



Basic indicator mineral math: Why visual analysis of the entire heavy mineral fraction of large sediment samples is required on indicator mineral exploration programs in glaciated terrains

Stuart A. Averill^{1*} and Remy G. Huneault².

¹Chairman, Overburden Drilling Management Limited, Unit 107 – 15 Capella Court, Nepean, Ontario, Canada, K2E 7X1, * Corresponding author email: stuaverill@storm.ca; ²President, Overburden Drilling Management Limited, Unit 107 – 15 Capella Court, Nepean, Ontario, Canada, K2E 7X1

Introduction

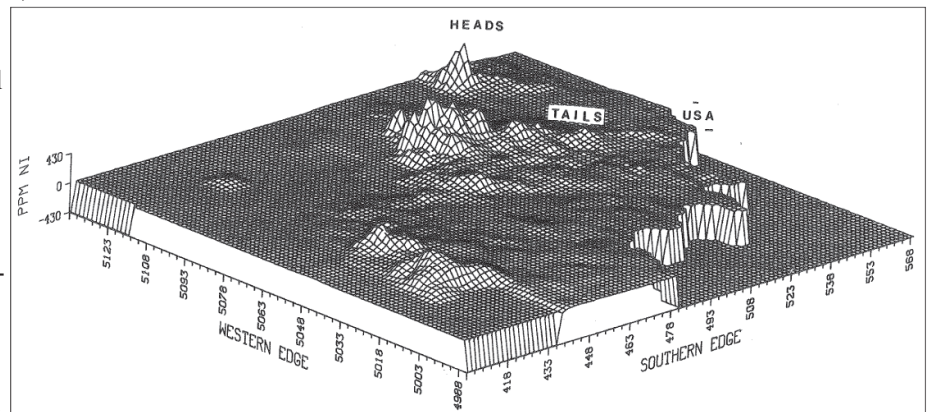
Mineral exploration in Canada has become increasingly reliant on identifying and tracing to a bedrock source anomalous concentrations of dispersed indicator mineral grains in till and, to a lesser degree, in glaciofluvial and alluvial gravel. Gold grains, for example, have been employed successfully in many exploration programs (e.g. Averill 1988, 2001, 2013, 2015) since the watershed discovery in northern Quebec in 1984 of the Casa Berardi gold deposits by following gold grain anomalies in till beneath thick clay cover (Sauerbrei *et al.* 1987). As well, many of the kimberlites that were discovered in the 1990s and the first decade of this century, including the pipes that host Canada's first diamond mine, Ekati in the Northwest Territories, were found by identifying and tracing kimberlite indicator mineral (KIM) dispersal trains in till (e.g. Blusson 1998; Kong *et al.* 1999; Strand *et al.* 2009; Grütter 2016). Now, indicator minerals are being used to explore for deposits of base metals and other commodities (Thorleifson 2009), particularly porphyry Cu, Ni-Cu-PGE and VMS deposits both in Canada (e.g. Averill, 2001; Plouffe & Ferbey 2015, McClenaghan *et al.* 2013, 2015a,b; Hashmi *et al.* 2015) and internationally (Averill 2011, Kelley *et al.* 2011).

The greatest strength of indicator mineralogy in exploring glaciated terrains is its ability to detect overburden-covered mineral deposits from afar with very widely spaced samples, thereby greatly reducing exploration costs. The Casa Berardi gold deposits in northern Quebec, Canada were found at a total cost of just \$248,000 CAN (1984 figures) using till samples from reverse circulation drill holes spaced 400 m apart (Sauerbrei *et al.* 1987). The gold grain dispersal train from the Rainy River gold deposit in northwestern Ontario, Canada is 15 km long (Averill 2013) and was initially detected by

the Ontario Geological Survey in till samples collected from holes drilled ~3 km apart across a previously untested clay belt (Bajc 1991). Most remarkably, Chuck Fipke and Stewart Blusson discovered the Ekati kimberlite field by tracing a KIM dispersal train for 600 km using alluvial and glaciofluvial (esker) gravel samples collected up to 40 km apart (Blusson 1998).

Shilts (1973, 1993) showed by sampling till up to 50 km down-ice from the large Thetford Mines (asbestos) ophiolite complex in Quebec that the concentration of ophiolite indicator minerals, clasts and elements in the till decreased exponentially with increasing distance from the ophiolite source; i.e. the glacial dispersal train had a strong but short head followed by an exponentially weaker but much longer tail (Fig. 1) that, in theory, would never completely dissipate. Thus, a mineral deposit can only be identified from

Figure 1. Three-dimensional plot of Ni concentrations in till down-ice from (southeast of) the Thetford Mines ophiolite belt, southeastern Quebec. Note the strong, short heads and exponentially weaker but much longer and very slowly dissipating tails of the Ni dispersal trains. Excerpted from Shilts (1993) under copyright licence No. 3907820314085.



continued on page 5

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Editor:

Beth McClenaghan (beth.mcclenaghan@canada.ca)

Business Manager:

Pim van Geffen 1-604-681-6765 (explorenewsletter@gmail.com)Back Issues contact: Al Arseneault (office@appliedgeochemists.org)

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TABLE OF CONTENTS

Basic indicator mineral math: Why visual analysis of the entire heavy mineral fraction of large sediment samples is required on indicator mineral exploration programs in glaciated terrains.....	1
Notes from the Editor.....	3
President's Message	4
Recently Published in Elements	14
Obituary: Jane Ann Plant.....	15
Distinguished Applied Geochemists Fund	16
AAG Council Needs You	16
Join Us for Exploration '17	16
AAG New Members	17
Emails to the Editor.....	17
RFG2018.....	18
Calendar of Events.....	18
Writing Geochemical Reports.....	20

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Olympus IMS.....	9
OREAS Certified Reference Materials	2
RockLabs	10
SciApps, Inc.	7

Notes from the Editor

EXPLORE 172 includes one technical article about indicator mineral abundance in sediment samples and automated mineral identification methods, written by Stu Averill and Remy Huneault. This issue also includes two *Emails to the Editor* that comment on the technical article in **EXPLORE** issue 171. We encourage readers to submit their comments about what they read in **EXPLORE** any time, both positive and negative. We thank all those who contributed to the writing and/or editing of this issue: Steve Amor, Dennis Arne, Stu Averill, Al Arseneault, Gwendy Hall, Remy Huneault, Martin McCurdy, Ryan Noble, Barry Smee, Dave Smith, and Erick Weiland.

Beth McClenaghan

Editor



President's Message

This year seems to be going too quickly for me. Around the time you are reading this September issue of Explore, the AAG will have had the Annual General Meeting and three regular Council meetings (or will shortly have the third). I am certain most of our readers do not have time or the inclination to read the minutes of these meetings, so I thought it might be helpful for me to highlight some the outcomes from the Council meetings. It is good to be transparent in our Council activities and I am also keen to have others in our community join in and contribute to the AAG. If you don't know what is happening, it is hard to contribute.

Our survey has been conducted and essentially the demographics and many responses/trends from current and past members are the same. The Strategy Committee will produce a full document that can be downloaded from the AAG website and the link published in the December issue of **EXPLORE**. Here are a few of the preliminary findings of the survey:

- Many members were happy with how we currently operate. However, those that think significant change is required are split in opinions almost 50/50. Of people that responded, there are equal numbers who want to expand our environmental geochemistry activities compared to those that want to focus on exploration

and essentially return to the former Association of Exploration Geochemists (AEG) mandate.

- Some of the suggestions to building membership are dominated by increasing education materials (online, short courses, enhanced web-based tools). Additional web content is currently being sought and we would welcome more input from our members. If you have a geochemistry-related educational presentation on YouTube, for example, we would be interested in collating these for our members to peruse in one area.
- Email, web, and hardcopy are the preferred communications although hardcopy is set to reduce, while LinkedIn seems to be the preferred social media platform, particularly for those 30-50 year olds.

Our membership is steady and based on the surveys conducted likely to be maintained at this level (I expect we can build our numbers). The survey responses indicated a need for stronger marketing, co-sponsoring events, mentoring and increased activity in universities. All of these ideas have merit and we hope to be able to develop these further over the next year.

Financially, we, like many associations, have taken a hit with investments over the past few years, but still are in a very stable and secure position. This is not the case in a number of other societies and it is in part due to being well managed (Gwendy Hall and the late Eion Cameron can take most of the credit here), but also to the fact that the AAG is fiscally conservative. Also, we have lot of volunteered hours and more contributed as in-kind to keep us running.

The AAG is in the process of updating some of our student and publication awards as well as increasing the awareness of our Distinguished Applied Geochemists Fund. I am particularly pleased that a new award will relate to the best publication in our journal GEEA. These are common in other societies and something I look forward to possibly presenting this new award at the next IAGS.

Speaking of which, our next IAGS is on track and will be a little different from past events in that it will partner with a larger conference. In a similar fashion, this is a financial risk mitigation strategy. We do hope to run a number of AAG short courses and if you have ideas please contact the LOC (Peter Winterburn or Steve Cook are good starting points). That is the latest news from Council. As always, if you have ideas or are keen to be more involved in the AAG, please contact me.

Personally, I am really looking forward to some great conferences in Canada over the next two years with our IAGS (Vancouver July 2018) as part of "Resources for Future Generations" and Exploration '17 (Toronto October 2017) prominent in my "Must Attend" list. For those in Australia, Target 2017 in April in Perth may also be well worth your time.

Warm regards,

Ryan Noble

AAG President

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Basic indicator mineral math:... *continued from page 1*

afar with a wide sample spacing, as in the Rainy River and Ekati examples, if the sampling method is sufficiently sensitive to detect the weak tail of the train with a high level of confidence. The required sensitivity is attained by (a) collecting large samples; and (b) employing a sample treatment method that provides a very low detection limit of one grain per sample for each targeted indicator mineral in the principal grain size fraction (*e.g.* 250-500 μm) within which that mineral would be expected to occur. A further caveat is that the indicator minerals must have a specific gravity sufficient to be concentrated to a level at which a single grain can be identified at a practical cost. While gravity concentrates can be refined by other means to further concentrate some indicator minerals and thereby ease their identification, not all minerals benefit from this treatment. Therefore the final caveat is that the grain size fractions of the heavy mineral concentrate (HMC) that match the expected sizes of the targeted indicator minerals must be examined in full to obtain the benefit of collecting a large sample.

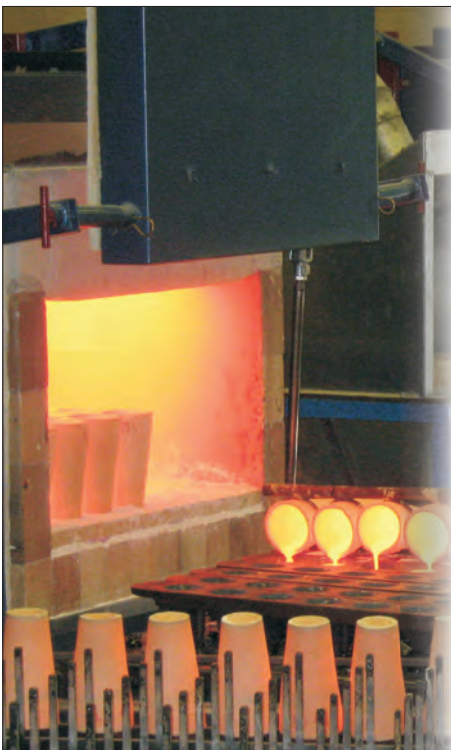
Kimberlite is such a rare rock that the till in most regions of Canada contains no KIMs. A sample size of 10 to 20 kg is generally adequate for detecting KIMs at very low concentrations in the distal parts of glacial dispersal trains (Grütter 2016). Gold grains, in contrast, are rather ubiquitous in till because: (a) auriferous bedrock is much more common than kimberlite; and (b) gold grains do not physically break down during glacial transport because gold

is malleable – the grains simply become reshaped (Averill 2001). On gold exploration programs, therefore, a till sample containing 10 kg of <2 mm (-10 mesh) material will be sufficient. The gold background in a sample of this size can range from just 0 to 5 grains in infertile regions to as much as 40 grains on the down-ice end or side of a long or wide auriferous belt such as the Abitibi Greenstone Belt in Ontario and Quebec (Averill 1988). In areas where the gold background of the till is high, anomalous populations of gold grains derived from nearby mineralized zones of potential economic interest are recognizable by: (a) their more uniform grain size; and (b) limited modification of their primary pristine morphology (Averill 1988, 2001, 2013).

The indicator mineral surveys that contributed to the discovery of the Casa Berardi, Rainy River and Ekati mines adhered closely to the above sample collection and treatment protocols. Large samples were collected, their heavy mineral fraction was extracted, either the entire concentrate or its most prospective grain size fractions were studied and the number of grains of each indicator mineral was established. The grains were identified and classified visually using stereoscopic microscopes (Fig. 2a), a process that requires ~15 minutes for gold grains and 2 hours for a full suite of kimberlite, base metal and other types of indicator minerals.

In recent years, software programs such as MLA® and QEMSCAN® have been developed that allow rapid,

continued on page 6



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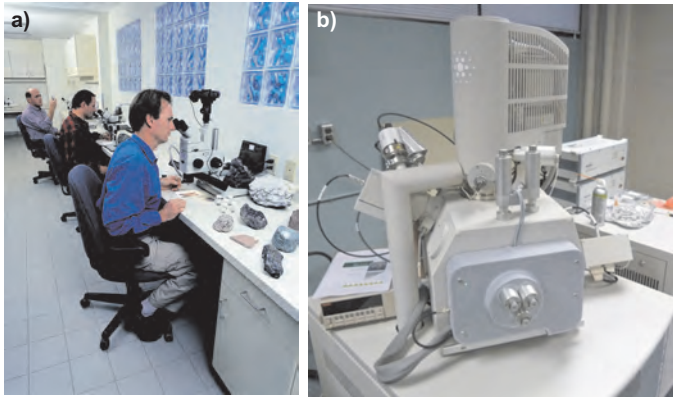


Figure 2. Examples of: (a) visual and (b) automated (MLA) methods of indicator mineral identification. Sources: (a) laboratory of Overburden Drilling Management Limited, Nepean, Ontario; (b) Queens University, Kingston, Ontario.

automated identification and analysis of the minerals in a HMC using scanning electron microscopy (SEM) (Fig. 2b) and energy dispersive x-ray spectroscopy (Sylvester 2012; Agnew 2015; Layton-Matthews *et al.* 2015). In this article, it is shown mathematically that the effectiveness of these automated techniques for indicator mineral surveys in glaciated terrains, where a large sample is required and its entire heavy mineral component or the most prospective grain size fractions thereof must be analyzed at a 1-grain detection limit, is presently constrained by: (a) the surface area of the block on which the grains are mounted, polished and analyzed being too small to hold the large numbers of mineral

grains that are present in a typical HMC; (b) the tendency of many indicator minerals to be relatively coarse grained, further limiting the number of grains that can be analyzed per block; and (c) the impracticality of analyzing multiple blocks per sample on a routine basis.

Preferred Natural Grain Sizes of Indicator Minerals

Till is an unsorted sediment deposited directly by glaciers (Goldthwait 1971; Dreimanis 1976). Within its $<2000 \mu\text{m}$ ($<2 \text{ mm}$) matrix, the particles range in size upward (Fig. 3) from clay ($<2 \mu\text{m}$) through very fine to very coarse silt ($2\text{-}63 \mu\text{m}$) to very fine to very coarse sand ($63\text{-}2000 \mu\text{m}$). For each successive particle size class shown in Figure 3, the width is double that of the adjacent smaller class. For example, the range for medium sand grains is $250\text{-}500 \mu\text{m}$, twice the $125\text{-}250 \mu\text{m}$ range for fine sand grains.

Most oxide, sulphide and silicate indicator minerals occur preferentially as sand-sized grains (Averill 2001, 2011; McClenaghan *et al.*, 2013, 2015a, b) but $\sim 90\%$ of gold grains and platinum group minerals (PGMs) occur as silt-sized or smaller grains ($<63 \mu\text{m}$ wide; Averill 2001). KIMs are relatively coarse grained, ranging up to 2 mm (Fig. 3), because they originally crystallized as macrocrysts in the mantle. The principal grain size targeted on KIM surveys is medium sand – i.e. $250\text{-}500 \mu\text{m}$ – because this is the peak grain size for most KIMs (Averill & McClenaghan 1994) including Cr-pyrope garnet as illustrated in Figure 3. Most of the base metal indicator minerals that are currently being

continued on page 8



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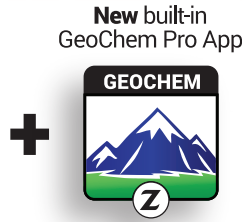
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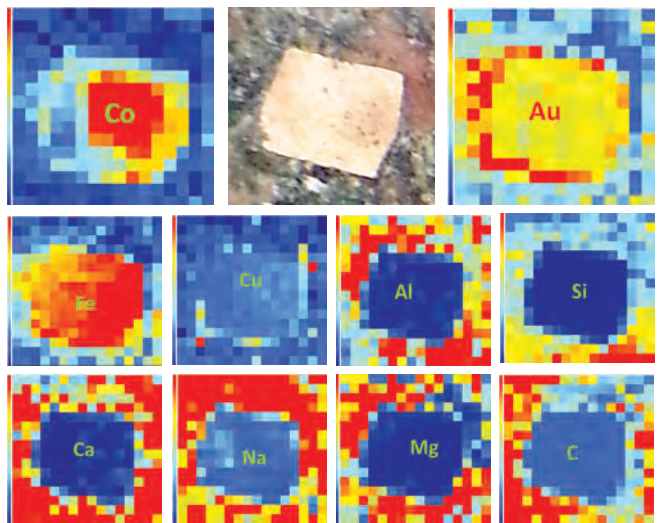
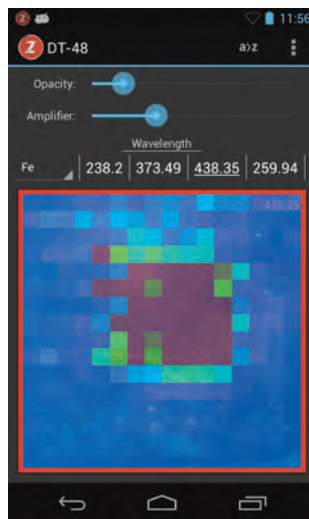
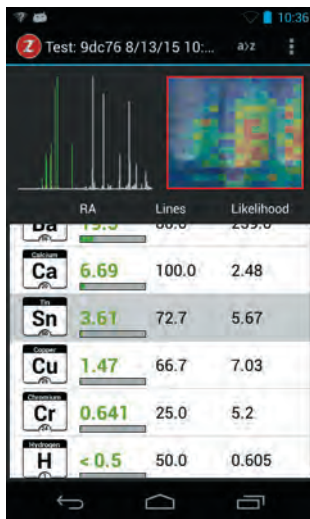
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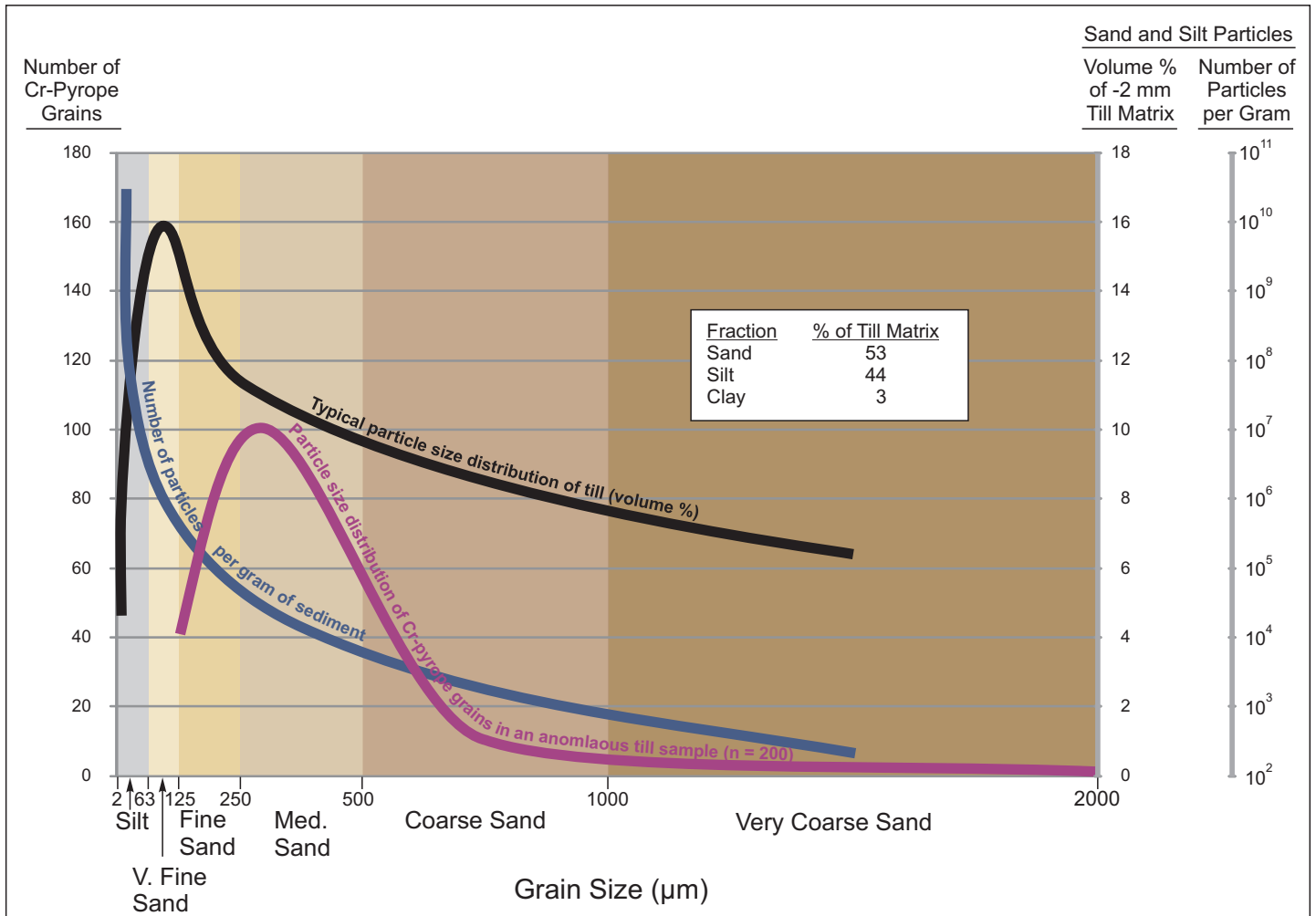


Figure 3. Typical size distribution of Cr-pyrope grains in an anomalous till sample in relation to the average proportion (%) of silt and sand-sized particles in till and the number of particles per gram of silt and very fine to very coarse sand. Note that fewer Cr-pyrope grains are present in the fine sand fraction than the medium sand fraction even though fine sand constitutes a higher proportion of the till and contains eight times more particles per gram than medium sand. Till particle distribution data from northern Quebec courtesy of Beth McClenaghan (Geological Survey of Canada).

utilized are sand sized because the main types of base metal sulphide deposits being targeted by indicator minerals are either magmatic (*e.g.* porphyry, skarn, IOCG, Ni-Cu) or metamorphosed (*e.g.* Broken Hill-type deposits and VMS and SEDEX deposits in amphibolite-facies terranes) and

thus relatively coarse grained (Averill 2011; McClenaghan 2013, McClenaghan *et al.* 2013).

The Grain Deficit Issue of Automated Analyzers

If an automated analyzer is used to identify and count the indicator mineral grains present in a HMC, grains of a similar size are mounted in an epoxy block, typically 25.4 x 25.4 mm, which is then polished to expose the grains. Only ~2000 grains of the commonly used 250-500 µm size fraction can be mounted on one 25 mm square block (Agnew 2015). However, each gram of 250-500 µm heavy minerals contains ~11,000 grains (Table 1), requiring analysis of 5.5 epoxy blocks to identify and count all of the contained indicator mineral grains. Moreover, the 250-500 µm heavy mineral fraction of a 10 kg till sample typically weighs ~20 g (Fig. 4) and thus contains ~220,000 mineral grains.

If a single, 25 mm square, 2000-grain epoxy block from the 220,000-grain, 250-500 µm fraction of the HMC is analyzed, the only representative analyses that are obtained will be for minerals that comprise >0.1 percent (1 grain in



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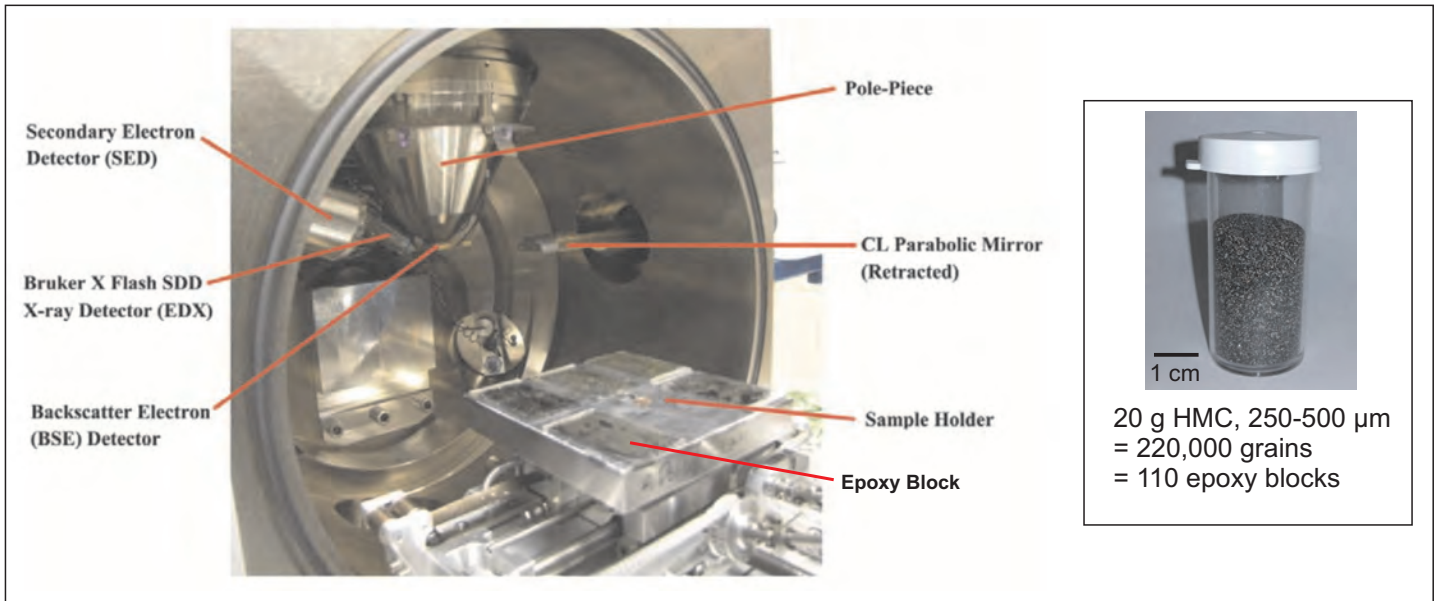


Figure 4. Grain capacity of an automated mineral analyzer. Each epoxy block in the sample tray will hold ~2,000 grains of 250-500 μm (medium sand) size or 8,000 grains of 125-250 μm (fine sand) size. However, a typical 10 kg till sample contains ~20 g of heavy minerals of each size and each gram contains 11,000 or 88,000 mineral grains, respectively, for a total of 220,000 or 1,760,000 grains requiring 110 or 220 epoxy blocks to be analyzed completely.

1000) of the HMC, i.e. minerals that would be obvious from a simple visual inspection of the HMC. The analyses obtained for the most commonly targeted indicator minerals will not be representative because these minerals normally occur at ppb levels in till and ppm levels in till HMCs (Averill 2001). In fact, grains of these minerals would seldom be detected by automated analysis of a single 2000 grain block even where present in significantly anomalous numbers in the HMC. Analysis of the entire 250-500 μm fraction of the HMC, or 110 epoxy blocks, would be required to determine the number of grains of each indicator mineral species that are present, if any. If this were not done, there would be no point in collecting such a large sample as the ability to detect mineralization from afar would be lost. Unfortunately,

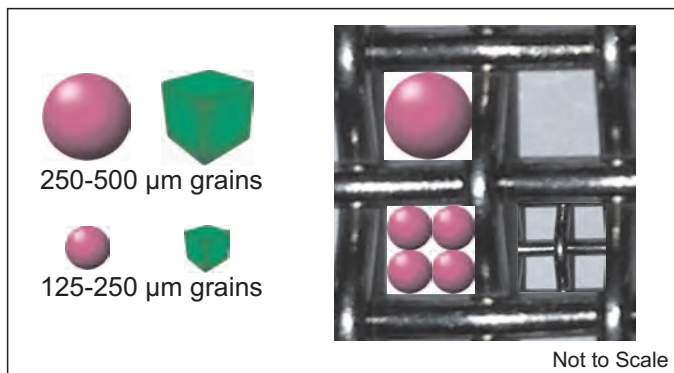


Figure 5. Relationships between grain diameter, area and volume. Halving the size of a spherical or cubic mineral grain from 250-500 μm (medium sand) to 125-250 μm (fine sand) quarters the surface area that the grain occupies on an epoxy block (area = πr^2 or d^2). However the volume of the grain decreases by a factor of eight (volume = $4/3\pi r^3$ or d^3) such that eight times more grains and twice as many epoxy blocks must be analyzed per gram of sample.

it is presently impractical to analyze multiple grain blocks from a large till sample on a routine basis because from 30 minutes (Agnew 2015) to 1-2 hours (Layton Matthews *et al.* 2015) are required to identify the targeted indicator minerals in each block. This time estimate does not include time required for mounting and polishing the grains and subsequent interpretation of the acquired analytical data.

In theory, analyzing the fine, 125-250 μm rather than medium, 250-500 μm sand fraction of the HMC would improve the detection limit of an automated analyzer because four times as many grains could be mounted on an epoxy block (Fig. 5, Table 1). However till generally contains a higher proportion of 125-250 μm grains than of 250-500 μm grains (~12% versus 10%; Fig. 3) and thus a greater weight of heavy minerals requiring examination. Furthermore, each 125-250 grain has only one-eighth the volume of a 250-500 μm grain (Fig. 5). Consequently, even if the weight of the 125-250 μm HMC does not exceed the 20 g weight of the 250-500 μm HMC, eight times as many grains and twice as many grain blocks (220) would need to be examined to identify the targeted indicator mineral grains in the 125-250 μm grain size fraction despite the fourfold increase in grain capacity per block for this fraction (Fig. 4, Table 1). Finally, the 125-250 μm fraction commonly contains fewer grains of coarse-biased indicator minerals such as Cr-pyropite (Fig. 3); i.e. the frequency of these mineral grains is less than one-eighth that in the 250-500 μm fraction, compounding the time and effort required to identify them among the many non-indicator mineral grains in the HMC.

Detection Limits for Gold Grains

As noted above, ~90% of gold grains in till are silt sized. While one 25-mm-square epoxy mount will hold up

Basic indicator mineral math:... *continued from page 11*

Class	Particle Size		Approximate Number of Heavy Mineral Grains		Approximate No. of Epoxy Blocks per Gram
	µm		Per Gram	Per Epoxy Block	Gram
Very coarse sand	1000-2000		170	125	1.5
Coarse sand	500-1000		1,400	500	3
Medium sand	250-500		11,000	2,000	5.5
fine sand	125-250		88,000	8,000	11
Very fine sand	63-125		700,000	32,000	22
Very coarse silt	32-63		5,600,000	130,000	45
Coarse silt	16-32		45,000,000	500,000	90

Table 1. Variation with particle size in the number of epoxy blocks required for automated analysis of 1 gram of heavy minerals.

to 200,000 mineral grains of this size (Agnew 2015), silt is a major component of till, typically comprising ~44% of the matrix of samples collected over the crystalline rocks of the Canadian Shield (Fig. 3). Moreover, a single gram of silt contains ~50 million mineral grains (Table 1, Fig. 3). Consequently, a typical 10 kg till sample contains 4400 g or ~220 billion grains of silt and one gold grain in this silt – the required detection level – represents just 0.0045 ppb or 4.5 ppt by volume. If the 4400 g of silt were simply reduced to a routine >3.2 specific gravity heavy mineral concentrate weighing 20 g, the targeted gold grain would still represent only 1 ppb by volume of the HMC and thus be essentially impossible to find either visually or with an automated mineral analyzer. However, since gold has a much higher specific gravity (~19 vs. 3.2-5.5) than most of the other minerals in HMCs, gold grains can be further concentrated to as much as 1000 ppm (1 grain in 1000). They can then be identified either visually in a few minutes or instrumentally by analysis of a single epoxy block.

Identifiable Mineral Associations and Grain Morphologies

When conducting an indicator mineral exploration program, it is important to recognize potentially useful associations between and physical features of the various minerals in the HMCs, including: (1) the major minerals that comprise the background suite in the HMC, particularly their implications for the main source rocks of the till and hence for the locations of the bedrock sources of any indicator minerals that the till contains; (2) the morphology of the indicator mineral grains, particularly their degree of wear relative to their susceptibility to wear (*e.g.* hardness, malleability, cleavage); and (3) any other indicators of the provenance of these grains such as the presence or absence of surface alteration, inclusions or mineral intergrowths. Also, as illustrated by the major Voisey's Bay Ni-Cu-Co discovery which ensued from the observation of anomalous concentrations of chalcopyrite grains in a KIM survey (McNish 1998), it is important to recognize minerals indicative of any type of mineral deposit, not just the type being targeted in the survey.

While most KIMs are sufficiently distinctive to be recognized visually in HMCs by a trained indicator mineral technician, visually analyzing a HMC for a full range of both background and indicator minerals while simultaneously evaluating the significance of these minerals, as described

above, requires an attentive geologist/mineralogist with an aptitude for mineral exploration and good knowledge of rock-mineral associations and ore deposit and hydrothermal alteration models. The grains are examined whole and thus can be turned and studied from any angle and compared to one another. If a SEM is available, any mineralogical uncertainties can be resolved in minutes by qualitative analysis of the natural (unpolished) surfaces of the problematic grains. Timely decisions such as placing more (or less) emphasis on specific minerals and mineral associations can be made based on the patterns observed in the initial samples of the survey. Significant trends normally become apparent as the work proceeds; therefore little further interpretation is required.

In the case of automated investigation of HMCs at the above level, all of the minerals grains of the most prospective sizes must be analyzed; it is not sufficient to selectively search for and analyze grains of the targeted indicator minerals. While the beneficial human element of a visual analysis is lost, a more precise and objective analysis is obtained, either as an actual grain count by analyzing the centre of each particle as is done with MLA® or as a modal mineral count by analyzing grid points as is done with QEMSCAN® (Layton-Matthews *et al.* 2015). As well, the chemical compositions of the grains are measured and the mineralogy of any small inclusions can be determined. Due to the need for a finely polished section of the grains, however, no information is obtained on their natural surface features. As well, the acquired data must still be interpreted in depth by a geologist with broad experience in both indicator mineralogy and mineral exploration.

Conclusions

Detecting a mineral deposit from afar with widely spaced till samples, as is required for practical, cost-effective indicator mineral exploration in glaciated terrains, requires: (a) large samples, typically 10 kg of the ~2 mm till matrix; (b) extraction of the heavy mineral fraction from the sample to concentrate the indicator minerals; (c) an ultra-sensitive detection limit of one grain in the particle size fraction of the HMC within which the targeted indicator minerals preferentially reside; and (d) examination of all of this size fraction of the HMC in order to determine how many indicator mineral grains are present, if any.

Basic indicator mineral math:... continued from page 12

While automated methods are now available for analyzing HMCs, only a very small portion of an HMC can presently be analyzed on a practical basis, typically 1 % of the most critical particle size fraction. Therefore traditional visual analysis is still essential to obtain meaningful indicator mineral data for exploration programs. Visual analysis can also provide important information on the physical features of the grains that is lost when grains are mounted and polished for automated analysis. If, however, a till HMC is known from visual analysis to be enriched in an indicator mineral to the 1000 ppm range, or if this mineral is present in a mineralized rock sample at the 10 ppm level and is distributed optimally as very small grains (<20 µm; Cabri 2015), automated analysis of a single epoxy block can reliably identify the mineral and determine its concentration in the sample. Automated analysis also determines the composition of each mineral and may identify mineral inclusions that are not apparent visually.

In summary automated mineral analysis, in its present form, is a useful complement to, not a replacement for visual analysis of HMCs in indicator mineral exploration in glaciated terrains.

Acknowledgements

The authors would like to thank Beth McClenaghan for encouraging them to submit this article and for providing particle size distribution data for tills on the Canadian Shield. The article also benefited significantly from a review by Steve Amor.

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Recently Published in Elements

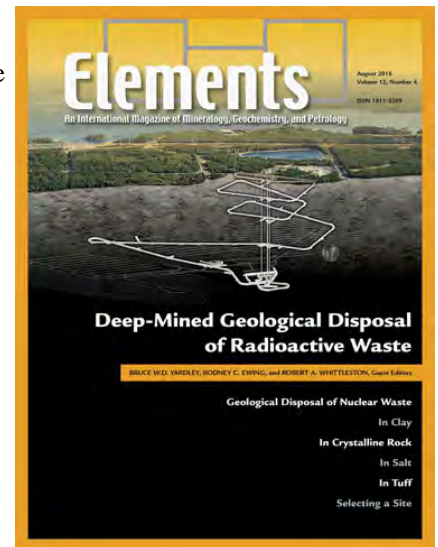
Volume 12, nos. 3 and 4



The June 2016 edition of Elements magazine is devoted to the subject of cosmic dust. An introductory article on *Cosmic Dust: Building Blocks of Planet Falling from the Sky* by Brownlee defines what cosmic dust is and how it is sampled. Taylor, Messenger and Folco describe in more detail the challenges associated with sampling cosmic dust in their article,

Cosmic Dust: Finding a Needle in a Haystack. Flynn, Nittler and Engrand discuss the origins of cosmic dust in their contribution, *Composition of Cosmic Dust: Sources and Implications for the Early Solar System*. *Organic Matter in Cosmic Dust*, some of the earliest preserved material in the solar system, is described by Sandford, Engrand and Rotundi. Peuker-Ehrenbrink, Ravizza and Winckler discuss *Geochemical Tracers of Extraterrestrial Matter in Sediments*, particularly helium, osmium and iridium. Finally, Westphal, Herzog and Flynn describe the *Analytical Toolset* available to geochemists to study cosmic dust at the sub-nanometer scale. A fascinating edition!

The August edition of Elements magazine is devoted to the subject of deep-mined geological disposal of radioactive waste, a recurring theme for the nuclear industry and one which has proved more intractable than initially thought. Ewing *et al.* provide an introduction to the topic in *Geological Disposal of Nuclear Waste: A Primer*. Granbow examines *Geological Disposal of Radioactive Waste in Clay*, whereas



Hedin and Olsson describe the use of *Crystalline Rock as a Repository for Swedish Spent Nuclear Fuel*. The *Russian Strategy of using Crystalline Rock as a Repository for Nuclear Waste* is presented by Laverov *et al.* and Berlepsch and Haverkamp describe *Salt as a Host Rock for the Geological Repository for Nuclear Waste*. The American perspective is provided by Swift and Bonano who discuss the *Geological Disposal of Nuclear Waste in Tuff: Yucca Mountain (USA)*. Metlay provides a wrap-up article on *Selecting a Site for a Radioactive Waste Repository: A Historical Analysis*. It's interesting to see how different countries have taken different approaches to the disposal of radioactive waste.

Dennis Arne



Obituary



Jane Ann Plant CBE (1945-2016)

It was with deep sadness that I learned of the death on March 4th 2016 of my friend, Jane Plant. Jane's legacy is rich: she was a pioneer in exploration and environmental geochemistry, a role model for women in science, a major influence on creating dialogue and collaboration amongst government, industry and academia to the benefit of all, and a strong force to improve the relevance and interdisciplinary nature of scientific curricula. She is also remembered for her long and extremely brave fight with cancer and for her books on diet and health.

Jane Ann Lunn was born in 1945 in Derbyshire, England, attended Ashby Grammar School and graduated with a first class honours degree in geology from the University of Liverpool. Her first marriage was to Dr. Ian Plant, with whom she had a son, Mark. She later married Peter Simpson, a colleague and collaborator at the British Geological Survey (BGS) and they have a daughter, Emma, and son, Thomas.

At the young age of 23, she joined the Atomic Energy Section of the BGS in London, under the direction of Stan Bowie. She was given the responsibility of leading a geochemical reconnaissance programme mapping the presence of elements in stream sediments in the Scottish Highlands and Islands. This formed the basis of her PhD from University of Leicester in 1977 – “Regional Geochemical Mapping in Great Britain with Particular Reference to Sources of Error” – and led to many of the protocols used in today's geochemical mapping projects worldwide. She recognised the numerous and varying applications of such databases, to be used in

mineral exploration, environmental issues and pollution, and in studying the health of ecosystems and humans. Her research areas also included metallogenesis and crustal evolution.

Jane took a sabbatical from the BGS in 1988-89 and worked as Vice-President of a junior exploration company in Ontario, Canada. It was during this time that she came to me at the Geological Survey of Canada to find the cause of a strange looking chondrite-normalised plot of REEs, a plot based on data from a newly available four-acid ICP-MS analysis. Comparison with data based on fusion INAA led to the conclusion that the four-acid digestion was not total for the heavy REEs; we published several papers on this and the application of REEs in exploration.

In 1990, she became Assistant Director of the Minerals, Environment and Geochemical Surveys Division of the BGS, while continuing her scientific research and ensuing publications. In 1997 Jane received the prestigious Commander of the Most Excellent Order of the British Empire (CBE) in recognition for her service to science and industry. She became the first female Chief Scientist of the BGS (2000-05) and then was elected first female President of the Institute of Mining and Metallurgy (2001-02). Jane is credited with establishing ‘Environment and Health’ as a significant area of research at the BGS. She left the BGS in 2005 and joined Imperial College as Anglo-American Professor of Geochemistry where she mentored graduate students and fostered the study of environmental factors and health.

All these accomplishments (and more) are outstanding in themselves but are particularly amazing in light of the fact that Jane battled cancer from the age of 42. It was at the Exploration '87 conference in Toronto, Canada when she discovered a lump in her breast and left us early to return to England for a full diagnosis and treatment. She was plagued by recurrences until 1993 when she adopted a dairy- and animal protein-free diet, as a result of drawing the link between the Asian diet and the low incidence of breast cancer. Her book – *Your Life in Your Hands* – has sold about two million copies and has been translated into 25 languages. Sadly, cancer returned several years ago and she died from a blood clot following chemotherapy. She leaves Peter Simpson (past President of the AAG), three children, six grandchildren and many friends. Her work in the field of geochemistry and the effect of diet on cancer will remain with us in her publications—a lasting legacy from a talented and influential scientist.

Those wishing to donate to the AAG's Distinguished Applied Geochemists Fund in Jane's honour may do so at: <https://www.appliedgeochemists.org/index.php/membership/donate-to-aag>

Gwendy E.M. Hall,
Ottawa

Distinguished Applied Geochemists Fund

The AAG's Distinguished Applied Geochemists Fund provides financial support students around the world to assist them in their travels to the International Applied Geochemistry Symposia. Donations may be made to the Fund in two ways:

- 1) using the AAG website: <https://www.appliedgeochemists.org/index.php/membership/donate-to-aag>
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- 2) using mail: AAG Business Office, P.O. Box 26099, 72 Robertson Road, Nepean, Ontario, Canada K2H 9R0, Phone: +1 613-828-0199

In 2015, the AAG provided \$400 to \$600 US to the following 12 students for travel to the 27th IAGS in Tucson, Arizona, USA.

1. Matthew Bodnar, University of British Columbia, Vancouver, Canada
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3. Oliver Delves, University of New South Wales, Sydney, NSW, Australia
4. Sarah Hashmi, Simon Fraser University, Vancouver, Canada
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9. Shane Rich, University of British Columbia, Vancouver, Canada
10. Kun Tang, Institute of Geophysical and Geochemical Exploration, Langfang, China
11. Thomas Bagley, Acadia University, Wolfville, Canada
12. Camilo Yáñez, University of Chile, Santiago, Chile



AAG Council Needs You!

Each year the Association of Applied Geochemists (AAG) needs motivated and energetic members to stand for election to the position of "Ordinary Councillor." If you are not yet a Fellow of the AAG, convert your membership status now so that you can stand for election and make a contribution to the AAG (see the website for details about how to become a Fellow).

Our next election will be in October-November, 2016 for the term of 2017-2018. Each Councillor serves a term of two years and has the option of standing for election to a second two-year term.

The affairs managed by Council vary from reviewing and ranking proposals to host our biennial Symposium, to approving applications for new membership, to developing marketing strategies for sustaining and growing our membership. Councillors are also encouraged to volunteer on committees or other assignments that greatly benefit the Association. It is a rewarding experience and a great way to meet other AAG members.

If you are interested in being considered for election to AAG Council, send an email to the AAG Secretary (Dave Smith, dsmith@usgs.gov) by October 10, 2016, and include a short (no more than 250 words) summary of your career experience. This summary should include the following:

- Your name
- Year you became a Fellow of AAG
- Earth sciences degrees obtained, year of graduation of each, and institution of each
- Employment - list major employers and state years worked for each, e.g. 1980-1990, and type of work
- Position held as part of AAG or other past contributions to AAG
- 1-2 sentences about your professional experiences in applied geochemistry

Dave Smith
Secretary, AAG



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Exploration '17 is the sixth of the very successful series of Decennial Mineral Exploration Conferences which have been held in the seventh year of every decade starting in 1967. The theme of the Exploration '17 conference is "Integrating the Geosciences: The Challenge of Discovery", featuring a multi-national, multi-disciplinary technical programme, exhibition, workshops and field schools.

Decennial Conference Proceedings from the past five conferences (1967, 1977, 1987, 1997, 2007) are available for download on the web site under the 'Resources' header.

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The use of digital libraries for reference search on a particular topic has revolutionized the accuracy and speed with which background information can be obtained. However, publications that pre-date this digital revolution are often not available directly or require careful sleuthing to discover. Many of the geochemical exploration methods that are the hot topics of research today, such as weak and selective extractions (covered in the footnote to section one of the Barringer book, movement of elements into and through vegetation (Chapter 2), the use of surface microlayers as a sampling medium (Chapter 3), methods to detect elements through foreign cover (Chapters 1 and 3), analysis by laser ablation (Chapter 10) including the references in each case, to name a few, were initially conceived and tested forty or more years ago.

Unless the origins of present research are pursued to their beginning, valuable information can be lost, and time and money can be wasted "rediscovering the wheel".

Reference:

Bradshaw, Peter M.D., 2015: Barringer, Back to the Future: Airborne Geochemistry and Many Related Topics. Association of Applied Geochemists. 159 p.

Barry W. Smee, Ph.D., P.Geo., FGC
Smee and Associates Consulting Ltd.
www.geochemist.com

Email to the Editor

I recently read the **EXPLORE** article on Hg in Rocks, Soils, and Sediments by Leybourne, Bloom, and Coughlin. I thought that this article was well researched and this complex area of analysis discussed in an extremely informative manner. I must admit that I'd like to see it expanded further into the environmental areas, but the principals and issues highlighted in this article relate directly to many of the same challenges faced by those of us not in exploration. Thank you for your efforts in putting this document together.

I am also reminded me of the many well researched and documented articles that have been published in **EXPLORE** over the years. This is of great value to our members to have these high quality articles published in an expedited manner rather than having to wait for the journal process to complete - so that we may all benefit. My thanks are also extended to Beth McClenaghan and her **EXPLORE** team that pull together the entirety of the content that ends up being **EXPLORE**. Your efforts are much appreciated.

Erick Weiland
(AAG Fellow since 1979)
Manager Source & Migration Control
Environmental Technology / Life Cycle Analysis
Freeport-McMoRan
Email: eweiland@fmi.com



Email to the Editor

I enjoyed the recent article in Explore 171 by Matt Leybourne, Lynda Bloom and Brenda Coughlin that presented a comprehensive review of Hg occurrences, speciation, analytical methods, and misconceptions on the use of Hg in mineral exploration. Although the article is current, many of the methods and conclusions noted were the topics of research and field practice in the 1960's and 70's by the team at Barringer Research Ltd. (BRL) as noted in Peter Bradshaw's recent book (Chapter 12). The importance of Hg speciation, the instrumentation for analysis by pyrolysis, the role of micro-organisms, and the misconceptions of significant Hg loss during sample preparation were known and applied to field methods at that time.



RFG 2018 Leaders

Leaders of CIM, MAC and GAC – staff supported by volunteers from academia, government and business – are combining their knowledge, networks and resources through the Steering Committee, Program Committee and other sub-committees to develop the scientific program, sponsorship, international relations, local activities, workshops, field trips, marketing and more. The community of volunteers and contributors growing around RFG 2018 includes diverse expertise all focused on empowering a new generation to address the availability and management of resources in the future.

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Provisional Critical Timeline

June 2016	Call for sessions opens
October 2016	1 st RFG Bulletin
February 2017	Call for abstracts, workshops and short courses opens
June 2017	Early-bird registration and housing central open 2 nd RFG Bulletin
October 2017	Call for abstracts, workshops and short courses closes
January 2018	Notification to authors of accepted abstracts, workshops and short courses
February 2018	3 rd RFG Bulletin
March 2018	Presenters registration deadline End of Early-bird registration
April 2018	4 th RFG Bulletin including Preliminary Program

Provisional Program At-A-Glance

June 16-17, 2018	Pre-conference workshops and field trips
June 16, 2018	Registration opens
June 17, 2018	1 st RFG opening reception and trade show
June 18, 2018	Opening Ceremony and first plenary
June 18-21, 2018	Technical program
June 17-19, 2018	Trade Show
June 21, 2018	Closing ceremony and last plenary
June 22-24, 2018	Post-conference workshops and field trips

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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.

2016

- 21-23 SEPTEMBER 2nd Virtual Geoscience Conference. Bergen Norway. Website: virtualoutcrop.com/vgc2016
- 25-28 SEPTEMBER SEG 2016 Conference: Tethyan Tectonics and Metallogeny. Çeşme Turkey. Website: www.seg2016.org
- 25-28 SEPTEMBER Geological Society of America Annual Meeting. Denver CO USA. Website: www.geosociety.org/meetings/2016
- 30 SEPTEMBER-2 OCTOBER SIAM Conference on Mathematics of Planet Earth. Philadelphia PA USA. Website: www.siam.org/meetings/mpe16
- 9-13 OCTOBER World Water Congress & Exhibition. Brisbane QLD Australia. Website: tinyurl.com/pgrbkwu

- 10-11 OCTOBER Annual International Conference on Geological & Earth Sciences (GEOS 2016). Singapore. Website: www.geoeearth.org
- 16-21 OCTOBER Water Rock Interaction 15. Évora Portugal. Website (pdf): tinyurl.com/lch75x8
- 16-21 OCTOBER Division for Planetary Sciences / European Planetary Science Congress. Pasadena CA USA. Website: aas.org/meetings/dps48
- 18-19 NOVEMBER Swiss Geoscience Meeting. Geneva Switzerland. Website: geoscience-meeting.ch/sgm2016
- 5-9 DECEMBER American Exploration and Mining Association Annual Meeting. Sparks NV USA. Website: www.miningamerica.org

continued on page 19

What can you expect from RFG 2018?

This conference aims to provide participants with a program that will explore four vital themes: **energy, minerals, water and the earth.**

Grounded in geoscience, the conference will serve as a forum for industry stakeholders to discuss their research initiatives and activities as well as the key issues and trends shaping the future of energy, minerals and water resources including the science of the earth that underpins their sustainable discovery and extraction.

Who will attend?

This joint venture is estimated to attract 4,000 to 5,000 scientists, policy-makers, industry representatives and members of civil society.

- Education**
4-day technical program
2,500+ oral presentations and poster sessions
Daily plenary followed by themed keynotes
- Discovery**
Short courses and field trips
- Community**
4,000 to 5,000 Canadian and international participants
- Exhibition**
3-day trade show
- Students & Emerging Leaders**
Special events and sessions dedicated to students and emerging leaders
- Networking**
Knowledge exchange and business opportunities



Our host city: Vancouver

Enjoy the spectacular recreational and cultural activities that this affordable, green, accessible and multi-cultural city has to offer.

The Vancouver Convention Centre is the world's first LEED® Platinum-certified convention centre with excellent facilities and a stunning view.

CALL FOR SESSIONS GET RESOURCEFUL - EMPOWER A GENERATION

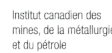
A call for sessions under the technical and non-technical themes and sub-themes making up the below matrix is now open. Proposals will be accepted until late fall 2016. Session ideas that depart from these themes, provided that they are relevant to the conference, will be considered.

Session proposals must include:

Proponents | Session title | Short summary | Relationship to conference partners | Expected participation

Energy	Minerals	Water	The Earth	Resources and Society
Conventional	Major minerals	Sub-surface water	Earth Evolution	Resources and indigenous people
Unconventional	Minor - critical minerals	Surface water	Earth Processes	Role of Geological Surveys
Sedimentary Basins	Technology and metals	Water - Minerals	Earth Systems	Resource frontiers - Arctic, Oceans
Geothermal - renewable	New sources	Water - Energy	GAC-MAC	Sustainability and climate
				Knowledge and education
				Geoethics
				Young leaders

Organizers



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
- GSC** Geological Survey of Canada

- IAH-CNCO** International Association of Hydrogeologists - Canadian National Chapter
- IAMG** International Association for Mathematical Geology
- IAPG** International Association for Promoting GeoEthics
- IUGG** International Union of Geodesy and Geophysics
- IUGS** International Union of Geological Sciences
- MAC** Mineralogical Association of Canada

Submit your session proposal at: RFG2018.org



CALENDAR OF EVENTS

continued from page 18

12-16 DECEMBER AGU Fall Meeting, San Francisco CA USA.
Website: fallmeeting.agu.org/2016/

2017

- 23-26 JANUARY Mineral Exploration Roundup 2017. Vancouver BC Canada Website: www.amebc.ca/roundup/about-roundup
- 2-3 MARCH 6th International Conference "Ecological & Environmental Chemistry-2017". Chisinau Moldova. Website: eec-2017.mrda.md
- 5-8 MARCH Prospectors and Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/convention
- 23-28 APRIL European Geosciences Union General Assembly 2017. Vienna Austria. Website: tinyurl.com/j3ff8wn
- 27-28 APRIL 3rd International Conference on

14-18 MAY

5-9 JUNE

16-21 JULY

4-9 AUGUST

12-17 AUGUST

13-17 AUGUST

Geographical Information Systems: Theory, Applications and Management. Porto Portugal. Website: www.gistam.org

Geological Association of Canada/Mineralogical Association of Canada Annual Meeting. Kingston ON Canada. Website: www.kingstongacmac.ca/

7th International Workshop on Compositional Data Analysis. Siena Italy. Website: www.compositionaldata.com/codawork2017

13th International Conference on Mercury as a Global Pollutant Providence RI USA. Website: mercury2017.org/initial/index.php

Magmatism of the Earth and related strategic metal deposits. Miass Russia. Website (Facebook): tinyurl.com/zxsjpb6. Email: va_zaitsev@inbox.ru

21st World Congress of Soil Science. Rio de Janeiro Brazil. Website: 21wcss.org/

5th International Conference on Selenium

continued on page 20



CALENDAR OF EVENTS

continued from page 19

- in the Environment and Human Health.
Stockholm Sweden. Website: se2017.se
- 13-18 AUGUST Goldschmidt 2017. Paris France.
Website: goldschmidt.info/2017
- 11-14 SEPTEMBER SIAM Conference Mathematical and
Computational Issues in the Geosciences.
Erlangen Germany.
Website: www.siam.org/meetings/g17
- 21-25 OCTOBER Exploration '17. Toronto ON Canada.
Website: www.exploration17.com
- 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



WRITING GEOCHEMICAL REPORTS

2nd Edition

Guidelines for Surficial Geochemical Surveys

Edited by Lynda Bloom, Analytical Solutions Ltd. with assistance from Principal Contributors Ivor Elliott, Consultant, Owen Lavin, Newmont Mining, Nigel Radford, Normandy Exploration Limited, and Dave Seneshen, Alberta Geological Survey.

Published by The Association of Exploration Geochemists,
now the Association of Applied Geochemists

In an environment of increasing accountability, the Association has taken the initiative to develop international standards for writing geochemical reports. The guidelines are applicable for the preparation of early-phase exploration geochemical surveys and are directed toward geologists and geochemists who write reports for distribution to joint venture partners, regulatory authorities or within a corporation. The guidelines focus on preparation of a report that provides a systematic and permanent record of the work performed. The underlying premise is that a reader must be able to confirm the interpretations of the writer particularly with regard to definition of areas prospective for mineralization. This document is available on the AAG website for free download, under AAG Publications.



THE ASSOCIATION OF APPLIED GEOCHEMISTS

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

OFFICERS

January - December 2016

Ryan Noble, President
CSIRO
P.O. Box 1130
Bentley, Australia 6102
TEL: +61 8 6436 8684
email: ryan.noble@csiro.au

Steve Cook, Vice-President
Teck Resources Limited
Suite 3300, 550 Burrard Street
Vancouver, BC
Canada V6C 0B3
TEL: +1 604 699 4329
email: stephen.cook@teck.com

David B. Smith, Secretary
U.S. Geological Survey
Box 25046, MS 973
Denver, CO 80225, USA
TEL: (303) 236-1849
email: dbsmith13@gmail.com

Gwendy E.M. Hall, Treasurer
110 Aaron Merrick Drive
Merrickville, ON K0G 1N0
Canada
TEL: +1-613-269-7980
email: gwendyhall@gmail.com

COUNCILLORS

2015-2016
Dave Cohen
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Dennis Arne
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Paul Morris
Erick Weiland
Matthew Leybourne
(ex officio)

Brazil
João Larizzatti
joao.larizzatti@cprm.gov.br

Northern Europe
Pertti Sarala
pertti.sarala@gtk.fi

Southern Africa
Theo Davies
theo.clavellpr3@gmail.com

Chile
Brian Townley
btownley@ing.uchile.cl

Southern Europe
Benedetto De Vivo
bdeviso@unina.it

UK and Republic of Ireland
Kate Knights
kknights@hotmail.com

China
Xueqiu Wang
wangxueqiu@igge.cn

Southeast Asia
Iftikhar Malik
malik.iftikhar@gmail.com

AAG COMMITTEES

New Membership
Nigel Radford,
nradford@inet.net.au

Admissions
Nigel Radford,
nradford@inet.net.au

Awards and Medals
Matt Leybourne
mleybourne@laurentian.ca
Chris Benn
Pertti Sarala
Romy Matthies

Education
Paul Morris,
paul.morris@dmp.wa.gov.au

Symposia
David Cohen,
d.cohen@unsw.edu.au

AAG COORDINATORS

AAG Student Paper Prize
David Cohen, d.cohen@unsw.edu.au

GEEA
Kurt Kyser, kyserk@queensu.ca

AAG Website
Gemma Bonham-Carter, webmaster@appliedgeochemists.org
Coordinator:
Bruno Lemiere, b.lemiere@brgm.fr

EXPLORE
Beth McClenaghan, beth.mcclenaghan@canada.ca

ELEMENTS
Dennis Arne, dennis.arne@csaglobal.com

Geoscience Councils
David Cohen, d.cohen@unsw.edu.au

AAG Regional Councillors
Stephen Cook,
stephen.cook@teck.com

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