



## Particle size fractionation and chemical speciation of REE in a lateritic weathering profile in Western Australia

### Introduction

Physical and chemical weathering of rocks and minerals leads to soil formation. During this processes, mineral transformations result in a mass flux change of elements within the mineral assemblage and among particle size fractions, which yields information on element partitioning and transportation within a profile. The concentration of metals in soils increases with decreasing particle size (Al-Rajhi et al. 1996; Ljung et al. 2006; Acosta et al. 2009) because fine particles usually have a larger specific surface area capable of retaining higher amounts of metals (Wang et al. 2006), or alternatively, metals are co-precipitated with fine-grained secondary minerals. In the course of weathering, weathered regolith shifting into smaller particle sizes can result in the relative accumulation of the REE as refractory elements (Caspari et al. 2006).

However, the substantial influence that the particle size exerts on the abundance and redistribution of REE in lateritic regolith is not well known. Most of the studies on the geochemical behavior of REE during supergene weathering concentrate on bulk regolith. Therefore, a systematic understanding of the occurrence of REE in different grain size fractions of lateritic regolith is needed. Understanding grain size effects would assist pedological interpretation of the fate of REE, and assessment of plant availability of REE under natural environmental conditions.

Currently, in uncontaminated soils, two different approaches for determining trace element location and associated phases are used: physical fractionation and chemical methods (especially sequential selective extraction). Although the sequential extraction method suffers from relying on operationally defined fractions, lack of selectivity for the potential for trace element redistribution and re-adsorption among phases during extraction, it is still considered useful for investigation of associated phases of trace metals in soils by many research workers (e.g. Cao et al. 2000; Aubert et al. 2004). The reactivity or mobility of REE largely depends on their chemical speciation in weathered profiles, however, few studies have dealt with the speciation of REE in non-contaminated soils (Aubert et al. 2004), especially in natural weathered profiles.

continued on page 2

## President's Message

The Association had a strong presence in August 2012 at the 34<sup>th</sup> International Geological Congress in Brisbane, Australia, thanks to several AAG members. Through its representation on the Australian Geoscience Council, AAG was a co-sponsor of the meeting. Organized and run by David Cohen, AAG sponsored a pre-symposium one-day workshop, *Geochemistry in Mineral Exploration*, with presentations by David Gray, Neil Rutherford, David Cohen, Graham Carr, Erick Grunsky, and Bob Eppinger/Karen Kelley. There were 40 participants in the workshop, mostly from the corporate sector. AAG also sponsored a symposium session, *Advances in Exploration Geochemistry*, with three keynote and 18 standard papers, most presented by AAG members. AAG members were also heavily involved in the session *Global Geochemical Mapping*. Finally, AAG maintained a booth where there was a steady flow of visitors. David Cohen in particular is thanked for overseeing this effort.



The 26th International Applied Geochemistry Symposium in Rotorua, New Zealand is fast approaching (18-21 November, 2013). Planning, under the stellar leadership of Local Organizing Committee Chairman Tony Christie, is well underway. This conference is promising to be a must-attend meeting, with an excellent technical program, a variety of workshops, and some amazing fieldtrip opportunities. AAG Members, their spouses, and other geoscience colleagues are encouraged to reserve dates for attending this meeting. Current information for the symposium is at <http://www.gns.cri.nz/iags/> (or Google "26<sup>th</sup> IAGS").

When I began my term as President, a major concern was in securing proposals for the 27<sup>th</sup> IAGS in 2015. At the Rovaniemi, Finland meeting, there was some discussion about having the symposium return to the USA. AAG Councillor Erick Weiland led a talented group of AAG members in developing a strong proposal for having the meeting in Tucson, Arizona. I am happy to report that this proposal was accepted unanimously by the AAG Council in September 2012. Desert wildflowers should be in full bloom for this April 2015 meeting. One of the planned fieldtrips will be a multi-day excursion on the geology of the Grand Canyon, by whitewater raft with professional guides! Having floated the Grand Canyon ten times myself (with another trip planned in June 2013), I highly recommend this trip! But space on the field trip will be limited.

Gemma Bonham-Carter has been chosen as AAG's new

continued on page 2

EXPLORE NEWSLETTER wishes to thank our Corporate Sponsors for their support



## Particle size fractionation and chemical speciation of REE...

continued from page 1

The objective of this study is to determine the distribution and fractionation of REE in various particle size fractions and associated phases. The concentrations of REE in different particle size fractions and extracted phases are quantified and fractionation of REE with respect to those fractions and phases are discussed.

### Materials and Methods

#### Description of the study areas and sampling

The profile studied (JG) is located at the Jarrahdale Railway cutting (32°17'46"S, 116°5'40"E), 45 m from Alcoa Road, 80 km south-east of Perth in the Darling Range, Western Australia, at an average elevation of 270 m above sea level (Fig. 1). The investigated lateritic JG profile is ca. 12 m deep overlying meta-granitoids. The meta-granitoid is intruded by a dark-colored dolerite dyke, which is seen at the base of the cutting by the contrasts in color and texture of the parent rock and weathered products. The profile is clearly zoned and consists of parent meta-granitoids, saprolite, mottled clay, ferruginous mottled zone,

ferruginous duricrust, upper ferruginous zone and horizon A regolith (Fig. 1). The mottled clay is pale white kaolinite-rich, consisting of a lower zone (JG2) at 8.6 m depth and an upper zone (JG3) at 6.5 m depth. The ferruginous duricrust (3 m depth) is gibbsite and goethite rich. The upper ferruginous zone (JG6, 1.5 m depth) is rich in red iron nodules. In contrast, the horizon A regolith (JG7-10, <1 m depth) is gravely sandy soil rich in dark brown to black loose nodules. The sampling of the profile was conducted on the 6th August, 2009. Based on the different properties (e.g. texture, color, coarse fragment content), each zone was identified and sampled at the depth given above in a 10×10 cm square and put into a sealed plastic box and transported to the laboratory and air dried.

The lateritic profiles at Jarrahdale are commonly considered to have undergone a long period (ca. 2650 Ma by Brimhall et al. (1994)) of in-situ intense weathering

continued on page 4

## President's Message ... continued from page 1

Website Coordinator and Webmaster, effective 1 October 2012, replacing former coordinator Jamil Sader and former webmaster Andrew Ransom. Thank you, Jamil and Andrew, for your volunteer efforts on running this important means of communication for AAG membership. As I am writing this message, we are in the final testing stages of release of the new AAG website. By the time you read this, the new website will be up and running. Please check it out! Gemma and her husband Dan have put a lot of work into this new web site and it shows. Most of the content had been transferred by Gemma in 2011, but we were stymied in moving forward by the need for specialized programming for the Members Area part of the website. Gemma and Jamil sought help from a website development service and Council approved the expenditure for this now-completed work. Any irregularities found in the new website should be brought to Gemma's attention for remedy.

Finally, I want to encourage AAG Members and Fellows to become more involved in running our organization. Without everyone's volunteer efforts, the various activities of AAG would not move forward. If you have not been active, it is your time to step forward. Members should consider upgrading their membership to Fellow. And Fellows should consider becoming more involved in Council and in serving on committees. We need your help and we need new blood to keep our association vital and relevant. Also, write about your research and project work and submit it to our journal GEEA-Gwendy Hall mentions that we need more content to fill coming issues-or to our newsletter **EXPLORE**, where Beth McClenaghan indicates that we need more industry case studies.

**Bob Eppinger**  
President



## Notes from the Editor

The December 2012 issue of **EXPLORE** features one article by Xin Du, Andrew Rate, Mary Gee that describes chemical speciation of REE related to particle size in a lateritic profile in Western Australia. This being the last issue of **EXPLORE** for the year 2012, **EXPLORE** thanks all contributors to the four issues this year: Steve Amor, Ravi Anand, Betty Arsenault, Chris Benn, Neil Breward, Eion Cameron, David Cohen, Tony Christy, Bob Eppinger, Bob Garrett, Ian Jonasson, Daniel Lamothe, João Larizzatti, Iftikhar Malik, Charles Maurice, Paul Morris, Vern Rampton, Dave Smith, Wendy Spirito, Roger Wallis, Erick Wieland, and Emily Wild. **EXPLORE** thanks the continued support of our six corporate sponsors in 2012: Actlabs, ALS Minerals, Geosoft, Olympus Innov-X, Maxwell Geoservices and SGS, as well as our advertizers.

Sarah Lincoln (**EXPLORE** Business Manager) and I wish all AAG members a safe holiday season and a successful 2013.

**Beth McClenaghan**  
Editor



## TABLE OF CONTENTS

Particle size fractionation and chemical specification of REE in a lateritic weathering profile in Western Australia.....	1
President's Message .....	1
Notes from the Editor.....	2
Calendar of Events.....	15
New AAG Web Site .....	17
News from Regional Councillors - Pakistan .....	17
AAG Distinguished Lecturer, 2013-2014.....	21
University of Ottawa: Introduction to the Physics and Chemistry of Hydrothermal Ore Depositis .....	22
Membership Application.....	23
2012 Student Paper Prize.....	24
AAG Student Support Initiatives.....	25
List of Advertisers.....	27



# CoreViewer™

**Core Box Photos**

**Geochemical Data**

Sample No	Start	End	Au	Ag	As	Bi	Cd	Co	Cu	Fe	Mn	Ni	Pb	Sb	Se	Si	Tl	Zn
Sample 14	79	79	0.187	0.25	2.78	2.5	100	0.25										
Sample 20	79	80	0.148	0.25	3.25	7	40	0.25										
Sample 22	80	83	0.136	0.25	1.83	31	20	0.25										
Sample 23	83	84	0.187	0.25	3.04	9	30	0.25										
Sample 24	86	91	0.213	0.25	2.87	2.5	30	0.25										

**CoreViewer™**

Project: ALS Minerals Test Hole: Demo Hole  
 Core Box: GRAPHICAL ANALYSIS  
 WET\_STRIP - Displaying core segment from: 241.85 to: 245.96  
 Approximate depth: 243.91

- Photo Archival
- Down-Hole Visual with Data
- Fracture Density Record
- On-Line Data Interrogation with Photos

[www.alsglobal.com](http://www.alsglobal.com)

**RIGHT SOLUTIONS RIGHT PARTNER**

Paid Advertisement

# Data Management for Exploration and Mining

Software - Services - Consulting - Auditing - Training

**maxwell**  
GEOSERVICES

[www.maxwellgeoservices.com](http://www.maxwellgeoservices.com)  
[sales@maxwellgeoservices.com](mailto:sales@maxwellgeoservices.com)

Paid Advertisement

## Particle size fractionation and chemical speciation of REE...

continued from page 2

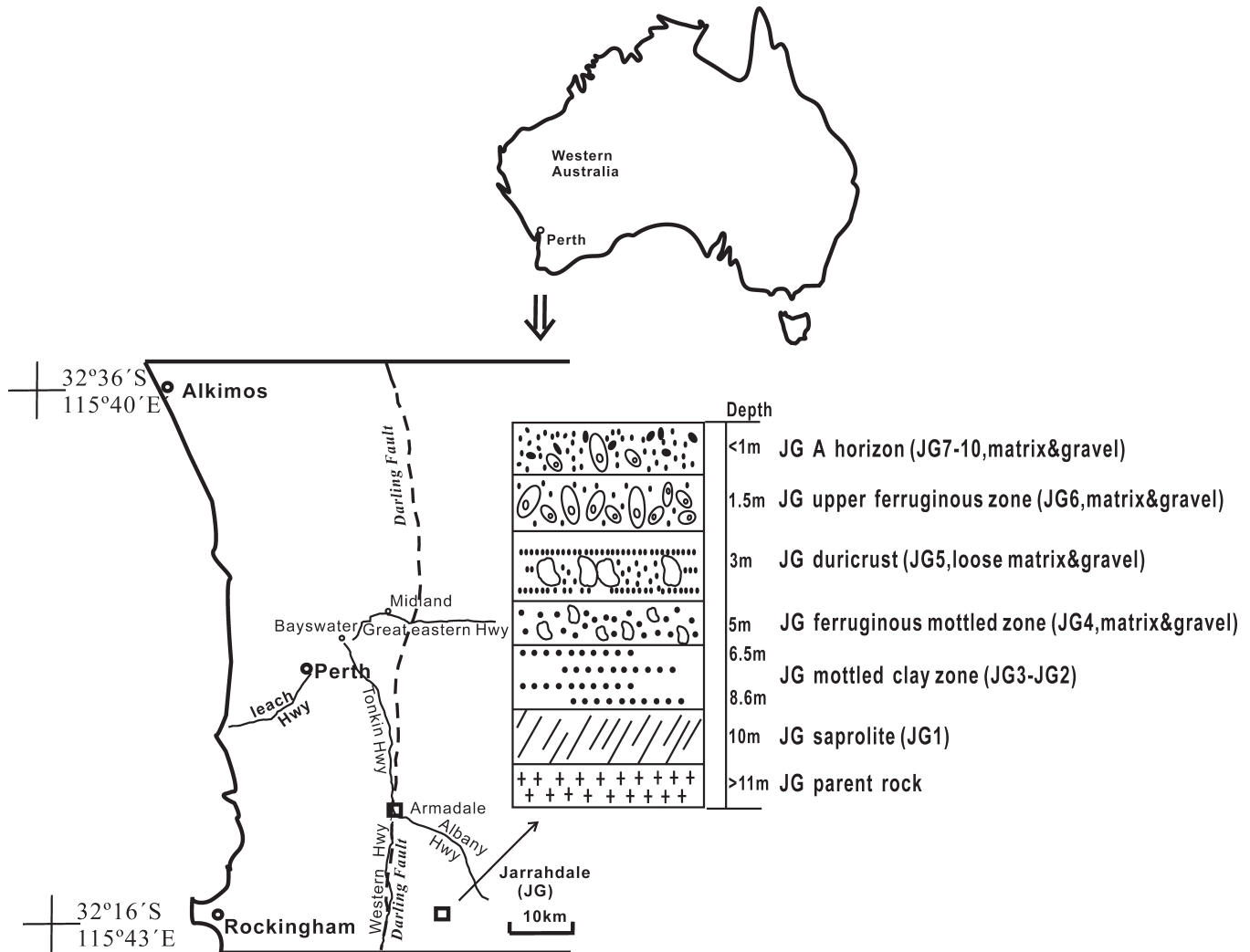


Figure 1 Location of sampling site in Western Australia, showing lateritic regolith profile (JG). The dashed line presents the western margin of the Darling Fault (known as Darling Range, (Gozzard 2007)).

(Sadleir & Gilkes 1976; Anand et al. 1991; Anand & Paine 2002; Anand & Butt 2010). Sadleir & Gilkes (1976) described in detail the lateritic profile at this site and showed significant depletion of Si in the upper part of profile consistent with intense weathering but preservation or enrichment of Al and Fe. The chemical weathering and mineralogy of regolith from lateritic bauxite in the Darling Range have been investigated in a number of studies (e.g. Anand et al. 1991; Anand & Paine 2002; Kew & Gilkes, 2007).

#### Analytical Methods

Pretreatment of the regolith samples included separation and weighing of each part of soil subsamples into a gravel (>2 mm) fraction, represented by 'g' and matrix (<2 mm) fraction, represented by 'm', with the exception of the mottled clay and saprolite, which have only matrix fractions. The fractions of matrix and gravel were oven dried at 105 °C overnight and ground to  $\leq 200 \mu\text{m}$  prior to fusion in order to determine trace element concentrations. The regolith matrix was further separated into the following three size fractions recommended by the International

Society of Soil Science (ISSS) (Prescott et al. 1934; Marshall 1947, 2003): clay (<2  $\mu\text{m}$ ), silt (2-20  $\mu\text{m}$ ) and sand (>20  $\mu\text{m}$ ) using the sedimentation and wet sieving methods (Day, 1965). Different particle size fractions were rinsed with deionized water three times, oven dried at 105 °C overnight and ground to  $\leq 200 \mu\text{m}$  prior to fusion. The matrix fraction (<2 mm) was used to determine the pH and total carbon (Table 1). Soil pH was determined potentiometrically in the supernatant in a 1:5 suspension of soil: deionized water (Rayment & Higginson 1992) and soil total carbon was determined by Elementar (Vario Macro, Hanau, Germany).

To investigate extracted phases and association behavior of trace elements, a sequential extraction procedure was performed. The matrix fraction (< 2 mm) from the saprolite (JG1m), upper mottled clay (JG3m) and ferruginous duricrust (JG5m) were selected. An in-house laboratory reference material was prepared together with selected samples. Regolith trace elements were extracted as five species (modified from Hall et al. 1996): (a) water soluble, adsorbed, and exchangeable and carbonates bound

continued on page 5



## Particle size fractionation and chemical speciation of REE...

continued from page 4

**Table 1** Selected properties of regolith matrix fraction (< 2 mm) from the JG profile.

Sample	Depth (m)	soil pH <sup>1</sup> (H <sub>2</sub> O)	clay% < 2 μm	silt% 2-20 μm	sand% > 20 μm	TC <sup>2</sup> %	Description
JG7	0.02	5.50	8.4	6.8	84.8	6.06	Horizon A
JG8	0.15	5.59	7.0	6.5	86.4	2.19	Horizon A
JG9	0.3	5.54	5.8	6.3	87.9	1.06	Horizon A
JG10	0.4	5.47	6.8	6.5	86.7	0.73	Horizon A
JG6	1.5	5.60	4.3	2.5	93.2	0.47	Upper ferruginous zone
JG5	3.0	5.08	6.5	3.5	90.0	0.30	Ferruginous duricrust
JG4	5.0	4.90	9.0	7.5	83.5	0.20	Ferruginous mottled zone
JG3	6.5	4.55	28.3	7.3	64.4	0.08	Upper mottled clay
JG2	8.6	3.76	29.6	8.5	61.8	0.17	Lower mottled clay
JG1	10.0	3.34	27.0	15.4	57.7	0.27	Saprolite

<sup>1</sup> pH was determined in a 1:5 suspension of soil: deionized water<sup>2</sup> TC refers to total carbon, determined by Elementar, Vario Macro, Hanau, Germany.

(WAE); (b) organic matter and sulphide bound (Org); (c) amorphous Fe-Mn (hydr) oxide bound (Am); (d) crystalline Fe-Mn (hydr)oxide bound (Cry) and (e) residual phase (Res). Since carbonates were unlikely to be present in the regolith being studied here (Anand & Paine 2002) due to low pH, species WAE is considered to include mainly water soluble, adsorbed or exchangeable elements. Sulphides are also scarce in the lateritic regolith, therefore it is assumed that the Org phase is mainly hosted by organic matter complexes. A brief summary of the method is shown in

Table 2. The residual samples and reference materials were rinsed with deionized water three times and oven dried at 105 °C overnight, then were ground to ≤200 μm prior to fusion.

Trace elements, including REE, in 10% HCl dissolved fusion beads were determined by inductively coupled plasma-mass spectroscopy (ICP-MS) by Genalysis Laboratory Services of Intertek Commodities in Maddington, Western Australia. Certified international standard reference material STSD-2, STSD-4 (Canada Centre for Mineral and

Energy Technology, CANMET) and an in-house standard material were prepared in the same way as the routine samples and analyzed together with samples to monitor the accuracy and precision. The variation between tested values and expected values was within 10% of the certified values. The concentrations of REE in different particle size fractions are given in Table 3 with REE chemical species in Table 4.

Polished thin sections of air dried resin-impregnated

continued on page 6




Olympus Innov-X  
 T: +1-781-938-5005  
 F: +1-781-938-0128  
 E: info@innovx.com  
 W: www.innovx.com



"INSTANT GEOCHEMISTRY"  
 Field Portable XRF & XRD Analyzers



## Particle size fractionation and chemical speciation of REE...

continued from page 5

regolith and outcrop samples were prepared and examined using a JEOL JSM-6400 scanning electron microscope (SEM) by means of secondary electron (SE) and backscattering electron (BSE) imaging, equipped with a Link analytic energy dispersive spectrometer (EDS) to determine textures, morphology and phase composition of individual grains at 15kV accelerating voltage with 3 nA beam current. Chemical composition of REE-bearing minerals were analyzed for selected representative mineral grains using a JEOL 8530 electron probe micro-analyzer (EPMA) at 20 kV accelerating voltage and 5

nA beam current. Standard REE-bearing references for microprobe calibration were synthetic glasses 612 from National Institute of Standards and Technology (NIST) and in-house standard synthetic phosphates; standard Brazil monazite was analyzed with samples for cross checking. All microscopy analyses were conducted at the Centre for Microscopy, Characterisation and Analysis (CMCA), University of Western Australia. Detection limits for elements determined by EMPA are listed in Appendix 1.

continued on page 7

**Table 2.** Sequential extraction procedures of REE in lateritic regolith

Step	Speciation	Reagent
a	water soluble, adsorbed, and exchangeable ( <b>WAE</b> )	To 1 g of soil sample, add 20 mL of 1.0M CH <sub>3</sub> COONa (adjust to pH 5 with CH <sub>3</sub> COOH), room temperature (25°C), shake 6h, centrifuge for 15min at 3000 rpm; rinse with 5 mL H <sub>2</sub> O twice, mark 30 mL; repeat.
b	organic matter bound ( <b>Org</b> )	Add 40 mL 0.1M Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> , room temperature (25°C), shake 1h, centrifuge; repeat; rinse with 5 mL H <sub>2</sub> O twice, mark 50 mL; repeat.
c	amorphous Fe (hydr)oxide bound ( <b>Am</b> )	Add 20 mL 0.25M NH <sub>2</sub> OH·HCl in 0.25M HCl, vortex, water bath at 60°C for 2h, centrifuge; rinse with 5 mL H <sub>2</sub> O twice, mark 30 mL; repeat.
d	crystalline Fe (hydr)oxide bound ( <b>Cry</b> )	Add 30 mL 1.0M NH <sub>2</sub> OH·HCl in 25%CH <sub>3</sub> COOH, vortex, water bath at 90°C for 3h, centrifuge; rinse with 10 mL 25% CH <sub>3</sub> COOH twice, mark 50 mL; repeat.
e	residue ( <b>Res</b> )	MilliQ water wash residue three times, oven dry at 60°C. Fuse with 12:22 Norrish flux (Lithium metaborate/ Lithium tetraborate), dilute with 100 mL of 10% HCl.

**Table 3**

sample	d.l.	Element concentrations (ppm)														
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
	d.l.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Saprolite	JG1sand	0.3	0.6	b.d.	0.3	0.2	b.d.	0.1	b.d.	0.1	b.d.	0.1	b.d.	0.2	b.d.	1.0
	JG1silt	1.3	2.3	0.2	0.9	0.3	b.d.	0.3	b.d.	0.3	b.d.	0.3	b.d.	0.5	0.1	2.2
	JG1clay	1.2	2.0	0.2	0.8	0.2	b.d.	0.1	b.d.	0.1	b.d.	0.1	b.d.	0.2	b.d.	0.8
	JG1matrix	1.3	2.4	0.2	1.1	0.3	0.1	0.3	0.0	0.2	0.0	0.2	0.0	0.3	0.1	1.3
Lower mottled clay	JG2sand	3.4	4.6	0.4	1.0	0.3	b.d.	0.2	b.d.	0.2	b.d.	0.2	b.d.	0.3	b.d.	1.3
	JG2silt	12.3	17.3	1.5	4.1	0.9	0.1	0.8	0.1	0.8	0.2	0.7	0.1	1.0	0.2	5.6
	JG2clay	9.1	12.1	1.0	2.4	0.4	b.d.	0.3	b.d.	0.3	b.d.	0.2	b.d.	0.3	b.d.	1.6
	JG2matrix	5.2	7.5	0.6	1.7	0.3	0.1	0.2	0.1	0.3	0.1	0.3	0.1	0.5	0.1	2.1
Upper mottled clay	JG3sand	7.0	9.9	1.0	2.5	0.4	b.d.	0.3	b.d.	0.4	0.1	0.4	b.d.	0.7	0.2	2.9
	JG3silt	27.0	38.2	3.5	9.7	1.7	0.3	1.2	0.2	1.4	0.4	1.1	0.2	1.7	0.3	10.2
	JG3clay	22.6	30.2	2.8	7.7	1.1	0.2	0.8	0.1	0.8	0.2	0.4	b.d.	0.5	0.1	4.0
	JG3matrix	10.5	14.8	1.3	3.6	0.6	0.1	0.5	0.1	0.4	0.1	0.3	0.1	0.4	0.1	2.7
Ferruginous mottled zone	JG4sand	4.5	16.0	0.7	2.0	0.4	b.d.	0.3	b.d.	0.3	b.d.	0.2	b.d.	0.3	b.d.	1.8
	JG4silt	20.2	40.7	3.4	10.8	2.2	0.4	1.7	0.3	1.9	0.5	1.6	0.3	2.2	0.5	12.6
	JG4clay	25.1	40.5	4.6	14.8	2.8	0.5	2.0	0.3	1.7	0.4	1.0	0.2	1.1	0.2	7.8
	JG4matrix	7.8	19.0	1.1	4.3	0.9	0.1	0.7	0.1	0.7	0.2	0.6	0.1	0.7	0.2	4.5
Duricrust	JG4gravel	5.0	107	0.6	1.9	0.3	0.1	0.7	0.0	0.4	0.1	0.2	0.0	0.4	0.1	2.1
	JG5sand	5.7	35.8	0.8	2.4	0.5	b.d.	0.4	b.d.	0.5	b.d.	0.3	b.d.	0.4	b.d.	2.5
	JG5silt	13.8	61.1	2.4	7.7	1.6	0.3	1.1	0.2	1.2	0.3	0.9	0.2	1.2	0.2	7.3
	JG5clay	14.9	63.2	2.9	10.1	2.1	0.4	1.5	0.2	1.3	0.3	0.8	0.1	1.0	0.2	5.8
Upper ferruginous zone	JG5matrix	6.1	37.2	0.9	3.0	0.6	0.1	0.7	0.1	0.5	0.1	0.3	0.1	0.5	0.1	3.2
	JG5gravel	6.0	224	0.7	2.4	0.4	0.1	1.6	0.1	0.4	0.1	0.2	0.0	0.3	0.1	2.0
	JG6sand	7.2	21.9	1.5	5.0	1.1	0.2	1.0	0.2	1.1	0.3	0.8	0.1	0.9	0.2	6.8
	JG6silt	14.6	60.1	3.1	10.3	2.0	0.3	1.8	0.3	2.0	0.5	1.5	0.3	1.8	0.4	13.1
Meta-granitoids	JG6clay	17.2	121	4.3	14.8	2.9	0.6	2.5	0.4	2.2	0.5	1.3	0.2	1.2	0.2	13.1
	JG6matrix	7.8	28.8	1.6	5.7	1.1	0.2	1.3	0.2	1.2	0.3	0.9	0.2	1.1	0.2	7.6
	JG6gravel	7.5	27.0	1.7	6.5	1.4	0.3	1.4	0.2	1.4	0.3	0.9	0.2	1.0	0.2	5.3
	Average PR	27.9	47.4	4.3	14.0	2.1	0.5	1.8	0.2	1.0	0.2	0.8	0.2	1.1	0.2	8.5

Table 3. Concentrations of REE in different particle size fractions in the lateritic JG profile in Western Australia. b.d. refers to values below detection limit; Average PR refers to average value of each REE in parent meta-granitoids.

## Particle size fractionation and chemical speciation of REE...

continued from page 6

$$GSF_{loading} = 100 \times \left( \frac{X_i \times GS_i}{\sum_{i=1}^n X_i \times GS_i} \right)$$

**Calculation of mass loading of REE in particle size fraction**

To index an element's partitioning into different particle size fractions, a mean element mass loading was calculated based on its concentration in a selected grain size of known mass percent (Sutherland 2003).

Where:

$X_i$  is the concentration of REE (ppm) in an individual grain size fraction (e.g. <2  $\mu$ m);

$GS_i$  is the mass percentage of an individual fraction, which has limits of 0-100%.

$GSF_{loading}$  is the element mass loading in a selected grain size and the summation of  $GSF_{loading}$  indices for each soil sample equals 100%.

In the ferruginous zone, four classes of particle sizes (clay, silt, sand and gravel) were defined and three in the mottled clay zone and saprolite (clay, silt and sand). Thus, if the REE concentration for a given fraction is very high but it forms only a small portion of the overall sample mass, the contribution of this fraction to the total sample REE loading will be minimal. The mass loading of each fraction of regolith samples are listed in Table 5.

**Results****Concentrations of REE in different particle size fractions**

In the lateritic profile studied (JG), silt and clay fractions generally contained the highest concentrations of REE, except in the saprolite (Fig. 2). In the ferruginous zone (from JG6 to JG4, 1.5-5 m depth) clay contained the highest concentrations of LREE (from La to Nd), followed by the silt fraction. In the duricrust (3 m depth) and ferruginous mottled zone (5 m depth), however, gravel was abnormally enriched in Ce. Concentrations of LREE in matrix were slightly higher than in sand in the ferruginous zone. In the mottled clay (6.5-8.6 m depth) and saprolite (10 m depth), the relative concentrations of LREE from high to low were: silt > clay > sand. MREE (from Sm to Ho) had different distribution patterns between the particle size fractions. From Sm to Gd, closer to LREE, the highest concentrations were in the clay fraction in the ferruginous zone but in the silt fraction in the mottled clay zone. From Tb to Ho, closer to HREE, silt fraction had the highest concentrations except the duricrust and upper ferruginous zone. HREE (from Er to Lu) and Y, showed mostly consistent distribution patterns. The silt fraction contained the highest concentration of HREE throughout the profile followed by the clay fraction in the ferruginous zone. In the saprolite and mottled clay, both clay and sand fractions had similar HREE concentrations.

continued on page 8

Sample	Element concentrations (ppm)														
	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
d.l.	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
JG1_WAE	0.140	0.290	0.040	0.149	0.032	0.007	0.021	0.003	0.017	0.004	0.013	0.002	0.018	0.003	0.055
JG1_Org	0.008	0.009	0.002	0.006	0.003	b.d.	0.001	b.d.	0.002	b.d.	0.001	b.d.	0.002	b.d.	0.007
JG1_Am	0.016	0.032	0.004	0.013	0.004	b.d.	0.003	b.d.	0.003	b.d.	0.002	b.d.	0.003	b.d.	0.016
JG1_Cry	0.023	0.014	0.001	0.003	0.001	b.d.	0.001	b.d.	0.001	b.d.	b.d.	b.d.	0.001	b.d.	0.007
JG1_Res	1.1	1.9	0.2	0.7	0.2	b.d.	0.2	b.d.	0.2	b.d.	0.2	b.d.	0.3	b.d.	1.3
JG3_WAE	0.938	0.905	0.168	0.531	0.083	0.018	0.086	0.014	0.070	0.016	0.041	0.006	0.031	0.005	0.277
JG3_Org	0.022	0.019	0.004	0.013	0.002	b.d.	0.002	b.d.	0.002	b.d.	0.001	b.d.	0.003	b.d.	0.012
JG3_Am	0.130	0.200	0.028	0.098	0.019	0.004	0.018	0.003	0.016	0.003	0.010	0.002	0.009	0.002	0.098
JG3_Cry	0.053	0.079	0.008	0.028	0.005	b.d.	0.004	b.d.	0.004	b.d.	0.002	b.d.	0.002	b.d.	0.023
JG3_Res	9.2	13.0	1.1	2.8	0.5	b.d.	0.3	b.d.	0.3	b.d.	0.2	b.d.	0.4	0.2	2.0
JG5m_WAE	0.422	2.744	0.149	0.586	0.146	0.031	0.102	0.015	0.073	0.014	0.037	0.005	0.030	0.005	0.164
JG5m_Org	0.031	0.563	0.015	0.058	0.014	0.003	0.009	0.001	0.006	0.001	0.005	0.001	0.012	0.003	0.028
JG5m_Am	0.127	2.553	0.054	0.221	0.060	0.012	0.042	0.007	0.038	0.008	0.020	0.003	0.020	0.003	0.108
JG5m_Cry	0.049	1.450	0.011	0.039	0.010	0.002	0.006	0.001	0.007	0.001	0.004	b.d.	0.004	b.d.	0.027
JG5m_Res	6.0	27.1	0.8	2.5	0.5	b.d.	0.3	b.d.	0.4	b.d.	0.3	b.d.	0.4	b.d.	2.4

**Table 4.** Concentrations of REE in different chemical species of representative regolith in the JG profile in Western Australia. All REE determined in extracted WAE, Org, Am and Cry have 0.001 ppm detection limit whereas in Res (fusion method) have 0.1 ppm detection limit by ICP-MS. b.d. refers to values below detection limit.



Particle size fractionation and chemical speciation of REE...

continued from page 7

**Table 5**

Sample	Mass loading (%)														
	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
JG1sand	24.9	27.9	n.a.	32.8	53.6	n.a.	44.1	n.a.	44.1	n.a.	44.1	n.a.	46.9	n.a.	51.0
JG1silt	28.7	28.5	36.3	26.2	21.4	n.a.	35.3	n.a.	35.3	n.a.	35.3	n.a.	31.2	n.a.	29.9
JG1clay	46.5	43.5	63.7	40.9	25.0	n.a.	20.6	n.a.	20.6	n.a.	20.6	n.a.	21.9	n.a.	19.1
JG2sand	36.0	36.0	36.8	36.8	48.7	n.a.	44.0	n.a.	44.0	n.a.	51.0	n.a.	51.6	n.a.	45.8
JG2silt	18.0	18.7	19.1	20.8	20.2	n.a.	24.3	n.a.	24.3	n.a.	24.6	n.a.	23.7	n.a.	27.2
JG2clay	46.1	45.3	44.1	42.3	31.1	n.a.	31.6	n.a.	31.6	n.a.	24.4	n.a.	24.7	n.a.	27.0
JG3sand	35.0	36.0	36.9	35.8	37.2	n.a.	38.1	n.a.	44.0	42.9	57.1	n.a.	61.2	72.0	49.5
JG3silt	15.2	15.7	15.3	15.7	17.8	27.8	17.2	33.9	17.4	19.4	17.7	n.a.	18.1	12.2	20.0
JG3clay	49.7	48.3	47.8	48.5	45.0	72.2	44.7	66.1	38.7	37.7	25.1	n.a.	20.7	15.8	30.5
JG4sand	34.6	14.6	34.9	32.7	34.9	n.a.	24.6	n.a.	31.1	n.a.	31.2	n.a.	33.4	n.a.	33.1
JG4silt	14.0	3.3	15.2	15.9	17.3	24.0	12.6	28.6	17.7	30.1	22.4	32.9	22.0	39.0	20.9
JG4clay	20.8	4.0	24.7	26.1	26.3	36.0	17.7	34.3	19.0	28.8	16.8	26.3	13.2	18.7	15.5
JG4gravel	30.6	78.1	25.2	25.3	21.5	40.0	45.1	37.2	32.2	41.1	29.6	40.9	31.3	42.3	30.5
JG5sand	43.0	13.6	44.7	41.8	46.2	n.a.	18.9	n.a.	49.1	n.a.	48.5	n.a.	47.7	n.a.	48.0
JG5silt	4.1	0.9	5.2	5.2	5.8	9.4	2.0	8.1	4.6	11.2	5.7	12.9	5.6	9.3	5.5
JG5clay	8.1	1.7	11.7	12.7	14.0	23.3	5.1	15.0	9.2	20.8	9.4	12.0	8.6	17.4	8.1
JG5gravel	44.8	83.8	38.3	40.3	34.0	67.4	74.0	76.9	37.1	68.0	36.5	75.1	38.2	73.3	38.4
JG6sand	15.9	13.6	14.8	13.2	13.4	12.7	12.4	15.3	13.6	17.1	15.3	11.8	15.0	18.1	20.2
JG6silt	0.9	1.0	0.8	0.7	0.7	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.8	1.0	1.0
JG6clay	1.7	3.4	1.9	1.8	1.6	1.7	1.4	1.4	1.2	1.3	1.1	1.1	0.9	0.8	1.8
JG6gravel	81.5	81.9	82.5	84.3	84.4	85.1	85.6	82.7	84.5	80.9	82.8	86.2	83.2	80.1	77.0

Table 5. Mass loading of REE in different particle size fractions in a lateritic profile in Western Australia. n.a. refers to not available since the element concentration was below the detection limit.

Mass loading of REE in different particle size fractions

Given the mass percentage of each particle size, the mass loading of selected REE in each particle size fraction was plotted in Fig. 3. Although silt and clay fractions had the highest concentrations of REE, their relatively low mass percentage compared with other fractions minimized the enrichment.

In the ferruginous zone, gravel dominated the distribution and abundance of Ce, with up to 84% Ce in the duricrust. In the upper ferruginous zone (1.5 m depth), gravel and sand accounted for more than 95% mass of REE, decreasing to ca. 80% in duricrust (3 m depth) and ca. 60% in ferruginous mottled zone (5 m depth). In the duricrust, the mass loading of each REE was higher in the clay fraction than the silt fraction. In the ferruginous

mottled zone, however, REE were fractionated; the mass loadings of LREE and MREE were higher in the clay fraction and the mass loading of HREE higher in the silt fraction.

From the upper mottled clay to the saprolite (JG3-JG1, 6.5-10 m depth), the regolith does not contain gravel. The clay fraction was the most important host for LREE in these zones (6.5-10 m depth), especially in the upper mottled clay zone (6.5 m depth) with ca. 48%-50% LREE was in the clay fraction. Higher mass loadings of HREE (44%-61%), however, were found to be in the sand fraction in the saprolite and mottled clay. The mass loading of REE in the silt fraction increased with depth from upper mottled clay to saprolite.

continued on page 9

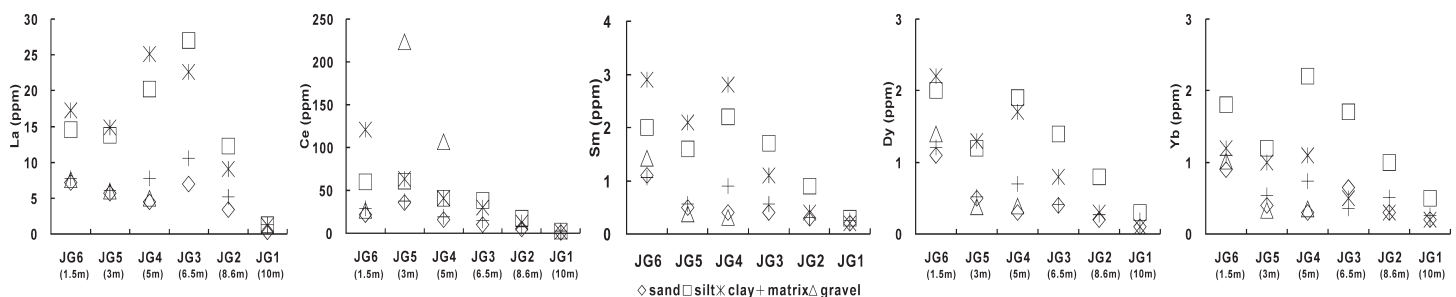
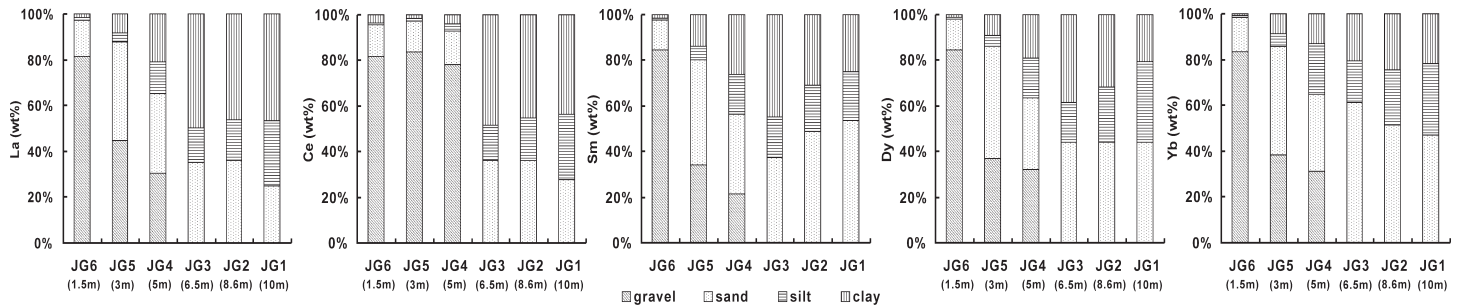


Figure 2. Concentrations of REE in different particle size fractions in the JG profile developed on meta-granitoids in Jarrahdale, Western Australia.



## Particle size fractionation and chemical speciation of REE...

continued from page 8



**Figure 3.** Mass loading of REE in different particle size fractions in the JG profile developed on meta-granitoids in Western Australia (JG6-upper ferruginous zone, 1.5 m depth; JG5-ferruginous duricrust, 3 m depth; JG4-ferruginous mottled zone, 5 m depth; JG3-upper mottled clay, 6.5 m depth; JG2-lower mottled clay zone, 8.6 m depth; JG1-saprolite, 10 m depth. Only selected REE are plotted here; other REE showed similar patterns).

### Speciation of REE from sequential extraction

The sequential extraction experiment revealed the percentages of total REE in each chemical phase of representative lateritic regolith in the JG profile (Fig. 4.) Generally, the total REE distribution percentage followed the order: Res > WAE > Am > Cry and Org. The Res and WAE phases dominated the distribution and abundance of REE, accounting for 89%-98% LREE, 87%-97% MREE and 91%-98% HREE. The saprolite Res had higher percentages of MREE (85%) and HREE (92%) than the upper mottled clay (75% MREE and 88% HREE) and duricrust (66% MREE and 82% HREE) and the percentages decreased from saprolite to duricrust. In addition, the saprolite WAE had higher percentage of LREE (13%) than the upper mottled clay (9%) and duricrust (9%). The percentages of MREE (12%) and HREE (7%) in saprolite WAE were lower than in the WAE of the upper mottled clay (20% MREE and 9% HREE) and duricrust (21% MREE and 9% HREE).

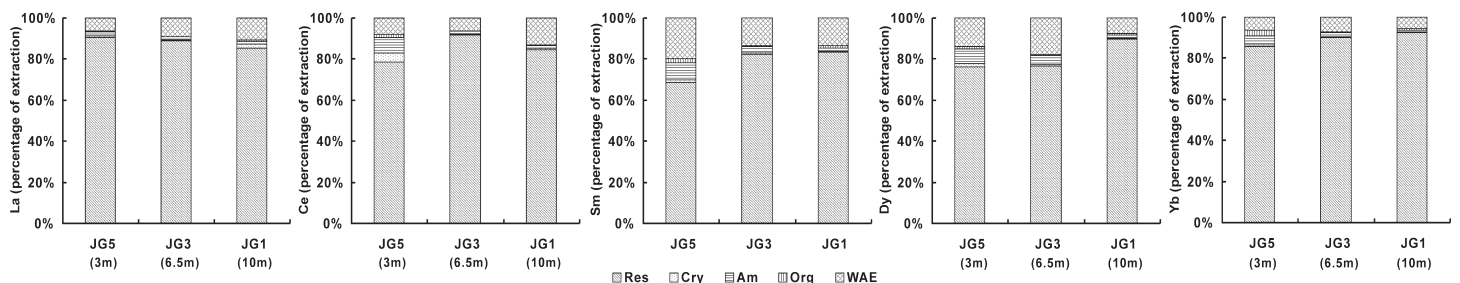
The duricrust Org had higher percentage of total REE (1.5%) than the Org in the saprolite (0.6%) and upper mottled clay (0.2%). The percentages of total REE hosted in the Am phase of the duricrust (6.6%) were also higher than in the Am phases of the saprolite (1.4%) and upper mottled clay (1.7%). Similarly, the Cry phase in the duricrust also had higher percentages of total REE (3.3%) than the total REE percentage in the Cry of saprolite

(0.8%) and upper mottled clay (0.6%). In addition, in the duricrust the percentage of REE in the Am phase (6.6%) was higher than the percentages of REE in the Cry (3.3%) and Org (1.5%) phases.

### Discussion

Although sequential extraction schemes do not extract chemically discrete forms of elements, the data have revealed variation of the REE distribution in different particle size fractions and extracted phases. Most of REE were hosted by the residual phase, indicating that both the abundance and distribution of REE are controlled by mineral phases in intensely weathered regolith. SEM imaging and EPMA analyses show that LREE are mostly hosted by secondary phosphates ca. 2-20  $\mu\text{m}$ -size, e.g. rhabdophane and florencite, and HREE are mainly contained in weathering-resistant minerals of varied grain size (1-100  $\mu\text{m}$ ), e.g. xenotime, zircon and anatase in the lateritic regolith (Fig. 5). The high concentration of REE in the silt fraction (2-20  $\mu\text{m}$ ) is in good agreement with the REE-bearing mineral size in the regolith, especially LREE-rich secondary minerals, indicating morphological and mineralogical change from REE-bearing accessory minerals e.g. apatite, fluorocarbonates and thorite in the parent meta-granitoids to secondary rhabdophane and florencite during intense weathering and lateritization (Fig. 5, Table

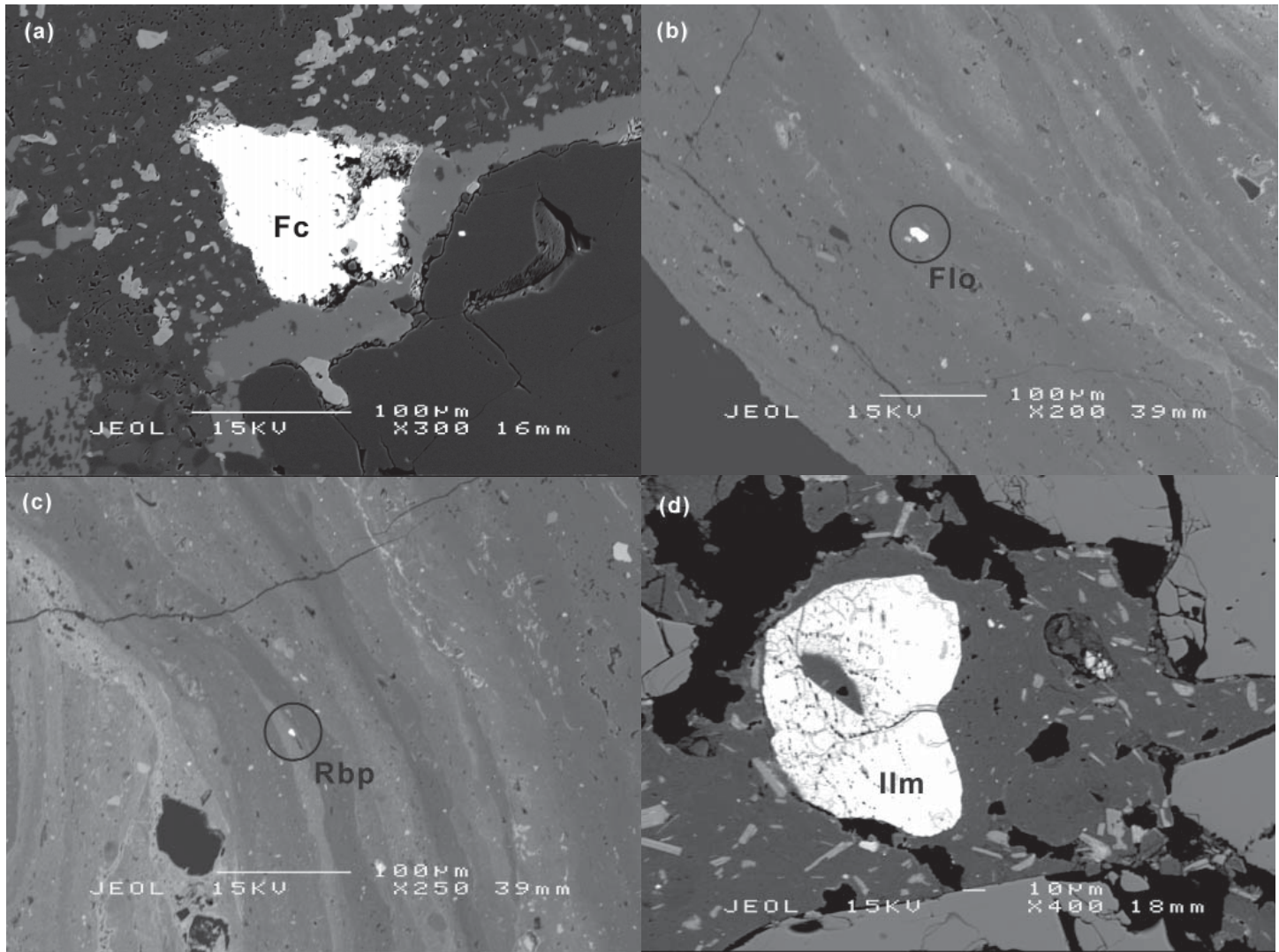
continued on page 10



**Figure 4.** Distribution of total REE among five sequential species of representative JG regolith. (Res: residual; Cry: crystalline Fe (hydr)oxides; Am: amorphous Fe (hydr)oxides; Org: organic matter; WAE: water soluble, adsorbed and exchangeable. JG5-ferruginous duricrust, 3 m depth; JG3-upper mottled clay, 6.5 m depth; JG1-saprolite, 10 m depth. (Some REE concentrations were below the detection limit of ICP-MS and are not presented here).

## Particle size fractionation and chemical speciation of REE...

continued from page 9



**Figure 5.** REE-bearing minerals in weathered lateritic regolith of JG profile: (a) fluorocarbonate in parent meta-granitoids; (b) and (c) secondary minute grains of florencite and rhabdophane respectively in ferruginous nodules; (d) ilmenite with REE in ferruginous mottled zone (elemental analyses of these minerals are listed in Table 6; Fc: REE-rich fluorocarbonate; Flo: florencite; Rbp: rhabdophane; Ilm: ilmenite).

Table 6

Sample Element concentrations (wt%)

Sample	Si	Ti	Pb	Th	U	Al	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Yb	Lu	Fe	Mg	Ca	P	S	F	O	total
a	2.2	0.03	0.23	0.64	0.18	0.44	0.06	20.8	27.7	2.85	5.97	0.52	0.06	0.27	b.d.	b.d.	b.d.	2.96	0.15	2.89	0.02	0.29	6.31	12.9	87.5
b	0.46	0.06	0.13	3.05	0.02	18.5	0.23	8.19	16.8	1.90	1.74	0.59	0.16	0.48	0.04	0.14	b.d.	0.47	b.d.	0.05	7.71	0.06	0.65	31.3	92.1
c	0.08	0.04	0.54	3.93	0.9	b.d.	1.61	11.8	23.2	2.55	9.07	1.58	0.21	1.05	0.45	0.35	0.03	0.45	b.d.	0.24	12.9	b.d.	0.91	26.3	98.3
d	b.d.	31.9	b.d.	b.d.	0.02	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	2.18	b.d.	b.d.	27.7	0.06	b.d.	b.d.	b.d.	b.d.	29.7	91.5

**Table 6.** Concentrations of REE and other elements in mineral phases in parent meta-granitoids and lateritic regolith of a profile in Western Australia, based on electron microprobe spot analyses. Concentrations of Ho, Er, Tm and Tb are below detection limits (b.d.). a, b, c and d represent minerals in Figure 5. a, fluorocarbonate; b, florencite; c, rhabdophane; d, ilmenite.

continued on page 11

Particle size fractionation and chemical speciation of REE...

continued from page 10

6). In addition, in the duricrust an abnormal enrichment of Ce was observed, especially in gravel. It suggests that Ce fractionated from other LREE and less likely to be mobile than the other REE during formation of duricrust and iron nodules. This agrees with high percentages of Ce in the Am and Cry extracted phases in the duricrust.

A significant proportion of REE bound to the WAE phase in natural uncontaminated soils is not common in previous studies and may suggest that a large amount of REE is bio-available in the regolith studied here. High deficiency of REE in the profile, especially in the saprolite, may be partially attributed to low soil pH which favors the conversion of metals from precipitated forms into dissolved forms (Harter 1983; Cao et al. 2001). In an acidic environment, such as this (pH ranges from 3.3 to 4.5 from

saprolite to mottled clay), the predominant REE phase in solution is the free Ln<sup>3+</sup> ion (Ln denotes REE). In the duricrust, REE may also partially occur as LnHCO<sub>3</sub><sup>2+</sup> complexes due to the slightly higher pH (5.1) and organic REE complexes due to relatively higher dissolved organic matter (total carbon 0.30%) than in the mottled clay below (total carbon 0.08%). Extraction of adsorbed or exchangeable REE in a spodosol profile has been reported to be closely related to pH, in the range 4.2 to 6.5 (Land et al. 1999).

In addition, the high proportion of REE bound to the WAE is probably relevant to high concentrations of REE in the clay fraction. Kaolinite and halloysite were identified in the saprolite and mottled clay. The transformation from kaolinite to halloysite during weathering is accompanied

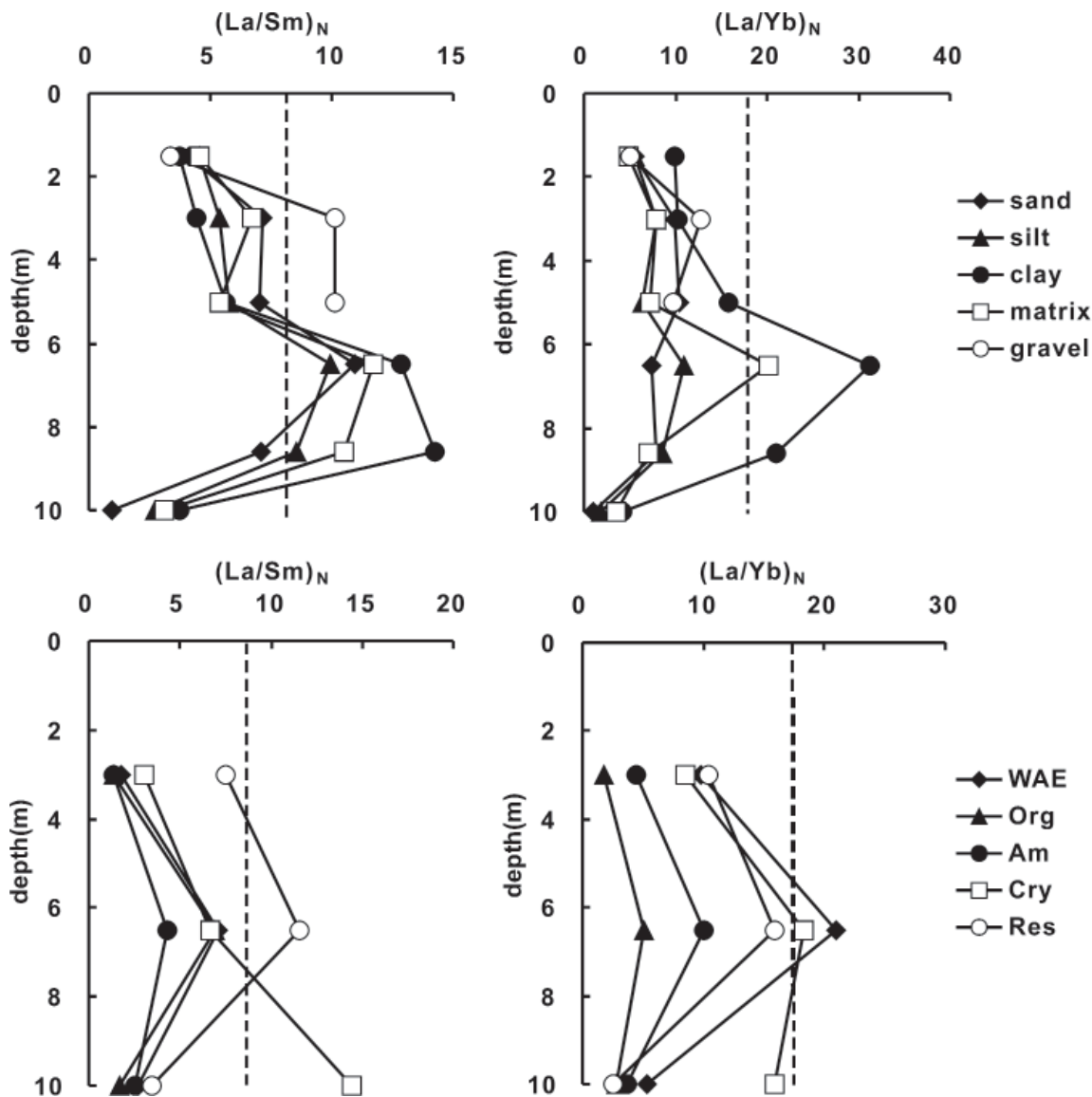


Figure 6. Normalized ratios of (La/Sm)<sub>N</sub> and (La/Yb)<sub>N</sub> in particle size fractions and sequential extracts in the JG profile developed on meta-granitoids in Western Australia (solid vertical lines are the normalized ratios of average parent meta-granitoids; average chondrite values were used as the reference (Anders & Grevesse 1989))



## Particle size fractionation and chemical speciation of REE...

continued from page 11

by an increase in hydration, a decrease in Si/Al ratio and an increasing cation exchange capacity (CEC) (Tari et al. 1999). The clay sized fraction of mottled clay had higher (La/Sm)<sub>N</sub> (12.9-14.3) and (La/Yb)<sub>N</sub> (21.0-31.3), compared with (La/Sm)<sub>N</sub> = 8.4 and (La/Yb)<sub>N</sub> = 17.5 of averaged meta-granitoids (Fig. 6). Chondrite values were used for REE normalization (Anders & Grevesse 1989). These higher ratios of LREE/MREE and LREE/HREE suggest that clay acts an important role in trapping REE, especially LREE. This is also supported by Cullers et al. (1987) who showed that heavy minerals (biotite, hornblende and sphene) in a soil developed from a granitic parent material appeared to be altering and making LREE available to the clay minerals forming in the soil. However, opposite fractionation (HREE more sorbed than LREE) onto kaolinite has also been reported (Coppin et al. 2002). Adsorption of REE by clay is controlled by the nature of the clay minerals, pH, ionic strength, the presence of additional ligands such as carbonate or organic complexes, surface coverage, and effects specific to the characteristics of the different REE (Koeppenkastrop & Decarlo 1992, 1993; Fendorf & Fendorf 1996; Coppin et al. 2002; Piasecki & Sverjensky 2008; Laveuf & Cornu 2009). As well as these controls, differences in clay mineralogy can affect fractionation of REE (Laveuf & Cornu 2009), potentially explaining the contradictory signatures of REE adsorbed by clay minerals. Usually, REE adsorption increases with increasing pH (Coppin et al. 2002), which may explain the increasing concentrations of REE in the WAE and clay fraction from saprolite to duricrust. The lowest values of (La/Sm)<sub>N</sub> (0.9) and (La/Yb)<sub>N</sub> (1.0) in the saprolite sand suggest that La was substantially fractionated from Sm and Yb and greatly depleted from the saprolite, especially in the sand fraction. It is probable that LREE-rich accessory minerals (e.g. fluorocarbonates and thorite), with grain sizes ca. 100 μm, in parent meta-granitoids break down at the initial stage of weathering. In addition, a high mass of HREE is observed in sand from saprolite to upper mottled clay, in contrast to most of LREE being present in clay in these zones. This may suggest that relatively large-grained (ca. 100 μm) and weathering-resistant minerals, e.g. zircon, anatase or ilmenite contained significant amounts of HREE, or, alternatively, HREE may be adsorbed onto larger-grained metal-oxide surfaces, e.g. rutile, hematite (Piasecki & Sverjensky 2008).

The Am and Cry had higher percentages of LREE and MREE than HREE throughout the regolith studied. In the duricrust the Am phase had a preference for MREE whereas the Cry showed a preference for LREE. Since there are negligible variations in complexation constants for the acetate ligand with various REE (Wood 1993), the fractionation in extraction of the Cry is not caused by the extractant solution (Land et al. 1999) in which the only other solute is NH<sub>2</sub>OH·HCl. The reasons why Am and Cry phases show different preferences for LREE and MREE is not clear, but are believed to be related to pH and the presence of other ligands such as organic complexes (Quinn

et al. 2006; Piasecki & Sverjensky 2008). The fractionation between LREE, MREE and HREE in Fe- (hydr)oxides is subject to debate (Laveuf & Cornu 2009) and varied fractionation with enrichments of LREE (Koeppenkastrop & Decarlo 1993), MREE (Bau 1999; Land et al. 1999) or HREE (Elderfield & Greaves 1981; Marker & Deoliveira 1994) have been observed. For example, Land et al. (1999), studying a spodosol profile, observed an enrichment of MREE in the Am and a clear HREE enrichment relative to the LREE in Cry and Org phases. The differences in REE fractionation between extracted phases probably also arise from the various proportions of the different types of Fe- and Mn oxides present (Laveuf & Cornu 2009). The affinity of Ce with Fe (hydr)oxides indicates surface sorption and oxidation/coprecipitation of Ce onto Fe (hydr)oxides, which have been examined by many authors (Davranche et al. 2004; Bau & Koschinsky 2009; Nedel et al. 2010). The Org phase plays an important role in complexing HREE in this study, especially in the duricrust in contrast to the Am which have a preference for MREE. Affinity of HREE for organic materials has been observed before (Land et al. 1999; Aubert et al. 2004). Organic ligands form complexes with HREE which are more stable than those with LREE (Henderson, 1984; Sonke & Salters, 2006). The proportion of total REE hosted by the Am is higher than both Org and Cry phases, indicating amorphous Fe (hydr)oxide plays a more important role than other solid components in controlling the mobility and bioavailability of REE in lateritic regolith.

### Conclusions

A systematic study of particle size fractionation and chemical fractionation of REE in a lateritic weathered profile developed on meta-granitoids in Jarrahdale, Western Australia showed that most of the REE (by mass) had partitioned into coarse-grained material (gravel and sand), despite the high concentrations in fine-grained (silt and clay) fractions. This partitioning by grain size was not consistent, however, across the REE series, with significant fractionation occurring. For example, in the lower profile most LREE mass was in the clay (<2 μm) fraction, but most HREE were associated with sand (>20 μm). The most significant fractionation of REE was shown by a strong Ce anomaly in ferruginous duricrust, consistent with formation of both ferruginous materials and the Ce enrichment by oxidative processes such as precipitation of ferric minerals. Particle size, sequential extraction, and electron microprobe data were consistent with REE occurrence being dominated, in intensely weathered regolith, by mineral phases resistant to weathering. The dominance of residual forms in sequential extracts supported this conclusion, but the existence of significant REE in water soluble, exchangeable or adsorbed forms was surprising and was likely to be related to the low pH of regolith materials. This study demonstrates that the distribution and fractionation of REE within different particle size

continued on page 13

## Particle size fractionation and chemical speciation of REE...

continued from page 12

fractions and chemically extractable species can be used as clues for better understanding geochemical behavior of REE in intensely weathered lateritic profiles. Both have potential implication for pedological interpretation of the fractionation of REE during weathering and lateritization, especially when a particle size sorting process is involved.

### Acknowledgements

This work was financially supported by the Association of Applied Geochemists (AAG) through its Student In-kind Support Grant, the University of Western Australia and the China Scholarship Council. We are thankful to R. Pearce, T. Quinn and M. Smirk for their analytical expertise. We also thank P. Duncan, J. R. Muhling, and D. Adams of the Centre for Microscopy, Characterisation and Analysis (CMCA) for microscopy and microanalysis. Special thanks are addressed to E. Weiland and J. Flynn for coordination the analyses. Ryan Noble is thanked for his constructive comments of the manuscript. The manuscript has been benefited from the editorial guidance of B. McClenaghan.

### References

- ACOSTA, J. A., CANO, A. F., AROCENA, J. M., DEBELA, F. & MARTÍNEZ-MARTÍNEZ, S. 2009. Distribution of metals in soil particle size fractions and its implication to risk assessment of playgrounds in Murcia City (Spain). *Geoderma*, 149, 101-109.
- AL-RAJHI, M. A., ALSHAYEB, S. M., SEAWARD, M. R. D. & EDWARDS, H. G. M. 1996. Particle size effect for metal pollution analysis of atmospherically deposited dust. *Atmospheric Environment*, 30, 145-153.
- ANAND, R. R., GILKES, R. J. & ROACH, G. I. D. 1991. Geochemical and mineralogical characteristics of bauxites, Darling Range, Western Australia. *Applied Geochemistry*, 6, 233-248.
- ANAND, R. R. & PAINE, M. 2002. Regolith geology of the Yilgarn Craton, Western Australia: implications for exploration. *Australian Journal of Earth Sciences*, 49, 3-162.
- ANAND, R. R. & BUTT, C. R. M. 2010. A guide for mineral exploration through the regolith in the Yilgarn Craton, Western Australia. *Australian Journal of Earth Sciences*, 57, 1015-1114.
- ANDERS, E. & GREVESSE, N. 1989. Abundances of the elements-meteoritic and solar. *Geochimica et Cosmochimica Acta*, 53, 197-214.
- AUBERT, D., PROBST, A. & STILLE, P. 2004. Distribution and origin of major and trace elements (particularly REE, U and Th) into labile and residual phases in an acid soil profile (Vosges Mountains, France). *Applied Geochemistry*, 19, 899-916.
- BAU, M. 1999. Scavenging of dissolved yttrium and rare earths by precipitating iron oxyhydroxide: Experimental evidence for Ce oxidation, Y-Ho fractionation, and lanthanide tetrad effect. *Geochimica et Cosmochimica Acta*, 63, 67-77.
- BAU, M. & KOSCHINSKY, A. 2009. Oxidative scavenging of cerium on hydrous Fe oxide: Evidence from the distribution of rare earth elements and yttrium between Fe oxides and Mn oxides in hydrogenetic ferromanganese crusts. *Geochemical Journal*, 43, 37-47.
- BRIMHALL, G.H., COMPOSTON, W., WILLIAMS, I.S., REINFRANK, R.F. & LEWIS, C.J. 1994. Darwinian zircons as provenance tracers in dust-size exotic components in laterites: mass balance and SHRIMP ion microprobe results, in: Ringrosevoase, A.J., Humphreys, G.S. (eds.), *Soil Micromorphology: Studies in Management and Genesis*. Developments in Soil Science, 65-81.
- CAO, X. D., WANG, X. R. & ZHAO, G. W. 2000. Assessment of the bioavailability of rare earth elements in soils by chemical fractionation and multiple regression analysis. *Chemosphere*, 40, 23-28.
- CAO, X. D., CHEN, Y., WANG, X. R. & DENG, X. H. 2001. Effects of redox potential and pH value on the release of rare earth elements from soil. *Chemosphere*, 44, 655-661.
- CASPARI, T., BAUMLER, R., NORBU, C., TSHERING, K. & BAILLIE, I. 2006. Geochemical investigation of soils developed in different lithologies in Bhutan, Eastern Himalayas. *Geoderma*, 136, 436-458.
- COPPIN, F., BERGER, G., BAUER, A., CASTET, S. & LOUBET, M. 2002. Sorption of lanthanides on smectite and kaolinite. *Chemical Geology*, 182, 57-68.
- CULLERS, R. L., BARRETT, T., CARLSON, R. & ROBINSON, B. 1987. Rare-earth element and mineralogical changes in holocene soil and stream sediment-a case study in the wet mountains, Colorado, USA. *Chemical Geology*, 63, 275-297.
- DAVRANCHE, M., POURRET, O., GRUAU, G. & DIA, A. 2004. Impact of humate complexation on the adsorption of REE onto Fe oxyhydroxide. *Journal of Colloid and Interface Science*, 277, 271-279.
- DAY, P. R. 1965. Particle fraction standard particle size analysis, Madison, American Society of Agronomy.
- ELDERFIELD, H. & GREAVES, M. J. 1981. Negative cerium anomalies in the Rare-earth element patterns of oceanic ferromanganese nodules. *Earth and Planetary Science Letters*, 55, 163-170.
- FENDORF, S. & FENDORF, M. 1996. Sorption mechanisms of lanthanum on oxide minerals. *Clays and Clay Minerals*, 44, 220-227.
- GOZZARD, J. R., 2007. Geology and landforms of the Perth Region. *Western Australia Geological Survey*, Perth.
- HALL, G. E. M., VAIVE, J. E., BEER, R. & HOASHI, M. 1996. Selective leaches revisited, with emphasis on the amorphous Fe oxyhydroxide phase extraction. *Journal of Geochemical Exploration*, 56, 59-78.
- HARTER, R. D. 1983. Effect of soil-pH on adsorption of lead, copper, zinc, and nickel. *Soil Science Society of America Journal*, 47, 47-51.
- HENDERSON, P. 1984. Rare earth element geochemistry,

continued on page 14

## Particle size fractionation and chemical speciation of REE...

continued from page 13

- Amsterdam, Elsevier Science Publishers.
- KEW, G. A. & GILKES, R. J. 2007. Properties of regolith beneath lateritic bauxite in the Darling Range of south Western Australia. *Australian Journal of Soil Research*, 45, 164-181.
- KOEPPEKASTROP, D. & DECARLO, E. H. 1992. Sorption of rare-earth elements from seawater onto synthetic mineral particles-an experimental approach. *Chemical Geology*, 95, 251-263.
- KOEPPEKASTROP, D. & DECARLO, E. H. 1993. Uptake of rare-earth elements from solution by metal-oxides. *Environmental Science & Technology*, 27, 1796-1802.
- LAND, M., OHLANDER, B., INGRI, J. & THUNBERG, J. 1999. Solid speciation and fractionation of rare earth elements in a spodosol profile from northern Sweden as revealed by sequential extraction. *Chemical Geology*, 160, 121-138.
- LAVEUF, C. & CORNU, S. 2009. A review on the potentiality of rare earth elements to trace pedogenetic processes. *Geoderma*, 154, 1-12.
- LJUNG, K., SELINUS, O., OTABBONG, E. & BERGLUND, M. 2006. Metal and arsenic distribution in soil particle sizes relevant to soil ingestion by children. *Applied Geochemistry*, 21, 1613-1624.
- MARKER, A. & DEOLIVEIRA, J. J. 1994. Climatic and morphological control of rare-earth element distribution in weathering mantles on alkaline rocks. *Catena*, 21, 179-193.
- MARSHALL, T.J., 1947. Mechanical composition of soil in relation to field descriptions of texture. Council for Scientific and Industrial Research, Australia.
- MARSHALL, T.J., 2003. Particle-size distribution of soil and the perception of texture. *Australian Journal of Soil Research*, 41, 245-249.
- NEDEL, S., DIDERIKSEN, K., CHRISTIANSEN, B. C., BOVET, N. & STIPP, S. L. S. 2010. Uptake and release of Cerium during Fe-oxide formation and transformation in Fe(II) solutions. *Environmental Science & Technology*, 44, 4493-4498.
- PIASECKI, W. & SVERJENSKY, D. A. 2008. Speciation of adsorbed yttrium and rare earth elements on oxide surfaces. *Geochimica et Cosmochimica Acta*, 72, 3964-3979.
- PRESCOTT, J. A., TAYLOR, J. K. & MARSHALL, T. J., 1934. The relationship between the mechanical composition of the soil and the estimate of texture in the field. Transaction 1st Commission International Society of Soil Science.
- QUINN, K. A., BYRNE, R. H. & SCHIJF, J. 2006. Sorption of yttrium and rare earth elements by amorphous ferric hydroxide: Influence of solution complexation with carbonate. *Geochimica et Cosmochimica Acta*, 70, 4151-4165.
- RAYMENT, G. E. & HIGGINSON, F. R. 1992. Australian laboratory handbook of soil and water chemical methods. Melbourne, Inkata Press.
- SADLEIR, S. B. & GILKES, R. J. 1976. Development of bauxite in relation to parent material near Jarrahdale, Western Australia. *Journal of the Geological Society of Australia*, 23, 333-344.
- SONKE, J. E. & SALTERS, V. J. M. 2006. Lanthanide-humic substances complexation. I. Experimental evidence for a lanthanide contraction effect. *Geochimica Et Cosmochimica Acta*, 70, 1495-1506.
- SUTHERLAND, R. A. 2003. Lead in grain size fractions of road-deposited sediment. *Environmental Pollution*, 121, 229-237.
- TARI, G., BOBOS, I., GOMES, C. S. F. & FERREIRA, J. M. F. 1999. Modification of surface charge properties during kaolinite to halloysite-7Å transformation. *Journal of Colloid and Interface Science*, 210, 360-366.
- WANG, X.-S., QIN, Y. & CHEN, Y.-K. 2006. Heavy metals in urban roadside soils, part 1: effect of particle size fractions on heavy metals partitioning. *Environmental Geology*, 50, 1061-1066.
- WOOD, S. A. 1993. The aqueous geochemistry of the rare-earth elements: critical stability constants for complexes with simple carboxylic acids at 25°C and 1 bar and their application to nuclear waste management. *Engineering Geology*, 34, 229-259.

**Xin Du\***, Andrew W. Rate, M.A. Mary Gee

School of Earth and Environment

University of Western Australia,

Crawley, 6009, WA, Australia

Email: dux01@student.uwa.edu.au

\*School of Environmental Studies

China University of Geosciences

430074, Wuhan, China

**Appendix 1:** Detection limits for elements determined by EMPA: a) fluorocarbonate; b) florencite; c) rhabdophane; d) ilmenite.

Sample Detection limit (wt%)

Sample	Si	Ti	Pb	Th	U	Al	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Yb	Lu	Fe	Mg	Ca	P	S	F
a	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.04	0.04	0.03	0.04	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.07
b	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.03	0.03	0.03	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.10
c	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.04	0.04	0.03	0.04	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.08
d	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.04	0.03	0.05	0.01	0.02	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.12







## 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](http://www.appliedgeochemists.org)  
<<http://www.appliedgeochemists.org>>

8-14 January 2013. 24th Colloquium of African Geology (CAG24). Addis Ababa, Ethiopia. Website: [www.cag24.org](http://www.cag24.org). et

16-19 January 2013. Granulites & Granulites 2013. Hyderabad, India. Website: <http://ggindia2013.com>

28-31 January 2013. Mineral Exploration Roundup 2013. Vancouver BC, Canada. Website: <http://tinyurl.com/cvt4jng>

10-15 February 2013. 2013 European Winter Conference on Plasma Spectrochemistry. Krakow, Poland. Website: [www.chemia.uj.edu.pl/ewcps](http://www.chemia.uj.edu.pl/ewcps)

16-23 February 2013. Introduction to the Physics and Chemistry of Hydrothermal Ore Deposits. Ottawa ON Canada. Website: [www.earth.uottawa.ca/short-course.html](http://www.earth.uottawa.ca/short-course.html)

3-6 March 2013. Prospectors and Developers Association of Canada Annual Convention. Toronto ON, Canada. Website: [www.pdac.ca/pdac/conv/index.aspx](http://www.pdac.ca/pdac/conv/index.aspx)

3-6 March 2013. Environmental Health 2013. Boston MA USA. Website: [www.environmentalhealthconference.com](http://www.environmentalhealthconference.com)

3-8 March 2013. Iron Biogeochemistry - From Molecular Processes to Global Cycles. Ascona, Switzerland. Website: [www.bayceer.uni-bayreuth.de/fimin/conference/](http://www.bayceer.uni-bayreuth.de/fimin/conference/)

13-15 March 2013. IsoG2013 — Environmental geochemistry - methods, trends, questions. Warsaw, Poland. Website: [www.ing.pan.pl/IsoG2013](http://www.ing.pan.pl/IsoG2013)

18-22 March 2013. 44th Lunar and Planetary Science Conference. Pasadena CA, USA. Website: [www.lpi.usra.edu/meetings/lpsc2013](http://www.lpi.usra.edu/meetings/lpsc2013)

27-29 March 2013. Volcanism, Impacts, and Mass Extinctions: Causes & Effects. London, UK. Website: <http://massextinction.princeton.edu>

7-12 April 2013. European Geosciences Union General Assembly. Vienna, Austria. Website: [www.egu2013.eu](http://www.egu2013.eu)

23-25 April 2013. 7th International Conference on the Impact of Environmental Factors on Health. Budapest, Hungary. Website: <http://tinyurl.com/cf2yp73>

*continued on page 16*



CANADA  
MEXICO  
CHILE  
BRAZIL  
ARGENTINA  
ECUADOR  
PERU  
GUYANA  
VENEZUELA  
TURKEY



### ROCKLABS

WORLD LEADERS IN SAMPLE PREPARATION EQUIPMENT AND REFERENCE MATERIALS FOR USE IN GOLD ASSAYING



Quality Reference Material complies with ASTM E 1831-96 and affordable for use on an every batch basis.

Used in over 90 countries and available in 2.5Kg jars and 30g, 50g, 100g sachets for laboratories and exploration geologists.

We also offer technical support for choosing the RM and statistically analyzing results.

[www.rocklabs.com](http://www.rocklabs.com)

Rocklabs Ltd, 157-161 Neilson Street, PO Box 18-142, Auckland, New Zealand  
Ph: 0064 9 634 7696; Fax: 0064 9 634 6896; e-mail: [sales@rocklabs.com](mailto:sales@rocklabs.com)



## AcmeLabs

ASSAYING & GEOCHEMICAL ANALYSIS

**New Vancouver Shipping Address**

1020 Cordova Street East, Vancouver, BC Canada V6A 4A3

Phone 604 253 3158 Fax 604 253 1716

Email [acmeinfo@acmelab.com](mailto:acmeinfo@acmelab.com)

# WWW.ACMELAB.COM



## CALENDAR OF EVENTS

*continued from page 15*

24-28 April 2013. Basalt 2013 - Cenozoic Magmatism in Central Europe. Goerlitz, Germany. Website: <http://tinyurl.com/cybv74v>

5-8 May 2013. Canadian Institute of Mining, Metallurgy, and Petroleum 2013 Conference & Exhibition. Toronto ON, Canada. Website: <http://web.cim.org/toronto2013beta>

12-16 May 2013. 13th European Workshop on Modern Developments & Applications in Microbeam Analysis. Porto, Portugal. Website: <http://tinyurl.com/8jp48zr>

19-22 May 2013. AAPG 2013 Annual Convention & Exhibition. Pittsburgh PA, USA. Website: [www.aapg.org/pittsburgh2013](http://www.aapg.org/pittsburgh2013)

22-24 May 2013. Geological Association of Canada/ Mineralogical Association of Canada Annual Meeting. Winnipeg MB Canada. Website: <http://gacmacwinnipeg2013.ca>

26 May – 2 Jun 2013. PEG 2013: Sixth International Symposium on Granitic Pegmatite. Bartlett NH USA. Website: <http://tinyurl.com/8b5fhnu>

9-14 June 2013. Water-Rock Interaction XIV Symposium. Avignon, France. Website : [www.wri14-2013.fr](http://www.wri14-2013.fr)

16-20 June 2013. 12th International Conference on the Biogeochemistry of Trace Elements. Athens GA USA. Website: <http://tinyurl.com/ca39d7g>

17-19 June 2013. Mineralogical Society Annual Meeting: Minerals for Life. Edinburgh UK. Website: [www.minersoc.org/minerals-for-life.html](http://www.minersoc.org/minerals-for-life.html)

17-20 June 2013. Conference on Mathematical and Computational Issues in the Geosciences. Padova, Italy. Website: [www.siam.org/meetings/gsl3/](http://www.siam.org/meetings/gsl3/)

30 June – 4 July 2013. 12th International Estuarine Biogeochemistry Symposium. Plymouth, UK. Website: [www.iebs2013.org](http://www.iebs2013.org)

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

10-13 July 2013. 11th International Congress of Applied Mineralogy. Mianyang China. Website: [www.icam2013.org/](http://www.icam2013.org/)

28 July-2 August 2013. 11th International Conference on Mercury as a Global Pollutant Edinburgh UK. Website: [www.mercury2013.com](http://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](http://www.microprobe.org/events)

*continued on page 17*

## A rock solid reputation for absolute accuracy

Since 1982, Becquerel Laboratories has been meeting the analytical requirements of clients in the geological and mineral exploration sector.

Our company is a world leader in Neutron Activation Analysis (NAA). An ultra-sensitive technique, NAA is an ideal quality control procedure to complement and verify results from other analytical techniques. It provides cost-effective, timely analysis and one simple method can analyze over 30 separate elements.

For absolute accuracy, trust the analytical expertise of Becquerel Laboratories.

For more information call 905-826-3080  
or visit [www.becquerellabs.com](http://www.becquerellabs.com)



\*Accredited to ISO 17025 by the Standards Council of Canada as a testing laboratory for specific tests.

**Becquerel**  
LABORATORIES

6790 Kitimat Road, Unit 4  
Mississauga, Ontario  
Canada L5N 5L9

absolute accuracy



**African Mineral Standards**  
web: [www.amis.co.za](http://www.amis.co.za) e-mail: [info@amis.co.za](mailto:info@amis.co.za)

**MATRIX MATCHED REFERENCE MATERIALS, INDEPENDENTLY CERTIFIED**



**tested by laboratories  
around the world**

Economic elements, major elements, trace elements, noble metals, base metals, energy elements, platinum, gold, copper, nickel, uranium, iron, vanadium etc.

**SEE OUR WEBSITE FOR DETAILS**

A division of Set Point Industrial Technology (Pty) Ltd



## CALENDAR OF EVENTS

*continued from page 16*

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

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

25-30 August 2013. Goldschmidt 2013. Florence, Italy. Website: [www.goldschmidt.info/2013](http://www.goldschmidt.info/2013)

2-10 September 2013. 10th International Eclogite Conference. Courmayeur, Italy. Website: [www.iec2013.unito.it/](http://www.iec2013.unito.it/)

24-27 September 2013. SEG Conference: Geoscience for Discovery. Whistler BC, Canada. Website: [www.seg2013.org](http://www.seg2013.org)

27-30 October 2013. GSA 2013 Annual Meeting. Denver CO USA. Website: [www.geosociety.org/meetings/2013](http://www.geosociety.org/meetings/2013)

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](http://www.gns.cri.nz/iags)

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

**Steve Amor**

*Geological Survey of Newfoundland and Labrador*

*P.O. Box 8700, St. John's NL Canada. A1B 4J6*

*Email: [StephenAmor@gov.nl.ca](mailto:StephenAmor@gov.nl.ca) 709-729-1161*



The Association of Applied Geochemists

### New AAG Web Site

The Association of Applied Geochemists has a new and improved website: [www.appliedgeochemists.org](http://www.appliedgeochemists.org). This new website is easier to navigate, has increased functionality, improved security measures, and highlights the work of the AAG and its members.

To obtain access to the 'Members Area', all AAG members are required to log in to the new AAG web site and establish a new password. Please follow these instructions:

1. Go to [www.appliedgeochemists.org](http://www.appliedgeochemists.org)
2. On the left hand side of the web page under 'Member Login', click "forgot password"
3. The next screen should ask for an email address. Enter your email address that is associated with your AAG membership.
4. Go to your email inbox and you will receive an email with verification code to choose a new password. Please follow the instructions in this email. In most cases, your username will consist of the **first letter** in your first name and last name (all one word and lowercase) as in this example for the name Betty Arsenault "barseneault".

If you come across any problems, non-functioning links, typographical errors, have any questions about the new website, or have content additions (such as for What's New), please direct these to our new webmaster, Gemma Bonham-Carter, at [webmaster@appliedgeochemists.org](mailto:webmaster@appliedgeochemists.org).



### News from AAG Regional Councillors — Pakistan

The University of Peshawar's National Centre of Excellence in Geology (NCEG; see <http://www.upesh.edu.pk/academics/researchcenter/nceg/nceg.html>) has recently completed a synthesis of the entire available geochemical dataset for gold and base metals in northern Pakistan covering a period of two decades (1992-2012). During this period, more than 5,000 samples have been analyzed by various agencies, such as the Pakistan Mineral Development Corporation (PMDC), the Sarhad Development Authority (SDA) and even international bodies like MINORCO. The entire dataset was scanned, digitized and stored in a GIS database. The database also includes satellite imagery, digital elevation model data, and other related information. From this, the NCEG has identified six target areas for further gold and base metal studies: (1) Bagrot Valley, (2) Golo Das, (3) Machulu Valley, (4) Shigri Bala, (5) Ranthak and (6) Chapursan Valley (see map). According to the NCEG, these areas may hold potential for gold mineralization.

*continued on page 18*



**Association of Applied Geochemists Student Membership \$10 US**

**Encourage a student to join!**



News from AAG Regional Councillors... continued from page 17

On the basis of above studies, a joint National Academies of Science funded program has been started with Houston University (see <http://www.geosc.uh.edu/features/geos-nsm/gold-prospecting.php>). Three field trips

were conducted in the northern areas of Pakistan in 2011 (see photograph). The first fieldtrip was conducted by the University of Peshawar group in April. During this trip, 30 water samples, 30 sediment samples and 25 blood, 25

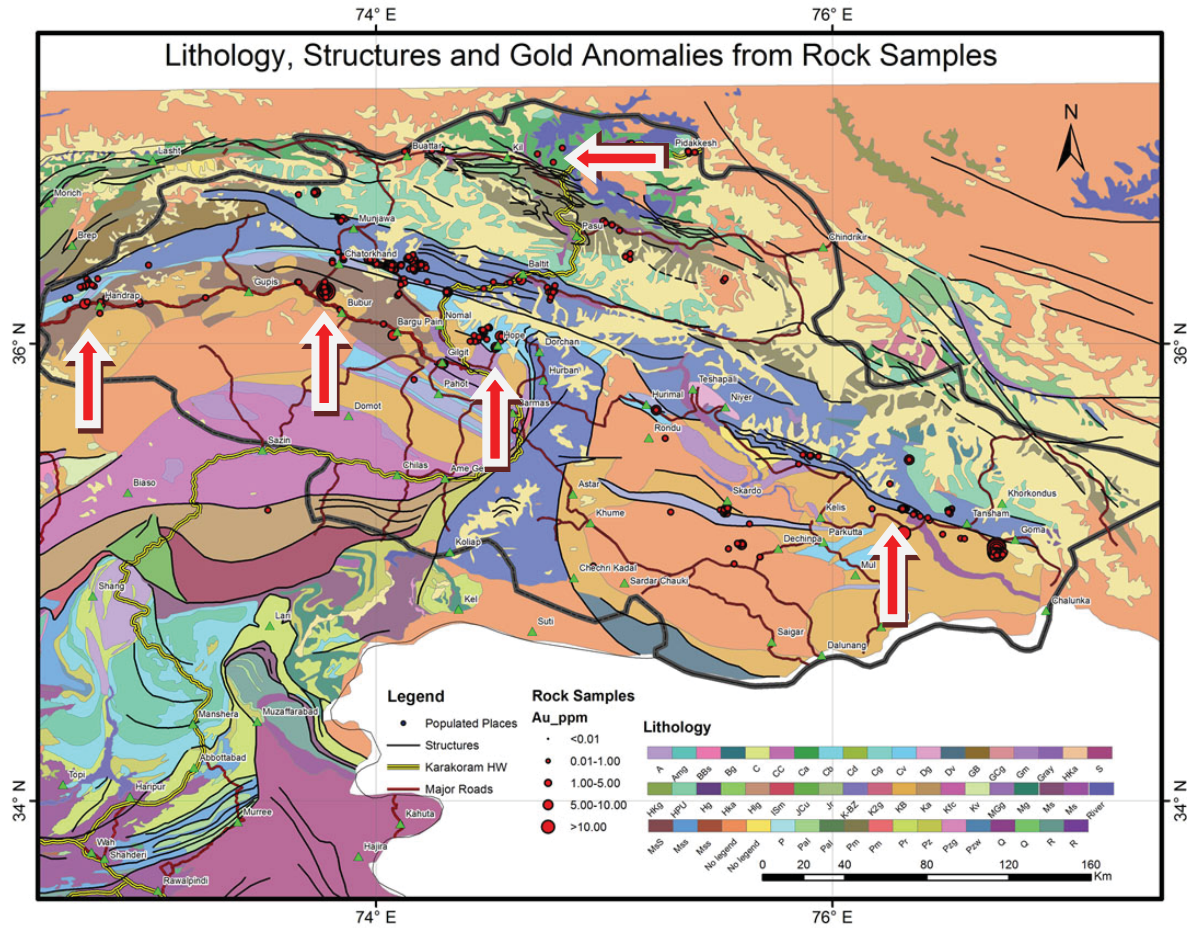


Figure 1: Geological map of northern Pakistan (after Searle & Khan, 1996, Oxford University) showing concentration of gold in rock samples, locations are indicated by arrows.



Figure 2: Sluicing of gold along the Gilgitriver in Gilgit area, north Pakistan by the local gold wاهر



Figure 3: Extraction of gold by mercury amalgamation process by the local gold washer along Gilgitriver in Gilgit area, north Pakistan.

continued on page 19



## News from AAG Regional Councillors... *continued from page 18*



*Figure 4: Taking blood of the local gold washer who usually carries out the mercury amalgamation for gold extraction.*

urine and 25 nail samples from the gold panners and their family members were collected along the Gilgit River. During the second field campaign in June, the University of Houston group collected 40 water and 37 sediment samples along Indus, Gilgit and Hunza Rivers. The third field campaign was conducted in July by the University

of Peshawar group, which collected more than 120 rock samples in four of the six identified target areas, the Bargot Valley, Golo Das, Machulu Valley and Shigri Bala areas. Currently, water and sediment samples are being analyzed at the University of Houston, while rock samples are being cut and pulverized at the University of Peshawar. About 90 thin sections were prepared for petrographic studies. Representative samples were selected for geochemical studies after proper splitting of the pulverized samples. Currently the University of Peshawar group has started laboratory work on these representative samples. About 90 rock chips have been shipped to the University of Houston for geochemical and spectral analyses. In parallel to this, remote sensing analysis is helping identify alteration zones that could contain gold. The project includes training Pakistani scientists in remotely sensed image processing and trace element geochemistry. The area's gold panners will also be trained in safer, more efficient methods of panning, which reduce mercury pollution of river and ground water. Prof Dr Tahir Shah of NCEG, University of Peshawar, is acknowledged for providing the above information.

**Iftikhar A. Malik**

([malik.iftikhar@gmail.com](mailto:malik.iftikhar@gmail.com))

AAB (pvt) Ltd Islamabad



*Prof Dr Tahir Shah flanked by graduate students Mr Laeiq Ahmad and Ms Sadaf Miandad of NCEG, University of Peshawar, during field work in the Bargot Valley*





Sampling a fumerol; White Island, New Zealand

# 26th International Applied Geochemistry Symposium, incorporating the New Zealand Geothermal Workshop

18-21 November, 2013  
Rotorua, New Zealand

[www.gns.cri.nz/iags](http://www.gns.cri.nz/iags) for  
First Circular & information on

- Technical programme
- Short courses
- Field trips
- Partner activities





## AAG Distinguished Lecturer 2013-2014

Dr. Ravi Anand, Chief Research Scientist at CSIRO Earth Science and Resource Engineering in Western Australia is the Association of Applied Geochemists' Distinguished Lecturer for 2013-2014. He has planned a round-the-world trip in February/March of 2013 to deliver the following talks:

- Understanding anomaly formation through transported cover: field and experimental approaches
- Regolith-landscape processes and evolution and their implications to mineral exploration
- Role of palaeoclimates, mineralogy and geochemistry in forming anomalies on interfaces in areas of deep basin cover—implications for exploration
- How supergene laterite gold deposits form—new insights into anomaly formation processes
- Mineral hosts for Au and trace elements in regolith
- Global-scale comparison of laterite and ferricrete forming processes in deeply weathered terrains of world and their implications to geochemical exploration
- Origin of ferruginous pisoliths in terrestrial environments—success in mineral exploration and clues to life on Mars



Contact Ravi directly for more information about his schedule.

Email: [ravi.anand@csiro.au](mailto:ravi.anand@csiro.au)



## Activation Laboratories Ltd.

Quality Analysis . . . Innovative Technologies



Actlabs is committed to bringing the most modern technologies and a higher level of competencies to the analytical laboratory for the mineral industry. We are continuously expanding existing facilities and opening new facilities as we strive to meet the needs of our customers.

State-of-the-art instrumentation allows us to offer services unavailable at other laboratories. We have developed the only robotic fusion system in the world to allow for rapid analysis of REE samples. We are also the first and only organization within North America to have a Field Emission Gun Scanning Electron Microscope (FEG-SEM)-FEI Quanta 650 with two EDX detectors and MLA quantitation software.

Activation Laboratories Ltd.

1336 Sandhill Drive Ancaster, Ontario L9G 4V5

Tel: (905) 648-9611 Fax: (905) 648-9613

[ancaster@actlabs.com](mailto:ancaster@actlabs.com) [www.actlabs.com](http://www.actlabs.com)



CANADA • AUSTRALIA • CHILE • MEXICO • VENEZUELA • PANAMA • GUYANA • COLOMBIA • GREENLAND • MONGOLIA • NAMIBIA • BURKINA FASO



uOttawa



## Introduction to the Physics and Chemistry of Hydrothermal Ore Deposits

February 16-23, 2013, Ottawa

- **A Practical Guide to the Ore Elements**  
*Feb. 16 & 17 (Sat-Sun)*
- **Physics and Chemistry of Ore Fluids**  
*Feb. 18 & 19 (Mon-Tue)*
- **Processes of Hydrothermal Alteration**  
*Feb. 20 & 21 (Wed-Thu)*
- **Fluids in Porphyry, Epithermal, and VMS**  
*Feb. 22 & 23 (Fri-Sat)*

*Thomas Monecke* (Colorado School of Mines)

*Steve Ingebritsen* (U.S. Geological Survey)

*Mark Hannington* (University of Ottawa)

*Iain Samson* (University of Windsor)

*Dan Kontak* (Laurentian University)

*Louis Cabri* (Cabri Consulting Inc.)

Fee: \$50 per session for students (\$75 after December 14).  
\$500 per session for professionals. Includes lunches,  
reception, and course notes. Credits applicable to grad  
programs/professional development where permitted.

Registration begins October 15, 2012. Contact [icsr@uottawa.ca](mailto:icsr@uottawa.ca)

**Association of Applied Geochemists**  
**APPLICATION FOR MEMBERSHIP\***



Please complete only the relevant section for membership. See below for mailing instructions.

I, \_\_\_\_\_, wish to apply for election as a \_\_\_Member / \_\_\_Student Member of the Association of Applied Geochemists. I have read the Code of Ethics of the Association and in the event of being elected a Member/ Student Member agree to honour and abide by them.

**MEMBER:** *State Employer and Employee title*

I am actively engaged in scientific or technological work related to applied geochemistry exploration and have been so for the past two years.

\_\_\_\_\_ as a \_\_\_\_\_  
(employer) (employment title)

**STUDENT MEMBER:** *Student status must be verified by a Professor of your institution or a Fellow of the AAG*

I certify that the applicant is a full-time student at \_\_\_\_\_ in pure or applied science.  
(institution)

\_\_\_\_\_  
(Professor/ AAG Fellow Signature) (Printed Name and Title)

Witness my hand this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_\_.  
(Signature of applicant)

**NAME AND ADDRESS:** PLEASE PRINT (to be completed by applicant)

Name: \_\_\_\_\_ Telephone bus: \_\_\_\_\_  
Address: \_\_\_\_\_ fax: \_\_\_\_\_  
\_\_\_\_\_ home: \_\_\_\_\_  
\_\_\_\_\_ e-mail: \_\_\_\_\_

**Annual Dues :**

All applications must be accompanied by annual dues . All payments must be in US funds. Select one of the four listed below.

1	2013 member dues	US\$	100	_____
2	2013 student member dues		10	_____
	- If receipt required, include a self-addressed envelope and add		2	_____
	- If your check is not drawn from a U.S.A. or Canadian bank, add		15	_____
	<b>TOTAL</b>			_____

Payment by check, International Money Order, UNESCO Coupons, International Postal Orders, VISA, American Express and Master Card are acceptable. For credit cards users, minor variations in your billing may reflect currency exchange rate fluctuations at time of bank transaction.

Type: VISA \_\_\_ American Express \_\_\_ Master Card \_\_\_ Credit card account number: \_\_\_\_\_  
Exp. date: \_\_\_\_\_ Name: \_\_\_\_\_ Signature: \_\_\_\_\_

**\*Application for voting membership (Fellow) requires the sponsorship of three voting members. Request a voting member application from the Association office.**

**Please note:** Your application form will be acknowledged upon receipt. The Admissions Committee reviews all applications and submits recommendations to Council, who will review these recommendations at the next Council Meeting or by correspondence. If no objection is raised the names, addresses and positions of candidates will be listed in the next issue of the AAG Newsletter. If after a minimum of 60 days have elapsed following submission of candidate information to the membership no signed letters objecting to candidates admission are received by the Secretary of the Association from any Member, the Candidate shall be deemed elected, subject to the receipt by the Association of payment of required dues. Send completed application, together with annual dues to:

*Association of Applied Geochemists*

**P.O. Box 26099, 72 Robertson Road, Ottawa, Ontario, CANADA K2H 9R0**

TEL: (613) 828-0199, FAX: (613) 828-9288, email: office@appliedgeochemists.org WEBSITE: http://www.appliedgeochemists.org



# The Association of Applied Geochemists

announces the

## 2012 AAG Student Paper Competition

The logo for SGS (Société Générale de Services) features the letters 'SGS' in a bold, grey, sans-serif font. A vertical orange line is positioned to the right of the 'S', and a horizontal orange line is positioned below the 'S'.

The AAG announces the 9th biennial Student Paper Competition. The paper must address an aspect of exploration geochemistry or environmental geochemistry related to mineral exploration and be based on research performed as a student.

The student must be the principal author and the paper must have been published in *Geochemistry: Exploration, Environment, Analysis* no more than three years after completion of the degree. All eligible papers in 2011 and 2012 volumes of *GEEA* will be reviewed by the selection panel.

The winner will receive:

- A cash prize of \$1000CAD generously donated by SGS Minerals Services;
- A 2-year membership of AAG, including the society's journal (*GEEA*); *EXPLORE* newsletter, publication of an abstract and CV of the winner;
- a certificate of recognition; and
- \$500US towards expenses to attend an AAG-sponsored meeting, courtesy of AAG.

The results of the 2012 competition will be announced at the 26th IAGS in Rotorua, New Zealand. Details are available from the Chair of the committee or the AAG Students' page (<http://www.appliedgeochemists.org/>).

David Cohen  
Chair, Student Paper Competition  
School of BEES  
The University of New South Wales  
UNSW NSW 2052 Australia  
Email: [d.cohen@unsw.edu.au](mailto:d.cohen@unsw.edu.au)

## **AAG Student Support Initiative**

### **In-kind Analytical Support for BSc (Hons), MSc and PhD Students**

In 2011, AAG began the process of implementing a coordinated program with analytical laboratories to provide In-Kind Student Support for applied geochemical research projects under the direction of AAG President Paul Morris. I am proud to announce that this program is officially underway. Laboratories have generously signed on to provide the In-Kind support in the form of laboratory analysis (see list of laboratories below that have signed up as of December 2011). The commitment by these laboratories is over \$35,000 in terms of analytical support. Additionally, AAG's Education Committee awarded its first applicant (Ms. Xin Du from University of Western Australia) with laboratory analyses that will be performed by Genalysis / Intertek in their Western Australia facility.

### Investment in Applied Geochemistry

As an investment in the future, the AAG wishes to encourage and support students whose area of study is Applied Geochemistry. AAG believes that by identifying appropriate students, using a set of simple criteria, and coordinating with analytical laboratories that are willing to offer in-kind support in terms of geochemical analyses, high quality research and training in fundamental geochemical principles can result.

### Today's students are tomorrow's clients

The Association of Applied Geochemists (AAG) invites analytical laboratories to participate in pairing their analytical facilities with student projects to develop emerging geochemists and their science.

### Laboratories Participating in the In-Kind Student Support Initiative

As of December 2011 AAG has enrolled four (4) analytical laboratories in this program:

- Becquerel Laboratories Inc., Mississauga, Ontario, Canada
- ALS Laboratory, 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 ([ErickWeiland@Terra-Technology.com](mailto:ErickWeiland@Terra-Technology.com) or [Erick\\_Weiland@fmi.com](mailto:Erick_Weiland@fmi.com)), 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 page under the In-Kind Student Support link.

**Erick Weiland**, Chair  
AAG Education Committee





# 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](http://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

Newsletter No. 157

DECEMBER 2012

Editor: Beth McClenaghan ([beth.mcclenaghan@NRCan-RNCAN.gc.ca](mailto:beth.mcclenaghan@NRCan-RNCAN.gc.ca))

Business Manager:

Sarah Lincoln, 1 (720) 881-6980 ([SARAH.LINCOLN@MMG.COM](mailto:SARAH.LINCOLN@MMG.COM))Back Issues contact: Betty Arseneault ([office@appliedgeochemists.org](mailto:office@appliedgeochemists.org))

EXPLORE is published quarterly by the Association of Applied Geochemists, P.O. Box 26099, 72 Robertson Road, Ottawa, ON Canada K2H 9R0.

EXPLORE is a trademark of the Association of Applied Geochemists.

Type and layout of EXPLORE: Vivian Heggie, Heggie Enterprises, Thornton, CO (303) 288-6540; [vmheggie@comcast.net](mailto:vmheggie@comcast.net)

## ADVERTISING RATES

Full page (Black & White)	241h x 190w mm	(9.5h x 7.5w in)	US \$ 970
Full page (Color)			US\$1165
Half page (Black & White)	241h x 89w mm	(9.5h x 3.5w in)	US \$ 530
or	124h x 190w mm	(4-7/8h x 7.5w in)	
Half page (Color)			US \$635
Third page (Black & White)	241h x 51w mm	(9.5h x 2w in)	US \$420
or	178h x 89w mm	(7h x 3.5w in)	
Third page (Color)			US \$505
Quarter page (B&W)	124h x 89w mm	(4-7/8h x 3.5w in)	US \$300
or	241h x 41w mm	(9.5h x 1-5/8w in)	
Quarter page (Color)			US \$360
Eighth page (Black & White)	60h x 89w mm	(2-3/8h x 3.5w in)	US \$190
Eighth page (Color)			US \$230
Business Card (B&W)	51h x 89w mm	(2h x 3.5w in)	US \$ 50
Business Card (Color)			US \$ 60

Please direct advertising inquiries to:

SARAH A. LINCOLN, MMG MINERALS AND METALS GROUP •  
390 Union Boulevard, Suite 200, Lakewood, CO 80228 USA

TEL: +1 (720) 881-6980 ([SARAH.LINCOLN@MMG.COM](mailto:SARAH.LINCOLN@MMG.COM))

## EXPLORE Publication Schedule

Quarterly newsletters in March, June, September, December

Deadlines for submission of articles or advertisements:

March newsletter: January 15

June newsletter: April 15

September newsletter: July 15

December newsletter: October 15

## Information for Contributors

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.geolosc.org.uk/template.cfm?name=geea\\_instructions\\_for\\_authors](http://www.geolosc.org.uk/template.cfm?name=geea_instructions_for_authors)

Submissions should be sent to:

Beth McClenaghan, Geological Survey of Canada, 601 Booth Street, Ottawa, ON, CANADA K1A 0E8 Email: [beth.mcclenaghan@NRCan-RNCAN.gc.ca](mailto:beth.mcclenaghan@NRCan-RNCAN.gc.ca)

## THE ASSOCIATION OF APPLIED GEOCHEMISTS

P.O. Box 26099, 72 Robertson Road, Ottawa,  
Ontario K2H 9R0 CANADA • Telephone (613) 828-0199  
[www.appliedgeochemists.org](http://www.appliedgeochemists.org)

### OFFICERS

January - December 2012

**Robert G. Eppinger**, *President*  
U.S. Geological Survey  
P.O. Box 25046, MS 973  
Denver, CO 80225  
USA  
TEL: (303) 236-2468  
email: [eppinger@usgs.gov](mailto:eppinger@usgs.gov)

**Matt Leybourne**, *Vice-President*  
ALS Global Minerals  
2103 Dollarton Hwy  
North Vancouver, BC V7H 0A7  
Canada  
TEL: (604) 998-0515  
email: [Matthew.Leybourne@alsglobal.com](mailto:Matthew.Leybourne@alsglobal.com)

**David B. Smith**, *Secretary*  
U.S. Geological Survey  
Box 25046, MS 973  
Denver, CO 80225, USA  
TEL: (303) 236-1849  
FAX: (303) 236-3200  
email: [dsmith@usgs.gov](mailto:dsmith@usgs.gov)

**Gwendy E.M. Hall**, *Treasurer*  
Geological Survey of Canada  
601 Booth Street, Room 561  
Ottawa, ON K1A 0E8, CANADA  
TEL: (613) 992-6425  
FAX: (613) 992-6425  
email: [ghall@nrcan.gc.ca](mailto:ghall@nrcan.gc.ca)

### COUNCILLORS

2011-2012	Councillor Emeritus	2012-2013
John Carranza	Sherman Marsh	Alejandro Arauz
Patrice de Caritat		Rob Bowell
Matt Leybourne		Bill Burstow
Romy Matthies		Bruno Lemiere
Cliff Stanley		Ryan Noble
Erick Weiland		Todd Wakefield
<i>Brazil</i>	<i>Northern Europe</i>	<i>Southern Africa</i>
Joao Larizzatti	Perti Sarala	Theo Davies
<i>Chile</i>	<i>Southern Europe</i>	<i>UK and Republic of Ireland</i>
Brian Townley	Benedetto De Vivo	Neil Breward
<i>China</i>	<i>Southeast Asia</i>	
Xueqiu Wang	Iftikar Malik	

### AAG COMMITTEES

<b>New Membership</b> Nigel Radford, <a href="mailto:Nigel.Radford@newmont.com">Nigel.Radford@newmont.com</a>	<b>Education</b> Erick Weiland, <a href="mailto:ErickWeiland@Terra-Technology.com">ErickWeiland@Terra-Technology.com</a> Eric Grunsky, <a href="mailto:Eric.Grunsky@NRCan-RNCAN.gc.ca">Eric.Grunsky@NRCan-RNCAN.gc.ca</a> Ryan Noble, <a href="mailto:Ryan.Noble@csiro.au">Ryan.Noble@csiro.au</a> Ray Lett, <a href="mailto:Raylett@Shaw.ca">Raylett@Shaw.ca</a>
<b>Admissions</b> Nigel Radford, <a href="mailto:Nigel.Radford@newmont.com">Nigel.Radford@newmont.com</a>	Nigel Radford, <a href="mailto:Nigel.Radford@newmont.com">Nigel.Radford@newmont.com</a>
<b>Awards and Medals</b> Paul Morris, <a href="mailto:paul.morris@dmp.wa.gov.au">paul.morris@dmp.wa.gov.au</a> Eion Cameron Chris Benn Perti Sarala	Nigel Radford, <a href="mailto:Nigel.Radford@newmont.com">Nigel.Radford@newmont.com</a>
	<b>Symposia</b> David Cohen, <a href="mailto:d.cohen@unsw.edu.au">d.cohen@unsw.edu.au</a>

### AAG COORDINATORS

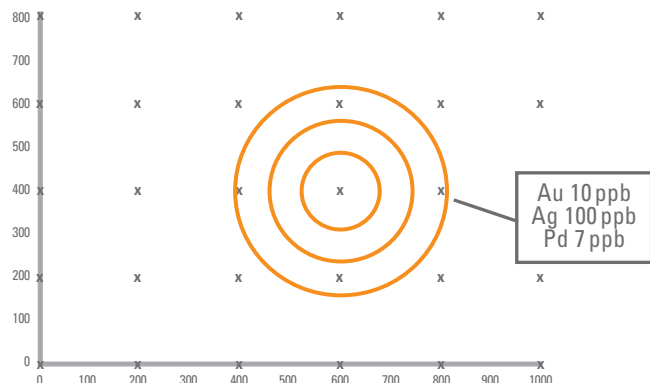
<b>AAG Student Paper Prize</b> David Cohen, <a href="mailto:d.cohen@unsw.edu.au">d.cohen@unsw.edu.au</a>	<b>EXPLORE</b> Beth McClenaghan, <a href="mailto:beth.mcclenaghan@NRCan-RNCAN.gc.ca">beth.mcclenaghan@NRCan-RNCAN.gc.ca</a>
<b>AAG Website</b> Gemma Bonham-Carter, <a href="mailto:webmaster@appliedgeochemists.org">webmaster@appliedgeochemists.org</a>	<b>ELEMENTS</b> Patrice de Caritat, <a href="mailto:Patrice.deCaritat@ga.gov.au">Patrice.deCaritat@ga.gov.au</a>
<b>Geoscience Councils</b> David Cohen, <a href="mailto:d.cohen@unsw.edu.au">d.cohen@unsw.edu.au</a>	<b>AAG Regional Councillors</b> Matt Leybourne, <a href="mailto:Mathew.Leybourne@alsglobal.com">Mathew.Leybourne@alsglobal.com</a>
<b>GEEA</b> Gwendy Hall, <a href="mailto:Gwendy.Hall@NRCan-RNCAN.gc.ca">Gwendy.Hall@NRCan-RNCAN.gc.ca</a>	

**Betty Arseneault**, *Business Manager*  
P.O. Box 26099, 72 Robertson Road, Ottawa, ON K2H 9R0 CANADA,  
TEL: (613) 828-0199 FAX: (613) 828-9288,  
e-mail: [office@appliedgeochemists.org](mailto:office@appliedgeochemists.org)

## LIST OF ADVERTISERS

Acme Analytical Laboratories, Ltd. ....	15	Maxwell Geoservices.....	3
Activation Laboratories Ltd.....	21	Olympus Innovx.....	5
ALS.....	3	Rocklabs.....	15
AMIS.....	16	SGS.....	28
Becquerel Laboratories, Inc.....	16	26th IAGS Symposium 2013 .....	20
IO Stipend.....	26		

# TARGET SUCCESS



NOW EXCLUSIVELY AVAILABLE AT SGS

# WITH MMI GEOCHEMISTRY

**Mobile Metal Ion (MMI) geochemistry** measures the mobile ions that accumulate in soil above mineralization. MMI is used successfully to reduce the cost of definition drilling programs and locate many deeply buried deposits, with few false positives. MMI geochemistry is now **exclusively** available at **SGS** laboratories.

**SGS IS THE WORLD'S LEADING INSPECTION, VERIFICATION, TESTING AND CERTIFICATION COMPANY**

ca.min@sgs.com www.sgs.com/geochem

WHEN YOU NEED TO BE SURE



Paid Advertisement

## EXPLORE

*Newsletter for The Association of Applied Geochemists*

Please send changes of address to: Association of Applied Geochemists  
P.O. Box 26099, 72 Robertson Road, Nepean, Ontario, K2H 9R0, Canada · TEL: (613) 828-0199 FAX: (613) 828-9288  
e-mail: office@appliedgeochemists.org • http://www.appliedgeochemists.org