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Determination of micro and nanoparticulate fraction gold in regolith

INTRODUCTION

Small gold particles (<2 µm) in regolith have recently been observed using field emission gun scanning electron microscopy (FEGSEM) (Hough et al. 2008), but the amount of micro and nanoparticulate gold cannot be quantified by this method. Knowing the amount of micro (<2 µm) and nanoparticulate (<0.2 µm) gold in soils and regolith in areas of mineralisation is important to understanding the formation and discovery of economic deposits, and contributes to knowledge of how secondary supergene enrichment and surface geochemical anomalies form.

A method to quantify gold in the microparticulate and nanoparticulate fractions was tested using soil samples from the East Wongatha area of Western Australia, where a regional regolith geochemical survey was carried out by the Geological Survey of Western Australia (Morris 2013). This survey showed that the <50 µm fraction of some regolith samples hosted appreciable gold content determined using an aqua regia digestion, when most samples were expected to be below detection limit (<1 ppb). The East Wongatha area is composed of Archean rocks of the Yilgarn Craton, and Archean – Proterozoic rocks of the Albany-Fraser Orogen, both of which are unconformably overlain by Proterozoic - Paleozoic rocks of the Gunbarrel Basin (Spaggiari et al. 2011; Fig. 1). Unconformity-hosted uranium, gold and base metal mineralisation has been reported from the margin of the Gunbarrel Basin, and elsewhere in the Yilgarn Craton, where gold mineralisation is spatially related to volcanic rocks (greenstones).

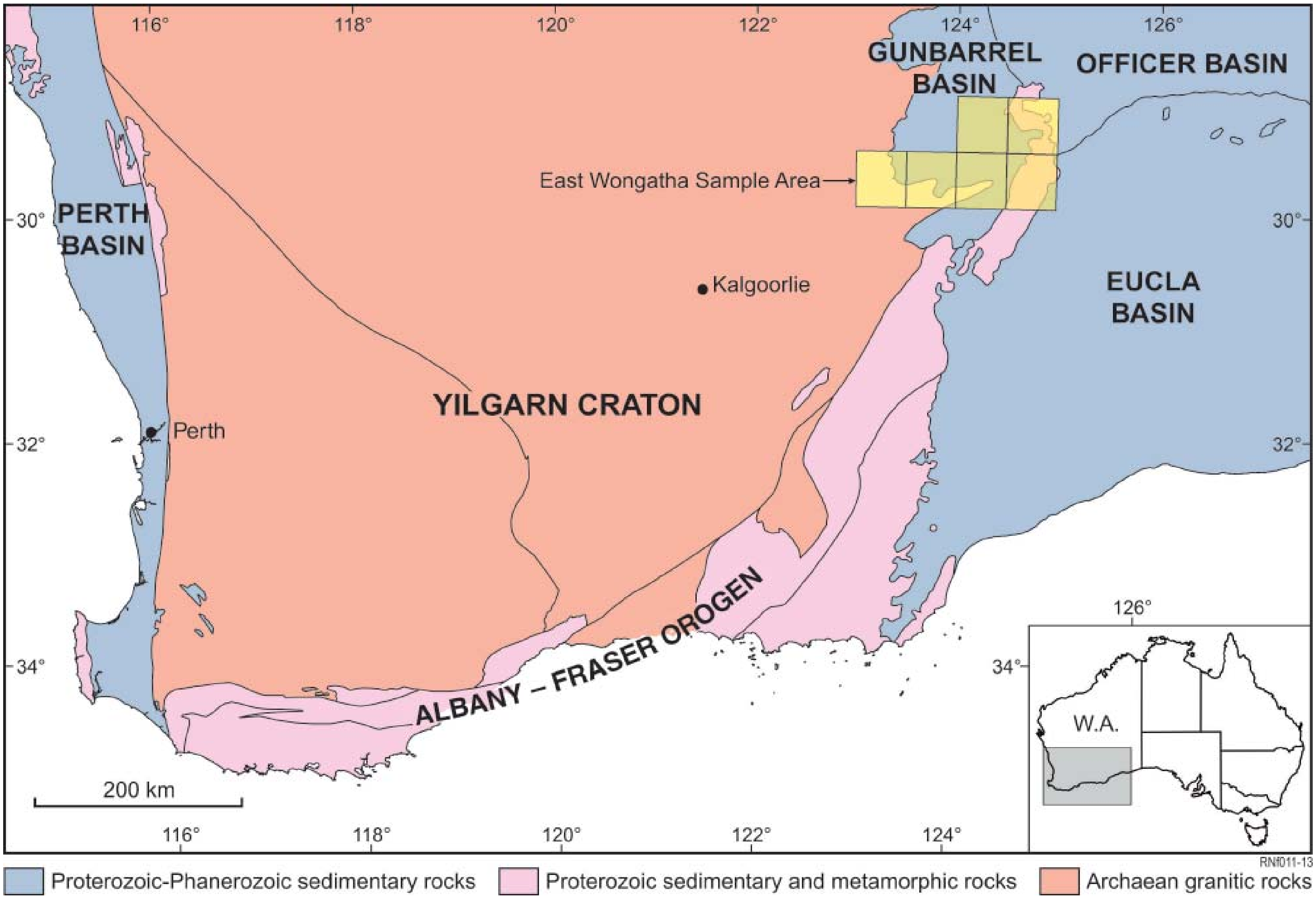

Figure 1. Samples used in this study are from the Gunbarrel Basin approximately 900 km ENE of Perth, Western Australia. East Wongatha area and interpreted 1:500,000 scale bedrock geology from Morris et al. (2013).

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President's Message

It is with pleasure that I announce the 2013 AAG Gold and Silver Medal recipients, unanimously approved by the AAG Council in February, 2013. This year we have two Gold Medal recipients, Clemens Reimann and Eric Hoffman, and one Silver Medal recipient, Gwendy Hall. Medals will be presented at the 26th IAGS conference dinner in Rotorua, New Zealand in November. And now a few words about our distinguished medal recipients.

The Association's Gold Medal is awarded in recognition of outstanding scientific accomplishment in the field of applied geochemistry. This year's recipients represent such accomplishments from both ends of the academic-industry continuum that defines the field of applied geochemistry. Clemens Reimann (Geological Survey of Norway) has had an outstanding scientific career on the academic side of this continuum. During more than 30 years of work in both government and academic circles, Clemens gained international recognition as a leader in the fields of environmental geochemistry, geostatistics, and geochemical mapping at scales ranging from local to continental. He has a prolific publication record (>130), including numerous refereed journal articles and book authorship. Clemens effectively led regional geochemistry projects in Europe across geographical and political boundaries and his work has subsequently influenced the formulation of regional surveys worldwide. His service to professional organizations has included AAG Distinguished Lecturer and Regional Councillor, and IAGC President and Vice President, and he has served on the editorial boards of Applied Geochemistry and Science of the Total Environment.

In contrast, Eric Hoffman is recognized for his career as an industry leader in bringing novel analytical techniques to commercial fruition. Through his company Activation Laboratories Ltd. (Actlabs), Eric has repeatedly been at the vanguard in bringing techniques developed by research laboratories to commercial viability for use by applied geochemists worldwide. He has anticipated the evolving needs of the applied geochemist through technique design and instrument modification for a variety of sample media. This has been particularly important as exploration has moved into progressively more difficult concealed terranes. Eric has published consistently throughout his career, but equally important he is always in attendance at scientific meetings to present and promote the latest in techniques and instrumentation.

The Silver Medal is awarded for outstanding service to our Association. In this regard, perhaps no one deserves this medal more than Gwendy Hall. Gwendy has served as AAG President, Vice President, Councillor, committee member and continues as our Treasurer since 1996. In all these roles, Gwendy has ensured that our relatively small organization not only survived, but thrived. The creation and ongoing success of our journal, *Geochemistry: Exploration, Environment, Analysis,* can be firmly credited to its editor, Gwendy Hall. Her spirit of volunteerism for AAG is commendable and a model to emulate. She is always there to offer sage advice to incoming AAG Officers and Councillors. As a now-retired research scientist at the Geological Survey of Canada, Gwendy's scientific contributions to applied geochemistry have been equally prolific, in terms of methods development, publications, committee participation, and scientific review, leading to her AAG Gold Medal awarded in 2005.

Bravo to Gwendy, Eric, and Clemens. I thank the Awards and Medals Committee (Paul Morris—chair, Chris Benn, Eion Cameron, and Pertti Sarala) for their careful consideration of nominees for these important awards recognizing leaders in the field of applied geochemistry and AAG. The committee awaits nominations from you, the AAG Membership, for the next awards cycle. Details on the nomination process are on the AAG website.

I encourage all of you to become more active in AAG by serving on Council, on a committee, or by simply contributing to our website. The 'What's News' section on our website is always looking for new content. The 2013 elections for Councillor are fast approaching, so enter your name. If not yet an AAG Fellow, then apply for Fellowship. Through your help, AAG continues to thrive and evolve.

Bob Eppinger
President

Notes from the Editor

The June 2013 issue of **EXPLORE** features one technical article by Ryan Noble, Marco Cavaliere, Paul Morris, Tenten Pinchand and Robert Hough describing the determination of content of ultrafine fraction gold in regolith soils. **EXPLORE** thanks all other contributors and reviewers for this second issue of 2013: Steve Amor, Andy Bajc, Charles Butt, Graham Carr, Bob Eppinger, Rob Hough, Jeff Jacks, Matt Leybourne, Bear McPhail, Ryan Noble, and Wendy Spirito.

Beth McClenaghan
Editor

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Mechanisms of metal enrichment leading to anomaly formation through soil are important to understand. Gold in soils could have been transported by wind, or regionally (laterally and/or vertically) by mechanisms such as gas, vegetation, seismic pumping, hydromorphic or mechanical dispersion. These mechanisms have all been considered viable in some settings (Aspandiar et al. 2004; Anand et al. 2007; Anand et al. 2009; Cameron et al. 2004; Klusman 1993; Noble et al. 2013a, b). The smaller-fraction gold in regolith of the East Wongatha area is believed to have a component associated with localised migration.

Supergene gold deposits form a significant resource globally, but understanding the previously termed "invisible" gold in the micro and nanoparticulate size range has been problematic (Hough et al. 2008). Hough et al. (2008, 2011) and Noble et al. (2009) described the morphology of this "invisible" gold, and observed nanoparticulate populations that seem to decrease as the detection/visualisation technology improves (Fig. 2). The populations appear to have an almost fractal nature. Gold as a target element for both resource definition and mineral exploration is notoriously difficult to analyse due to its nuggety nature (Stanley

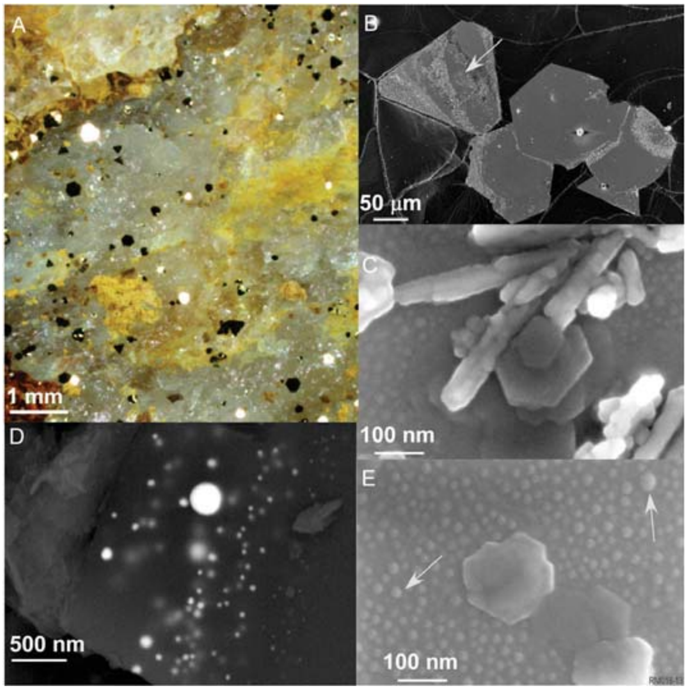

Figure 2. Multiple sizes and generations of gold particles on the surface of a weathered quartz fracture shows the supergene nanoparticulate gold population hosted on larger gold particles. A) light microscope image of black and shiny gold triangular and hexagonal crystals; B) FEGSEM image of gold microparticles (hexagons and triangles); C) a close-up of the darker band arrowed in B with nanoparticulate gold (hexagons) and halloysite (rods); D) gold nanospheres; E) 20 nm nanospheres arrowed in the background next to coarser gold nanoparticles are near the limits of present FEGSEM imaging capabilities (from Hough et al., 2011).

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2006). To determine the nature of gold at the nanoparticle scale and, if it is nuggety, requires separation and quantification of gold in different size fractions.

Recently, Leybourne & Rice (2013) emphasised the importance of improving detection limits for gold, particularly for exploration through cover where signatures are subtle and poorly understood. Lower detection limits are vital for analysing the transported signature in soils, however, a large portion of each of these samples is made up of/composed of coarse, quartz-rich material with only a small number of target and pathfinder elements associated with this fraction (bound to cutans of goethite and hematite). The abundance of quartz dilutes the already low gold signature. To minimise this effect, a number of partial extractions may be used (Kelley et al. 2003; Noble 2012; Noble & Stanley 2009; Mann et al. 1998, 2005; Williams & Gun 2002). Partial extractions are more likely to release a significant proportion of the gold from the bulk sample especially if it is in an ionic form, or the digest (e.g., cyanide) specifically targets gold. If the gold is associated with the cutans on coarse grains, the partial extractions will work well. However, if the gold is associated with the smaller particles, an alternative is to concentrate the size fraction that contains the gold.

"Fine fraction" analysis of soil and regolith (i.e., silt particle size and smaller) has been used for geochemical exploration in several studies, with the <63 or <50 µm size fractions used to enhance target and pathfinder element contents (Morris 2013; Noble 2012; Scott & van Riel 1999). Most of the loosely bound ions will be adsorbed to particles in the smaller size fractions because the clays, organic compounds and various oxides that dominate this fraction have a greater exchange capacity than the larger minerals such as quartz (Hawkes & Web 1962; Hall 1998).

These smaller fractions clearly influence the content of metals such as gold. Common questions arise as to which size fraction is optimal, and how fine is fine? We will not tackle the first question, but in this paper we will provide a method to quantify the gold content of the micro and nanoparticulate fractions in soil samples from the East Wongatha area of Western Australia and demonstrate the remarkably different gold contents associated with these fractions compared to the bulk regolith.

METHODS

Fourteen soil samples from a large regional regolith survey in the East Wongatha region of Western Australia (Morris 2013; Fig. 1) are discussed here. The <50 µm fraction of these samples had been analysed for gold by the Geological Survey of Western Australia, following aqua regia digestion of 1 g of sample, producing gold contents from <1 ppb to 29 ppb (Morris 2013). All soil samples are quartz-rich, and from a region of largely allochthonous thick transported regolith. In most cases, the <50 µm fraction is <5% of the bulk soil. Approximately 5 kg of bulk soil was collected at a depth of about 90 cm at each site using a power auger. A split of c. 1 kg from each sample was used in this study.

Five fractions were separated from each bulk sample (e.g., Figs. 3, 4 and 5) and the average weight % of each fraction was determined (Table 1). Bulk sample dry weight was determined and the material was then soaked in deionized water overnight. Following this, the soil suspension was placed in an ultrasonic bath for 20 minutes and then poured through nylon mesh sieves at 2 mm, 250 µm and 53 µm. The suspension that passed through all sieves (<53 µm) was placed in a 1 L graduated cylinder and filled to 1L with

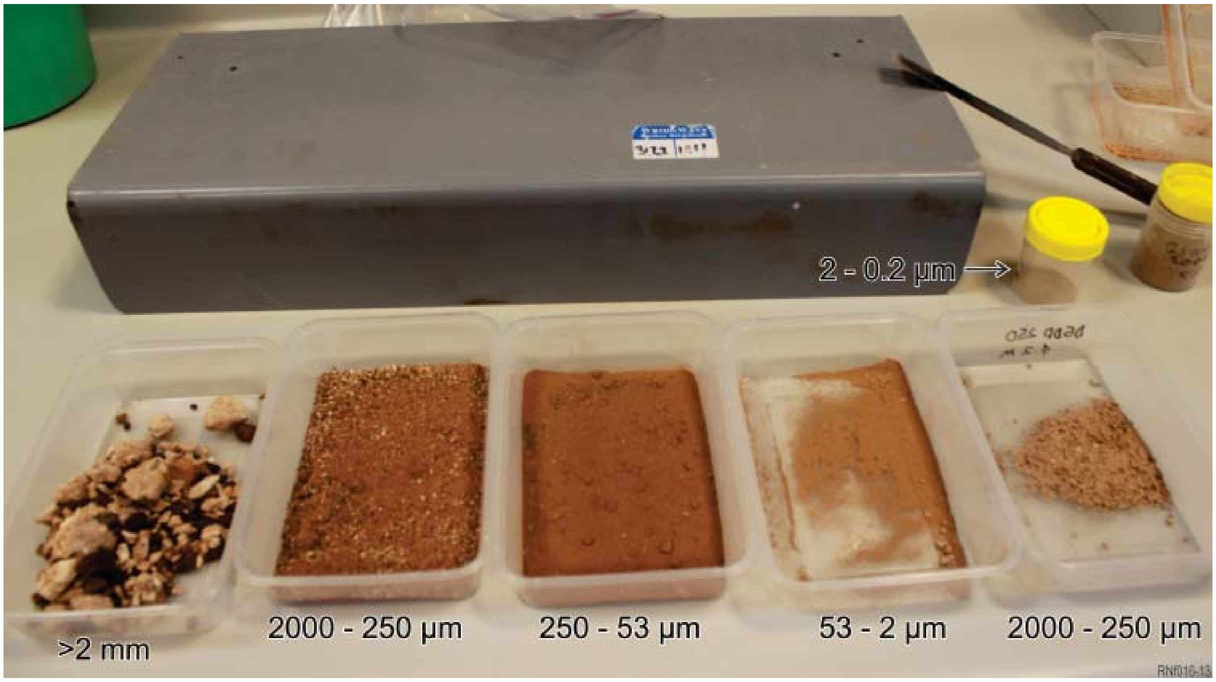

Figure 3. Examples of the 2 mm to the <2 µm size fractions separated from the 1 kg bulk soil sample using wet sieving.

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Spinifex Ridge Iron Ore Mine, Western Australia, courtesy Moly Mines Limited

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Figure 4. Using centrifugation to separate the <0.2 µm (or 200 nm) size fraction results in dry films (dark red material) of soil weighing between 0.1 and 0.5 g that were then subject to aqua regia digestion.

deionized water. This fraction was then mixed and left standing. After 5.5 hours (at 25° C) the top 8 cm was drawn off (~ 200 mL with only <2 µm sized particles in solution), and the remainder along with the other sieved fractions was dried in an oven at 80ºC for approximately 1 week. The samples were then cooled to room temperature and weighed. Full details for particle size separation are available in Gee & Bauder (1986).

The <2 µm solution drawn off the top of the 1 L cylinder was placed in a centrifuge tube and spun at >3000 Relative Centrifugal Force (RCF) for 1 hr at 25°C. The particles remaining in solution were approximately <0.2 µm using a conservative adjustment of the methods by Gee & Bauder (1986) and Kilmer & Alexander (1949). This solution (<0.2 µm) and the separate fraction (<2 µm to 0.2 µm) at the bottom of the tube were then dried and weighed in the same manner as the larger fractions (Fig. 4). A flow chart of the procedure traces the sample separation steps (Fig. 5).

All fractions were subjected to an aqua regia digestion at CSIRO Laboratories, Kensington, Western Australia. For the <2 µm fraction and coarser soil samples, 0.8 ± 0.01 g of soil were subjected to a conventional aqua regia

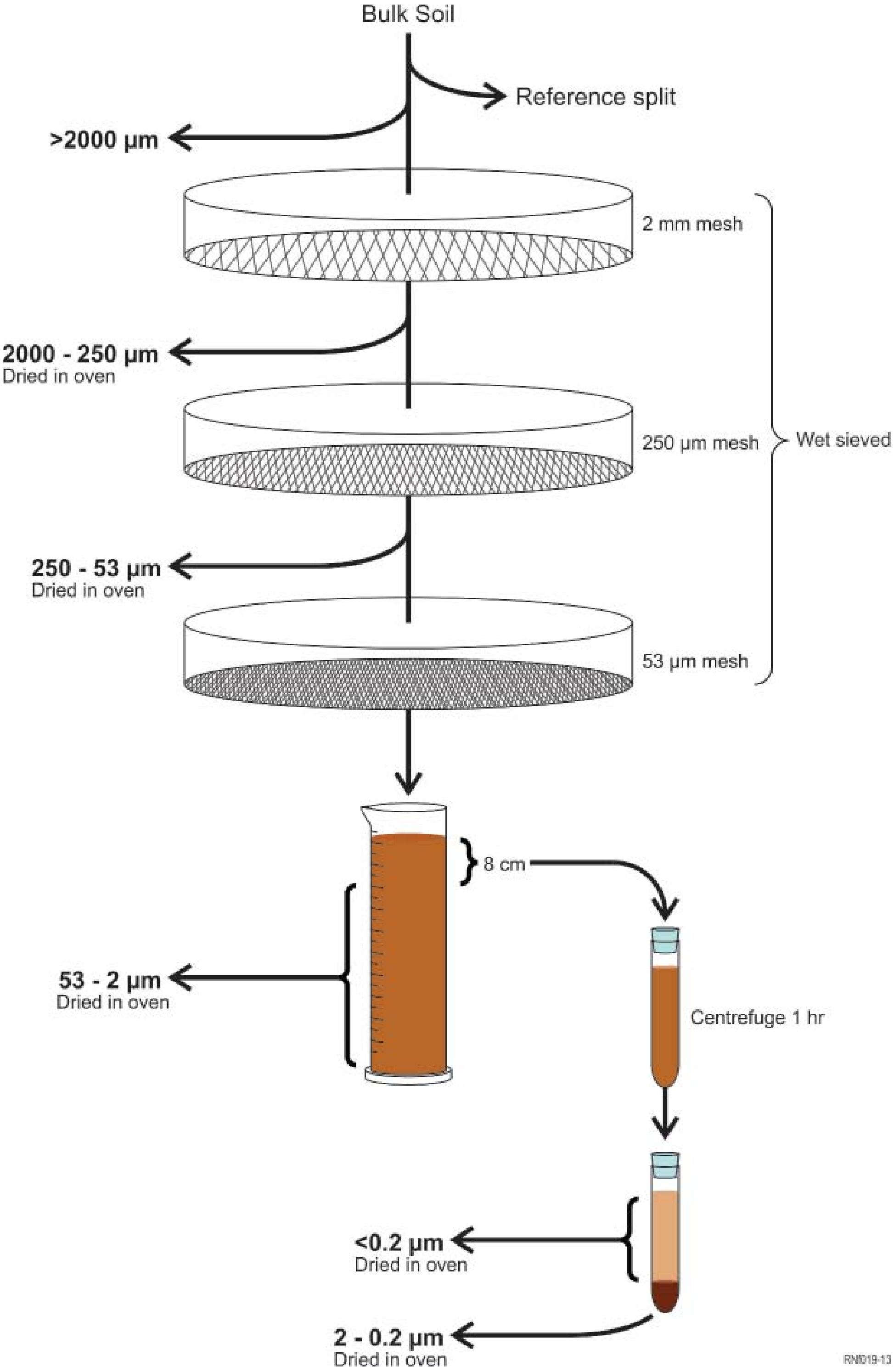

Figure 5. Flow chart of the method used to separate the particle size fractions used in this study.

Table 1. Mean data and standard deviation for the weight (g) of the 14 samples used for particle size separation in this study.

Fractions	Coarse			Medium	Microparticulate	Nano-particulate	
Size	>2 mm	2000-250 µm	250 -53 µm	53 -2 µm	2 – 0.2 µm	<0.2 µm	Lost
Mean Wt.(g)	175.2	694.8	200.9	84.4	16.4	0.18	13.1
Std Deviation	281.9	342.9	69.4	92.9	13.3	0.12	26.3
Mean Wt. %	14.80	58.69	16.97	7.13	1.38	0.02	1.11

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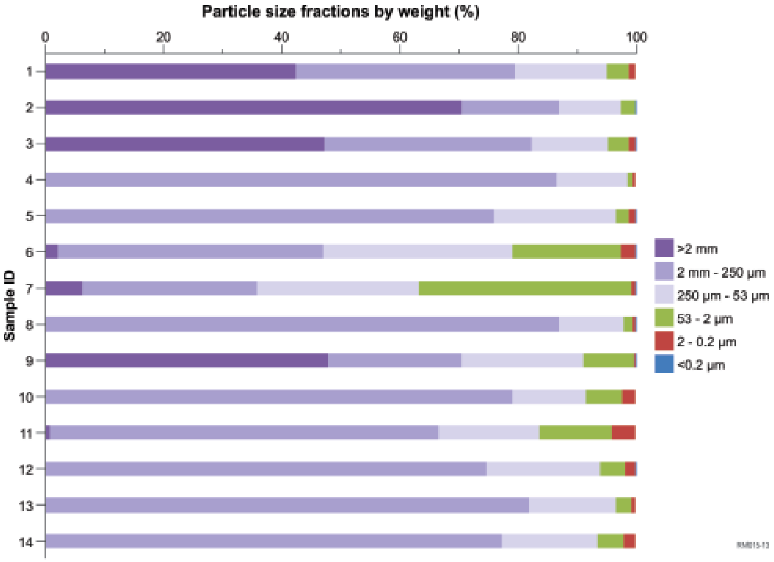

Figure 6. Size fractions by weight % for the samples used in this study.

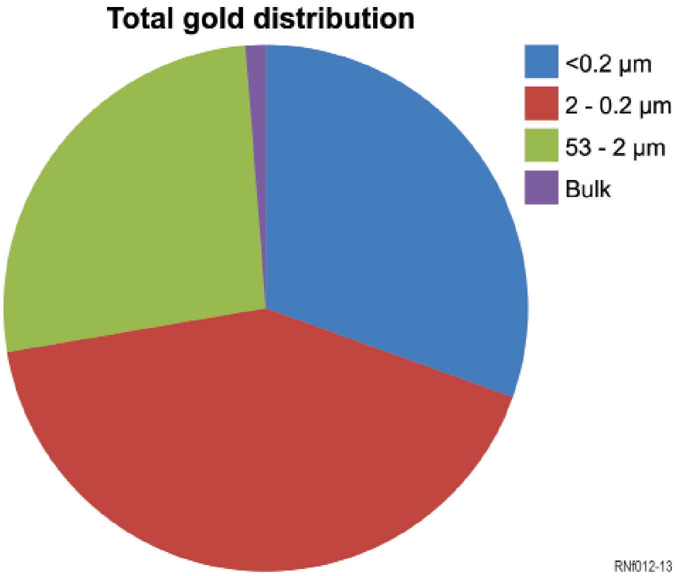

Figure 7. Average total gold distribution by size fraction. A large proportion of the gold is in the microparticulate (<2 µm) and nanoparticulate (<0.20 µm) fractions. The bulk category (purple) represents all the combined fractions and is dominated by particles > 53 µm.

(3:1concentrated $HCl:HNO_3$, respectively) digestion (Chen & Ma 2001) to determine their readily soluble bulk chemical composition. For the nanoparticulate fraction (<0.2 µm), the remaining sample available was much smaller. As a result a smaller sample weight of 0.1g to 0.4 g was digested, with most samples c. 0.2 g.

Each sample was weighed into 250 ml glass conical flasks, 25 ml of aqua regia was added, watch glass lids were placed on top, and the flasks placed on hotplates at 110°C for 3 h. After evaporation to near dryness, the sample was diluted with 20 ml of 2% (v/v with H_2O) HNO_3 and the samples were transferred into a 100 ml volumetric flask after filtering through Whatman no. 42 paper and diluted to 100 ml with milliQ water. This extraction was used to determine the contents of elements in soil particles, excluding those substituted within the crystal lattice of highly resistant minerals. The solutions were directly analysed using an ICP-MS (Perkin Elmer Optima 7500A) by Bureauveritas Pty Ltd, Perth, Australia.

For all analyses, blanks and analytical duplicates were included. The half absolute relative difference (HARD) error was calculated as a percentage for all compounds using duplicates according to the methods described by Stanley & Lawie (2007):

$$\text{HARD} = (|\text{assay1} - \text{assay2}| / (\text{assay1} + \text{assay2})) \times 100.$$

RESULTS

Approximately 75% of the weight of most samples was comprised of particles >250 µm, with two exceptions that had approximately 45% of their weight in this fraction (samples #6 and 7; Fig. 6). Mineralogically, the microparticulate and nanoparticulate fractions consist of kaolinite, goethite and hematite along with quartz. Although the soils tend to be dominated by the coarse, quartz-rich soil fraction, the gold analysis on all the size fractions shows that the majority of the gold is small and hosted in the <53 µm fraction. The average total gold distribution within the size fractions for all samples used in this study is shown in Figure 7. The gold associated with the bulk, coarse fraction dominated materials is less than 2% and, on average, almost insignificant (Fig. 7).

Gold is not consistently hosted within a specific size fraction, i.e., significant variability exists between the samples analysed (Fig. 8). Proportionally, the majority of gold is associated with the silt size fraction (2-53 µm) such as in samples #1 and 4 (Fig. 8), whereas other samples exhibit the majority of gold in the clay-sized microparticulate fraction (<2 µm), such as samples #3, 9 and 10. Three out of the fourteen samples have the majority of their gold hosted in the ultrafine, nanoparticulate (<0.2 µm) size fraction (Samples #2, 5 and 8; Fig. 8). One of those samples (#8) has over 95% of its gold in the nanoparticulate fraction. We have presented gold proportions, but actual contents of gold are commonly large (>100 ppb) in the two finest fractions (Fig. 9). Analysing the bulk soil and the medium fraction (<53 µm) for gold resulted in samples that were below detection (1 ppb) or in the low 10s of ppb range for gold. However, analysis of the micro (<2 µm) and nanoparticulate (<0.2 µm) soil fractions revealed contents commonly in the 100s of ppb range and in some cases, in the ppm concentrations of range for gold (Fig. 9). Selecting and analysing the nanoparticulate gold fractions via particle size separation results in gold concentrations that span three orders of magnitude. It should be noted that these results are determined by digesting a sample size that is smaller than normal (~0.2 g compared to a few grams in most aqua regia digests), so there are increased errors in accuracy, but these trends of increased gold in the smaller particle size fractions are expected to be real. Table 2 shows the percentage half absolute relative difference between duplicate analyses, with significant variation recorded. The duplicates could

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not be prepared for the nanoparticulate fraction due to the limited sample mass recovered, but a potentially larger variability is expected in this fraction. The limited sample size has an increased propagation of error when calculating the mg/kg of gold in soil.

Spatially, the results plot differently and do not give a clear indication of which sample is the most prospective for mineralisation in the East Wongatha area as the different fractions do not show the same distribution of samples with the greatest gold contents. The sample with the greatest bulk gold content does not contain the greatest amount of gold in the micro and nanoparticulate fractions (Fig. 10). Normalised ratios of the gold content in each fraction to the weight of that specific fraction recovered only change the patterns slightly from the direct gold content plots of the micro and nanoparticulate fractions (Fig. 10) Orientation surveys are required to assess the exploration benefit of this technique. The area studied has U, REE and Ni prospects and deposits adjacent to the samples, but known gold occurrences are commonly further away to the northeast and to the south (Fig. 10; Morris 2013). The micro and nanoparticulate fractions are remarkably different, with no single sample showing larger contents in both of these fractions compared to the rest of the samples assayed (Fig. 10). This indicates that gold tends to be nuggety regardless of the size fraction analysed.

DISCUSSION

Tens of ppb gold in soils may be considered anomalous when exploring in transported, covered areas of Western Australia. In this study, we have shown that the weight percent of the fine size fractions may significantly influence the gold content and perhaps smoothing the data based on particle size is warranted. Research has shown gold to be preferentially concentrated in the fine (<63 µm) size fraction of soils and using this size fraction improved explora-

Table 2. Percentage half absolute relative difference (HARD) results for four fractions with duplicates. Note these were full method duplicates subject to the full separation technique prior to chemical digestion and analysis.

Sample ID	Size fraction duplicated	% HARD
3	53 -2 µm	8.8
4	53 -2 µm	37.4
6	2 – 0.2 µm	14.3
11	2 – 0.2 µm	86.5

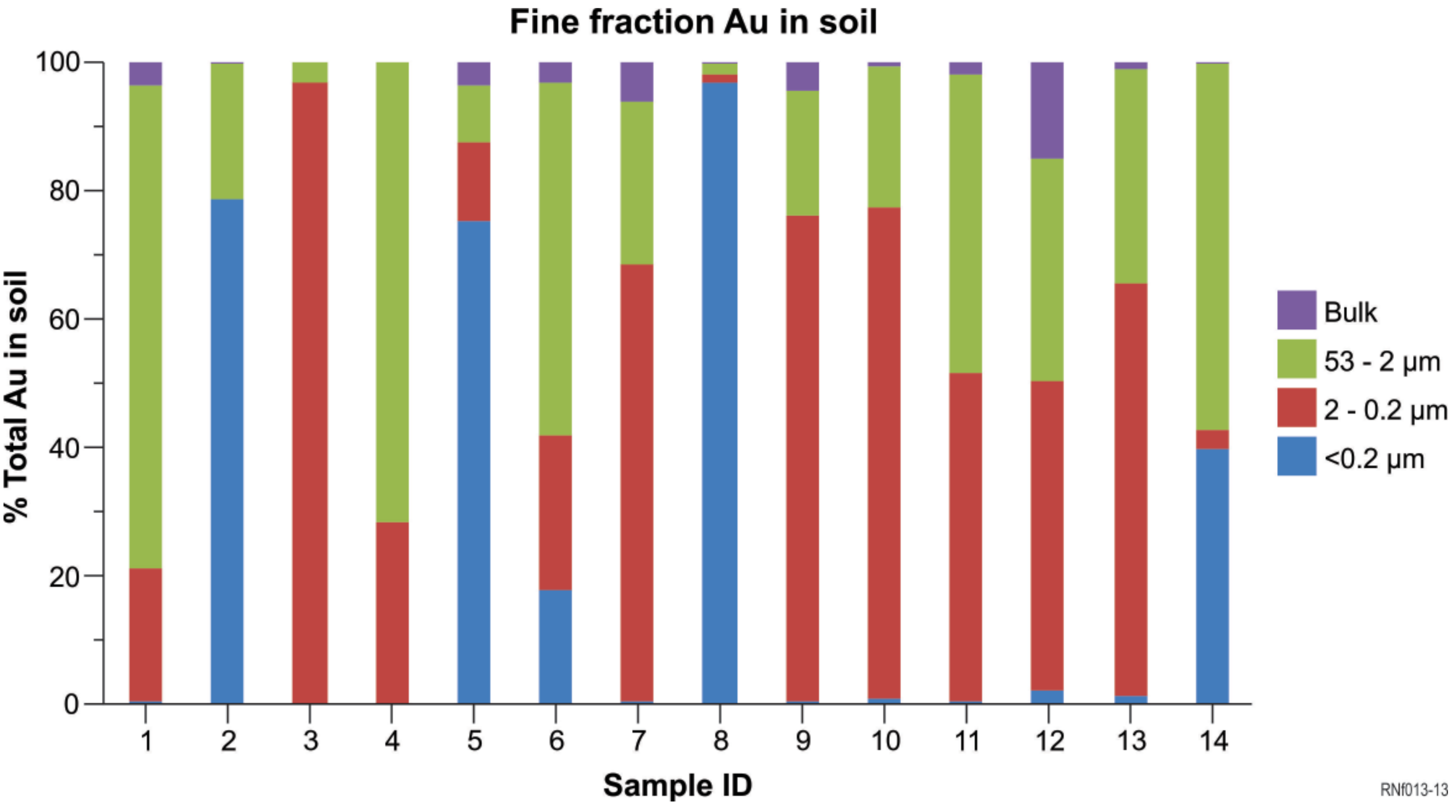

Figure 8. The percentage total gold in each size fraction for the individual samples. A large, but not uniform, proportion of the gold is in the fine (<2 µm) and ultrafine (0.002 µm) fractions. The bulk is all the combined fractions and dominated by particles > 53 µm.

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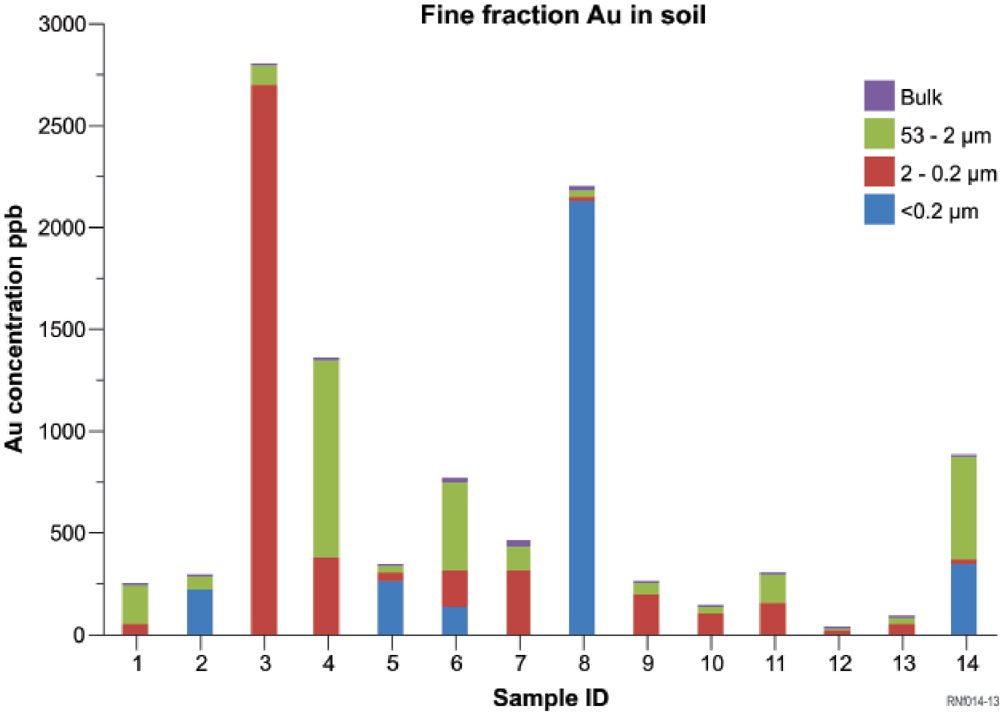

Figure 9. Gold contents in each sample separated by size fractions. The bulk category represents all the combined fractions and is dominated by particles > 53 µm.

tion through cover at the Goornong South gold deposit in northern Victoria, Australia (Scott & van Riel 1999). It is not known if exploration potential is improved by using the ultrafine fractions as samples over known mineralisation sources were not part of this study i.e., no orientation survey. An assessment of the gold content in the fractions should be normalised by the mass or calculated surface area of that fraction in the sample to truly test the exploration potential because just using the finer fractions tends to elevate the content of gold (and other pathfinder metals) in all samples including background samples contents. The normalisation in this study only slightly changed the results from the direct fraction contents. Without an orientation survey in areas with known gold deposits, the effectiveness of this normalisation cannot be assessed. For bulk gold results,

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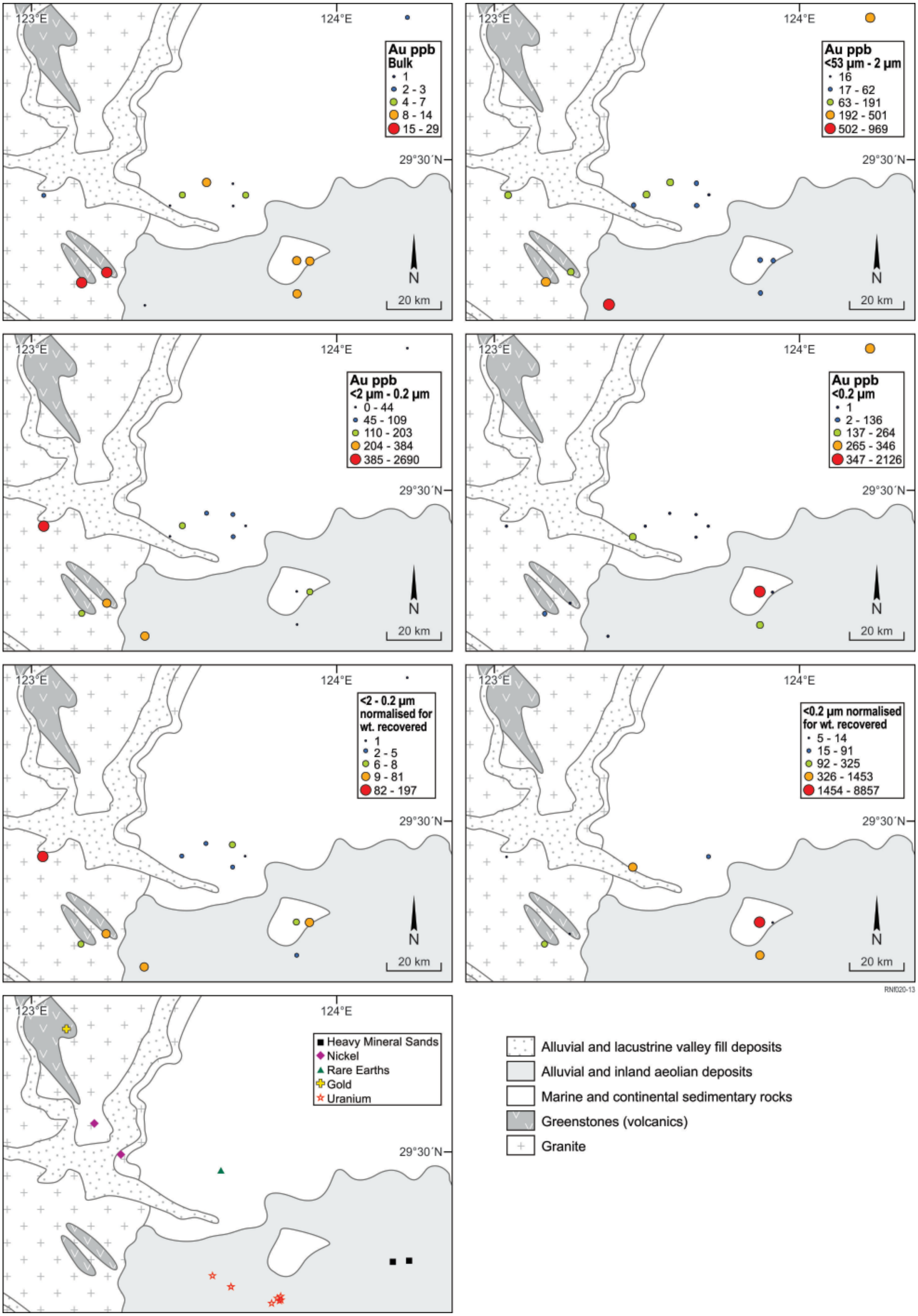

Figure 10. Spatial plots for the gold content by size fractions and the microparticulate and nanoparticulate fractions normalised to the weight of that fraction recovered. Targeting by a specific fraction may give significantly different targets. See Figure 3 of Morris (2013) for explanation of regional geology.

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the greatest contents are located near mapped greenstones that are generally the host lithology of gold deposits in the Yilgarn Craton. However, the gold content of the micro and nanoparticulate fractions (and the normalised results) highlight other areas, mostly in basins with deeper cover that possibly represent other mineralisation targets. The elevated gold content in the micro and nanoparticulate fractions could be indicative of aeolian transport of fine fraction gold (false anomalies) or more extensive local mobility of the smaller fraction as suggested by Morris (2013).

The results of Lintern (2007) also support the work of Morris (2013) in that gold in sand dunes from South Australia was dominantly microparticulate and spatially associated with buried mineralisation. In this South Australian study, it was determined that vegetation cycled gold from deeper beneath the dunes via evapotranspiration, particularly in drier years when the plants were required to tap the groundwater supply as the shallow regolith pore water was unavailable (Lintern 2007). These and other studies show micro and nanoparticulate gold (Hough et al. 2011) as well as ionic gold (Lintern et al. 2009) are the common forms and that cycling between both types is viable. Noble et al. (2009) showed experimentally that both forms can result from secondary mobilisation.

In the samples used in this study, cycling between ionic and particulate gold would influence the gold contents associated with the various fractions. Ionic gold would be solubilised in the water during sieving and centrifuging and could increase the gold content of the nanoparticulate fraction, although the original ionic crystal may have been much larger *i.e.,* $>2\ \mu$m. For example, results by Noble et al. (2009) showed that AuCl crystallised along with the pure metal particles. The ionic gold salts were micron-sized, so this potential increase into the nanoparticulate fraction may be viable, although kinetic studies of the dissolution process would be required to confirm the assumption that this leads to greater nanoparticulate fraction gold. Support for the presence of ionic gold is provided by results of deionized water digestion of $< 50\ \mu$m fraction regolith from the East Wongatha area, which showed a strong positive correlation with aqua regia gold (Morris 2013).

Both the potentially larger ionic gold and the nanoparticulate gold are likely to be highly mobile in the surficial weathering environment. The mechanisms of gold mobility could be driven by vegetation (Lintern 2007; Anand et al. 2007), groundwater (Grimes et al. 1995; Gray 2001) or carrier gases (Cao et al. 2009; Gao et al. 2011). Understanding these processes is not part of this study, but how gold mobility affects particle size of the gold should be pursued in future studies.

Excluding the aeolian transport mechanism, the size of gold particles in soils in Western Australia does not necessarily indicate distance from source. Experiments have shown that the size of gold precipitating from solutions in proxy experiments for supergene mobilisation and recrystalization varies, so the size of the gold fractions in these transported soils is not necessarily indicative of distance from ore deposits (Noble et al. 2009; Hough et al. 2011).

The methods presented in this paper show a large and variable amount of micro and nanoparticulate gold. The visualisation of these size populations and the apparent nanoparticulate population of gold $<0.20\ \mu$m (Hough et al. 2008; Hough et al. 2011; Fig. 2) are corroborated in this research with significantly large gold contents found in the nanoparticulate fractions. The results of the study by Hough et al. (2011) suggest that with increasing technology developments improving the resolution of scanning electron microscopy, soil and regolith samples will also host a significant population of nanoparticulate gold at the 0.02 μm size and smaller. With increased centrifugation of the technique reported in our methods, these even smaller fractions can be analysed separately, too.

The particles remaining in solution for the nanoparticulate fraction are approximately $<0.2\ \mu$m using a conservative adjustment of the methods by Gee & Bauder (1986) and Kilmer & Alexander (1949). A number of assumptions are used to relate the particle size and density in the above methods and a direct calculation using Stoke's Law and the assumption of quartz mineral density of 2.65 g/cm2 do not directly agree (J. Robertson *pers. comm.*, unpublished data). Future research will image the dried suspension using FEGSEM and determine the maximum particle size in each step, removing the need for the previously applied theoretical assumptions.

CONCLUSIONS

This study assessed soil size fractions from bulk soil to the nanoparticulate ($<0.2\ \mu$m) fraction and the associated gold contents. It has demonstrated the method to quantify gold in these very small size fractions and shown there are differences in the micro and nanoparticulate fractions compared to the bulk or medium fractions that are routinely analysed in mineral exploration. The study is limited by the fact that the samples are not oriented with respect to known gold mineralisation and by the small number of samples and the small weight of nanoparticulate sample size material recovered. The small volumes of material analysed result in increased errors, but has effectively demonstrated that the size fractions can be separated, analysed and provide different information. The results are plotted spatially as an example for exploration feasibility, but do not assess which fraction provides the best exploration sample medium. Future research requires a more rigorous assessment of the method to exactly quantify the nanoparticulate size fraction separated, along with more focused orientation surveys to determine if significant benefit exists for analysing the micro and nanoparticulate fractions of soils for gold exploration; a process that is not currently conducted by industry.

Acknowledgements

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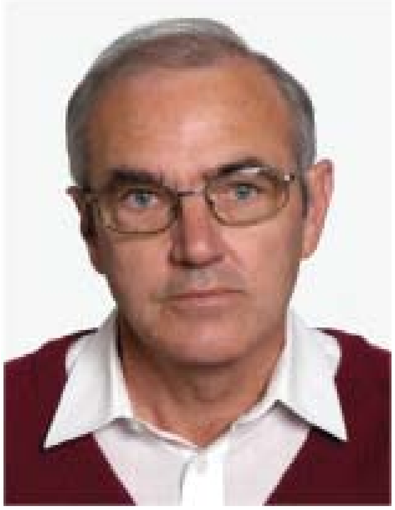
Obituary

Keith Scott

(1948-2013)



The geochemical community has lost a valued colleague with the passing of Keith Malcolm Scott on April 23, 2013 after a career spanning more than 40 years. He joined CSIRO at North Ryde, Sydney, Australia after graduating with a BSc from the University of Adelaide. He later completed an MSc in 1975 at Macquarie University. His exemplary research career with CSIRO continued until 2004, after which he became an Honorary Research Fellow.

Keith's research focussed on understanding the processes involved in the weathering of ore deposits, with the aim of developing better methods of geochemical exploration for base metals and gold. He worked throughout Australia, particularly in the Mount Isa region, the Yilgarn Craton, the Drummond Basin and the Lachlan Fold Belt. In much of his work, Keith's approach was generally as a mineralogist first and geochemist second, but he was always keen to link the two disciplines. He was widely recognized for his expertise in the mineralogy of weathered sulphide deposits. In particular he developed a life-long interest in the alunite-jarosite solid solution series on which he published 8 papers, one of which has 122 citations. He was closely involved in the development of radiometric and hyperspectral mineral logging technology and, more recently, was actively developing the use of rutile composition in exploration as part of CSIRO's Distal Footprints project. He had even coined 2013 as the "year of rutile" given the global research interest in the mineral he had done so much work on.

Keith was a valued member and Honorary Fellow of the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME), of which he was acting Program Leader in 2003-2004. He maintained close contacts with many of the organizations affiliated with the CRC, and was greatly respected by the exploration industry, with which he collaborated throughout his career. Keith not only published over 40 peer-reviewed papers and numerous other reports and articles, but latterly also assumed the role of editor. He co-edited a special issue (actually two issues) on the Yilgarn Craton for Volume 1 of *Geochemistry: Exploration, Environment, Analysis* (2001) and was a member of the editorial team that compiled the regolith case histories and supporting chapters (contributing 13 articles himself) in the popular CRC LEME Thematic Volume: *Regolith Expressions of Australian Ore Systems* (2005). From 2004 to early 2006, Keith was editor of CRC LEME *Minerals Brief* and in 2008 co-editor and author of one of very few text books on the regolith, *Regolith Science* (pictured below) published by CSIRO and Springer. This valuable addition to any geochemist's or exploration geologist's library is a fitting reminder of the time, research and effort Keith put in to regolith studies, particularly in the Australian environment to support the Australian mineral exploration industry. Most recently, he helped edit Geoscience Australia's landmark book *Shaping a Nation: A Geology of Australia,* which was prepared for the International Geological Congress in Brisbane in 2012.

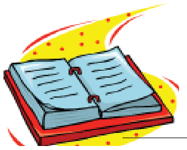
In addition to his CSIRO Honorary Fellowship, Keith was also a Visiting Fellow at the Research School of Earth Sciences, Australian National University (ANU). Through both these positions he continued to pursue his science interests. He was an excellent mentor to Honours, Masters and Ph.D. students, at ANU and elsewhere, always willing to take the time to talk to them about their projects and the existing and potential applications of their studies. Keith was very supportive of numerous Education and Training activities, and participated in Exploration Geochemistry MSc Short Courses at CODES (University of Tasmania), in CRC LEME-sponsored MSc courses and most recently in a 4th-year regolith course at ANU. The course at ANU focussed on regolith geoscience and mineral exploration, as part of the Minerals Tertiary Education Council programs sponsored by the Minerals Council of Australia.

He sought to break down barriers between researchers from different institutions and at different locations. He encouraged university students studying regolith and provided an industry perspective to their studies. He actively collaborated with faculty members and students at ANU, including studying the impacts of aeolian dust in Australian landscapes and trace element signatures in ironstones and other regolith materials.

Keith had been a Fellow of the Association of Applied Geochemists for 33 years and regularly attended and presented at the international symposia. He was someone who was happy to take the time to discuss any aspects of geochemistry and mineralogy, particularly having a kind and approachable way of discussing science with junior geoscientists and students.

Keith is survived by his wife Lyn (Lynette), his three children Elizabeth, Gwenyth and Andrew, and two grandchildren Aiden and Abigail.

Compiled by **Ryan Noble, Graham Carr, Bear McPhail, Charles Butt and Rob Hough.**



CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry. These events also appear on the AAG web page at: www.appliedgeochemists.org

30 June – 4 July 2013. 12th International Estuarine Biogeochemistry Symposium. Plymouth, UK. Website: www.iebs2013.org

3-5 July 2013. 8th International Conference on the Environmental Effects of Nanoparticles and Nanomaterials. Aix-en-Provence France. Website: www.nano-environment2013.org

3-5 July 2013. Second International Workshop on the Geology of Critical Metals. Ulaanbataar Mongolia. Website: www.criticalmetalsmeeting.com/

5-13 July 2013. 11th ICAM International Congress for Applied Mineralogy. Mianyang China. Website: www.icam2013.org

8-12 July 2013. 29th European Conference of the Society for Environmental Geochemistry and Health. Toulouse, France. http://segh2013.sciencesconf.org/

15-17 July 2013. 3rd International Conference on Environmental Pollution and Remediation. Toronto ON Canada. Website: http://icepr2013.international-aset.com/

16-19 July 2013. WOMS 2013 — International Workshop on Organic Matter Spectroscopy. Toulon France. Website: http://woms13.univ-tln.fr/

20-24 July 2013. American Crystallographic Association (ACA) Annual Meeting. Honolulu HI USA. Website: http://tinyurl.com/aruja56

20-24 July 2013. IAVCEI general assembly - 2013: forecasting volcanic activity. Kagoshima Japan. Website: http://tinyurl.com/caclzjj

22-24 July 2013. 2nd International Conference on Earth Science & Climate Change. Las Vegas NV USA. Website: http://tinyurl.com/cwfreet

25-27 July 2013. International Conference on Water, Wastewater & Isotope Hydrology. Bangalore India. www.ijwwish.com

28 July-2 August 2013. 11th International Conference on Mercury as a Global Pollutant Edinburgh UK. Website: www.mercury2013.com

28 July – 2 August 2013. Gordon Research Conference: Atmospheric Chemistry. West Dover VT USA. Website: http://tinyurl.com/8ashaoc

4-8 August 2013. Microscopy & Microanalysis 2013. Indianapolis IN USA. Website: www.microprobe.org/events

12-15 August 2013. 12th SGA Biennial Meeting. Uppsala, Sweden. Website: www.conference.slu.se/sga2013

18- 23 August 2013. EnvironMetal Isotopes EMI 2013. Ascona Switzerland. Website: www.ibp.ethz.ch/events/conference

25-30 August 2013. Goldschmidt 2013. Florence, Italy. Website: www.goldschmidt.info/2013

25-29 August 2013. ECM 28 - XXVIII European Crystallographic Meeting. Warwick UK. Website: http://ecm28.org

25-29 August 2013. 5th International Conference on Medical Geology. Arlington VA USA. Website: http://tinyurl.com/cvcaxfv

1-7 September 2013. International Conference on Gas Geochemistry 2013. Patras Greece. Website: http://conf12.ic-gg.org

2-10 September 2013. 10th International Eclogite Conference. Courmayeur, Italy. Website: www.iec2013.unito.it

2-6 September 2013. 15th Conference of the International Association for Mathematical Geosciences. Madrid Spain. Website: http://tinyurl.com/9wo8kmo

22-27 September 2013. 10th Applied Isotope Geochemistry Conference. Budapest Hungary. Website: www.aig10.com

24-27 September 2013. SEG Conference: Geoscience for Discovery. Whistler BC, Canada. Website: www.seg2013.org

13-18 October 2013. International Symposium on Environmental Biogeochemistry. Wuhan China. Website: www.isebiogeochemistry.com

27-30 October 2013. GSA 2013 Annual Meeting. Denver CO USA. Website: www.geosociety.org/meetings/2013

28-29 October 2013. 2nd Annual International Conference on Geological & Earth Sciences (GEOS 2013). Phuket Thailand. Website: www.geoearth.org

29-31 October 2013. 9th Fennoscandian Exploration and Mining Meeting. Levi, Finland. Website: http://fem.lappi.fi/en

18-21 November 2013. 26th International Applied Geochemistry Symposium, Rotorua, New Zealand. Website: www.gns.cri.nz/iags

2-6 December 2013. Northwest Mining Association: 118th Annual Meeting, Exposition & Short Courses. Sparks/Reno NV USA. www.nwma.org/pdf/2013Announcement.pdf

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CALENDAR OF EVENTS

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6-11 January 2014. 2014 Winter Conference on Plasma Spectrochemistry. Amelia Island FL USA. Website: http://tinyurl.com/ck2s5eu

27- 30 January 2014. Mineral Exploration Roundup 2014. Vancouver BC Canada. Website: www.amebc.ca/roundup

2-5 March 2014. Prospectors and Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/pdac/conv/index.aspx

9-13 June 2014. Goldschmidt 2014. Sacramento CA USA. Website: http://goldschmidt.info/2014

29 June - 2 July 2014. 2nd International Conference on 3D Materials Science. Annecy France. Website: www.tms.org/Meetings/2014/3DMS2014/home.aspx

3-7 August 2014. Microscopy & Microanalysis 2014. Hartford CT USA. Website: www.microprobe.org/events

24-27 August 2014. 7th International Conference on Environmental Catalysis. Asheville NC USA. Website: www.efrc.lsu.edu/ICEC/

1-5 September 2014. 21st General Meeting of the International Mineralogical Association (IMA2014). Johannesburg South Africa. Website: www.ima2014.co.za/

19-22 October 2014. GSA 2014 Annual Meeting. Vancouver BC Canada

27 July -2 August 2015. 19th INQUA Congress (Quaternary Perspectives on Climate Change, Natural Hazards and Civilization). Nagoya, Japan. Website: http://inqua2015.jp

8-14 August 2015. Geoanalysis 2015. Leoben, Austria. Website: http://geoanalysis.info/

Please let us know of your events by sending details to:

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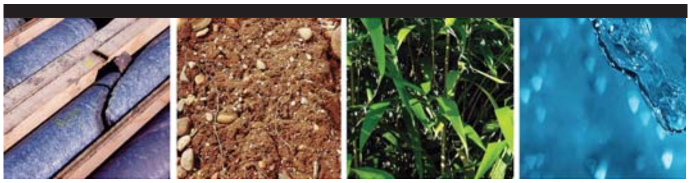

Exploring Through Cover — What Works, What Dosn't and Why

This short course was conducted on Friday January 25, 2013 in conjunction with the Association for Mineral Exploration British Columbia (AME BC) in Vancouver, Canada. The course was sponsored by Activation Laboratories Ltd. and organized by Craig Hart, Director of the Mineral Deposit Research Unit at the University of British Columbia. Over 100 participants attended the course, which was sold out.

The one-day short course focused on successful techniques and case studies for locating buried mineral deposits. This course included presentations that discussed geological, geochemical and geophysical techniques that have been successfully used to locate and map mineral deposits beneath cover. Methods that have failed were also discussed as well and why the methods failed to work.

Presentations were given by experts from industry, the Geological Survey of Canada, the BC Geological Survey and Universities. Topics included:

- Quaternary geology and geochemical exploration; the value of media specific data sets (Vic Levson, Quaternary Geosciences Inc. and Travis Ferbey, British Columbia Geological Survey),
- Know your cover: Role of soil sampling suitability mapping in mineral exploration (Robin McKillop, Palmer Environmental Consulting Group, Inc.),
- A guide to Mineral Exploration in Complex Glacial Terrains (Ralph Stea, Stea Surficial Geology Services),
- Indicator mineral exploration methods in glaciated terrain (Beth McClenaghan, Geological Survey of Canada),
- How to find the source or provenance region of mineralized boulders in the glaciated Cordillera (Alain Plouffe, Geological Survey of Canada),
- Drift Prospecting for Porphyry Copper-Gold, VMS Mineralization and Base metal Veins in the QUEST Project Area, Central BC (Brent Ward, Simon Fraser University),
- Using the BCGS till geochemical database – Caution and creativity (Ray Lett, British Columbia Geological Survey (Emeritus)),
- Getting it right – Identifying the keys to failure (Dave He-

Exploring Through Cover —

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berlein, Heberlein Geoconsulting),

- The Use of Soil pH: the IDH Factor (Barry W. Smee, Smee and Associates Consulting Ltd.),
- Biogeochemical Exploration – sometimes highly successful, and sometimes not. Why is that? (Colin Dunn, Colin Dunn Consulting Inc.),
- Exploring through cover – advances in analytical techniques and technologies (Matthew Leybourne and Sarah Rice, ALS Geochemistry),
- Using airborne geophysics (gravity, magnetic and EM) for regional mapping beneath cover (Mel Best, Bemex Consulting International).

Examples were given from glaciated terrains in Canada.

The morning sessions were a good review of identifying glacial stratigraphy, sampling in glacial terrains and taking care to identify the appropriate sample material within the glacial stratigraphy using time honored geochemical methods to locate mineralization. The afternoon focused on identifying fatal flaws in geochemical programs and recent geochemical methodology and analytical advances and their application, as well as the use of newer geochemical protocols to delineate mineralization under exotic overburden.

Participants were given a chance to submit specific exploration questions to a panel of international geochemical expertise that resulted in some lively discussions at the end of the session. The overall quality of the presentations was excellent and the ability of the presenters to answer the questions from the audience was good. The reader is encouraged to contact the presenters with any additional questions of interest.

Jeff Jacks
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New Frontiers for Exploration in Glaciated Terrain

This one day short course held in conjunction with the 2013 Prospectors and Developers Association annual meeting was organized by Roger Paulen and Beth McClenaghan of the Geological Survey of Canada (GSC) and brought together a collection of some of the most experienced researchers in the field of drift prospecting and geochemistry representing government, academia and industry. The objective of the short course was to provide an update on recent advances in drift exploration in complex glaciated terrains with a focus on indicator minerals and drift geochemistry.

The short course was well attended by 65 delegates representing 6 countries and attests to the continued interest in the application of drift prospecting techniques as a tool for discovering mineral deposits which, in many cases, are concealed beneath thick deposits of glacial sediment. The short course consisted of 11 presentations, the first two of which provided a nice overview of the history and evolution of drift prospecting in Canada (Harvey Thorliefson, Minnesota Geological Survey) followed by a discussion of the importance of understanding glacial processes, ice dynamics and ice flow history for the successful interpretation of compositional datasets both at the regional and property scale (Roger Paulen, GSC).

These talks were followed by enlightening presentations on the implementation of QA/QC protocols into the design of indicator mineral surveys, a practice which has historically been ignored by practitioners (Alain Plouffe, GSC), the management of large geochemical datasets highlighting the importance of implementing robust data management plans well documented by metadata using examples from the GSC database (Wendy Spirito, GSC) and an interesting presentation on the integration of till geochemical, indicator mineral and clast lithological data using multivariate statistical methods and GIS for a dataset from the Thompson Nickel Belt in Manitoba (Eric Grunsky and Beth McClenaghan, GSC).

A pair of indicator mineral case studies were presented for the Rainy River gold deposit in northwestern Ontario (Stu Averill, Overburden Drilling Management), a discovery attributed almost exclusively to the follow-up of a gold grain anomaly in till published by the provincial geological survey and the Chidliak diamond project in Nunavut (Jennifer Pell, Peregrine Diamonds Limited), the most recently recognized diamond province discovered to date in Canada. Both presentations clearly documented the evolution of the discoveries highlighting sampling design and new analytical methods that aided in the interpretation and subsequent recognition of source areas for the anomalies. A subsequent presentation by Martin McCurdy of the GSC detailing the results of regional stream and water geochemistry and stream sediment heavy mineral sampling in Victoria Island, NWT demonstrated the application of this survey design for delineating areas of elevated Pb-Zn potential in areas underlain by carbonate rocks.

Presentations dealing with new advancements in the application of indicator mineral assemblages to volcanogenic massive sulphide exploration and geochemistry of iron oxides, a heavy mineral fraction traditionally not investigated, to fingerprint a vast array of mineral deposit types were given by Beth McClenaghan, GSC and Georges Beaudoin, Université Laval, respectively. These presentations clearly illustrate the potential for new avenues of research in indicator mineral technologies.

The day wrapped up with a presentation by Gwendy Hall of the GSC on the application of portable XRF for the rapid analysis of geological samples in the field. Gwendy provided a blind comparative analysis of five commercially available instruments highlighting some of their limitations and deficiencies. This study was undertaken as part of a CAMIRO investigation. She also presented the results of a comparative analysis of portable XRF results on 88 unsieved till samples versus conventional ICP aqua regia analyses on the -63 μm fraction and commented on the apparent positive correlation.

All in all, the subject material of the workshop was well balanced and presented information was, for the most part, current. The applied focus of the presentations was appreciated and of value to all in attendance. It was nice to obtain a series of extended abstracts that include figures, many of which were presented in the talks as well as a list of references should one wish to delve deeper into the subject matter.

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Lake Rotorua and Rotorua city in the foreground

AAG Student Support Initiative
Analytical Support for BSc (Hons), MSc and PhD Students in Applied Geochemistry

In 2011, AAG implemented a coordinated program with analytical laboratories to provide In-Kind Student Support for applied geochemical research projects. We are off to an exciting start with several students currently being assisted, multiple laboratories participating, and the first student paper published in EXPLORE #157: "Particle size fractionation and chemical speciation of REE in a lateritic weathering profile in Western Australia". Ms. Xin Du is from University of Western Australia with Genalysis Laboratory Services (Intertek) sponsoring the analyses. The latest Student/Laboratory match-up is Markham Phillips from the University of Otago in New Zealand who is being supported by ALS Geochemistry in Vancouver, Canada on his research into *"Granite host and it's alteration suites as well as geochronology of gold bearing sulphide minerals"* in New Zealand.

Investment in Applied Geochemistry

The AAG Council believes that securing both the future of the Association and that of applied geochemistry requires attracting more students to the science. As an investment in the future, the AAG wishes to encourage and support students whose area of study is Applied Geochemistry. For students of applied geochemistry, a major cost component in any research is the geochemical analyses. AAG believes that by identifying appropriate students, using a set of simple criteria, and coordinating with analytical laboratories that are willing to offer support in terms of geochemical analyses, high quality research and training in fundamental geochemical principles can result. The research is then published through the AAG journal (***Geochemistry: Exploration, Environment, Analysis***) or the ***EXPLORE*** newsletter.

Laboratories Participating in the In-Kind Student Support Initiative

Four laboratories generously signed on to provide the analytical support to students during 2012; committing over $35,000 in terms of analytical support:

- Becquerel Laboratories Inc., Mississauga, Ontario, Canada
- ALS Geochemistry, North Vancouver, BC, Canada
- Genalysis / Intertek, Gosnells, Western Australia
- Ultratrace / Bureau Veritas, Canning Vale, Western Australia

If your laboratory or student is interested in being a part of this program, please contact the chair of AAG's Education Committee, Erick Weiland (education@appliedgeochemists.org), who can provide you with details of this program. Student applications and instructions may also be found on the AAG web site: http://www.appliedgeochemists.org/ student's page under the Student Support link.

Education Committee
Eric Grunsky, Ray Lett, Ryan Noble, Nigel Radford, Erick Weiland (Chair)

ioStipend

In-kind Analytical Research Fund for BSc(Hons), MSc and PhD students

Much has been said and written about the broadening gulf between the demand for qualified explorationists and the supply coming out of our colleges, technical institutes and universities. One merely has to attend any geo-conference and gaze out over the sea of grey to fully grasp the situation our industry faces. This is all the more evident in the field of exploration geochemistry whose members have always been in short supply.

As consultants and service industries, we owe our livelihood to mining and exploration and thus have a vested interest in its development. We believe that any aid to promote fresh faces into our sector is helping to secure our future.

Acme Analytical Laboratories Ltd. and **ioGlobal** are taking the bold initiative of directly aiding students in the geosciences via the **ioStipend**. The **ioStipend** is a grant available to students conducting exploration-related geochemical studies at a recognized educational institution. The grant is in the form of analytical services using any package provided by Acme Analytical Laboratories Ltd. Students and/or their teachers/advisors can apply for the grant by submitting the application to ioGlobal who will vet the proposals.

The grant is intended to promote the collection of high quality, base-line data for comparison with more “esoteric data” (eg, isotopic data, partial digests, non-standard sample media) generated during the course of research, and to promote broad training in fundamental geochemical principals across the geosciences.

The **ioStipend** allows for amounts of approximately $5,000 (AUD, CAD or equivalent) for in-kind analytical work. Successful applicants will also be provided with 3 academic licences of **ioGAS**, the new exploratory data analysis software package available from ioGlobal.

The application form is available at www.ioglobal.net.

It is envisaged that three or four of these awards will be made each year.

Applications are reviewed by an expert group of ioGlobal’s geochemists

Eligibility Criteria

Preference will be given to:

- students with no other source of funding
- students working on exploration geochemistry projects
- projects no or very minimal confidentiality requirements

The ioStipend is international. Applications are welcome from qualified institutions globally.

Some technical input may be provided by ioGlobal on request.

Requirements for receiving the ioStipend

Firstly, there are minimal strings attached. Recipients would have to agree to

1. Have their project promoted on the ioGlobal web site in an area devoted to R&D carried out under the program (couple of passport photo shots, brief description)
2. Acknowledge ACME Labs and ioGlobal for support in technical and public presentations of results
3. Write a short article for Explore describing the project outcomes, and allow this to be published on the ioGlobal web site.

David Lawie, John Gravel

EXPLORE

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Manuscripts should be double-spaced and submitted in digital format using WORD. Photos and figures (colour or black and white) should be submitted as separate digital files and as high resolution jpeg or PDF files. Tables should be submitted as separate digital files in EXCEL format. All scientific/technical articles will be reviewed. All contributions may be edited for clarity or brevity.

Formats for headings, abbreviations, scientific notations, references and figures must follow the Guide to Authors for *Geochemistry: Exploration, Environment, Analysis* (GEEA) that are posted on the GEEA website at: http://www.geolsoc.org.uk/template.cfm?name=geea_instructions_for_authors

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