where Au enrichment zones are present either in the lateritic residuum or top of saprolite. However, the contrasting nature of the Au enrichment in these zones results in different distribution patterns, background values and dispersion halos and exploration results must be interpreted accordingly.

The research was the result of collaboration between CRC LEME and the Australian minerals industry through AMIRA. CRC LEME is supported by the Australian Cooperative Research Centres Program.

## Environmental impact and acid drainage related to mineral exploitation: a case study in Cundinamarca Department, Colombia

#### **Gloria Prieto and Luz Mery Duitama**

INGEOMINAS, Diagonal 53 # 34-53 Santa Fé de Bogotá, Colombia; gprieto@ingeomin.gov.co

Minerals in Cundinamarca are exploited by small and medium-scale operations that use underground and surface exploitation systems without appreciable levels of technology in none of the mining stages. Acid drainage generation is the main environmental effects of these operations, resulting from weathering and oxidation of sulphides (pyrite present in the mineralised bodies). In addition a significant amount of particulate matter (coal dust) is emitted to the air, surface waters, soils, biota and affect the labour force (health and safety risk), and improper disposal of coal wastes results in deterioration of soils, waters and biota. As well vegetal cover removal and excessive use of forestry resources produce soil and biota degradation. Nevertheless, employment and royalties generation, as well as impulse to the regional economy can be mentioned as positive socio-economic effects.

Water pH and conductivity measurements allowed to substantiate the occurrence of acid mine drainage (AMD) in the region. Running water contains high levels of ions in solution, possibly heavy metals (toxic) leached from the mineralised bodies. Along the coal mining area, acid mine drainage (pH 2.6-5.5) with high values of conductivity (up to >3000 $\mu$ S/cm) were detected. Previous data, showed that although total sulphur contents in Cundinamarca's coal field are fairly low (0.84%), there is a positive correlation between acidity generation (AMD) and sulphur concentrations (pyrite FeS<sub>2</sub>) in the exploited coal. AMD is causing economic losses, such as equipment and infrastructure corrosion, and is contributing to make more acidic soils and waters, in addition to biota degradation. On the other hand, it is evident the lack of knowledge about AMD, and also the absence of AMD treatment or remediation systems in this region. Therefore, most of these AMD are draining directly to agricultural lands and also to surface waters used for drinking and irrigation.

Simple and cheap indicators (pH, CE) demonstrated the occurrence of AMD with high levels of dissolved ions in Cundinamarca's coal mining zones. A thorough AMD characterisation study is required in this area, to propose mitigation and remediation plans for the affected areas.
## Application of geostatistical methods to the recognition of geochemical anomalies in the Montemor-o-Novo area, Southern Portugal

A.P. Reis<sup>1,2</sup>, A.J. Sousa<sup>1</sup>, and E. Cardoso Fonseca<sup>3</sup>

<sup>1</sup>Bolseira Programa Praxis XXI – <u>pmarinho@geo.ua.pt</u> <sup>2</sup>CVRM, Instituto Superior Técnico, Av. Rovisco Pais 1049-001 Lisboa, Portugal <sup>3</sup>Departamento de Geociências, Universidade de Aveiro, 3810, Aveiro, Portugal

This study concerns the application of multivariate analysis to geochemical exploration in the Montemor-O-Novo area (Southern Portugal).

The area is characterised geologically by a Hercynian basement with small granitoid intrusions and limited at NE by a gneiss-migmatite complex. This Hercynian basement consists of: a) an Upper Proterozoic unit of micaschists and paragneisses with major leptites and lidites intercalation; b) a Cambrian unit of feldspar micaschists with minor leptites; c) and Ordovician – Silurian (?) unit of amphibolites, greenschists and phyllites.

The Montemor-O-Novo area is structurally characterised by an antiform that is limited at W and NE by two major thrust zones.

The mineralizations (Banhos, Caeiras, Falés, Gamela, Malaca and Monfurado) occur as "shearzone" auriferous mineralizations and present different geological and paragenetic scenarios. Banhos mineralisation lies in the contact between the amphibolites, the leptites and small granitic intrusions. Gold is in association with arsenopyrite. Monfurado, Gamela and Caeiras mineralizations occur in the micaschists and the gold is associate to pyrite. Malaca and Falés mineralizations appear in the micaschists/lidites unit and the gold is in association with arsenopyrite/stibnite.

The 1211 soil samples collected in Banhos, Caeiras, Falés, Gamela, Malaca and Monfurado areas were analysed for Cu, Pb, Zn, As, Ba and Au by atomic absorption spectrometry with hydride generation.

The use of multivariate analysis allowed the study of the spatial structure for geochemical data and therefore the identification of geochemical patterns and significant anomalies related to the auriferous mineralizations.

To account for spatial structure, simple and cross variograms were computed for the main directions of the grid sampling. From the experimental variograms a linear model of coregionalization was fitted to the six variables which allowed the recognition of 3 structures of continuity (a nugget effect and two anisotropic spherical structures). The coregionalization matrices deduced from the theoretical model have shown the relationships between the variables at different scales. The results were compared with those obtained by principal component analysis.

This structural analysis implies that the spatial variability of the variables is the sum of 3 structures, the nugget effect C0 representing the small-scale events, the first structure C1 representing local events and a second structure C2 representing a regional event. This methodology was the basis for estimating the corresponding spatial components (Y0, Y1 and Y2) using univariate factorial kriging analysis. Maps of raw data, Y0, Y1 and Y2 were made for each variable.

The application of geostatistical methods to the data soil of Montemor-O-Novo has identified anomalies that were undetected by the geochemical mapping of raw data and enhanced others that appear as week anomalies.

## Dispersion into the Tertiary Southern Cross Formation sediments from the Scott and Cindy lodes, Pajingo, N.E. Queensland

## I. D. M. Robertson

Cooperative Research Centre for Landscape Evolution and Mineral Exploration, CSIRO Exploration and Mining, Private Bag 5, Wembley WA 6913, Australia; <u>i.robertson@per.dem.csiro.au</u>

Auriferous epithermal quartz veins occur at Pajingo within relatively flat-lying Devonian andesites, tuffs, and sediments. The host rocks are relatively fresh on the Mt Janet Range but are weathered and mottled on the pediments, where they are partly covered by the coarse grained Tertiary Southern Cross Formation sediments and by more recent colluvia and alluvia. The Tertiary sediments were derived from relatively fresh rock, saprolite and pisolitic materials and were then mottled by later weathering. Dispersion of Au from the Devonian basement into the thick (20-80 m) Southern Cross Formation sediments was investigated at the Scott and Cindy deposits.

Within the Southern Cross Formation, regional background Au concentrations are at 5-10 ppb but, at just over 1 km from known Au mineralisation, they are slightly elevated (>30 ppb). The sediments proximal to the Scott Lode, exposed by mining, are Au rich (>100 ppb) as they were largely derived from the Scott Lode and its environs. Here, local Au anomalies of >500 ppb occur near the base and well above the base of the sedimentary profile. In contrast, sediments proximal to the Cindy mineralisation contain significantly less Au, as their detritus was derived from up slope. A very localised Au anomaly (150-500 ppb) occurs near the base of a palaeochannel that drained the eastern side of the Cindy mineralisation. All this suggests mechanical Au dispersion. Partial extractions indicate that only about 18% of the Au is soluble in 0.1 M KI (a weak Au extractant) so there may have been minor relocation of Au by weathering. Compared to total Au analysis (INAA), only about half the Au is dissolved by KCN.

Analysis of exploration data confirmed that Au is dispersed into the Southern Cross Formation at several levels. Horizontal dispersions of 100-300 m occur not only at Scott and Cindy but also near zones of numerous auriferous quartz veins, unrelated to economic mineralisation.

Implications for exploration are that: - i) Dispersion from buried mineralisation into the Southern Cross Formation was initially mechanical but did not necessarily occur at the base of the sediments. There was minor hydromorphic relocation of Au during subsequent weathering. ii) Dispersion may be traceable for 100-300 m down slope from mineralisation or from areas of numerous auriferous quartz veins without economic mineralisation. iii) Large dispersion patterns are most likely where mineralisation was exposed for a long period during sedimentation (Scott) and less likely where mineralisation was covered by early sediments or quickly smothered by material from up slope (Cindy) so an understanding of palaeotopography is essential. iv) Elevated local backgrounds of >25 ppb Au may indicate distal mineralisation. v) Total Au analysis is important as about half of the Au is occluded from cyanide attack.

The research was the outcome of productive collaboration between CRC LEME and the Australian minerals industry through AMIRA. CRC LEME is supported by the Australian Cooperative Research Centres Program.

# "Doughnuts" in the Desert : Success in the Application of Partial Extraction Geochemistry to Deep Cover Mineral Exploration

## P. J. Rogers

## Chavin Consulting Limited, Shubenacadie, Nova Scotia BON 2H0, Canada; proger3@attglobal.net

The Atacama Desert of Northern Chile presents a particularly stern test for any explorationist involved in the search to discover new mineral deposits beneath its hostile surface environment. Despite this handicap of deep gravel, salar and barren sedimentary and volcanic rock cover significant new discoveries have been made at Spence, Gabi, El Penon and others. All of these deposits have a detectable and specific surface geochemical signature revealed by partial extraction geochemistry. Unfortunately, the commercial market place abounds with a bewildering array of different partial extraction techniques whose only common denominator seems to be one of high price, large numbers of determinations and a strong dependence on substrate composition, particularly that of carbonate. The question is how can an exploration geologist apply this technology with confidence in areas of deep and deeper cover?

Observations from over 100 studies of buried targets in the Atacama Desert indicates that these surface anomalies have no set response by deposit or partial extraction type. The familiar concept of pathfinder elements is not generally applicable as the local environment can radically alter the response to this geochemistry. This variation can be detailed by conducting orientation surveys (of at least 3 lines) over several deposit types and environments to test and compare the efficiency of each partial extraction. However, apart from the difficulty of finding an untouched buried target this is also a very costly exercise of arguable application as the mixed results presented to date have shown.

In this paper a more practical multi method integrated approach is presented independent of partial extraction method to allow rapid and cost effective screening of a property. Most buried reduced bodies produce a surface halo pattern commonly revealed by Self Potential geophysics, soil conductivity and pH. This halo pattern is detected by partial extraction geochemistry often as a "doughnut" shaped anomaly or central low. The size and dimensions of the "doughnut" are closely related to deposit type - a porphyry system has an area of around 2km2 while a gold deposit is only 300m2. Correct sampling grid design is crucial in detecting these haloes from 500m for a buried porphyry to 25m (or less) for a vein gold type deposit. There is also differential response, well illustrated by porphyry copper deposits where the presence of an oxide cap radically reduces the Enzyme Leach halogen response while a buried sulphide body will have an anomaly to background response in the millions! Add to this the effects of pre and post mineral faulting which stream water and ions along structures which in turn produce imposed peaked signatures onto and often displaced from the haloes. All of the main partial extraction techniques, Enzyme Leach, Mobile Metal Ion, Regoleach and others all have a variable response for most of the common economic elements. In order to apply this technology without prohibitive cost a considered mix of methods is required firstly to detect the haloes and then to assess them in detail for the quantity of metal present and define drill targets.

## MAGSAM<sup>®</sup>: An Effective Geochemical Exploration Tool for PGM Mineralisation

C. S. Rugless<sup>1</sup>, Z. Lubieniecki<sup>2</sup>, and A. Vanderplank<sup>3</sup> <sup>1</sup>Pathfinder Exploration Pty Ltd, 11 Dennison Drive, Ocean Reef, W.A. 6027; <u>pfinder@one.net.au</u> <sup>2</sup>Silver Asset Pty Ltd, 1 Cupar Close, Beldon, W.A. 6027 <sup>3</sup>Consultant, 41 Harvey Street, Victoria Park, W.A. 6100

Increased interest in platinum group metals (PGM) has provided the impetus to trial geochemical exploration techniques that can be cost effectively used in a various regolith regimes. The MAGSAM<sup>®</sup> sampler utilises a retractable rare earth magnet within a stainless steel sleeve that is capable of collecting the magnetic fraction in stream sediments (wet or dry) as well as the surface magnetic lag fraction or maglag samples. A number of studies have shown that the magnetic fraction represents an effective medium for the chalcophile elements in arid climates (Marshall, 1995, Alipour et al., 1997) while the PGM have been shown to be preferentially concentrated in the magnetic fraction in tills occurring distally to mineralisation in the Tulameen ultramafic complex in British Columbia (Cook & Fletcher, 1994). The 2000 gauss MAGSAM<sup>®</sup> sampler can effectively collect magnetic and paramagnetic phases including magnetite, maghemite and ferrochromite. The -2 mm magnetic fraction has been analysed at low levels by ICP - MS & AES techniques for a multi-element suite (PGE, Au, Cu, Ni, Co, Pb, Zn, Cr, V, As, Te, Bi, Fe, Mn, Mg & Ca) using various digests including a mini Aqua Regia digest, a concentrated 10M HCl (Cc) digest and a micro cyanide leach (MCL) developed by Ultra Trace Laboratories in Perth, Western The MAGSAM<sup>®</sup> sampler has been successfully trialed over PGM deposits and Australia. prospects occurring in diversified regolith regimes including the Panton Sill deposit and the Copper Hills/Harbutt Range prospects in the East Kimberley and East Pilbara regions respectively of northern Western Australia, the Platreef PGM horizon in the Bushveld Complex of South Africa and the Tonsina ophiolite - hosted chromitites (Foley et al, 1997) in the Border Ranges of Alaska.

Systematic *maglag* grid sampling and limited MAG stream sampling employed at the Panton Sill and Copper Hills/Harbutt Range project areas in northern Australia have both targeted and discriminated between different horizons and styles of PGM mineralisation. Orthomagmatic PGM mineralisation (2.2 Mt @ 5.6 g/t PGE) associated with chromitite horizons in the Paleoproterozoic (1850 Ma) Panton Sill lopolithic layered intrusive (Hoatson, 2000), occurring within the Halls Creek Orogen, is associated with anomalous Au, PGE, Ni, Cu, Co, Bi and Te maglag values. A total of 1414 maglag samples were taken on a 200 m x 50 m DGPS grid established over hilly terrain flushed by seasonal monsoonal rains. Skeletal soils and scree slopes mantle resistant hills comprising fresh rock, with the development of residual to colluvial soils in the valleys. The orientation programme showed that *maglag* samples analysed after using a stronger Aqua Regia digest provided the best anomaly contrast and provided more discrete anomalies than soil samples. Peak values of 1020 ppb Pt, 820 ppb Pd and 365 ppb Au were achieved with Pt/Ir and Pd/Ir ratios providing a potential discriminant for the upper and lower chromitite seams. Single elements and element ratios such as Mg, Cr, V, Mg/Ca and Mg/Fe represent valuable lithological guides while the potential for remobilised or hydrothermal PGM mineralisation was highlighted by anomalous Pd, Os, As, Se, S, Cu and Co values coinciding with NNW and NW trending cross – faults as well as the nose of the syncline folding the layered complex.

Copper Hills and Harbutt Range in the east Pilbara represent a different regolith regime with transported aoelian sand, locally developing parallel sief-like dunes, overlying the weathered, lower saprolitic host rocks of the Paleoproterozoic Rudall Complex (Bagas and Smithies, 1997) that has been intruded by a series of arcuate, layered ultramafic intrusions spatially associated with thrust faulting. Over 8000 *maglag* samples were collected on regional 400 m to 500 m x 100m DGPS

grids and analysed using a partial 10M HCl digest that was found to release most elements as effectively as the less sensitive Aqua Regia digest. Minor orthomagmatic PGM mineralisation (0.6 g/t PGM), occurring within serpentinised cumulate dunite at Harbutt Range, is associated with anomalous PGE, Co, Bi, Ni and Cr *maglag* values while the ultramafic host is associated with enhanced Mg values and concomitant lows for Fe, Sn, Mo, K, Rb & REE. In contrast, the Copper Hills prospect is not directly related to an ultramafic source and contains bonanza PGM grades (0.49% Pt, 0.34% Pd, 0.23% Au, 11% Cu & 3.5% Ag) occurring in a low temperature mineral assemblage including Pt and Pd selenides (Nickel, 1997), interpreted to have a hydrothermal – possibly epithermal origin. The metasomatic hydrothermal mineralisation at Copper Hills has been defined as more subtle anomalies for Ag, Pt, Cu, Zn, Pb, Ti & V within a broader halo defined by high background to anomalous Mg, K, Ca, Rb, Cr and REE values.

The Platreef mineralisation in the Bushveld complex is associated with a similar *maglag* response as the Panton Sill with a strong response for Aqua Regia Pt & Au (up to 1370 ppb Pt & 76 ppb Au), being an order of magnitude greater than the response achieved by using the partial 10M HCl digest and confirming that the geochemistry is responding to a primary dispersion in residual soils. A similar strong Au, Pt and Pd *maglag* response has been achieved using an Aqua Regia digest at the Tonsina prospect in Alaska and confirms a primary geochemical dispersion within the stream MAG samples. Deposit signatures gleaned from cluster analysis, factor analysis and spider plots confirm geochemical similarities for mineralisation at the Panton Sill, Bushveld Complex (Platreef) and Harbutt Range as a Pt – Pd – Au – Ni – Co – Cr – Mg  $\pm$  Cu  $\pm$  As  $\pm$  Te association while the metasomatic mineralisation at Copper Hills exhibits a Pt – Au – Cu – Pb – Sn - V – Zn – Hf – Ca association.

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# Gold redistribution in the regolith at the Twin Peaks and Monty Dam deposits, Western Australia

N. B. Sergeev and D. . Gray

Cooperative Research Centre for Landscape Evolution and Mineral Exploration, Australia; <u>n.sergeev@per.dem.csiro.au</u>

The geochemistry of Au and other elements in the regolith and groundwater has been studied at the Twin Peaks and Monty Dam Au deposits, Western Australia. The deposits are located about 100 km NE of Kalgoorlie at 30°04' S and 122°18' E. Gold mineralization occurs primarily within felsic volcanogenic sediments of andesitic to dacitic composition. Mineralization consists of a quartz stockwork, associated with arsenopyrite at Twin Peaks and pyrite at Monty Dam, respectively. The sites are deeply weathered and probably truncated to mottled zone and upper saprolite. Twin Peaks is situated on a very gently sloping erosional plain and Monty Dam is in low position on the southern margin of a playa, Lake Rebecca. At Twin Peaks, the residual regolith, 50–55 m thick, is partly concealed beneath 0.5-4.0 m of transported overburden, commonly calcareous in the top 0.5-1.0 m, whereas at Monty Dam the regolith, 40-45 m thick, has little transported material or carbonate.

At Twin Peaks, below a 40 m deep depleted zone, Au enrichment (310 ppb of Au, three times bedrock) occurs in a 6-9 m thick horizon at the top of the lower saprolite. In contrast, at Monty Dam, Au is progressively depleted upward through the regolith profile, with strongly depleted zone above the mid to lower saprolite transition. This supergene enrichment at both sites is coincident with a Fe2+/ Fe3+ redox front and a porosity barrier in the lower saprolite. and occurs as high-fineness supergene Au crystals, some of which are associated with Ca-REE-phosphates. Gold is also correlated with Ce, Y and Yb in the depleted and enrichment zones. At Twin Peaks, Au is also concentrated close to the surface, forming a dispersion halo within pedogenic carbonate and soil. At Monty Dam, with little surface carbonate, Au concentrations at the surface are low (20-30 ppb).

The high salinity of groundwaters in the district implies that Au will be soluble as chloride (AuCl2-) complexes where acid and oxidizing conditions are present. The low concentrations of dissolved Au (average 0.05 ppb) for the Twin Peaks groundwaters, despite optimum conditions for dissolution (commonly pH 3 - 4, Eh 460 - 690 mV). This is probably because the groundwaters could only be sampled within the Au-leached zone. In comparison, where conditions are suitable, groundwaters at and near Monty Dam (sampled from 2 - 35 m below surface, with the water table 1 - 5 m below surface) have high dissolved Au concentrations (0.5-1.0 ppb).

These sites have supergene Au distributions characteristic of the southeastern Yilgarn Craton. Twin Peaks has surface expression of Au mineralization within calcrete, strong Au depletion in the clay-rich upper regolith and Au enrichment below the depleted zone at the top of the lower saprolite. Prevalence of Au depletion at Monty Dam relates to different hydrogeochemistry due to the low geomorphologic position of the site. Gold has presumably dissolved in highly saline, oxidized groundwaters, with deposition at the Fe redox front.

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## Fluoride problem in geothermal waters of India

#### S. K. Sharma

GRI, 24 National Road, Dehradun, India; <u>anuj2@nde.vsnl.net.in</u>

Endemic fluorosis is a public health problem in India. Around million people of 150 Districts in 15 States are affected by this disease; States like Andhra Pradesh, Gujarat, Rajshthan, Tamil Nadu, Uttar Pradesh have between 50% to 100% of their Districts affected by Fluorosis. The remaining 10 States report less than 30% to 50% of their Districts affected by this disease. As per World Health Organization (WHO, 1994), the drinking water should not contain more than 1 ppm of fluoride.

The geochemical analyses of 150 water samples collected from the geothermal waters from wells as well as from surface from all over India indicate the presence of Fluoride around 20 ppm which is much more than the prescribed limit of water consumption by human/living beings by the WHO.

The paper deals with the sources of Fluorine in water and its medical complications, if consumed by living beings and the necessity to put Defluoridation units in India.

# Lithogeochemical Vectors Associated with the Kabanga Ni-Cu Deposit in North Western Tanzania

## A. Simon and C. D. Okujeni

## Department of Earth Sciences, University of the Western Cape, Bellville 7535, RSA.; cokujeni@uwc.ac.za

The Kabanga Ni-Cu deposits are associated with ultramafic intrusions in meso-Proterozoic metasedimentary rocks of the Kibaran Belt in North Western Tanzania. Nickel-copper occurs as disseminated and massive ores within peridotite-pyroxenite layers and also in proximity and detached from the ultramafic complexes in metasedimentary rocks.

Exploration work aimed at increasing the ore reserves and enhance the profitability of the deposits is to date fraught with problems of target generation and inability to distinguish mineralised from nonmineralised ultramafic intrusions. These investigations were therefore aimed at developing a repetitive robust geochemical method that can vector towards Ni-Cu ores during subsurface and surface exploration.

This paper presents and discusses key findings on the use of a series of element ratios, to distinguish mineralised from barren ultramafic intrusions and also in vectoring towards locations of mineralisation based on a genetic geochemical models of ore deposition.

Element ratios of about 40 trace and major elements and their patterns of dispersion were studied, by applying associations derived from various multivariate statistical analyses. Particularly successful element ratios are expressed in [(Ni/Cr)x(Cu/V)] in fresh ultramafic rocks at subsurface and [(Ni/Cr)x(Cu/Pd)] as well as Pd/V ratio for weathered rocks and on the surface.

The above ratios are based on element fractionation patterns resulting from segregation of immiscible sulphide melt from silicate host magma during deposition of the Ni-Cu ores and a trend depicting increased separation of sulphides from refractory minerals, such as chromite and magnetite in zones with massive ores. For example, Ni/Cr, Cu/V ratios increase in consonance with pentlandite/pyrrhotite towards the centre of massive ore bodies.

# Primary dispersion haloes about the Mt. Charlotte mesothermal au-quartz vein system, Kalgoorlie, Western Australia: Implications for distal lithogeochemical exploration parameters and deposit genesis

C. R. Stanley<sup>1</sup> and N. Radford<sup>2</sup>

<sup>1</sup>Department of Geology, Acadia University, Wolfville, Nova Scotia, B0P 1X0, <u>cliff.stanley@acadiau.ca</u> <sup>2</sup>Normandy Mining Ltd., 10 Richardson St., West Perth, Western Australia, 6005, Australia, <u>nigel.radford@normandy.com.au</u>

The Mt. Charlotte mesothermal gold deposit, Kalgoorlie, Western Australia, is a two-dimensional stockwork vein system bounded by several steeply dipping faults within the Archean Norseman-Wiluna greenstone belt. Host rocks include three upper units of the Golden Mile dolerite, a differentiated mafic sill with zoned cumulate, ophitic and granophyric textures that intrudes black shales folded by the Kalgoorlie syncline and was metamorphosed to greenschist grade. Native gold mineralization occurs within quartz, ankerite, pyrite, scheelite, tourmaline veins and bleached alteration envelopes about the veins. Two mutually crosscutting vein sets exhibit modal orientations of approximately 270/30 and 160/70, and vein densities are commonly high enough to warrant bulk stope mining methods. At a 3 gpt cut-off grade, combined production and reserve of the deposit is 17.4 Mt at 4.9 gpt Au.

Host rocks consist of ophitic and granophyric textured microgabbros and ferrogabbros that originally contained plagioclase of intermediate composition, clinopyroxene, subordinate orthopyroxene, quartz, skeletal titanomagnetite with ulvospinel exsolution lamellae, and trace apatite. These were incompletely deuterically altered into an assemblage of actinolite and epidote, leaving residual albitic plagioclase, quartz and clinopyroxene. This deuteric alteration was magnetite, but not ulvospinel, destructive.

Deuterically altered rocks were then distally hydrothermally altered to an assemblage consisting of calcite, chlorite, albite (residual), quartz, magnetite, rutile, with trace pyrite, chalcopyrite and pyrrhotite. This alteration zone extends at least 70 m away from mineralization. Despite the substantially different mineralogy, textures and colours in this zone are commonly preserved, making it difficult to identify this alteration style in hand sample.

Inside this outer cryptic alteration zone, a muscovite, quartz, ankerite, albite, pyrite alteration assemblage predominates. This alteration accompanies substantial bleaching of the host rocks, but occurs in restricted envelopes typically less than 1 m wide. Immediately adjacent to the veins in these envelopes, albite predominates over muscovite, whereas on the outer edge of these envelopes, muscovite predominates over albite.

Metasomatism associated with each of these alteration styles is substantially different. Deuteric alteration was isochemical, involving only the addition of H (as  $H_2O$ ) to the rocks. In contrast, the cryptic alteration underwent substantial C (as  $CO_2$ ) and H addition. Finally, the bleached alteration envelope exhibits K, C and S addition and Si and H loss. The reactant and product minerals, plus the material transfers associated with these alteration zones, constrain the net water-rock reactions responsible for each of these alteration zones:

2 Anorthite + 22 Clinopyroxene + 27 Orthopyroxene + Magnetite + 11 Quartz + 11 H<sub>2</sub>O =>

2 Epidote + 10 Actinolite, 50 Actinolite + 12 Epidote + 38 Anorthite + 3 Ulvospinel + 144  $H_2O$  + 162  $CO_2 =>$ 25 Chlorite + 162 Calcite + 362 Quartz + 3 Rutile + 6 Magnetite, and: 3 Chlorite + 24 Calcite + Magnetite + 24  $CO_2$  + 4 K<sup>+</sup> + 16 H<sup>+</sup> + 18 S<sup>-2</sup> => 4 Muscovite + 9 Pyrite + 24 Ankerite + 16  $H_2O$  + 6  $H_4SiO_4^{\circ}$  + 16 e<sup>-</sup>, respectively.

Volume changes associated with each of these alteration reactions vary significantly. The deuteric alteration reaction results in moderate volume losses of approximately 14 %. Given that not all of the clinopyroxene or quartz are affected, and only the anorthite component of the plagioclase is involved, this resulted in an approximate 5 % volume loss (probably through porosity development). In contrast the cryptic and bleached hydrothermal alteration reactions involve significant volume increases of 16 % and 29 %, respectively. The cryptic alteration did not affect the entire rock (albite and quartz were stable); so simple re-filling of the pore spaces created by the deuteric alteration probably accommodated this volume increase. In contrast, the large volume increase associated with the bleached alteration was probably accommodated by tectonic extension as this alteration occurred only immediately adjacent to the veins (based on the density and thickness of the quartz veins, this expansion was at least 20 %). It is thus possible that volume restrictions were responsible for the limited spatial extent of the bleached alteration envelopes.

Results suggest that several lithogeochemical haloes exist at Mt. Charlotte that could be effective exploration parameters. Hydrothermal alteration is geochemically detectable as a zone of distal (to at least 70 m)  $CO_2$  and  $H_2O$ , and proximal (to ~1 m)  $CO_2$ , K and S enrichment. Si was lost in the proximal alteration zone, but probably re-precipitated immediately in the adjacent veins. In contrast, no significant Al, Na, Fe or Mg metasomatism occurred. These lithogeochemical patterns could be used in a regional geological program as intermediate exploration targets.

Similarly, results provide constraints on the genesis of the Mt. Charlotte vein system. Fluid composition, temperature and pressure are constrained by the deduced chemical reactions, and appear to be similar to other mesothermal Au vein fluids. An additional hypothesis that explains why specific units of the Golden Mile dolerite host Au vein deposits throughout the Kalgoorlie gold field is also suggested. These units were the last to crystallize, exhibit granophyric textures, and thus were most likely affected by intense deuteric alteration. The pores created by this alteration may have then become fluid filled, and during subsequent tectonism facilitated the development of 'stress corrosion'. This could have resulted in high frequency brittle fracturing and hydrothermal fluid influx only in the most deuterically altered units of the dolerite, and thus may explain the lithological control for Au deposits within the camp.

# Primary lithogeochemical alteration haloes associated with the Cannington Broken Hill-type Ag-Pb-Zn sediment hosted massive sulphide deposit, Mt. Isa Inlier, Queensland: Implications for genesis and mineral exploration

C. R. Stanley<sup>1</sup>, S. Walters<sup>2</sup>, J. Stuart<sup>3</sup>, and D. Lawie<sup>4</sup>

 <sup>1</sup>Department of Geology, Acadia University, Wolfville, Nova Scotia, BOP 1X0; <u>cliff.stanley@acadiau.ca</u>
<sup>2</sup>GeoDiscovery Group, P.O. Box 59, Sherwood, 4075, Queensland, Australia, <u>sgw@geodiscovery.com.au</u>
<sup>3</sup>BHP Cannington, PO Box 5874 MC, Townsville, Queensland, 4810, Australia
<sup>4</sup>Pasminco Exploration, G.P.O Box 1291K, Melbourne, Victoria, 3001, Australia, <u>lawied@pasminco.com.au</u>

The Cannington Ag-Pb-Zn deposit, Mount Isa Inlier, Queensland, Australia was discovered in 1990 by BHP Minerals as a result of systematic investigation of aeromagnetic anomalies within the Soldiers Cap Terrane on the southeastern margin of the Mt. Isa Inlier. The deposit is blind with up to 70 m of Recent and Cretaceous cover sequences. Mineralisation is considered to be a 'Broken Hill-type' (BHT) sediment hosted massive sulphide (SHMS) deposit, and is characterised by argentiferous galena, sphalerite and pyrrhotite-dominant ore types (current resource of 44.4 Mt grading 518 g/t Ag, 11.5 % Pb and 4.6 % Zn), with minor arsenopyrite, loellingite, chalcopyrite and pyrite. Economic mineralisation is hosted by strongly zoned and complex quartz, hedenbergite, fayalite, pyroxmangite, almandine, magnetite and fluorite gangue assemblages that have locally retrograded to hornblende, ilvaite, chlorite, pyrosmalite and greenalite.

Dominant host rocks to the deposit are metasedimentary gneisses assigned to the Mesoproterozoic Solders Cap Group (~1670 Ma). These comprise quartzo-feldspathic pelitic and semi-pelitic paragneisses with subordinate schists containing quartz, plagioclase and biotite with minor muscovite, garnet, potassium feldspar and sillimanite. The host rocks underwent amphibolite facies metamorphism and at least four periods of deformation, resulting in complex fold repetition of the mineralised package. A zone of fine grained, disseminated almandine garnet with more abundant potassium feldspar forms a visible alteration halo in the metasediments extending up to 250 m into the structural hanging wall of the deposit. The full lateral extent of this alteration halo is poorly defined by current drilling at Cannington.

Systematic lithogeochemical sampling (n = 442) of visibly altered and unaltered paragneiss and schist from exploration diamond drill core in the Cannington area were analyzed for major oxide and trace elements. Thin sections from a subset of samples were also examined. Results were used to characterize the alteration and to develop a zoning model to improve knowledge of deposit genesis and assist in exploration for other BHT deposits. Molar element ratio analysis was used to evaluate the compositional variations in these samples.

Despite the high grade metamorphism associated with gneissic compositional layering and abundant migmatite development, lithogeochemical data analysis of Cannington host rocks indicates that observed compositional variations are attributable to primary and secondary geological and geochemical processes related to rock formation and mineral deposit genesis. Relatively unaltered, predominantly gneissic samples exhibit compositional variations consistent with the sorting of plagioclase and quartz. These variations are interpreted to have occurred as a consequence of

sedimentary fractionation caused by differential gravitational settling, saltation, entrainment and winnowing during sediment deposition. The proportional involvement of quartz and albitic plagioclase (3:2 by volume), plus the presence of additional Al that probably resided in clay minerals, indicates that unaltered gneiss samples were probably originally relatively immature mudrocks, feldspathic wackes and arkosic arenites.

More proximal samples exhibit compositional variations consistent with a zoned system involving at least three styles of hydrothermal alteration. The most distal alteration (up to 300 m into the structure hanging wall sequence) is identified by metasomatic Na, Si and subordinate Ca loss, and is interpreted to be a consequence of alkali depletion during albitic plagioclase destruction. The precursor (premetamorphic) alteration mineral produced by this metasomatism cannot be precisely constrained, but candidate minerals include kaolinite, dickite and pyrophyllite (depending on temperature). Inward from this alteration is a second (medial) zone characterized by K addition that is interpreted as sericitic and potassic alteration overprinting the outermost alkali depletion zone. This alteration resulted in the formation of pre-metamorphic muscovite and, in more intensely altered rocks, potassium feldspar, as deduced from whole rock K/Al ratios. This zone also represents the outer limit of a low level Pb and Zn primary dispersion halo containing amazonite (plumbian potassium feldspar) and trace ganite. Finally, the innermost (proximal) alteration zone is characterized by Fe, Si and Mn addition that overprinted the sericitic and potassic alteration and probably resulted in the formation of pre-metamorphic pre-metamorphic pre-metamorphic pre-metamorphic halo containing amazonite (plumbian potassium feldspar) and trace ganite.

All alteration styles observed likely involved the addition of H and the formation of hydrous minerals. Unfortunately, the 'hydrolytic' character of these alteration styles cannot be demonstrated because intense metamorphism subsequently dehydrated the rocks. As a result, not only was their mineralogy changed from lower temperature, probably hydrous, 'precursor' mineral assemblages to higher temperature metamorphic 'successor' mineral assemblages, but other volatile elements (*e.g.* -  $CO_2$ ,  $S_2$ ) were also likely driven off during metamorphism, complicating reliable deduction of the alteration zone precursor mineral. Metamorphism also affected the primary Pb and Zn dispersion halo, moving Zn from sphalerite to gahnite and Pb from galena to amazonite (Pb-bearing) potassium feldspar.

Nevertheless, the observed metasomatic additions and losses, and suspected or constrained precursor mineral assemblages, do allow formulation of a comprehensive zoning model consistent with geochemical thermodynamics. A distal zone of kaolinite (or dickite or pyrophyllite) alteration is interpreted to surround successive medial sericitic and potassic, and proximal chloritic alteration zones. These inferred precursor mineral assemblages constrain the hydrothermal fluid composition responsible for mineralization. They also restrict the alteration reactions to have occurred at epithermal temperatures (100°C to 300°C). Volume changes associated with constrained metasomatic reactions responsible for these alteration zones are consistent with the alteration textures and the overprinting relationships observed in each alteration zone, and explain why certain zones are spatially restricted, and others are widespread.

The recognition of multiple and extensive alteration zones associated with economic BHT Pb-Zn-Ag SHMS deposits is an important new lithogeochemical tool in regional and prospect scale exploration. Data from other BHT systems with more constrained geometry, such as the Broken Hill Main Lode, indicates that these lithogeochemical halos can extend for 3-4 km along strike from economic mineralisation. The absence of sulphides and magnetite in these alteration halos makes them poor geophysical targets but significantly extends the geochemical exploration target size.

## **Objective assessment of new analytical geochemistry exploration methods: Distinguishing between scientifically valid approaches and 'witching sticks'**

#### C. R., Stanley

## Department of Geology, Acadia University, Wolfville, Nova Scotia, B0P 1X0, <u>cliff.stanley@acadiau.ca</u>

Over the past several years there have been a large number of 'new' selective extraction methodologies introduced to the mineral exploration industry. Some of these are truly novel, employing emerging technologies and recent chemical discoveries to digest specific mineral components of geochemical samples. Others represent improved, but recycled, historic approaches that benefit from advanced instrumentation and knowledge to surpass the performance of historic partial digestion techniques. Nowadays, most major commercial geochemical laboratories offer their own versions of a variety of selective extraction approaches, and all claim that their versions offer significant exploration advantage over conventional analytical techniques. Unfortunately, or fortunately, there remain a significant number of geochemists that remain unconvinced regarding the advantage that some of these selective extraction techniques offer. This is due to a very large number of factors, one of which deals with the design and methods of interpretation of results of orientation surveys undertaken as part of empirical assessment of these analytical techniques.

The objective of an empirical assessment is to determine whether a new technique provides exploration advantage over competing, established methods. This must involve a large number of tests over areas with mineralization, where detectably anomalous samples should consistently be produced, and where non-anomalous samples should not occur. However, for an exploration technique to be efficient and effective, it must not only reliably identify real anomalies (guiding exploration expenditures into prospective areas), but it must also not create false anomalies (preventing exploration expenditures from being wasted in non-prospective areas). Both 'false positive' and 'false negative' responses should be minimized by an effective exploration technique. Thus, a large number of tests of any new exploration technique must also be made over areas without mineral deposits, to ensure that false anomalies are not produced over barren ground. Unfortunately, these 'false anomaly' empirical tests are rarely undertaken to evaluate the performance of these new selective extraction techniques.

Empirical tests of selective extraction techniques should also compare the results of the new method with conventional digestions in common practice today (*e.g.* – aqua regia). Only with rigorous *comparative* tests of both methodologies can a full empirical assessment be considered complete. These comparative test results are essential to assessing whether a selective extraction technique actually works, because without a conventional analytical response, one does not know if there is a geochemical signature developed over a mineral deposit. If there is a response detectable using a conventional technique, one can determine if any exploration advantage is offered by a new technique via simple statistics (*e.g.* – comparing the magnitudes of geochemical contrast). However, if there is no conventional geochemical anomaly, no comparison can be made because one does not have evidence that there is a real geochemical anomaly! In such cases, independent corroborative mineralogical or geochemical evidence is required to demonstrate that a geochemical response not be detected by conventional methods actually exists. Otherwise, any anomalous response generated by these new analytical techniques must be considered 'false'. Unfortunately, comparative tests are not always undertaken when assessing the performance of these new selective extraction techniques.

Finally, the criteria used to judge the performance of the orientation surveys testing these new selective extraction techniques are extremely broad. An ideal empirical test result should be where all of and only the samples over mineralization are anomalous. Unfortunately, although significantly less clear-cut results are common, many of these are interpreted as 'successful'. Case histories that exhibit anomalies in only a small proportion of the sample sites overlying mineralization have a large proportion of samples that should have been anomalous but weren't (false negatives). These can hardly be considered successful, and indicate a low level of reliability of the new analytical technique! Other case histories are deemed to have successful results only if additional complicating physical or chemical factors are invoked to explain the apparent deviations from 'success'. 'Rabbit ear' anomalies have been attributed to electrochemical processes; anomalies displaced some distance laterally from mineralization have been attributed to down slope clastic creep, soil deflation-related translation, shallowly dipping structural controls, hydromorphic and even gaseous dispersion. Unfortunately, these claims are almost universally accepted by the exploration community, despite the absence of necessary, additional data that would validate these explanations for the lateral deviation of the anomaly. The absence of these additional data should force us to interpret displaced anomalies as 'false', and conclude the test a failure!

The factors used to explain why selective extraction anomalies do not plot directly above mineralization have now become so numerous that just about every close-call can be considered a 'successful' case history. Why this is so is not entirely clear, but the inherent optimism of mineral explorationists is almost undoubtedly a factor. In many cases, this self-delusion is so significant that case histories are considered 'successful' despite the fact that anomalies located using a random number generator could produce a similarly 'successful' geochemical signature a very significant proportion of the time.

In fact, testing the probability that a 'successful' empirical result could have been produced at random is an excellent quantitative test of the results. This approach requires the use of the hypergeometric distribution. To determine the random probability of an orientation survey result, the total number of sample sites (t) and the number of sample sites that should be anomalous (a; known because the location of mineralization is known) in an orientation survey must be known. Then, using the number of samples that are observed to be anomalous (k), the probability that a random number generator would produce the same number of 'correct' anomalies (x) can be determined from:

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

With typical orientation surveys testing these new selective extraction techniques, the probability of obtaining results similar to those observed by a random number generator can actually be quite high! For example, a soil profile of 30 sample sites (t), six of which overlie mineralization (a) that reports 4 anomalous samples (k), two of which overlie mineralization (i.e. - are correct; x), the random probability of obtaining this or a better result is approximately 17 % (or 1 in 6). Obviously, empirical tests of new exploration techniques requires rigorous and quantitative interpretation to ensure the results obtained are significant and indicate that the exploration technique represents a real step forward and is not merely a 'witching stick'.

# Geochemical maps of West Greenland: signatures of environments with gold, high-technology metals and kimberlites

## A. Steenfelt

#### *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen, Denmark;* <u>ast@geus.dk</u>

The Geological Survey of Denmark and Greenland has recently published part one of 'Geochemical Atlas of Greenland' as a CD-ROM covering the Precambrian region of West and South Greenland. A total of 43 major and trace element distribution maps display concentrations of the < 0.1 mm grain size fraction of stream sediment samples collected at a density of 1 sample per 30 km<sup>2</sup>. The maps demonstrate considerable geochemical variation over the region, and show a clear distinction in geochemical signature between Archaean and Proterozoic terranes as well as between different Palaeoproterozoic mobile belts. Composite grid images are well suited to illustrate the geochemical differences.

Areas with gold mineralisation are known from several parts of Greenland, although so far, an economic grade/tonnage is substantiated in one place only. Not surprisingly, gold occurrences are outlined by anomalies for As, Sb, Au +/- W or Mo. However more interestingly, high Cs is seen to characterise several known areas of gold showings, a relation that may be used in modelling of, at least certain types of, epigenetic gold mineralisation. Hydrothermal activity in the zone above a rising granitic magma favours mobilisation of Au and pathfinder elements from the surrounding rocks. Cs-anomalies outlines such environments because Cs, being a lithophile element with very high ionic radius, is concentrated in the uppermost aplitic-pegmatitic phases of granitic magmas.

High-technology metals comprise elements such as Nb, Ta, Y, REE, Zr, Hf, Ga, Be, that are particularly enriched in alkaline igneous rocks and carbonatites. A Mesoproterozoic province in South Greenland of rift-related alkaline intrusives hosts several deposits of one or more of the high-technology metals. The province is characterised by a regional-scale Nb-Th-Rb-Zn-REE-anomaly, within which local anomalies reflect individual deposits of Nb-Ta, Y, Zr-Y-REE, U-Th.

Kimberlite indicator minerals (KIM) are widely used in the search for diamond-bearing kimberlites and associated rocks. Investigation of the KIM content of the 0.25 to 1 mm grain size fraction of stream sediments from all over the Archaean craton in West Greenland showed significant distributions of several of these minerals in relation to known kimberlite provinces, despite the small amounts of available sample material. However, KIM investigations are very expensive, and the distribution of elevated Nb-concentrations in the fine fraction of stream sediments seems, in fact, adequate as a reconnaissance tool for outlining areas with kimberlite/lamproite intrusions.

Keywords: Geochemical mapping, gold, high-technology metals, kimberlites, Greenland

## Enhancing effectiveness and success rates in modern exploration

## P. M. Taufen

Chief Geochemist, WMC Resources, 8008 E. Arapahoe Court, Englewood, Colorado, USA 80112; paul.taufen@WMC.com.au

Modern explorationists are working at an especially challenging time. Our industry is shrinking while technology expands more quickly than ever. Shareholder interest in mining companies is low when sustained investment is needed for exploration success. Exploration, associated research spending, and staffing are down. In the face of these trends, we need to work faster, better, and smarter.

Due to poor decision making, which ignored costs and technical risk issues over the past 10 to 20 years, the mining industry now is characterized by over-capacity and over-capitalization. Investors generally place discounted value on mining shares as they look for high returns and short-term performance. This can be at odds with long-term investments, particularly grass roots exploration.

This short talk is about how to enhance success in mineral exploration by applying the discipline of geochemistry.

The mineral exploration industry is under considerable pressure to accomplish more with less, and to do it in more varied, complex, remote and infrastructure-poor locations around the world. The increase variety of exploration terrains the industry now works in requires more shared knowledge of appropriate exploration applications. More complex operating environments lead to higher costs in money and time and in turn to less work completed, and therefore decreased success unless the programs are executed differently. Clearly, today's explorationists are more exposed to decreased exploration success.

What is stopping and slowing discovery success? Factors that come quickly to mind are:

- stressed information integrity
- poor applications of known technology
- > fewer survey designs appropriately matched to the target deposit type and exploration setting
- reduced research, innovation and applied technology
- Less work getting completed (if done the same old way)

Professionally applied geochemistry can address a number of these factors, and thereby improve the discovery success rate. Provided below are some examples of how this can work.

#### Information integrity in minerals exploration

Without quality information, bad decisions and wasted expenditure in exploration are inevitable. When exploration groups work in new countries, they often rely on unproven and unknown support and infrastructure.

It is important for exploration groups t develop internal standard materials that can be used to quickly evaluate laboratory performance, especially in exploration areas where laboratory quality is unknown. Laboratories often look to be of high quality, but despite appearances and polished reputations, poor laboratory performance scuttles the success of an exploration program and wastes precious investment resources.

#### Appropriate applications of known technology

Appropriate applications of known technology likewise can enhance exploration success. A clear example is in the modern application of partial leach geochemistry. Sometimes weak, selective leach solutions applied to surficial sample media on transported cover do not have sufficient buffering capacity to maintain stable leach pH conditions. As a result, samples within the survey are leached under a range of pH conditions, resulting in an analytical data set that has little or nothing to do with buried mineralization. Selective leach solutions with appropriate buffering capacity applied in the same setting can yield very different results, and detect blind mineralization under the right conditions. Knowledge of what partial leach solutions can be used to detect buried mineralization in which exploration settings can help improve discovery rates.

## Matching survey design to the deposit target type and exploration setting

Tailoring the geochemical survey design to the deposit type, survey scale, and exploration setting can improve the deposit discovery rate.

Examples are provided at various scales of exploration. At super regional scale, chrome diopside in heavy mineral concentrates serves to detect the Ni mineralization setting at Thompson, Manitoba. At a regional scale, increased sulphate concentrations in stream water successfully identify a blind porphyry copper system at 300 to 700 m depth in a desert environment in Arizona. An appropriate geochemical exploration application at still more local scale is the use of carbon dioxide soil gas to detect buried mesothermal lode gold mineralization beneath glacial drift.

## Appropriate research and innovation can increase the discover rate

There is no doubt that working smarter and innovating can lead to an increased discovery rate. Just as the new application of airborne input electromagnetics led to the discovery of Kidd Creek in Ontario 30 years ago, so emerging technologies today have potential to provide similar breakthrough discoveries.

An example of newly emerging technology in exploration geochemistry is found in the trace hydrocarbon concentrations found in volcanogenic massive sulphide deposits compared to other graphitic electric conductors or barren pyrite. Hydrocarbon signatures are quite distinctive in VMS systems versus graphite conductors. Detection limits are constantly going down in new analytical instrumentation available in today's expanding technology era. How long will it take before we can reliably detect trace hydrocarbon signatures at surface?

## New ways of working

Exploration groups are working more in areas of difficult access around the world. High transportation and logistical costs are associated with these exploration programs, and under tighter budgets less work gets accomplished, especially if exploration surveys require numerous repeat visits to the field and slow turnaround times for analysis results.

The shift to more remote exploration areas call for an improvement in field portable analysis capability. Small, portable instruments are emerging in the market. One such instrument type is the field portable X-Ray fluorescence instrument. These are becoming more sensitive and achieving

steadily lower detection limits for elements explorationists are commonly interested in determining. Having this information in the field allows more work to be completed for less expenditure.

## Conclusion: What our industry can do

To increase our discovery rate, the minerals exploration industry should consider:

- > Worlwide audits and quality reports on commercial laboratories to improve information integrity
- > Better documentation to capture and distribute geochemical knowledge
- > Geochemistry templates and orientation surveys around target deposits types in various settings
  - Innovation and new technology applied here
  - Break the paradigm of "geochemical exploration game over" with cover
- > Development of improved field portable geochemical analysis capability

# Gold exploration in covered areas: Gold nugget morphology and core crystallochemistry as an exploration aid

B. K. Townley<sup>1,2</sup>, C. Palacios<sup>2</sup>, V. Maksaev<sup>2</sup>, and G. Herail<sup>3,2</sup>

<sup>1</sup>SRK Consulting, Matilde Salamanca 736, 5<sup>th</sup> Floor, Providencia, Santiago, Chile <sup>2</sup>Departamento de Geología, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile; <u>btownley@cec.uchile.cl</u>

<sup>3</sup>IRD, France

The results of active research in the use of gold nugget morphology as distance to source indicator are here presented. Microprobe crystallochemical studies from gold crystal cores recovered from various primary gold deposits are also indicated. These results were used to develop an exploration aid tool in terms of methodology.

Gold nugget morphology for over 1500 nuggets recovered from 60 active stream sediment samples in the Coastal Cordillera of Central Chile, show morphological variations (general shape, outline, surface, primary crystal imprints, associated minerals, flatness index) characteristic of three distance ranges (0 to 50 m; 50 to 300 m; over 300 m) from source. Studies from other districts allowed comparison of gold morphology characteristics in different climatic environments (arid, semi-arid, wet, lateritic, fluvial, fluvio-glacial and glacial). Common parameters to be used as distance to source indicator independent from climatic environment (outline, surface, associated minerals, flatness index) were determined.

The previous studies assist in target approximation but tell nothing with respect to source type. Most gold mineralization occurs in hydrothermal deposits, resulting as precipitation from a hydrothermal fluid. Different gold-mineralized hydrothermal systems precipitate gold under different thermodynamic conditions. Gold accepts full solid solution with silver (gold – electrum – silver) and partial with Cu, Fe, As, Bi among others. Gold crystallochemistry hence is a function of thermodynamic conditions of precipitation. Study of gold composition via electron microprobe analysis of crystal cores from epithermal, gold-rich porphyry and gold-rich porphyry copper systems indicated Au-Ag-Cu contents as the best discrimination tool for these different types of gold bearing deposits. In addition, analysis of gold crystallochemistry from crystals recovered at different vertical levels from the Cerro Casale gold-rich porphyry have shown that gold crystallochemical signature for a single type of deposit can also aid in determination of vertical position. Hence, current level of erosion and in-ground potential of the remaining source.

As an exploration methodology: at least 20 or more gold nuggets need to be recovered from active sediments in any given range from a sought source (for possible mixed population determination). Study of gold nugget morphology should assist as an indicator of distance to source. Microprobe analysis of nugget cores and composition can be keyed into Au-Ag-Cu diagrams for source type estimation. If source is indicated as gold-rich porphyry, composition can then be keyed to vertical position within the porphyry system and hence aid in determination of in-ground remaining potential of source target.

Much more research is yet needed to improve these combined tools for gold exploration in covered areas and many limitations are envisioned. Gold liberated from rock fragments already distant to source would be common in cordilleran and glacial environments, but should reflect though as a mixed population of gold morphology groups. These techniques are only applicable for coarse gold sources. Estimate of erosion level of liberated gold is limited to the case here presented, more research pending.

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These techniques are in no case self sufficient, just one more tool among many. Tool and data integration is by far the best chance at exploration success.

# Fluid Inclusion Petrography and Microthermometry as an Assisting Tool in Exploration: An Example for Precious Metals Epithermal Mineralization in the Chilean Patagonia

## B. K. Townley

## SRK Consulting, Matilde Salamanca 736, 5<sup>th</sup> Floor, Santiago, Chile, and Departamento de Geología, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile; <u>btownley@cec.uchile.cl</u>

The study of fluid inclusions in minerals of hydrothermal deposits date as far back as the 19<sup>th</sup> Century. Fluid inclusion petrography and microthermometry have been widely used in ore deposit modeling, abundant literature existing in these topics. Despite this use, fluid inclusions tend to be considered among many explorationist as a research oriented tool, deemed as timely and too sophisticated for exploration purposes. Fluid inclusion studies for exploration can have turnaround times not longer than exploration geochemistry, and can provide valuable information for target potentiality assessment. Study procedure and some examples of precious metals exploration in the Chilean Patagonia are here presented.

Fluid inclusion petrography is the initial step of any fluid inclusion study, from feasibility to determination of fluid inclusion characteristics (hosting mineral, fluid inclusion type, phases, daughter minerals, etc.). In epithermal environments evidence of boiling can be distinguished by large variations of filling degree on two phase fluid inclusions (from vapor-rich, 10% fill, to liquid-rich, 90% fill) coexisting in a single crystal. Macroscopic and microscopic evidence of boiling are crucial in epithermal environments, considering the key role boiling processes have in controlling ore deposition.

Fluid inclusion microthermometry (homogenization temperature and NaCl % equivalent salinity) coupled with petrography, alteration and mineralization studies provide details with respect to hydrothermal fluid thermodynamics and possible source of water. Epithermal environments, being shallow, normally do not require a pressure temperature correction of homogenization temperature hence temperature and salinity range can be used for a depth of emplacement estimate. Determination of boiling zones, system overprints and depth of emplacement is most useful for target potentiality assessment.

A fluid inclusion study at the Fachinal precious metals epithermal deposit (immediately west of the town of Chile Chico, XI Region) indicated relative positioning of boiling zones for 11 different vein and breccia systems (at or estimated below or above current erosion surface). Evidence of system overprint indicated in some cases potential for a deeper boiling zone and associated mineralization. As mineralization in this deposit is strictly vein and structure associated, and alteration and mineralization are typical of low sulphidation systems, location of boiling zones is crucial for ore body targeting.

In another exploration case, the Quebrada Chica area (immediately south of Chile Chico), fluid inclusion studies of surface samples in an unknown potential target indicated temperature and salinity typical of epithermal environments. Coupled with observed alteration, mineralization and geochemistry, the target was interpreted as a high potential near surface low sulphidation epithermal system. Widespread argillic and advanced argillic alteration at surface and polymetallic mineralization associated with vein, stockwork and breccia systems in a larger than 1 Km<sup>2</sup> area suggests high potential.

In other types of environments the use of fluid inclusion studies have a broad range of applications, from determination of hydrothermal fluid type and thermodynamics associated to any given hydrothermal system, to observation of sulphide daughter minerals indicating potential metal budget. Preliminary knowledge of potential ore deposit type mineralization or erosion surface/depth of emplacement is an advantage in any exploration target.

## Partial and selective extraction studies in the Yandal Greenstone Belt, Yilgarn Craton, Western Australia

## J. E. Wildman<sup>1</sup>, R. R. Anand<sup>1</sup>, and G. D. Longman<sup>1</sup>

<sup>1</sup>CRC for Landscape Evolution and Mineral Exploration, CSIRO Exploration and Mining, Private bag 5, Wembley 6913.

The Yandal Greenstone Belt, in the northern part of the Archaean Yilgarn Craton, is 250 km long and up to 40 km wide. It consists of mafic to ultramafic basal units and calc-alkaline, dacitic and felsic upper sequences. The gold deposits in the Yandal belt are shear hosted in quartz veins and surrounded by broad carbonate alteration with proximal K-mica and Fe sulphides. Brittle structures are thought to have played a major role in locating Au. About 90% of the belt is covered by deeply weathered profiles up to 160 m deep, consisting of weathered bedrock, with an overlying cover of transported overburden of varying thickness and age. Regolith-landform mapping, regolith characterisation and geochemical dispersion studies were conducted over several deposits and their immediate environments. These established the regolith processes and landscape evolution at both local and district scales, and assessed the geochemical effectiveness of a variety of residual and transported materials. The extent of transported overburden in the Yandal belt, estimated at 30% with more than 5 m of transported cover, makes it a critical testing ground for surface geochemical methods. This paper presents results on the effectiveness of several selective and partial extraction techniques at five sites (Mt Joel 000N, Mt Joel 2400N, Vause, Karra and Bronzewing).

The five sites have different depths of transported overburden and different bedrock lithologies above known mineralisation. Two separate sites were chosen at Mt Joel with 10 and 20 m of colluvial-alluvial cover respectively. Mineralisation here is in sulphide-poor quartz veining in sheared basalts. The two sites are 2.4 km apart along strike and had similar underlying mafic lithologies and similar felsic-derived cover over a residual surface of ferruginous saprolite. At the Vause prospect, drilling had detected mineralisation on a basalt-porphyry contact. The chosen traverse covered a wedge of transported cover 1-6 m deep. At the Karra prospect, low sulphur quartz veins occur within intermediate volcanics with a shallow 6-7 m cover over saprolite. At Bronzewing, palaeochannel with up to 30 m of transported clays and ferruginous gravels is overlain by silicified colluvium and alluvium. Mineralisation occurs in sheared basalt. The extractants used are water, pH5 acetate, hydroxylamine hydrochloride, HCl, KI, KCN and MMI<sup>®</sup>. Except for MMI, the methods achieve a detection limit for Au of 0.1 ppb by concentrating the Au onto a carbon sachet that is then analysed by INAA. Bulk samples were analysed by INAA and XRF.

At Mt Joel (000N and 2400 N) and Karra, with over 5 m of transported cover, a confident prediction of underlying mineralisation could not be made. Measured Au in soil are all less than 0.65 ppb with only minor variation across traverses. At Bronzewing, only enzyme leach Cu showed a questionable single point anomaly over mineralisation. At Vause, with 1-3 m of transported cover, gave a multi-element response, including Au, but also produced a Au only response in transported material not related to underlying mineralisation. Where the bulk analyses detected Au (>5 ppb), the extractions provided no additional information.

In conclusion, soil geochemical surveys are ineffective in areas of more than 5 m of cover. The extractions do not give any additional exploration information that cannot be obtained using standard bulk analyses. These conclusions are broadly similar to those reported for other parts of the Yilgarn Craton.

The research was the outcome of productive collaboration between CRC LEME and originally Great Central Mines Ltd and now Normandy Yandal Ltd. CRC LEME is supported by the Australian Cooperative Research Centres Program.

## Exploration for epithermal gold mineralisation in the Andes of Ecuador using enzyme leach soil analysis

## T. M. Williams and A. G. Gunn\*

British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK; agg@bgs.ac.uk

Enzyme Leach<sup>SM</sup> (EL) soil surveys were undertaken over known epithermal mineralisation at El Mozo and Beroen, Azuay, Ecuador to assess the utility of the technique for identifying such deposits in the Ecuadorian Andes. At El Mozo gold mineralisation exhibits many typical high-sulphidation epithermal features with oxidised vuggy silica replacement ores overlying pyrite-enargite assemblages. At Beroen high grade gold-silver ores of low-sulphidation type occur in steep structurally controlled zones characterised by multiple phases of silicification, brecciation and veining. In both areas the mineralisation occurs at shallow depths in calc-alkaline continental-margin sub-aerial volcanic sequences of Miocene age.

The results of the soil surveys indicate the development of both apical- and oxidation-type EL anomalies over auriferous structures at the two sites, the former systematically incorporating Au, and the latter Cl and Br. The spectrum of elements responsive to mineralisation at El Mozo (Cl, Br, I, La, Ce, Nd, Cu, Pb, Au, As, Sb, Ag, Zr, I, Sr) was found to be considerably greater than at Beroen (Cl, Br, Au, As, Sb, Ag, Zn), probably reflecting the contrasting high- and low-sulphidation assemblages of the two prospects. Ratios of EL versus aqua-regia extractable trace element concentrations ranged from 1:<100 for Mn to 1:>400 for chalcophile elements such as Pb, Sb, As, Bi and Ag. Strong correlations between the concentrations of several analytes (including Mn, Sr, Cu, Co, As) extracted by the two procedures indicate, however, that EL datasets are extensively influenced by bulk matrix composition. Spatial variations of EL extractable Mn were found to exert no major influence on apical or oxidation suite anomaly patterns at El Mozo. However, Mn-normalisation of halogen data for Beroen elucidated otherwise obscure oxidation features, potentially related to Au mineralisation. Ratios between elements subject to apical enrichment and those of the oxidation suite (e.g. Cl/Au and Bi/Br) were found to highlight known Au targets with improved clarity.

The formation mechanism of the recorded Au anomalies is uncertain, but may involve physical enrichment of Au in the soil during pedogenesis with subsequent *in-situ* formation of (EL soluble) Au halide complexes. The strength of such apical features is, in part, probably a function of the minimal depths to mineralisation which characterise El Mozo and Beroen. Oxidation halos formed by volatile non-metallic elements such as Cl and Br may, therefore, provide more valuable EL pathfinders for more deeply concealed epithermal targets.

\* speaker

# Wide-spaced geochemical survey in arid saline terrenes, Northwestern China

W. Xueqiu<sup>1</sup>, Ch. Qinghua<sup>1</sup>, Ch. Zhizhong<sup>1</sup>, L. Dawen<sup>1</sup>, Z. Wenzhi<sup>2</sup>, and Y. Youquan<sup>2</sup> <sup>1</sup>The Institute of Geophysical and Geochemical Exploration (IGGE), China <sup>2</sup>Geological Survey of Xinjiang, China

Northwestern China is a large unexplored or under-explored terrain. Into the new century, interest was rekindled by the discovery of a large porphyry copper deposit with copper reserves of more than 10 millions of tons in the eastern Tianshan mountainous belt, Xinjiang, northwestern China. In order to quickly get an overview of the mineral potential of the entire eastern Tianshan terrain, a large regional geochemical survey project was commenced in 1999 in area of 150 000 km<sup>2</sup>.

The surveyed terrain is extremely arid with the average annul rainfall of less than 50 mm. The substantial areas are covered by regolith sediments concealing prospective bedrock sequences. The regolith sediments include alluvium, residuum, windblown sand and caliche horizon. Commonly, the regolith sediments can be divided into three layers: loosely windblown sand and lag gravel, weakly cemented sandy horizon, and strongly cemented caliche horizon.

Conventional soil geochemical methods (total analysis) and deep-penetration geochemical methods (selective leaching of mobile metals) are both used. The orientation study shows sampling of coarse fraction (>20 mesh) of the loose surface soils (pisolite) is effective in the mountainous or hilly areas, whereas many elements are concentrated in the cemented sandy horizon in any landscape. Wide-spaced sampling of the cemented sand can delineate large and clear geochemical patterns generated by metallogenic belts. The anomalies using selective leaching of mobile metals in soluble salts and onto oxide coatings of cemented sand have greater contrast than those using total analysis.

After the orientation study, wide-spaced sampling was carried out in an area of approximately 150 000 km<sup>2</sup> at density of one sample per 100 km<sup>2</sup>. Soil samples were collected from the weakly cemented sandy horizon at a depth of 20-30cm. The soil samples were subjected to total analysis and selective leaching of mobile metals. Thirty elements were determined by ICP-MS, GF-AAS and AFS. Geochemical atlas and interpretation geochemical maps using GIS were generated. The results not only give prominent expression to the known metallogenic belts but also show new large-scale geochemical patterns of copper, gold, uranium and tungsten. New occurrences of copper have been discovered by preliminary follow-up survey within these new geochemical anomalies.

## New discovery of gold mineralization in Bleida Mine (South of Morocco) using geochemistry tool.

## Y. Zinbi, L. Maacha, A. Saquaque, and H. Baoutoul

REMINEX – Managem, 52 Avenue Hassan II, Casablanca- Morocco; zinbi@rcr.managem.co.ma

The Bleida Mine is geographically situated in the south of Morocco, it is about 100 Km to the south of Ouarzazate. This mine has been recognised as the first one in North Africa regarding production of copper (bornite, chalcopyrite and chalcocite). The production in Bleida lasted from 1982 until 1997. After the closing down of this mine, a regional geochemical exploration program has started in 1997.

Geologically, the Bleida Mine is located in the inlier of Bouazzer El Grara. The geological formations that constitute this inlier are:

-	Low Precambrian	: Gneiss – Granites
-	Medium Precambrian I	: Lava basaltic, schists and sandstone
-	Medium Precambrian II	: Conglomerate and mudstone
-	Upper Precambrian	: Rhyolite
-	Low Cambrian	: dolomites and sandstone

The Bleida Mine is enclosed in the formations of low Medium Precambrian I. The geochemical exploration "Stream Sediment" undertaken in the inlier\_of Bouazzer El Grara has allowed us to discover a gold bearing deposit "Far-West" which is 10 Km westward of the mining site of Bleida.

Two fractions of the "Stream Sediment" have been analysed (< 63  $\mu$ m and the fraction between 250 and 500  $\mu$ m). The analysis results of 550 samples have shown that the content for the first fraction varies between 0 and 300 ppb of gold with an average of 20.6 and a standard deviation of 47.1 while the content of the second fraction varies from 0 to 520 ppb of gold with an average of 22.3 and a standard deviation of 44.

Results of soil geochemistry have shown variable contents in gold which can be as high as 3600 ppb of gold.

The "far-west" formations enclosed, which are constituted of green stone belt affected by a metamorphism, are deformed by the Panafricain tectonic phase.

Leaning on these two geochemical techniques, the auriferous mineralization has been discovered near the Bleida Mine.

The development of this deposit is in the phase of realisation with a drilling program.

*Results of this communication will be presented in the form of a poster*