

Breathing new life into old assay data using machine learning methods

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INTRODUCTION

Significant under- or over-estimation of assay parameters can occur when incorrect laboratory assay methods are used (e.g., Abzolov 2008; Anderson 2020; Meuzelaar *et al.* 2021). The cost of re-analysis can be very high when such errors are repeated over the scale of thousands of samples. Machine learning algorithms can offer a low-cost alternative to expensive re-analysis; a small subset of samples can be re-analyzed, and an algorithm trained to: 1) recognize relationships between the corrected parameter and other assay parameters in the subset, and 2) estimate corrected values for the larger dataset.

As a proof-of-concept, machine learning algorithms were applied to 5,580 bedrock samples from the Touro exploration assay dataset to assess whether (corrected) sulfur values can be predicted from the other assay parameters in the dataset. When Atalaya Mining, Cobre San Rafael (Atalaya) acquired a majority interest in the Touro project, it inherited multiple legacy assay datasets with noticeable inconsistencies in sulfur assay data. Further investigation revealed that the data were acquired using laboratory assay methods insufficient to digest metamorphosed sulfides (predominantly pyrrhotite). Machine learning algorithms trained on a dataset with correct sulfur data were able to derive a relationship between other assay variables which enabled reproducing the sulfur concentrations with 93% accuracy. Predictive success is largely a function of: 1) the number of samples, 2) the number of assay parameters, and 3) material/deposit geochemistry.

GEOLOGICAL BACKGROUND

Proyecto Touro is a brownfield copper project located in the A Coruña province of the Galicia Autonomous Region in northwestern Spain. Copper mineralization occurs in metasediments that comprise the Órdenes Complex (Fig. 1), in the northwest portion of the Iberian Massif, an allochthonous metamorphosed unit that is part of the Variscan belt of Europe. The Órdenes Complex consists of a thick sequence of metamorphosed turbidites with interbedded volcanic lenses. These material types have undergone extensive metamorphism with sedimentary units expressing as paragneiss and volcanic units as metabasites and amphibolites. Copper mineralization occurs in the metavolcanic units as disseminated sulfides within metabasites and coarse garnet amphibolite. Sulfides are predominantly pyrrhotite and chalcopyrite, with lesser pyrite.

Touro was originally recognized as a metamorphosed Cu-Zn type volcanogenic massive sulfide (VMS) deposit (Badham and Williams 1981; Williams 1983). However, more recent studies suggest that the lithologic setting, morphology, and mineralogy more closely reflect a Besshi-type (mafic-siliciclastic) VMS deposit (Arias *et al.* 2021), equivalent to pelitic-mafic VMS deposits (Shanks *et al.* 2012). Besshi-type deposits occur in mature oceanic back-arc successions with thick marine sequences of clastic sedimentary rocks and intercalated mafic (occasionally ultramafic) volcanic rocks. The mafic component consists largely of volcanic material types with mid-ocean ridge basalt (MORB)-like affinities.

The Touro project consists of five separate mineralized zones: Arinteiro, Bama-Brandelos, Vieiro, Arca, and Monte Minas, the first three of which were mined from 1973 to 1986 (Ore Reserves Engineering 2018). Mineralization occurs

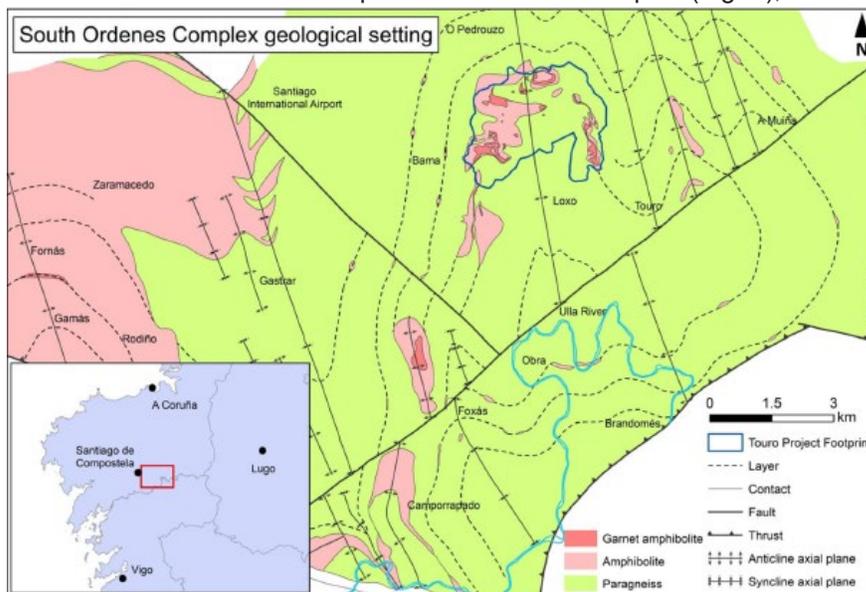


Figure 1. Location of the Touro project area in central Spain (inset) and detailed bedrock geological map.



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- **Figures and/or photos** (colour or black and white) should be submitted as separate high resolution (2000 dpi or higher) tiff, jpeg or PDF files.
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- 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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Correction notice for EXPLORE issue 192

EXPLORE issue 192 featured an article describing the geochemistry of LCT pegmatites in part of northeastern Nasarawa state, northcentral Nigeria by A. Chukwu, S.C. Obiora, and T.C. Davies. On page 6, the Methodology Section should read that the trace and rare earth elements were determined by sodium peroxide fusion.

Beth McClenaghan,
Editor

Notes from the Editor

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President's Report

How quickly two years have passed! After what has been an eventful two years, I find myself composing a final report as President of the AAG. One regret I have is that I did not have the opportunity to preside over the 29th IAGS in Chile, but I am confident that things are gradually returning to some semblance of normal and that we will have a successful, albeit hybrid, conference next year. I am sure many of you are keen to renew contact with colleagues and friends.

Several initiatives are progressing although none will be completed during my tenure. A draft of the revised edition of "Writing Geochemical Reports" should be close to completion by the end of the year and include appendices on a variety of survey methods. My thanks to Linda Bloom and Owen Lavin for driving this re-write.

Work is underway on a series of review papers on exploration and mining geochemistry to appear in GEEA. Council agreed at the last meeting to fund the Open Access charges for these review papers with our publisher, The Geological Society. This has been well received by potential authors and has added some impetus to the work of approaching potential contributors. Contributions can be published online as soon as they pass through the review process as GEEA is no longer available in print form. These review papers will become important references for exploration and mining geochemistry in years ahead. I am grateful to all those who have been involved in advancing this project and to all those that will devote their time and expertise to preparing manuscripts over the coming year.

Finally, AAG members will have a prominent involvement in the upcoming virtual SGA conference in March next year. Arianne Ford and John Carranza are hosting a session on "Spatial data analysis for mineral exploration". Walid Salama, Dave Cohen and Ryan Noble are convening a session on "Mineral exploration in weathered and covered terrains". Dave Cohen and I will be preparing an on-line exploration geochemistry short course "Exploration geochemistry: applying the fundamentals" that will serve as a prototype for future CPD material for the AAG. We will partner with Argos Education (<https://argos.education/>) to coincide with the launch of their platform in early 2022.

John Carranza will take over as President in 2022 and 2023, leaving the AAG in very capable hands. Yulia Uvarova has agreed to replace John as Vice-President. I will replace Steve Cook as chair of the AAG Awards and Medals Committee, although I expect an appearance in Chile from him next year to help hand out the backlog of medals and awards that have accrued over the past two years! I am appreciative to these individuals for taking on leadership roles within the AAG, as well as to all those currently serving, or who have formerly served on Council and the various AAG committees. A special thanks goes out to our Business Manager, Al Arsenault, who keeps the administrative wheels turning.

I wish you all the best for the approaching holiday season and hope that you will have the opportunity to re-connect with friends and family.

Dennis Arne
President



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within the Arinteiro antiform, representing the final deformation episode. The antiform has NE-SW orientation with its axis plunging towards the north. The lenticular and stratiform nature of materials reflect seafloor deposition of fine-grained sediments and turbidites, intrusion of MORB basalts, and concomitant subduction/orogeny. This resulted in the current/final assemblage of mineralized amphibolites (volcanic) hosted within larger bodies of paragneiss. In Arca and Monte de Minas zones, massive sulfide-style mineralization also occurs in brecciated rocks below and near the lower amphibole contact, with breccia clasts cemented by pyrrhotite.

TOURO SULFUR DATA

Atalaya Mining acquired a majority interest in the Touro project in 2015. The acquisition included various legacy assay datasets with parameters obtained using different methods. Atalaya Mining noticed that sulfur was frequently underestimated, analyzed via multiple different lab methods, with concentrations highly inconsistent from database to database. Sulfur data are important from both an exploration and environmental perspective, as they are used in understanding ore assemblages and grade, as well as long-term waste material environmental behavior given a proportion of waste materials is likely to be acid-generating. Further investigation (Golder 2018) indicated that seven different methods for sulfur analysis had been employed over time at three different labs. Results were inconsistent between the various methods as each employed digestants of various aggressiveness, frequently resulting in partial or incomplete digestion of variably metamorphosed sulfides (Meuzelaar *et al.* 2021). Total sulfur by Leco and ICP aqua regia (Digiprep digestion) were adopted as acceptable sulfur analysis methods for the project, because results suggested near complete sulfide digestion, consistently higher sulfur assays compared to the other methods, and strong correlation between the two methods (Golder 2018).

One legacy database, with 5,880 samples and 49 assay parameters (in addition to sulfur) offered a unique opportunity to test the viability of assessing whether sulfur concentrations could be predicted from other assay parameters using machine learning algorithms. Sulfur values in this particular database were obtained by ICP-AES (four-acid) and were deemed to be of sufficient quality for this proof-of-concept evaluation as mean sulfur ICP-AES concentrations (3.4 wt. %) are 8.7% lower than the preferred Leco and Digiprep¹ concentrations (both at 3.9 wt. %). Additionally, scatterplots for these datasets indicated high coefficients of determination between both ICP-AES and Leco (0.944) and ICP-AES and Digiprep (0.955).

If successful, the methodology offers the opportunity to correct legacy datasets with misestimated parameter values without having to conduct expensive laboratory re-analysis.

METHODS

Data

A geochemical dataset from Atalaya Mining containing 5,880 samples with analysis of 49 elements was used for this evaluation. Samples for eight different bedrock lithologies were contained within the database. The sulfur values in the database ranged from below detection (<0.01) to 11.8 wt.%. A summary of the database including the lithologies, sample numbers, and median sulfur value is presented in Table 1.

Table 1. Dataset used in the study

Lithology	Code	Number of samples	Median Sulfur (wt.%)
Amphibolite	AF	1742	1.9
Garnet Amphibolite	AFG	716	3.0
Ca-poor Amphibolite	AG	1361	3.5
Breccia-Massive Sulfide	BSM	32	11.7
Biotitic Schist	DSC	297	4.3
Massive Sulfide	MS	155	5.9
Pelitic paragneiss	PG	1305	0.8
Pelitic paragneiss with sulfide	PGS	272	10.4

¹Leco and Digiprep analyses of a subset of 97 fully digested samples were used to assess differences between ICP-AES and the total-digest analytical methods

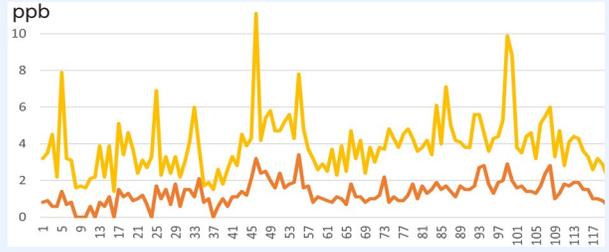
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Data Preparation

Raw geochemical data are typically not fit for advanced multivariate analysis (e.g., principal component analysis, machine learning) because of two commonly observed properties: the data are compositional in nature and may contain non-detect or censored values. Both properties of the data require mathematical transformation prior to the data being used. Compositional data present several challenges prior to statistical evaluation: 1) they are restricted to a constant sum (e.g., numeric closure), and 2) they are proportional which means when one value changes other values must also change (Grunsky and de Caritat 2020). The issue of numeric closure may be addressed with logarithmic ratios, such as the centered-log ratio (clr) (Aitchison 1982; Pawlowsky-Glahn and Egozcue 2006), which was used in this study to transform the data from concentrations to clr-transformed values. Censored data represent values below a certain analytical detection limit (DL) and are represented as being less than a value (<DL; left-censored) or greater than a value (>DL; right censored). No right-censored values were present in the dataset and left-censored values were imputed with an estimate that considers the composition of the entire sample (Sanford *et al.* 1993) using a compositional variant of the expectation-maximization (EM) algorithm (Palarea-Albaladejo and Martín-Fernández 2015). All data processing was performed in the R statistical computing environment (R Core Team 2017).

Statistical Methods

Machine learning methods can identify patterns and structures within multivariate datasets that are difficult to discern with traditional data exploration methods such as bivariate scatter plots. The objective of this study was to identify if an accurate relationship could be derived between sulfur and other elements in the database (e.g., iron, cadmium, zinc) such that sulfur concentrations could be predicted based on the composition of other elements. The relationship between sulfur and other elements is complex and highly non-linear based on the mineral stoichiometry of the lithologic units of the Touro deposit.

Multiple statistical learning methods were employed to predict the sulfur content of the Atalaya dataset. These methods included multiple linear regression, boosted decision trees (BDT; Friedman 2001), random forest (RF; Breiman 2001), and artificial neural networks (ANN; Goodfellow *et al.* 2016). Each model was built inside the Microsoft Azure Machine Learning Studio (AMLs) environment. A wide range of model complexity was chosen from simple (multiple linear regression) to advanced (ANN) to evaluate the most appropriate method. Additional complexity does not always equal additional predictive value. The relative effectiveness of any particular method is generally a function of both data density and heterogeneity.

Model accuracy was evaluated based on its ability to predict sulfur concentrations in the dataset, using both the mean squared error (MSE) and coefficient of determination (r^2). Training each model involved hyperparameter tuning of specific algorithm parameters to the dataset.

Algorithm results were interpreted by calculating the variable importance for each model by using the permutation feature-importance algorithm built in AMLs (Breiman 2001). Variable importance computes importance scores by quantifying the contribution of a specific variable (e.g., Cu, Fe, Ni etc.) on the overall model performance. In other words, variable importance computes how important each variable is in predicting sulfur.

RESULTS

Model predictive accuracy was evaluated by two metrics: mean squared error (MSE) and the coefficient of determination (r^2). Both metrics for the four models evaluated are presented in Table 2, which shows that the BDT and ANN performed significantly better than the multiple linear regression and RF models. The BDT and ANN models had very similar results, both an order of magnitude more accurate than multiple linear regression and RF. Because the BDT and ANN models performed better than multiple linear regression and RF, only those two are considered in the remaining discussion.

The predicted sulfur concentrations for the BDT and ANN are presented with the raw sulfur concentrations in Figure 2,

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Table 2. Model Results

Model	MSE	r ²
Multiple Linear Regression	2.47	0.66
Random Forest	9.56	0.22
Boosted Decision Trees	0.46	0.93
Artificial Neural Network	0.43	0.93

which shows a graph of the kernel density distribution for the predictions and raw sulfur data for all 5,880 samples from the dataset. As can be seen, a good approximation for the raw sulfur distribution is generated by both models, except for the lower range of sulfur concentrations (less than 0.1 wt. %), where both models underperformed. Figure 2 illustrates that the BDT model does a slightly better job at predicting low sulfur concentrations than the ANN model.

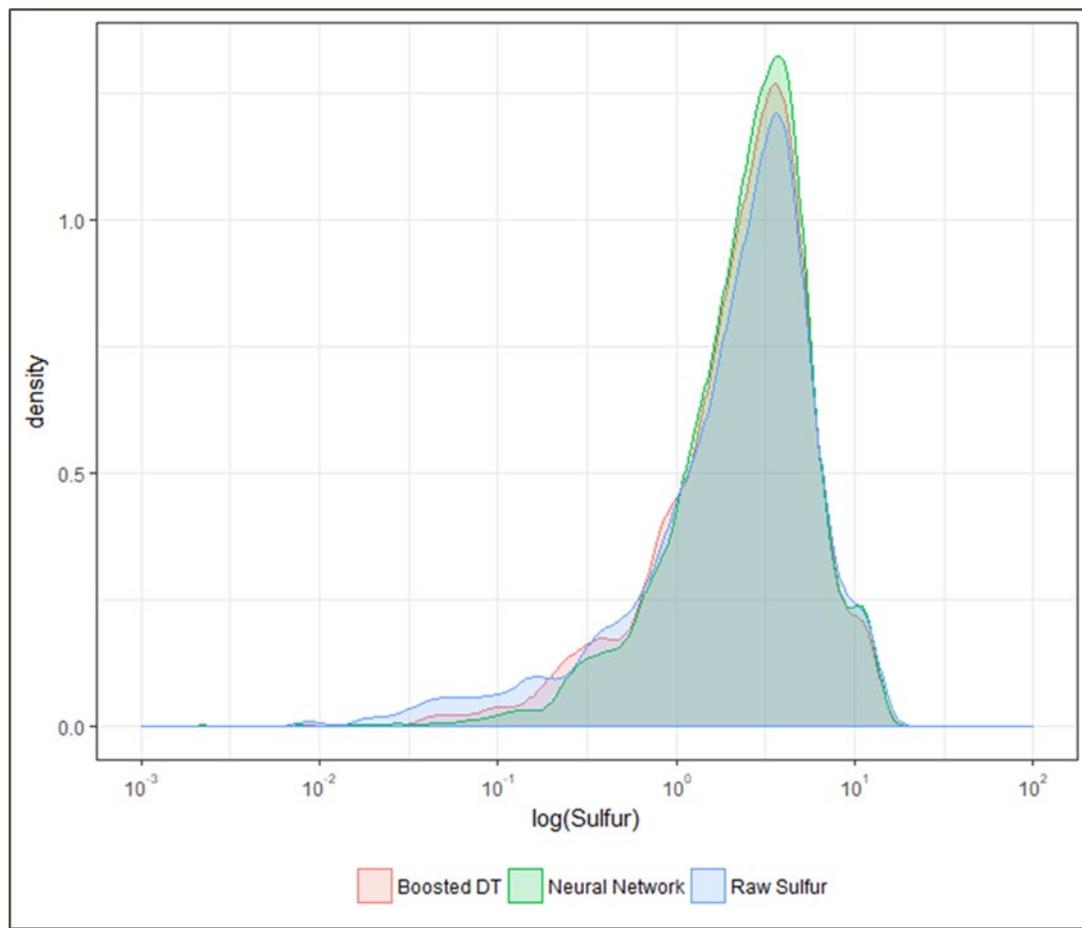


Figure 2. Distribution of predicted and raw sulfur concentrations.

The variable importance results for the top 10 ranked elements (out of 48 available) are summarized in Table 3 for the BDT and ANN models. The variables are ranked by their normalized effect on model accuracy. The top 10 elements for the BDT model are predominantly siderophile and chalcophile elements commonly associated with sulfide minerals (with Al and Na the only two exceptions). The highest ranked elements for the ANN model are more varied including elements commonly associated with sulfides (Fe and Ti), but also elements associated with carbonates (Ca, Sr, Rb, and U), and other lithophiles like Cr.

DISCUSSION

The predictive accuracy (Table 2) and variable importance (Table 3) results confirm the viability of the approach. The BDT results, in particular, are intuitive as the bulk of the elements that are important in predicting sulfur concentrations are chalcophile metals that reside in pyrite and pyrrhotite. For both methods, Fe is by far most influential which is, again,

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Table 3. Variable importance rank for Boosted Decision Trees and Artificial Neural Networks

Ranking	Boosted Decision Trees		Artificial Neural Network	
	Element	Normalized Ranking	Element	Normalized Ranking
1	Fe	0.234	Fe	0.283
2	Cd	0.134	Sr	0.089
3	Zn	0.109	Th	0.069
4	Co	0.064	Ti	0.068
5	Ag	0.060	Tl	0.053
6	Cr	0.054	Cr	0.046
7	Al	0.051	Ca	0.030
8	Ni	0.034	Ba	0.030
9	Na	0.030	U	0.029
10	Se	0.025	Rb	0.026

intuitive given it is the primary component along with sulfur in primary sulfide minerals in Touro metasediments and metavolcanics. The success of the approach relies on the fact that multi-element mineral chemistry is ultimately governed by simple stoichiometric, crystallographic, and mass balance rules and is, therefore, predictable.

The fact that sulfur in this dataset is somewhat underestimated (~9% relative to Leco and Digiprep) due to incomplete digestion likely indicates that predictive accuracy would be even higher had metamorphosed pyrrhotite and pyrite been completely digested by the four-acid method. Prediction of sulfur concentrations in this dataset was intended as a proof-of-concept for the machine learning approach. Virtually all sulfur resides in two sulfide minerals of similar composition (e.g., pyrrhotite and pyrite). A simpler approach of re-analyzing sulfur for a subset of samples and using simpler regression methods based on sulfur alone was also tried and provided similar results. Hence it should be noted that a multivariate approach is not always merited when, in some cases, simpler approaches will suffice. However, in cases where parameters are distributed across multiple mineral groups (e.g., calcium in carbonates, feldspars etc.) the multivariate approach generally proves superior. The success of the approach is also dependent on sample number and geologic context. Some datasets are insufficiently small for a multivariate approach. Additionally, some datasets reflect geologic systems where parameters are distributed more randomly than others (e.g., disseminated vs. stratabound ore); such datasets will require more samples to achieve sufficiently high predictive accuracy.

Finally, multi-element geochemistry can be used to predict many other things using the machine learning approach. For example, the authors and others have used the approach successfully to predict lithology, alteration, material density, long-term environmental behavior, ore grade, metallurgical characteristics, ore vectors, and more.

ACKNOWLEDGMENTS

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Notes from the Editor

Welcome to the fourth and final **EXPLORE** issue of 2021. This issue features an article describing the use of machine learning to assess whether (corrected) sulfur values can be predicted from the other assay parameters in a dataset. It was written by Tom Meuzelaar, Morgan Warren, Alice Alex, and Pablo Núñez Fernández.

EXPLORE thanks all those who contributed to the writing and/or editing of the four issues in 2021, listed in alphabetical order: Alice Alex, Steve Amor, Dennis Arne, Al Arsenault, Geoffrey Batt, Nigel Brand, Christabel Brand, John Carranza, Tony Chukwu, Steve Cook, David Crook, Theo Davies, Pablo Núñez Fernández, Bob Garrett, Stuart Kerr, David Leng, Dave Lentz, Tom Meuzelaar, Paul Morris, David Murphy, S. Obiora, Naomi Potter, Jessey Rice, Sophie Sciarrone, Dave Smith, and Morgan Warren.

EXPLORE gratefully acknowledges our advertizers for their financial support in 2021. Below is the team that has provided readers with four excellent issues this year. We wish all AAG members and other readers of **EXPLORE** a successful year in 2022.

Beth McClenaghan, Editor
 Steve Cook, Business Manager
 Steve Amor, Calendar of Events
 Al Arsenault, New members list, email circulation, AAG business office
 John Carranza, *Elements* content
 Dennis Arne, President's Letter
 Dave Smith, AGM Minutes, Council Elections, and other AAG business
 David Leng, Editing assistance
 Richard Dyer, Editing assistance
 Jessey Rice, Editing assistance
 Yulia Uvarova, **EXPLORE** master article listing
 Vivian Heggie, Page layout, hard copy mailing
 Tom Meuzelaar, Liaison with AAG website

Beth McClenaghan
 Editor

Steve Cook,
 Business Manager

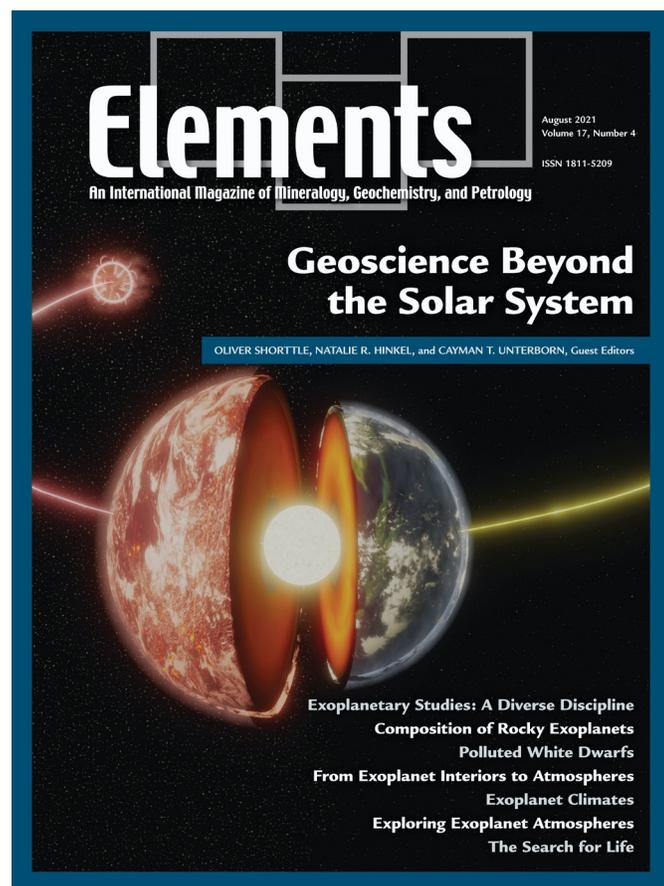
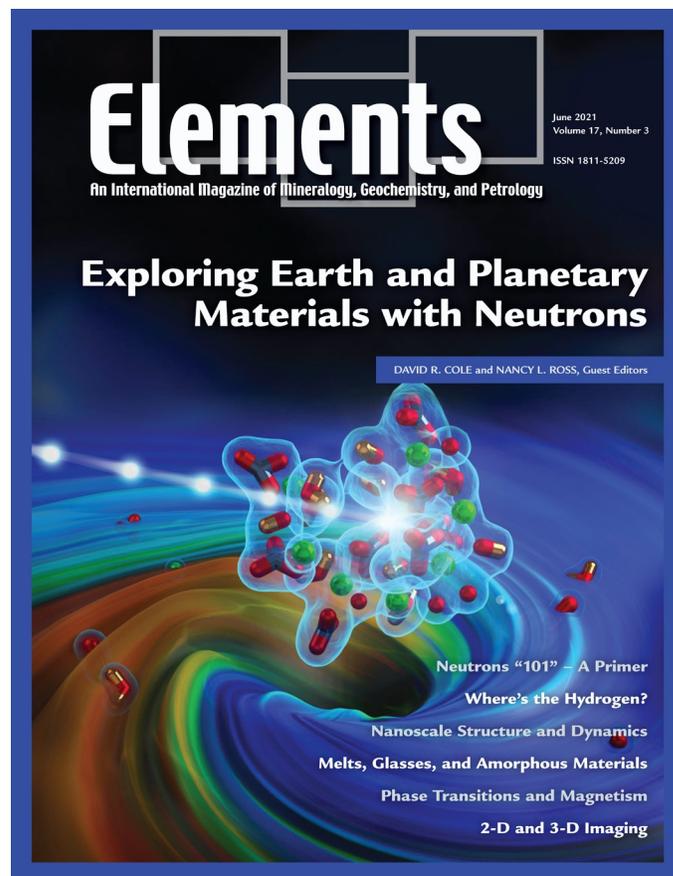


Recently Published in Elements

June 2021, volume 17, no. 3, Exploring Earth and Planetary Materials with Neutrons

The articles in this issue explain to the readers the basic concepts of neutron scattering, the methods that are accessible to Earth scientists, offer a summary of facilities worldwide, and present key applications of neutron scattering.

There are two AAG news items in this issue. First, message from AAG President Dennis Arne, which also appeared in issue 190 (March 2021) of the **EXPLORE** newsletter. Second, obituary for Ed Dronseika (1953 – 2021), which also appeared in issue 191 (June 2021) of the **EXPLORE** newsletter.



August 2021, volume 17, no. 4, Geosciences Beyond the Solar System

The articles in this issue underscore the countless prospects exoplanets represent for examining fundamental geological processes and the prospects for the geosciences to further this exciting young field.

There are two AAG news items in this issue. The first presents brief biographies of the AAG Councillors for 2021 – 2022; these also appeared in issue 190 (March 2021) of the **EXPLORE** newsletter. The second is an abstract of an article that appeared in issue 189 (December 2020) of the **EXPLORE** newsletter, namely “Measurement of seasonal variations in stream water chemistry using a portable photometer: case histories from central and southwestern British Columbia, Canada” by Ron Yehia, David R. Heberlein, and Ray E. Lett.

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

John Carranza



Association of Applied Geochemists Silver Medal Award for 2021 -



Dr. Paul Morris

The Association of Applied Geochemists **Silver Medal** is awarded for dedicated service to the Association, to those individuals who voluntarily devote extraordinary time and energy to advancing the affairs of the AAG. For 2021, the Association is pleased to announce that the Silver Medal is awarded to Dr. Paul Morris, recently retired Chief Geochemist of the Geological Survey of Western Australia (GSWA).

Paul completed his B.Sc. (Hon) in geology at the University of Otago, New Zealand, in 1976, and his PhD at the Victoria University of Wellington in 1981. He held various teaching positions at the University of Sydney and Shimane University in Japan, and in 1987 joined the Geological Survey of Western Australia, becoming Chief Geochemist in 1997. He retired in 2018 after a 30-year career at the GSWA, including 22 years as Chief Geochemist.

The award of the Silver Medal to Paul honours his long-standing and continuing service to the Association, on the Executive, on no less than six Association committees, and through many other AAG activities over the course of his long and distinguished career. He served as President during 2010-2011, served five terms as an Ordinary Councillor, and notably was co-Chair of the very successful 2005 Perth IAGS. He has been a tireless contributor to the AAG's journals over the years and has reviewed numerous technical articles in the EXPLORE newsletter. His committee service has been marked by a record of thoughtful evaluation and improvements. He is a most worthy recipient of the 2021 Silver Medal.

This is the first award of the Silver Medal since 2016. More information on this and other awards of the Association is available on the AAG website at <https://www.appliedgeochemists.org/association/awards>. Formal presentation of the Medal to Dr. Paul Morris will take place at the 29th International Applied Geochemistry Symposium (IAGS) in Chile in October 2022.

Stephen Cook

AAG Past President,
Chair, Awards & Medals Committee





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Association of Applied Geochemists Cameron-Hall Copper Medal Award for 2020 -

Dr. David Cooke



The AAG is pleased to announce that the **Cameron-Hall Copper Medal** for 2020 is awarded to Dr. David Cooke, Director of the Centre for Ore Deposit and Earth Sciences (CODES), University of Tasmania, for his paper which appeared in GEEA volume 20 (p. 176-188):

“Recent advances in the application of mineral chemistry to exploration for porphyry copper–gold–molybdenum deposits: detecting the geochemical fingerprints and footprints of hypogene mineralization and alteration” by David R. Cooke, Paul Agnew, Pete Hollings, Michael Baker, Zhaoshan Chang, Jamie J. Wilkinson, Ayesha Ahmed, Noel C. White, Lejun Zhang, Jennifer Thompson, J. Bruce Gemmill, Leonid Danyushevsky and Huayong Chen.

David Cooke completed his PhD at Monash University in Melbourne, Australia in 1991. He joined the faculty of the University of Tasmania and since 1998 has led numerous team-based industry-funded research projects. He has been CODES Director since 2017.

The Cameron-Hall Copper Medal is the newest medal of the AAG, first awarded last year for the year 2019. The Association

annually awards the medal to the lead author of the most outstanding scientific publication in our journal *Geochemistry: Exploration, Environment, Analysis* (GEEA). It is named in honour of two prominent and highly published AAG members and past editors of GEEA, Eion Cameron and Gwendy Hall. Both are the only AAG Gold and Silver Medal awardees since the Association was formed over 50 years ago. Selection of the winning paper is highly competitive. The GEEA Editorial Board first recommends 4 nominees from those papers published during the year. The members of the AAG Awards & Medals Committee vote on the list of recommendations, and their selection must then be approved by a majority vote of the AAG Council. More information is available on the AAG website <https://www.appliedgeochemists.org/association/awards>

Formal presentation of the Cameron-Hall Copper Medal to Dr. Cooke will take place at the 29th International Applied Geochemistry Symposium (IAGS) in Chile in October 2022.

Stephen Cook

AAG Past President

Chair, Awards & Medals Committee



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Institute of Sciences
Varanasi, Uttar Pradesh
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NIGERIA 400102
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Mr. Brahim Vall Isselmou
Geochemist, ANARPAM
Zone Administrative Nouakchott-Ksar
BP 654, Nouakchott
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Fellows

Fellows are voting members of the Association and are actively engaged in the field of applied geochemistry. They are Regular AAG Members that are nominated to be a Fellow by a Fellow of the Association by completing the Nominating Sponsor's Form. Consider becoming a Fellow of the AAG. Download the form here:
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Dr. Jamil Sader
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Vancouver, BC, V6N 2G6
CANADA
Membership No. 3774



Recently published by the Geological Survey of Canada

Bleeker, W. and Houlié, M.G. (ed.). 2020. Targeted Geoscience Initiative 5: Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems - Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions. Geological Survey of Canada, Open File 8722, 225 p. <https://doi.org/10.4095/326702>

Mercier-Langevin, P., Lawley, C.J.M., and Castonguay, S. (ed.). 2020. Targeted Geoscience Initiative 5: Contributions to the understanding of Canadian gold systems. Geological Survey of Canada, Open File 8712, 328 p. <https://doi.org/10.4095/323661>



Geochemistry: Exploration, Environment, Analysis Volume 21, Number 4 November 2021

Geochemical exploration for buried sandstone-hosted uranium mineralization using mobile U and Pb isotopes: case study of the REB deposit, Great Divide Basin, Wyoming

[M. Z. Abzalov](#)

Geochemistry: Exploration, Environment, Analysis October 25, 2021, Vol.21, geochem2021-043. doi:<https://doi.org/10.1144/geochem2021-043>

Geochemistry and environmental effects of rare-earth elements in laterites from Yunnan province, SW China

[Bin Liang](#); [Guilin Han](#); [Jie Zeng](#); [Rui Qu](#); [Man Liu](#); [Jinke Liu](#)

Geochemistry: Exploration, Environment, Analysis October 26, 2021, Vol.21, geochem2021-039. doi:<https://doi.org/10.1144/geochem2021-039>

Synthesis of a Fe/Ca-based phosphate material and its application for adsorption of uranium ions from aqueous solution

[Haiyan Liu](#); [Weimin Zhang](#); [Jingyi Mo](#); [Zhen Wang](#); [Jiahong Chen](#); [Junhua Chen](#); [Zhen Zhuo](#)

Geochemistry: Exploration, Environment, Analysis October 26, 2021, Vol.21, geochem2021-052. doi:<https://doi.org/10.1144/geochem2021-052>

Thematic collection: Hydrochemistry related to exploration and environmental issues

Lead, zinc and arsenic contamination of pit lake waters in the Zeida abandoned mine (High Moulouya, Morocco)

[Lamiae El Alaoui](#); [Abdelilah Dekayir](#); [Mohammed Rouai](#); [El Mehdi Benyassine](#)

Geochemistry: Exploration, Environment, Analysis September 22, 2021, Vol.21, geochem2021-009. doi:<https://doi.org/10.1144/geochem2021-009>

Hydrogeochemical characteristics and geothermometry of hot springs in the Altai region, Mongolia

[Bolormaa Chimeddorj](#); [Dolgormaa Munkhbat](#); [Battushig Altanbaatar](#); [Oyuntsetseg Dolgorjav](#); [Bolormaa Oyuntsetseg](#)

Geochemistry: Exploration, Environment, Analysis October 25, 2021, Vol.21, geochem2021-016. doi:<https://doi.org/10.1144/geochem2021-016>

Geochemistry of natural acid rock drainage in the Mt Evans area, Anaconda–Pintler Range, Montana, USA

[C. H. Gammons](#); [M. F. Doolittle](#); [K. A. Eastman](#); [S. R. Poulson](#)

Geochemistry: Exploration, Environment, Analysis November 12, 2021, Vol.21, geochem2021-068. doi:<https://doi.org/10.1144/geochem2021-068>





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.

The status of the meetings was confirmed on November 12th 2021, but further changes are likely, and users of the listing are strongly advised to carry out their own research as to the validity of an announcement.

Please let us know of your events by sending details to:
Steve Amor, Email: steve.amor2007@gmail.com
or

Tom Meuzelaar, AAG Webmaster, tom@lifecyclegeo.com

2022

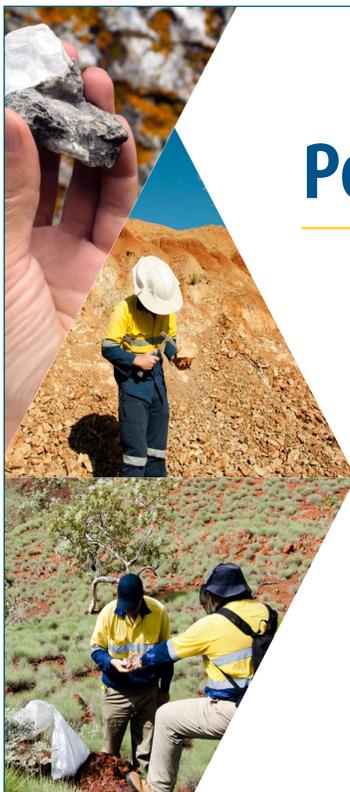
Virtual Meetings

- 27 FEBRUARY – 4 MARCH Ocean Sciences Meeting. Website: www.aslo.org/osm2022
- 28-31 MARCH 15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Website: tinyurl.com/ykkf5wx8
- 19-21 JULY William Smith Virtual Meeting 2021: Geological Mapping - of our world and others. Website: tinyurl.com/4k576cns
- 24-29 JULY 15th International Conference on Mercury as a Global Pollutant. Website: tinyurl.com/2ch7e6fa
- 27-29 APRIL International Conference on Geographical Information Systems Theory, Applications and Management. Website: www.gistam.org

In-Person or Hybrid Meetings (status as of November 12th 2021)

- 16-22 JANUARY Winter Conference on Plasma Spectrochemistry. Tucson AZ USA. Website: icpinformation.org/winter-conference
- 31 JANUARY - 3 FEBRUARY Mineral Exploration Roundup 2022. Website: roundup.amebc.ca
- 11-12 FEBRUARY Atlantic Geoscience Society Annual Colloquium. Fredericton NB Canada. Website: tinyurl.com/x693e56h
- 7-11 MARCH Prospectors and Developers Association of Canada Annual Convention. Website: www.pdac.ca/convention/programming

continued on page 17



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pXRF-34	Portable XRF scan of an unmineralised pulverised sample. Ranges:				
	Si 0.5%-47%	Ti 0.1%-60%	Zr 5ppm-5%		

*pXRF methods available as an add-on to multi-element analysis only.



CALENDAR OF EVENTS... *continued from page 16*

- 22-23 MARCH International Mining Geology Conference 2022. Brisbane QLD Australia. Website: tinyurl.com/sk4uc
- 30 APRIL-1 MAY Biogeochemical Processes Across Space and Time (Gordon Research Conference). Castelldefels Spain. Website: tinyurl.com/bnknc845
- 1-4 MAY CIM Convention. Vancouver BC Canada. Website: convention.cim.org
- 2-5 MAY Geological Society of Nevada 2022 Symposium. Sparks NV USA. Website: www.gsnsymposium.org
- 15-18 MAY GAC/MAC Annual Meeting. Halifax NS Canada. Website: tinyurl.com/349h4fp3
- 22-27 MAY Geochemistry of Mineral Deposits (Gordon Research Conference). Castelldefels Spain. Website: tinyurl.com/yxtyprqc
- 23-25 MAY 16th International Congress of the Geological Society of Greece. Patras Greece. Website: gsg2022.gr
- 31 MAY-2 JUNE 10th World Conference on Sampling and Blending. Kristiansand Norway. Website: wcsb10.com
- 6-9 JUNE 12th International Conference on Environmental Catalysis. Awaji Japan. Website: catsj.jp/event/6373
- 27-29 JUNE Australasian Environmental Isotope Conference. Ballina NSW Australia. Website: www.conferences.com.au/2022aeic
- 7 JULY Target 2022: Innovating now for our future. Perth WA Australia. Website: www.aig.org.au/events/target-2022
- 10-15 JULY Goldschmidt 2022. Honolulu HI USA. Website: tinyurl.com/3p95at6w
- 11-14 JULY 9th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology
- 13-16 JULY Euroscience Open Forum 2022. Leiden Netherlands. Website: www.esof.eu
- 18-22 JULY 23rd General Meeting of the International Mineralogical Association. Lyon France. Website: www.ima2022.fr
- 30-31 JULY Organic Geochemistry (Gordon Research Seminar). Holderness NH USA. Website: tinyurl.com/sywd9ma
- 31 JULY-5 AUGUST World Congress of Soil Science 2022. Glasgow UK. Website: www.soils.org.uk/wcss2022
- 3-5 AUGUST 12th International Conference on Environmental Pollution and Remediation. Prague Czech Republic. Website: icepr.org



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continued on page 19



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)

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



CALENDAR OF EVENTS... *continued from page 17*

- 6-12 AUGUST Geoanalysis 2022. Freiberg Germany. Website: geoanalysis2021.de/en
- 14-18 AUGUST 6th IAGOD Quadrennial Symposium. Dublin Ireland. Website: www.iagod.org/node/116
- 14-19 AUGUST Biominalization (Gordon Research Conference). Castelldefels Spain. Website: tinyurl.com/5865ckbt
- 22-26 AUGUST International Sedimentological Congress. Beijing China. Website: www.isc2022.org.cn/En
- 23-26 AUGUST International Symposium on Environmental Geochemistry. Moscow Russia. Website: iseg2022.org
- 27-30 AUGUST SEG 2022 Conference. Denver CO USA. Website: tinyurl.com/3e4yfms2
- 11-15 SEPTEMBER IWA World Water Congress & Exhibition. Copenhagen Denmark. Website: worldwatercongress.org
- 12-16 SEPTEMBER 10th International Conference of the International Association of Geomorphologists. Coimbra Portugal. Website: www.icg2022.eu
- 13-15 SEPTEMBER 14th International Symposium on Nuclear and Environmental Radiochemical Analysis. York UK. Website: tinyurl.com/4mw4n924
- 9-12 OCTOBER GSA 2022 Annual Meeting. Denver CO USA. Website: tinyurl.com/fuyh2t3z
- 16-22 OCTOBER 29th International Applied Geochemistry Symposium (IAGS). Viña del Mar Chile. Website: iags2021.cl

2023

- 29 JANUARY-3 FEBRUARY Winter Conference on Plasma Spectrochemistry. Ljubljana Slovenia. Website: ewcps2021.si
- 25-27 JULY 6th International Archean Symposium. Perth WA Australia. Website: 6ias.org



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AAG Student Paper Prize

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