EXPLORE
Newsletter for the Association of Applied Geochemists
www.appliedgeochemists.org
NUMBER 179 JUNE 2018

Catchment Analysis of Re-analyzed Regional Stream Sediment Geochemical Data from the Yukon

Dennis Arne, Rob Mackie, Chris Pennimpede
CSA Global, Vancouver, Canada

Introduction

CSA Global was contracted in 2015 and 2016 to generate a series of map products targeting different mineral deposit types using catchment analysis following the completion of an extensive re-analysis program by the Yukon Geological Survey (YGS) (Mackie *et al.* 2015). The re-analysis program resulted in new ICP-MS data for the <0.177 mm fraction of 24,279 archived regional stream sediment samples collected by the YGS and the Geological Survey of Canada (GSC) for the southern two-thirds of the Yukon (Fig. 1). Interpretation of the new geochemical data investigated two approaches to correct for the influence of variable bedrock lithology and metal scavenging on commodity and pathfinder elements of interest for mineral exploration. One was Z-score levelling of specific commodity and pathfinder elements by dominant bedrock lithology, and the second was a new approach – regression analysis of commodity and pathfinder elements against principal components that can be related to regional lithological variations and/or metal scavenging.

Digital copies of deposit-specific geochemical prospectivity maps and data packages are available for all maps sheets from the YGS web site (http://data.geology.gov.yk.ca/; see listing in Mackie *et al.* 2017). The results of both approaches are presented in the form of weighted sums models for specific mineral deposit types that were visually tested against known mineral deposits and occurrences on each map sheet. A subsequent review of data quality, including an assessment of geochemical data quality, sample locations, and geomorphological controls on dilution was provided by Mackie *et al.* (2017). A previous contribution to **EXPLORE** No. 176 demonstrated the wide variability of Au data from the re-analyses of archived stream sediment samples by modified aqua regia/ICP-MS using a small (0.5 g) sample aliquot (Arne 2017). This

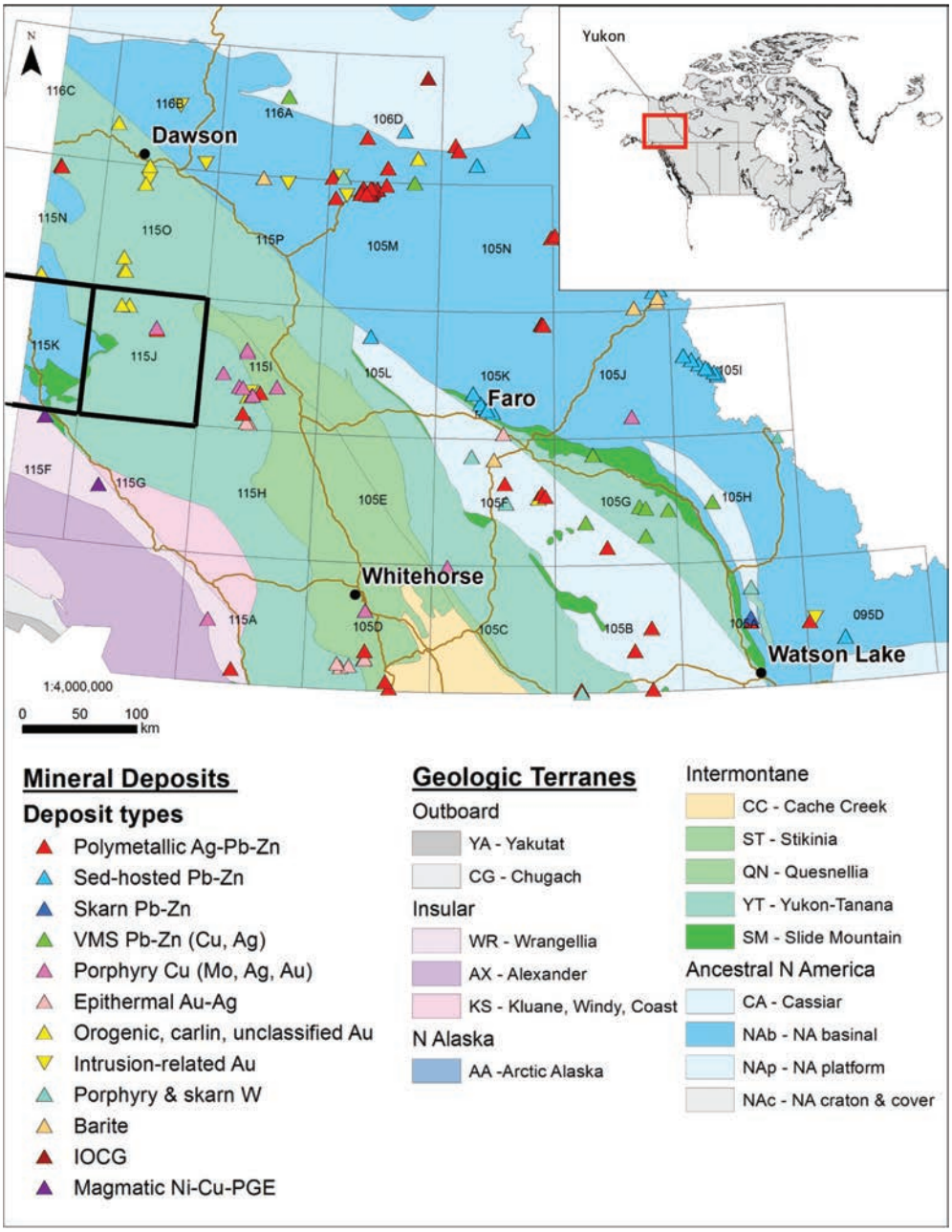

Figure 1 – NTS map sheets included in the YGS stream sediment re-analysis and interpretation project superimposed on geological terranes from http://www.geology.gov.yk.ca/bedrock_terrane.html. The distribution of mineral deposit types is also illustrated. The Stevenson Ridge area is shown by the heavy black map sheet outline.

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EXPLORE

Newsletter No. 179 June 2018

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Back Issues: AAG Website (www.appliedgeochemists.org)

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

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

EXPLORE Publication Schedule

Quarterly newsletters in March, June, September, December

Deadlines for submission of articles or advertisements:
March newsletter: January 15
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Manuscripts should be double-spaced and submitted in digital format using Microsoft® WORD. Do NOT embed figures or tables in the text document. Each photo and/or figure (colour or black and white) should be submitted as separate high resolution tiff, jpeg or PDF (2400 dpi resolution or better) file. Each table should be submitted as separate digital file in Microsoft® EXCEL format. All scientific/technical articles will be reviewed. All contributions may be edited for clarity or brevity.

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

In addition to the technical article, authors are asked to submit a separate 250 word abstract that summarizes the content of their article. This abstract will be published in the journal **ELEMENTS** on the 'AAG News' page.

Submissions should be sent to the Editor of **EXPLORE**:
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Notes from the Editor

Welcome to the second issue of 2018. **EXPLORE** issue 179 includes one technical article that describes catchment analysis of regional stream sediment geochemical data from the Yukon, Canada. It was written by Dennis Arne, Rob Mackie, and Chris Pennimpede. This issue also includes an update on the status of Robert (Bob) Boyle's book on the history of geochemistry and cosmochemistry written by Graham Wilson as well as an introduction to our new Editor-in-Chief for GEEA, Scott Wood.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue: Steve Amor, Dennis Arne, Al Arsenault, Peter Bradshaw, Graham Closs, David Cohen, Steve Cook, Bob Garrett, John Gravel, Nikita La Cruz, Owen Lavin, David Leng, Rob Mackie, Paul Morris, David Murphy, Simon Nordstad, Chris Pennimpede, Madhu Raghav, Dave Smith, Pim van Geffen, Graham Wilson, and Scott Wood.

Beth McClenaghan
Editor

President's Message

For nearly 50 years, the Association of Applied Geochemists has, since 1970, served our global community of exploration and environmental geochemists. Now, as our new 2018-2019 Council begins to close out the 5th decade of the Association's existence, we are also in a position to influence its course for the beginning of its 6th decade. Looking forward over the coming two years, there are many ways in which we may continue to improve the Association and its services, but there are three particular objectives which I would like to achieve in preparation for that point in time. I set this out as a challenge to myself, our Council, and to our Regional Councillors and membership around the world, so that we will enter out 6th decade in a stronger position to help further the work of applied geochemists in mineral exploration and environmental research.

First, I would like to continue efforts to increase our membership, particularly among those younger geochemists who may have had little in the way of interaction with the AAG to this point. My goal, and my challenge to all Fellows and Members, is to increase our stable membership by a minimum of 10% by the end of 2019. This would equate to some 35-40 new members, a sizeable but not impossible increase.

Secondly, I would like to increase involvement in the Association by those who are already members. I would urge current eligible Members to convert to Fellow status, so that they will have the opportunity to partake more fully in the activities and direction of the AAG. Taking this another step further, we must foster the involvement of new members with the various AAG committees, publications, and online resources. Providing assistance and support to those stalwart members who have been the bedrock of the Association will give a new generation of geochemists the tools to, with time, succeed them. As we have already seen two long-serving committee chairs step down this year, there is no time to lose in recruiting the next wave of AAG leaders.

Finally, I would like to see us continue and expand our level of educational research support for the next generation of geochemists, those who will advance the science in the coming decades, whether in industry, the universities, or the public sphere. It's critical to the discipline, and to the Association that serves it, that young geochemists with new ideas and new technologies at their disposal have the encouragement and the resources they need to succeed in their work.

Looking at the nearer term, the most exciting event for the AAG this year will be the upcoming Resources for Future Generations (RFG 2018) meeting, to be held in Vancouver in late June, just about the time that this report will make its way to you. We have partnered with this large conference, which will bring many societies and associations together under a single roof at the Vancouver Convention Centre, to hold our 28th International Applied Geochemistry Symposium (IAGS). The large contributions that the AAG is making to this important meeting – technical sessions, short courses and field trips – are way out of proportion to the relatively small size of our membership. It speaks to both the scientific curiosity and the public spirit of the geochemical community that we will be playing such a prominent role in ensuring the success of this conference. I invite all Members and Fellows to attend our AAG sessions at the conference, our AAG Banquet at the Vancouver Aquarium in Stanley Park, and our Annual General Meeting (AGM) which will be held there. The AAG Banquet is a long-standing tradition of IAGS Symposia, and this dinner will be held at a truly unique location. We will be presenting Medals of the Association to honoured recipients at the banquet, and that will be a subject of my next Presidents Message. As a final note, we are saddened to learn of the recent passing of Dr. Ian Nichol, long-time professor of geochemistry at Queen's University in Kingston, Ontario. Ian was a giant of exploration geochemical research who supervised many graduate students who rose to prominent positions in industry, government research and academia.

Stephen Cook

2018 AAG Dues Reminder

Reminder that AAG membership fees for 2018 are now due.

Membership fees can be paid on AAG's website (www.appliedgeochemists.org).

Catchment Analysis of Re-analyzed Regional Stream Sediment… *continued from page 1*

contribution introduces the concept of regressing commodity and pathfinder elements against principal components. A case study from the Stevenson Ridge area near the Coffee Au and Casino Cu deposits examines the removal of scavenging effects of Fe and Mn in the production of a weighted sums geochemical anomaly map.

Catchment Analysis Approach

The approach to catchment analysis used in this study is aligned with the concept of productivity described by Hawkes (1976) and further expanded on by Pan & Harris (1990) and Moon (1999). Bonham-Carter & Goodfellow (1986) demonstrated that catchment bedrock lithology was the main control on observed variation in stream sediment geochemical data from the Nahanni region of the Yukon Territory. Other effects, such as catchment area, possible adsorption of some elements onto secondary Fe or Mn hydroxides, or onto organic material, and water pH were considered minor by comparison. A similar conclusion was reached by Carranza & Hale (1997) in a study of the main controls on stream sediment geochemical dispersion in the Philippines. Bonham-Carter *et al.* (1987) applied a similar approach to the analysis of stream sediment data from the Cobequid Highlands of Nova Scotia and further concluded that use of the dominant lithology in the catchment basins was not as effective as including the areal extent of all lithological units in the catchment using multiple regression analysis, an approach further developed by Carranza (2009). An intermediate, computationally efficient option is to use the presence of a single lithological unit to assess catchment basins in a pass/fail approach, and this may be as effective as using the entire catchment geology (Bonham-Carter *et al.* 1987; Arne & Brown 2015).

The rationale for levelling stream sediment data for variable lithology and/or the effects of metal scavenging is to remove these effects on commodity and potential pathfinder elements to reveal subtle geochemical anomalies that might be associated with undiscovered mineral deposits. For example, Arne & Bluemel (2011) levelled re-analyzed stream sediment data from the Geoscience BC QUEST South project area using the dominant bedrock lithology identified in the catchments, as well as regression analysis against iron to correct for the effects of possible metal scavenging onto secondary iron hydroxides. Levelled geochemical data were then used to generate additive elemental indices associated with different mineral deposit types. Heberlein (2013) levelled newly acquired modified aqua regia/ICP-MS data for two map sheets in the Yukon using dominant bedrock lithology after demonstrating bedrock control on the dispersion of some elements, such as Cu. Weighted sums models (Garrett & Grunsky 2001) were generated for different mineral deposit types. The simplified approach used by Arne & Bluemel (2011) and Heberlein (2013) may not always be appropriate in large catchment basins where multiple lithological units are to be anticipated, as argued by Bonham-Carter *et al.* (1987), nor

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does it account for variable erosion rates within the catchment (Granger & Schaller 2014). A spatially insignificant rock unit may contribute disproportionately to the geochemistry of a stream sediment sample from the catchment if it is relatively enriched in commodity or pathfinder elements, and this contribution is not easily modelled.

A more reliable approach to levelling stream sediment geochemical data for the effects of variable lithology would be to estimate a background value for each catchment and elements of interest using average values for individual lithological units weighted on the basis of the proportion of each unit exposed within the catchment. Such weightings assume a constant supply of sediment from each lithology and may require adjustment to account for local variations in relief and erosion. Topography and variable weathering effects because of slope aspect are no doubt important factors in controlling the geochemical input from each lithology in a catchment basin (e.g. Mackie *et al.* 2017) but are difficult to correct data for. Differences between calculated background metal values and those observed would indicate the presence of an anomalous metal source within a catchment basin relative to the expected metal concentrations based on known bedrock geology.

Methodology

One approach used by Mackie *et al.* (2015) levelled individual elements by the dominant bedrock lithology within the catchment basins using the approach described by Arne & Bluemel (2011) and Heberlein (2013), and as requested by the YGS. The catchment basins used were generated from a digital elevation model (DEM) by the YGS using the hydrology module in ESRI ArcMap™. Levelled data were then used to construct weighted sums models for specific mineral deposit types. This approach requires that the sample location be accurately located on the stream that was sampled, assumes constant sediment supply from all lithological units, and requires that the geology of the catchment basins is well constrained. The influence of geochemically distinct but geographically minor lithological units is under-estimated using this approach.

As noted by Bonham-Carter *et al.* (1987) and Arne & Brown (2015), levelling the geochemical data by the dominant lithology in the catchment basin does not necessarily provide the best interpretative outcome. Therefore, the second approach used by Mackie *et al.* (2015) involved exploratory data analysis of the geochemical data using principal component analysis to identify geochemical associations related to lithology, scavenging of metals by organics, clays or secondary Fe and/or Mn hydroxides, or (rarely) to mineral deposits. Principal component analysis was undertaken on centred-log transformed data to reduce the effects of closure on the data (Aitchison 1986). Individual commodity and pathfinder elements were regressed against one or more principal components in which they were prominent to normalize the data for the effects of variable lithological background geochemistry and/or the effects of metal scavenging. Weighted sums models were generated using residuals calculated for individual samples following least squares regression. Even though the catchments were not used to derive geology for the samples using this second approach, the usefulness of the resulting weighted sums models and correction of the data for the effects of dilution depends very much on identifying the correct catchments for further investigation. This approach relies on the main principal components clearly reflecting lithological or scavenging element associations. Regression against principal components also has the benefit of being applicable in areas where the bedrock geology is poorly known as no direct knowledge of bedrock geology is required for its application.

Processing of the geochemical data was carried out over 29 complete and partial NTS 1:250,000 map sheets covering the southern Yukon (Fig. 1). The study covered several different cordilleran terranes, and individual map sheets sometimes crossed significant terrane boundaries, thereby introducing substantial lithological variation within a single data set (Fig. 1). The southern Yukon includes a wide variety of mineral deposit types, including, but not restricted to: volcanic and sediment hosted base metal deposits, porphyry Cu-Au deposits, polymetallic epigenetic vein systems and skarn deposits, epithermal and orogenic Au deposits, and magmatic base metal and platinum group elements (PGE) deposits (Fig. 1).

Stevenson Ridge

The Stevenson Ridge region has variable relief, from elevations close to 3,500m to just over 300m, with large areas of subdued topography (Fig. 2). It lies in an area that was largely unglaciated during the late Wisconsin-McConnell glaciation (http://www.geology.gov.yk.ca/quarternary.html). The area hosts porphyry Cu-Au deposits at Casino, as well as the Coffee orogenic Au deposit (MacKenzie *et al.*, 2015). Both deposit types are known to be elevated in As associated with the mineralization. However, gridded percentile plot images indicate raw As data are also elevated in the low-lying regions (Fig. 3), where they correlate positively with Fe and Mn. They correlate, to a lesser degree, with loss on ignition (LOI) values (used as a surrogate measure for organic material, secondary hydroxides and clay in the samples), as well as a number of other elements, such as Ca, Sr, Cu, Co and Zn. Simple and multiple regression of As against Fe, Mn or LOI shows little significant variation from the distribution of raw As, and so proved inadequate to correct for the possible effects of metal scavenging onto secondary materials. This secondary, or scavenging, association of elements and LOI is evident in positive loadings on principal component 1 (PC1; Fig. 4), indicating a very strong influence of metal scavenging on the stream sediment geochemical data from this region.

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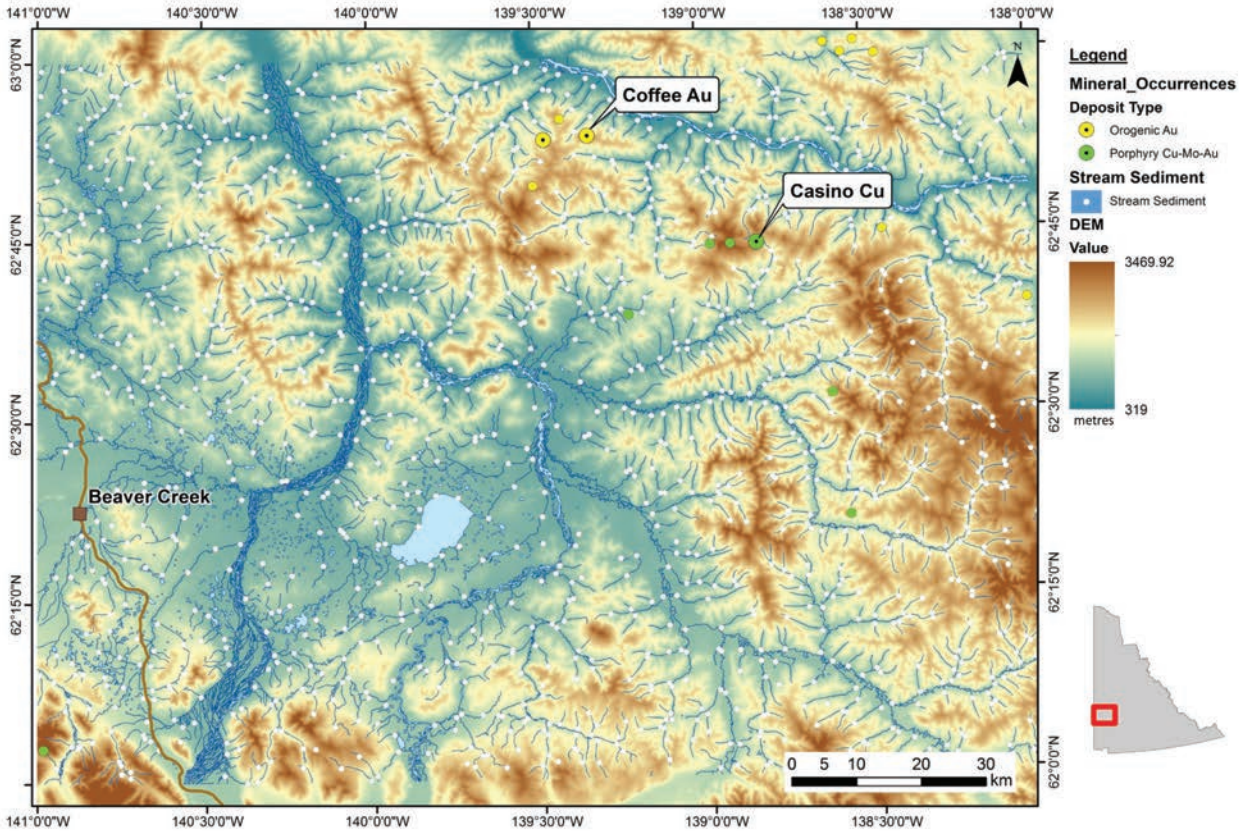

Figure 2 – Digital elevation model (DEM) of the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

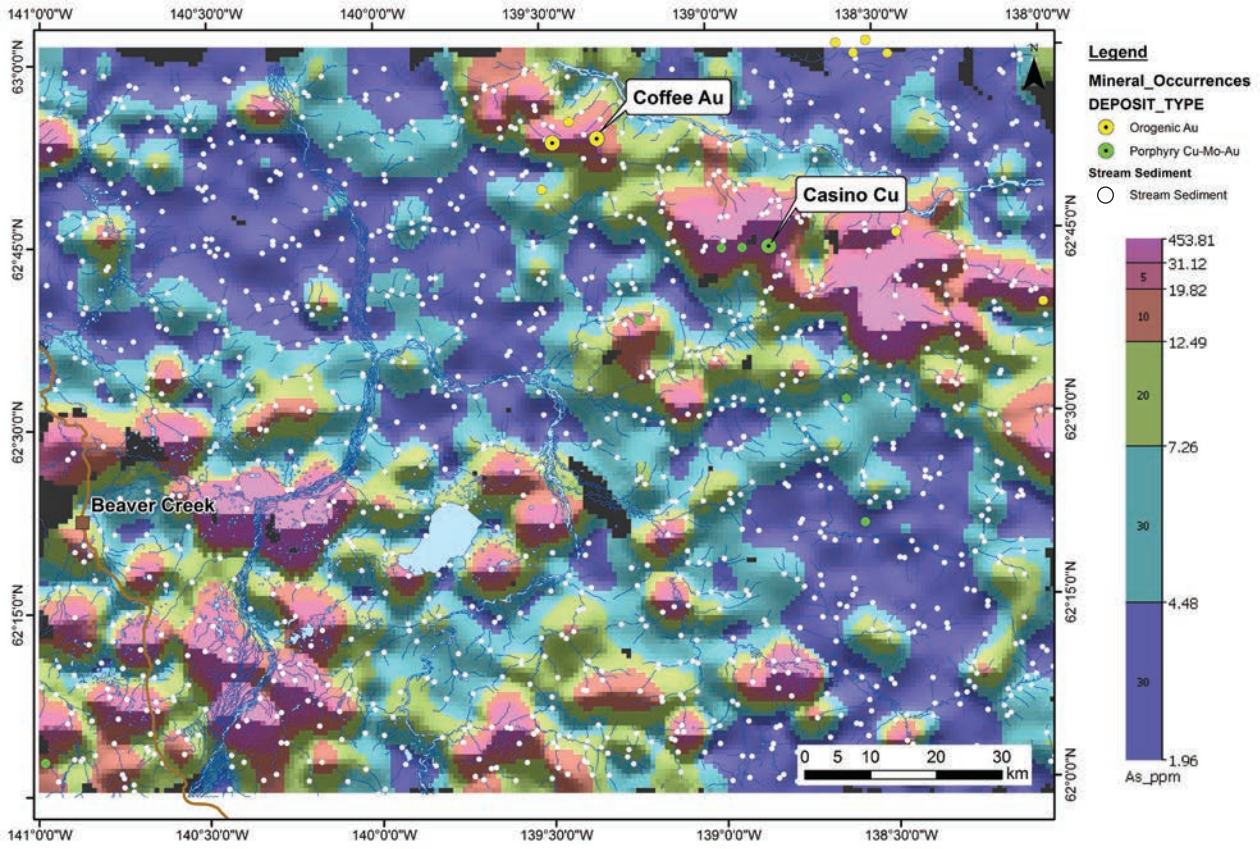

Figure 3 – Gridded percentile image of raw As data (aqua regia/ICP-MS <0.177 mm) from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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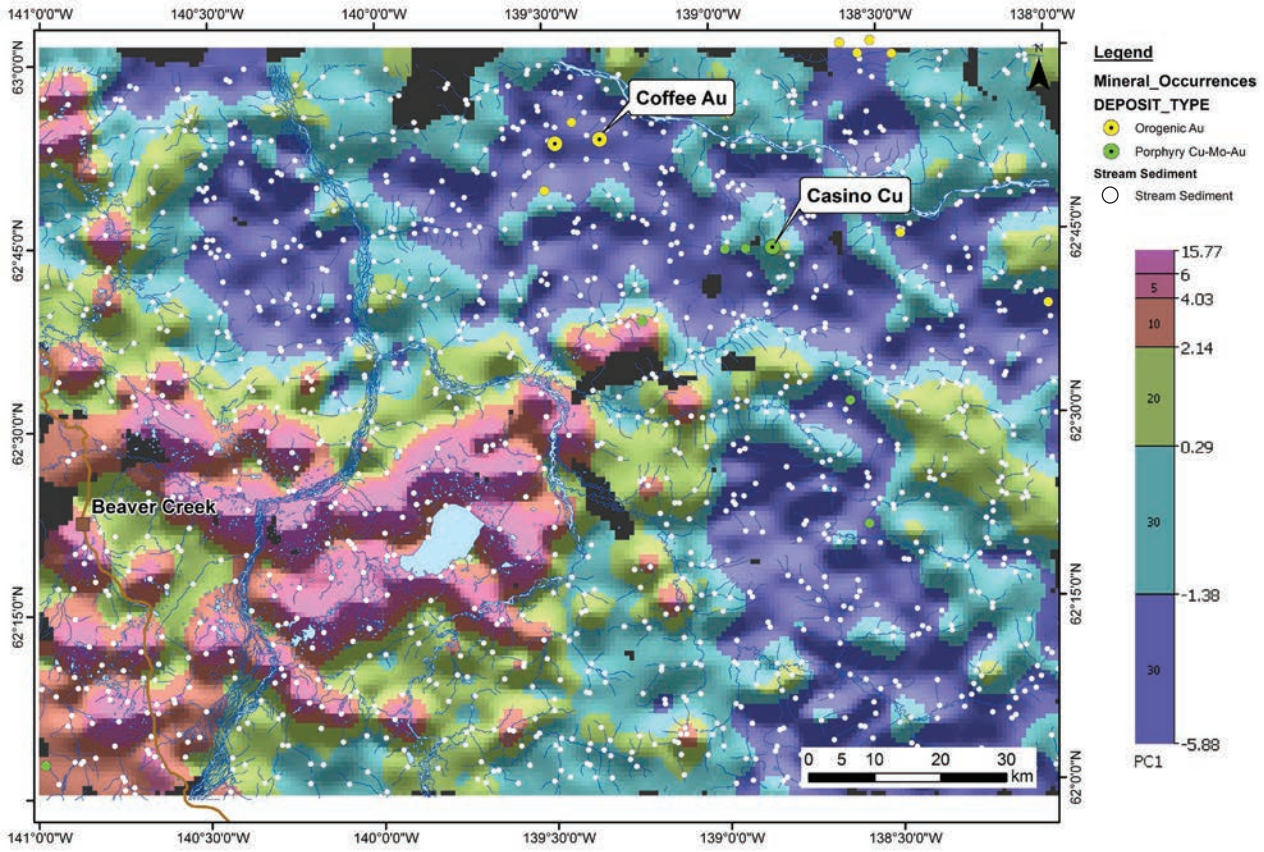

Figure 4 – Gridded percentile image of principal component 1 scores for individual stream sediment samples from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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Regressing As against PC1 and plotting residuals results in a reduction of the scavenging effects and emphasizes the association of As with both porphyry Cu-Au and orogenic Au deposits in the region along a distinct northwest trending belt (Fig. 5). Although the effects of possible metal scavenging in low-lying areas has not been entirely removed, the process has resulted in an incremental improvement in regional As anomaly contrast. The resulting As residuals (4) were combined with raw Au (3) and Te (1), as well as residuals for Sb (1) and Cu (-2) to generate an orogenic gold weighted sums model (importance rankings are shown in parentheses) for the region once the scavenging effects of secondary Fe and Mn hydroxides were reduced (Fig. 6). A negative weighting for Cu has been included in the weighted sums model to subdue the influence of porphyry Cu-Au mineralization on the orogenic model. Levelling of As data using catchment basin lithology was not successful in this area because one of the main controls on the distribution of As in stream sediment samples is the presence of secondary Fe and Mn hydroxides in the samples, rather than the lithology of the catchment basin bedrock geology.

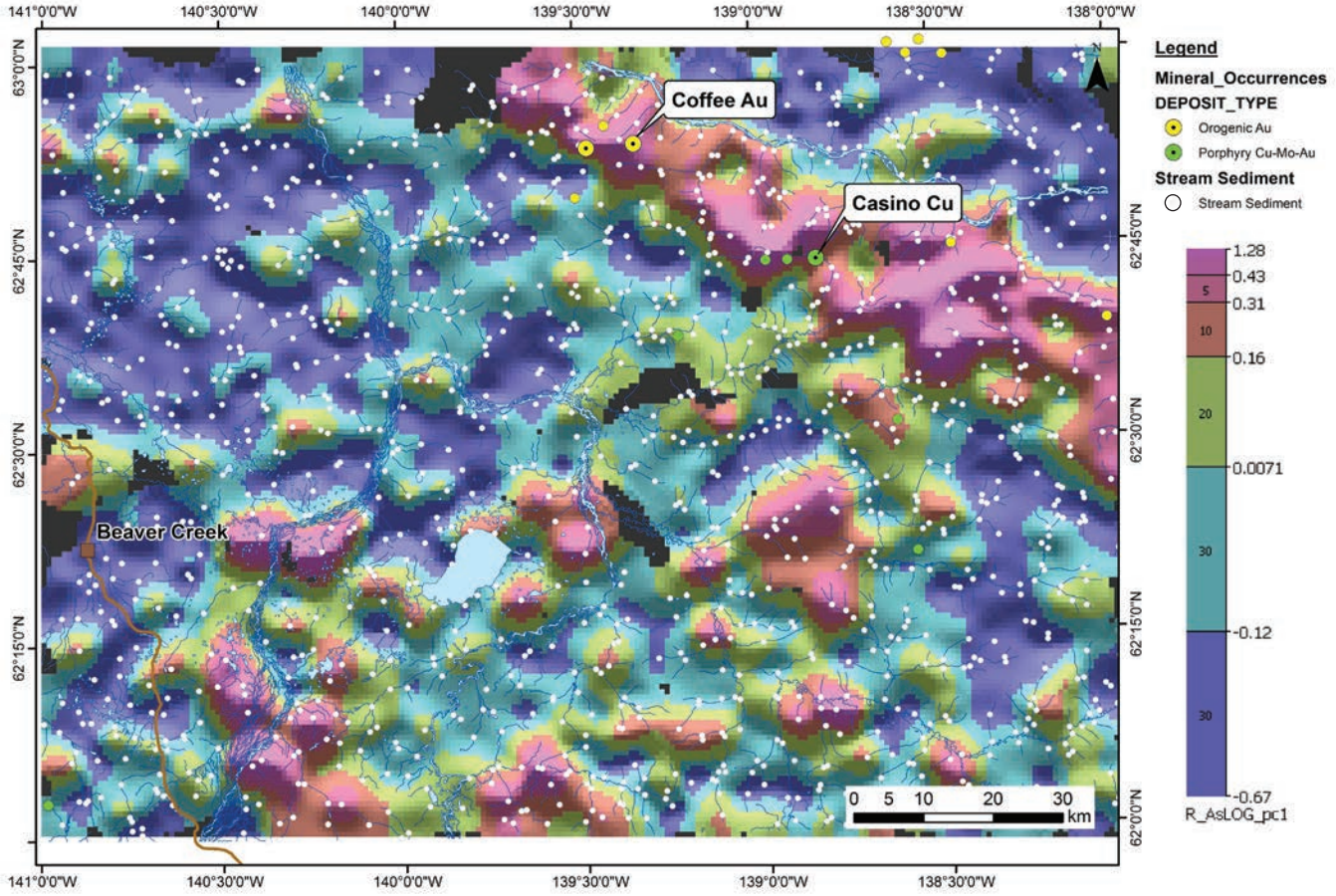

Figure 5 – Gridded percentile image of As residuals following regression against principal component 1 from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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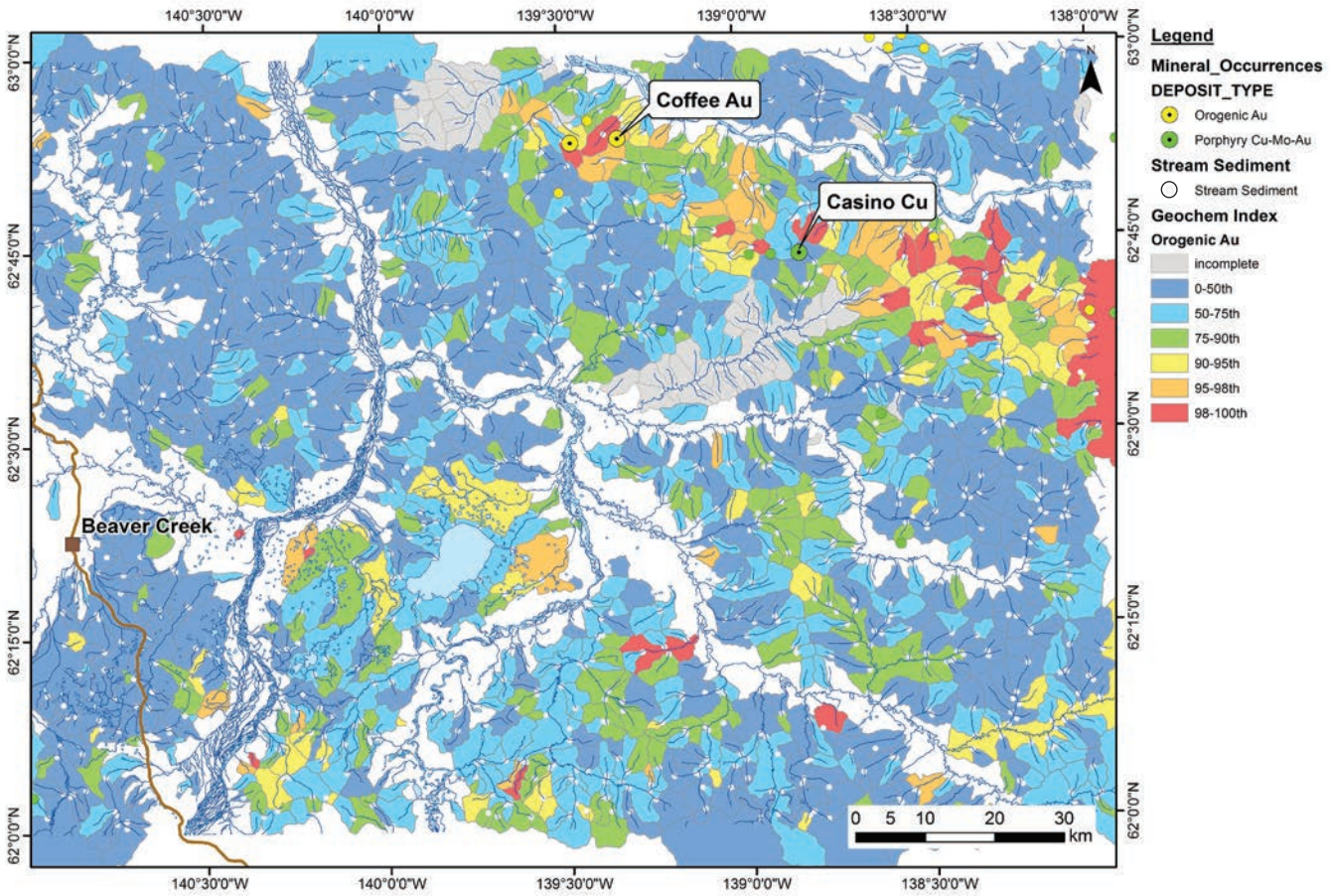

Figure 6 – Final orogenic Au weighted sums model for the Stevenson Ridge area constructed using Au, As residuals, Sb, Te and negative Cu. Catchment basins are thematically coloured based on percentile intervals of weighted sums scores.

Conclusions

A number of methods of varying sophistication have been proposed to level stream sediment geochemical data for the effects of variable catchment basin lithology so that geochemical anomalies potentially associated with mineral deposits are more apparent. Many of these approaches rely on the following assumptions:

1. The location of the sample is accurately known and the catchment from which sediment was sourced can be defined;
2. The bedrock and surficial geology of the catchment basin is known with confidence; and
3. Each lithological unit in the catchment basins contributes proportionally to the stream sediment sample collected at the basin outlet such that each unit's weighted contribution to background geochemical values can be estimated.

A qualitative review of catchment basin quality from the YGS southern Yukon re-analysis and enhanced interpretation of geochemical data suggests that the above requirements are not always honoured (Mackie *et al.* 2017; Fig. 7). For example, the low-lying region near Beaver Creek in the Stevenson Ridge area scored poorly in terms of over-all catchment basin quality in this review. Regression analysis of key commodity and pathfinder elements against principal components, where the latter can be readily attributed to either lithology or metal scavenging, provides a method to correct for these effects independent of the spatial location of the samples. These residuals can then be used in weighted sums models to develop mineral deposit-specific geochemical targeting maps for mineral exploration. The approach is internally consistent and entirely data-driven, although some subjectivity in the interpretation of principal components is involved.

Deciding whether regression analysis of individual elements against principal components is warranted or even desirable requires thorough exploratory analysis of the data. While removing the spatial aspect of levelling the geochemical data for background lithological or scavenging effects is certainly convenient, ultimately knowing where the stream sediment sample was collected is desirable. This approach may also be preferred to more classical data treatments in greenfields areas where the bedrock and/or surficial geology is poorly defined. This approach will also have application in other situations, such as lithogeochemistry or the interpretation of residual soil data.

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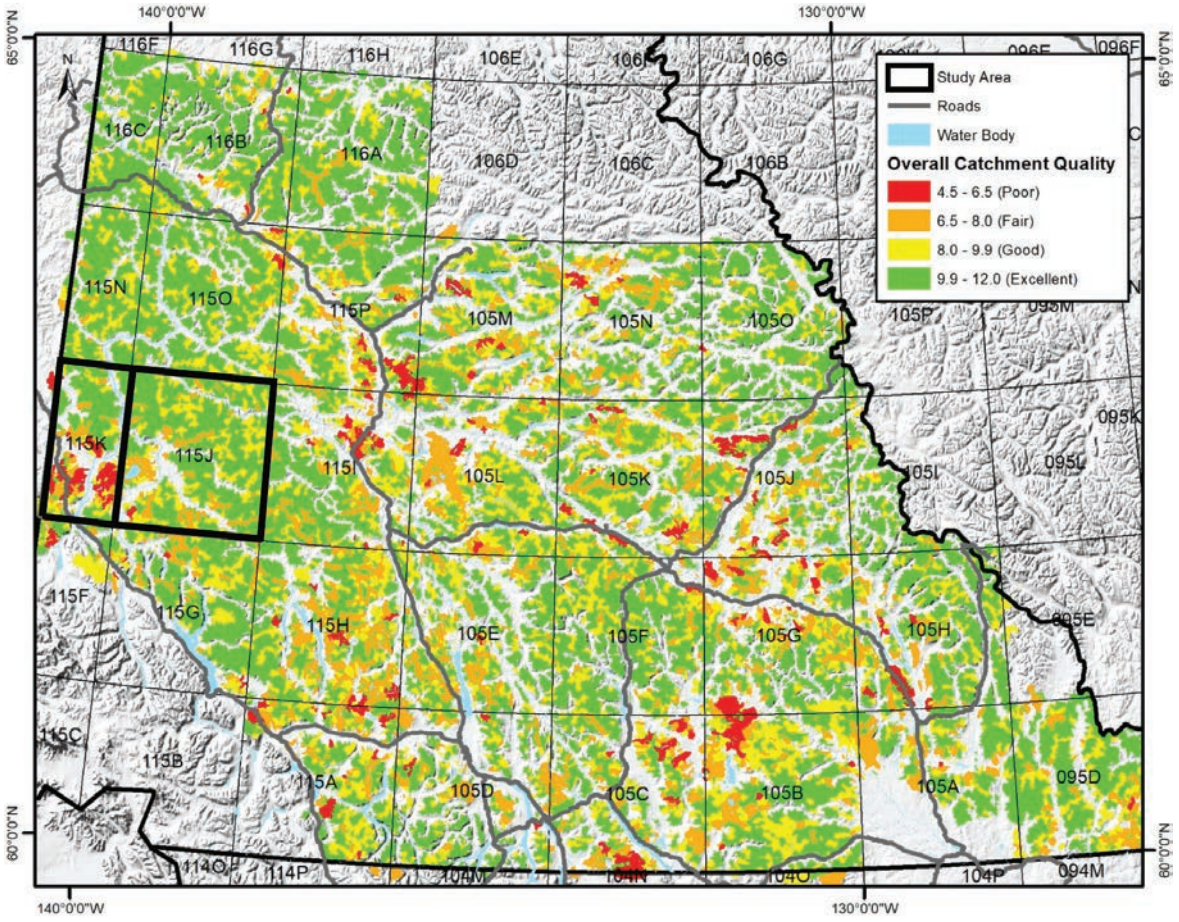

Figure 7 – Thematic summary of qualitative catchment basin quality from Mackie et al. (2017). The Stevenson Ridge area is shown by the heavy map sheet outlines.

Acknowledgements

Funding for this work was provided to the YGS by Canadian Investment in Northern Economic Development (CanNor) through the Strategic Investment in Northern Economic Development (SINED) program. The authors thank Eric Grunsky for guidance and reviews of our work. However, the authors take full responsibility for the conclusions presented here. Wayne Jackaman is acknowledged for his contributions to the sample recovery and reanalysis aspects of the project, and for providing the geochemical quality control data. Olwyn Bruce, Drift Geomatics, Bailey Staffen and Brett Elliot are thanked for digitizing catchment basins. Kristen Kennedy and Patrick Sack of the YGS are thanked for their management of the work and for shepherding final map products and reports through to final production and release. The authors would like to thank Ray Lett for a peer review of this contribution and Beth McClenaghan for editorial corrections.

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Recently Published in Elements

Volume 14, no. 1, Luminescence Dating: Reconstructing Earth's Recent History

This volume of Elements reviews the state of the art in luminescence dating, an important field of study for understanding rates of surficial weathering processes. The AAG contribution to this edition included messages from both the outgoing and incoming presidents, as well as a summary of the **EXPLORE** article in issue 177 "Quantitative Interpretation of Orientation Surveys".

Volume 14, no. 2, Comets

The name says it all really. Everything you ever wanted to know about comets but were afraid to ask! Our AAG news for this edition consisted of a summary of presentations given at the highly successful PDAC short course "Exploration Geochemistry: Fundamentals and Case Histories" held in Toronto last March, and organized by Lynda Bloom and Beth McClenaghan.

Dennis Arne

Short course “Exploration Geology” at the University of Freiburg, Germany

Germany may not be known as a major global producer of metal commodities. Nevertheless, scientists at various German universities and academic institutions have, over the years, contributed greatly to a better understanding of how mineral deposits are formed and thus helped the exploration for mineral resources worldwide. I was lucky enough to be able to participate in the short-course “Exploration geology”, which was held for the first time at the University of Freiburg, on 19-22 March 2018, with partial support from the German Mineralogical Society (DMG) and the Society for Geology Applied to Ore Deposits (SGA) with its newly-founded local SGA student chapter “Black Forest-Alpine”. The waiting list was sufficiently full to already be able to fill next year’s course, which shows the great interest and subsequent demand for such a course. The course was attended by participants not only from Germany but also from Switzerland, Sweden, Finland, Belgium, and the UK, providing a great opportunity for networking.

Participants of the “Exploration Geology” course (photo: K. Schlöglova).

The course was extraordinarily well organised and had a perfect mixture of science and real world examples of mineral exploration. After lectures on sampling, basic principles used in geochemistry, and treatment of geochemical data presented by Prof. David Dolejs (University of Freiburg) and Dr. Denis Schlatter (Helvetica Exploration Services) we were presented with numerous data sets of up to 20,000 analyses containing both major- and trace-element concentrations. The necessary tools to answer the essential questions, such as “now what?” and “which rocks host the actual deposit?” were explained in hands-on exercises during these 3 days. The data were handled using ioGAS and GCDkit software in which we obtained basic training by Dr. Katerina Schlöglova. Furthermore, we received an introduction to ore microscopy by Dr. Malte Junge, which can be a powerful tool allowing a large array of interpretations without time consuming and costly analyses. The short course included a plenary lecture by Prof. Hartwig Frimmel (University of Würzburg) entitled "How Gold Became Concentrated to Ore Grade in the Earth's Crust", and a student poster session. The aim was to set up a show case of diverse projects the students are working on, hosted in a relaxed atmosphere of the local university.

The social programme included a course dinner in a typical rustic restaurant serving good traditional German food and a wine tasting after the field trip. During the field trip, we visited local distinctive deposits, i.e. Germany’s only carbonatite occurrence in the Kaiserstuhl (Emperor’s Chair), zeolite mineralization at the Fohberg phonolite deposit, and a 1000 year old underground Ag-Pb-fluorite-barite mine at Teufelsgrund (Devil’s Ground). After the official end of each day, we found time to relax and to stroll through the medieval city of Freiburg and debauch in one of the many inviting bars.

I have no doubt this course is and will be helpful for both students and geoscientists already working in the industry, as it gives insight to the forefront of geochemical research applicable to exploration.

Simon Nordstad
Kiel University, Germany

Exploration Geochemistry: Fundamentals and Case Histories Prospectors and Developers Association of Canada (PDAC) Short Course, March 2-3, 2018

This year at PDAC 2018, geoscientists had the opportunity to participate in an excellent 2-day exploration geochemistry short course that was convened by Beth McClenaghan and Lynda Bloom. Short course participants were treated to a variety of presentations which highlighted important geochemical concepts, provided insight into considerations that should be made prior to conducting a geochemical survey, sample collection, data treatment and interpretation, and finally, on the use of geochemical data in the discovery of ore deposits. Day 1 reviewed the fundamentals of exploration geochemistry and day 2 presented case studies for different deposit types and exploration methods in various parts of the world.

Lynda Bloom started off the presentations by discussing the things we need to consider when designing a geochemical survey. One of the first points that she made was that it is important to think about the type of deposit being targeted.

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Exploration Geochemistry: Fundamentals and Case Histories… *continued from page 14*

This is useful because if we know what we are looking for and understand how it forms, then we know which elements, and/ or minerals, can be used as pathfinders to the mineralization. We also know the size/ footprint of the deposit being targeted, and this helps us plan sampling intervals. Christian Ihlenfeld, in his presentation about the use of geochemistry in the discovery of the Sakati Ni-Cu-PGE deposit, showed that sulphide geochemistry (i.e., the Cu and Ni content of the sulphides) was instrumental in indicating that they had not found the entire ore body. Sulphide melts fractionate during ore genesis, such that the sulphides are initially Ni rich and become progressively Cu rich towards the external portions of the melt/ ore body. The sulphides in the mineralization intersected initially at Sakati was very Cu rich, so the exploration team knew that deeper drilling was needed to find the Ni rich sulphides in the ore body.

Additionally, Lynda Bloom made the point that we must consider the environment in which the deposit forms and how the geochemical signature, and associated pathfinder elements being targeted can be affected by climatic factors and processes, such as weathering and erosion, after formation. This was supported by Dennis Arne, Juan Carlos Ordóñez Calderon, and Stu Averill during their presentations, which focused on using exploration geochemistry in weathered terrains, and using gold grains, transported during glacial advance to vector towards the source of gold mineralization. Lynda also discussed the importance of proper sampling techniques during geochemical surveys. The first step to acquiring good data is ensuring that we collect the right samples, and that we collect them properly. In addition to emphasizing that we should “put the right stuff in the sample bags,” Lynda spoke about the importance of sample size, and sample particle sizes as these can affect the results that we obtain. Matt Leybourne built on this during his discussion of practices and considerations necessary for the collection of samples for aqueous geochemistry, which can be a powerful tool for exploration.

Finally, Lynda discussed the generation of geochemical data. Once the samples are collected, they are sent to the laboratory, and prior to sending them, we need to think about which technique(s) will be utilized for the analyses and how we will address QA-QC (quality assurance – quality control). Lynda Bloom, Chris Benn, and Juan Carlos Ordóñez Calderon spoke about different techniques that can be used for the collection of geochemical data, e.g., fire assays, acid digests, ICP-MS, and about the importance of understanding the techniques, and the concentrations that can be achieved using the various techniques. Chris and Juan Carlos went further by pointing out that it is important to conduct orientation studies before large geochemical surveys. In the orientation studies, multiple analytical techniques, sample intervals, etc., should be used to assess which techniques best provide the data that are necessary for the deposit being targeted. These studies are important as they may end up reducing the cost of the larger geochemical survey and provide confidence in the data being generated.

Another important theme of the short course was interaction with geochemical data. While all presenters spoke about how geochemical data can be used for the discovery of ore deposits, a few presenters carefully highlighted useful practices and things that should be considered before the interpretation of our geochemical data. For instance, Pim van Geffen talked about the importance of going through geochemical data to ensure that they do not contain negative values, that there are no missing data, and that we are aware of the units being utilized. Since the data also contain a spatial component, multiple presenters (Pim van Geffen, Dennis Arne) emphasized checking to ensure that the samples plot in the correct locations. The presenters also made the point that if there are data that were collected in different surveys, using different analytical techniques, which have different limits of detection, they should not be combined.

Finally, the presenters used a variety of case studies which indicated that (large) geochemical datasets, plus some ‘out of the box thinking’, can result in the discovery of ore deposits. I was particularly fascinated by Colin Dunn’s discussion of using biogeochemistry, i.e., the concentrations of trace elements in plant tissues as a tool for mineral exploration. Pim van Geffen and Réjean Girard, respectively, showed that exploratory data analyses and artificial intelligence using large geochemical datasets are useful in the discovery of ore deposits. Beth McClenaghan discussed the use of the geochemistry of resistate minerals as a vector towards ore deposits. Further, Beth and Stu Averill showed that the shape and textures of gold grains can be used to infer whether they were transported over long distances by glaciers. Finally, Leybourne highlighted that non-traditional stable isotopes, e.g., Tl, Se, and stream and groundwater geochemistry can be utilized during exploration.

As a student pursing a Ph.D. in economic geology, with a focus on geochemistry, this course was beneficial because it indicated that geochemistry is an important aspect of exploration. During the course, it was refreshing to see how the theories and geochemical concepts that I learned in class are applied in the search for ore deposits. It was also encouraging to see that mineral geochemistry and other aspects of my dissertation research are being used for exploration. I am happy that I participated in this short course because in addition to learning a great deal about using geochemistry in mineral exploration, I had opportunities to network with geochemists from both academia and industry.

Nikita La Cruz
University of Michigan

Geochemistry

EXPLORATION, ENVIRONMENT, ANALYSIS

The journal is abstracted and/or indexed in *AGI's Bibliography and Index of Geology, Chemical Abstracts, Current Contents, Engineering Index, GEOBASE, GeoRef, Mineralogical Abstracts, PASCAL/CNRS, GeoArchive, Thomson ISI database (SCIE, CC/PC & ES)*

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Obituary

Ian Nichol
1933 - 2018

Ian Nichol was born in Newcastle-on-Tyne, grew up in Berwick-on-Tweed, and was educated in Northumbria, UK, his interest in geology naturally led him to the University of Durham. He graduated with a BSc in 1956, and immediately left for Queen's University, Kingston, where he started what was to be a lifelong association with Canada and Queen's. His MA research was on the trace element chemistry of sulphide minerals, Trace element study of contemporaneous sulphides, pyrite, pyrrhotite and chalcopyrite, under the guidance of Professor Ed Hawley. He completed this MA in 1958 and returned to Durham to undertake his PhD under the supervision of Roy Phillips, A study of some manganese minerals, which was awarded in 1962.

On completing his thesis he was recruited by Professor John Webb to join the Geochemical Prospecting Research Centre, shortly to become the Applied Geochemistry Research Group (AGRG), at Imperial College, London, in 1961. Ian immediately became immersed in regional geochemical surveys in the tropical lateritic terrains of Zambia and Sierra Leone, and by 1966 his students had completed three PhDs and one DIC (Diploma of Imperial College). During that time he started his teaching career providing a geochemical prospecting course, with Cliff James, to Mining Geology undergraduates, Mineral Exploration DIC students, and new graduate students to the AGRG, together with running the associated annual spring field camps. In 1965 AGRG interests shifted to the British Isles, and Ian's students completed a further four PhD studies to support the interpretation of the data that would be generated from the 1969 field sampling (after Ian left for Canada) for the Wolfson Atlas of England and Wales (1978). Africa was not forgotten, and one more PhD study was completed in Zambia. It was during this time that Ian recognized the potential of computing to assist in data interpretation and map preparation, and supervised a further PhD and MSc on these topics. In total, Ian guided and encouraged nine successful PhD, one MSc and two DIC students during his time at Imperial (Table 1-page 18).

In the late 1960s interest was expressed by the Canadian minerals industry and government agencies for more applied geochemical research to be undertaken at universities and the need for a graduate school. In 1969 Ian accepted an invitation to return to Queen's University as an Associate Professor to set up a research group along the lines of John Webb's AGRG. He was to focus on developing geochemical exploration methods for the Canadian environment, generating future geochemists for employ by industry, government, and academia; the latter to carry on teaching future generations of applied geochemists. One of his first actions was to hire Bob Foster, an analytical chemist working at the AGRG, to set up a laboratory facility for the new group. Similarly, he brought in Jan-Ola Larsson, a Swedish geochemist with experience in glacial terrains who had gained his PhD with Ian in London, and later, Alf Björklund, a Finnish geochemist, would join to group to help guide research (1971-73) on method development for glaciated terrains.

The projects that Ian's students undertook in his early days at Queen's (Table 1) were funded by the minerals industry, who had a need for geochemists to support their work, and find solutions to practical exploration problems. The focus was two-fold, firstly, in the surficial environment, investigations of geochemical dispersion in till sheets, and lake and stream sediments. Studies were undertaken of the morphology of gold grains in glacial deposits to estimate travel distances, and for comparison, those in lateritic soils. The second focus was in bedrock environments, including studies of element dispersion and the formation of haloes in the immediate surroundings of mineral deposits, particularly volcanic massive sulphide deposits so important in Canada. The ultimate aim was to generate 'vectors to ore' for use in drilling programs. These themes were carried through latter projects, but with an increasing focus on gold. Behind these projects lay the work of the analytical laboratory, leading to one thesis project on analytical methodologies, and commercial laboratories that provided support. Additionally, three projects involved the evaluation of statistical tools for aiding interpretation, one leading to the development of the Q'GAS software that was used by many students in their thesis work.

As the value and quality of the work being led by Ian and his students for industry was being recognized, he was increasingly successful in raising research funds from Canadian federal and provincial government (NSERC, CIDA, OGRF, OGMCU) and international (UN) agencies. The intent of the CIDA and UN funded research projects was to train and return new geochemists to undertake mineral exploration in their own countries, these included Chile, China and Thailand.

In 1987 Ian was granted a one-year leave of absence from Queen's and took a post with the United Nations Revolving Fund for Natural Resources Exploration (UNRFNRE) in New York. Whenever he could, he returned to Kings-

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ton to his family and follow the progress of his students. His work took him to Benin, Brazil, Haiti, India, Thailand and Yemen, amongst others, and a return to Sierra Leone to a field area with which he was familiar from Imperial College days. In this work the African lateritic terrain experience he had gained at Imperial College proved valuable, along with all the knowledge he had gained in the intervening twenty years. On his return to Queen's he had gained a better understanding that both the lateritic and glacial surficial processes could easily upgrade a gold anomaly to many times its source concentration. To address these confusing results, Ian and his students would often (tediously) dissect samples into their component parts, based on grain-size, magnetic susceptibility and gravity. They would then examine each separated fraction individually to explain what how false anomalies differed from legitimate anomalies.

Over the years Ian organized a number of well-attended workshops at the Donald Gordon Conference Centre at Queen's. These were often timed to run before or after major conference events in Toronto, e.g., the Exploration '77, '87 and '97 conferences, as well as the Prospector and Developers Association of Canada (PDAC) meetings (e.g., 1996, 1998, and 2000), open to industry and the Queen's Mineral Exploration MSc. students. The speakers were both leaders and innovators, some his current and former students, who made presentations on current research topics and best practices. Notably, attendees included overseas students whose attendance was supported by international development agencies.

During his career at Queen's Ian was made a full Professor in 1971, was Chairman of Graduate Studies from 1976 to 1985, became emeritus in 1996, and fully retired in 1999. Over his 30 years at Queen's 35 graduate students (14 PhDs and 21 MScs) benefitted from Ian's guidance and the opportunities he gave them (Table 1). While there, Ian made sure that in addition to acquiring and generating new geochemical knowledge they also gained experience in technical writing, oral presentations, meeting deadlines and networking with the world wide community of exploration geochemists. He was able to keep graduate students focused on their project objectives and deliver promised results to their research sponsors on time. When short course participants are added to this number, the impact of Ian's contributions to developing geochemical methods and imparting that knowledge to the wider geochemical and mineral exploration community is as significant as any in the 20th century. In essence, he brought together students from around the world to his 'incubator' where he helped them develop their potential as exploration geochemists.

The Association of Exploration Geochemists (AEG) was formed in 1970 at the International Geochemical Exploration Symposium in Toronto. Ian was a founding member and the Association's Secretary for its first two years and remained on Council until 1975, being President for 1973-74. Subsequently he served on a number of its committees. The Association founded the Journal of Geochemical Exploration (JGE) with Elsevier Scientific in 1972. In 1976 he joined the Editorial Board and served there until 1978 when he became an Associate Editor until 1983, and returned to the Board until 1995. The majority of the papers he co-authored with his students where published in the JGE, of the 17 papers listed on his Queen's ResearchGate page, all but one were published in its pages. A thread that runs from his MA, through his PhD, and the topics he guided students through was the importance of understanding the trace element compositions in minerals in relation to the ore deposits with which they were associated. When the AEG founded its Distinguished Lecturer series in 1984, Ian was the first to take on this role for 1985-86. Ian was elected an Honorary Member of the Association in 2005, and the citation states, 'In recognition of a lifetime commitment to teaching, leading graduate studies, and fostering the improvement of the application of geochemistry in mineral resource exploration'.

Ian Nichol's greatest contribution to exploration and applied geochemistry were the students that passed through his hands, who he encouraged, supported and then graduated into professional careers. Some remained as working geochemists, some took on management roles where their geochemical knowledge helped fashion exploration strategies and research programs, both in industry and government. Some entered academia, or became involved in providing continuing education opportunities, where they carried on Ian's work of supporting the next generation of exploration and applied geochemists – Ian was particularly gratified to see that.

Bob Garrett, Graham Closs, Owen Lavin, Beth McClenaghan

List of Graduate Students supervised or co-supervised by Ian Nichol at Imperial College, London, UK, 1961-1969, and Queen's University, Kingston, Canada, 1969-1997

Last Name	Initials	Title	Type	Year
Viewing	K.A.	Regional Geochemical patterns related to mineralization in central Sierra Leone	Ph.D.	1963
James	L.D.	Regional geochemical reconnaissance in the northern and southern sections of the Sula Mountains schist belt, Sierra Leone	Ph.D.	1965
Garrett	R.G.	Regional geochemical reconnaissance in eastern Sierra Leone	Ph.D.	1966
Taylor	D.	The interpretation of lead and zinc stream sediment anomalies related to contamination and mineralization in the UK	Ph.D.	1968

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Horsnail	R.F.	The significance of some regional geochemical patterns in northwest and southwest England	Ph.D.	1968
Khaleelee	J.	The application of some data processing techniques in the interpretation of geochemical data	M.Sc.	1969
Dixon	C.	The application of some data processing techniques in the interpretation of geochemical data	Ph.D.	1969
Larsson	J.O.	Mineralogical and geochemical studies in areas of blanket peat in western Ireland	Ph.D.	1970
Armour-Brown	A.	Provincial and regional geochemical studies in Zambia	Ph.D.	1971
Butt	C.R.M.	The influence of environment on regional geochemical patterns in Northern Ireland	Ph.D.	1971
Blain	C.F.	Regional Geochemistry in the Superior Province of the Canadian Shield	Ph.D.	1972
Davenport	P.H.	The Application of Geochemistry to Base Metal Exploration in the Birch-Uchi Lakes Volcano-Sedimentary Belt, Northwestern Ontario	Ph.D.	1972
Callahan	J.E.	A Regional Heavy Mineral Petrographic and Stream Sediment Geochemical Survey Applied to Mineral Exploration, Churchill Falls Area, Labrador	Ph.D.	1973
Closs	L.G.	An Evaluation of Selected Multivariate Mathematical Techniques, as Aids in Interpretation of the Reconnaissance Geochemical Stream Sediment Data of the Halls Bay Concession, Newfoundland	Ph.D.	1973
Coker	W.B.	Lake Sediment Geochemistry in the Superior Province of the Canadian Shield	Ph.D.	1974
Gunton	J.E.	Geochemical Dispersion Associated with Porphyry-type Mineralization in the Canadian Cordillera	Ph.D.	1974
Foster	J.R.	Efficiency of Acid Digestion Procedures on Rocks	M.Sc.	1975
Jackson	R.G.	The Application of Lake Sediment Geochemistry to Mineral Exploration in the Southern Slave Provinces of the Canadian Shield	M.Sc.	1975
Klassen	R.A.	Geochemistry of Lakes and Lake Sediments in the Kaminak Lake Area, District of Keewatin, N.W.T.	M.Sc.	1975
Armstrong	R.C.	The Dispersion of Mercury and Other Metals Related to Mineral Deposits in the Canadian Cordillera	Ph.D.	1975
Lavin	O.P.	Lithogeochemical Discrimination Between Mineralized and Unmineralized Cycles of Volcanism in the Sturgeon Lake and Ben Nevis Areas of the Canadian Shield	M.Sc.	1976
McConnell	J.W.	Geochemical dispersion in Wallrocks of Archean Massive Deposits	M.Sc.	1976
Bogle	E.W.	The Primary Geochemical Dispersion Associated with the Lac Frotet Volcanic Cycle, Quebec	M.Sc.	1977
Sopuck	V.J.	A Lithogeochemical Approach in the Search for Areas of Felsic Volcanic Rocks Associated with Mineralization in the Canadian Shield	Ph.D.	1977
Larsen	C.R.	Stream Sediment and Soil Geochemistry of an Area of Paleozoic Formations in Southeastern Ontario	M.Sc.	1978
Bloom	L.B.	Dispersion and Mode of Occurrence of Uranium in Drainage Sediments	M.Sc.	1980
Pirie	I.D.	Lithogeochemical Dispersion in the Area of the Norbec Deposit, Noranda, Quebec	M.Sc.	1980
Bogle	E.W.	Factors Affecting Lake Sediment Geochemistry in the Southern Grenville Province	Ph.D.	1980
Staargaard	C.F.	Lithogeochemical Features Associated with Volcanogenic Massive Sulphide Mineralization in the Sturgeon Lake Area of Ontario, Canada	M.Sc.	1981
Allen	M.E.T.	The Geochemistry of Heavy Mineral Concentrates from Rocks Associated with the South Bay Massive Sulphide Deposit, Ontario: an Exploration Technique	M.Sc.	1982
Allen	M.S.	An evaluation of stream sediment and heavy mineral concentrate geochemistry as aids in geologic mapping and mineral exploration in Northern Colorado	M.Sc.	1982
Guindon	D.	The Geochemistry of Free Gold and its Application in Exploration	M.Sc.	1982
Amor	S.D.	Application of Discriminant Analysis to a Study of Geochemical Dispersion around Massive Sulphide Deposits in Superior Province	Ph.D.	1983

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Whyte	J.B.	Primary Dispersion in Wall Rocks of the A1 and A2 Zones of the Selbaie Deposit, Quebec	M.Sc.	1984
Shelp	G.	The Distribution and Dispersion of Gold in Glacial Till Associated with Gold Mineralization in the Canadian Shield	M.Sc.	1985
Cohen	D.R.	Biogeochemistry: A Geochemical Method for Gold Exploration in the Canadian Shield	M.Sc.	1986
McClenaghan	M.B.	Quaternary Geology and Geochemical Exploration in the Matheson Area, northeastern Ontario	M.Sc.	1989
Lavin	O.P.	The Development and Application of Some Personal Computer Based Programs to Weathered Rock Geochemical Data from Broken Hill, Australia	Ph.D.	1989
Bree	D.G.	The Nature of Gold in Humus: Implications for Geochemical Exploration	M.Sc.	1990
Thomas	D.A.	The Application of Mineralogy, Whole Rock Chemistry, and Mineral Chemistry to Volcanogenic Massive Sulphide Exploration at the Winston Lake Zn-Cu Deposit, Northwestern Ontario	M.Sc.	1991
Nuchanong	T.	Geochemical Dispersion of Gold Associated with Copper-Gold Mineralization in Northeastern Thailand	Ph.D.	1991
Davies	J.P.E.	The Application of Lithogeochemistry to Gold Exploration in the Casa Berardi Area, Northwestern Quebec	Ph.D.	1994
Zhou	X.	The Applicability of Detecting Low Level Gold Anomalies in Glaciated Terrain, Northern Ontario	M.Sc.	1994
Jiang	R.	Secondary Dispersion of Gold Associated with Some Gold Deposits in the Semi-Arid Environment of Northwestern Hebei Province, China	M.Sc.	1995
Seneshen	D.M.	The Applicability of Partial Extractions to Mineral Exploration in Areas of Transported Overburden	Ph.D.	1997

Obituary

Alan Archer (1933-2018)

Earlier this year we received the sad news that Al Archer, a founding member of the Association of Exploration Geochemists in 1970, which is now the Association of Applied Geochemists (AAG), had passed away in January. He was in fact Member Number 1 of the Association, and was a real pioneer in mineral exploration in the Yukon as well as a very early adopter of geochemistry. The following story of his life and career is adapted from an obituary that appeared in the Vancouver Sun on February 2 2018:

Al Archer passed away in Vancouver, Canada on January 9, 2018. Al was born May 26, 1933 in Winnipeg, Manitoba. He graduated from the University of British Columbia in Geological Engineering in 1957 and worked in his chosen profession until his retirement in 2003. His first position as a geologist was with United Keno Hill Mines in the Yukon and, after a short time at Texada Mines, he returned to United Keno Hill Mines as Chief Geologist. In 1966, Al and Bob Cathro formed Archer Cathro & Associates Ltd., opening a Whitehorse consulting office which specialized in Yukon mineral exploration and engineering. Archer Cathro is still in operation after more than 50 years, and Al was proud that the firm was one of the first to hire female geologists.

In the late 1960s, Al discovered a large copper-gold deposit in the Casino area, which established Archer Cathro as an industry leader. Archer Cathro began compiling a mineral inventory database for the Yukon in 1972, which was later purchased by the Yukon Government to become the foundation for the current Yukon MINFILE database. During the 1980s, the company conducted high-grade silver mining in the Keno Hill district, which led to the discovery of extremely rare silver crystals formed in ice. The crystals were donated to the Canadian Museum of Nature in Ottawa in 1990. Archer Cathro recognized the scenic value of the Tombstone Mountains and, in 1994, voluntarily forfeited its Tombstone mineral claims to help with the creation of the Tombstone Territorial Park. In 1998, Al was a recipient of the H.H. “Spud” Huestis Award for excellence in prospecting and exploration, and in 2002 Archer Cathro was inducted into the Yukon Prospectors Hall of Fame. Al was married to his wife Maureen for 62 years.

Steve Cook and Peter Bradshaw

A History of Geochemistry and Cosmochemistry by Robert W. Boyle: an updated reference work for the 21st century

Graham C. Wilson [1]
[1] *Turnstone Geological Services Ltd., P.O. Box 1000, Campbellford, Ontario K0L 1L0*

Many members of AAG will have met, and many more have heard of, the late Geological Survey of Canada geologist and geochemist Robert W. Boyle (1920-2003). Boyle's best-known works were books and monographs on the occurrence and ore deposits of gold, silver and other metals, and accounts of famous Canadian mining camps such as Yellowknife, Keno Hill, Bathurst and Cobalt. He helped to pioneer methods of geochemical surveying, and advanced the concept of pathfinder elements, such as arsenic and antimony, for delineation of hidden mineralization. His influence is still felt today, as articles he wrote and samples he collected reappear in new work (e.g., Wilson, 2018). He published many articles, most appearing circa 1951-1993. However, he was not idle, certainly not resting on his laurels, in the final two decades of his life.

Instead, Boyle travelled extensively, visited many libraries around the world, and compiled voluminous notes on the vast project that headlines this brief summary. He was clearly fascinated with the Earth sciences in a broad, "Renaissance" manner, and eschewed narrow specialization. His writing ranges over many facets of field geology, mineralogy and geochemistry, and – in this final work - soars off into many other fields of scholarship in a one-man attempt to encapsulate the long history of human endeavours concerning rocks and minerals, metals and materials science.

Boyle's original draft was completed just before his death. The product of his efforts was rather formidable: an 1,827-page double-spaced manuscript in binders, entirely lacking in illustrations, with a giant bibliography of 2,875 references at the end. The author organized the work in a logical chronology, in 15 chapters of wildly uneven length, from far prehistory to the end of the 20th century. The work was split into three volumes of similar length, as follows:

1. Prehistory to the end of the Classical Period (A.D. 476),
2. Early Medieval Period through the 19th Century, and
3. The 20th Century.

The author's passing posed a challenge to third parties, even though the draft text was complete. The task was formidable and, as with any large mineral deposit, progress was and continues to be episodic, with a build-up of pressure, periods of rapid activity, quiescent phases, and more pressure…..

The work had been completed with the aid of friends, colleagues, family. However, there was no formal publication agreement in place. Some years passed. At length, Charles Butt, an eminent geochemist with CSIRO in Australia, agreed to judge whether the original manuscript was suitable for publication. Happily, he far surpassed his mandate, and eventually provided annotated suggestions for all three volumes. Bob Garrett, one of Boyle's colleagues at the GSC, provided further commentary. This done, a consolidating edit, update, and – in particular – illustration was required. In 2015, twelve years after the author's passing, the topic arose with the AAG. Ryan Noble, then vice-president of AAG, published a note in **Explore**. The project thus became known to a wider audience. Graham Wilson, a geoscience consultant of diverse interests, was intrigued and – critically – had the freedom to tackle the challenge of final editing, albeit sans institutional funding. Once the AAG approved Wilson to tackle the task, the project evolved as time allowed, with occasional communications to an ad hoc community of seven persons, as named herein. Over two years, the text and its edits were considered, the vast bulk of Dr Butt's suggestions were acted upon. Inevitably, the burnishing of "Boyle" involved a little bloat of the bare text, with the finished manuscript of volume 1 now a hefty xxxviii+706 pages, including 104 figures (comprising some 145 individual illustrations), 6 numbered tables and 585 references (Fig. 1).

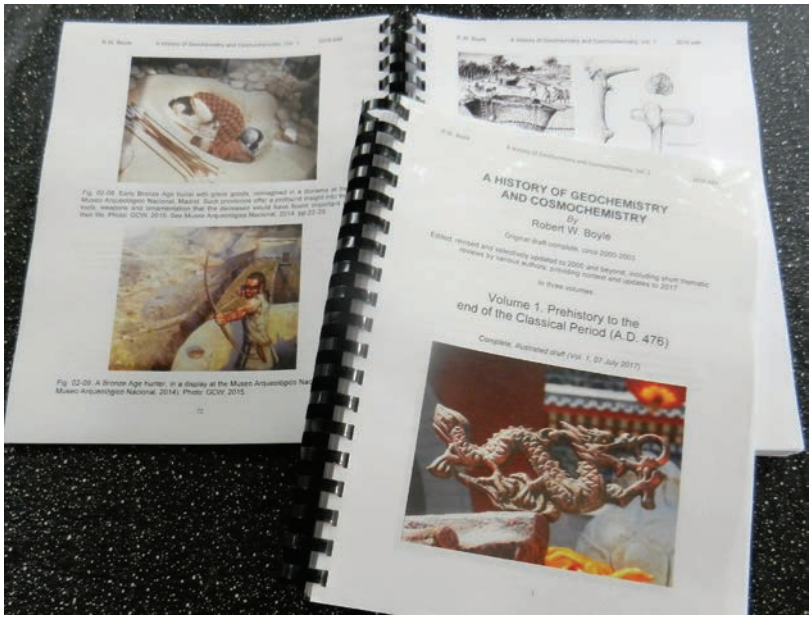

Figure 1. The editor's bound draft copy of Volume 1, complete.

The current goal is to see "Boyle" conclusively edited, illustrated, revised and selectively updated, including as many as 14 short thematic reviews ("text boxes") by various authors, most slated for Volume 3, providing context and updates

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A History of Geochemistry and Cosmochemistry… *continued from page 23*

to the time of publication, circa two decades into the 21st century. The trilogy is an ambitious history of science, of potential interest to scholars and students of diverse fields, including geology, mineralogy, mining, metallurgy, archaeology and ancient history. A non-specialist can also glean a lot from this book. Each volume in the upgraded version is designed to stand alone. Boyle's references and selected additional citations all reside in a database to facilitate dispersal amongst the volumes and within specific sections, to minimize the need for a reader to flick back and forth.

The completed volume 1 commences with a preamble, an appreciation of R.W. Boyle (reprinted from Garrett, 2003) and a new, biographical note by Boyle's daughter, the biochemist Heather Robinson 2. As per the long development of the operation, the roster of help includes editors: Graham Wilson, Charles Butt and Robert Garrett, with a range of advice, insights and text boxes extant or planned by a flexible cast of experts (Table 1). The evolving volumes are summarized below.

Table 1. Key project personnel, "pre-publisher" stages.

Name	Specialities, tasks in Boyle "History" project	Country of residence
Rob Bowell	Geochemistry, exploration, hydrogeochemistry, mineralogy, environmental geochemistry	U.K.
Charles Butt	First detail editor; geochemistry, exploration	Australia
Fiona Eddison	Chapter edits; deposit models, alteration, mineralogy	Australia
Robert Garrett	Early concept editor; geochemical surveys, exploration	Canada
Ray Lett	Chapter edits; geochemistry	Canada
Heather Robinson	Administration; biochemistry	Canada
Graham Wilson	Final detail editor; bibliography; exploration, mineralogy, geoarchaeology, meteoritics	Canada

Volume 1 is a particularly attractive text, of interest to archaeologists as much as geologists, and to a wide range of chemists, metallurgists and historians. The text is worldwide, not just the Near East in ancient times, but also the Greek and Roman empires, ancient Egypt, the successive kingdoms and empires of India and China, and shorter notes on other human endeavours across six continents, to the fall of the Roman Empire in the West. A sprawling chapter 3, split into six sections, is perhaps the standout feature, with historical notes on many metals and non-metallic minerals.

Volume 2 will also have some alluring highlights, including the flowering of science under Islam in Al-Andalus (the Iberian peninsula) and the Moghuls of India, the 18th and 19th century rise of inorganic chemistry, and early insights into modern materials science, such as the Periodic Table and the discovery of radioactivity.

Volume 3 will obviously highlight the staggering progress of science in the 20th century and the early 21st century, approaching 120 years of advances. Obvious highlights will include facets of modern economic geology (mineral exploration and mining of critical resources), analytical science (technological change enabling remarkable amplification of sensitivity to trace elements) and applications to both the latest developments (environmental geochemistry and global change) and the search for origins (analytical work on meteorites, cometary and planetary materials, shedding light on astrophysical processes that in some cases predate our solar system, some 4,570 million years and more into the past).

In conclusion, the work is proceeding in episodic bursts of productivity. Progress is ongoing, with minimal budget. In 2017, as Volume 1 was completed, second thoughts arose concerning the best publisher for such a detailed scientific work. At the time of writing, the final choice of publisher remains to be confirmed. Funding of editorial and related expenses would speed publication, but the goal remains in sight.

Queries on this project may be addressed to:

Content: Graham Wilson, turnstonerocks@yahoo.ca
Administration: Heather Robinson, harobinson123@outlook.com

References

GARRETT, R.G. 2003. Robert William Boyle - a tribute: 3 June 1920-5 August 2003. *Geochemistry: Exploration, Environment, Analysis* **4**, 3-5. Also available at: https://www.appliedgeochemists.org/index.php/component/content/article/2-uncategorised/34-memorial-bob-boyle

WILSON, G.C. 2018. Galena from two mining camps in North America. http://www.turnstone.ca/rom200ga.htm

New Editor in Chief of *Geochemistry: Exploration. Environment, Analysis*

Hello Everyone,

My name is Scott Wood and I have been selected as the next Editor-in-Chief of the journal ***Geochemistry: Exploration, Environment, Analysis***. I will start handling manuscripts submitted on and after August 1, 2018 while Dr. Gwendy Hall will see manuscripts submitted prior to that date through to publication. I am excited to take on this new role.

Please allow me to provide some information about myself by way of introduction. Born and raised in Utica, New York, USA, I received my BA in Geology and Chemistry from Hamilton College in Clinton, New York in 1980. I received my PhD in 1985 from Princeton University under the supervision of Dr. David A. Crerar on the topic "Some Aspects of the Physical Chemistry of Hydrothermal Ore Forming Solutions." I have held faculty positions at McGill University, the University of Idaho, and North Dakota State University, serving as Dean of Science and Mathematics for a total of eleven years at the latter two institutions. My research has focused on the geochemistry of water-rock interactions related to mineral deposits, environmental issues, and geothermal energy with particular emphasis on the aqueous geochemistry of the platinum-group and rare earth elements.

Along with my students and colleagues, I have published more than 120 refereed articles and supervised 20 MS and PhD thesis on these topics. My previous editorial experience includes 11 years as an Associate Editor of *Geochimica et Cosmochimica Acta*, 7 years as founding Editor-in-Chief of *Geochemical Transactions*, and ten years as Special Publications Editor for the Geochemical Society. Other professional activities include co-organizing the 15th Annual V.M. Goldschmidt Meeting in Moscow, ID in May 2005; service on grant panels for the U.S. Department of Energy, the U.S. National Science Foundation, and the National Science and Engineering Research Council of Canada; and service on the selection committees for the Lindgren Award (Society of Economic Geologists) and the Geochemistry Division Medal Committee (American Chemical Society).

In the coming months, I will be providing details about my vision for GEEA in the form of editorials in the publications. However, a major overarching goal is to increase further the visibility and impact of the journal, building on the excellent work of my predecessors. I'd like to take this opportunity to encourage readers of **EXPLORE** to submit manuscripts documenting their best research on geochemistry related to exploration, including environmental and analytical aspects to GEEA.

Scott Wood
Editor-In-Chief, GEEA
scott.wood@ndsu.edu

AAG's Student Support Initiative

The Association of Applied Geochemist's (AAG) Student Support Initiative links applied geochemistry students with commercial analytical laboratories to help students defray the costs of acquiring geochemical data associated with thesis work. AAG acts as an intermediary between applied geochemistry students and participating laboratories by assessing applications and recommending those with merit to supporting laboratories for in-kind support in terms of sample analysis. AAG's Education Committee that oversees this program includes geochemists from industry and government. Students who receive support through this program are obliged to publish their results and include an acknowledgement to the Association and the supporting laboratory.

Five laboratories are involved with the program: ALS, BV Minerals (Perth), BV Minerals (Vancouver), Intertek-Genalysis, and LabWest. These laboratories offer a range of analytical services suitable to both mineral exploration and environmental assessment. In many cases, the in-kind support is a complement to data generated from other sources, rather than the complete analytical requirements of the thesis. The program now supports a diversity of research projects, in terms of geographical distribution of recipients, and diversity of thesis topics

This program fosters the science of applied geochemistry and offers applied geochemistry students the opportunity to learn through personal experience about generating geochemical data. All participating laboratories are staffed by skilled analysts who can provide valuable advice on the most suitable analytical approach, itself a valuable contribution to the thesis work. The application form and conditions of support for this program can be found on the Students webpage on the AAG website, under the heading RESOURCES (www.appliedgeochemists.org).

David Murphy
AAG Education Committee
davidmkmurphy@gmail.com

AAG Councillor Elections for the Term 2019-2020

Each year the Association of Applied Geochemists (AAG) needs motivated and energetic AAG Fellows to stand for election to the position of "Ordinary Councillor." Fortunately, each year some of our most outstanding Fellows are ready, willing, and able to meet this challenge. However, this year I'm sending this to ALL MEMBERS, to encourage those Members that have the experience and enthusiasm to be involved, to convert your membership status and look to make a bigger contribution to the AAG (see the website for details).

This note is the annual reminder to AAG Fellows (and Members that could become Fellows) that we need your participation on Council. It is our sincere hope that this email might entice more people to step forward for election to this important position. If you are not eligible to become a Fellow, but want to be more involved, please send me an email message as we are looking to get more of our junior members active in the AAG and other opportunities will be coming available.

Councillor Job Description

The AAG By-laws state that "the affairs of the Association shall be managed by its board of directors, to be known as its Council." The affairs managed by Council vary from reviewing and ranking proposals to host our biennial Symposium to approving application for new membership to developing marketing strategies for sustaining and growing our membership. These affairs are discussed and decisions made at Council teleconferences usually held 3-4 times per year. Each teleconference lasts about 1 hour. In addition, there is often a running email discussion about a selected issue or two between each teleconference. So for a commitment of about 5 hours of your time per year, you can help influence the future of your Association. If you want to spend more than the minimum time required, there is plenty of opportunity to do so through committee assignments and voluntary efforts that greatly benefit the Association.

Qualifications and length of term

The only qualification for serving as Councillor is to be a Fellow in good standing with the Association. Please note the difference between being a Member of AAG and being a Fellow. A Fellow is required to have more training and professional experience than a Member. Consult the AAG web site, Membership section, for further details. If you are not currently a Fellow and have an interest in serving on Council, please go through the relatively painless process of converting to Fellowship status in AAG.

Each Councillor serves a term of two years and can then stand for election to a second two-year term. The By-laws forbid serving more than two consecutive terms, although someone who has served two consecutive terms can stand for election again after sitting out for at least one year. Elections are usually held in October-November of the year for a term covering the following two years. Our next election will be in October-November 2018 for the term of 2019-2020.

How to get on the ballot

If you are interested in placing your name into consideration for election to AAG Council, simply express your interest to the AAG Secretary (Dave Smith, email: dsmith@usgs.gov) by October 15, 2018 and include a short paragraph (no more than 250 words) summarizing your career experience. This summary should include the following:

- Your name
- Year that you became a Fellow of AAG
- Earth science 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

All that is asked is that you bring energy and ideas to Council and are willing to share in making decisions that will carry the Association forward into a successful future. We look forward to hearing from you.

Steve Cook
President, Association of Applied Geochemists
Email: Stephen.Cook@teck.com

NOTICE OF AAG ANNUAL GENERAL MEETING

MONDAY, JUNE 18, 2018 FROM 5:30 TO 6:30 PM
VANCOUVER, CANADA, AS PART OF THE *RESOURCES FOR FUTURE GENERATION CONFERENCE*
VANCOUVER CONVENTION CENTER, ROOM 208-209

The AAG-SGS Student Presentation Prize

The Association of Applied Geochemists, through the support of SGS Mineral Services, awards a prize for the

Best oral presentation by a student at the biannual International Applied Geochemistry Symposium (IAGS)

Next IAGS will be part of the RFG2018 Conference, Vancouver, June 16-21, 2018 (rfg2018.org)

The intent of this prize is to encourage the presentation of high quality research by students at an International Applied Geochemistry Symposium (IAGS) and provide further incentive to publish the results of the research in the Association's journal, Geochemistry: Exploration, Environment, Analysis (GEEA). The winner is determined based on feedback from a group of judges that includes Fellows and Members of the Association. Criteria for judging the presentations include excellence and originality in research design, research execution, interpretation, and the oral presentation itself. Honours, Masters, and Doctoral students are all eligible. The format of the presentation may vary between IAGS.

The Rules

1. The paper must be presented by the student at an IAGS as an oral paper, in the format specified by the IAGS organizing committee.
2. The conference presentation and paper must be largely based on research performed as a student. The student's supervisor or Head of Department may be asked to verify this condition.
3. The decision of the AAG Symposium Co-ordinator (in consultation with a representative from SGS) is final and no correspondence will be entered into.
4. Entry in the competition is automatic for students (but students may elect to “opt out”).
5. The detailed criteria and process for assessing the best paper will be determined by the AAG Symposium Co-ordinator in consultation with the AAG Council and the LOC.
6. A paper substantially derived from the material presented at the IAGS and submitted for publication in the Association’s journal Geochemistry: Exploration, Environment, Analysis within the timeframe specified by the AAG (normally 12 months) will be eligible for the increased value of the prize.

The Prize

1. $700 CAD from SGS Minerals Services (normally presented to the winner at the end of the relevant IAGS) with a further $300 CAD from AAG if a paper related to the oral presentation is submitted to GEEA within the nominated time frame after the IAGS;
2. A 2-year membership of the Association, including subscription to GEEA and EXPLORE; and
3. A certificate of recognition.

David Cohen
Chair of Student Prize Committee
University of New South Wales
Email: d.cohen@unsw.edu.au

To all RFG2018 Participants

The Association of Applied Geochemists invites you to a **Gala Dinner** on **Wednesday, June 20**, 2018 for a truly one-of-a-kind experience, dining amongst the 50,000 inhabitants in the halls and galleries of the spectacular Vancouver Aquarium. The evening will include travel by private coach to scenic Stanley Park. A welcome reception drink and tour of the aquarium's outdoor exhibits or participating in the AAG awards ceremony. Dinner prepared by executive chef Ned Bell while enjoying BC Okanagan wine. Then touring the aquarium's interior exhibits or taking in presentations by the aquarium's science staff on research conducted in the high-arctic and the Pacific Northwest. Private coaches will return our guests to the Conference Centre.

Tickets are CDN $120 and can be ordered on-line from the RFG2018 Registration site. When ordering, please select your choice of meal from the Sea, from the Farm or from the Garden. If you purchase more than one ticket, then please select your guest's meal choices. Seating is arranged so please indicate who you wish to sit with (other than your guests) and we will do our best to arrange seating.

We hope you will join us!

Please direct any questions to John Gravel: john.gravel01@gmail.com

AAG New Members

Members

Members are non-voting members of the Association and are actively engaged in the field of applied geochemistry at the time of their application and for at least two years prior to the date of joining.

Dr. Eduardo Duarte Marques
Senior Researcher
CPRM ¬ Geological Survey of Brazil
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Membership # 4371

Ms Erin Newman
Geologist, Newmont Mining Corporation
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Membership # 4372

Mr. Takalani Mandiwana
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Oxford Corner, Rosebank
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SOUTH AFRICA 2196
Membership # 4373

Dr. David Foyle
Dean¹s Professor
University of Kansas
Department of Geology
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Membership # 4374

Prof. Eduardo Ferreira da Silva
Universidade de Aveiro
Departamento de Geociencias
Campus de Santiago
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Membership # 4377

Mr. Luis Quispe Renteria
Geologo, Ingemmet
Urbanizacion El Galeno Mz. J lote 01
Trujillo
PERU 13007
Membership # 4378

Mr. Claudio Gonzalez-Solis
Geologist, Lumina Gold
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125 Oeste. Portones blacos, techo rojo
Vasquez de Coronado, San José
COSTA RICA 11101
Membership # 4379

Mr. Hui Wu
Geochemist
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Hebei Sheng
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Membership # 4380

Mr. Ruihong Li
Geochemist
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Mr. Qinghai Hu
Geochemist
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CHINA 065000
Membership # 4382

Mr. Jérémie Melleton
Geochemist
BRGM
3 av. Claude Guillemin
Orléans
FRANCE 45000
Membership # 4383

Student Members

Student Members are students that are enrolled in an approved course of instruction or training in a field of pure or applied science at a recognized institution. Student members pay minimal membership fees to belong to the Association.

Mr. Pearce Luck
MSc Student
University of British Columbia
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Membership # 4368

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AAG New Members... *continued from page 29*

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Membership # 4369

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Vivian Ruiz
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Membership # 4375

Mr. Garrett Gissler
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Golden, CO
UNITED STATES 80401
Membership # 4376

CALENDAR OF EVENTS

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

Please let us know of your events by sending details to:
Steve Amor
Geological Survey of Newfoundland and Labrador
P.O. Box 8700, St. John's, NL, Canada, A1B 4J6
Email: StephenAmor@gov.nl.ca Tel: +1-709-729-1161
Or Tom Meuzelaar, AAG Webmaster,
Email: Tom_Meuzelaar@golder.com

2018

10-13 JUNE	4th International Congress on 3D Materials Science. Helsingør Denmark. Website: tinyurl.com/yahh2uxb
16-21 JUNE	**Resources for Future Generations (Energy, Minerals, Water and the Earth). Vancouver BC Canada. Website: rfg2018.org. See announcement in current issue of Explore**.
16-21 JUNE	GAC/MAC Annual Meeting. Vancouver BC Canada. Website: rfg2018.org
26-28 JUNE	3rd European Mantle Workshop. Pavia Italy. Website: emaw2018iggpavia.unipv.it
30 JUNE – 6 JULY	13th International Platinum Symposium. Polokwane South Africa. Website: 13ips.com
1-6 JULY	7th International Congress on Arsenic in the Environment. Beijing, China. Website: www.as2018.org
2-7 JULY	34th SEGH International Conference on Sustainable Geochemistry. Livingston Zambia. Website: segh2018.org
7-8 JULY	Gordon Research Seminar — Ocean Biogeochemistry. Hong Kong China. Website: tinyurl.com/y98s7dwe
8-13 JULY	Geoanalysis 2018. Sydney NSW Australia. Website: 2018.geoanalysis.info
10-13 JULY	Granulites and Granulites 2018. Ullapool UK. Website: tinyurl.com/yc53c23z
21-25-JULY	ICHMET 2018: 19th International Conference on Heavy Metals in the Environment. Athens GA USA. Website: tinyurl.com/ya52lw4p
21-28 JULY	27th Colloquium of African Geology. Aveiro Portugal. Website: cag27.web.ua.pt
5-10 AUGUST	Gordon Research Conference - Gordon Research Conference - Geochemistry of Mineral Deposits. Waterville Valley NH US. Website: tinyurl.com/ybnhv8mv
5-9 AUGUST	Microscopy & Microanalysis 2018 Meeting. Baltimore MD USA. Website: tinyurl.com/yc9alqdk
6-10 AUGUST	2018 IGU Regional Conference. Quebec City QC Canada. Website: igu2018.ulaval.ca
12-17 AUGUST	Goldschmidt 2018. Boston MA USA. Website: goldschmidt.info/2018
12-17 AUGUST	21st World Congress of Soil Science. Rio de Janeiro Brazil. Website:www.21wcss.org

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CALENDAR OF EVENTS... *continued from page 30*

13-17 AUGUST	International Sedimentological Congress. Quebec City QC Canada. Website: www.isc2018.org
19-21 AUGUST	8th International Conference on Environmental Pollution and Remediation. Madrid Spain. Website: tinyurl.com/yburvkck
22-24 AUGUST	3rd Virtual Geoscience Conference. Kingston ON Canada. Website: virtualoutcrop.com/vgc2018
28-31 AUGUST	15th Quadrennial IAGOD Symposium. Salta Argentina. Website: www.iagod.org/node/76
2-8 SEPTEMBER	19th Annual Conference of International Association for Mathematical Geosciences. Olomouc Czech Republic. Website: www.iamg2018.org/
3-7 SEPTEMBER	4th Annual World Multidisciplinary Earth Sciences Symposium. Prague, Czech Republic. Website: www.mess-earth.org
3-7 SEPTEMBER	International Conference on Magmatism of the Earth and Related Strategic Metal Deposits. Moscow Russia. Website: magmas-and-metals.ru
9-12 SEPTEMBER	Fourth International Symposium on Ethics of Environmental Health. Budweis Czech Republic. Website: iseeh.org
10-13 SEPTEMBER	XXI Congress of Carpathian Balkan Geological Association. Vienna Austria. Website: cbga.sbg.ac.at
13-15 SEPTEMBER	SIAM Conference on Mathematics of Planet Earth (MPE18). Philadelphia PA USA. Website: www.siam.org/meetings/mpe18
16-21 SEPTEMBER	IWA World Water Congress & Exhibition 2018. Tokyo Japan. Website: tinyurl.com/ybpmakrc
17-25 SEPTEMBER	13th International Symposium on Nuclear and Environmental Radiochemical Analysis: ERA13. Cambridge UK. Website: tinyurl.com/y9tbav7m
18-25 SEPTEMBER	13th International Symposium on Nuclear and Environmental Radiochemical Analysis: ERA13. Cambridge UK. Website: tinyurl.com/y9tbav7m
22-25 SEPTEMBER	SEG 2018. Keystone CO USA. Website: www.seg2018.org
23-27 SEPTEMBER	10th International Conference on Environmental Catalysis. Tianjin China. Website: tinyurl.com/yazebbz5
29-30 OCTOBER	ICESCC 2018: 20th International Conference on Earth Science and Climate Change. Paris France. Website: tinyurl.com/y9b6l3mr
14-18 OCTOBER	Australian Geoscience Council Convention. Adelaide SA Australia. Website: tinyurl.com/zqxc6n2
25-26 OCTOBER	Sampling 2018. Lima Peru. Website: www.encuentrometalurgia.com/Sampling-2018
4-7 NOVEMBER	GSA 2018 Annual Meeting. Indianapolis IN USA. Website: tinyurl.com/yb859e9n
12-15 NOVEMBER	XIII Latin American Symposium on Environmental Analytical Chemistry. La Serena Chile. Website: tinyurl.com/yc92c5jk
12-15-NOVEMBER	1st Conference of the Arabian Journal of Geoscience. Hammamet Tunisia . Website: www.cajg.org
4-8 DECEMBER	American Exploration & Mining Association (AEMA) Annual Meeting. Reno NV USA. Website: www.miningamerica.org/2018-annual-meeting
10-14 DECEMBER	AGU Fall Meeting. Washington DC USA. Website: tinyurl.com/yclg7sut
13-14 DECEMBER	ICGG 2018 : 20th International Conference on Gas Geochemistry. Bangkok Thailand. Website: tinyurl.com/ycw4ma8v

2019

6-9 JANUARY	International Soil Science Meeting. San Diego CA USA. Website: tinyurl.com/y9oorlm4
10-11 JANUARY	ICCEEST 2019 : 21st International Conference on Chemical, Ecological, Environmental Science and Technology. Singapore. Website: tinyurl.com/y7yo7r6r
3-6 MARCH	Prospectors and Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/convention
10-14 MARCH	Minerals, Metals & Materials Society Annual Meeting & Exhibition. San Antonio TX USA. Website: www.tms.org/tms2019
7-12 APRIL	EGU General Assembly. Vienna Austria. Website: www.egu2019.eu
6-9 MAY	9th World Conference on Sampling and Blending. Beijing China. Website: www.wcsb9.com

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CALENDAR OF EVENTS... *continued from page 31*

21-26 JULY	16th International Symposium on Water-Rock Interaction. Tomsk Russia. Website: wri16.com
25-31 JULY	INQUA 2019. Dublin Ireland. Website: www.inqua2019.org
18-23 AUGUST	Goldschmidt 2019. Barcelona, Spain. Website: goldschmidt.info/2019
27-30 AUGUST	15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Glasgow UK. Website: www.sga2019glasgow.com

2020

2-8 MARCH	36th International Geological Congress. Delhi India. Website: 36igc.org
20-24 MAY	Geological Society of Nevada 2020 Symposium Vision for Discovery: Geology and Ore Deposits of the Basin and Range. Sparks NV USA. Website: www.gsnv.org/2020-symposium
17-21 AUGUST	34th International Geographical Congress. Istanbul Turkey. Website: www.igc2020.org/en
24-28 AUGUST	Eurosoil 2020. Geneva Switzerland. eurosoil2020.com

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