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Application of Fourier Transform Infra-Red Spectroscopy (FTIR) for Mineral Quantification

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Introduction

Fourier-transform infrared spectroscopy (FTIR) (Griffiths & de Haseth 2007) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid, or gas. An FTIR spectrometer simultaneously collects high-spectral-resolution data over a wide spectral range. In this study we utilised the range 500 – 4000 cm-1 with a resolution of 4 cm-1. It is an established experimental technique for determining qualitative mineral identification. In this paper we examine the use of the Bruker Alpha II unit (Fig. 1) in the quantitative determination of common rock forming minerals.

For this paper, we used an attenuated total reflection (ATR) sample analysis unit. ATR is a sampling technique used in conjunction with infrared spectroscopy which enables samples to be examined directly in the solid state without further preparation (Perkin Elmer Life and Analytical Sciences 2005). ATR uses a property of total internal reflection resulting in an evanescent wave. A beam of infrared light is passed through the ATR crystal in such a way that it reflects at least once off the internal surface in contact with the sample. The ATR system used in this study was based on a diamond system which made it ideal for minerals which have a high hardness index.

Figure 1. Bruker Alpha FTIR fitted with ATR unit inset showing sample plate (image courtesy of Bruker) used in the quantitative determination of common rock forming minerals.

Experimental

Rock samples of between 200-300 g with a wide range of mineralogy were dried and pulverised until 100% passed a 75 µm sieve. A split was then taken for analysis by high resolution X-ray diffraction (XRD) to act as calibration standards. The remaining portion was then analysed with the FTIR using the ATR attachment.

Method optimisation was determined using artificial intelligence (AI). The frequency region and preprocessing method as well as the resulting RMSECV value were displayed in order of relationship to the analyte calibration values. The selection frequency parameters were then checked against the known spectral response to the pure minerals to ensure that the parameters selected were valid. Further to this, samples which gave a result more than 20% from the calibration line were removed as outliers. The method was then recalibrated with the outliers removed.

The samples selected for validation encompassed the full concentration range for each analyte with the same variability in sample characteristics as contained in the calibration set. The validation set contained about 50% as many samples as the calibration set and 5 samples were selected for independent testing.

Results and Conclusions

R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. 0.00% indicates that the model explains none of the variability, a result of 100% would mean all the data fits the model. So, R-squared can take a value between 0 and 1 where values closer to 0 represent a poor fit while values closer to 1 represent an excellent fit. If R-squared=0.93, then it infers that 93% of the variations in dependent variable Y are explained by the independent variables present in the model. The R-squared results for some of the mineral methods are displayed in Table 1. It is noted that

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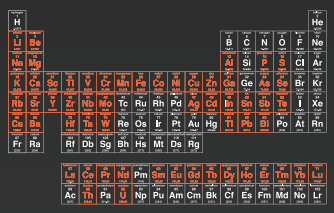

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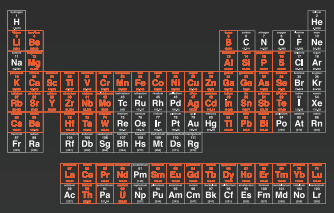

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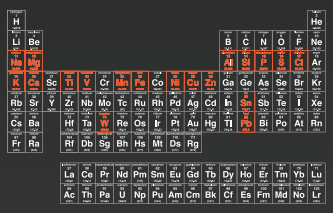

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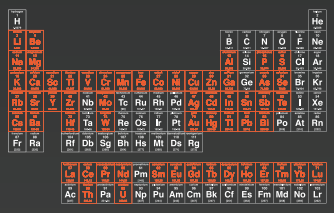

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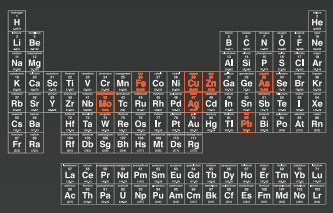

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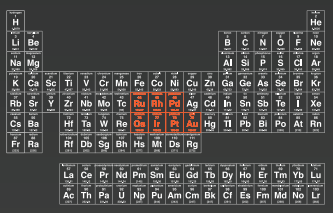

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All scientific/technical articles will be reviewed. All contributions may be edited for clarity or brevity.

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: https://www.geolsoc.org.uk/geea-authorinfo

An abstract of about 250 words must also be submitted that summarizes the content of their article. This abstract will be published in the journal ELEMENTS on the 'AAG News' page.

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Notes from the Editor

Welcome to the first **EXPLORE** issue of 2019. This issue includes two articles. The first describes the application of Fourier transform infra-red spectroscopy (FTIR) for mineral quantification and was written by John Woods. The second is a review of exploration geochemistry talks presented at the decennial Exploration '17 conference in Toronto, Canada in October, 2017 and was written by Hugh de Souza. Also in this issue, the new AAG Councillors for 2019-2020 are introduced.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue, listed in alphabetical order: Steve Amor, Dennis Arne, Al Arsenault, John Carranza, Steve Cook, Patrice de Caritat, Bob Garrett, Dave Heberlein, David Leng, Tom Meuzelaar, Pim van Geffen, and Renguang Zuo.

Beth McClenaghan
Editor

2019 AAG Dues Reminder

Reminder that AAG membership fees for 2019 are now due. Membership fees can be paid on AAG's website www.appliedgeochemists.org/membership/renew-membership

President's Message

In my first message of 2019, I would ask our readers' indulgence as I comment on what I think it will take for geochemistry to be a successful component of modern mineral exploration over the coming decades. My goal here is to help stimulate further discussion among the membership, especially as we approach the 50th anniversary of the Association next year.

This is not a new topic by any means. In fact, in this very issue you will find a review by Hugh de Souza of the geochemical presentations given at the Exploration '17 conference, which was held in Toronto, Canada, just over a year ago. Hugh summarizes the geochemistry keynote presentation given by Paul Agnew and the two main geochemical sessions, as well as other presentations involving the integrated use of geochemistry with geology and geophysics. The proceedings of that meeting, and Dr. de Souza's concise appraisal of it, serve as a timely reminder to all of us in the broader mineral exploration community that an intelligent combination of both classical and innovative new geochemical techniques are going to be a prerequisite for success in geochemical exploration programs, both now and in the years to come. In all areas of geochemical exploration – whether involving area selection, field sampling, laboratory analysis or data interpretation, for example – methods and approaches that have been widely used for years are now being augmented, reinforced and in some cases replaced by innovative new approaches all along the exploration pipeline.

In area selection, the ability to efficiently interpret very large and diverse datasets, both public and proprietary, will provide an advantage to those explorationists able to harness the advanced statistical methods and machine learning tools available. We can also expect that these datasets will include material not conventionally used in the past by exploration geochemists. In the field, the rapid expansion of mineral chemistry methods over the past few years has added a powerful new tool to the toolbox, building on classical indicator mineral approaches. The field sampling skills and mineral identification techniques needed to execute these programs remain, but the evolving new methods for the determination and interpretation of mineral chemistry may well revolutionize our approaches to both deposit fertility assessment and property-scale vectoring within hydrothermal systems. In covered terrain, research into the application of genomic methods to discovery of buried deposits may provide a new window into the subsurface, an area that has been a source of frustration to geochemists for many years.

To sum up, geochemical exploration success in the coming decade is likely to require a fusion of both the classical approaches in field, lab, and office with innovative new approaches in those areas where the traditional methods have been found wanting. The aging demographics of our profession have long been a cause for concern, but the flip side to that is the many opportunities that will arise for bright young geochemists to make a significant impact in both research and exploration. The AAG is pleased to be able to contribute to the continued learning at all levels with our sponsorship of scientific meetings. First, in the coming months we will be co-sponsoring the upcoming PACRIM 2019 (Mineral Systems of the Pacific Rim) congress in New Zealand (April 3-5, 2019). Here, the AAG will support the travel of three members – Peter Winterburn, Juan Carlos Calderon, and Steve Piercey - to Auckland to give keynote presentations on exploration geochemistry, as well as to chair sessions and run geochemistry short courses. Secondly, in 2020 the Association will be holding its flagship conference, the 29th IAGS in Viña del Mar, Chile, in November.

As a final note, we recently learned of the death of Dr. Gerry Govett, long-time professor of geochemistry at the University of New South Wales, Australia and, before that, at the University of New Brunswick, Canada. Gerry was a founding member of the Association of Exploration Geochemists in 1970, and served a term as President. He supervised many graduate students who rose to prominent positions around the world, and was the recipient of the AAG's Gold Medal at the 24th IAGS in Fredericton, Canada in 2009. We will reflect further on his life, career and legacy in a later issue of EXPLORE. In the meantime, please refer to Wayne Goodfellow's Gold Medal citation article in EXPLORE No. 144 (September, 2009) for an informative and amusing account of Gerry's many achievements. It can be downloaded from the AAG website at: https://www.appliedgeochemists.org/images/Explore/Explore,%20Number%20144%20September%202009.pdf

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only one of the methods has an R-squared value of less than 0.90, therefore for nearly all the methods covered in this report have a 90% fit. The presence of outliers is determined based on the Mahalanobis distance (Mahalanobis 1936) and displayed in Table 1.

Table 1. Mineral Quantification Methods – Performance quality of mineral methods with statistical assessment of error.

Mineral/ Analyte	R squared	Mahalanobis distance
Apatite	99.59	0.22
Calcite	98.66	0.24
Chlorite	99.67	0.44
Dolomite	99.05	0.21
illite	98.39	0.55
Kaolinite	99.86	0.52
K-Feldspar	96.07	0.21
Muscovite	95.36	0.17
Petalite	89.18	0.8
Plagioclase	95.29	0.31
Quartz	98.63	0.17
Siderite	98.23	0.26
Smecite	98.79	0.18
Spodumene	97.65	1.2

The calibration graph for illite is displayed in Figure 2 and the validation graph for illite is displayed in Figure 3. Outliers are displayed in red. RMSEE is the root mean square error of estimation RPD is the residual predication deviation, RMSECV is the root mean square error of cross validation and bias is the value for the rank displayed in the graph.

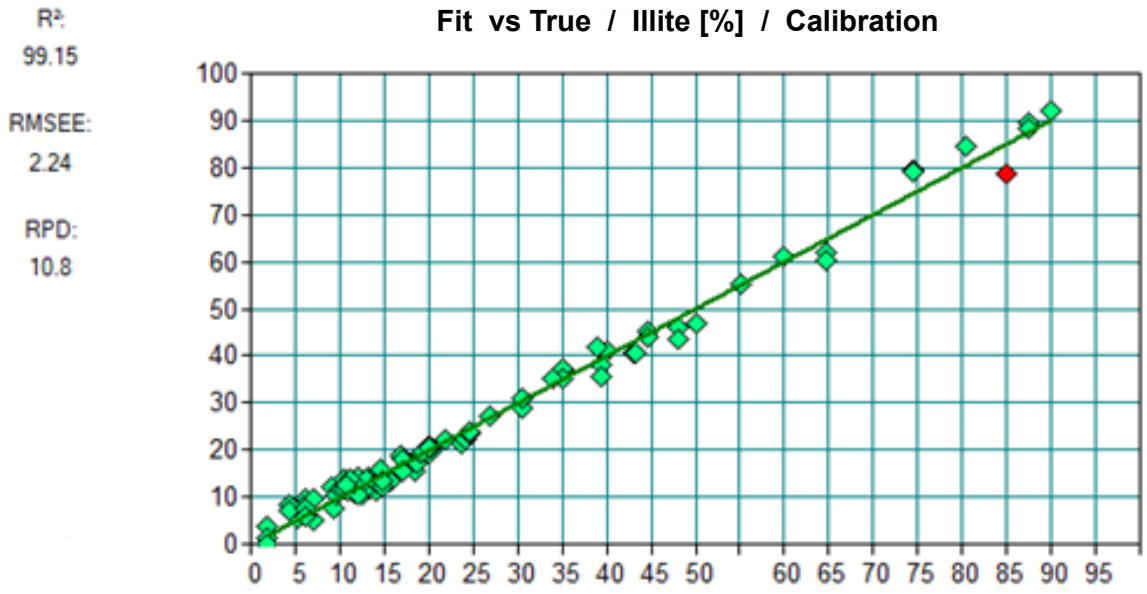

Figure 2. Calibration graph for illite.

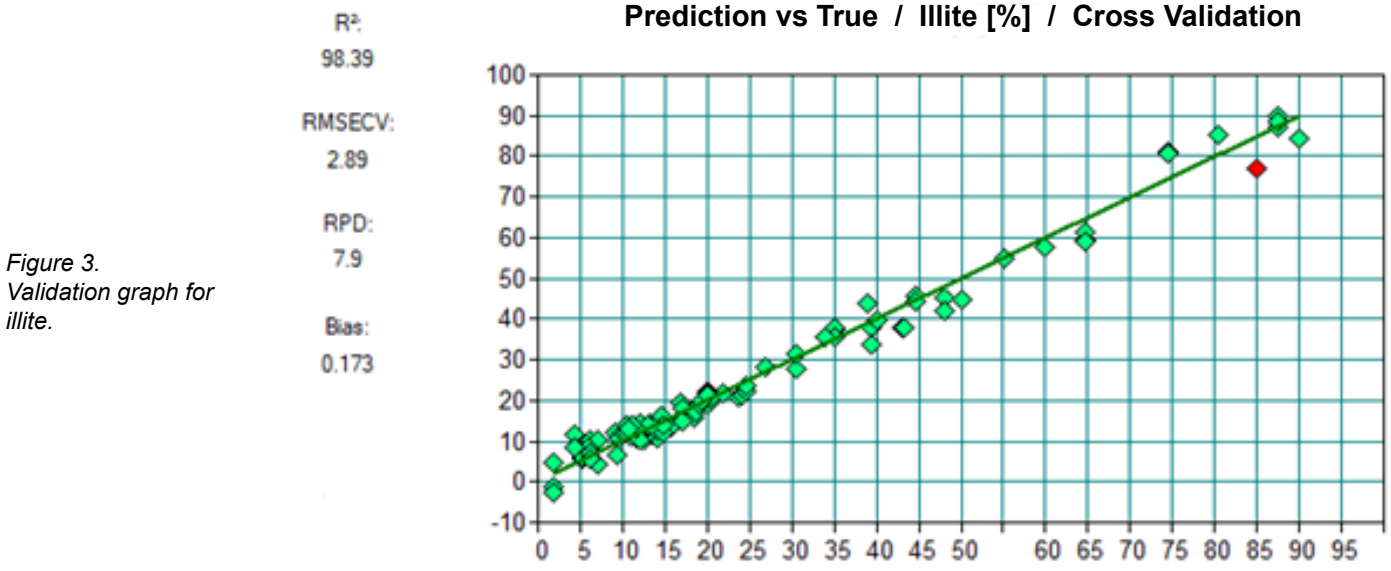

Figure 3. Validation graph for illite.

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Application of Fourier Transform Infra-Red Spectroscopy (FTIR)… *continued from page 5*

From these data FTIR can provide a highly accurate method for the determination of a wide range of minerals. The degree of accuracy is in general better than that achieved by X-ray diffraction (XRD), namely that it has errors of less than 10% from true rather than being in the order of 20%. The degree of accuracy is, in general, better than that achieved by X-ray diffraction (XRD) in that it has error of less than 10% from true, rather than being in the order of 20%. This is especially notable for clay minerals that present considerable difficulties for XRD analysis where preparation is a limiting factor in accuracy.

As the FTIR only requires that the samples are dry and ground to less than 75 microns this offers the opportunity for low cost, rapid mineralogical analysis without the need for complex preparation. This type of instrumentation is portable and robust and as the range of minerals that can be quantified expands may supplant more traditional technologies for a wide range of industrial applications.

There are, however, limitations to what the technology can provide. Firstly, the technique relies on there being bonds present within a mineral that have a vibrational mode. Halite and galena do not possess this type of bonding and so will always remain beyond the capability of this type of instrumentation to identify and quantify. Secondly, although there have been significant improvements in detector technology limits of quantification for most minerals in a complex rock matrix remain at about 5% w/w.

Further Work

As mentioned in the previous section, the list of minerals that can be analysed and quantified by FTIR is ever expanding. New methods are currently under development that will provide accurate determinations of minerals such as biotite mica, potash, ferroan dolomite, haematite, goethite, topaz and sellaite. Other minerals will soon follow as commercial requirements dictate.

Acknowledgments

I thank my co-worker Katie Donnelly and reviewers Hugh de Souza, Peta Hughes, and Bob Garrett (Geological Survey of Canada) for their reviews of the manuscript.

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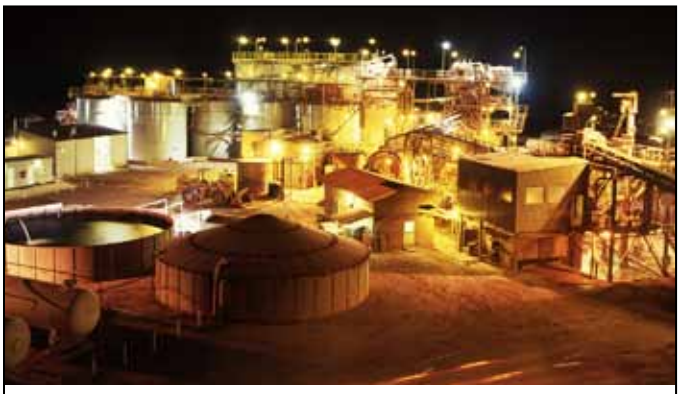

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Geochemistry at Exploration '17

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The Decennial Mineral Exploration Conferences are held every ten years in Toronto, Canada and offer a unique opportunity to review developments in mineral exploration technology, methods and thinking over the previous decade and to reflect on the best geological, geochemical and geophysical approaches for the discovery of specific deposit types. The sixth such conference was held in October 2017 with the theme of 'Integrating the Geosciences: the Challenge of Discovery'. Two of the sixteen sessions held were devoted specifically to geochemistry, one on Geochemistry and another on Analytical Methods, in addition to a plenary address given by Paul Agnew of Rio Tinto Exploration Pty Ltd (Agnew 2017). The organizers of the geochemistry sessions faced a challenge in selecting topics as in many areas of geochemistry there has been a gradual evolution of methods and approaches based on continuous improvements in technologies and computer software but few real advances in laboratory methods. The previous 2007 meeting offered a vision of a bright future for geochemistry highlighted by advances in ICP-MS instrumentation and portable XRF technologies and applications such as selective leach geochemistry and biogeochemistry (Cohen et al. 2007). Instead the decade saw a dramatic decline in discovery rates in which, Agnew contends, geochemistry also played a role. Both Agnew and Peter Winterburn expressed concerns over the aging demographics of professional geoscientists. Based on current AAG membership rolls, about 49 % are over 60 years of age. This age profile is compounded by fewer new geochemists - only 6% are under 30.

Agnew commented on the continuing demise of large geochemical surveys globally despite their effectiveness in discovery, particularly in underexplored regions. On the other hand, the release of legacy data by governments has hugely expanded the availability of digital regional geochemistry data sets enabling some companies to cover large regions in searching for prospective areas. He proposed detailed geostatistical evaluation of existing data sets augmented by new data from low detection limit geochemistry, use of portable real time technologies, spectral techniques and an expanded use of mineral chemistry as a fertility and vectoring tool. These approaches were discussed in more detail by specialists in the Geochemistry and Analytical Methods sessions and elsewhere.

Eric Grunsky and Patrice de Caritat (Grunsky & de Caritat 2017) discussed how a geochemical database, with 50 or more elements determined to sufficiently low detection limits, represents a multi-dimensional geochemical space that can be studied using multivariate statistical methods from which patterns reflecting geochemical/geological processes are described (process discovery). These patterns then form the basis for creation of probabilistic predictive maps (process validation). A different approach was presented in the Targeting - Mine Site to Camp Scale session, where Guy Desharnais and colleagues discussed the application of artificial intelligence and machine learning for exploration targeting, a methodology that is growing rapidly among exploration companies, particularly those looking for gold.

Cliff Stanley (Stanley 2017) described the advantages of using molar element ratio analysis in mineral exploration. Conversion of elemental data to molar ratios avoids the closure problem and provides insights into lithogeochemical processes. The other advantage of using molar ratios is that it allows investigation of rock composition in terms of minerals – a proxy for mineralogical studies. It is also the basis for Pearce Element Ratio analysis or General Element Ratio Analysis and can be applied for "change of basis" rock classification based on matrix algebra. This method is similar to normative mineral calculations using linear algebra.

Exploration under cover remains a special challenge for the industry and for geochemists in particular, and we were presented with two different approaches to this issue in the Geochemistry session. The first by Winterburn and colleagues (Winterburn et al. 2017) surveyed various investigations over the last decade in surficial geochemistry in different terrains globally. They called for more fundamental research into how surficial geochemical anomalies are generated and the development of other, less conventional, analytical tools such as hydrocarbon geochemistry and genomics. The other approach uses the chemistry of indicator minerals both as vectors to ore and as indications of fertility, building on the successes of

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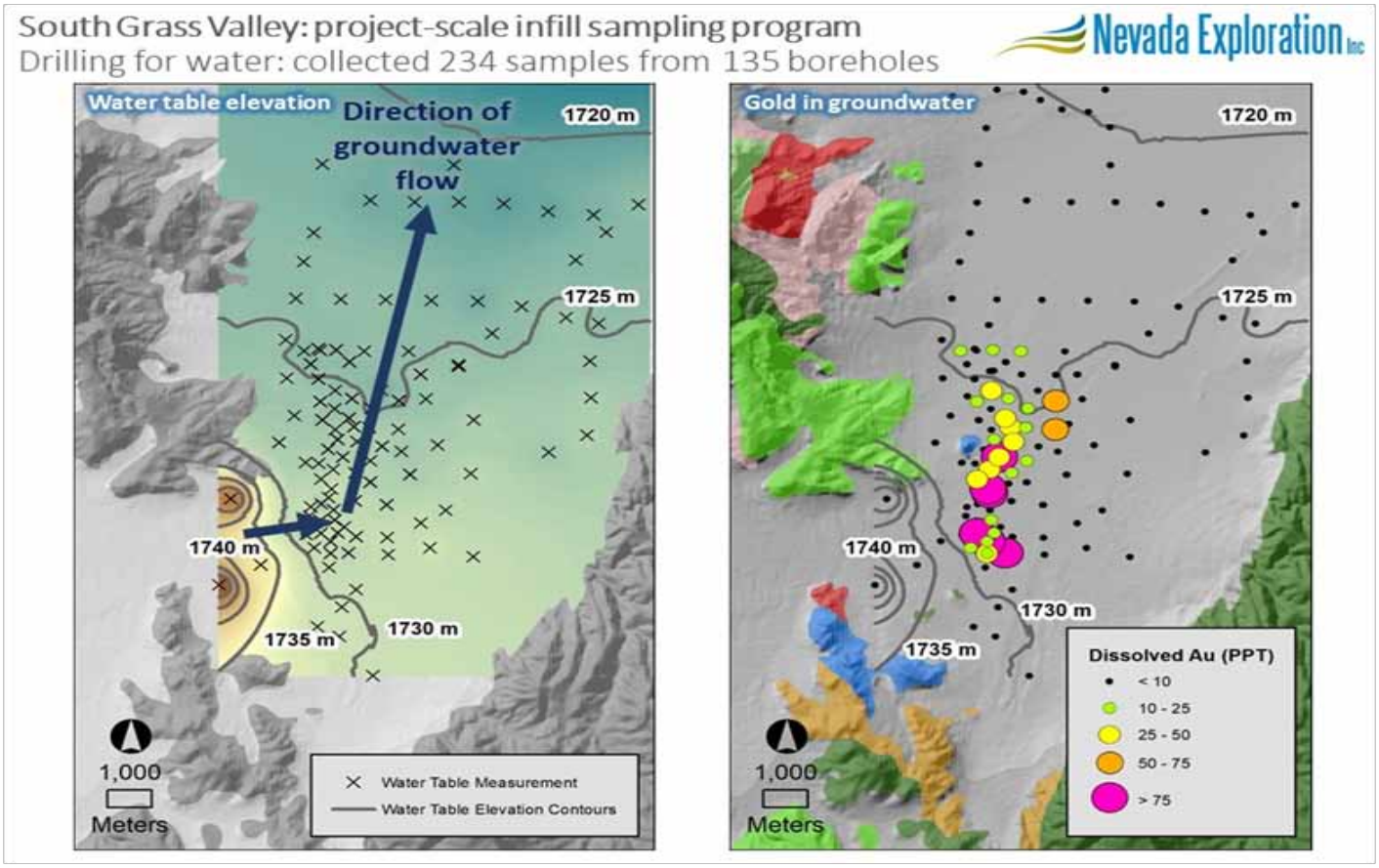
Geochemistry at Exploration ’17… *continued from page 8*

the use of indicator minerals in kimberlite exploration. David Cooke and colleagues (Cooke et al. 2017) discussed how automated mineralogy in conjunction with developments in laser ablation ICP-MS can be applied to generating detailed mineral chemistries for a range of magmatic and hydrothermal minerals in the exploration of porphyry style mineralization. They used the example of porphyry indicator minerals in sediments, soils, tills or rock that can be used to identify the presence of potential mineralization while porphyry vectoring and fertility tools using the composition of hydrothermal minerals can predict the direction and distance to mineralization. Industry use of these techniques has validated their effectiveness and efficiency but their uptake has been slow due to limited availability of the technology from commercial laboratories.

The session on Analytical Methods had at its core the impact that developments in instrumentation have had in the laboratory and in the generation of geochemical data. Jamil Sader and Shawn Ryan (Sader & Ryan 2017) reviewed advances in ICP-MS technology over the decade including the application of collision/reaction cells in ICP-MS and the development of triple quadrupole ICP-MS instruments. These technologies allow much reduced detection limits for elements such as As and Se that can be key to the lithogeochemical understanding of mineralizing events in many different ore systems, complementing the indicator mineral studies above. Another development is the use of laser ablation ICP-MS for multi-element determination on Li-borate fused glass disks, eliminating the use of potentially hazardous reagents. They did comment that despite the availability of such advanced instrumentation, the uptake among explorationists has been limited, possibly because of the downturn in the industry in the latter half of the decade. There is no doubt, however, of the role of multi-element geochemical data in conjunction with focused surficial sampling in the discovery of several gold deposits in the White Gold district in the Yukon and the revitalization of the territory as a destination for gold exploration.

Potentially low detections limits for elements like Au by ICP-MS has also led to a re-consideration of water as a sampling medium in the sub-surface. The paper by James Buskard and colleagues points out that water is usually available for sampling in every drill hole yet has been underutilized by the exploration community as a means for generating targets under cover. Yet it can be a relatively straightforward process as the water can be analyzed directly using specialized ICP-MS analysis and geochemical anomalies for elements like Au are often proximal to mineralization. They illustrated applications of this approach at regional and project scales in Australia and in Nevada where detection of deeply buried gold deposits can be further limited by thick cover. Anomalies are at the part-per-trillion level as illustrated in Figure 1 which depicts a south to north hydrogeochemical plume of elevated gold values approximately 1,000 x 4,000 m in size above a potential target.

Figure 1. South Grass Valley water sampling project reported by Buskard et al (2017) at Exploration ’17, showing groundwater sample sites, water table elevation in boreholes and dissolved Au concentrations (ppt).



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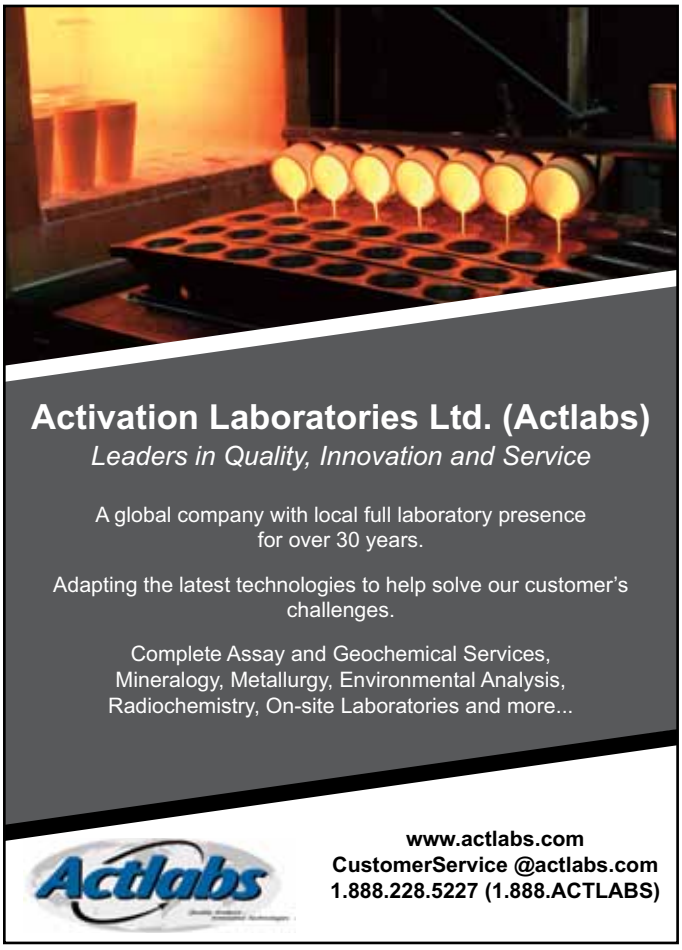
Isotopic analysis is not often used in exploration partly because of perceived high costs, long turnaround times and limited understanding of applications. A review of advances in the use of isotopes in geochemical exploration was prepared by Kurt Kyser (Kyser 2017) just prior to his untimely death and was presented by Matthew Leybourne. Advances in instrumentation such as in ICP-MS and automated sample preparation are making isotopic analysis faster and more affordable and therefore accessible to geochemists in trying to understand and validate processes in ore formation and elemental dispersion in the surficial environment.

Portable XRF technology has undoubtedly been one of the key analytical developments over the past decade as it provides analytical capability in real time that is particularly useful in remote exploration programs. Both Agnew and Winterburn commented on the impact of the technology while Bruno Lemière and Yulia Uvarova (Lemière & Uvarova 2017) reviewed the current capabilities of portable XRF instruments. In addition, they surveyed the growing array of field portable devices that can provide a range of chemical and mineralogical analyses as well as novel developments such as Lab-at-Rig that combine both XRF and XRD analyses. They discuss too the generation of fit-for-purpose data that allows rapid decisions making in the field when directing exploration programs. Agnew commented on the impact of new core logging technologies (reviewed in the Spectral Geology and Remote Sensing session) that can provide vast amounts of data in real time, improving the quality of logging of alteration systems particularly when combined with geochemical data.

Some geochemistry talks were also included in other sessions such as Technical Innovation. Furthermore, many of the case studies discussing integrated approaches in exploration, a key theme of the conference, had a geochemical component. Several workshops focused on geochemistry, from indicator mineral applications to assay quality control to field portable technologies. A well attended Trade Show showcased many of the technologies under discussion.

Most of the presentations and accompanying papers are available at www.DMEC.ca at the Exploration 17 microsite (http://www.dmec.ca/Resources/Exploration-Site.aspx). Proceedings of the previous Exploration conference from 1967, 1977, 1987, 1997, and 2007 can also be reviewed there under the "Resources" heading on the Home page. Together these proceedings form an extraordinary resource for mineral exploration professionals. Despite the impact of the deep recession in the industry there is much to be optimistic about the current state of Exploration Geochemistry from regional to prospect scale. New technologies and particularly the rise of portable instrumentation are changing the way geochemical data are generated. AI and Machine Learning may provide a whole new way of data analytics for the rapidly increasing volume of data.

Nevada Exploration Inc. and James Buskard are thanked for permission to reproduce an image from their talk as Figure 1. Stephen Cook and Beth McClenaghan are thanked for their reviews which significantly improved the article.



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Geochemistry at Exploration '17… *continued from page 10*

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Geochemistry

EXPLORATION, ENVIRONMENT, ANALYSIS

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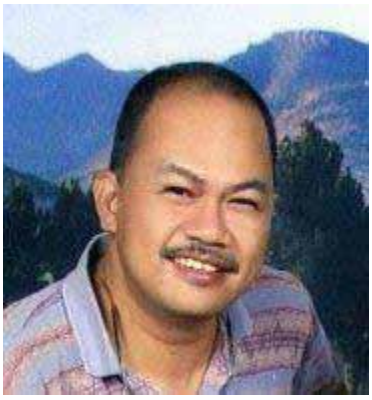
AAG Councillors 2019-2020

John Carranza



John has been a Member of the Association of Applied Geochemists (AAG) since 1991 (when it was formerly Association of Exploration Geochemists), became a Fellow in 2019, and has served twice before as Councillor (2009–2010, 2011–2012). He started his career as exploration geologist/geochemist (1983–2001) in the Bureau of Mines & Geosciences of the Philippines. He was researcher (2001-2003) then Associate Professor (2003-2012) at the Department of Earth Systems Analysis of the International Institute of Geo-information Science and Earth Observation (The Netherlands). He was Associate Professor (2013–2016) and currently Adjunct Associate Professor (2017-present) in the School of Earth and Environmental Sciences of James Cook University (Australia). He was Visiting Professor (2015-2017) at the Institute of Geosciences of the State University of Campinas (Brazil). He is now Professor of Geological Sciences (2017-present) at the University of KwaZulu-Natal (South Africa). His fields of expertise are geochemistry (for mineral exploration, ore genesis and geo-environmental studies), spatial mathematics/statistics (for predictive modelling of mineral resources and geological hazards) and remote sensing for geological/mineral exploration. He has written a book "Geochemical Anomaly and Mineral Prospectivity Mapping in GIS". He is Editor-in-Chief of Natural Resources Research journal, Senior Associate Editor of AAG's Geochemistry: Exploration, Environment, Analysis, and Associate Editor of Ore Geology Reviews and Journal of Geochemical Exploration.

Patrice de Caritat

Patrice's university training is in geology, mineralogy and geochemistry, and his research interests include environmental and exploration geochemistry, hydrogeochemistry, isotope geochemistry, low-density geochemical mapping, and, most recently, forensic geochemistry. In 2017-18, Patrice was seconded as subject matter expert to the Australian Federal Police (AFP) to assist with the development of a forensic and intelligence soil provenancing capability. Currently Patrice is Principal Research Scientist at Geoscience Australia (GA); Adjunct Professor of Applied Geochemistry at the University of Canberra (UC); and Visiting Fellow at the Australian National University (ANU). Until its successful completion in June 2011, he was leader of the National Geochemical Survey of Australia (NGSA; www.ga.gov.au/ngsa) project. Between 2007 and 2014, Patrice was also a Senior Researcher in the Otway project of the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC). Before joining GA in 1997 to be Program Leader in the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME), he was Senior Research Scientist at the Geological Survey of Norway for several years. Prior to that, he was a Post-Doctoral Fellow in the Department of Geology & Geophysics of the University of Calgary (Canada), and in the Department of Geology and the Research School of Earth Sciences of the ANU in Canberra. Patrice has a Lic Sci (BSc Hons) degree from the University of Louvain (Belgium), and PhD from the ANU. Patrice is Councillor for the International Association of GeoChemistry (IAGC) (since 2015) and Associate Editor for Applied Geochemistry. He is a Fellow of the Association of Applied Geochemists (AAG), Associate Editor for Geochemistry: Exploration, Environment, Analysis, and was AAG Councillor in two previous terms (2011-12 and 2013-14) and AAG's Society News Editor for ELEMENTS (2011-15).

Dave Heberlein

Dave has been involved in mineral exploration since 1979. He holds a B.Sc. (Hons.) in Geology from the University of Southampton and a M.Sc. from the University of British Columbia. He has world-wide experience in exploring for both precious and base metal deposits. Prior to joining Barrick Gold Corp. in 1994, he worked for several senior mining companies. From 1995 to 2002, he was Barrick's Exploration Manager for Argentina and Chile. After returning to Canada in 2002, he became Barrick's Chief Geochemist for global exploration. He left Barrick in 2007 and after a brief stint as VP Exploration for a junior company, he set up his consultancy, Heberlein Geoconsulting. He is currently a consulting exploration geochemist based in North Vancouver, Canada.

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AAG Councillors 2019-2020… *continued from page 12*

Tom Meuzelaar

Tom holds a B.Sc. in geology from the University of Utah (1991), M.Sc. in economic geology/geochemistry from Washington State University (1995) and a Ph.D. in economic geology/geochemistry from the Colorado School of Mines (2015). Tom currently runs Life Cycle Geo, a company that provides innovative geoscience solutions across the mining and oil/gas project life cycle, with focus on using machine learning to optimize materials management processes. Tom previously worked for Golder Associates Inc. (2011-2018) as a senior consultant specializing in geology and geochemistry. He ran a diverse practice providing technical expertise to clients in the mining, oil and gas and power sectors through all project life cycle stages (exploration, production, closure). Prior to that, Tom was employed at RockWare Inc. (from 1999 to 2011) as software consultant, manager of the Geochemist's Workbench account, and general software marketer and business developer. He has extensive experience as petrographer, mineralogist and geologist, and is skilled in statistical evaluation and reduction of large geochemical datasets. He has also taught or co-taught over 35 geochemical modeling short courses, including courses at Goldschmidt conferences, federal research organizations, multinational energy corporations, environmental and mining consultancies and major universities. His primary interest in joining the AAG Council is to help direct marketing strategies for sustaining and growing membership.

Renguang Zuo

Renguang Zuo became a Fellow of AAG in 2016. He received his Ph.D from the China University of Geosciences (CUG) in 2009. As a jointly supervised PhD candidate by CUG and York University (Toronto, Canada), Renguang studied for one year at York University (supervisors: Prof. Qiuming Cheng and Prof. Frits Agterberg) during 2007-2008. He has been working at the state key laboratory of Geological Processes and Mineral Resources at CUG since he obtained his Ph.D. in 2009. At the end of 2012, he was promoted to a full professor. In 2014 as a senior visiting scholar, he worked together with John Carranza for four months at the James Cook University (Townsville, Australia). He is currently serving as an associate editor for Geochemistry: Exploration, Environment, Analysis, Journal of Geochemical Exploration, Natural Resources Research, and Computers & Geosciences. As a guest editor, he organized four special issues related to geochemical mineral exploration and mapping mineral prospectivity. Renguang has published more than 70 peer-reviewed papers. He was awarded the Kaharaka Award by the International Association of Geochemistry in 2015 to honour his contributions to applied geochemistry. Renguang's work promoted GIS-based geochemical mineral exploration and built a wide range of international cooperation.

28th IAGS Abstracts

28th IAGS session abstracts that formed part of the Resources for Future Generation (RFG) conference held in Vancouver, Canada between June 16-21, 2018 are now available for download from the AAG website: https://www.appliedgeochemists.org/sites/default/files/documents/Symposia/2018%2028th_IAGS_Abstracts_Vancouver.pdf

28th IAGS Sessions included the following:

MIN24: Stable and Radiogenic Isotope Systems: Applications in Exploration and the Environment
MIN25: Exploration Case Studies - Out of the Box Concepts, Methodologies and Practices
MIN26: Towards Big Data: Applications of Data Analytics in Geochemistry
MIN27: Footprints of Giant Orebodies - Mineralogical, Spectral and Geochemical Vectors to Discovery
MIN28: Micro- to Macro-Biogeochemistry: Exploration, Processing, Remediation and the Environment
MIN29: Exploration Undercover - Techniques, Technology and Strategy
MIN30: Mineral Exploration in Extreme Environments
MIN48: Hydrocarbons in the Exploration for Metaliferous and Non-Metaliferous Deposits
MIN55: Analytical Technology in the Search for Minerals: Space to the Lab to the Field

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MIN58: Geometallurgy-Session i
WA14: Hydrogeochemistry: Environment and Exploration

Proceedings and abstracts from past IAGS (2015 back to 2007) and IGES (2005 back to the beginning in 1966) symposia are also on the AAG website and available for download at: https://www.appliedgeochemists.org/events

27th International Geochemical Exploration Symposium (IAGS 2015)
Date: April 20-24, 2015
Location: Tucson, USA
Abstracts

26th International Geochemical Exploration Symposium (IAGS 2013)
Date: November 17-21, 2013 Location: Rotorua, New Zealand
Abstracts

25th International Geochemical Exploration Symposium (IAGS 2011)
Date: August 21-26, 2011 Location: Rovaniemi, Finland
Abstracts

24th International Geochemical Exploration Symposium (IAGS 2009)
Date: June 1 - 4, 2009 Location: Fredericton, Canada
Abstracts

23rd International Geochemical Exploration Symposium (IAGS 2007)
Date: June 14-19, 2007 Location: Oviedo, Spain
Program and Extended Abstracts

2007 Exploration'07 Exploration in the New Millennium
Date: September 9-12, 2007 Location: Toronto, Canada
Workshops 2 and 3 oral presentations

22nd International Geochemical Exploration Symposium (IGES 2005)
Date: September 19-23, 2005 Location: Perth, Australia
Abstracts and oral presentations

21st International Geochemical Exploration Symposium (IGES 2003)
Date: August 28 - September 3, 2003 Location: Dublin, Ireland
Abstracts and oral presentations

20th International Geochemical Exploration Symposium (IGES 2001)
Date: May 6-10, 2001 Location: Santiago, Chile
Abstracts and oral presentations

19th International Geochemical Exploration Symposium (IGES 1999)
Date: April 10-16, 1999 Location: Vancouver, Canada
Abstracts

18th International Geochemical Exploration Symposium (IGES 1997)
Date: May 25-30, 1997 Location: Jerusalem, Israel
Program and Abstracts

17th International Geochemical Exploration Symposium (IGES 1995)
Date: May 15-19, 1995 Location: Townsville, Australia
Abstracts, Excursions, Field trips

16th International Geochemical Exploration Symposium (IGES 1993)
Date: September 1-6, 1993 Location: Bejing, China
Program and Abstracts

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15th International Geochemical Exploration Symposium (IGES 1991)
Date: April 29-May1, 1991 Location: Reno, USA
Program and Abstracts

14th International Geochemical Exploration Symposium (IGES 1990)
Date: June, 1990 Location: Prague, Czechoslovakia
Abstracts

13th International Geochemical Exploration Symposium (IGES 1989)
Date: October 1-6, 1989 Location: Rio de Janeiro, Brazil
Abstracts

12th International Geochemical Exploration Symposium (IGES 1987)
Date: April 23-26, 1987 Location: Orléans, France
Program and Abstracts

11th International Geochemical Exploration Symposium (IGES 1985)
Date: April 28-May 2, 1985 Location: Toronto, Canada
Program and Abstracts

1984 Exploration for Ore Deposits of the North American Cordillera
Date: March 25-28, 1984 Location: Reno, USA
Program and Abstracts

10th International Geochemical Exploration Symposium (IGES 1983)
Date: August 29-September 2, 1983 Location: Helsinki, Finland
Program and Abstracts

9th International Geochemical Exploration Symposium (IGES 1982)
Date: May 12-14, 1982 Location: Saskatoon, Canada
Program and Abstracts

1981 Precious Metals in the Northern Cordillera
Date: April 13-15, 1981 Location: Vancouver, Canada
Programme and Abstracts

8th International Geochemical Exploration Symposium (IGES 1980)
Date: 1980 Location: Hanover, Germany
Abstracts Volume

7th International Geochemical Exploration Symposium (IGES 1978)
Date: April 17-19, 1978 Location: Golden, USA
Program and Abstracts

1976 Exploration Geochemistry in the Appalachians
Date: April 22-23, 1976 Location: Fredericton, Canada
Program and Abstracts

6th International Geochemical Exploration Symposium (IGES 1976)
Date: August, 1976 Location: Sydney, Australia
Weblinks to proeedings
http://www.sciencedirect.com/science/journal/03756742/8/1-2
http://www.sciencedirect.com/science/article/pii/B9780444416537500044

5th International Geochemical Exploration Symposium (IGES 1974)
Date: April 1-4, 1974 Location: Vancouver, Canada
Program with Abstract

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28th IAGS Abstracts… *continued from page 15*

4th International Geochemical Exploration Symposium (IGES 1972)
Date: April 17-20, 1972 Location: London, England
Program with Abstracts

3rd International Geochemical Exploration Symposium (IGES 1970)
Date: April 16-18, 1970 Location: Toronto, Canada
Program with Abstract

2nd International Geochemical Exploration Symposium (IGES 1968)
Date: April 17-20, 1968 Location: Golden, USA
Program and Abstracts

1st International Geochemical Exploration Symposium (IGES 1966)
Date: April 20-22, 1966 Location: Ottawa, Canada
Program and Abstracts, Proceedings

Student Support Initiative

The AAG collaborates with analytical laboratories to broker in-kind analytical support for applied geochemistry students. The laboratories are made aware of the important focus that AAG puts on applied geochemistry and that students of applied geochemistry are the laboratory's future customers. The majority of theses undertaken by applied geochemistry students involve analytical work, the cost of which can be onerous, particularly for students in developing countries with limited resources.

Actlabs, ALS, Bureau Veritas, Intertek-Genalysis and LabWest are currently participating or have supported students currently participating in the initiative. These laboratories offer a wide range of analytical services for research in applied geochemistry spanning the environmental and mineral exploration fields. Students can apply for support through the AAG web site https://www.appliedgeochemists.org/students/student-support-initiative and, if successful, must report on their results either in GEEA or EXPLORE.

The following students are currently participating in the initiative:

Student	University	Topic	Laboratory
Matthew Bodnar	University of British Columbia	Surface metal mobility	ALS
Victor Vincent	Modibbo Adama University of Technology	Sediment-hosted sulfide deposits, Nigeria	ALS
Anthony Chukwu	University of Nigeria, Nsukka	Petrology of Ta-Nb pegmatites	Intertek-Genalysis
Chinedu Ibe	University of Nigeria, Nsukka	Geochemistry of Precambrian rocks	Bureau Veritas
Hamid Zekri	Ifsan University, Iran	Dispersion through cover	Actlabs
Sonia Mulongo	University of Lubumbashi	Mining exploitation impact, Lubumbashi City	Bureau Veritas

David Murphy
AAG Education Committee
Email: davidmkmurphy@gmail.com

29th International Applied Geochemistry Symposium (IAGS)

Viña del Mar, Chile

November 9-13, 2020

The 29th International Applied Geochemistry Symposium (IAGS) will be held in the “Garden City” of Viña del Mar, Chile in November 9-13, 2020. The city of Viña del Mar, in central Chile, is located 120 km northwest of the capital city of Chile, Santiago. It is a well-known tourist destination, famous for its beaches, the neighboring world heritage city of Valparaiso and abundant parks. The city lies west of the coastal cordillera in which wineries thrive among the valleys, together with other productive activities that include gold and base metal mining. The location of Viña del Mar provides easy access and represents a great starting point for pre- and post-conference activities, including field trips and social or tourist activities.

Chile is an easily accessed country. Its international airport is well connected world wide, and most nationalities do not require a visa for entry. The official language of Chile is Spanish, but the official conference language is English.

Information about the conference, venue, program, workshops, and pre and post conference field trips will provided in early 2019.

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

2019

15-16 MARCH	2nd International Conference on Geoinformatics and Data Analysis. Prague Czech Republic. Website: www.icgda.org
18-21 MARCH	Exploration Geology short course. Theoretical foundations and practical training in mineral exploration geochemistry and geology, alteration geochemistry and ore interpretation. Uni Freiburg, Freiburg im Breisgau, Germany. Website: http://www.minpetro.uni-freiburg.de/expgeo
18-22 MARCH	48th Lunar and Planetary Science Conference Woodlands TX USA www.hou.usra.edu/meetings/lpsc2019
7-12 APRIL	EGU General Assembly. Vienna Austria. Website: www.egu2019.eu
10-12 APRIL	Mongolia Mining 2019. Ulaanbaatar Mongolia. Website: mongolia-mining.com
15-16 APRIL	3rd International Conference on Earth Science & Climate Change. Toronto ON Canada. Website: tinyurl.com/y7cnnkvd
16-19 APRIL	26th International Mining Congress and Exhibition of Turkey. Belek Turkey. Website: www.imcet.org.tr
28 APRIL - 1 MAY	CIM Convention. Montreal QC Canada. Website: convention.cim.org
3-5 MAY	International Conference on Geographical Information Systems Theory, Applications and Management. Heraklion Greece. Website: www.gistam.org
5-9 MAY	15th International Conference on the Biogeochemistry of Trace Elements. Nanjing China. Website: icobte2019.csp.escience.cn
6-9 MAY	9th World Conference on Sampling and Blending. Beijing China. Website: www.wcsb9.com
13-15 MAY	GAC-MAC-IAH/CNC Annual Meeting. Quebec City QC Canada. Website: tinyurl.com/y9dffld5
22-23 MAY	7th International Conference on Earth Science, Climate Change & Space Technology. Rome Italy. Website: earthscience.alliedacademies.com
3-8 JUNE	8th International Workshop on Compositional Data Analysis. Terrassa Spain. Website: tinyurl.com/y7prnhoo
4-5 JUNE	15th International Estuarine Biogeochemistry Symposium. Vigo Spain. Website: iebs.gal
4-5 JUNE	International Uranium Conference. Adelaide SA Australia. Website: uranium.ausimm.com
9-13 JUNE	2nd Geobiology Society Conference. Banff AB Canada. Website: cms.eas.ualberta.ca/geobiology2019
23-28 JUNE	Gordon Research Conference: Catchment Science: Interactions of Hydrology, Biology and Geochemistry. Andover NH. Website: tinyurl.com/y9dsvkac
24-27 JUNE	Quantitative Microanalysis 2019. Minneapolis MN USA. Website: tinyurl.com/y8fayprt
24-27 JUNE	13th International Eclogite Conference. Petrozavodsk Russia. Website: igkrc.ru/konferencii-2/922
1-5 JULY	35th International Conference for Society for Environmental Geochemistry and Health. Manchester UK. Website: https://www2.mmu.ac.uk/segh-19/
14-19 JULY	Gordon Research Conference: Discovering Chemical Processes and Mechanisms in a Changing Ocean. Holderness NH USA. Website: tinyurl.com/yahb7f7o
15-18 JULY	6th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology
21-26 JULY	16th International Symposium on Water-Rock Interaction. Tomsk Russia. Website: wri16.com
22-23 JULY	6th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology
25-31 JULY	INQUA 2019. Dublin Ireland. Website: www.inqua2019.org
28 JULY – 2 AUGUST	Atmospheric Chemistry (Gordon Research Conference). Newry ME USA. Website: tinyurl.com/yczryngx
4-8 AUGUST	Microscopy & Microanalysis 2019 Meeting. Portland OR. Website: tinyurl.com/y9ejytzy

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CALENDAR OF EVENTS... *continued from page 26*

10-16 AUGUST	20th Annual Conference of the International Association for Mathematical Geosciences. State College PA USA. Website: www.iamgconferences.org/iamg2019
12-15 AUGUST	8th International Conference on Medical Geology. Guiyang China. Website: www.medgeo2019.com
18-20 AUGUST	9th International Conference on Environmental Pollution and Remediation. Lisbon Portugal. Website: icepr.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
1-6 SEPTEMBER	29th International Meeting on Organic Geochemistry . Gothenburg Sweden. Website: www.imog.eaog.org
2-5 SEPTEMBER	2nd Australasian Exploration Geoscience Conference. Perth WA Australia. Website: 2019.aegc.com.au
8-13 SEPTEMBER	14th International Conference on Mercury as a Global Pollutant. Krakow Poland. Website: www.mercury2019krakow.com/gb
11-14 SEPTEMBER	9th European Conference on Mineralogy and Spectroscopy Prague Czech Republic. Website: ecms2019.eu
17-18 SEPTEMBER	21st International Conference on Isotope Hydrology and Geochemistry. Rome Italy. Website: tinyurl.com/y8excuwr
22-25 SEPTEMBER	2019 GSA Annual Meeting. Phoenix AZ USA. Website: tinyurl.com/yblcfomo
22-27 SEPTEMBER	International Society for Environmental Biogeochemistry. 24th Symposium. Potsdam Germany. Website: tinyurl.com/y9yngecm
23-27 SEPTEMBER	14th International Congress on Applied Mineralogy. Belgorod Russia. Website: www.geo.komisc.ru/icam2019/en
25-28 SEPTEMBER	Mines and Wines Conference 2019. Wagga Wagga NSW Australia. Website: www.minesandwines.com.au
7-20 OCTOBER	SEG 2019: South American Metallogeny: Sierra to Craton. Santiago Chile. Website: tinyurl.com/y7k4dm6j
27-30 OCTOBER	6th International Conference on Selenium in the Environment and Human Health. Yangling/Xi'an China. Website: icsehh2019.csp.escience.cn
29-30 OCTOBER	12th Fennoscandian Exploration and Mining. Levi Finland. Website: fem.lappi.fi/en
6-8 NOVEMBER	XIV Latin American Symposium on Environmental Analytical Chemistry. Bento Gonçalves Brazil. Website: laseac2019.furg.br/inscricoes

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
24-25 MAY	Geochemistry of Mineral Deposits (Gordon Research Conference). Castelldefels Spain. Website: tinyurl.com/ybkjgl37
16-20 AUGUST	12th International Kimberlite Conference. Yellowknife NT Canada. Website: 12ikc.ca
17-21 AUGUST	34th International Geographical Congress. Istanbul, Turkey. Website: www.igc2020.org/en
24-28 AUGUST	Eurosoil 2020. Geneva, Switzerland. eurosoil2020.com
18-23 OCTOBER	IWA World Water Congress & Exhibition 2020. Copenhagen Denmark. tinyurl.com/y8tpg3jt

Recently Published in Elements

Volume 14, no. 6, ***Marine Biogeochemistry of Trace Elements and Their Isotopes***

This volume focuses on the marine biogeochemistry of trace elements and their isotopes, and how they are used to monitor changes in the oceans. Summary abstracts for the first three technical articles in **EXPLORE** were presented under AAG news.

Volume 15, no. 1, ***Planet Mercury***

The first issue of 2019 is out of this world, literally! The topic is the geology of the planet Mercury. AAG news includes a message from our President and announces the venue of the 29th IAGS at Viña del Mar, Chile in 2020.

Reminder: AAG members can access past issues of Elements at http://elementsmagazine.org/member-login/ using their e-mail address and member ID.

Dennis Arne

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