President's Message

David Cohen

As I complete my two year term as President of the Association of Applied Geochemists I take this opportunity to thank all those who have contributed in so many ways to the activities of the AAG and reflect on our future.

Reviewing the message by my esteemed predecessor, Rob Bowell, when handing over the presidency at the end of 2007, I note that most of the key contributors to our Association have continued in those roles during these last two years. I have received tremendous support from the incumbents of the four critical offices within the Association. David Smith has continued to deliver great service as Secretary, ensuring our meetings operate efficiently and keeping track of the many organisational tasks such as the Council elections. Gwendy Hall has continued to achieve much for the Association in the highly demanding dual roles of Editor-in-Chief of GEEA and the AAG Treasurer. GEEA continues to gain in status and impact – both of which are crucial to attracting high quality papers. Eion Cameron has maintained our investments with great wisdom and expertise, ensuring that potential losses during the recent financial crisis were minimized. Beth McClenaghan has ensured **EXPLORE** continues to be a very high quality and interesting news-letter which, along with GEEA and the website, is crucial to the marketing and profile of AAG. All four contribute large slabs of their time to these roles and we are indebted to them for this work.

I thank the other members of Council as well as the many AAG members who contribute their time to various activities – symposia, web site, bibliography, student paper competition, distinguished lecturer, medals, etc. I acknowledge those who must dial into Council meetings in the wee hours of the morning. I also thank our corporate sponsors who take out ads in **EXPLORE** and booths at symposia.

It has been an interesting couple of years for the minerals industry. While it fared better than other sectors, uncertainty in commodity prices and markets has dampened (though certainly not extinguished) exploration activity for various metals. Gold continues to shine. On the academic front, science is gaining popularity with students and the earth sciences are benefitting from these gains. It is becoming clearer to students that the earth sciences (especially geochemistry) provide an interesting and rewarding sphere of study (intellectually and financially) and an important discipline to throw into the cross-disciplinary mix when addressing issues as diverse as climate change to the evolution of life.

The Association has completed a two-year cycle with a very successful 24th IAGS (and thanks again to Dave Lentz for chairing the organising committee), and various other educational activities. While the meeting held in Fredericton saw a number of "new faces" presenting papers and posters, we must renew efforts to attract a new generation of geochemists into the AAG. We must continue to expand our geochemical orbit and to further develop strategic linkages with kindred societies and organisations, while still preserving our distinctive contribution to research and education in applied geochemistry relating to mineral resources and associated environmental issues.

I am sure that the AAG will continue to grow under the current Vice-president, Paul Morris, who succeeds me as President in 2010. I look forward to catching up with many AAG members at the next IAGS in Finland in 2011, if not before.

David Cohen
President, AAG

Europium-rich dark monazite – a potential new ore mineral for Alaska, USA?

Introduction

Mineralogical drainage surveys carried out between 2004 and 2008 in the Taylor Mountains quadrangle, Alaska, USA, have identified three areas containing a distinctive dark monazite in panned stream sediment concentrate samples. Similar dark monazite of unknown or limited extent has been observed in sediments from elsewhere in Alaska (12 occurrences), France, Taiwan, Zaire and Russia (Rosenblum & Mosier 1983). Systematic mineral identification of panned concentrate samples by R. Tripp led to the discovery of dark gray to black, pellet-like, crystalline monazite grains collected from streams draining sedimentary rocks in the eastern quarter of the quadrangle (Fig. 1). A few sites at the western edge of the quadrangle also contained dark monazite in concentrate samples.

Figure 1a: Location of the Taylor Mountains quadrangle, Alaska, USA with adjoining portions of Lake Clark and Dillingham quadrangles;

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The Taylor Mountains quadrangle is largely underlain by Cretaceous flysch sequences that overlap several older terranes (Miller et al. 2004). Much of the flysch in the quadrangle had previously been assigned to the Upper Cretaceous Kuskokwim Group; however, newer mapping may indicate that the flysch includes multiple, genetically unrelated units. Late Cretaceous to early Tertiary igneous rocks (Sleitat Mountain) intrude the flysch and this is where the central study area (TA559) of this report is located, as shown on Figure 1. Well- developed hornfels consisting of metasiltstone, metasandstone, and metashale surrounds Sleitat Mountain. Cordierite, corundum and sillimanite were collectively found in concentrate from streams draining the hornfels around Sleitat Mountain and several other igneous intrusions. In contrast, andalusite and dark monazite were observed in almost every concentrate sample, suggestive of low-grade regional metamorphism of the flysch in the eastern quarter of the quadrangle.

Sample Collection and Laboratory Analysis Methods

Heavy-mineral concentrate samples collected primarily from first-order and second-order streams (as determined from the 1:63, 360 - scale quadrangle maps) consisted of numerous grab samples along a 9 to 30 m length of an active stream channel. The grab samples were composited into a single 3 to 4 kg sample and screened in the field with a 2.0 mm (10-mesh) stainless steel screen to remove the coarse material. The <2.0 mm fraction then was panned to remove lower-density material such as quartz, feldspar, organic material, and clay-size particles.

The concentrate samples were air-dried in the laboratory and then sieved through a 0.5 mm (35-mesh) screen. The <0.5 mm fraction was further separated using bromoform heavy liquid (2.89 g/cm^3) to remove any remaining lighter minerals with specific gravities of less than 2.85 g/cm^3. A Frantz Isodynamic Magnetic Separator was used to split the processed concentrate samples into two mineral fractions: a magnetic fraction containing magnetite, ilmenite, garnet, amphibole, pyroxene, epidote, and other high-iron silicates and a relatively non-magnetic fraction containing most ore-related minerals including both dark and yellow monazite.

The non-magnetic fraction was scanned visually under a ring light-illuminated binocular microscope using up to 56X magnification. In most cases, the monazite grains could be identified from their physical properties, but X-ray diffraction and six-step semi-quantitative emission spectrography (Grimes & Marranzino 1968) were used to confirm the identification of monazite. This non-magnetic fraction commonly contained andalusite, apatite, cordierite, epidote, muscovite, rutile, sphene, tourmaline, and zircon. Some samples also contained gold, cinnabar, and corundum.

Schist and phyllitic rock, as well as numerous monazite grains, were initially examined with a JEOL 5800LV scanning electron microscope (SEM) to identify monazite in the rock and acquire information on the distribution of inclusions and possible chemical zoning. Next, twenty-five detrital monazite grains from TA559 concentrate were analyzed using a JEOL 8900 fully-automated five spectrometer electron probe microanalyzer operated at 20 keV accelerating voltage, 150 nA current (cup), and 5 μm beam diameter. The K_α x-ray lines were analyzed for Al, Si, and P, the L_α x-ray lines for Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, and Er, and the M_α x-ray lines for Pb, Th, and U. The count times (peak plus background) were 1320 seconds for Al, Si, and Ca, 40 seconds for P and 200 seconds for the remaining elements. Linear background corrections were assumed for all elements. Interferences of off peaks on the analyzed peaks were corrected using the electron microprobe software Probe for Windows by Probe Software, Inc. The distribution of selected elements within the dark monazite was determined using wavelength dispersive spectrometry (WDS) by the JEOL-8900 electron microprobe.

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Notes from the Editor

The December issue of **EXPLORE** (No. 145) includes two technical articles. The first is written by Richard Tripp, William Benzel, David Adams, Heather Lowers, Gregory Lee and Elizabeth Bailey from the USGS and describes dark monazite distribution in stream sediments in western Alaska, USA. The second article describes the use of geophysics in support of geochemical data for detecting deeply buried mineralization in Australia. This second article in **EXPLORE** is a reporting requirement for the authors as recipients of the ioStipend. Scientific and technical editing assistance for this **EXPLORE** issue was provided by Paul Morris, Geological Survey of Western Australia, Ray Lett, British Columbia Geological Survey, Steve Amor, Geological Survey of Newfoundland & Labrador and Janet Campbell, Geological Survey of Canada. Coming in the March (No. 146) issue of **EXPLORE** will be an article about groundwater surveys in Australia.

Beth McClenaghan

Europium-rich dark monazite... *continued from page 2*

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Distribution of detrital dark monazite

In total, 838 heavy mineral concentrate samples were collected from streams in the Taylor Mountains quadrangle over a period of four years. In addition, 14 samples were collected in the adjacent Lake Clark and Dillingham quadrangles (Fig. 1b). Of these, 229 samples (27%) contained dark monazite in varying amounts. Most dark monazite occurs in the eastern Taylor Mountains quadrangle with a western limit along the Nushagak River south of Butch Mountain and north-northeast to the northern border of the quadrangle. Dark monazite extends into the Lime Hills quadrangle to the northeast to the Mosquito River drainage in the Lake Clark quadrangle to the east and into the Dillingham quadrangle to the south. Two smaller areas of dark monazite in stream concentrates occur along the western edge of Taylor Mountains quadrangle.
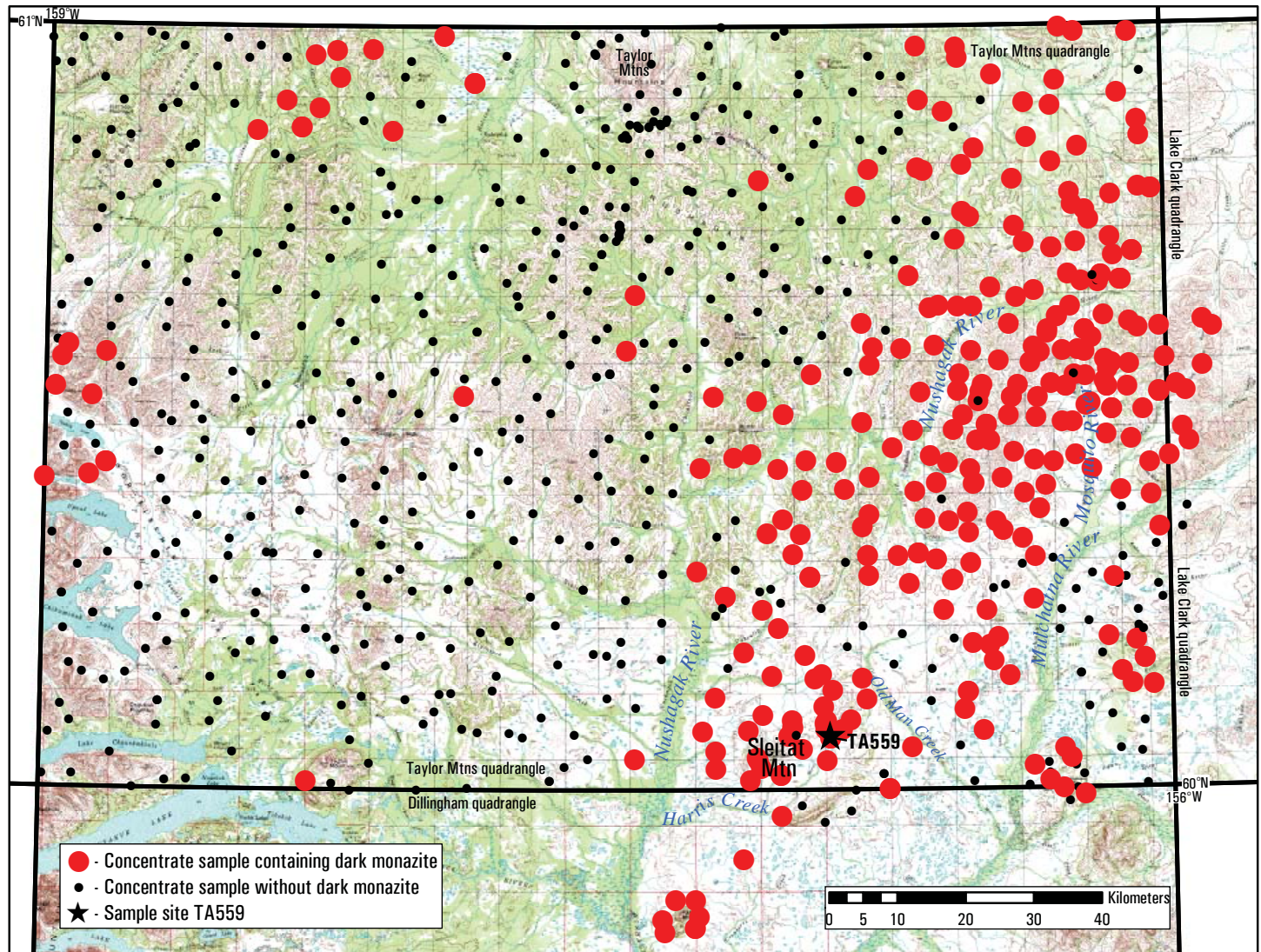
Figure 1b: Black dots indicate stream sediment concentrate locations that did not contain monazite. Red dots indicate locations where monazite was observed in the samples. The solid black star indicates site TA559 of the monazite study area in this report.

During the field season of 2008, a concerted effort was made to locate the source rocks of the dark monazite, in the southern part of the Taylor Mountains quadrangle, with particular emphasis on collecting rubble crop along the ridge extending northward from Sleitat Mountain towards Old Man Creek. Additional concentrate samples were collected from virtually every stream draining the ridge. All concentrate samples contained dark monazite and most contained gold colors and tiny flakes (Fig. 2). The likely lode source, gold-bearing quartz veins, is less than 1000 m from the sample location.

Comparison of yellow and dark monazite

The characteristics of the more common yellow monazite are in sharp contrast to dark monazite. Yellow monazite (Fig. 3) is a light rare earth element (REE) phosphate mineral, typically a cerium (Ce), lanthanum (La), yttrium (Y) phosphate [(Ce,La,Y)(PO$_4$)]. Lanthanum is ordinarily present in a 1:1 ratio with Ce. Thorium oxide (ThO$_2$) can substitute for Ce and La in amounts up to 12 wt.%; Th-free monazite is rare. Uranium (U) has been occasionally reported (Palache et al. 1951) in amounts up to approximately 1

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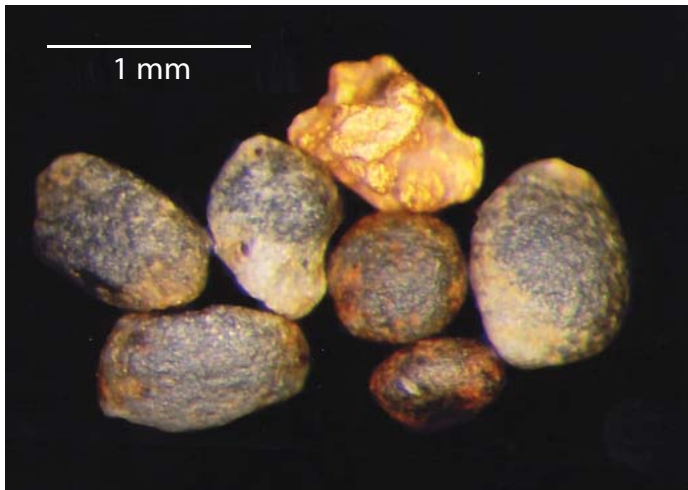

Figure 2. Photomicrograph of monazite grains together with gold. The gold from these samples is "fresh" looking with rough hackly surfaces and angular three-dimensional morphology, suggesting that the source is nearby.

Figure 3. Photomicrograph of typical detrital "yellow" monazite grains showing color, shape, and luster. Yellow monazite colors range from yellow to reddish brown, greenish, to nearly white. Scale in photo is 0.1 mm per graduation.

wt.% U_3O_8. The yellow variety occurs as monoclinic platelets to prismatic crystals that are commonly small, but sometimes large and coarse (Fig. 3). The physical properties of the yellow monazite include:
- one well-developed cleavage plane [100];
- well-marked parting plane [001];
- conchoidal to uneven fracture;
- hardness of 5 to 5½;
- varying specific gravity from 4.6 to 5.4 g/cm^3, but mostly in the range of 5.0 to 5.2 g/cm^3;
- luster can be variable, usually resinous or waxy, but may incline towards vitreous to adamantine;
- colors range from yellow to reddish brown, greenish, to nearly white;
- small crystals of yellow monazite range from sub-transparent to sub-translucent.

　　Yellow monazite is widely disseminated as an accessory

mineral in granitic and gneissic rocks. Monazite is of sufficient hardness to form considerable detrital deposits such as those found in gold sands of the southern Urals, Russia; in black sands of the Manajary basin, Madagascar; in sands of the Embabaan district, Swaziland, southern Africa; in tin placers of the Moolyella district, Western Australia; the west coast of Ceylon; and in the provinces of Bahia, Espirito Santo, Minas Gerais, and Rio de Janeiro, Brazil (Hedrick 2004). In the United States, considerable amounts of yellow monazite occur in the sands of Burke, Cleveland, Lincoln, McDowell, Polk and Rutherford Counties in North Carolina and the beach sands in Florida (Hedrick 2004). Since yellow monazite may contain appreciable amounts of Th and U, this variety has largely been eliminated from commercial use as a REE source because of concerns about radioactivity hazards.

　　Dark monazite, in contrast to yellow monazite, contains low levels of Th and U, but relatively high Eu values. Detrital dark monazite occurs in rounded to discoidal, inclusion-rich, xenoblastic forms, commonly with white sericitic "tails and rims" (Fig. 4). However, there is evidence of forms showing idioblastic features as well. Dark monazite shows
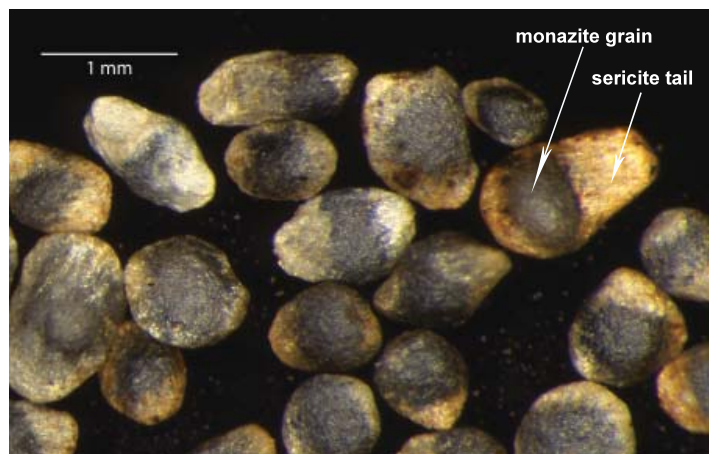

Figure 4. Photomicrograph of dark monazite grains with attached "tails and rims" of white sericite. Most stream sediment sample locations yield dark monazite with attached sericite, although in some areas, erosion was sufficient to totally remove the sericite. (Magnification 31X)

fracture and hardness similar to yellow monazite, but contrasts in specific gravity, luster, and color, with the following properties:
- well-developed cleavage (see Fig. 5);
- well-marked parting plane;
- specific gravity from 4.25 to 4.70 g/cm^3 (Rosenblum & Mosier 1983);
- luster ranges from submetallic in the blackest of grains, glittery vitreous on tiny crystalline facets to variable resinous;
- color ranges from light gray on thin edges, to black and sometimes inclining towards beige.
- grains range translucent to opaque

　　The presence of microscopic clouds of amorphous carbon, detrital and authigenic rutile, and inclusions of silt-sized

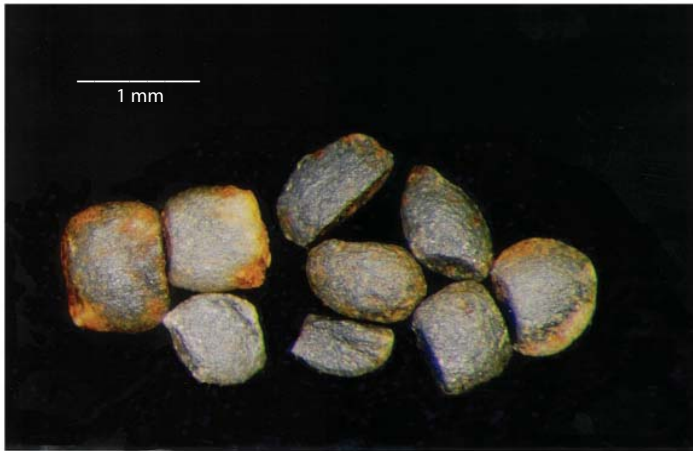# Europium-rich dark monazite... continued from page 4

Figure 5. Photomicrograph of dark monazite grains showing well developed cleavage and parting surfaces similar to those of yellow monazite (magnification 31X).

detrital quartz, feldspar, chlorite, sericite, and apatite affect its specific gravity, luster and color. Grain morphology, which includes an apparent annular ring structure (produced by growth ridges), has microcrystalline faces reflecting the glittery vitreous luster (Fig. 6). The black spots were shown by X-ray diffraction to be amorphous and therefore are interpreted to be organic carbon inclusions.
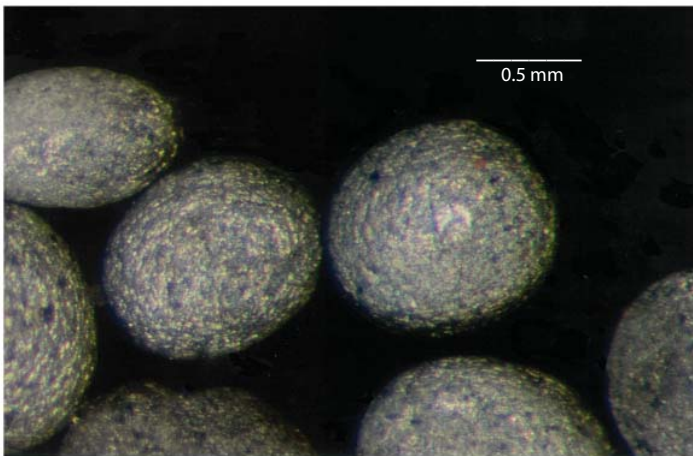
Figure 6. Photomicrograph of dark monazite grain morphology. Note the apparent annular ring structure produced by growth ridges and microcrystalline faces. The black spots are organic carbon inclusions. (Magnification 56X)

Scanning electron microscope and electron probe microanalysis of dark monazite

The primary stream sediment sample site (TA559, Fig. 1b) selected for this study is in the upper reaches of Harris Creek. A typical inclusion distribution within a monazite grain is quartz, albite, muscovite, chlorite, rutile and apatite (Fig. 7). Chemical zoning was not observed under the SEM, but later observations using the electron microprobe indicated distinct zoning.

In the upper reaches of Harris Creek, numerous grab samples of rubble crop were collected for the purpose of finding the dark monazite in source rocks. The bedrock in
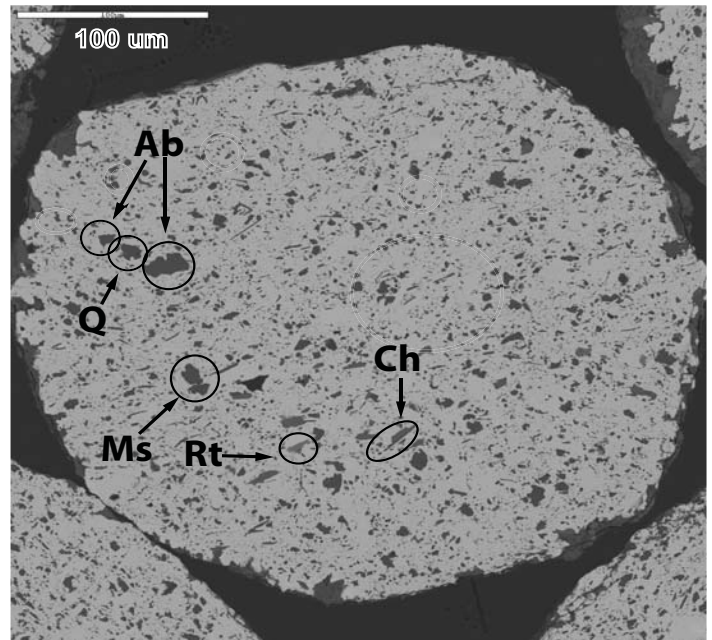
Figure 7. SEM photomicrograph showing typical inclusion distribution within a dark monazite grain from TA559 concentrate. The observed inclusions are quartz (Q), albite (Ab), muscovite (Ms), chlorite (Ch), and rutile (Rt).

this area is composed of mid-Cretaceous clastic sedimentary rocks of the Kuskokwim Group. The common presence of sericite schist at the TA559 site suggests that the rocks have been subjected to low-grade metamorphism. The sericite schist contains numerous tiny black inclusions (Fig. 8a) which when viewed more closely are dark monazite grains, typically 0.5 to 1 mm in size (Fig. 8b). If one did not know to look for these grains, they could easily be overlooked. A grab sample was split and scanned by SEM backscatter to reveal the internal morphology of the monazite in the cleavable sericite schist (Fig. 8c). Examination of the halves (plus a smaller piece that broke off during the split) clearly show how monazite (the white colored material in the photo) grew between the schist cleavages showing it has both lateral growth along a cleavage plane as well as thickness across cleavage planes. Additional SEM scans performed on sericitic schists, metasiltstones, metagraywackes, and quartzites to determine which rock-types host the dark monazites suggest that sericitic schists host more occurrences of dark monazite than the other rock-types. The siltstone was also found to host monazite, mostly in the sericitic portions of the rock. Thus, monazite is present, but less commonly than in the schist.

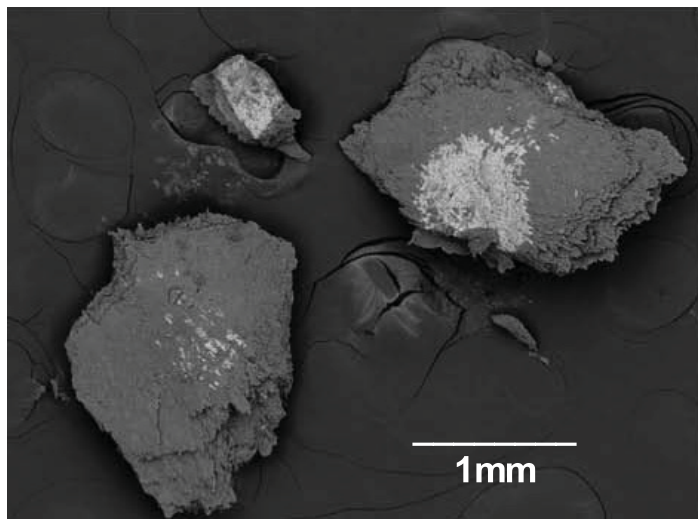**Chemical composition of detrital dark monazite**

The results of the electron microprobe analyses are given in Table 1. None of the analyses showed Pb contents above the detection limit of 200 ppm. For this reason, no attempt was made to date these monazites.

Thorium oxide concentrations of the dark monazite range from 0.02 to 1.75 wt.%, with the average being 0.61

Europium-rich dark monazite... *continued from page 5*
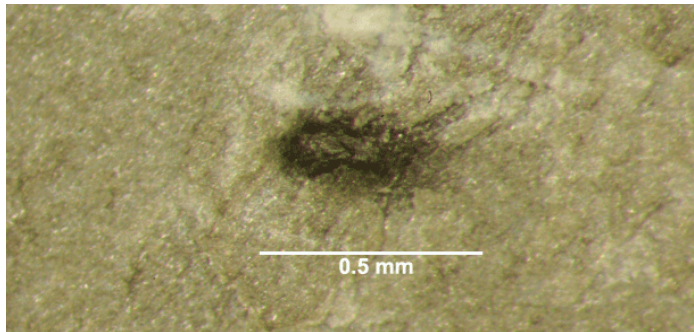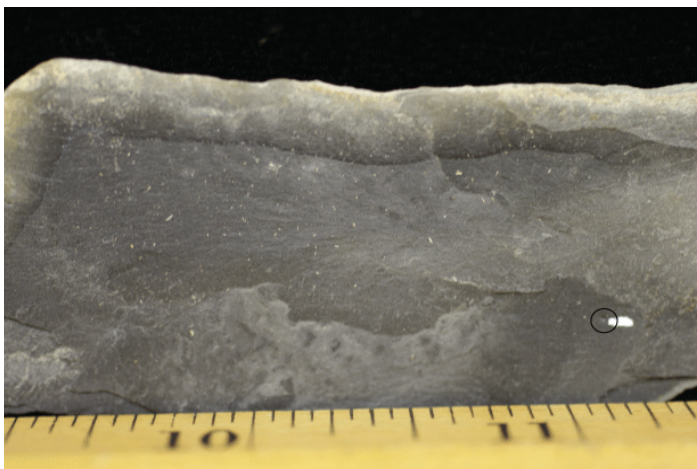
Figures 8. Photographs and photomicrograph of in situ dark monazite in phyllitic schist. (a) photograph of schist showing in situ monazite, scale is in inches. The monazite grain studied in detail is located just to the left of the white spot painted on the rock and enclosed by the circle. (b) close-up of the in situ dark monazite, approximately 1 mm in length, in sericite schist (light color). (c) SEM backscatter image of the schist split along a cleavage plane containing the dark monazite (bright material) showing it has both lateral growth along a cleavage plane as well as thickness across cleavage planes.

Europium-rich dark monazite... *continued from page 6*

| Grain	Al	Si	Ca	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Er	Pb	Th	U	P	O	Sum
1	bd	1.37	0.10	0.55	7.11	24.20	3.60	15.42	2.97	0.56	1.17	0.18	bd	bd	0.78	0.03	13.3	28.4	99.7
2	bd	bd	0.06	0.43	4.91	22.00	3.93	20.02	4.49	0.62	1.52	0.21	bd	bd	0.15	0.01	13.7	27.6	99.7
3	bd	bd	0.12	0.48	6.60	25.00	3.95	16.79	2.99	0.52	1.12	0.18	bd	bd	0.96	0.01	13.7	27.7	100.1
4	0.02	0.01	0.15	0.49	5.32	22.20	3.91	18.66	3.75	0.72	1.32	0.13	bd	bd	1.11	0.02	13.6	27.4	98.8
5	bd	bd	0.03	0.30	13.83	30.90	3.05	9.91	0.89	bd	0.16	0.12	bd	bd	0.18	bd	13.9	28.1	101.4
6	bd	bd	0.12	0.64	9.75	26.90	3.24	13.03	2.16	0.36	0.85	0.22	bd	bd	0.73	0.03	13.8	27.8	99.6
7	0.10	1.73	0.12	0.46	6.32	22.80	3.45	15.70	3.23	0.60	1.28	0.15	bd	bd	1.12	0.02	13.0	28.2	98.3
8	bd	bd	0.08	0.45	6.93	26.10	3.98	17.27	2.73	0.34	0.93	0.15	bd	bd	0.32	0.01	13.8	27.9	101.0
9	bd	bd	0.04	0.29	10.52	29.90	3.66	12.95	1.29	0.20	0.49	0.11	bd	bd	0.10	0.01	13.6	28.0	101.2
10	bd	bd	0.08	0.49	6.59	25.40	3.94	17.45	3.05	0.35	1.05	0.19	bd	bd	0.78	0.02	13.7	27.8	100.9
11	bd	bd	0.03	0.37	10.20	29.00	3.57	13.50	1.96	0.36	0.72	0.14	bd	bd	0.16	0.02	13.8	28.1	101.9
12	bd	bd	0.12	0.49	10.95	28.20	3.32	11.81	1.49	0.23	0.66	0.09	bd	bd	1.12	0.03	13.6	27.6	99.7
13	bd	bd	0.05	0.46	8.26	27.60	3.73	15.27	2.39	0.31	0.78	0.17	bd	bd	0.20	0.02	13.9	28.0	101.1
14	bd	bd	0.10	0.60	5.32	22.50	3.90	19.81	4.19	0.61	1.41	0.23	bd	bd	0.56	0.01	13.8	27.9	100.9
15	bd	bd	0.01	0.32	11.22	30.50	3.60	12.63	1.48	0.23	0.59	0.11	bd	bd	0.04	bd	13.8	28.1	102.6
16	0.01	1.51	0.14	0.55	6.99	25.20	3.79	15.95	2.87	0.59	1.16	0.20	bd	bd	0.83	0.01	13.3	28.9	102.0
17	bd	bd	0.16	0.58	6.99	25.40	3.57	15.98	2.88	0.71	1.05	0.21	bd	bd	1.75	0.02	13.8	27.8	100.9
18	bd	bd	0.09	0.50	7.81	26.90	3.64	15.49	2.71	0.31	0.93	0.19	bd	bd	0.75	0.02	13.7	27.8	100.8
19	bd	0.05	0.12	0.35	11.47	28.70	3.29	11.29	1.37	0.10	0.54	0.10	bd	bd	1.27	bd	13.8	27.9	100.4
20	bd	bd	0.02	0.24	9.59	29.20	3.62	13.58	2.02	0.21	0.63	0.10	bd	bd	0.14	bd	13.8	27.9	101.1
21	bd	bd	0.10	0.35	10.49	30.00	3.47	12.29	1.43	0.16	0.51	0.12	bd	bd	0.75	bd	14.0	28.3	102.0
22	0.10	bd	0.04	0.56	9.77	29.20	3.71	13.66	1.86	0.34	0.85	0.24	bd	bd	0.02	0.03	13.9	28.4	102.7
23	bd	bd	0.05	0.29	7.71	27.30	3.92	15.81	2.48	0.32	0.88	0.12	bd	bd	0.69	0.01	13.8	28.0	101.4
24	bd	bd	0.04	0.26	13.17	30.50	3.14	10.41	1.04	0.05	0.27	0.07	bd	bd	0.54	0.01	13.8	28.0	101.3
25	bd	bd	0.11	0.70	4.88	21.60	3.85	20.53	5.04	0.61	1.72	0.27	bd	bd	0.18	0.03	13.8	27.8	101.1
AVG	0.06	0.93	0.08	0.45	8.51	26.70	3.63	15.01	2.51	0.39	0.90	0.16	bd	bd	0.61	0.02	13.7	28.0	101.7
1σ	0.05	0.83	0.04	0.13	2.55	3.00	0.27	2.94	1.08	0.20	0.38	0.05	bd	bd	0.46	0.01	0.0	0.3	1.1

* bd - below detection limit

Table 1. Electron microprobe chemical analyses of 25 detrital dark monazite grains from TA559 concentrate showing the average REE concentrations and confirming the high Eu content. All values are in wt. %.

wt.%. Uranium oxide concentrations are mostly below 0.03 wt.%. Conversely, Eu_2O_3 contents are very high, ranging from 0.05 to 0.72 wt.%, the average being 0.39 w.t%. Neodymium (Nd) concentration, which is closely associated with Eu content at the cores of the dark monazite, ranges from 9.91 and 20.53 wt.% Nd_2O_3, with an average of 15.01 wt.%. Lastly, Ce_2O_3 concentrations range from 21.6 to 30.9 wt.%, with an average of 26.7 wt.%.

X-ray mapping of Eu content in these detrital dark monazite grains (Fig. 9) shows they are highly zoned, with the Eu concentrated in the cores and decreasing substantially outward toward the rims. Conversely, La content is low in the grain cores and increases sharply at the rims. Cerium concentration is more chemically homogenous throughout the grains, usually with the cores only slightly reduced in content as shown by the limited range in color from green to red

Figure 9. Electron microprobe photomicrograph of element distributions within detrital dark monazite grains. Colors indicate variation in elemental concentration, where dark colors (blue) are the lowest concentration and bright colors (white) are the highest concentration as shown by the color bar at the right of the figure. Monazite grains are zoned with Eu at the core and La at the rim.
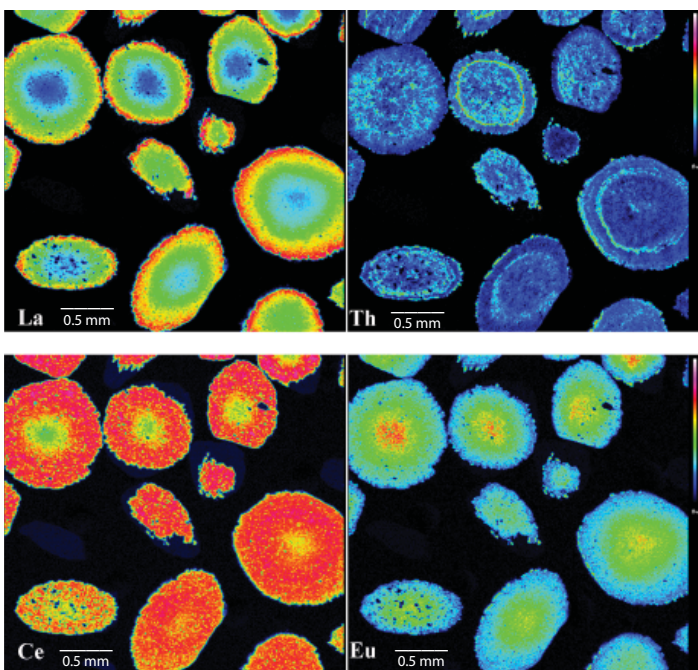
Europium-rich dark monazite... *continued from page 7*

on the elemental map. Elevated Th contents occur with the highest La concentrations as narrow enriched zones in only a few of the monazite grains and satellite spots in the rims of other grains

Chemical composition of in situ dark monazite

SEM spectral imaging was collected on dark monazite imbedded in sericitic schist. A backscattered electron image of one of these monazite growths, together with elemental X-ray maps of Ce, La, and Eu concentrations, is given in Figure 10. As seen here, the monazite appears as complex idioblastic intergrowths with mica and quartz rather than a well-formed separate discoidal grain. The element maps suggest homogeneous distributions of Ce and Eu, but subtle differences in La distribution across the growth; note the darker yellow colors at the outer edge of the growth compared to the brighter yellow in the interior. Unfortunately, no samples of in situ dark monazite could be polished to a flat surface suitable for microprobe analysis. At this time, there are insufficient data to show whether the in-situ monazite grows to become discoidal grains such as those that are found in the stream sediments.

Occurrences of detrital gold

Angular to sub-rounded detrital gold (Fig. 2) was found with dark monazite in virtually every concentrate sample from streams draining the northeast-trending ridge from
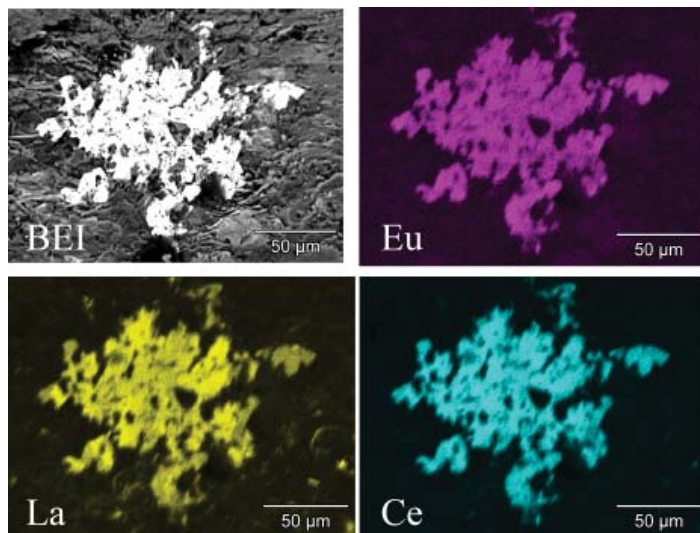
Figure 10. SEM backscatter image (BEI) of in situ dark monazite in sericite schist together with element distribution maps for Eu, La, and Ce. REE distribution is relatively homogenous across the monazite growth. For each element (color) the dark regions represent lower concentration than bright regions. There is a slight decrease in La concentration at the outer boundaries, especially noticeable at the upper right area of monazite.

Sleitat Mountain. The gold may come from quartz veins, associated with the Sleitat Mountain stock, which cuts the mid-Cretaceous clastic sedimentary rocks of the Kuskokwim Group. Five to ten ounces of gold was recovered from a wolframite-bearing pegmatite vein nearby (Mertie 1938). A magnetic survey of Taylor Mountains quadrangle which included the Sleitat Mountain area shows a possible cupola to the northeast of Sleitat Mountain (available at: A Website for the Distribution of Data, World Wide Web: http://pubs. usgs.gov/ds/2006/224/ and http://pubs.usgs.gov/ds/2006/224/ Data/USGS_TaylorMtsMagFinalReport.pdf). The 2008 sampling traverse conducted across this ridge revealed igneous rubble crop at that location.

Conclusions

The relatively high Eu concentration, with generally very low contents of U and Th in dark monazite, from the Sleitat Mountain area and elsewhere in the Taylor Mountains quadrangle points to the desirability of this variety of monazite becoming a potential source for REE. Europium oxide has gained considerable commercial interest (Haxel et al. 2002; Hedrick 2004). Utilized principally as a phosphate activator, Eu-activated yttrium (Y) compounds produce red color in television, computer monitor, and light emitting diodes (LED). Certain alloys of Eu are used in the petroleum industry, such as cracking catalysts in refineries. Currently, Eu is separated from bastnaesite $[(Ce,La)(CO_3)F]$ ore found in China and California, and the ionic clays of southern China; however, all contain only small concentrations of Eu. Europium is difficult to separate from the other REE, especially in the presence of U and Th, making it one of the most expensive REE. The United States once was self-sufficient in

Europium-rich dark monazite... *continued from page 8*

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the production of REEs, but in the last 20 years has become dependent largely upon imports from China (Bayan Obo deposit and lateritic deposits of tropical southern China).

The thickness of the bedrock at Sleitat Mountain that contains the dark monazite is not known at this time. However, the heavy mineral concentrate surveys indicate the lateral distribution of the dark monazite to be widespread (Fig. 1b). The costs of mining the dark monazite possibly could be offset by the recovery of gold. The Th content of the dark monazite is low and the paucity of Th-rich yellow monazite suggests that radioactive hazards may be of little economic consequence. The importance of ensuring domestic resources of REE, and particularly the scarcity of national Eu resources, suggests that this area of the Taylor Mountains quadrangle would be an important region to evaluate as a potentially significant source of Eu.

Acknowledgements

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Geophysical support for geochemistry in detecting deeply buried mineralisation: a case study from Mandamah, Australia

Introduction

The effects on the composition of transported and residual overburden by the oxidation of underlying sulfide mineralisation have been the subject of a large number of empirical and theoretical studies over the last two decades (Cohen et al. 2007). These studies have benefitted from advances in analytical techniques and the development of various geochemical dispersion models. Development of reliable techniques to detect mineralisation through thick transported overburden opens up previously underexplored areas, many of which are located in arid terrains. Whilst most studies have focused on the mineral associations and distribution of trace elements, others have looked more broadly at physico-chemical changes in, or characteristics of the overburden profile or groundwater. A recurring theme in most geochemical dispersion models and empirical studies is that of variations in the measured pH in regolith or groundwater due to the presence of oxidised or oxidising sulfides, or the effects that pH changes have had on regolith or overburden mineralogy and geochemistry (e.g. Govett 1976; Smee 1998; Hamilton et al. 2004; Mokhtari et al. 2009).

Electromagnetic surveys are commonly employed in exploration for primary sulfide ore bodies, and have been extended to soil and regolith studies to map salinity (mainly for agricultural purposes) and even to recognise regolith structure. Such methods have not been used extensively in exploration for deeply buried mineralisation in overlying transported regolith, despite various models indicating the potential for development of weak alteration haloes which may affect the composition of the blanketing regolith cover.

A comparison between the geochemical characteristics of the upper part of the transported regolith and the shallow EM response (reflecting soil conductivity) has been undertaken over the sub-economic Mandamah porphyry Cu-Au deposit (~0.3% Cu) in central NSW, Australia (Fig. 1). Here, structurally-controlled quartz-pyrite-chalcopyrite mineralisation is hosted by altered andesitic Siluro-Ordovician Gidginbung Volcanics. A central zone of sericite-pyrite alteration (containing higher grades of mineralisation) is surrounded by a zone of sericite-chlorite-magnetite-albite alteration (MacCorquodale, 1997). Discontinuous zones of pyrite alteration (and acid-generating potential in the regolith) extend beyond the zone of Cu mineralisation.

Mineralisation was discovered by Gold Mines of Australia when drilling aeromagnetic geophysics-defined targets as part of a regional reconnaissance program. The deposit is overlain by 30 m of in-situ regolith and 50 m of alluvium containing quartz, lithic fragments, kaolinitic clays and minor amounts of Fe-oxides. The upper 70 cm of the profile contains discontinuous carbonate-rich patches (mainly magnesian calcite). Recent drainage lines, with narrow zones of alluvium accumulation, contain slightly lower K values, as indicated by the regional airborne radiometrics dataset, than the surrounding areas.
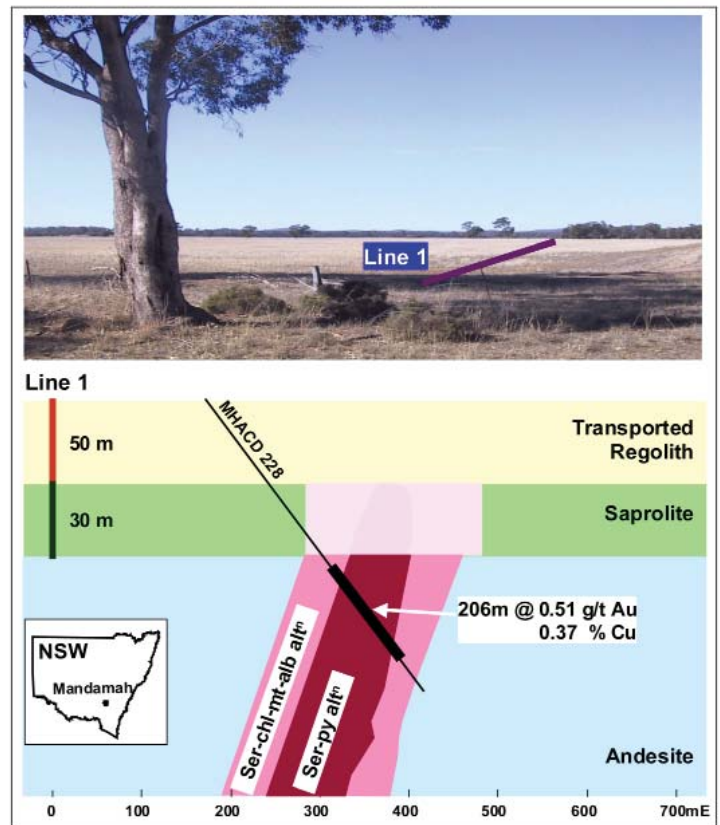

Figure 1. View across the Mandamah site in central NSW, Australia, with geological and regolith profile below Line 1.

Methods

AurionGold completed an extensive reverse circulation exploration drilling program, analysing aqua regia-extractable Cu, Au and other elements at 2 m intervals from surface to ~100 m depth (Fig. 2). In the current study, various soil physical and geochemical parameters were measured on more than 550 regolith samples collected from a series of 1.5 m deep pits and 1.8 m soil cores, along two traverse lines crossing the zone of buried Cu mineralisation (Figs. 3 & 4). Samples from 20-cm increments down the cores and pit faces were subjected to both ammonium acetate (pH 5)

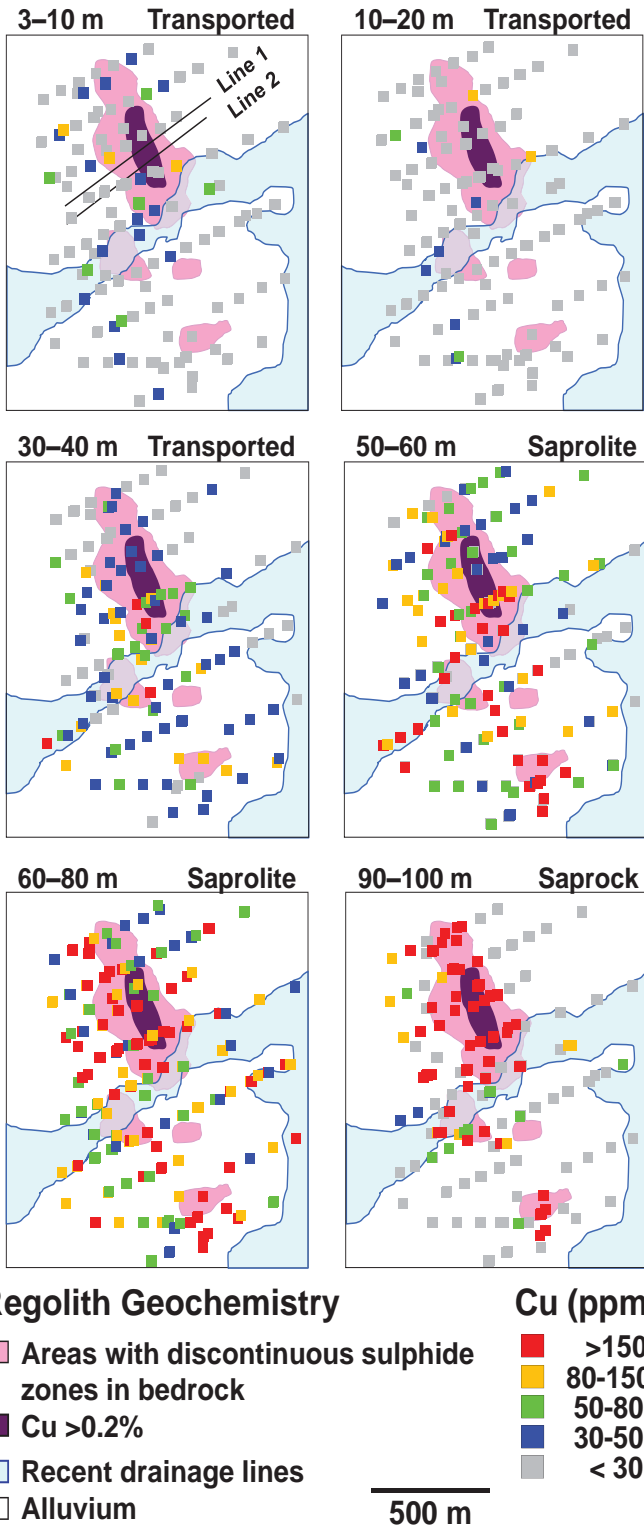# Geophysical support for geochemistry... *continued from page 11*

Figure 2. *Location of deeply buried sulfide mineralisation and spatial variation in aqua regia Cu contents of various intervals within residual and transported regolith at Mandamah.*
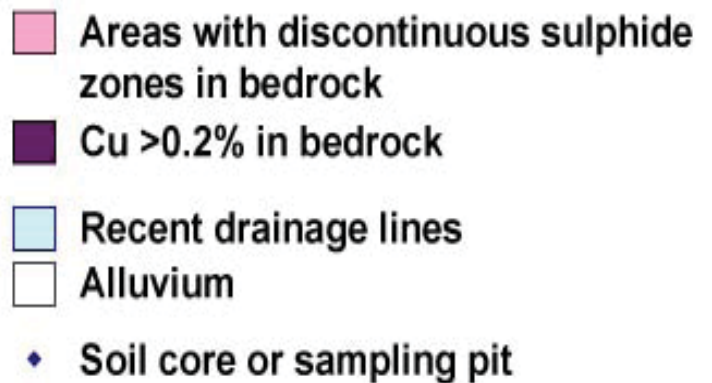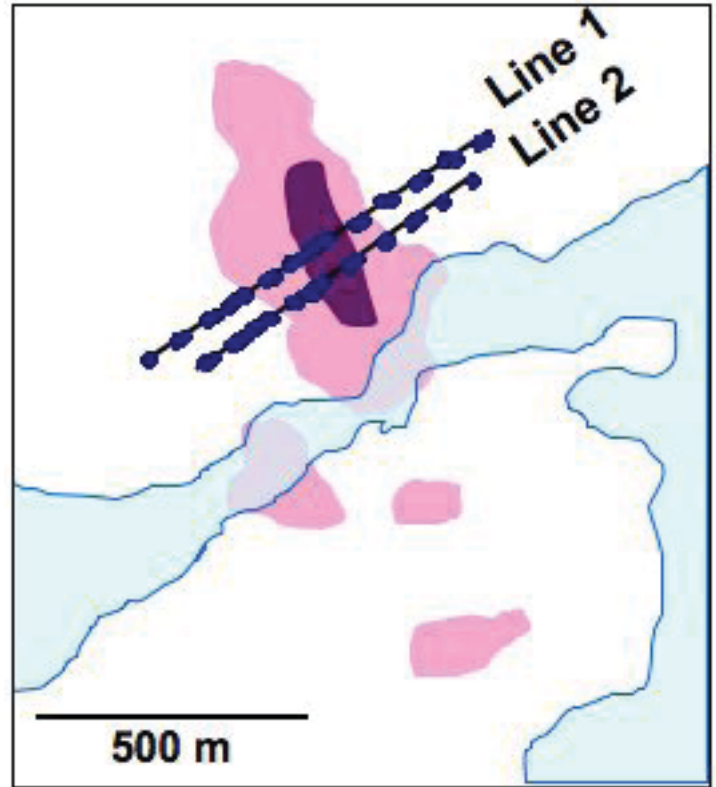
Figure 3. *Location of soil core and sampling pit sites along Lines 1 and 2.*

and aqua regia digestion followed by ICP-MS analysis, as well as measurement of slurry pH, EC and methylene blue cation exchange capacity (CEC). The shallow EM response was measured at 10 m spacing along both traverses using a Geonix frequency-domain EM-38 device, that provides around 1.5 m penetration in vertical dipole mode and 0.75 m in horizontal mode (Fig. 4). Following a study of the scale of variation in the EM data, this survey was subsequently extended to examine patterns across the property, based on a series of 5,000 measurements taken every 10 m along 30 traverses with 25 to 50 m line spacings. This second phase of the EM mapping followed a 2-year dry spell where just 450 mm total rain fell across the period 2006-07, compared with 910 mm across 2004-05, and corresponded with a reduction in the average conductivity of the soil (though similar patterns in conductivity variation along lines re-sampled in phase 1).
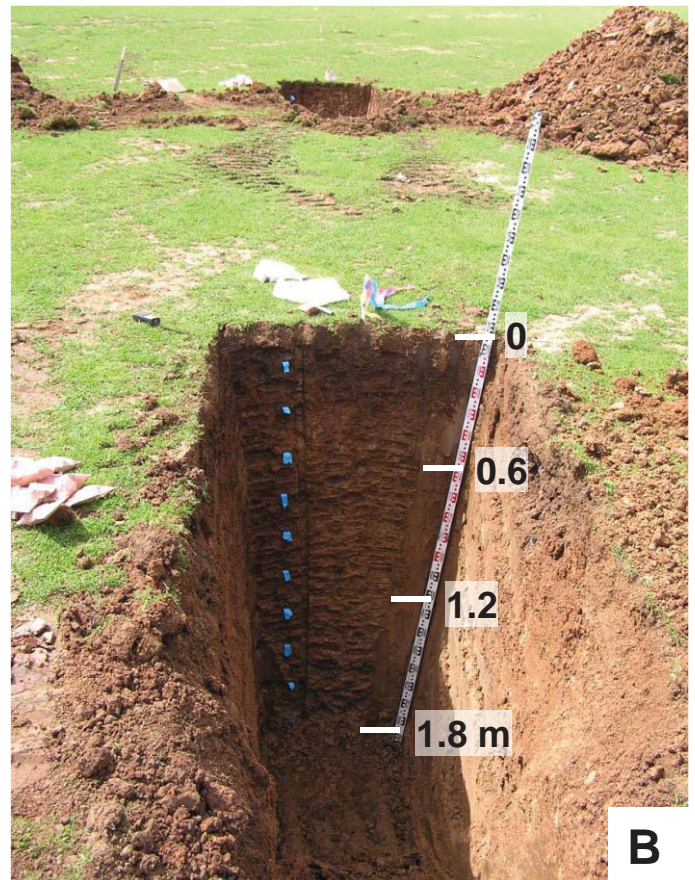
Geophysical support for geochemistry... continued from page 12

Figure 4. (A) Measurement of shallow EM measurements using a Geonix EM38. (B) Example of typical profiles through the upper 1.5 m of transported regolith at Mandamah. The upper 30 cm is disturbed by ploughing and displays near-neutral pH. Between 30 cm and ~70 cm depth there is carbonate accumulation and the pH is 9 to 9.5. Below 70 cm the regolith displays pH 5 to 6 and Fe mottling.

Results

Elevated total Cu values (>80 ppm) in the saprock are generally restricted to the zone directly overlying the zones where Cu values exceed 0.2% (Fig. 2). There is substantial lateral dispersion in the overlying saprolite and the base of the transported regolith cover. The upper 20 m of transported cover contains a few slightly elevated Cu values above and to the west and southwest of the underlying mineralisation. On Line 1, both the vertical and horizontal mode EM configurations display a discontinuous zone of low conductivity above the eastern (and high grade) section of buried mineralisation (Fig. 5). A similar EM response to that of Line 1 is observed on Line 2, although there is a slight (50 m) shift between the centre of the low-conductivity zone and underlying mineralisation (Fig. 6). Above mineralisation on both lines, the variation between the magnitudes of responses in the different modes is lower than areas away from mineralisation. These vertical patterns cut across the horizontal mineralogical and pH zonation in the upper 2 m of the regolith in the area.

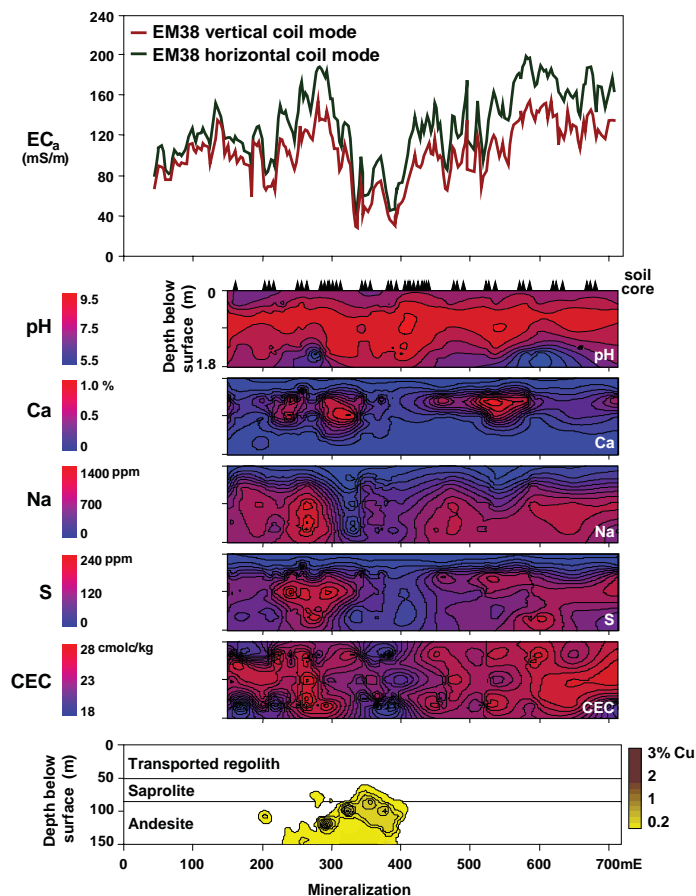# Geophysical support for geochemistry... *continued from page 13*

Line 1

Figure 5. Comparison between surface EM response and profiles for pH, CEC and aqua regia Ca, Na and S in the upper 2 m regolith profile across mineralisation on Line 1.
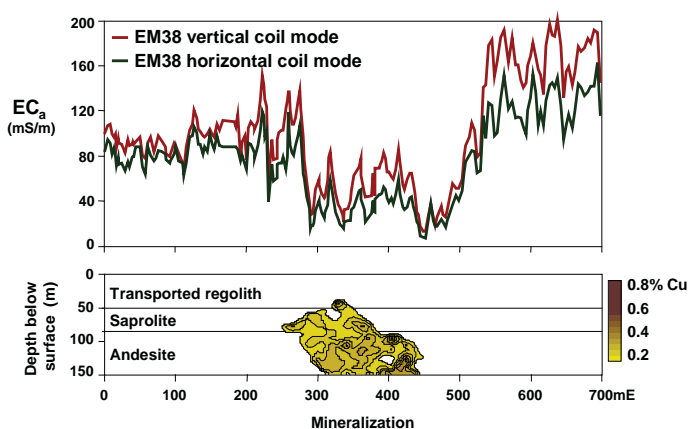
Line 2

Figure 6. Shallow EM response within the upper 2 m regolith profile across mineralisation on Line 2.

Chemical analysis of the transported regolith shows that electrical conductivity is correlated with CEC and aqua regia-extractable Na and S contents. Calcium concentration displays a classic "rabbit ears" anomaly pattern with accumulations of magnesian calcite either side of the low conductivity zone. The high pH zone on Line 1 does not, however, correspond with elevated pedogenic carbonate con-

centrations. Aqua regia and ammonium acetate-extractable trace elements patterns in the upper 2 m of regolith do not indicate detectable mass transport of ore-related elements (e.g. Cu, Mo, Au) from mineralisation into the upper part of the overlying transported regolith.

The results of the shallow EM mapping are presented in Figure 7. At the scale of a few metres, there is a high degree of variability in the EM response in the southern part of the property and central part of the western side related to formation of "gilgai" structures produced by swelling clays in the soil (particularly in the northern part of the area). When the effects of local variation on the scale of tens of metres are measured using the absolute value of the first derivative for the smoothed raw data (Fig. 7B), the zone of higher grade Cu mineralisation is characterized by consistently low variation above the mineralization, but a number of zones displaying high variability around the projected edge of the mineralisation (as also indicated in Figs. 5 & 6). Small zones of low-grade, discontinuous sulfide mineralisation to the south of the main Cu mineralisation zone also display limited EM variation in the regolith above mineralisation and increased variation in some places around their projected edges. It is difficult to define a distinct relationship between the EM variability and the location (and edges) of the low-grade sulfide mineralisation that envelopes the higher grade Cu mineralisation.

Discussion

The EM response across the property is controlled by various factors and at different scales. At the broad scale, shallow-depth regolith conductivity is mainly controlled by the effects of recent landscape-modifying processes. These effects include low-conductivity zones in the areas of recent deposition of alluvium along shallow drainages zones (shown in light blue) and a recently ploughed paddock on the NW corner of the area, with generally elevated values elsewhere on the property (Fig. 7A).

The regolith evolution model being developed for Mandamah (Mokhtari et al. 2009) involves the development of an acidic chimney in transported regolith over oxidizing mineralisation during a period (of unknown duration) of more elevated ground water levels. This also resulted in a leaching of carbonate from at least the upper 2 m of regolith above mineralisation and the acid-induced alteration of clays from a 2:1 to 1:1 structure. With the subsequent Late Miocene onset of aridity and reduction in the amount of acid moving to the surface, an influx of Na and Ca and their exchange with clays generated a shallow zone of non-carbonate soil alkalinity at surface over mineralisation. Broad controls on the shallow EM response (soil conductivity) in the area are dominated by the effects of recent alluvium deposition and flushing of salt out of the upper few m of the regolith along recent drainage lines, and the effects of farming activities. There is however a local trend of low conductivity in the shallow regolith over a number of mineralised zones at the site (relative to the surrounding area) and increased variability at the tens of metres scale at the edge of mineralisation.

Geophysical support for geochemistry... *continued from page 14*

Normalised EM response (mS/m)
-1.2 -0.7 -0.3 0.1 0.4 0.7 1.1

E-W 1st derivative from (A) (*abs* mS/m²)
0–2 2–3.3 >3.3

Recent drainage/sheetwash

Alluvium

- - - Roads

Cu mineralisation (>0.2% Cu)
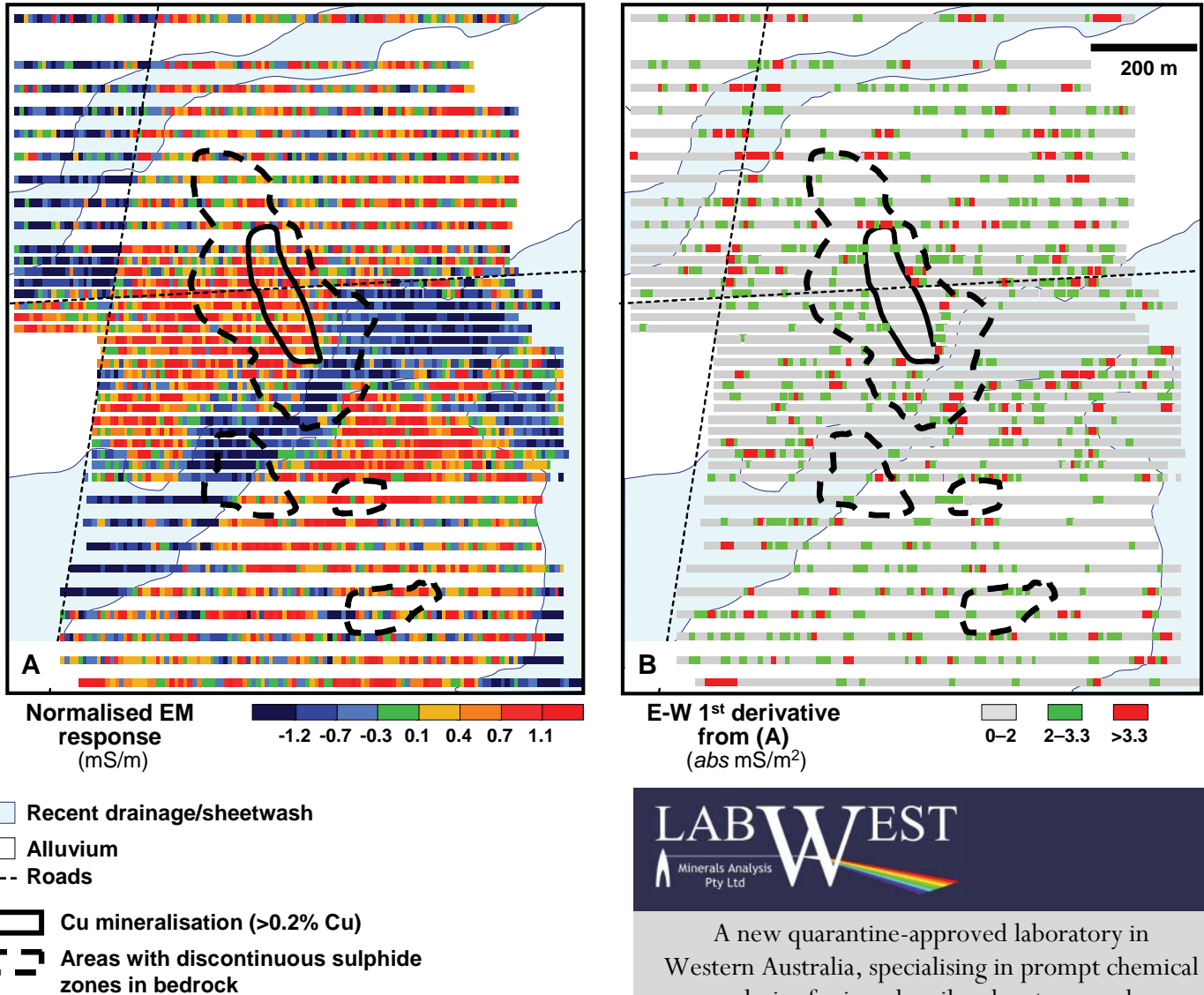
Areas with discontinuous sulphide zones in bedrock

Figure 7. (A) Vertical dipole mode EM response across the Mandamah site, normalised on a line-by-line basis. (B) Absolute value of the first derivative of the vertical mode EM response in the E-W direction.

EM patterns tend to be more strongly developed if preceded by recent rain showers. The EM patterns observed above mineralisation are not unique within the property, and there are other areas at Mandamah with circular to elongate zones of low EM variability. Whether these other zones also display non-carbonate alkalinity is the subject of ongoing research at the site.

Conclusions

Geochemical and mineralogical patterns in the upper parts of transported regolith at Mandamah may be explained in terms of the effects of a (now inactive) acid chimney that developed within transported regolith above buried sulfide mineralisation. Whereas the EM patterns that appear spatially related to the effects of mineralisation on the overlying transported regolith are subtle, and patterns similar to those

Geophysical support for geochemistry...

above mineralisation are observed in areas of the property with no known mineralisation, this study should encourage further evaluation of shallow EM methods, in combination with measurement of various soil chemical parameters (mainly pH and carbonate content), to assist in the detection of deeply buried mineralisation.

Acknowledgements

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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 site at: www.appliedgeochemists.org. 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; telephone: 709-729-1161

2009

■ 30 November-4 December 2009. Northwest Mining Association 115th Annual Meeting, Exposition and Short Courses, Reno-Sparks NV USA. Website: www.nwma.org/ pdf/09cv.pdf

■ 1-3 December 2009. 7th Fennoscandian Exploration & Mining, Rovaniemi Finland. Website: www.lapinliitto.fi/ fem2009/index.htm

■ 1-5 December 2009. 6th Symposium on the Atlantic Iberian Margin, Oviedo Spain. Website: www.uniovi.es/ mia09/index-ing.html

■ 7-11 December 2009. AGU Fall Meeting, San Francisco CA USA. Website: www.agu.org/meetings

2010

■ 3-9 January 2010. 2010 Winter conference on Plasma Spectrochemistry. Fort Myers FL USA. Website: http:// icpinformation.org/2010_Winter_Conference.html

■ 12-14 January 2010. 2010 North American Environmental Field Conference & Exposition, Tampa FL USA. Website: www.envirofieldconference.com/

■ 18-21 January 2010. Mineral Exploration Roundup 2010, Vancouver BC Canada. Website: www.amebc.ca/roundup/ overview.aspx

■ 4-7-February 2010. 6th International Dyke Conference, Varanasi India. Website: www.igpetbhu.com

■ 13-20 February 2010. Short Course: Geoenvironmental Modeling of Ore Deposits, Ottawa ON Canada. Website: www.earth.uottawa.ca/short_course.html

■ 12-16 February 2010. 2010 AGU Ocean Sciences Meeting, Portland OR USA. Website: www.agu.org/meetings/os10/ index.php

■ 7-10 March 2010. Prospectors and Developers Association of Canada Annual Convention, Toronto ON Canada. Website: www.pdac.ca/pdac/conv/index.html

■ 6- 9 April 2010. 13th Quadrennial IAGOD Symposium "Giant Ore Deposits Down-Under", Adelaide Australia. Website: http://tinyurl.com/caoys8

■ 26-28 April 2010. The First International Applied Geological Congress, Mashhad Iran. Website: www.iagc.ir/

■ 2-7 May 2010. European Geosciences Union General Assembly 2010, Vienna Austria. Website: http://meetings. copernicus.org/egu2010/

■ 3-7 May 2010. 2nd International Applied Geochemistry Workshop, Vancouver BC Canada. Website: www.ioglobal.net

■ 10-13 May 2010. GAC/MAC Annual Meeting, Calgary AB, Canada. Website: http://www.geocanada2010.ca/

■ 11-12 May 2010. Sampling 2010 (AusIMM), Perth Australia. Website: www.ausimm.com.au/sampling2010/

■ 17-21 May 2010. 3rd International Congress on Arsenic in the Environment, Tainan City Taiwan. Website: www. As2010tainan.com.tw

■ 6-11 June 2010. Gordon Research Conference: Natural Gas Hydrate Systems, Waterville ME USA. Website: http:// tinyurl.com/yh23to4

■ 13-18 June 2010. Goldschmidt 2010, Knoxville TN USA. Website: www.goldschmidt2010.org

■ 16-17 June 2010. International Uranium Conference (AusIMM), Adelaide Australia. Website: http://tinyurl.com/ yefy5a2

■ 21- 24 June 2010. 11th International Platinum Symposium, Sudbury ON Canada. Website: http://11ips.laurentian.ca

■ 27 June-2 July 2010. 27th Society for Environmental Geochemistry and Health, European Conference, Galway Ireland. Website: www.nuigalway.ie/segh2010

■ 4-8 July 2010. Australian Earth Sciences Convention (AESC) 2010, Canberra, Australia. Website: www.gsa.org.au/

■ 7-11 July 2010. EMU School: High-resolution electron microscopy of minerals,. Nancy France. Website: www.lcm3b. uhp-nancy.fr/emu10/

■ 1-6 August 2010. Gordon Research Conference: Organic Geochemistry, Holderness NH USA. Website: http://tinyurl. com/yzgvra9

■ 15-18 August 2010. Uranium 2010, Saskatoon SK Canada. Website: www.metsoc.org/u2010/

■ 15- 20 August 2010. Gordon Research Conference: Biomineralization, New London NH USA. Website: http:// tinyurl.com/yf6l3gz

■ 21-27 August 2010. International Mineralogical Association 20th General Meeting, Budapest Hungary. Website: www.ima2010.hu/

■ 1- 4 Sep 2010. International Symposium: Geology of Natural Systems, Iasi Romania. Website: http://tinyurl.com/ yl7ap3d

CALENDAR OF EVENTS

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■ 5-10 September 2010. 11th IAEG (International Association For Engineering Geology and the Environment) Congress, Auckland New Zealand. Website: www.iaeg2010.com/

■ 15-17 September 2010. 11th International Symposium on Environmental Radiochemical Analysis, Chester UK. Website: http://tinyurl.com/yghqp3o

■ 19-24 September 2010. IWA World Water Congress and Exhibition, Montreal, Canada. Website: www.iwa2010montreal.org/

■ 23-26 September 2010. Carpathian Balkan Geological Association XIX Congress, Thessaloniki Greece. Website: www.cbga2010.org/

■ 2-5 October 2010. SEG 2010 Conference, Keystone CO USA. Website: www.seg2010.org/

■ 31 October-3 November 2010. Geological Society of America Annual Meeting, Denver CO USA. Website: www.geosociety.org/meetings/index.htm

2011

■ 25-27 May 2011. GAC/MAC Annual Meeting, Ottawa ON Canada. Website: www.gac.ca/activities/index.php

■ 22- 26 August 2011. 25th International Applied Geochemistry Symposium, Rovaniemi Finland. Website: http://www.iags2011.fi/

■ August 2011. 10th International Congress for Applied Mineralogy, Trondheim Norway. Website: www.icam2011.org

AAG Member News

Erick Weiland has been appointed by Arizona Governor Janice Brewer to the State Board of Technical Registration. This two-year appointment will serve geology professionals and the public, and he will represent the State of Arizona on the Association of State Boards of Geologists (ASBOG) in the licensing and certification of geologists in the USA.

Erick has been an active member of Association of Applied Geochemists (previously Association of Exploration Geochemists) since 1979.

25th
IAGS2011

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22 - 26 August 2011
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Towards sustainable geochemical exploration, mining and the environment

OBITUARY

A.R. (TONY) BARRINGER

A. R. (Tony) Barringer passed away August 15, 2009 in Golden Colorado in his 84th year. He will be remembered as a unique individual whose prodigious efforts in scientific discovery and invention spanned 50 years, during which time he generated an enormous body of ideas and technologies covering fields as diverse as mineral and oil exploration to health and security. Barringer must rank as a genius if not for his achieved contributions then for the shear breadth of his imagination regarding the measurement of physical aspects of the Earth that few had conceived of before or since.

Born in England in 1925, he received B.Sc. and Ph.D. degrees in economic geology (1954) at the Royal School of Mines, Imperial College, London. Tony's tertiary education was interrupted however, by the Second World War where he quickly became an officer and served in the Middle East Theater in the waning months of the war. For his formal education he chose geology; this he attributed to early influences of a neighbor who was an avid amateur geologist and his father who had worked as a mining engineer in Canada.

Upon receiving his doctoral degree, Tony joined the Selco Exploration, the Canadian exploration branch of the British company Selection Trust. The mid-1950s were very exciting times in minerals exploration in Canada and airborne geophysics was seen by many groups as the way to explore the vast tree-covered interior of Canada. What was unique about Tony was that he quickly developed a concurrent vision of the importance of airborne geophysics employed together with ground geochemistry. Later he extended his geochemical concepts so as to demonstrate that remote geochemical sampling could be achieved as well. After four years as an exploration geologist with Selco, Tony approached the chairman of Selection Trust, Chester Beatty with the idea for an new airborne EM system that Tony felt would be a significant improvement over the technology then in use. Beatty backed Tony to work on what became the INPUT (*I*nduced *PU*lse *T*ransient) EM system. Field testing began in 1960 and the Mark V system was introduced in 1964, the first commercial version of INPUT. In 1967 INPUT was licensed to Questor Surveys Ltd, a division of Selco in Toronto and also to Geoterrex Ltd., based in Ottawa. INPUT was Tony's best known and most commercially successful legacy and is attributed with being used in the discovery of more than 25 orebodies worth collectively over 100 billion dollars. The majority of the modern day airborne systems owe all or at least part of their inheritance to the design of the INPUT system.

Barringer Research Ltd was created in 1961 by Selco and Barringer so as to allow Tony to pursue independently the development of his ideas. Over the next almost 30 years a steady stream of ideas and technologies emerged from the Barringer organization. In the field of geochemical measurement, the AIRTRACE and SURTRACE systems were two of his major achievements. Tony developed the E-Phase and Radio-Phase airborne EM instruments used for shallow mapping. This work appeared to shape his later thinking about how natural EM fields could be used for mapping deep structures remotely; a topic that was the focus of his energies in the later years of his life. Barringer presented over 80 technical papers and was awarded over 70 patents.

Tony could not have achieved his dreams single-handedly. He related very well to other people at all levels and was an exciting and motivational person to work for. One of his greatest legacies is what has become termed the *alumni* of the *Barringer University*. Many of these people went on to become industry leaders in their own right. As a tribute to Tony on the approach of his 80th birthday in 2004, a large group of the *alumni* gathered to honor him in Denver, USA during the Society of Exploration Geophysicist's annual meeting.

Tony's contributions and knowledge were well recognized by others. He was a visiting scientist to NASA and a visiting professor at his alma mater in London. Various geoscience and industry groups bestowed their highest honors on Tony; this included the Geological Association of Canada's Logan Medal (1977), Society of Exploration Geophysicists' Virgil Kauffman Gold Medal (1980), American Institute of Mining and Petroleum Engineers' Daniel C. Jackling Award (1985) and induction into the Canadian Mining Hall of Fame (1998).

Barringer officially retired in 1989 but remained professionally active until the last few months of his life. In late 2004, he wrote the following about his 'current project' using natural EM fields to find oil and gas deposits from an airborne platform; he remained engaged in this project until his death.

"The underlying physics is sound and we can penetrate to 20,000 ft. We also detect the definitive plume 'signatures'. All that is now needed is one success and we can move forward. I hope that my final biography will record this success."

Tony is survived by his wife Jean of 60 years, their five children and four grandchildren. The family has requested that anyone wishing to make donations in Tony's honour do so through the KEGS Foundation (www.kegsfoundation.org) Pioneer Fund.

Laurie Reed *(lereed@aztec-net.com)*
Ken Witherly
Peter Bradshaw
with ideas and remembrances from many Barringer alumni.

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This list comprises titles that have appeared in major publications since the compilation in **EXPLORE** Number 144. Journals routinely covered and abbreviations used are as follows: Economic Geology (EG); Geochimica et Cosmochimica Acta (GCA); the USGS Circular (USGS Cir); and Open File Report (USGS OFR); Geological Survey of Canada papers (GSC paper) and Open File Report (GSC OFR); Bulletin of the Canadian Institute of Mining and Metallurgy (CIM Bull.): Transactions of Institute of Mining and Metallurgy, Section B: Applied Earth Sciences (Trans. IMM). Publications less frequently cited are identified in full. Compiled by L. Graham Closs, Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401-1887, Chairman AEG Bibliography Committee. Please send new references to **Dr. Closs,** not to **EXPLORE**.

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