

The Log Transformation Explained

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INTRODUCTION

Numerous papers have been written on the logarithmic distribution of trace elements and ore metals over the years. One of the first was Razumovsky (1940), followed some years later by the influential work of Ahrens, typified by his 1954 paper (Ahrens 1954). Vistelius (1960) argued that lognormal distributions came about naturally on physical grounds due to the processes of rock formation. Similar physical processes, involving repetitively splitting a volume of material into portions containing increased or decreased elemental concentrations, have been studied by DeWijis (1951), Brinck (1976) and Garrett (1986). This process leads to logbinomial distributions. Limpert *et al.* (2001) demonstrated how a similar process leads to the lognormal distributions so common in the physical sciences.

The reality of applied geochemistry is that data are derived from surficial and bedrock environments that are, more often than not, complex and field data sets are rarely symmetrically distributed. The data, as observed, are drawn from the various populations and geochemical processes present in the survey or study area. They do not exhibit 'bell-shaped' distributions and are frequently polymodal. They can be 'tortured' towards normality with tools like the Box-Cox power transform (e.g. Howarth and Earle 1979), of which a logarithmic transform is a special case. Furthermore, such transforms may obscure polymodality that conveys useful information. Alternately, a power transformation that expands the data to a range with maximum spread and/or contrast to provide an improved visualization, may be employed for map presentations and distributional displays (Stanley 2005).

BACKGROUNDS AND THRESHOLDS

In applied and exploration geochemical surveys, the range of background values must be established for each of the diverse surficial and bedrock environments present. The threshold can be defined as the upper limit of background variation (Reimann and Garrett 2005). These geochemical parameters are best estimated through appropriate orientation surveys and inspection of the data using maps, histograms (Hawkes and Webb 1962), and probability plots (Lepeltier 1969; Sinclair 1976).

If the former did not lead to the choice of a geochemically justified threshold, Hawkes and Webb (1962) proposed that threshold values could be estimated as the mean of the background data plus two standard deviations (SD). An estimate that would, assuming normality, identify the value below which 98% of background data should fall. In any subsequent survey using similar procedures in a geologically and geochemically similar area, applying that threshold would identify 2% of the data for further investigation. These, hopefully, would include any samples related to non-background processes and mineral occurrences of interest. Whether or not this approach is appropriate, and how it should be accomplished, has been the topic of numerous papers, for example, Matschullat *et al.* (2000), Reimann and Filzmoser (2000) and Reimann *et al.* (2005). Methods not requiring normality, non-parametric methods, may be employed. However, even then normality lurks in the background: the median replaces the mean; however, underlying the calculation of the Median Absolute Deviation (MAD), the equivalent of the standard deviation, lies a factor based on the normal distribution. Recently, procedures to unmix complex geochemical data sets have been investigated (e.g. Eschenfelder *et al.* 2023), however, some are based on the assumption of normality (e.g. Lucero-Álvarez *et al.* 2021).

This is further complicated by the fact that geochemical data are compositional, i.e., they sum to a constant, and therefore, as some values increase, others must decrease. The impact of this and the necessity for compositional data analysis procedures have been discussed by Barceló *et al.* (1996), Mateus-Figueras *et al.* (2005) and Buccianti *et al.* (2006), among others.

BACK TO FIRST PRINCIPLES

Statistical estimates of the background range and threshold are based on an assumption of underlying normality. "Normality assumes that the continuous variables to be used are normally distributed. Normal distributions are symmetric around the center (a.k.a. the mean) and follow a 'bell-shaped' distribution" (Statistics Solutions 2013). This begs the question, what is a continuous variable? "A continuous variable is one which can take on an uncountable set of values. For example, a variable over a non-empty range of the real numbers is continuous, if it can take on any value in that range" (Wikipedia 2019a). So, what is a real number? "A real number is a value of a continuous quantity that can represent a distance along a line. The adjective real in this context was introduced in the 17th century by René Descartes, who distinguished between real and imaginary roots of polynomials. The real numbers include all the rational numbers, such as the integer -5, the fraction 4/3, and all the irrational numbers, such as $\sqrt{2}$ " (Wikipedia 2019b).

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Notes from the Editor

Welcome to the second EXPLORE issue of 2023. This issue features an article describing the use of log transformations and was written by Bob Garrett. EXPLORE thanks all those who contributed to the writing and/or editing of this issue including: Elizabeth Ambrose, Steve Amor, Dennis Arne, Al Arseneault, John Carranza, Patrice de Caritat, Bob Garrett, David Leng, Jessey Rice, and Cliff Stanley.

For more than 33 years, the EXPLORE page layout, printing and hard copy mailing has been carried out by Vivian Heggie. We thank Vivian for her dedication to this task, her patience with our numerous last-minute changes during page layout, and her professional page layout and graphic design services. This issue is the last that Vivian will help out with as Elizabeth Ambrose takes over responsibilities for page layout and design for this and future EXPLORE issues.

Beth McClenaghan
Editor

Steve Cook,
Business Manager



TABLE OF CONTENTS

The Log Transformation Explained	1
Notes from the Editor	3
President's Report	4
PDAC 2023 Student-Industry Mineral Exploration Workshop	14
Articles in Past Issues of EXPLORE	14
AAG Gold Medal 2022	15
Welcome New AAG Members	16
Geochemistry: Exploration Environment Analysis	16
Recently Published in Elements	17
Calendar of Events	17

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President's Report

Greetings and Peace to you all! I hope 2023 is moving along well for all of you. As you all may or may not be aware, Australia is an honoured bidder to host the 30th International Applied Geochemical Symposium (IAGS) in 2024. Their initial proposal was discussed during in the last AAG Council meeting in March. Their 10-member Local Organizing Committee (LOC) is led by Dr Anna Petts from the Geological Survey of South Australia and our Vice-President Yulia Uvarova. The AAG Council was given comments/suggestions for the LOC to address. We have received their revised proposal, which will be discussed soon and hopefully a final decision will be made by either the AAG Executive or the AAG Council on or before the AAG Council meeting in June.

Nominations for 2023 AAG awards are open. Significant contributions to applied geochemistry or service to AAG are recognized by award of either the AAG Gold or Past Presidents' (Silver) medals, respectively. The history of how the AAG medals came about and the guidelines for their awarding are explained in the April 1992 issue of EXPLORE on the AAG website: <https://www.appliedgeochemists.org/explore-newsletter/explore-issues>

Guidelines for nominating individuals for either medal are posted in 'The Association' section of the AAG website (www.appliedgeochemists.org) under the 'Awards' area: <https://www.appliedgeochemists.org/association/awards>

Nominations can be submitted any time to Dennis Arne (arne.dennis@gmail.com; Past President, Awards & Medals Committee Chair) and will be considered in the year following nomination provided they are received prior to December 1.

As our Members and Fellows may or may not be aware, AAG's Student Support Initiative (SSI) provides in-kind analytical support to applied geochemistry students. The SSI aims to identify applied geochemistry students worthy of support and put them in touch with participating analytical laboratories who will consider providing geochemical analysis either free of charge or at a reduced rate. We have confirmation of continued support for the SSI from LabWest and ALS laboratories. You can check your student's or your eligibility for this support at our webpage: <https://www.appliedgeochemists.org/students/student-support-initiative>

There is a new addition in Table 2 of our Geochemical Atlases webpage (<https://www.appliedgeochemists.org/resources/geochemical-atlases>), the Geochemical Soil Atlas of the Netherlands. I would like to thank Dr Jasper Griffioen (TNO (The Netherlands Organisation for Applied Scientific Research) Geological Survey Netherlands) for letting us publish this geochemical atlas of their country on our AAG website. In this geochemical atlas, the sample medium is soil at 0–20 cm below surface and 100–120 cm below surface. When a lithological change was observed between 80–130 cm below surface, a sample was collected at 30–10 cm above this change where the minimum depth should be 50–70 cm below surface. A site was not sampled at all when this minimum depth could not be reached. In total, 358 sites were sampled over 26,000 km², which gives a sampling density of 1 site per 72.6 km². This area has agricultural or natural land use and comprises 76% of the terrestrial surface of the Netherlands. Urban areas and areas with pre-Quaternary sediments at or very near the surface were discarded. Five substrates were distinguished based on soil type and sampling was random within these substrata: peat, sand, fluvial clay, marine clay, and loess. This particular geochemical atlas would be useful for interpreting geochemical anomalies as well as for identifying local pollution to support land planning or risk management.

I wish everyone the best for the next few months – hopefully a busy and fruitful field season for all.

John Carranza
President





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ANALYTICAL CHEMICAL DATA

Analytical data meet the criteria for being continuous and real. However, they are measured on what McCue (2007) defines as 'ratio scales' that are "numeric and are associated with a true zero – meaning that nothing can be measured. For example, weight is a ratio scale". Furthermore, Mosteller and Tukey (1977) define 'counted fractions' as scales that are bounded by zero and one. Thus 'weight per weight' analytical geochemical data expressed, e.g. in mg/kg, are measured on 'ratio scales' and are 'counted fractions'; they are constrained to vary between zero and 100%, 10^6 mg/kg, etc., and are bounded.

Thus, data at the extremes, close to zero or the maximum of the ratio scale, can be positively (right) or negatively (left) skewed, respectively, as their possible values cannot fall below zero or exceed the scale maximum. In the central part of the range, the spread of the data may be unconstrained by the bounds and behave like a normal distribution, i.e., following a 'bell-shaped' distribution. Therefore, if parametric statistical procedures are to be applied to the data approaching the scale minima and maxima, they need to be transformed towards normality. Referring specifically to 'Proportions and Percentages', Deacon (2020) offers three procedures:

1. Convert to arcsine values (see Holland 2017);
2. A logarithmic transformation; and
3. Converting to probits.

Wilson *et al.* (2010) and Warton and Hui (2011) report that the arcsine transformation is losing popularity, despite its use in the geosciences (Miller and Kahn 1962; Krumbein and Graybill 1965; Holland 2017). If the data are drawn from an underlying Poisson distribution, which is uncommon in geochemistry, the arcsine transform will induce homoscedasticity, i.e. equal spread across the range of the data, a desirable statistical property (Stanley pers. comm. 2023). The logarithmic transform only works for the lower part of the ratio scale as demonstrated below. Converting to probits, though it does cover the full range with reference to the normal distribution, it is more suitable for instances where the values are zero or one and therefore not continuous; it will not be discussed further.

LOGITS AND THE LOG TRANSFORM

The reality is that analytical data are measured on ratio scales and are counted fractions. What is required is a transform that breaks the bounds of counted fractions and permits values to occupy the complete range of real numbers, i.e. $-\infty$ to $+\infty$. Such a transform is the logit (Berkson 1944; Holland 2017; Wikipedia 2020), the log of the odds for some probability p .

$$\text{logit}(p) = \log\left(\frac{p}{1-p}\right)$$

As a mechanism by which to transform a zero-to-one counted fraction, or any concentration that can be rendered zero-to-one through division by the scale maximum, to a real number, the logit transformation suffices. It matters not whether a Napierian logarithm to the base e , or a logarithm to the base 10 is employed; here the former is applied.

The relationship of the logit to the zero-to-one proportion scale is shown in Figure 1 (left). When the proportion is plotted with logarithmic scaling (Fig. 1, right) the relationship between logit and $\log(\text{base } 10)$ proportion appears to be linear between low proportions and 0.1 (i.e. 10%). The estimated linear (Pearson) correlation coefficient is >0.9999 between proportions equivalent to $1 \mu\text{g/kg}$ (ppb) and 10%. Clearly, there is an operational equivalency between the logit of a proportion, counted fraction, or concentration and its logarithm up to concentrations of 10%.

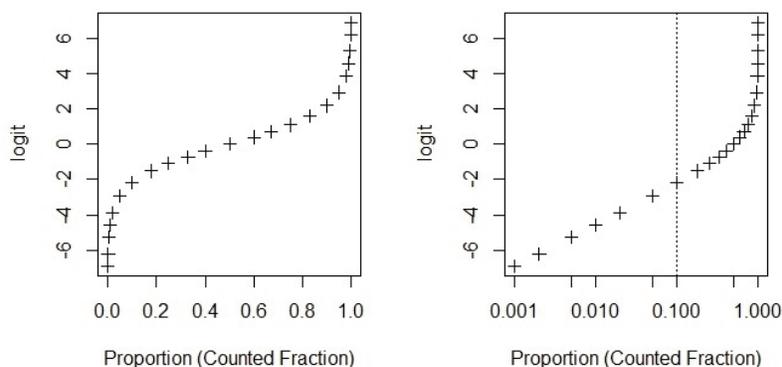


Fig. 1. The logit function versus proportion (left), with logarithmic scaling (right).

LOGIT APPLIED TO GEOCHEMICAL DATA

From Figure 1 (left) the logit transformation should be effective for reducing skewness across all concentrations, i.e., for both distributions exhibiting negative skews as they approach the scale maxima, and positive skews as they approach scale minima. In both instances, the logit transformation releases the data from their bounding restrictions. The silica data in Figure 2 range from 59 to 95% and a negative skew is apparent. The application of a logit transformation (Fig. 2, right) opens the data as it approaches 100% and leads to a more symmetric (normal) distribution.



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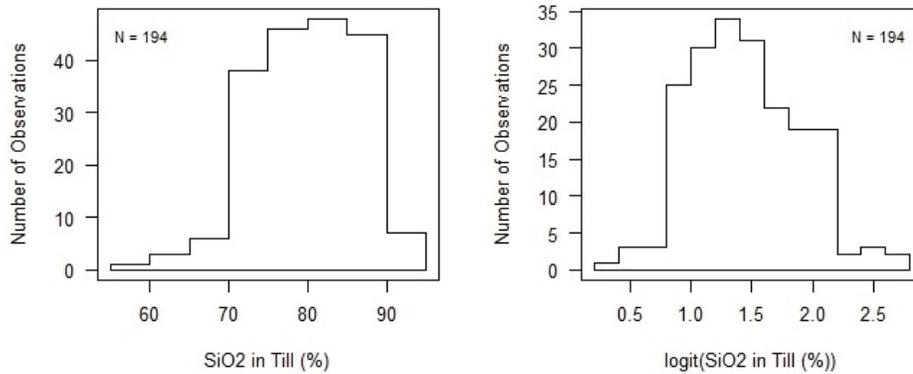


Fig. 2. Silica concentration (SiO_2 , Li-metaborate fusion) in $<63 \mu\text{m}$ till (left), and with a logit transformation (right).

The applicability of the logit transform across a wide range of concentrations is demonstrated with a set of soil organic carbon data ranging from 0.5 to 77% (Fig. 3, left) exhibiting extreme positive skew.

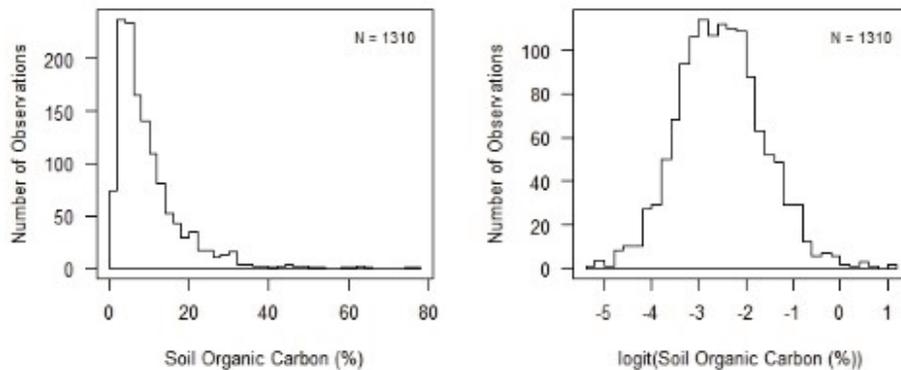


Fig. 3. Organic carbon concentration (Loss-on-Ignition) in $<2 \text{ mm}$ soil (left), and with a logit transformation (right).

The logit transform effectively removes the positive skew and leads to a symmetric, more normal, distribution suitable for the application of parametric (normality-based) statistical methods.

An example of an extreme positive skew across almost three orders of magnitude, with data ranging from 0.2 to 96 mg/kg, familiar in trace element studies, is shown in Figure 4 (left). Again, the logit transform is effective in leading to a more symmetric distribution (Fig. 4, right), although still with outliers due to contamination from an anthropogenic sources in the study area.

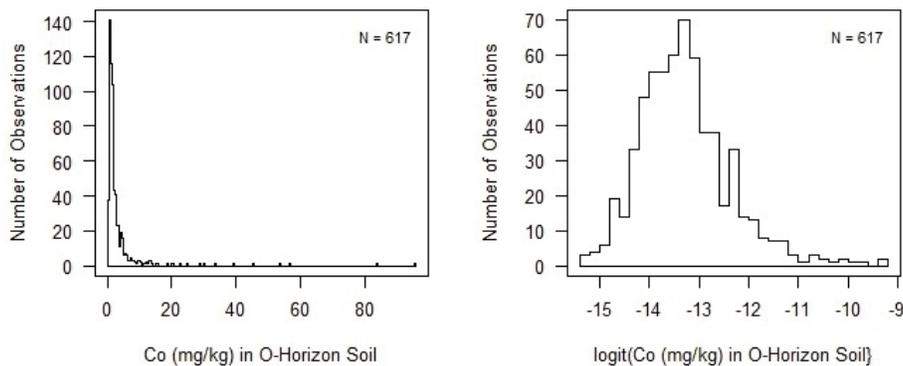


Fig. 4. Cobalt concentration (HNO_3 digestion) in $<2 \text{ mm}$ O-horizon soil (left), and with a logit transformation (right).

As demonstrated in Figure 1 (right) at levels below 10% (100,000 mg/kg) the logarithmic and logit transforms are equivalent. Figure 5 provides a visual comparison with the Co data exhibited in Figure 4, where plotting Co concentrations with logarithmic scaling is equivalent to logit transforming the data.

In multivariate data analysis, full compositional data analysis procedures, i.e. log-ratios, are required. However, bivariate displays fall between univariate and multivariate and may benefit from logarithmic scaling. If the data span more than one-and-a-half to two orders of magnitude, they probably display a lack of homogeneity of variance. This feature, also known as heteroscedasticity, is visually expressed by the data points spreading out in an increasingly broader 'fan'



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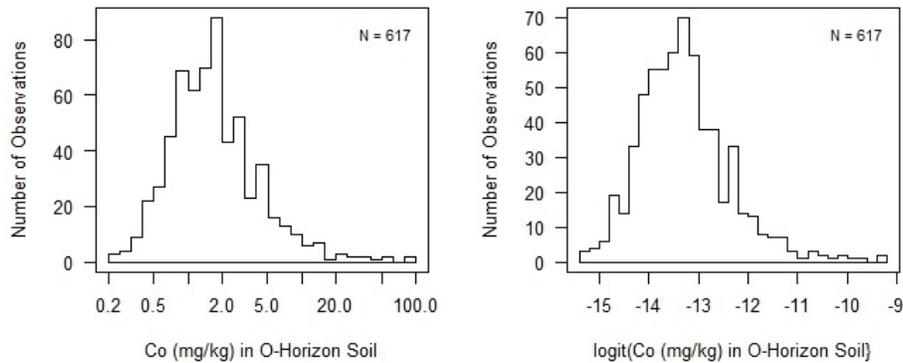


Fig. 5. Histograms for cobalt concentration (HNO_3 digestion) in <2 mm O-horizon soil, with logarithmic (left) and logit (right) transformations.

with increasing concentration when plotted on the original scale (Fig. 6, left). Plotting geochemical data with logarithmic scaling provides a quick graphical check for heteroscedasticity. If it is present, the data plot as a band of equal spread with increasing concentration, see Figure 6 (right). A statistical assumption of regression-line (Ordinary Least Squares) fitting is that across the range of the data the variances, or spreads, of the data are independent of concentrations, i.e. they do not 'fan out'.

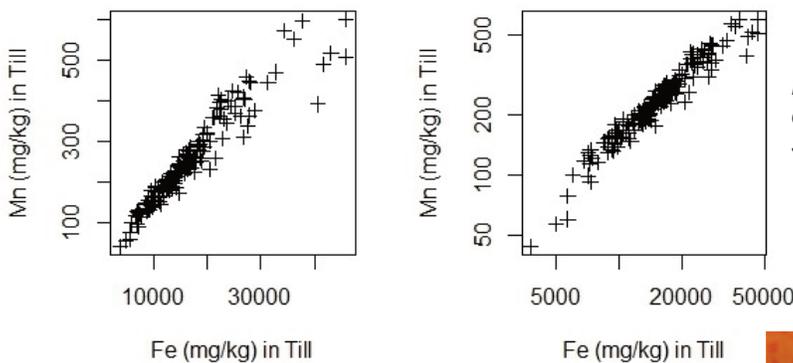


Fig. 6. Plots of manganese vs. iron concentrations (four-acid digestion) in <63 μm till, without (left) and with logarithmic scaling (right).

The procedure applied by statisticians in undertaking analyses based on squared differences, e.g. regression modeling and Analysis of Variance, is to logarithmically transform the data (Bartlett 1947; Weissberg 1980, and others).

However, Figure 6 does not tell the whole story, as the Fe and Mn, as well as being counted fractions individually, are members of an even larger 'counted fraction', the overall chemical composition of the sample.

The solution to this problem is the use of log-ratios (see, for example, Aitchison 1984 and Pawlowsky-Glahn *et al.* 2015). The simplest approach is to use an arithmetic log-ratio, dividing the elements by another member of the composition and taking the logarithm, or simply plotting the ratios with log-scaling, as is familiar in petrochemical studies (see Pearce 1968). Again, taking the logarithm of a ratio turns it into a real number. Figure 7 (left) displays the same Fe and Mn data as ratios to Al, a major component in the overall composition, plotted with logarithmic scaling. The relatively 'tight' band in Figure 6 (right) has been broadened as a result of the recognition that the data are compositional; as some components (parts) increase others must decrease. The data do not 'fan out' and homogeneity of variance is maintained, though the spread has increased due to taking account of at least one of the other elements in the composition.

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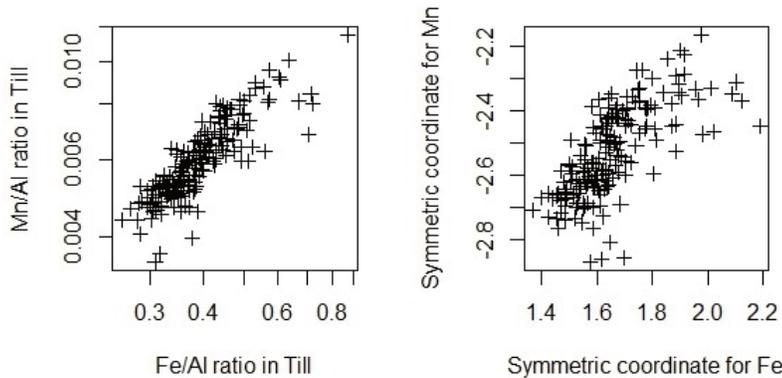


Fig. 7. Iron and manganese concentrations for $<63 \mu\text{m}$ till, plotted as a log-ratios to aluminum (left), and as symmetric coordinates in the context of all available major and minor components (right). All data after a four-acid digestion.

The use of symmetric coordinates (Garrett *et al.* 2017; Kynčlová *et al.* 2017), a complex log-ratio, allows all the major and minor element concentrations to be included. The concentration data for Figures 6 and 7 were determined following a four-acid (HF-HClO₄-HNO₃-HCl) near-total digestion, Si was not determined. The major and minor elements included in the calculations of symmetric coordinates were Al, Ca, Mg, Na, K, Fe, Mn, Ti, Cr and P. The result of including the nine major and minor elements beyond Al is displayed in Figure 7 (right). Homogeneity of variance has been maintained, but the spread (uncertainty in the inter-element relationship) has been further increased as a result of taking the almost-complete suite of major and minor elements into account.

DISCUSSION

It has been shown that logarithmic distributions can come about due to rock-forming processes. Furthermore, the very nature of analytical data as counted fractions, i.e. relative data, requires a transformation to better visualize their distributions and is necessary if statistical procedures that assume normality are to be employed. For example, if there is no prior

knowledge of the threshold for an exploration program, or it cannot be derived by graphical inspection or analysis, an option is to select some percentile of the data (e.g. 98th percentile) or employ statistical estimation. The nature of trace element geochemical data requires a transformation. Without transformation, estimates for the upper limits of the background values (i.e. thresholds), by median+2*MAD, or mean+2*SD, may exceed the upper bound of the data; alternatively, a lower bound of less than zero may be estimated. These thresholds are impossible and their presence is a reminder of the need for a transformation. Trace element data visualization benefits from logarithmic scaling: simple calculations should be undertaken following a logarithmic transform, and the results back-transformed to the original scaling. An advantage of visualization with logarithmic scaling is that differences are appreciated as ratios, conforming to the way applied geochemists consider their data, i.e. levels are twice, or half, etc., some other value, not as absolute arithmetic differences.

At higher concentrations, especially when approaching scale maxima, visualizations may benefit from a logit transformation (e.g. Figs. 2 and 3). In the mid ranges, it may not be necessary to undertake any transformation. Webster and Oliver (1990) state that for the arcsine transformation, “When the observed values fall in the range 30–70 percent, there is very little to be gained by the transformation, and it is unlikely that there will be much gain when only a small proportion of the observations fall outside this range”. This statement applies equally to the logit transformation. Prudent investigators will study their data visually and determine if a lack of symmetry or homogeneity of variance requires a data transformation before proceeding further.

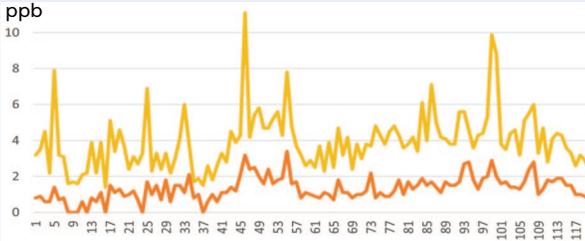
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The Log Transformation Explained *continued from page 10*

centred and isometric log-ratios) are required to reveal true inter-element relationships independent of closure. For bivariate relationships the arithmetic log-ratio transformation, as discussed above, is sufficient. A common thread in all these procedures is that a logarithmic transformation is used to turn a zero lower bounded ratio into a real number.

With the availability of machine learning methods and other advanced or non-parametric methods, data transformations to reduce skewness in data prior to analysis may not be necessary. However, for many visualization tasks, a transformation will assist geochemists in their interpretational tasks.

CONCLUSIONS

Geochemical data are not real numbers in mathematical terms, they are counted fractions lying between bounds, and they can neither fall below, nor rise above, those bounds. To convert the counted fractions to real numbers suitable for statistical analysis, a logit transformation is sufficient. At concentrations below 10%, logit and logarithmic transformations are equivalent. Thus, when trace element data are plotted with logarithmic scaling the values become real, the positive skew is reduced, and the data appear to be more symmetrical and normally distributed. Furthermore, many of the geological processes controlling the distribution of elements in nature are multiplicative, leading to logbinomial or lognormal distributions.

The logarithmic transformation is relevant and useful for two reasons. Firstly, it effectively converts trace element geochemical counted fractions to real numbers and improves data visualization by 'decompression' at low concentrations. Secondly, if the assumptions that underlie parametric statistical methods, the estimation of means, variances (standard deviations), and other procedures that are based on squared differences, are to be met, the data should approach normality and variances need to be independent of concentration, i.e. homoscedastic. A logarithmic transformation of trace element data meets both these requirements.

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NOTE

All calculations and plot preparation was undertaken with R 3.4.3 (R-Project 2020) and package 'rgr' version 1.1.16 (Garrett 2013).

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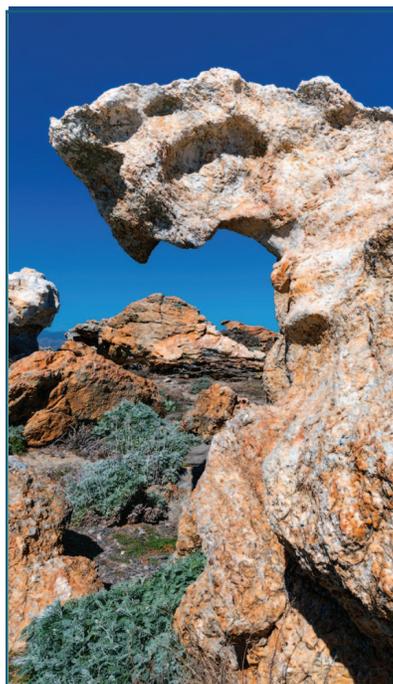
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continued on page 13



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Method	Analyte	Detection Level (ppm)
sodium peroxide fusion	Li	2
	B*	8
	Cs	0.1
	Dy	0.03
	Ho	0.01
	Nb	0.8
	Ta	0.04

*a selection of analytes reported by ME-MS89L™.
Boron can only be reported as an add-on to ME-MS89L™.

The Log Transformation Explained *continued from page 12*

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EXPLORE Publication Schedule

Quarterly newsletters are published in March, June, September, December

- **Deadlines** for submission of articles or advertisements:

March newsletter: January 15

June newsletter: April 15

September newsletter: July 15

December newsletter: October 15

- **Manuscripts** should be double-spaced and submitted in digital format using Microsoft® WORD. Articles should be between 2000 and 3000 words. Do **not** embed figures or tables in the text file.
- **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.
- **Tables** should be submitted as separate digital files in Microsoft® EXCEL format.
- All scientific/technical articles will be reviewed. 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.

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

Beth McClenaghan

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Ottawa, ON, CANADA K1A 0E8

Email: bethmcclenaghan@sympatico.ca

PDAC 2023 Student-Industry Mineral Exploration Workshop

In an effort to attract more students into the mineral exploration industry, the Prospectors & Developers Association of Canada (PDAC) ran its 14th annual Student-Industry Mineral Exploration Workshop (S-IMEW) on May 4–16, 2023 in Sudbury and the surrounding region. Students from 22 post-secondary geoscience institutions (universities and colleges) were selected from across Canada to participate this year. Students attended lectures, presentations, and hands-on activities covering exploration techniques, bedrock mapping, mineral deposits geology, geophysics, and geochemistry, and environmental, health and safety, and social responsibility issues. A field trip to Kirkland Lake was included in the workshop, allowing students from across the country to see what this world-class mining region has to offer.

Among the highlights of the workshop was 'Geochemistry Day', organized and taught by Beth McClenaghan and Chris Beckett-Brown of the Geological Survey of Canada, and Grant Hagedorn, Marcus Burnham, and Riley Mulligan of the Ontario Geological Survey. They introduced students to exploration geochemical techniques through hands-on experiences that they are unlikely to be exposed to at university or college. The students experienced the microscopic world of indicator minerals, learned how to collect till samples and determine glacial transport directions, and toured the OGS' Geoscience Laboratories. A new activity added this year was a competitive exploration exercise in which teams interpreted regional geochemical data and designed follow-up drill programs to discover mineralization.

S-IMEW Geochemical Team



The organizers of "Geochemistry Day 2023" at the evening banquet. From left to right: Grant Hagedorn (Ontario Geological Survey), Beth McClenaghan (Geological Survey of Canada) and Chris Beckett-Brown (on his last day with the Geological Survey of Canada, and now with the Ontario Geological Survey).



Students looked at heavy mineral concentrates with microscopes to learn about indicator minerals.



Grant Hagedorn, from the Ontario Geological Survey, explained to the students how to collect a till sample and how to determine glacial transport directions from striated bedrock.

Articles in Past Issues of EXPLORE

5 years ago EXPLORE 179 (June 2018)

Catchment analysis of re-analyzed regional stream sediment geochemical data from the Yukon

10 years ago EXPLORE 159 (June 2013)

Determination of micro and nanoparticulate fraction gold in regolith

20 years ago EXPLORE 120 (July 2003)

- i) Effective 3-D modelling solutions have a lot to offer*
- ii) 3-D vectoring and data integration*

30 years ago EXPLORE 80 (July 1993)

The diagnostic capabilities of selective leaching

<https://www.appliedgeochemists.org/explore-newsletter/explore-issues>

AAG Gold Medal 2022

Robert G. Garrett

Dr. Robert (Bob) G. Garrett has been awarded the Association of Applied Geochemists' (AAG) Gold Medal for 2022 for his outstanding scientific achievements in exploration and environmental geochemistry. Bob will receive the medal at a small ceremony in Ottawa in June.

Bob has an extensive publication record spanning more than 50 years that includes 38 years as a Research Scientist and 17 years as an Emeritus Scientist (still active) at the Geological Survey of Canada (GSC). His research and resulting publications cover a wide range of topics including the design of regional geochemical surveys, management of geochemical data, geochemistry of organic lake sediments, drainage geochemistry, metals in the environment, and the influence of geology on agricultural soils and crops. Over the course of his career, he has authored or co-authored over 150 published papers, articles, and government reports, some 30 Open File reports, and 15 National Geochemical Reconnaissance data releases (1975–1977).

Bob's extensive scientific achievements include the following:

- Founding member of the GSC team that designed and implemented Canada's National Geochemical Reconnaissance (NGR) program in 1975 - whereby systematic regional geochemical surveys were conducted across Canada in support of mineral resource assessments. This program established the first national guidelines for sampling, analysis, and interpretation of regional geochemical data and went on to collect samples at more than 300,000 sites. Benefits are still being realized from the original work, and the program continues in a modified form today.
- Bob led important investigations and developments of statistical and mathematical methods for the interpretation of regional geochemical data and their application to mineral exploration. He was one of the very first to recognize early on the importance and power of EDA (exploratory data analysis) for data analysis in geochemistry. He created the IDEAS program library in the 1980s, and more recently, wrote the 'RGR' package as part of the R Open Source statistical computing and graphics package to provide easy access to many powerful data analysis techniques and to assist applied geochemists in interpreting their data. He has written extensively on this subject, including co-authoring a textbook on statistical data analysis and two chapters in the Statistics and Data Analysis in Geochemical Prospecting volume of the Association's Handbook of Exploration Geochemistry series.
- His knowledge of field sampling methods, data management and processing contributed to a benchmark publication "A global geochemical database for environmental and resource management", which was the foundation for the Global Geochemical Baselines IUGS Workgroup (now Commission).
- His regional-scale till and soil studies in the Canadian Prairies and collaborations with soil and agricultural scientists in Canada and the United States led to a new understanding of the phytoavailability of trace elements and their accumulation in food grains, demonstrating the influence of geology on the chemistry of agricultural soils and crops.
- Bob's participation in Canadian International Development Agency exploration geochemistry projects in Brazil (1977–79), Malaysia (1985–86), and Jamaica (1984–93) guided the development and implementation of successful regional geochemistry programs to support resource assessments in these countries.
- Bob made important contributions at a higher level to numerous national and international committees and working groups focused on research about, and regulatory aspects of, metals in the environment, heavy metals and the North America Free Trade Agreement, and toxic substances management and research.

Bob has been a member of the Association of Applied Geochemists since its founding in 1970. Since then, his commitment to the Association and its goals to advance the science of applied geochemistry has been demonstrated by his numerous presentations at several IAGS Symposia and other conferences, and his many scientific contributions to the Association's journal GEEA and newsletter EXPLORE and his continued service on the editorial board of both. He has also served as a reviewer for other prestigious journals such as Science of the Total Environment, Applied Geochemistry, Environmental Science & Technology, and Journal of Geochemical Exploration.

In summary, Bob has made lengthy and outstanding scientific contributions to applied geochemistry over his 50+ year career, most of which he spent guiding applied geochemical research at the GSC. He has greatly contributed to applied geochemistry through his numerous scientific journal papers, government publications, and book chapters, most notably in the development and application of statistical and mathematical methods to the interpretation of regional and exploration geochemical data.



Dennis Arne

Chair, AAG Awards and Medal Committee



Welcome New AAG Members

Regular Members

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

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Ayodeji Olorunyomi
University of Lagos, Nigeria
Akoka Yaba, Lagos State
NIGERIA
Member no. 4511



Geochemistry: Exploration, Environment, Analysis

Volume 23, Issue 1, February 2023

Litho-geochemistry in exploration for intrusion-hosted magmatic Ni–Cu–Co deposits

Stephen J. Barnes,
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<https://doi.org/10.1144/geochem2022-025>

Distribution and attribute analysis of soil selenium in Hebei Province, China

Liting Zhang et al.
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<https://doi.org/10.1144/geochem2022-055>

On the use of laser-induced breakdown spectroscopy data for mineralogical investigations – constraints and application of a clustering method

Fontana F. Fernando et al.
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<https://doi.org/10.1144/geochem2023-003>

Thematic collection: Applications of innovations in geochemical data analysis

Introduction to the thematic collection: applications of innovations in geochemical data analysis

Wenlei Wang et al.
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<http://dx.doi.org/10.1144/geochem2022-058>

Thematic collection: Continental-scale geochemical mapping

Introduction to the thematic collection: a review of continental-scale geochemical mapping projects in Australia, Europe, and the conterminous United States

David B. Smith et al.
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<https://doi.org/10.1144/geochem2022-058>

Thematic collection: Geochemical processes related to mined, milled, or natural metal deposits

Thallium isotopes as indicators of ore mineralization at the Zn-rich sediment-hosted massive sulfide TL Deposit, British Columbia, Canada

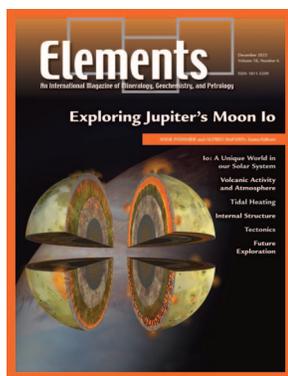
Derek R. Knaack et al.
Geochemistry: Exploration, Environment, Analysis
(2023), 23 (1)
<https://doi.org/10.1144/geochem2022-042>



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Don Cummings, PhD, PGeo
cummings1000@gmail.com / 819-213-4714 /
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Recently Published in Elements



December 2022, volume 18, no. 5 Exploring Jupiter's Moon Io

The articles in this issue review existing knowledge of Jupiter's Moon Io, highlighting its composition, interior dynamics, and surface processes. Perspectives for future missions to Io are given as well. There is one AAG news item in this ELEMENTS issue, namely the obituary for John Somerville Tooms (1927–2021) written by Richard J. Howarth.

February 2023, volume 19, no. 1, Alkaline Lakes

The articles in this issue explore the distinctive settings controlling the formation of alkaline lakes, the unique dynamic microbial ecosystems that live in them, their characteristic chemistry and mineralogy, their function as societally valuable economic resources, and their potential to have originated life on Earth as well as Mars. The guest editors hope that these overviews will bring

about the critical import of alkaline lakes to the broad readership of Elements and incite continual probes of these fascinating geological systems.

The AAG news items in this Elements issue are abstracts for the following articles: (1) "Lithium Analysis of Brines and Minerals for Exploration and Resource Definition" by Hugh de Souza, Alexander Seyfarth, Nicholas Turner, John Woods, and SGS Natural Resources (in issue 194 (March 2022) of the EXPLORE newsletter); (2) "Whole-rock geochemistry for intrusion-hosted magmatic Ni-Cu-Co exploration: identifying prospective host rocks" by Steve Barnes (in issue 195 (June 2022) of the EXPLORE newsletter); and (3) "New Era of Geochemical Survey in the Kingdom of Saudi Arabia" by Mazen B. Balkheyour, Ibrahim Osman Abdella, and Christopher C. Johnson (in issue 197 (December 2022) of the EXPLORE newsletter).

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

John Carranza
President




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 May 17, 2023, but 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

Elizabeth Ambrose, Email: eambrose0048@rogers.com

2023

- | | |
|------------|--|
| 18–23 June | Catchment Science: Interactions of Hydrology, Biology and Geochemistry (Gordon Research Conference). Andover NH USA. Website: tinyurl.com/3ep4uf2e |
| 18–23 June | Interior of the Earth (Gordon Research Conference). South Hadley MA USA. Website: tinyurl.com/7jf7wkvt |
| 19–22 June | SIAM Conference on Mathematical & Computational Issues in the Geosciences. Bergen Norway. Website: tinyurl.com/4eesycan |
| 26–27 June | International Workshop on the Characterisation and Quantification of Lithium. Paris France. Website: cqlmns.sciencesconf.org |
| 2–6 July | 38 th International Conference on Geochemistry and Health. Athens Greece. Website: segh.net/welcome-to-segh-2023 |
| 3–7 July | 2023 International Platinum Symposium. Cardiff UK. Website: tinyurl.com/2wcshfeh |
| 9–14 July | Goldschmidt 2023. Lyon France. Website: tinyurl.com/32zcw7es |
| 10–13 July | 10 th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology |
| 14–20 July | 21 st INQUA Conference. Rome Italy. Website: inquareoma2023.org |

continued on page 18



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

- 15–17 July 2023 6th International Workshop on Environment and Geoscience. Kunming China. Website: www.iwegconf.org
- 16–21 July 2023 Chemical Oceanography (Gordon Research Conference): Chemical Tracers in the Sea. Manchester NH USA. Website: tinyurl.com/mu7ybfz6
- 23–27 July 2023 Microscopy and Microanalysis 2023. Minneapolis MN USA. Website: www.microscopy.org/MandM/2023
- 25–27 July 2023 6th International Archean Symposium. Perth WA Australia. Website: 6ias.org
- 28 July 2023 Target 2023: Innovating now for our future. Perth WA Australia. Website: www.aig.org.au/events/target-2023
- 30 July – 4 August Atmospheric Chemistry Gordon Research Conference. Newry ME USA. Website: tinyurl.com/4jsfuvnb
- 5–12 August 22nd Annual Conference of the International Association for Mathematical Geosciences. Trondheim Norway. Website: www.iamgconferences.org/iamg2023
- 9–11 August 13th International Conference on Environmental Pollution and Remediation. London UK. Website: icepr.org
- 12–18 August 5th International Symposium on Environmental Geochemistry. Galway Ireland. Website: www.nuigalway.ie/iseh-iceph
- 18–22 August Water-Rock Interaction WRI-17/ Applied Isotope Geochemistry AIG-14. Myago Japan. Website: www.wri17.com
- 26–29 August SEG 2023 Conference: Resourcing the Green Transition. London, England. Website: tinyurl.com/2p8b7mue
- 28 August – 1 September 8th World Multidisciplinary Earth Sciences Symposium. Prague Czech Republic. Website: mess-earth.org
- 28 August – 1 September 17th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Zurich Switzerland. Website: sga2023.ch
- 28 August – 1 September 17th International Symposium on Biomineralization. St. Etienne France. Website: www.biomin2023.com/en
- 10–15 September International Meeting on Organic Geochemistry. Montpellier France. Website: imogconference.org
- 10–15 September 10th Hutton Symposium on Granites and Related Rocks. Baveno Italy. Website: hutton10.eu
- 11–15 September IWA World Water Congress & Exhibition 2023. Beijing China. Website: www.worldwatercongress.com
- 26–29 September 29th Colloquium of African Geology. Windhoek Namibia. Website: tinyurl.com/2s4hpydx



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continued from page 18

2–5 October	5th Euro-Mediterranean Conference for Environmental Integration. Rende Italy. Website: tinyurl.com/4776md4f
4–6 October	Mongolia Mining 2023. Ulaanbaatar Mongolia. Website: mongolia-mining.com
15–18 October 22–27 October	GSA Connects 2023. Pittsburgh PA USA. Website: community.geosociety.org/gsa2023 2nd Joint Symposium of the International Societies for Environmental Biogeochemistry & Subsurface Microbiology. Banff AB Canada. Website: iseb-issm2023.org
31 October – 2 November	14th Fennoscandian Exploration and Mining conference. Levi Finland. Website: femconference.fi
26 November – 1 December 27–30 November	XVI Congreso Geológico Chileno (Chilean Geological Congress). Santiago Chile. Website: congresogeologicochileno.cl/en Mediterranean Geosciences Union Annual Meeting. Istanbul Turkey. Website: medgu.org
28 November – 1 December	28th International Mining Congress and Exhibition of Turkey (IMCET 2023). Belek Turkey. Website: tinyurl.com/4z2cvzy8
4–8 December	American Exploration and Mining Association Annual Meeting. Sparks NV USA. Website: www.miningamerica.org/annualmeeting

2024

14–19 January	Gordon Research Conference: Geobiology: Past, Present and Future. Galveston TX USA. Website: www.grc.org/geobiology-conference/2024
14–19 January	Gordon Research Conference: Geobiology: Past, Present and Future. Galveston TX USA. Website: www.grc.org/geobiology-conference/2024
3–6 March	Prospectors & Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/convention
18–21 March	XV Latin American Symposium on Environmental Analytical Chemistry. Ouro Preto Brazil. Website: tinyurl.com/3v76363s
21–23 May	11th World Conference on Sampling and Blending. Muldersdrift South Africa. Website: tinyurl.com/ycx9psc8
23–28 June	Geochemistry of Mineral Deposits (Gordon Research Conference). Newry ME USA. Website: tinyurl.com/bddja374
8–12 July	12th International Kimberlite Conference. Yellowknife NT Canada. Website: 12ikc.ca
21–26 July	International Conference on Mercury as a Global Pollutant. Cape Town South Africa. Website: tinyurl.com/mw37tdh4
11–15 August	IWA World Water Congress & Exhibition. Toronto ON Canada. Website: worldwatercongress.org
18–23 August	4th European Mineralogical Conference. Dublin Ireland. Website: emc-2024.org
24–30 August	35th International Geographical Congress. Dublin Ireland. Website: igc2024dublin.org
25–31 August	37th International Geological Congress. Busan, Republic of Korea. Website: www.igc2024korea.org
15–19 September	Geoanalysis 2024. Wuhan China. Website: tinyurl.com/yeyj8nuh
6 March	Prospectors & Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/convention
18–21 March	XV Latin American Symposium on Environmental Analytical Chemistry. Ouro Preto Brazil. Website: tinyurl.com/3v76363s
21–23 May	11th World Conference on Sampling and Blending. Muldersdrift South Africa. Website: tinyurl.com/ycx9psc8

continued on page 20



CALENDAR OF EVENTS

continued from page 19

23–28 June	Geochemistry of Mineral Deposits (Gordon Research Conference). Newry ME USA. Website: tinyurl.com/bddja374
8–12 July	12 th International Kimberlite Conference. Yellowknife NT Canada. Website: 12ikc.ca
21–26 July	International Conference on Mercury as a Global Pollutant. Cape Town South Africa. Website: tinyurl.com/mw37tdh4
11–15 August	IWA World Water Congress & Exhibition. Toronto ON Canada. Website: worldwatercongress.org
18–23 August	4 th European Mineralogical Conference. Dublin Ireland. Website: emc-2024.org
24–30 August	35 th International Geographical Congress. Dublin Ireland. Website: igc2024dublin.org
25–31 August	37 th International Geological Congress. Busan, Republic of Korea. Website: www.igc2024korea.org
15–19 September	Geoanalysis 2024. Wuhan China. Website: tinyurl.com/yeyj8nuh



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