The use of automated indicator mineral analysis in the search for mineralization – A next generation drift prospecting tool

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Introduction

The natural endowment of glacial and stream sediment covering bedrock poses a significant challenge to the discovery of buried mineral deposits in Canada and elsewhere. As such, indicator mineral surveys have become a common exploration tool in till covered regions of Canada (cf. Averill 2001; 2011) with industry and research organizations, such as the Geological Survey of Canada and Geological Survey of Finland, conducting much research on the examination of fine heavy mineral fractions of till. The standard preparation techniques involve the field collection of 10-20 kg till (or other surficial sediment) samples, sieving the collected material into a range of grain sizes, then preparation of a heavy mineral concentrate (HMC) from the 0.25-2.0 mm size fractions through labour-intensive gravity techniques that ultimately involve the use of heavy liquids (McClenaghan 2011). The resultant 0.25-2.0 mm grain size samples are optically examined using a binocular microscope. Grains of specific "indicator" minerals are identified through some combination of colour, hardness, cleavage, lustre, and crystal morphology properties. They are then counted and selected grains are removed from the HMC; so-called "traditional visual analysis" or TVA (Averill & Huneault 2016). The mineral phases determined are those indicator minerals that are specific to the type of mineral deposit(s) or bedrock lithologies being explored for. The full range of mineral phases present in these samples, however, cannot be ascertained purely through visual analysis. Furthermore, positive identification of each mineral phase picked typically requires subsequent micro-analyses by scanning electron microscope or electron microprobe (e.g., McClenaghan 2011).

Over the past seven years, in collaboration with Altius Minerals Inc. and Vale Newfoundland and Labrador Ltd., we have developed a method with a FEI Scanning Electron Microscope-Mineral Liberation Analyser (SEM-MLA) to quantitatively evaluate the mineralogy of surficial sediments including till, stream sediments, soils, and gossans collected in Newfoundland and Labrador, Canada (Fig. 1). In this discussion, we will elaborate on this work with respect to indicator minerals in tills. However, the method is not restricted to use with till and stream sediments in glaciated terrain, but can be used for all types surficial sediments in
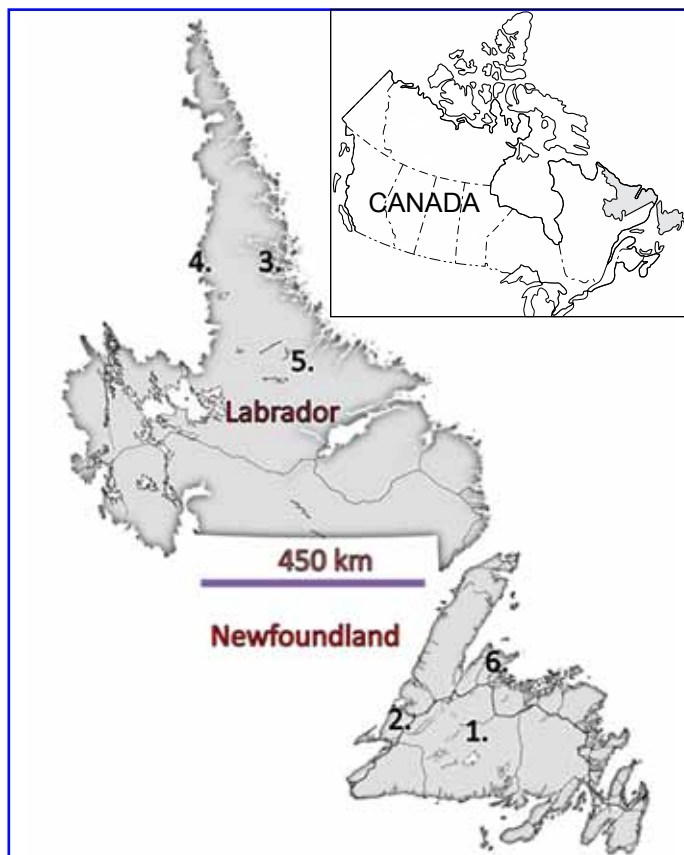

Figure 1. Map of Newfoundland and Labrador, Canada, with locations discussed in text. 1 = central Newfoundland ophiolite (Pipestone Pond); 2 = western Newfoundland ophiolites (Lewis Hills); 3 = location of Vale's Voisey's Bay Ni-Cu Mine and the village of Nain; 4 = Strange Lake REE deposit; 5 = Florence Lake PGE occurrences; and 6 = abandoned Baie Verte asbestos mine.

all terrain types. SEM-MLA analysis is also available at commercial labs in Canada and other countries.

The basis for Mineral Liberation Analysis (MLA) studies is the energy dispersive fingerprint for each mineral or mineral association; referred to as a Species Identification Protocol or SIP[1]. The SIP matches the observed EDX

SIPs is a terminology typically used by QEMSCAN users. The term also quite concisely defines our MLA library; the terms Mineral Reference Editor and MR lists or spectral libraries have also been used.

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Notes from the Editor

Welcome to the first issue of 2017. **EXPLORE** issue 174 includes one technical article that describes the use of automated indicator mineral analysis as an exploration tool and was written by Derek Wilton, Gary Thompson, and David Grant.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue: Steve Amor, Patrice de Caritat, Alecos Demetriades, Mike Gadd, Fred Gaidies, Bob Garrett, Sofie Gouwy, David Grant, Dan Layton-Matthews, David Leng, Jan Peter, Ryan Noble, Dave Smith, Gary Thompson, Xueqiu Wang, and Derek Wilton.

Beth McClenaghan, *Editor*

2017 AAG Dues Reminder

**Reminder that AAG membership fees for 2017 are now due.
Membership fees can be paid on AAG's website
www.appliedgeochemists.org**

President's Message

I hope your 2017 is off to a positive and productive start. In my corner of the globe (Western Australia) there are subtle indicators that the minerals industry is gradually improving from what has been referred to as an *extended* downturn. A lot of these activities are cyclical, but perhaps 2017 is trending in a positive direction, fingers crossed. The consultancy sector is one that is probably worst affected, and this trickles down (no reference to the U.S. election) from applied exploration geochemistry related consultancy through resource recovery and into remediation and the applied environmental geochemistry realm. I recognise these times are challenging for a number of our AAG members and in particular I'd like to thank you for your loyalty to the AAG.

Similar to the slight positive direction of the minerals industry, I expect positive things for the AAG in 2017. The numbers of members has increased and I think this is something we can build further. We all know at least one person that would benefit from and enjoy being part of the AAG. If we can actively add a few members, the AAG will be in a strong position for the future regardless of industry trends and commodity demand cycles. I implore you to have a conversation with your colleague and encourage them to join or attend our IAGS just to better understand the applied geochemistry landscape.

The continuing success of the AAG relies on the dedicated work of many of our members that work behind the scenes. If you would like to be more involved with the AAG, please contact me as we are always looking for new people and ideas to carry us forward.

By now, I hope that you have paid your AAG membership dues for 2017. You will notice that we are changing to a more consistent digital delivery of our publications, including GEEA and **EXPLORE**, as well our member notifications. This shift to digital allows more freedom with content volume so I expect we will see more articles and more figures. The electronic only subscription also saves the AAG a significant amount of money in terms of postage and hard copy printing. The money saved will be used to increase support for students (IAGS travel/attendance) as well as a couple of new awards for publications in GEEA. I fully expect the next IAGS in Vancouver in 2018 will be our biggest yet, partly because of the collaboration with the other organizations to host the meeting. I also expect our AAG sessions will be better attended than previous IAGS. So please add this event to your calendars now (June 16-21, 2018) as part of RFG 2018. A large student presence is important, so please encourage students to apply for AAG travel grants. I am looking forward to it.

2017 is also the year that the Geological Survey of Canada celebrates in 175th year. The GSC continues to be an important contributor to, and mentor of, students in applied geochemistry and on behalf of the AAG, I congratulate Canada for the continued success of this important scientific institution and wish it well for the next 175 years.

Ryan Noble
AAG President
ryan.noble@csiro.au

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(energy-dispersive X-ray) scanning electron (SEM) spectra of each particle against the MLA database of stored spectra (i.e., "fingerprints"). The Memorial University group (MUN) in Newfoundland, Canada, has developed a sophisticated library of SIPs that can identify almost all minerals present within a given sample, down to < 0.3% unknowns (e.g., Wilton & Winter 2012; Wilton et al. 2015), using a matching threshold of 70% in the MLA software. New minerals are added to the library as they are identified. At present we can analyse a till/stream sediment sample and accurately identify up to 99.7% of mineral particles present in the sample; a given individual sample when prepared for analysis can contain up to 20,000 particles. A typical analysis time per sample is 1-2 hours.

The SEM-MLA can define what indicator minerals are present in both ore and ore-associated rock, including alteration haloes. The latter may actually represent a much larger reservoir of indicator minerals than the deposit itself, in that the ore-associated rock and/or alteration halo will contain its own suite(s) of indicator minerals that is larger than the deposit itself. As such, the greater volume of potential indicator minerals may produce a more significant target signal for the mineral deposit system than the deposit alone.

Alteration of country rocks by hydrothermal fluids involves the development of new minerals that replace the original mineralogy (i.e., the original minerals were susceptible to alteration). Most of the potential indicator minerals of interest will be in a HMC, but lighter density, distinctive alteration minerals, such as micas, can also be present in a till sample. The HMCs produced for SEM-MLA work will typically include some lighter density phases, in particular as intergrowths with denser HMC minerals. In our SEM-MLA techniques, we analyse some of the non-HMC (i.e., light mineral concentrate) mineral separates to make sure that no potential indicator minerals are missed. A further advantage to using MLA is that it collects a spectra of all grains that are distinctive in BSE and these data can be re-visited and queried offline at a later date if a new indicator mineral relevant to mineral exploration is discovered. Traditional visual analysis, or TVA, (cf. Averill & Huneault 2016) in which HMC are observed with a binocular microscope, would not allow such querying of a data set. Presumably if an important new indicator mineral has an apparently distinct visual appearance, then the operator can go back through the HMC and pick out the new phase of interest. Otherwise, all phases with similar visual aspects would have to be picked and subsequently analysed by EMP to determine their presence.

The SEM-MLA can define a greater range of indicator minerals for each deposit variety, along with mineral intergrowth textures, such that a matrix or assemblage of indicator minerals can be defined that might be specific to each deposit type. The ultimate aim would be to use the automated quantitative mineralogy capabilities of the MLA to parse through a surficial sediment sample HMC and define whether, and what, indicator minerals of any mineral deposit type are present.

Sample Preparation

The initial till sample as collected in the field consists of about 10 kg of material. The till is air-dried after which we typically sieve into nine size fractions: $< 63\,\mu m$, 63-125 μm, 125-180 μm, 18-250 μm, 250-500 μm, 500 μm – 1 mm, 1 - 2 mm, 2-4 mm, >4 mm; although only one fraction is actually used for the SEM-MLA analysis, the other fractions are retained in case additional information is required. To determine the optimum grain size of till HMC minerals for SEM-MLA analysis, a series of different size fractions were analyzed and it was found that the 125-180 μm fraction provided the optimal results (Wilton & Winter 2012). If the grain size was smaller than 0.125 mm, the analyses took longer (30-50%) and the minerals were more difficult to definitively identify as the X-ray beam is statistically more likely to miss a grain centroid and instead land on a grain boundary or crack/pit producing an unwanted result. If the grain size was larger than 0.180 mm, the number of particles that could be analyzed in a given grain mount decreased by 25 to 75% and the range of observable intergrowth textures decreased. The 0.125-0.180 mm grain size was the easiest to evaluate for contamination, as, in general, any airborne contaminant grains in a processing (sieving) facility, or contaminant grains introduced to the mount during polishing, would be demonstrably finer grained.

The 125-180 μm size fraction is processed using a shaking (Wilfley) table to separate lighter from denser minerals; our specific gravity threshold between heavy and light minerals using the shaking table is about 2.7-2.8. In general, we would only use one pass over the table, as we wished to analyse minerals of intermediate density and/or dense-light intergrowths to fully understand the till material. The table concentrate, of course, can be repeatedly processed over the table using different splitting parameters, tilt, etc. to produce a higher density HMC. We do not use heavy liquid or magnetic separation techniques on the separates.

The resultant HMC for each sample is then partitioned using an automated micro-riffler to produce a 0.3 g separate that is poured as a 25 mm in diameter layer within a 30 mm mold in diameter (Fig. 2a). This amount of material settles as a mono-layer such that there is no gravity-induced separation of denser particles. The mould is filled with epoxy and the hardened puck is polished (Fig. 2b). We use a round
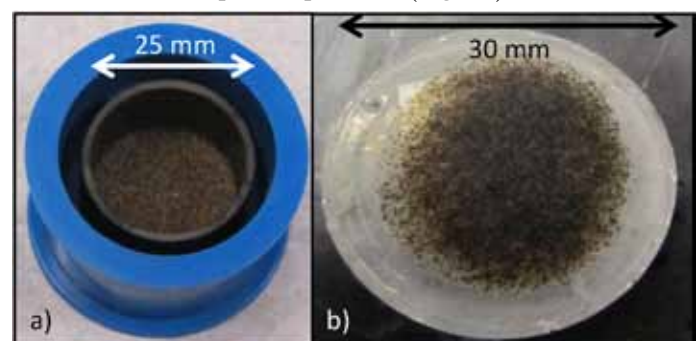

Figure 2. a) Till HMC separate (0.3 g of 125-180 μm fraction) forming monolayer within inner 25 mm diameter plastic ring within 30 mm in diameter puck (blue); **b)** polished puck containing upwards of 20,000 particles.

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mould for the till samples, but the Core Research Equipment and Instrument Training (CREAIT) network group at MUN (Grant et al. 2016) have also produced 30 x 17 mm (x 10 mm) rectangular moulds that hold up 1 g of material. Sample pucks are carbon-coated and the grains are analysed via the SEM-MLA. For the 30 mm round pucks we use an 8-Round sample holder so that eight samples are analysed per run. Figure 3 shows the SEM sample chamber and 8-Round sample holder for the 30 mm pucks.
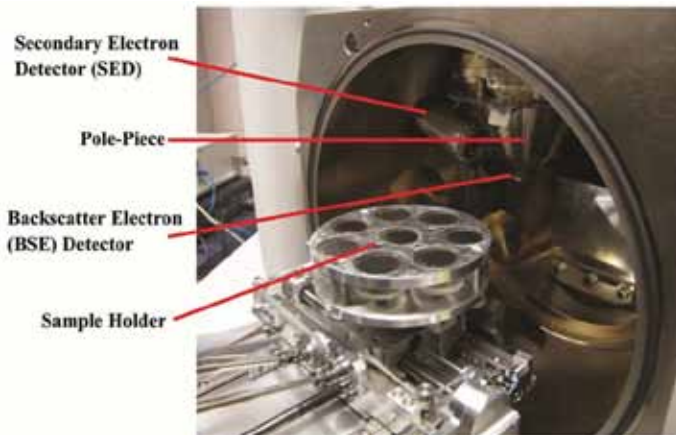

Figure 3. The SEM sample chamber with 8-round (30 mm) holder for epoxy grain mounts (from Sylvester 2012).

Samples can also be directly prepared from surficial sediment material without going through the processes of sieving and density separation. In such a case, a split is removed from the sample and mounted in the epoxy puck;

obviously grains must be less than 25 mm in diameter or they won't fit in the mould.

SEM-MLA analytical techniques

Sylvester (2012) provides a detailed overview of the theory and systematics of the SEM-MLA system. The SEM portion of the SEM-MLA laboratory in the CREAIT facility at MUN consists of a FEI Quanta 400 environmental SEM equipped with a Bruker XFlash EDX Detector. The SEM electron gun uses a tungsten filament at an operating voltage of 25 kV and a beam current of 13 nA. The working distance between sample and detector is 12 mm. The SEM is equipped with Mineral Liberation Analyser (MLA) software developed at the University of Queensland (Australia) Julius Kruttschnitt Mineral Research Centre (JKTech) (e.g., Pietersen et al. 2009). The sophisticated MLA software associated with the SEM allows for quantitative evaluation of the abundance, association, size and shape of minerals in automated, systematic fashion. In other words, the MLA allows for the quantitative mapping of mineral phases in individual grain mounts and/or polished thin sections, essentially providing a digital point count of mineral species. The MLA software requires that the SEM be configured in back-scatter electron (BSE) image mode wherein minerals that contain denser elements produce brighter images. Essentially the MLA detects mineral particles in the grain mount based on variations in BSE grey scale and then analyses each particle. The particles can be inclusions, or, as in many cases several inclusions, within a larger grain.

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For till HMC samples, the grey-scale "threshold" was set with the epoxy as black and metallic copper as white. The dwell time (i.e., time spent acquiring data) for each X-ray analysis of a particle is 60 microseconds. Image size resolution was set at 800 dpi and minimum particle diameter detected was about 5 μm. The MLA compares the elemental spectra for any particle analyzed with a "library" of mineral spectra to identify the particular phase. If the MLA software cannot identify a mineral during analysis, it is recorded as an "unknown" and the analyst manually re-examines the spot analysed after the automated run to ascertain whether it truly is an unidentified mineral or a defect in the polished surface (i.e., crack, hole, etc.). In rare cases, the analysis is obtained on a boundary between two minerals in a particle containing more than one mineral species and is therefore a mix of two mineral spectra.

During the post-processing of the MLA run, the operator can also query the location and/or form of particular particles. The instrument can be engaged to return to specific particles of interest and the operator can examine the particles in detail up to, and including, the conducting of real-time EDX analyses of the mineral and intergrown phases. The operator can also obtain higher resolution BSE images at this stage. During the analytical run, spatial registration points can be taken for the grain mount, such that all particles can be precisely located if future analyses, such as Laser Ablation ICP-MS, or EPMA, are to be performed on the grains of any particular mineral phase.

The MLA maps each grain mount in terms of frames per mount, typically using a horizontal field width (HFW) of 1-2 mm. About 100-120 frames are measured with approximately 100 particles/frame, this is sufficient for a typical MLA analysis as >100 particles will saturate the X-ray detector, thus missing X-rays and leading to inadequate results; each frame represents a portion of the mount. The particles in each frame are analyzed and then their relative and absolute abundances can be calculated. The EDX spectrum collected by the MLA simply indicates what elements are present in the mineral and their relative concentrations; it does not determine the crystallographic nature of the particle (e.g., gypsum cannot be readily distinguished from anhydrite). Furthermore, as the MLA analyses are spectrum-based, the EDX component cannot identify minor (trace) elements within individual minerals. Thus, any elements identified in a mineral are significant (>1%) components of the given mineral phase.

The confidence level for the spectral match is set during the initial analysis; typically set at about 90% probability. The software scales the probability between 0% and 100%, with 100% as a perfect match (probability of 1) whereas 50% has a probability match of 1.00E-80 which termed an "average match" (Mateo 2010). With post-processing and identification of unknowns, the confidence level can be reset to another level. A higher threshold would require a closer match between observed and stored spectra increas-

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ing the precision on the results. Generally during the initial processing stage the level is adjusted to 90% ensuring all atypical mineral spectra are examined in detail. During this stage it may be possible to identify multiple variants of the same mineral, i.e., magnetite with high or low Ti contents. The frame is the fundamental organizational template for the MLA technology. The software can produce a BSE map of all particles in a frame (Fig. 4a) and a false-color map (Fig. 4b) of particles based on an assigned color legend for each particle.
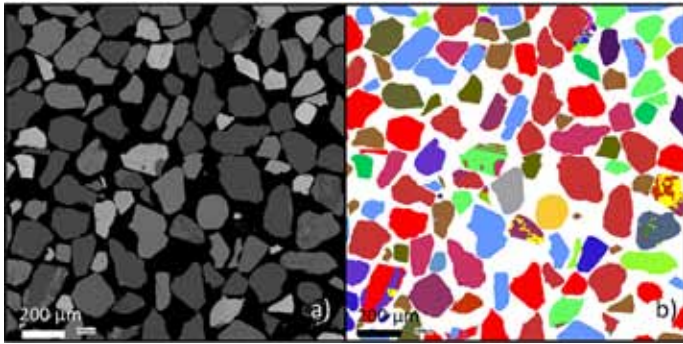

Figure 4. a) BSE map of single frame; **b)** MLA false colour map of the same frame (note scale bars are 200 μm long); plagioclase grains are red and magnetite grains are green on the MLA map.

The frames can be stitched together to provide a map of the entire grain mount analyzed (Fig. 5). More detailed queries can provide information on a particle, and thus mineral grain size and shape.
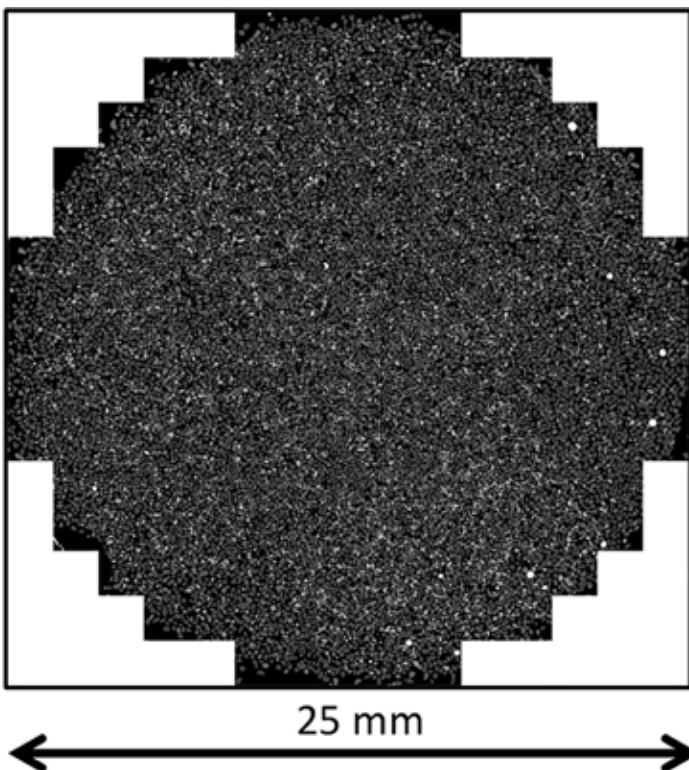

25 mm

Figure 5. BSE map of entire sample made from stitching all frames together; sample contains upwards of 20,000 particles.

Our SEM-MLA routinely analyzes and identifies 10,000 to 20,000 particles in an individual 0.3 g grain mount; "particles" include larger mineral grains as well as inclusions within a larger grain. Following standardization of the amount of material mounted in an epoxy puck and also the analytical parameters, the range of particles typically identified in a grain mount is 10,000 to 17,000. The analytical area is set as close to 25 mm in diameter as the grain mount allows.

Using the mineral library, a typical analysis of a grain mount would be completed in 1 to 2 hours with post-processing of 1 to 1.5 hours for a total analytical time per grain mount (or till HMC separate) of 2 to 3.5 hours. The initial analytical times, prior to derivation of a more complete SIP library, were on the order of 4 to 6 hours per sample. Using the MUN spectral library, unknown particles in a grain mount generally make up less than 0.25%, a remarkably low proportion of the more than 10,000 particles identified in a sample (i.e., generally less than 25 particles). Many of these "unknown" particles are actually misidentified phases. If a truly "new" (i.e., previously unseen) mineral phase is identified, a clean spectrum is collected and added to the spectral library.

Data Output

Table 1 illustrates the type of digital data produced from the MLA analysis of each mineral in a till sample; for the sake of brevity, the ten most abundant phases in the sample are listed. Each mineral present in a sample is mapped in terms of weight % (based on the proportion of the mineral in sample compared to all minerals in the sample from the ideal molecular weight of the mineral), area % that the mineral represents compared to all other minerals in the sample, the actual area of the mineral in the sample as mapped by the MLA (in μm), the number of particles of the mineral mapped in the sample, and the number of grains of the mineral in the sample. The number of grains is always greater than the number of particles, as the MLA definitions can have a particle that is composed of 2 or more minerals, such as a quartz inclusion in a magnetite

Table 1. Digital output for sample T-001 - ten most abundant minerals mapped using SEM-MLA.

Mineral	Wt%	Area%	Area (micron)	Particle Count	Grain Count
Total	100.00	100.00	161347556.25	13579	22959
Ilmenite	29.45	23.95	38640787.50	3588	3920
Magnetite-Ti	14.04	10.74	17329350.00	1804	2095
Plag-An50	7.50	10.97	17696937.50	1672	1762
Almandine	9.72	9.05	14608650.00	1350	1397
Hypersthene	7.16	7.87	12701712.50	1206	1286
Plag-An25	4.59	6.76	10902475.00	1249	1477
Quartz	3.36	4.95	7990918.75	939	1063
Magnetite	5.40	4.06	6544631.25	644	677
Grunerite	2.60	2.95	4754506.25	516	575
Cpx_Diop	2.08	2.39	3851768.75	443	489

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grain. Because many of the potentially important indicator minerals may represent less than 0.01% of the sample, the mineral's area in microns is the best parameter to use for comparing mineral contents between samples. Note that the SEM-MLA can detect variations in magnetite composition and identify magnetite grains that contain significant Ti; traditional visual analyses would not be able to detect such variations. The MLA software has tools for advanced classification, including 1) using EDX spectral windows to characterize percentage of elements that must be present to match a particular species ID, or 2) the ability to place thresholds of minimum and maximum elemental percentages on classification scripts that can be used, for example, to further distinguish a pure magnetite from titano-magnetite.

Examples of the use of SEM-MLA in indicator mineral search

Awaruite in Newfoundland

The Altius-MUN SEM-MLA surficial sediment indicator mineral work was initiated to evaluate whether the mineral awaruite was present in Newfoundland ophiolites (Wilton & Winter 2012). Awaruite (Ni_3Fe) is a magnetic, dense, nickel-iron alloy formed during the serpentinization of ultramafic, particularly olivine-bearing, rocks (Filippidis 1985). In 2009, First Point Minerals Corporation began an exploration and economic evaluation program on the Decar Property in northern British Columbia, Canada. The target units on the property were serpentinized ultramafic rocks (Verley 2011). Nickel assay values of up to 0.1 to 0.15% in the ultramafic rocks suggested that the property might represent a new class of potentially commercial nickel deposits, consisting of disseminated awaruite *(op cit)*.

Using the First Point concept of disseminated awaruite as a potentially commercial source of nickel, and based on the large number of ophiolitic ultramafic complexes in western and central Newfoundland, Canada, Altius Resources Inc. initiated an exploration program for awaruite in Newfoundland with a joint venture partner Cliffs Natural Resources Inc. But exploration for awaruite in the ophiolites was problematic because awaruite had not been previously reported, and the ophiolites, themselves, represented two contrasting targets. On the one hand, western Newfoundland ophiolites (Fig. 1 location 2) comprise huge massifs of barren outcrop in which it would have been extremely difficult to define prospective awaruite-bearing horizons without intense, detailed mapping and petrographic examination. In contrast, ophiolites in central Newfoundland (Fig. 1 location 1) are very poorly exposed as widely separated patches of bedrock outcrop extensively covered by till.

In order to evaluate the two different ophiolite areas (massifs with 100% outcrop vs. till-covered outcrop remnants), the Altius-MUN group decided to sample stream sediments from the massifs and till from the till-covered units and then analyse derived HMC separates via SEM-MLA for awaruite and any associated minerals. Awaruite was detected in both the tills and stream sediments (Fig. 6) along with the rare pair of hydrated Ni-bearing minerals, asbolane ($(Ni,Co)_2$-$xMn^{+4}(O,OH)_4 – H_2O)$) and pecoraite

($Ni_3(Si_2O_5)(OH)_4$). The SEM-MLA technique proved successful and identified areas in both ophiolite regions in which awaruite is present in outcrop (Wilton & Winter 2012).
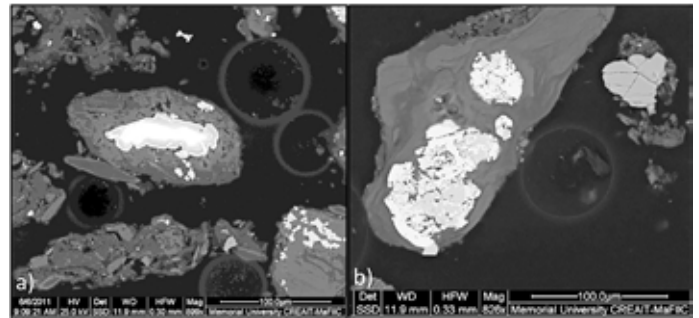
Figure 6. BSE images of awaruite grains mapped by MLA: **a)** awaruite (white) in serpentine grain (darker grey) with Cr-bearing awaruite rim (medium grey) from a till sample collected in central Newfoundland (location 1 on Figure 1); **b)** awaruite (white) intergrown with magnetite (medium grey) within serpentine grain (dark grey) from a stream sediment sample collected in western Newfoundland (location 2 in Figure 1).

Awaruite is a silvery-white mineral that can be mistaken for chromite, magnetite or some other metallic phases in traditional visual analysis (Fig. 7). It was the EDX component of the SEM-MLA system that actually defined its presence in the surficial material. The mineral would be difficult to identify using TVA.
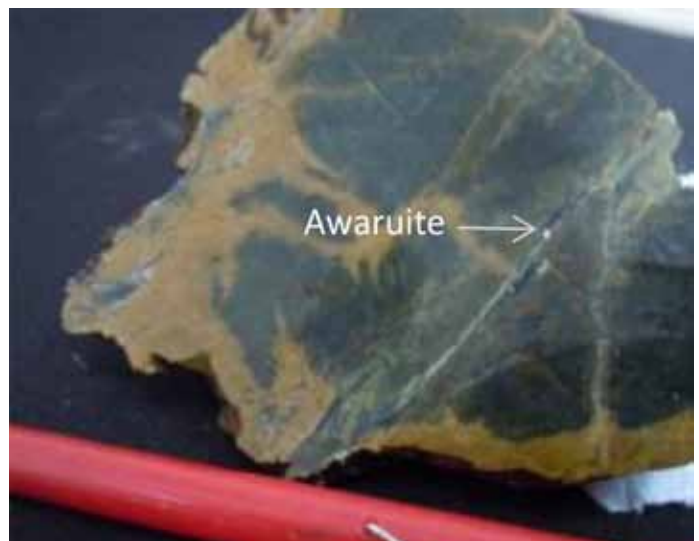
Figure 7. Awaruite grain in serpentinized ultramafic rock, Pipestone Pond Ophiolite Complex, central Newfoundland (location 1 in Figure 1) from Piller (2012). The outcrop was discovered in follow-up mapping after the identification of awaruite in till using SEM-MLA.

Sulphides in surficial sediments around Voisey's Bay

In a 2009 study (unpublished Vale report), we examined indicator minerals in till and stream sediments around the Voisey's Bay region of northern Labrador (Fig. 1 location 3), Canada, using the SEM-MLA. We subsequently conducted a more detailed SEM-MLA analysis of surficial sedi-

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ments in the vicinity of the Voisey's Bay orthomagmatic Ni-Cu-Co sulphide deposit (Evans et al. 2000; Lightfoot et al. 2012) to ascertain whether there were detectable sulphide minerals present and whether they might be a vector towards Ni-Cu sulphide mineralization. The surveys included a cross-section from bedrock gossan through overlying till in the Ovoid mine pit wall, and the sampling of till in a sonic drill hole 7 km north of the Ovoid open pit and five split spoon till cores surrounding the Ovoid open pit (Wilton at el. 2014, 2015). The split spoon core was collected by hammering a 10 cm in diameter plastic pipe through the till to bedrock.

In the cross-section study, data from the BSE and MLA were used to identify a previously unrecognized regolith developed on the massive sulphide bedrock beneath overlying till (Fig. 8). The regolith material contained angular to acicular grains composed mainly of oxidized Fe-sulphides (Fig. 8a), whereas the till was composed of rounded dominantly silicate phases with Fe-oxide rims (Fig. 8b). The age of this regolith remains undetermined but it could be as old as Cretaceous (cf. Conliffe 2015). The recognition of this regolith by SEM-MLA provides an important clue for future exploration.

Figure 8. BSE images of grains recovered from **a)** regolith, and **b)** till samples in cross section from bedrock through regolith to till in the Ovoid Open Pit, Voisey's Bay Mine, NL, (location 3 in Figure 1) as determined by SEM-MLA (from Wilton et al. 2015).

Core from the sonic drill hole was sampled at five different intervals over its 26 m length; the sample material was not sieved, nor tabled and was simply mounted in epoxy. The mineralogy of the till material in all five samples as analysed by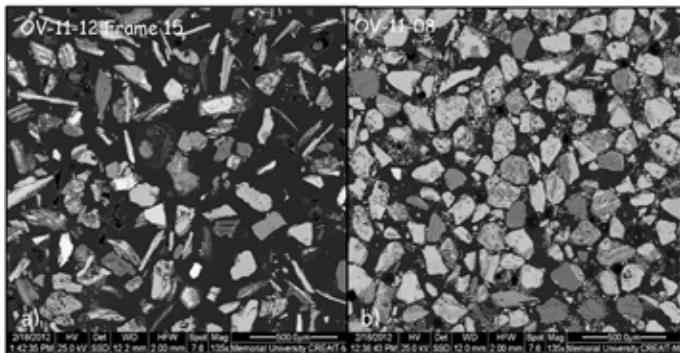 the SEM-MLA was basically the same with the dominant minerals being quartz, clay minerals, feldspars and hornblende. Diopside was prominent in the lowermost two till samples. Similarly, there is more hedenbergite and ilmenite in till samples further down the hole. Epidote and biotite are more abundant in the upper three samples. Thus it appears that the two deepest samples, from just above bedrock, have greater concentrations of minerals that would be considered to be derived from the local mafic igneous rocks. Other minerals, such as hercynite and magnetite, associated with Voisey's Bay mineralization do not have any downhole variation. Sulphide grains, very predominantly iron sulphides (gossan) and/or oxidized iron sulphides were detected in the till, but are only abundant (43 grains) in the

bottom 1.2 m of the hole. Chalcopyrite (four grains) and sphalerite (1 grain) were detected in till at the bottom of the hole.

The five split spoon holes were all drilled around the Ovoid mine. Seventeen till samples (four each from two holes, and three each from the others) were analysed by SEM-MLA. These samples were not sieved, nor tabled, and represent a complete sample of the material, excepting larger pebbles and cobbles. All 17 samples were poorly sorted diamicton (i.e., typical till). Largest grains were up to 600 μm in diameter and fine fraction material was clay-sized ($<5\,\mu$m). Some samples were more equigranular and clay-rich than others. Locally, portions of the samples were clast-supported. The dominant modal mineralogy, all samples contain variations of quartz, feldspars, clay minerals, hornblende, micas and scapolite.

The split spoon holes contained variable amounts of sulphide and the SEM-MLA was able to identify pyrrhotite (up to 25 grains in a single sample), oxidized Fe-sulphide (gossan – up to 65 grains), pentlandite (up to 20 grains), chalcopyrite (up to 14 grains) and tetrahedrite (up to 3 grains). Pentlandite grains are variably (little to complete) oxidized. Some pyrrhotite grains have exsolved pentlandite and chalcopyrite (Fig. 9).
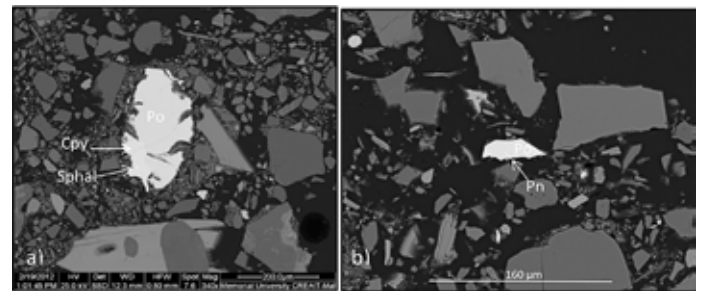
Figure 9. BSE images of till from split spoon drill holes near Ovoid Open Pit Mine, Voisey's Bay, NL as mapped by SEM-MLA: **a)** ragged pyrrhotite grain (Po) intergrown with chalcopyrite (Cpy) and sphalerite (Sphal) to lower left; **b)** pyrrhotite (Po) exsolved pentlandite lamellae (Pn).

The SEM-MLA analyses proved successful in identifying the dominant modal mineralogy of each split spoon sample and essentially classified the mineral composition as being typical till. No systematic spatial variations between holes of silicate (e.g., hercynite) or oxide (magnetite) indicator minerals typical of Voisey's Bay mineralization were observed. In terms of identifying trace sulphide minerals, the MLA analyses likewise proved quite useful. Altogether, the amounts of pyrrhotite-pentlandite intergrowths, abundance of pentlandite and chalcopyrite particles, and presence of metal-rich sulphide grains suggest that at least some of the minerals in the split spoon till samples were derived from a nickeliferous source, likely the nearby Voisey's Bay mineralization.

One final point to note is that, although the SEM-MLA analyses indicated that sulphide minerals could be detected in the till samples, they were few in number (< 200 particles

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in a sample with >10,000 particles). Also, the particles/ grains were minute, rarely > 100 μm (i.e., 0.1 mm) in diameter; the largest sulphide grain detected was only 1.25 mm long. These observations from the SEM-MLA work are at odds with those of Averill (2001) who stated that heavy mineral concentrates derived from 10 kg surficial sediment samples from the Voisey's Bay area contained chalcopyrite and an "overabundance of garnet" (p.74). The survey referred to by Averill (op cit.) was of bulk river sediment samples (Chislett 1994) from a ca. 7-km grid spacing. SEM-MLA analysis of till around the mine site did not indicate the presence of appreciable garnet. The split spoon and sonic samples contained < 0.65% (mainly <0.40%) and 0.41%, respectively, garnet. Chislett (op cit.), in fact, did not actually report the presence of any chalcopyrite in the river sediment samples.

Sourcing till origins

One of the most significant observations from our work on tills with the SEM-MLA is its ability to define source regions for till. In one spectacular case, the SEM-MLA was able to identify gittinsite ($CaZrSi_2O_7$) grains (Fig. 10) in till samples collected across a very limited region near Nain (Fig. 1 location 3), which is within the glacial ice stream extending from the Strange Lake REE deposit over 100 km to the east.
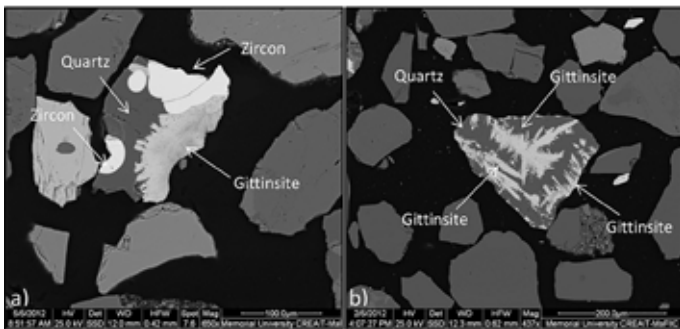

Figure 10. BSE images of till from near Nain NL, as mapped by SEM-MLA: **a)** gittinsite intergrown with zircon and quartz; **b)** feathery-shaped gittinsite intergrown with quartz (dark grey).

The Strange Lake deposit (Miller 1990; Gysi et al. 2016) is a 6 km wide peralkaline granite complex (Fig. 1 location 4), that hosts REE, Zr, Y, and Nb mineralization in granite, aplite, and pegmatite phases along with associated quartz veins. Zirconium is dominantly contained within gittinsite, a common phase in the complex (Kerr 2013). Due to the point-source nature of the granite and associated REE mineralization and well-developed surficial geochemical signatures, the deposit has become a classic example of a glacial dispersal train (e.g., Batterson 1989a; Batterson & Taylor 2009; McClenaghan 2007). McConnell and Batterson (1987) determined that the Strange Lake REE mineralization signal could be detected in till, stream sediment, stream waters, lake sediment and lake waters along a northeastern trend from the deposit. Batterson (1989b) reported that a ribbon-shaped, northeast-trending, geochemical dispersal train extended for up to 40 km from the deposit, and he concluded (p. 27) "there is evidence of

considerable transport distances. Within the study area, maximum transport is at least 40 km, with expectation that a clearly defined dispersal train extends for at least 55 km and probably farther".

The SEM-MLA study of mineral grains in till samples proved Batterson's (1989) supposition that the Strange Lake dispersal train extended much further to the northeast. The SEM-MLA data allows for the rapid and precise identification of unique minerals that can define the source, or at least a portion, of the till material at distances (i.e., >100 km), well past the decay rate (rate of elemental concentration decrease with distance down ice) for till geochemistry.

Zircon is a common component in any surficial sediment HMC and we use the abundance, size and shape of zircons in each sample as monitors of a variety of parameters in our surveys, including bedrock types, sample quality, etc. The ability to of the SEM-MLA to examine zircon interiors, allows for the derivation of fundamental information on probable sources of the till material. For instance, internal zoning within a zircon grain with a very well-developed core overgrown by an equally well-defined rim (Fig. 11a) suggests origin from a high-temperature granitic source (Cox 2003). In other examples, altered zircon grains are observed to contain uraninite-galena or thorite-huttonite inclusions (Figs 11b and c). Such zircons were derived from a U or Th rich source, but because of their metamict nature and inherent fragility, these zircons could not have been transported any significant distance (Cox 2003). Finally in some other zircon grains that we have mapped in till samples, the MLA analysis revealed xenotime overgrowths on zircon (Fig. 11d). These types of overgrowths occur during diagenetic reactions in sediment (e.g., Prost et al. 2013)
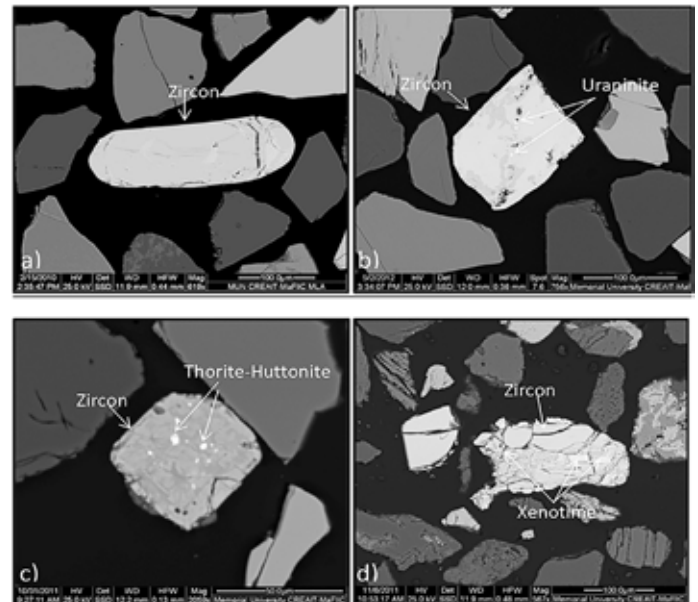

Figure 11. BSE images of zircon grains in till from northern Labrador, as mapped by SEM-MLA: **a)** zircon with well-defined core and rim; **b)** altered zircon with uraninite inclusions inclusions; **c)** altered zircon with thorite and huttonite inclusions inclusions; **d)** altered zircon overgrown by xenotime.

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indicating that the till was derived in part from a potentially low-grade sedimentary bedrock unit.

Inclusions and minerals that should not exist in tills

Traditional visual analysis (TVA) cannot see inside mineral grains unless they are removed from the concentrate, mounted and subsequently polished. Furthermore TVA is predicated on the fact that all representative minerals will be of a common size and generally monomineralic. This is not the case in nature, minerals are intimately mixed with each other from full-fledged intergrowths to inclusions of one mineral within another.

Aside from the ability to quantify and identify all mineral phases in samples, the most significant aspect of the SEM-MLA till analysis is the ability to define inclusions within other mineral grains and the ability to see through alteration rims to detect the true nature of a grain. In many cases resistant minerals mantling less resistant minerals allows for the detection of minerals in a till that should not be there because of their inability to withstand physical or chemical weathering. Figure 12 contains images of sulphide minerals that can be mapped as inclusions by the SEM-MLA, including galena, stibnite, sphalerite and arsenopyrite. Without the capabilities of the SEM-MLA, these inclusions would not have been detected by TVA.

The detail provided by the SEM-MLA can also include the identification and quantification of exsolution textures (Fig.
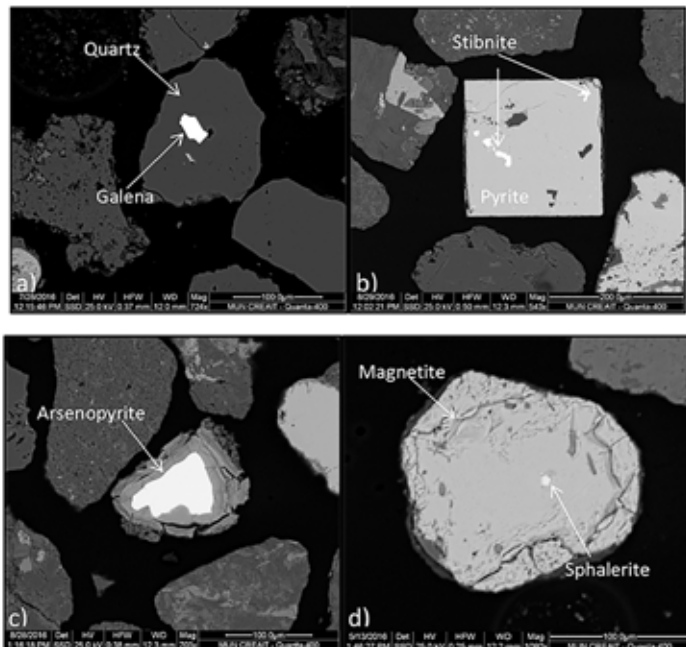

Figure 13. BSE images of sulphide mineral exsolution in inclusions from tills in NL, as mapped by SEM-MLA. **a)** pentlandite exsolved from pyrrhotite in pyroxene; **b)** troilite exsolved from pyrrhotite in pyroxene; **c)** -bornite (white) exsolved from chalcopyrite in magnetite; **d)** Ir-Rh alloy exsolved from cobaltite (cube) intergrown with pyrrhotite (note this is from a broken rock sample not till).

produce "anthropogenic" till (Wilton et al. 2016). As unmixing (exsolution) of sulphide phases is such a common and intrinsic feature of orthomagmatic sulphide deposits (e.g., Naldrett 2013), the observation of these types of textures in mineral grains from a till would strongly suggest the presence of such mineralization in the source area of the till. Such fine and delicate features would not be observable via TVA.

Precious metals and proxies

Because of inherent densities, and hence extreme brightness in BSE image mode, gold and silver are readily identified by the SEM-MLA (Fig. 14). Not only can the SEM-MLA locate and define these minerals, the innate capability to identify precious metal inclusions means that the mineralogical context or association of precious metals can be defined. The EDX component of the SEM-MLA can also distinguish different Au-Ag contents in electrum grains (Fig. 14b – upper right), aiding in definition of source and mineralization type (e.g., Chang et al. 2011).

The SEM-MLA examination of mineral grains in till (and other surficial sediments) can determine the presence of robust proxy minerals for gold that would have greater abundances that gold itself (Fig. 15). For instance, tourmaline can be a common accessory in orogenic gold deposits (e.g., Beaudoin & Chiaradia 2016). Cinnabar is likewise associated with many epithermal-type auriferous deposits (e.g., Sillitoe 1994).

Evans (1995) reported that leucoxene is a common

Figure 12. BSE images of mineral inclusions in other minerals from tills in NL, as mapped by SEM-MLA. **a)** galena in quartz; **b)** stibnite in pyrite cube; **c)** arsenopyrite surrounded by Fe-oxide alteration rim; **d)** sphalerite in magnetite.

13) such as pentlandite or troilite from pyrrhotite, bornite from chalcopyrite and Ir-Rh alloys from cobaltite minerals. The grains in Figure 13d were actually derived from crushed host rock to the Florence Lake PGE occurrence in northern Labrador (Fig. 1 location 5), Canada, in a study to
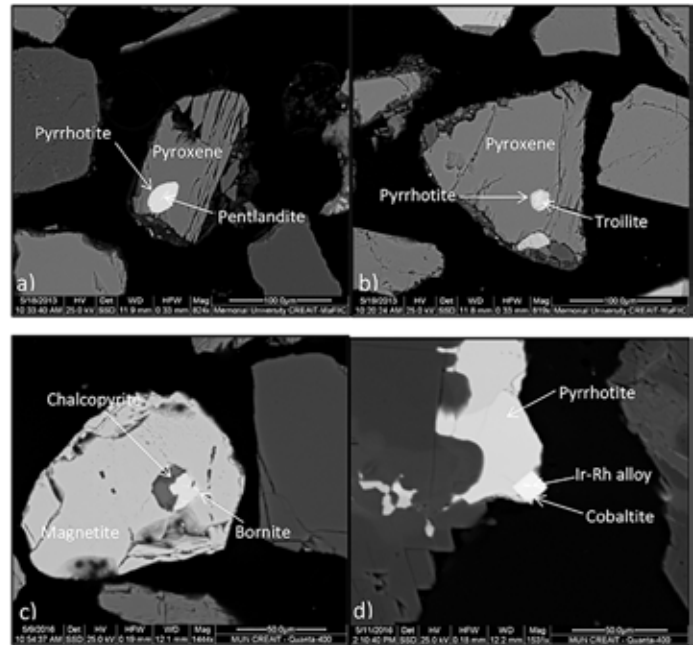
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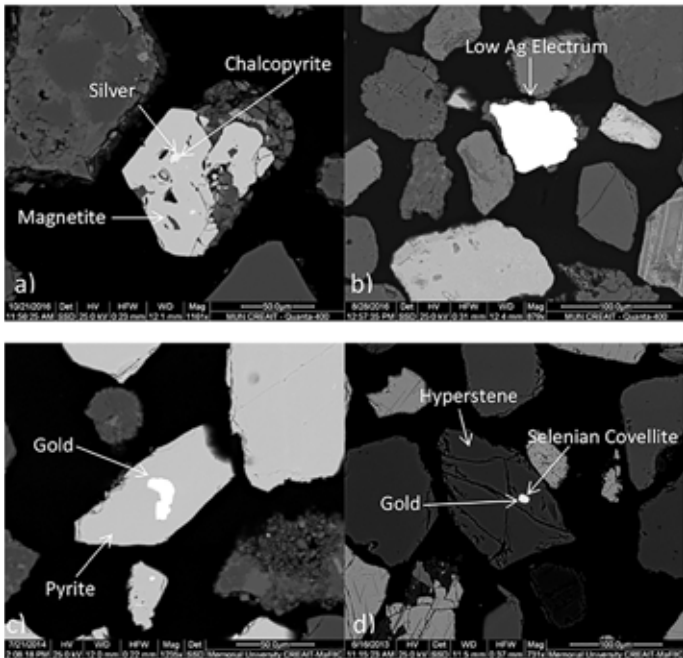

Figure 14. BSE images of precious metals in grains from tills in NL, as mapped by SEM-MLA. **a)** silver intergrown with chalcopyrite in magnetite; **b)** low-silver electrum; **c)** gold in pyrite; **d)** inute gold grains intergrown with selenian covellite in hypersthene.
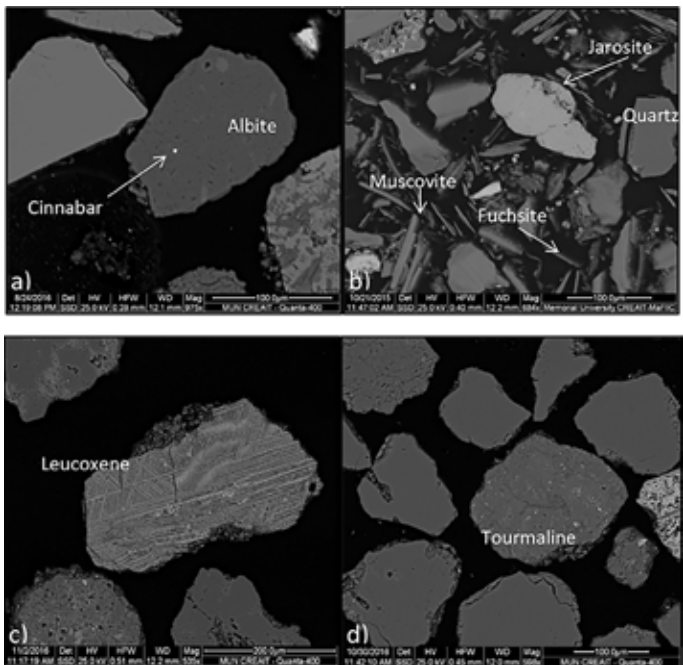

Figure 15. BSE images of proxy minerals for auriferous mineralization from tills in NL, as mapped by SEM-MLA: **a)** cinnabar in albite; **b)** jarosite grains with muscovite, fuchsite and quartz, note this is a regolith developed on the Klondyke Schist; **c)** a grain of leucoxene (altered rutile) with rutile lamellae (white); **d)** tourmaline (spongey gray).

alteration mineral surrounding gabbro-hosted gold deposits in Newfoundland. Leucoxene forms as fine-grained alteration of primary titanium minerals, primarily ilmenite and/or Ti-rich magnetite, and as Ti and its constituent minerals

are widely viewed (eg., Govett 2013) as being immobile to chemical transport, the presence of leucoxene in a surficial sediment would suggest that the sediment has sampled a region of hydrothermal alteration that might be associated with an auriferous system. Deysel (2007) demonstrated that the SEM-MLA can reliably distinguish between leucoxene and ilmenite, something that would be difficult by TVA.

Kelley et al. (2011) reported on a detailed examination of indicator minerals in till down ice of the Pebble porphyry Cu-Au-Mo deposit of Alaska, USA. Minerals of particular interest include gold, jarosite, cinnabar, Mn-epidote, andradite, apatite and pyrite. The study indicated that the different mineral phases were each important, though they may have reflected a different component of the ore-forming system. Indicator mineral identification in the study (op cit.) was based on TVA techniques, but selected grains had to be analysed by electron microprobe to confirm their identity. In contrast, the SEM-MLA can readily identify and quantify these same minerals immediately, including mineral phases such as jarosite (Fig. 15b) which can easily be mistaken for limonite in simple visual observation.

Mine remediation

A project with the Centre for Applied Health Research, Memorial University, involved examining surface sediment samples around the tailings piles at the Baie Verte Asbestos Mine (Fig. 1 location 6) in Baie Verte NL by SEM-MLA (Wilton 2013). The aim of the study was to evaluate the possible presence of asbestos minerals and, if present, the extent of their distribution. A secondary aim was to determine whether any asbestos present was solely chrysotile, or was the more toxic grunerite variety present as well. The SEM-MLA mapping identified and quantitatively defined chrysotile contents (Fig. 16) and no grunerite was detected
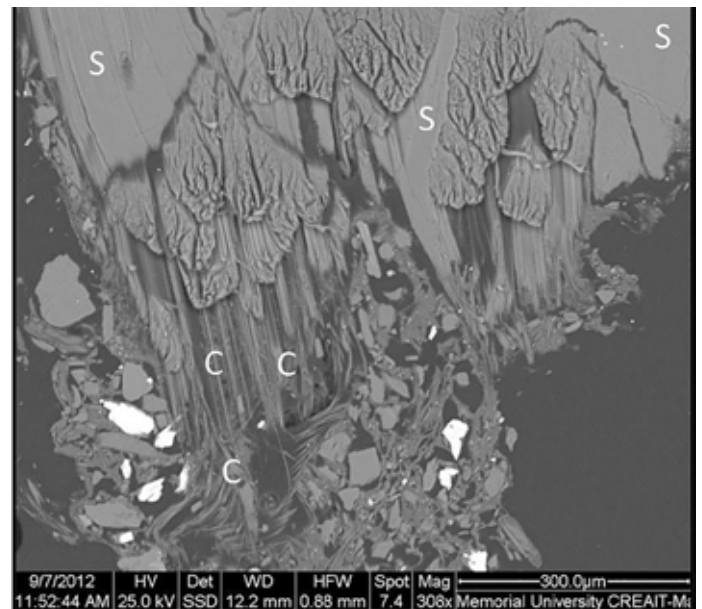

Figure 16. BSE image of serpentine (S) terminating into chrysotile (C) asbestos along the bottom; from surface sample at the abandoned Baie Verte asbestos mine tailings dump, NL (location 6 in Figure1).

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in the surface sediment around the tailings. This type of environmental monitoring can be readily conducted for other mining operations and could even be used to evaluate air-borne mineral contaminants.

Conclusions

The SEM-MLA is an important new tool that quantifies indicator mineral species in the fine fraction (<0.25 mm) in surficial sediment surveys. The data provided by SEM-MLA will not only provide the information that helps to vector towards the mineralization for a wide variety of mineral deposit types, but also to define source of the sediment itself. The SEM-MLA provides information that helps to define alteration haloes around ore bodies, and thus allows for the confirmation of till transport directions based on bedrock geology. The SEM-MLA can identify a range of minerals as inclusions in larger mineral grains that would not usually survive weathering, such that the inclusions are also indicator minerals.

Acknowledgements

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Global-scale Geochemical Baselines Mapping: Steps forward in 2016

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Global-scale geochemical mapping refers to conducting geochemical surveys of very large areas (millions of km²) of the Earth's continents using very low sampling densities (1 site per a few thousand km²). This has been a subject of formal discussion and consideration in the geoscience community since at least 1988 (see below). In 2016, two events occurred that have the potential to greatly further the cause of global-scale geochemical mapping. In May 2016, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) International Centre for Global-Scale Geochemistry (hereafter referred to as 'the Centre') opened in Langfang, People's Republic of China. This opening was followed in August by the International Union of Geological Sciences (IUGS) establishing the Commission on Global Geochemical Baselines (hereafter referred to as 'the Commission'). The purpose of this article is to describe each of these new organizations and to summarize the mission of each. As will be seen, each organization has strong ties to the Association of Applied Geochemists (AAG).

IUGS Commission on Global Geochemical Baselines

According to IUGS Bylaws, one of the primary objectives of IUGS Commissions is to "coordinate long-term international cooperative investigations to establish standards in appropriate fields." The long-term mission of this Commission is to work with applied geoscientists throughout the

Left to right: Zhang Qin (Chief of Laboratory, IGGE), Patrice de Caritat, Shi Changyi (Deputy Director, IGGE), David Smith, Peng Xuanming (Director of IGGE and the Centre), Xueqiu Wang (Executive Director of the Centre), and Alecos Demetriades stand in front of the Centre's new facility in Langfang, May 2016.

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world to standardize methods for conducting global-scale geochemical baseline studies.

The new IUGS Commission is led by a four-person steering committee: David Smith (U.S. Geological Survey, retired, and long-time AAG Secretary), Xueqiu Wang (Institute of Geophysical and Geochemical Exploration and UNESCO International Centre on Global-scale Geochemistry, China, and current AAG Regional Councillor for China), Alecos Demetriades (Institute of Geology and Mineral Exploration, Greece, retired, and current AAG Fellow), and Patrice de Caritat (Geoscience Australia, former AAG Councillor and Society News editor for ELEMENTS).

The Commission is essentially a continuation of the Task Group on Global Geochemical Baselines, which operated from 1997 to 2016 under the auspices of both IUGS and the International Association of GeoChemistry (IAGC). The Task Group, in turn, was a follow-on of Projects 259 (International Geochemical Mapping, 1988–1992) and 360 (Global Geochemical Baselines, 1993–1997) of the International Geological Correlation Program (IGCP), now known as the International Geoscience Program. Both these projects were initiated under the leadership of Arthur G. Darnley (Geological Survey of Canada). The final report of IGCP 259, A global geochemical database for environmental and resource management (Darnley et al., 1995), was published by the Earth Sciences Division of UNESCO with financial support from IUGS, IAGC, Association of Exploration Geochemists (now the AAG), International Atomic Energy Agency, and the Royal Society. This report, fondly known in the geochemical mapping community as the Blue Book, is still the fundamental reference on global geochemical mapping and provides very useful information for geochemical mapping at any scale.

Soon after publication of the Blue Book in 1995, the Directors of the Forum of European Geological Surveys (FOREGS) approved the first multi-national, continental-scale, multi-media geochemical mapping of Europe according to Blue Book specifications. The culmination of this project was the publication of the two-volume Geochemical Atlas of Europe (Salminen et al. 2005; De Vos et al. 2006). Other global-scale geochemical mapping projects have since been completed in Australia (Caritat and Cooper 2011), China (Wang et al. 2015), India, Mexico, and the United States (Smith et al. 2013, 2014).

In 2008, the Task Group organized the First Arthur Darnley Symposium on Geochemical Mapping in conjunction with the International Geological Congress (IGC) in Oslo. Organizing a symposium has continued every four years at the IGC in Brisbane (2012) and Cape Town (2016). The new Commission plans to convene the fourth Darnley symposium at the IGC in Delhi in 2020.

More information about the activities of the Task Group can be found on its website at http://www.globalgeo-chemicalbaselines.eu/. Please note that this same URL will be used for the Commission in early 2017.

UNESCO International Centre on Global-scale Geochemistry

Although much progress was made during the tenure of the IUGS Task Group on Global Geochemical Baselines, the authors of the Blue Book recognized that it would be virtually impossible for such an ad hoc group of scientists, working under a non-government organization, to sustain and manage an international sampling effort to establish a global geochemical database. This was the impetus for the establishment of the new Centre.

The Centre is a "Category 2" research centre operating under the auspices of UNESCO. Though not legally part of UNESCO, the Centre is associated with UNESCO through formal arrangements between UNESCO and the People's Republic of China. The long-term mission of the Centre includes: (1) fostering knowledge and technology of global-scale geochemistry, (2) documenting the global concentration and distribution of chemical elements in the Earth's surface, (3) training scientists in global-scale geochemical mapping methods and providing technical assistance to developing countries, and (4) developing a bridge from the scientific community to both decision makers and the general public in the field of global-scale geochemistry.

The establishment of the Centre was spearheaded by Xie Xuejing (AAG Gold Medal recipient). In 2009, he presented a draft proposal to the attendees at the Global-scale Geochemical Mapping Symposium in Langfang. The revised proposal was signed by Xie Xuejing, David B. Smith, and Wang Xueqiu (co-leaders for the IUGS/IAGC Task Group on Global Geochemical Baselines). In 2010, the proposal was formally submitted to UNESCO and included a letter of support from AAG signed by AAG President Paul Morris. It took another six years for the proposal to gain official approval by UNESCO and the Chinese government. In May, 2016, the festive opening ceremonies of the new Centre took place in Langfang in the Centre's new seven-story building located on the premises of the Institute of Geophysical and Geochemical Exploration (IGGE). The new facility includes offices, chemical laboratories, sample storage space, a data centre and five apartments for visiting scientists.

The Centre is led by a Director (Peng Xuanming, who is also the Director of IGGE) and an Executive Director (Xueqiu Wang). The functioning of the Centre is overseen by an international Governing Board and technical guidance is provided by a Scientific Committee composed of geoscientists from all over the world.

The Centre has established a global cooperation network with 80 countries participating in the Global Geochemical Baselines Project and International Project on Mapping the Chemical Earth. In 2016, the Centre financially and technically supported 12 countries (Mongolia, Russia, Laos, Cambodia, Indonesia, Papua New Guinea, Iran, Turkey, Mexico, Peru, Madagascar and Pakistan) to carry out global geochemical baselines mapping.

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Although the missions of the Centre and Commission overlap considerably, there is a notable difference. The Commission is tasked with establishing standards for global-scale geochemical baselines mapping, whereas the Centre is tasked with implementing these standards through international collaborative agreements with participating countries. Both the Centre and the Commission will work together to provide training in geochemical mapping techniques, particularly for the developing countries.

More information about the Centre can be found on its website (www.globalgeochemistry.com).

Questions about either the Centre or the Commission can be addressed to the corresponding authors of this article.

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From the EXPLORE Archives...

The **EXPLORE** archives on the AAG website are an invaluable reference tool and provides a record of how our industry is constantly changing. In this edition of **EXPLORE**, we are highlighting an article that was published in April 1997, (EXPLORE issue 95).

The "Technical Note: SEARCHMAP – Interactive Map Interpretation System for Mineral Exploration" describes how software can be used for data presentation and interpretation purposes. To read the article, please click on: https://www.appliedgeochemists.org/images/Explore/Explore,%20Number%2095%20April%201997.PDF.

Software continues to play an increasingly important role in our industry. Continued improvements in instrumentation provides lower detection limits and a wider array of elements than could ever have been dreamt of 20 years ago. It is interesting to consider how software has evolved in order to keep up with datasets that become progressively larger and more complex with time. It also brings up questions of how software is being used in risk reduction or the decision making process. What sort of limitations are imposed by software? Human thought vs. software predictions? The questions posed are virtually endless – but consider the role that software currently has in your career versus 20 years ago. We expect it would be a rather lively debate.

By highlighting an article from the **EXPLORE** archives, we hope to promote discussion and encourage you to revisit a publication or perhaps reconnect with an author. Old ideas that may have been overlooked could provide solutions for current problems. Please visit the **EXPLORE** archives by clicking https://www.appliedgeochemists.org/index.php/publications/explore-newsletter/2-uncategorised/93-explore-issues.

David Leng,
RGCI

Technical Note:

In situ 3D modelling of conodonts using x-ray micro-tomography

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The understanding of whether or not the multiple Ni-Mo-Zn-PGE mineralized showings and prospects that are exposed over several hundred kilometers in the Yukon, Canada are part of a single time-stratigraphic layer would have major exploration implications for this style of mineralization. A new method for imaging conodont elements reported here may provide age constraints for these mineralized shales. Conodont elements are feeding apparatuses of eel-like marine chordates comprising the mineral hydroxylapatite (but commonly altered to fluorapatite during diagenesis). They are widespread throughout Paleozoic strata and are commonly used as index fossils for Paleozoic epochs. We have identified, during optical microscopic examination of polished thin sections, the presence of abundant conodont elements within Devonian-aged hyper-enriched black shale (HEBS) Ni-Mo-Zn-PGE deposits in the Yukon Territory, Canada, that were previously overlooked. These conodont elements may provide key information on regional biostratigraphic correlation of the geographically widespread mineralized layer. Correct identification of conodont subspecies requires documentation of 3D morphology, but extraction of conodont elements from indurated shales is typically problematic and requires the use of harmful, environmentally deleterious reagents (e.g., hydrofluoric acid). The conodont elements are very delicate and physical and chemical extraction methods may fracture or destroy ornamentation. Our previous attempts at extraction using electric pulse disaggregation resulted in the destruction of these microfossils. However, recent advances in high-energy x-ray micro-computed tomography allow detailed, ultra-high-resolution (5 micron), 3D models of the
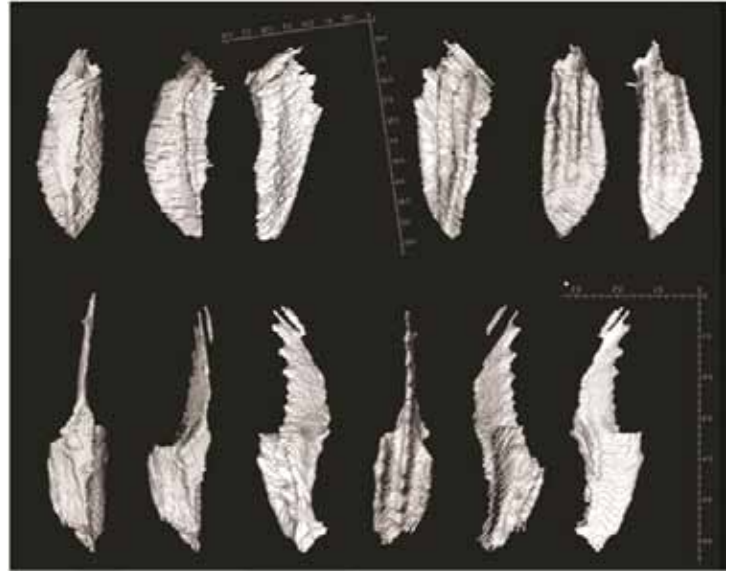

Figure 1: X-ray microtomography-generated 3D models of conodont elements within semi-massive sulfides of the HEBS layer at Peel River.

conodont elements inside intact rock samples (Fig. 1) to be constructed. Such models could potentially be used to identify key conodont subspecies, which are typically confined to narrow zones within Paleozoic epochs and thus provide age constraints for the HEBS layer that are currently lacking. High-energy x-ray micro-computed tomography has other important applications to support mineral exploration. For example, these methods can be used to image indicator minerals to characterize surface textures and determine distance of transport from source.

AAG 2017-2018 Ordinary Councillors

David Cohen

David has been a Fellow of AAG since 1997. He obtained a BSc (hons) in 1983 from Sydney, an MSc in 1986 from Queen's University, and a PhD in 1990 from UNSW. David has been at the University of New South Wales from 1991 to present where he is a Lecturer and researcher. Currently, he is head of the School of Biological, Earth and Environmental Sciences. David is a former Vice President and President of the AAG and is currently the AAG's Symposia Coordinator, Chair of the AAG-SGS Student Paper Prize Committee, AAG's representative on the Australian Geoscience Council, and chair of the Education Committee. He has undertaken research and taught geochemistry for over 30 years, including work on biogeochemistry, selective extractions and regional mapping at the University of New South Wales. He was the 2013 AusIMM visiting lecturer to New Zealand. He has supervised a substantial number of honours and postgraduate students and attended 12 IAGS. He is committed to helping develop and implement the new strategic plan for the AAG.

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Juan Carlos Ordóñez Calderón

Juan Carlos has been a Fellow of AAG since 2014. In 2001, he obtained his B.Sc. in geology at the Universidad Industrial de Santander in Colombia, and graduated with the Summa Cum Laude distinction. He holds a M.Sc. and a Ph.D. in geochemistry and petrology, respectively, from Shimane University (2003) in Japan and the University of Windsor (2008), Canada. Following his Ph.D., he started an industry-oriented postdoctoral fellowship funded by NSERC, MERC-Laurentian University, the Geological Survey of Canada-TGI3 Initiative, and Hudbay. In 2010, he worked for the Ontario Geological Survey as a Precambrian Geoscientist. Later he opted for a career as a corporate geoscientist and since 2011 he has worked as an applied geochemist for Hudbay in Toronto. Juan Carlos unique expertise resides in the integration of geochemistry and field methods of physical volcanology and structural geology to evaluate projects at mine to regional scale. Motivated by the large volume of geoscience data typically generated in the mining industry, over the past 6 years he has applied compositional data analysis and advanced data analytics techniques for exploration and mining projects. His geochemical work along the Americas has covered diverse mineral systems including porphyry, skarn, VMS, IOCG, sediment hosted, and epithermal deposits. Juan Carlos advocates collaborative work between industry, government, and academia in order to solve the most immediate needs of society without leaving future generations lacking of the necessary foundations for future applications.

Ray Lett

Ray obtained a B.Sc. at the University of London, UK, in 1968, a M.Sc. University of Leicester, UK in 1970, and a Ph.D. from the University of British Columbia in 1979. He is a geochemical consultant and university sessional lecturer in geochemistry and economic geology at the University of Victoria, Canada. He was a laboratory supervisor and senior geochemist for the British Columbia Geological Survey between 1990-2010. Prior to that he was a geochemist for Barringer Research/ Magenta from 1980 to 1990 and an exploration geochemist/ geologist for Amax Exploration/Fox Geological/BP Minerals in Vancouver, BC between 1970 and 1979. Ray served as AAG Secretary 1980 to 1985; as a Councillor: 1990 - 1992, 1999-2000, 2006-2009; member of the AAG Education Committee 2010-2014 and the Strategy Committee 2016-2017. Ray retired from the BC Geological Survey after 20 years with government as a geochemist and now spends his time consulting, teaching (part time) undergraduate university courses in geochemistry and economic geology and serving on various geoscience committees. Since joining the Association in 1972, he has seen it evolve from an organization primarily aimed at encouraging the use of geochemistry for mineral exploration to one that is now a leading advocate for applying the science to a wider range of applications including environmental and urban geochemistry and geoanalysis..

Renguang Zuo

Dr. Renguang Zuo became a Fellow of AAG in 2016. He received his Ph.D. degree from the China University of Geosciences (CUG) in 2009. As a jointly supervised PhD candidate by CUG and York University (Toronto, Canada), Renguang studied for one year at the York University (supervisors: Prof. Qiuming Cheng and Prof. Frits Agterberg) during 2007-2008. He has been working at the state key laboratory of geological processes and mineral resources (GPMR) at CUG since he obtained Ph.D. in 2009. In the end of 2012, he was promoted as a full professor. In 2014, as a senior visiting scholar, he worked together with John Carranza for four months at the James Cook University (Townsville, Australia). He is currently serving as an associate editor for Journal of Geochemical Exploration (JGE) and Nature Resources Research. As a guest editor, he organized two special issues (JGE, 2012, v.122, and 2016, v.164) related to geochemical mineral exploration. He and John Carranza are currently organizing another special issue of current methods of data analysis for geochemical mineral exploration in GEEA. He also acted as a convener of GIS-based geochemical mineral exploration both in Goldschmidt (2016, Japan) and in 35th International Geological Congress (IGC, 2016, South Africa). Renguang has published more than 60 peer-reviewed papers. He was awarded the Kaharaka Award by the International Association of GeoChemistry in 2015 due to his contributions to applied geochemistry. Renguang's work documented the advance of GIS-based geochemical mineral exploration, and build a wide range of international cooperation.

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Tom Meuzelaar

Tom holds a B.S. in geology from the University of Utah (1991), M.S. in economic geology/geochemistry from Washington State University (1995) and a Ph.D. in economic geology/geochemistry from the Colorado School of Mines (2015). He is currently employed (since 2011) at Golder Associates, Inc. as senior consultant specializing in geology and geochemistry. He runs a diverse practice providing technical expertise to clients in the mining, oil and gas and power sectors through all project life cycle stages (exploration, production, closure). Prior to his current position, he was employed at RockWare, Inc. (from 1999 to 2011) as software consultant, manager of the Geochemist's Workbench account, and general software marketer and business developer. He has extensive experience as petrographer, mineralogist and geologist, and is skilled in statistical evaluation and reduction of large geochemical datasets. He has also taught or co-taught over 35 geochemical modeling short courses, including courses at Goldschmidt conferences, federal research organizations, multinational energy corporations, environmental and mining consultancies and major universities. His primary interest in joining the AAG Council is to help direct marketing strategies for sustaining and growing membership. His past contributions to AAG include attending and presenting at the 2014 IAGS conference in Tucson, USA.

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Workshop 6 - Advances in Geophysical Technology

Workshop 7 - Seismic Methods & Exploration

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Workshop 9 - Status & New Developments in Field Portable Geochemical Techniques and Site Technologies for Mineral Exploration

Workshop 10 - Future of Mineral Exploration Drilling & Sampling

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Partners

AAG	Association of Applied Geochemists
BCGS	British Columbia Geological Survey
CFES	Canadian Federation of Earth Sciences
CGEN	Canadian Geoscience Education Network
CGS	Canadian Geotechnical Society
CIM	Canadian Institute of Mining, Metallurgy and Petroleum
CSEG	Canadian Society of Exploration Geophysicists
CSPG	Canadian Society of Petroleum Geologists
GAC	Geological Association of Canada Geoscientists Canada
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IAPG	International Association for Promoting GeoEthics
IUGG	International Union of Geodesy and Geophysics
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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.

Please let us know of your events by sending details to:
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2017

20-26 MARCH	48th Lunar and Planetary Science Conference. Woodlands TX USA. Website: www.hou.usra.edu/meetings/lpsc2017
11-14 APRIL	25th International Mining Congress and Exhibition of Turkey. Antalya Turkey. Website: imcet.org.tr/defaulten.asp
22-23 APRIL	Petrochronology: Methods and Applications. Vienna Austria. Website: vienna2017.petrochronology.org
23-28 APRIL	European Geosciences Union General Assembly 2017. Vienna Austria. Website: tinyurl.com/j3ff8wn
27-28 APRIL	3rd International Conference on Geographical Information Systems: Theory, Applications and Management. Porto Portugal. Website: www.gistam.org
30 APRIL-3 MAY	Canadian Institute of Mining, Metallurgy, and Petroleum 2017 Conference & Exhibtion. Montreal QC Canada. Website: convention.cim.org/en/Montreal/2017/Home.aspx
6-11 MAY	European Workshop on Modern Developments and Applications in Microbeam Analysis. Konstanz Germany. Website: www.microbeamanalysis.eu/
9-11 MAY	8th World Conference on Sampling and Blending (WCSB8). Perth WA Australia. Website: www.wcsb8.com/
11-12 MAY	19th International Conference on Earth Science and Climate Change. Montreal QC Canada. Website: waset.org/conference/2017/05/montreal/ICESCC
14-18 MAY	Geological Association of Canada/Mineralogical Association of Canada Annual Meeting. Kingston ON Canada. Website: www.kingstongacmac.ca/
15-17 MAY	XVIth International Conference: Geoinformatics, Theoretical and Applied Aspects. Kyiv Ukraine. Website: tinyurl.com/j54kayw
4-7 JUNE	14th International Estuarine Biogeochemistry Symposium. Rimouski QC Canada. Website: www.iebs2017.com/
4-7 JUNE	FUTORES II — Future understanding of tectonics, ores, resources, environment and sustainability. Townsville Qld Australia. Website: www.jcu.edu.au/futores
4-9 JUNE	Interior of the Earth (Gordon Research Conference). South Hadley MA USA. Website: www.grc.org/programs.aspx?id=14762
5-9 JUNE	13th International Congress of Applied Mineralogy Taranto Italy. Website: www.scientevents.com/amam-icam2017
5-9 JUNE	7th International Workshop on Compositional Data Analysis. Siena Italy. Website: www.compositionaldata.com/codawork2017
6-8 JUNE	7th International Conference on Environmental Pollution and Remediation. Rome Italy. Website: icepr.org
11-14 JUNE	1st Geobiology Society Conference. Banff AB Canada. Website: cms.eas.ualberta.ca/Geobiology2017
11-16 JUNE	11th International Symposium on Geochemistry of the Earth's Surface. Guiyang China. Website: www.datas-online.net/ges2017/
12-14 JUNE	14th Australasian Environmental Isotope Conference. Wellington New Zealand. Website: tinyurl.com/juoqtqy
13-15 JUNE	PEG2017 – 8th International Symposium on Granitic Pegmatites. Kristiansand Norway. Website: tinyurl.com/h8hwo9g
23-28 JUNE	Tourmaline 2017. Nové Město na Moravě Czech Republic. Website: tourmaline2017.cz
25-30 JUNE	Catchment Science: Interactions of Hydrology, Biology & Geochemistry. Lewiston ME USA. Website: tinyurl.com/zst629v
26–30 JUNE	14th International Conference on Sustainable Use and Management of Soil, Sediment and Water Resources – AquaConSoil 2017. Lyon France. Website: www.aquaconsoil.org
30 JUNE-4 JULY	33rd International conference of the Society for Environmental Geochemistry and Health. Guangzhou China. Website: segh2017.csp.escience.cn
4-8 JULY	32nd International conference of Society for Environmental Geochemistry and Health. Brussels Belgium. Website: segh-brussels.sciencesconf.org/
16-20 JULY	International Conference on the Biogeochemistry of Trace Elements. Zurich Switzerland. Website: icobte2017.ch/
16-21 JULY	13th International Conference on Mercury as a Global Pollutant Providence RI USA. Website: mercury2017.org/initial/index.php
23-28 JULY	80th Annual Meeting of the Meteoritical Society. Santa Fe NM USA. Website: metsoc2017-santafe.com
23-28 JULY	Chemical Oceanography (Gordon Research Conference). New London NH USA. Website: www.grc.org/programs.aspx?id=11096
30 JULY-4 AUG	Atmospheric Chemistry (Gordon Research Conference). Newry, ME USA. Website: www.grc.org/programs.aspx?id=10916
4-9 AUGUST	Magmatism of the Earth and related strategic metal deposits. Miass Russia. Website: magmas-and-metals.ru

CALENDAR OF EVENTS
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6-10 AUGUST	Microscopy & Microanalysis 2017. St Louis MO USA. Website: microscopy.org/MandM/2017
12-17 AUGUST	21st World Congress of Soil Science. Rio de Janeiro Brazil. Website: 21wcss.org/
13-17 AUGUST	5th International Conference on Selenium in the Environment and Human Health. Stockholm Sweden. Website: se2017.se
13-18 AUGUST	Goldschmidt 2017. Paris France. Website: goldschmidt.info/2017
20-23 AUGUST	14th Biennial SGA Meeting. Quebec City QC Canada. Website: sga2017.ca/
20-29 AUGUST	12th International Eclogite Conference. Åre Sweden. Website: www.geology.lu.se/IEC12
28 AUGUST- 1 SEPTEMBER	7th International Conference on Medical Geology. Moscow Russia. Website: www.medgeo2017.org
2-9 SEPTEMBER	18th Annual Conference of International Association for Mathematical Geosciences. Fremantle WA Australia. Website: iamg2017.com
11-14 SEPTEMBER	SIAM Conference Mathematical and Computational Issues in the Geosciences. Erlangen Germany. Website: www.siam.org/meetings/gs17
17-20 SEPTEMBER	SEG 2017. Beijing China. Website: www.seg2017.org/
17-22 SEPTEMBER	28th International Meeting on Organic Geochemistry. Florence Italy. Website: www.houseofgeoscience.org/imog/
18-19 SEPTEMBER	19th International Conference on Gas Geochemistry. Rome Italy. Website: www.waset.org/conference/2017/09/rome/ICGG
18-22 SEPTEMBER	11th International Kimberlite Conference. Gaborone Botswana. Website: www.11ikc.com
25-29 SEPTEMBER	23rd International Symposium on Environmental Biogeochemistry. Palm Cove QLD Australia. Website: www.iseb23.info
21-25 OCTOBER	Exploration '17. Toronto ON Canada. Website: www.exploration17.com
22-25 OCTOBER	GSA Annual Meeting. Seattle WA USA. Website: www.geosociety.org/meetings/2017/
31 OCTOBER- 2 NOVEMBER	10th Fennoscandian Exploration and Mining. Levi Finland. Website: fem.lappi.fi/en
7-8 DECEMBER	19th International Conference on Nuclear and Environmental Radiochemical Analysis. Sydney NSW Australia. Website: tinyurl.com/jsh9gsu

2018

16-21 JUNE	28th International Applied Geochemistry Symposium. Vancouver BC Canada. Website: rfg2018.org
8-13 JULY	Geoanalysis 2018. Sydney NSW Australia. Website: 2018.geoanalysis.info

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