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Nature's Sentinels: Lichens as Biomonitors

A guide with case study and methodological insights

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INTRODUCTION

Lichens are cost-effective and powerful tools to evaluate atmospheric deposition. Lichens are symbionts of fungi and algae/cyanobacteria, having evolved unique traits to capture both wet and dry deposition for their use as nutrients (Bargagli and Mikhailova 2002; Nash 2008). These traits allow them to reach an equilibrium with their environment, forming a representative fingerprint of their inputs, either natural or anthropogenic (Loppi and Paoli 2015). This article covers deposition and how it influences lichen elemental concentrations, followed by an introduction to the workflow and important considerations from design, field, and laboratory work through to analysis. Salient points are illustrated with novel data from multiple experiments and a case study from Sudbury, Ontario, Canada. The goal is to tackle the leading barriers to wider adoption of biomonitoring: the lack of understanding surrounding the utility and methodology (Blett et al. 2003).

The key to the ability of lichen to reflect atmospheric deposition is their lack of roots (Sloof and Wolterbeek 1993). Without root uptake, lichens rely on atmospheric deposition to provide nutrients, having developed traits such as a lack of protective cuticles and porous surfaces to promote aerosol capture (Wolterbeek et al. 2003). As they accumulate nutrients, lichens also absorb significant levels of metals and potentially toxic elements (PTEs) (Bargagli et al. 2002). The slow growth rates, lack of seasonal senescence, and common abundance have led lichens to be exploited for various aims, serving as powerful screening tools to identify pollution sources, to describe spatial distributions from contamination sources, and to monitor air quality dynamics across hundreds of studies (Bargagli and Mikhailova 2002; Blett et al. 2003). Lichen studies can help in the identification of previously unrecognized sources of pollution, as well as environmental anomalies and "hot spots", which have, in some cases, been related to previously unknown bedrock mineralization (Richardson 1992; Purvis et al. 2013).

The Sudbury Transect study referenced throughout this article was conducted in Sudbury, Ontario, in central Canada, following a 130 km transect northward from the city limits to track deposition from the city's two active Ni-Cu smelter operations (Lakanen et al. *in prep.*). Four biomonitors (rock, soil, and tree lichen, and moss) were collected, together with snow and soil samples, at twenty-one sites in the fall and winter of 2022/2023 (Fig. 1). This work follows the path of a similar transect conducted fifty years earlier (Tomassini et al. 1976), but highlights the significant changes in deposition patterns following decreased smelter emissions to meet the changing Clean Air Regulations (Beckett 1995; SARA Group 2008).

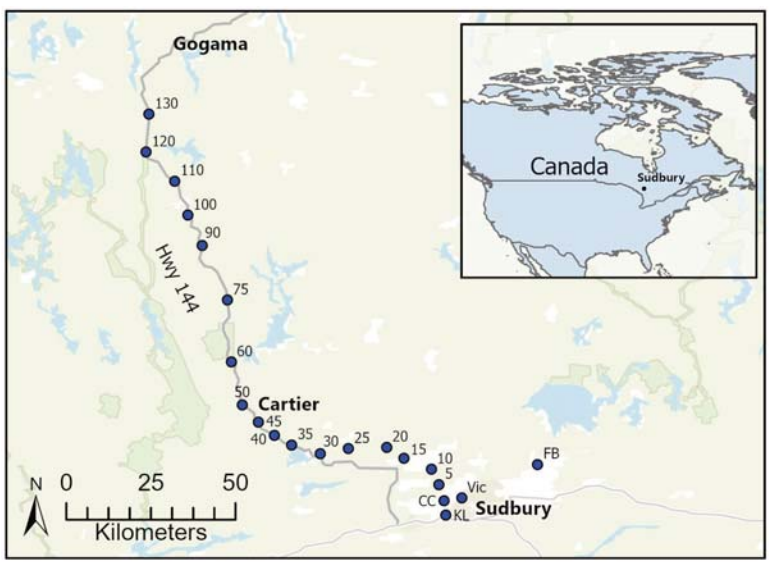

Fig. 1. *Location map for the Sudbury Transect, which includes 21 sites spanning 130 km in a northwest direction from Sudbury, Ontario, Canada. Sites are spaced at regular intervals as well as multiple sites (CC, KL, Vic, FB) near the two operational smelters (smelters are located at sites CC and FB). Numeric site codes represent the distance (in km) from Sudbury.*

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Note from the Editor

Welcome to the first EXPLORE issue of 2025. This issue features an article describing the use of lichens as biomonitors and includes a case study and methodological insights. It was written by M. Lakanen, J. Anderson, B. Halvorson, M. Brown, M. Charbonneau, F. Caron, P.J. Beckett, M. Leybourne, and G. Spiers. This issue is the first to include a DOI number as part of its publication. You can read more about this new DOI feature in this issue.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue, listed in alphabetical order: Elizabeth Ambrose, J. Anderson, M. Brown, P. de Caritat, F. Caron, J. Carranza, M. Charbonneau, S. Cook, P.J. Beckett, A. Demetriades, J. Graham, B. Halvorson, M. Lakanen, R. Lett, D. Leng, M. Leybourne, J. Rice, G. Spiers, Y. Uvarova, and E. Weiland.

Beth McClenaghan
Editor

Steve Cook,
Business Manager

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President's Message

Welcome to the first issue of EXPLORE in 2025, and welcome to our AAG Councillors for 2024–2025, Pedro Acosta-Góngora, Aaron Baensch, Ray Lett, Anna Petts, and Sam Scher. You can read about them later in this issue of EXPLORE. We are finalising a few new appointments to our Regional Councillors at the time of my writing this message, and I will communicate about those in the next EXPLORE issue. Lat year, AAG Council made a decision to refresh our Strategic Plan, and we now have two committees - Strategic Plan Revision and Website Review – working together on building a plan and a platform for promoting all things related to geochemistry and the Association, attracting new members, and helping to develop the next generation of geochemistry. They will be in touch with a request to fill out a short survey that will assist us set long-term, aspirational goals for the AAG, and I kindly ask you to take a moment and help the Committee with this task.

In our last Council meeting in 2024, we reviewed a proposed bid to host the next International Applied Geochemistry Symposium (the 31st IAGS) in Beijing, China, in 2026, with the lead applicants Professor Qiuming Cheng and the AAG VP Renguang Zuo. The bid was approved unanimously by the Council, and I am confident the LOC is already working hard on organising the event; stay tuned for more information!

Last year, we awarded 4 AAG medals (Gold, Silver, and two Cameron-Hall Copper) to celebrate advancements and achievements in geochemistry or recognise dedicated service to the Association. Please, think about who among your peers has done something great in the field of geochemistry or proactively supported the Association and submit a nomination or two! If you have any ideas in this regard, please get in touch with John Carranza, who is our Chair of the AAG's Awards and Medals Committee.

Wishing you a great year ahead, and I'm looking forward to working with you all!

Yulia Uvarova
President

CALL FOR AAG MEDAL NOMINATIONS

Significant contributions to applied geochemistry or service to AAG are recognised by award of either the AAG Gold or Past Presidents' (Silver) medals respectively. The history of how the medals came about and the formulation of guidelines for their award are discussed in the April 1992 issue of EXPLORE, issue 75, which can be found on the AAG website under Publications/EXPLORE newsletter/1990–1994.

Guidelines for nominating individuals for either medal are posted in 'The Association' section of the AAG website (www.appliedgeochemists.org) under the 'Awards' area. Past discussions of the guidelines indicated that the process for nominating individuals for either medal was a little cumbersome, to the extent that some nominations were not being made, and others took an unnecessarily long time to resolve. With this in mind, the 2012–2013 Awards & Medals Committee (Chair: Paul Morris. Committee members Eion Cameron, Pertti Sarala, and Chris Benn) revisited the guidelines to make the nomination process a little friendlier, with a more concise time frame for resolution. The revised guidelines for nominations are presented below.

3.0 NOMINATIONS

3.1 To be eligible for consideration for either award, nominations must be received by the Chairman of the Awards and Medals Committee on or before December 1st of any year.

3.2 For acceptance by the Awards and Medals Committee, nominations must be signed by a minimum of four (4) Fellows (voting members) of the Association in good standing.

Nominations should include the following:

(a) A one-page recommendation from each of the four nominators;

(b) A resume or curriculum vitae of the nominee;

(c) An itemized list of the outstanding scientific achievements (Gold Medal) or the dedicated service to the Association (Silver Medal) of the nominee (maximum two pages).

Since members of the Awards Committee may not have personal knowledge of the nominee, the completeness and quality of the nomination will be critical in terms of evaluation and selection.

Nominations for either medal can be made any time to ejmcarranza@gmail.com and will be considered in the year of the nomination provided they are received prior to December 1.

John Carranza
AAG Past President
Chair, Awards and Medals Committee

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AERIAL ELEMENTAL TRANSPORT AND ACCUMULATION BY LICHENS

Lichens can absorb elements from the environment by three mechanisms: particulate capture, extracellular binding, and intracellular uptake (Garty 2001). Particulate matter (PM) capture is commonly attributed as a major source of elements in lichen (Nieboer et al. 1978; Mamun et al. 2020). The commonly sampled size fractions of particulates, (i) fine (<2.5 μm) and (ii) coarse (>2.5 μm), have very different characteristics, elemental composition, and dispersal patterns (Mamun et al. 2020). Fine particulates are commonly generated from anthropogenic activities where combustion and heat volatilize elements that condense around nucleation points, producing particulates that are commonly high in PTEs like lead, arsenic, and cadmium (Graney et al. 2019; Mamun et al. 2020). Fine particulates can travel hundreds to thousands of kilometers and contribute to the global elemental background (Graney et al. 2019). In contrast, coarse PM is generally geogenic in origin, produced through erosion processes, and is high in lithophile elements such as iron, aluminum, and silicon (Mamun et al. 2020). Coarse PM's larger size leads to more heterogeneous dispersal patterns, being prone to more regionalized, much shorter distance travel and sedimentation processes active over minutes to hours (Garty 2000; U.S. EPA 2004). However, dispersal is highly dependent on weather patterns and emission characteristics (U.S. EPA 2004).

Different lichens may also have different capture rates depending on the particle size (Puckett 1988). Solutes captured by lichens are more bioavailable and represent a large portion of the total elemental concentration (Branquinho 2001). Exchange processes are passive, rapid, and highly effective but have been shown to saturate in high-deposition environments (Bargagli and Mikhailova 2002). Intracellular uptake is, in most cases, an active process that has been shown to occur for nutrients, metals, and anions, including phosphate, arsenate, and uranyl (uranium) (Bargagli and Mikhailova 2002). Toxic effects are generally related to this intracellular fraction of elements rather than total concentrations (Branquinho 2001). Complexation is thought to be an important method of toxicity avoidance, with various organic crystals within lichens containing chelated metals (Purvis et al. 1987).

The measured concentrations in lichens are a function of both accumulation and the release of captured elements (Nieboer et al. 1978). Particulates, resistant to washout from precipitation, have been observed deep within the medulla of the lichen (Fig. 2) and are expected to decompose over time by the action of organic acids, metal-complexing agents, and mechanical disintegration caused by wet/dry cycles (Nieboer et al. 1978; Garty et al. 1979). The retention rates of elements, although originally thought to reflect the age of the lichen (some lichens are thousands of years old), have been shown to range from two to seven years, depending on the element and its chemical form (LeRoy and Koksoy 1962; Nieboer et al. 1978; Richardson 1992). These relatively short time scales have been determined through comparisons of samples collected before and after the cessation of pollutant

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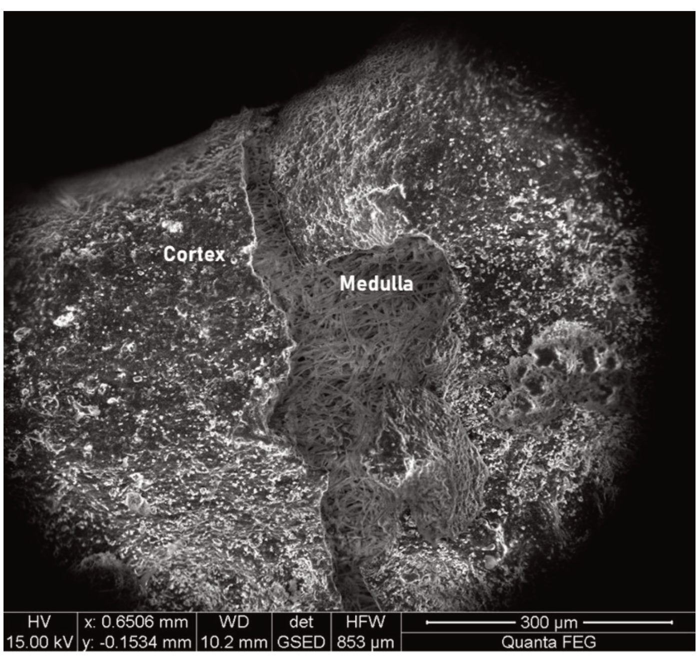

Fig. 2. *Secondary backscattered electron image of the surface (cortex) of* Evernia mesomorpha *with a crack showing the network of thread-like hyphae that make up the interior (medulla) where particulates have been shown to accumulate (photograph by M. Lakanen 2024).*

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sources, transplantation studies, and radiotracer experiments (Nieboer et al. 1978; Deruelle 1984; Walther et al. 1990).

The accumulation of elements from substrata is controversial. Rock-dwelling lichens are well known to slowly dissolve their substrate, and copper-organic crystals have been observed growing on lichens colonizing copper-bearing ores (Nieboer et al. 1978; Purvis et al. 1987). However, some studies suggest the substrate of lichens growing on less enriched rocks are not a significant source of elemental loads (Chiarenzelli et al. 1997). The observed correlation between lichen and substrate has been suggested to be from absorption from solubilized elements from the water interface during precipitation and/or collected particulates from the substrate itself (Richardson et al. 1980).

STUDY DESIGN: LICHEN SPECIES, QUANTITY AND QUALITY?

Several aspects need to be considered in the design of a lichen biomonitoring study. This section explores the impacts of study scale, the practical aspects influencing the selection of a suitable lichen species, and the need for standard operating procedures (SOPs) and replication.

Biomonitoring studies are generally structured as either linear transects extending from a source or an areal mapping survey across a study region. In either case, the key factor is matching sampling density to the suspected deposition gradient (Ferretti and Erhardt 2002). Sites should be selected strategically to meet financial, analytical and statistical constraints, and 'convenience sampling' should be avoided to reduce bias (Jackson et al. 1993).

A nested grid approach is commonly recommended to accurately describe gradients from a source, with increased sampling density nearer to the presumed source and fewer distal sites to quantify the 'local background' free of anthropogenic contamination (Ferretti and Erhardt 2002; Landis et al. 2019). The sampling distance and gradient can be informed by previous studies (e.g. the Sudbury Transect benefited from the data collected fifty years prior), or a preliminary/pilot study may be required. The number of background sites to be included should be sufficient to provide a reliable mean and standard deviation, as biomonitoring relies on a comparative approach. Due to the sensitivity of lichens to atmospheric deposition, it is vital to confirm that 'background sites' are representative of the region's natural environment and free from local anthropogenic sources such as power lines, highways, railways, road dust, agriculture, or historic soil contamination which may be resuspended by wind, animals, or foot traffic.

The selection of the lichen species determines where and how many specimens can be sampled. The local presence and distribution of the target species across the study region vitally impact site selection. Ideally, the target lichen is found at both the 'contaminated' sites and 'natural' sites. This can be difficult in practice, as the two environments can be very different ecological niches. For example, in the Sudbury Transect, the most proximal sites to the smelters only had *Stereocaulon*, which is tolerant and grows well on the eroded rocky terrain, but was difficult to find in the forested northern reaches of the transect. Figure 3 shows a large mat of *Stereocaulon* growing on an exposed cliff, a habitat we had to target to find northern specimens. Tolerance to pollution is an important consideration. In the field, the major contributors to the decline of lichen populations are gaseous pollutants (sulphur dioxide) and pH, with toxic effects of metals being rarer and typically involving zinc, copper, or lead

Fig. 3. *Photograph of the collection of* *Stereocaulon* *spp. samples growing in a dense mat on a rocky outcrop north of Sudbury, Ontario, Canada (photograph by J. Anderson 2022).*

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(Richardson 1992; Bargagli and Mikhailova 2002). Combining multiple/complimentary species can extend the range, however, it also increases the cost and labour of the study. Methods to compare across multiple species are available, such as the Bioaccumulation Scale, discussed in more detail in a later section (Cecconi et al. 2019b).

Other factors for determining the targeted lichen species include the field crew's ability to identify the correct species, analyte concentration in the organisms, minimizing influence from the soil/substrate (the reason epiphytes are typically targeted), and the ease of harvesting and processing (Will-Wolf et al. 2020). Ideally, a single foliose (leaf-like) or fruticose (coral-like) lichen species with a history of use as a biomonitor is selected. Examples include *Evernia mesomorpha*, *Hypogymnia physodes*, *Xanthoria parietina*, *Flavoparmelia caperata* (Bargagli and Nimis 2002; Will-Wolf et al. 2017). Figure 4 is a photograph of *Evernia mesomorpha*, the epiphyte targeted for comparison in the Sudbury Transect Study.

Consistency is key to producing valid and repeatable findings. A set of standard operating procedures (SOPs) must outline how each step of the field and laboratory work is performed to minimize systematic error (Taylor 1988). Biological samples are naturally variable, and replication is needed to describe this variance and determine real differences between conditions (Bourke et al. 1988). Replication also helps confirm, or provides a rationale to dismiss, data outliers such as unexpected spikes that could result from previously unrecognized sources or contamination from bird droppings or elsewhere. However, replicating all sites is costly, and the effort must be balanced against budgetary and time constraints. Although specific recommendations are limited, several large-scale surveys have replicated 10–15% of sites to allow estimation of intra-site/sampling variability (Will-Wolf et al. 2017; Landis et al. 2019).

SAMPLING: WHAT TO DO IN THE FIELD

The goal of sampling a site is to obtain a representative sample. The main challenge in achieving this goal is the different small-scale dynamics the lichens are exposed to. The goal of developing a sampling SOP is to minimize these artifacts and, when an appropriate sampling SOP is followed, consistent sampling is achieved regardless of expertise level (Jackson et al. 1993; Will-Wolf et al. 2017). One of the major sources of unrepresentative variance is differences in water exposure. This exposure can include flooding/pooling in low spots when collecting ground lichen or sampling tree lichen in the path of 'stemflow'— water enriched with scavenged elements transported down from the canopy (Bargagli and Mikhailova 2002). Generally, influences are minimized by targeting epiphytes (tree lichen) growing at least one metre above the ground, to within arm's reach, from the same species of tree, and collecting from branches in either a selected or in all compass directions (Bargagli and Nimis 2002). When it is not possible to target tree lichens, it is important to reduce the collection of the substrate along with the lichen to prevent contamination of the sample with soil when in transport back to the lab.

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Fig. 4. *Photograph of epiphytic lichen* Evernia mesomorpha *(green fruticose lichen), one of three targeted lichen species in the Sudbury Transect, growing among foliose lichen (grey scaly lichen) on a black spruce tree branch (photograph by M. Lakanen 2022).*

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When collecting lichens, a composite sample is typically required due to the small size of individual lichen specimens. Composites also help to pool individual variance to produce an 'average sample' across the site (Garner et al. 1988). A general guideline is to collect at least six individual lichen specimens from three different trees/substrates per site to form one composite sample (Bargagli and Nimis 2002). More lichens may be required to produce sufficient mass for chemical analysis—it is suggested to collect enough lichen to produce one gram of processed/cleaned lichen (Will-Wolf et al. 2020). Smaller collected samples are more time-consuming to clean (to prevent unnecessary loss of material) and produce lower quality data (Will-Wolf et al. 2020).

Canopy cover is an interesting consideration, with the general advice being consistency and to sample only from within tree stands for comparability (Will-Wolf et al. 2020). However, the situation can be rather complex, as forests act as filters to capture aerosols which can deposit on lichen as canopy drip (Nickel et al. 2022). Designers of spatial surveys may wish to measure the influence of deposition patterns across a target area, independent of forest canopy density.

Sampling lichens is straightforward: the thallus (lichen body) is removed from the substrate with gloved hands or with plastic/ceramic/Teflon-coated scrapers/knives/forceps. Sampling lichen mats can be simplified and optimized by using a sampling ring (~10 cm in diameter) to 'punch' a hole in the mat, with a plastic spatula being slid underneath for removal (Fig. 5). The majority of substrate should be removed in the field to prevent contamination of the sample during transport. Lichen samples can be collected in various container types, with small lichen samples being folded in metal-free filter paper (Bargagli and Nimis 2002). Care must be taken to ensure the container does not contaminate the sample with the target analytes (e.g. Kraft paper is known to contain sulphur) (Jackson et al. 1993). Breathable containers are suggested as sealed bags can promote rot.

Fig. 5. *Photograph of* Cladonia rangiferina*, a fruticose lichen, growing on soil (terricolous) with a sample ring inserted into the mat to facilitate sampling. This lichen is one of three lichen species targeted in the Sudbury Transect (photograph by M. Lakanen 2022).*

SAMPLE PREPARATION: WHAT TO DO IN THE LAB

Collected lichens should be air-dried quickly after sampling, a process significantly facilitated by using breathable sampling containers (Will-Wolf et al. 2020). Lichen are poikilohydric, meaning they rapidly equilibrate with the moisture in the air (Branquinho 2001). Any sufficiently dry environment should prevent mold growth before processing, but desiccator packs can be used in humid environments (Will-Wolf et al. 2020). Store samples in a dark, dry location at ambient temperature. Freezing samples is not recommended for elemental analysis (Jackson et al. 1993).

Cleaning is a time-intensive step in lichen biomonitoring, with at least half an hour per sample suggested (Will-Wolf et al. 2020). Plastic tweezers, commonly aided by a dissection microscope, are used to remove debris and substrate from the lichen (Will-Wolf et al. 2020). The difficulty of cleaning different lichen species can vary significantly.

The importance of consistency in cleaning cannot be overstated. Only viable (living) lichen should be used for analysis, dismissing tattered or dead/decaying lichen (Bargagli and Nimis 2002). Dead cells show higher exchange capacity

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SOCIETY OF ECONOMIC GEOLOGISTS
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The skills, knowledge, and capabilities of economic geologists are more important than ever before for the world's population as we seek to source and help produce the mineral supply that will feed the increasing metal demand of the energy transition. SEG 2025 attendees will learn about the most inspiring and impactful developments that address many facets of this challenge. Resources and developments in the Asia Pacific region will be in focus, but economic geology innovation is global, and attendees can expect to experience a global breadth in the conference program. The conference content will range from cutting-edge science to practical discovery case studies, delivered through a mix of field trips, workshops, posters, and an innovative combination of shorter- and longer-format technical presentations. In addition, the conference will present a great opportunity to build networks and collaborations across an international group of attendees that will span industry, government, and academia and cater to everyone from students and early career geoscientists to industry and discipline leaders.

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- COLLABORATIONS: Major economic geoscience initiatives in support of resources for the future
- INVESTMENT AND POLICY: Geoscience underpinning investment, policy, and governance
- SECONDARY METALS AND REMEDIATION: Secondary metal sources, economic geology, and remediation across the mining value chain

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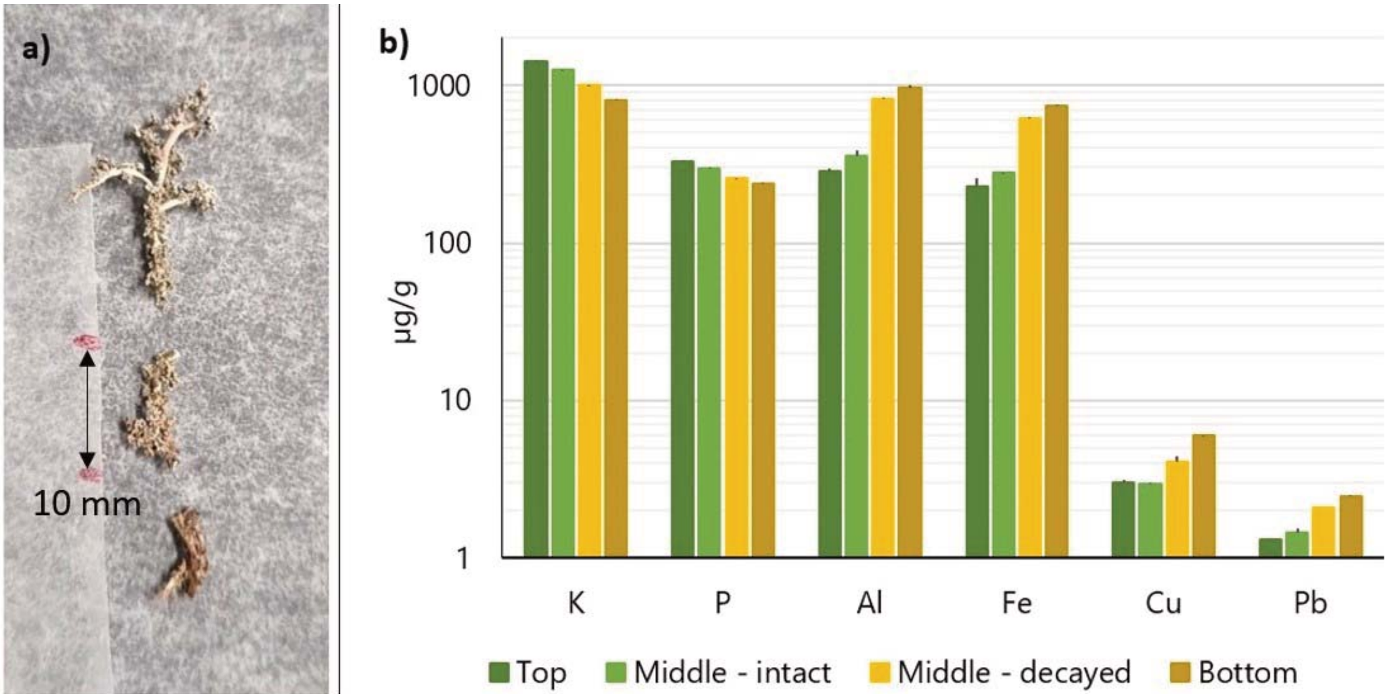

***Fig. 6. a)** Photograph of a sectioned 'stalk' of* Stereocaulon *sp. from a 'background' site, north of Sudbury, Ontario, Canada (see Fig. 3).* ***b)** A plot of a selection for elements to compare their concentrations across the gradient from top to bottom of a stalk of* Stereocaulon. *Error bars represent the standard deviation of the two composite duplicates. Nutrient (K and P) concentrations tend to be higher in metabolically active top portions, and lithogenic (Al and Fe) and PTEs (Cu and Pb) accumulate in the lower portions. A consistent selection of visually similar top portions is suggested for analysis.*

due to access to intracellular exchange site and cannot accumulate from intracellular transport (Bargagli and Mikhailova 2002). These and other factors can produce internal gradients within lichen that should be minimized by consistent cleaning (Bargagli and Nimis 2002). In practice, achieving this can be rather straightforward, if tedious. Preliminary results using *Stereocaulon* demonstrated that collecting visually homogeneous material is generally sufficient. In the experiment, podetia (individual stalks) were removed from a lichen mat and sectioned into three parts: the top 15 mm, the middle 10 mm, and the remaining bottom section (Fig. 6a). The middle sections were further categorized based on their resemblance to either the top or bottom sections in color, with yellow tones indicating age or decay. Results showed that visually similar tops and middle sections had comparable elemental concentrations (Fig. 6b). The data also aligns with known trends: metabolically active tops contained higher levels of key nutrients (e.g. K, P), whereas decaying parts show higher metal contents, likely due to an increase in exchange sites (Gao et al. 2020).

After cleaning, samples should be dried to a constant mass in a drying oven set just above ambient temperature (40ºC) to assist grinding and moisture uniformity for analysis (Jackson et al. 1993). An agate mortar and pestle are sufficient to grind many lichen species; however, more mechanically resistant species may require a mortar chilled in a liquid nitrogen bath or a mill for powdering and homogenization. Care should be taken with the selection of the mill to minimize contamination, cross-contamination, and loss of sample material (Jackson et al.

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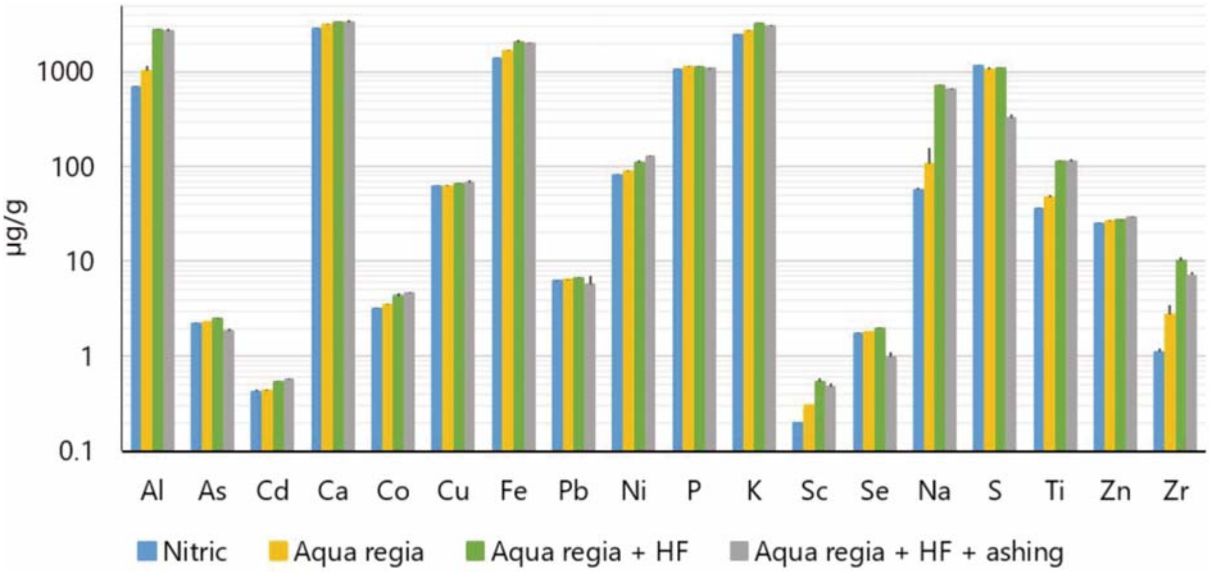

Fig. 7. *A comparison of four digestion techniques applied to* Stereocaulon *spp. that was collected from Sudbury, Ontario, Canada. Each digestion was replicated four times (error bars represent standard deviation). Dry ashing reduced volatile element concentrations (As, Pb, Se, S), whereas HF increased the recovery of elements typically found in silicate/oxide minerals (e.g. Al, Sc, Ti, Zr). The digestion method had only a minor influence on nutrients (Ca, P, Zn, K), with the exception of Na. The general consensus is to use a three-acid mix without dry ashing. Acid volumes: nitric acid (9 ml), hydrochloric acid (3 ml), hydrofluoric acid (1.5 ml), heated at 110ºC for 2.5 hr after 1.5 hr ramp to temperature in polypropylene disposable digestion tubes in a Hotblock (Questron Technologies Corp.).*

1993). Ground samples are best stored in small, sealed vials or Eppendorf tubes, with storage in a desiccator being recommended to prevent absorption of atmospheric humidity before weighing for analysis. Clean, dried, and sealed, the sampled lichens are safe for storage (Jackson et al. 1993).

Depending on the analytical technique, dissolving the sample into a liquid phase may be necessary (Rusu 2002). Partial digestions, such as nitric acid with hydrogen peroxide, may suffice for certain studies (Rusu 2002). However, a 'near-total' digestion using hydrofluoric acid is commonly recommended, particularly for studies involving specific elemental ratios (e.g. Fe:Ti) or intended for use of the Bioaccumulation Scale (Cecconi et al. 2019a). Some commercial laboratories offer these digestions as part of their services. Different digestion methods release different elements, and reporting digestion methods are required for reliable comparison with other studies (Cecconi et al. 2019a). A comparison of four common digestion methods—nitric acid, aqua regia (ratio of 3:1 nitric acid to hydrochloric acid, also known as 'reverse' aqua regia), aqua regia with hydrofluoric acid (HF), and dry ashing (500°C overnight) followed by aqua regia with HF digestion on the ash – is illustrated in Figure 7 using *Stereocaulon* from the Sudbury Transect (Lakanen et al. *in prep.*). Concentrations were measured by ICP-MS. Dry ashing reduced volatile element concentrations (As, Pb, Se, S), whereas HF increased the recovery of elements typically found in silicate/oxide minerals (e.g. Al, Sc, Ti, Zr). The digestion method had only a minor influence on nutrients (Ca, P, Zn, K), except Na. The general consensus is to use a three-acid mix without dry ashing. Acid volumes: nitric acid (9 ml), hydrochloric acid (3 ml), hydrofluoric acid (1.5 ml), heated at 110ºC for 2.5 hr after a 1.5 hr ramp to temperature in polypropylene disposable digestion tubes in a Hotblock (Questron Technologies Corp.).

Quality control and assurance (QA/QC) is important in all analyses and many texts are dedicated to the topic. In this example, recoveries were supported with the lichen certified reference material BCR-482 (European Commission's Joint

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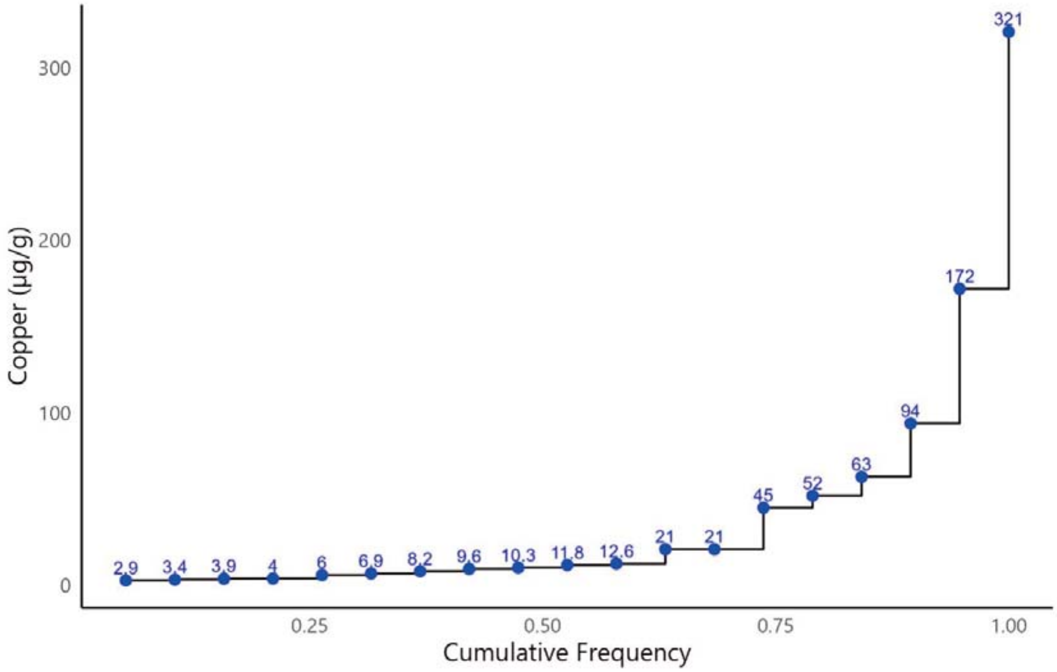

Fig. 8. Cumulative frequency plot of copper concentrations in Stereocaulon *spp. collected along the Sudbury Transect. Background concentrations range from 2.9 µg/g to 21 µg/g with a mean of 9.4 µg/g and a standard deviation of 6.1 µg/g.*

Research Centre) alongside other required QA/QC procedures such as analytical replicates, digestion blanks, and sample spikes. The added benefit of sample replication is quantifying sampling error, which allows for an analysis of variance to determine analytical (from analytical replicates) and sampling variability, confirming that the sensitivity of the analytical technique is adequate for the concentrations seen in the samples (Landis et al. 2019).

DATA INTERPRETATION AND APPLICATION

The choice of data analysis methods is closely tied to the study's objectives. Perhaps the simplest approach is highlighted by the Sudbury Transect, where concentrations are plotted against distance from the source. From this, an exponential decay function can be fitted to model the gradient. Other models may be used depending on normality, with log-transformations commonly employed to linearize the data (Jackson et al. 1993). Background concentrations and other populations can also be identified using cumulative frequency plots (Fleischhauer and Korte 1990), as shown alongside the drop-off for copper in *Stereocaulon* in the Sudbury Transect (Fig. 8, 9).

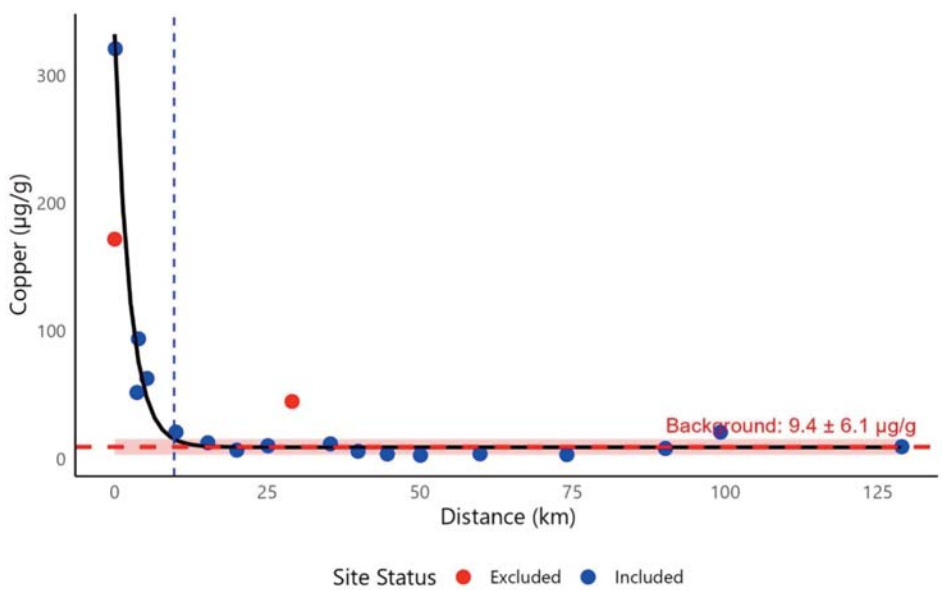

Fig. 9. Exponential decay model fit to copper concentrations in Stereocaulon *spp. with distance from the city limit. Two points have been excluded: one site not on the transect (proximal to another smelter) and the other site at 30 km, which was contaminated by local sources. The 'distance to background' is 9.7 km, which was determined when the modeled drop-off meets the background calculated from the cumulative frequency plot (see Fig. 8) and is illustrated here by the blue vertical dashed line.*

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Interpretive scales have also been developed, such as the Bioaccumulation Scale, which allows for comparison across lichen species and to interpret contamination severity (Cecconi et al. 2019b). The scale aims to provide context to lichen concentrations and their implications on environmental and human health (Cecconi et al. 2019b). From a health perspective, lichen PTE concentrations have been strongly correlated with cancer rates and PTE concentrations in human blood samples (Cislaghi and Nimis 1997; Garty 2001).

Various geostatistical analyses are commonly employed, such as elemental ratios/correlations/cluster analysis, enrichment factors, isotopic signatures, and factor analysis techniques (Nieboer et al. 1978; Puckett 1988; Steinnes et al. 1992; Wolterbeek and Bode 1995; Graney et al. 2019; Anderson et al. 2022). These methods have been used to identify different sources within a sample set and to examine/understand relationships among elements. Elemental ratios of a target element to a lithogenic element, like Al, Si, Ti, Sc, or Zr can help estimate levels of soil deposition across the sites, which might obscure anthropogenic sources (Nieboer et al. 1978).

Mapping using biomonitors has been successfully applied in many studies, ranging from city, regional, to continental scales in the European Moss Survey, which is repeated every five years to investigate transborder emission deposition (moss is another commonly used biomonitor) (Frontasyeva et al. 2020). The resulting maps address limitations in other sampling techniques, such as active air sampling, through sheer sampling numbers. Naturally deployed, lichens offer superior scalability compared to technical methods, although they share some limitations, such as variability caused by microclimate effects (e.g. wind speed/patterns) and stray contamination (Garty 2001; Krug et al. 2017). The ability of lichens to accumulate multiple types of deposition is particularly advantageous, capturing dissolved solutes (and gases) as well as a wide range of particulate sizes via sedimentation, impaction, and interception (Wolterbeek et al. 2003). No single technical method can replicate this capability, although bulk deposition samplers come close (and are correlated with lichen concentrations) but tend to underestimate fine particulates (Branquinho 2001). An issue with lichen surveys is the incompatibility with the measurement units typical of regulatory bodies, although some have proposed 'calibrating' lichen values with deposition meters (Branquinho 2001; Blett et al. 2003). Other challenges include the variable capture efficiency and time frame for retention. An important consideration is that concentrations found in lichens may not show a linear relationship with deposition rates (Mikhailova 2002). Despite these limitations, lichens still excel at identifying changes in elemental deposition patterns due to their high accumulation of PTEs, which allow for contamination/anomalous sites to be many times, if not magnitudes, higher than background concentrations (as seen in Fig. 9 of the Sudbury Transect).

Outside of environmental contexts, there is some promise for using lichen in geochemical exploration.

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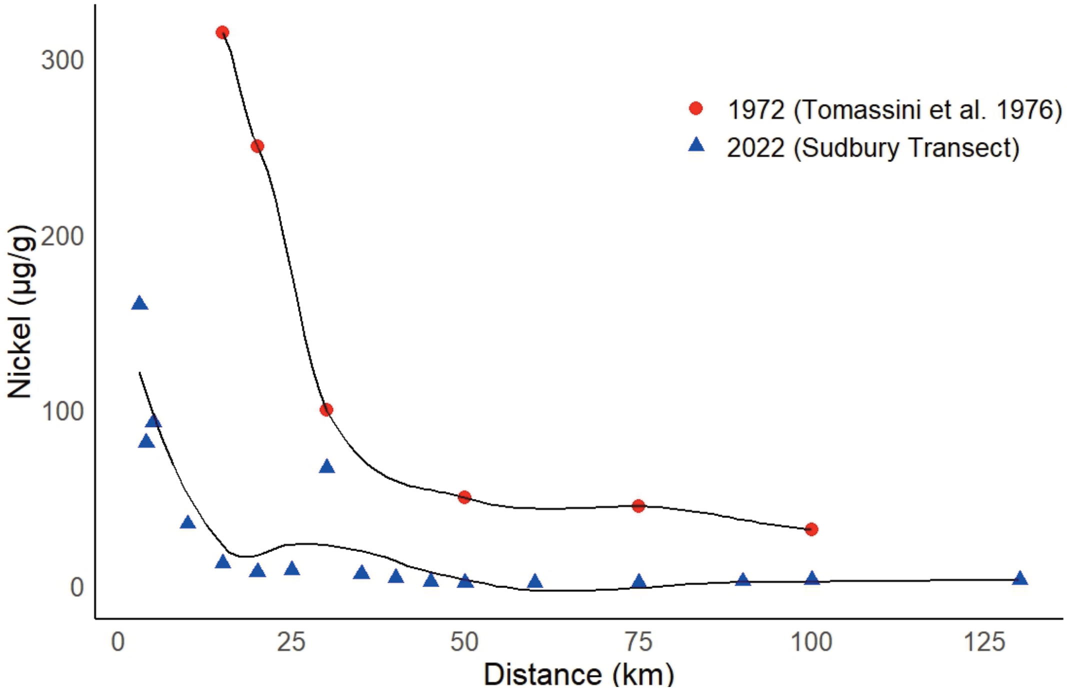

Fig. 10. *Fifty years of pollution control as measured in lichen. The nickel content of* Stereocaulon *spp. from two studies (with LOESS smooth) conducted fifty years apart following a similar transect from Sudbury, Ontario, Canada. In 2022, lichen was found near the base of the smelter compared to ~15 km from the smelter in 1972. The spike in Ni content at 30 km in 2022 is suspected to be due to local contamination from a railway.*

Previously, lichen color and species composition have been used as indicators of specific minerals in their substrate, however, such assessment 'requires a trained eye' (Easton 1994). Furthermore, the ability of lichens to trap and accumulate particulates from weathered geological material suggests their potential for biogeochemical prospecting. Elevated background concentrations around ore deposits have been reported (Dongarrà et al. 1995; Chettri et al. 1997; Garty 2001). A lichen survey in the Northwest Territories, Canada, indicated elevated copper levels in an area where a mineral deposit was later discovered (Richardson 1992). In the Sudbury Transect, an elevation in Mn concentrations in all lichen species, but not in snow (or moss), corresponded to a large spike of Mn in soils. Follow-up XRF analysis of rock samples indicated the presence of several percent Mn at the site, highlighting the ability of lichen to identify local geogenic anomalies. However, without the corresponding increase in soil, the Mn concentrations in lichen, although consistent, would likely have been overlooked as natural variation in the background (60 mg/g at the site compared to a mean of 47 ± 41 mg/g), however the mineral soil had a Mn concentration of 5340 mg/g compared to the background of 373 ± 222 mg/g. The elevated Mn concentrations seen in the lichen are likely derived from soil or weathered rock particulates deposited by wind. In use, if it is reasonable to assume that weathered surface material is a marker of potential ore deposits, then lichen may serve as a relatively cheap and easy screening tool by capturing and accumulating the airborne signals.

Lichens are also effective for monitoring changes over time (Beckett 1995). The Sudbury Transect was previously sampled fifty years ago (Tomassini et al. 1976), revealing significant shifts in metal loads with distance from Sudbury (Fig. 10). Over this fifty-year period, the spatial extent of the smelter operations has decreased from approximately 45 km to 17 km, and background concentration of Ni has fallen

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from approximately 30 µg/g to 3 µg/g as measured in lichen. These reductions highlight substantial progress in clean air initiatives and smelter emission controls by the mineral processing industries (SARA Group 2008).

A COST-EFFECTIVE SURVEY TARGET

Lichens are powerful tools for monitoring the deposition of metals and potentially toxic elements. They commonly accumulate tens to hundreds of times higher concentrations at anomalous sites compared to background levels, making them sensitive monitors (Blett et al. 2003). Lichens are a relatively homogeneous sample type that collect from virtually all air fractions and do not require sophisticated sampling equipment, making them particularly well suited for survey or monitoring studies (Wolterbeek et al. 2003). Their versatility, scalability, and cost-effectiveness have made lichens an excellent choice for environmental surveys, whether assessing human impact or investigating natural anomalies.

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Did you know?

There are links to more than thirty geochemical atlases on the AAG Website!

Geochemical atlases are maps or databases providing regional coverage for a given media type (soil, sediment, groundwater, rocks, etc) at a large scale. They often cover a whole country or a larger region. They may be designed for the needs of mineral exploration, agriculture, land planning or risk management, but in most cases, they may also be used for other purposes. They are most useful for interpreting geochemical anomalies as well as for identifying local pollution.

They may be available free of charge – as a public service – or for a moderate publication cost. The earlier ones are available in printed form, while more recent ones are available online, sometimes with GIS features.

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The use of bulk cyanide leach in gold assays of drill core and rock samples

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https://doi.org/10.70499/QRGX6581

INTRODUCTION
The use of cyanide in the form of NaCN to digest Au and other metals for analysis is well established (e.g. Wang and Forssberg 1990). Most exploration geologists will be familiar with the use of bulk cyanide leach (BCL), also referred to as bulk leach extractable gold (BLEG), applied to surficial samples, such as stream sediments and soil (Rate et al. 2010). This contribution reviews some of the advantages of using BCL on rock and drill core samples.
The analysis of pulverized rock material may be conducted using a standard BCL, with or without agitation such as a

In March 2024, the AAG Council resolved to pursue the matter of obtaining DOIs for the technical articles published in our newsletter, EXPLORE. A Digital Object Identifier (DOI) is a unique, persistent identifying URL (Universal Resource Locator) of the type https://... for a document published online. Its purpose is to be a permanent, precise identifier for an individual document, regardless of its location on the Internet; a document retains its DOI even if its URL location changes. Scholarly materials benefit from being registered with a DOI because this facilitates and guarantees their discoverability into the future. EXPLORE articles are scholarly works that should and can be cited, thus should have a DOI.

This March 2025 issue of EXPLORE is the first new issue to have a DOI registered to its science article. In addition to articles in current and future issues being assigned a DOI, we are working toward obtaining DOIs for previously published science or technical articles that are deemed relevant in past issues, hopefully back to the year 2000 at least. The process comprises three major steps:

1. generating and registering the DOI suffix of an article (consisting of a random code of four letters and four digits) with Crossref, which includes uploading data and metadata (bibliography, ORCIDs) for the article and its authors;
2. preparing a ‘clean’ PDF stamped with the DOI’s full URL; and
3. updating the EXPLORE past issues webpage on the AAG website (https://www.appliedgeochemists.org/explore-issues/explore-issues) to publish the link to the landing page (a required cover page showing essential bibliographic information of the article) and make the final article PDF visible.

So far, 27 articles, back to 2018, have been processed, with each article taking an average of two to three hours of work to process. It is hoped the DOI attribution will be completed to 2000 during the course of this year. Authors will be informed as this process progresses, whenever possible.

AAG members now have access to fully citable and referable scientific works in EXPLORE that are both free to publish and free to read. It is hoped this will make publishing in EXPLORE more attractive, particularly to the academic- and government-based members and especially Early Career Researchers (ECRs).

Patrice de Caritat

AAG WEBSITE UPDATE

At the Association's last AGM/Council Meeting, I volunteered to review the AAG website to assess its relevance and address the current and future content plus the look and feel of the website moving forward.

For those who have not worked with me, I joined AEG (the predecessor of AAG) in 1978 while working with Tony Barringer. AAG has always been the association that has provided timely contacts and information, and I trust that the website will be the go-to window into the organization for our young professionals along their career paths now and well into the future.

The website has undergone several renovations since its inception but is once again at the point where it requires updating and addressing challenges in its routine maintenance. To that end, I am working with our Office Manager (Jane Graham), Treasurer (Gwendy Hall), Website Administrator (Elizabeth Ambrose), and Strategic Planning representative (Sam Scher) to identify challenges with the current website, evaluate options to “fix” the issues, and update the website with relevant material for today’s membership. If you find an issue with, or a suggestion for, the website, please email me the information. We will take the information under advisement while we work through the updates. This process will take some time to ensure that we address all the challenges and will, hopefully, generate a website that the membership can be proud of.

Thank you in advance.

Erick Weiland (AAG member #318)
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REVIEW OF THE WORKSHOP ON GLOBAL- TO REGIONAL-SCALE GEOCHEMICAL MAPPING

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INTRODUCTION

The Association of Applied Geochemists (AAG) and the International Union of Geological Sciences (IUGS) co-sponsored a technical workshop at the 37th International Geological Congress (IGC) in Busan, Republic of Korea. The three-day Global- to Regional-Scale Geochemical Mapping workshop was held from 30 August to 1 September 2024. The focus of this training course was the sampling methods described in the I*nternational Union of Geological Sciences Manual of Standard Methods for Establishing the Global Geochemical Reference Network* (i.e. IUGS Manual of Standard Methods, Demetriades et al. 2022). The workshop tutors were the authors of this article, with able assistance in the form of short, interesting tutorial presentations by David Cohen (University of New South Wales, Australia, former President of AAG (2008–2009), and current Treasurer of IUGS (2024–2028)).

LECTURES AND HANDS-ON EXERCISES

The introductory lecture gave an overview of the history of the global geochemical baselines project (*see* Smith et al. 2018, for a detailed history). Starting in 1984 at the International Atomic Energy Agency's workshop in Sweden, the global mapping of naturally occurring radioactive elements (K, U, Th), using ground and airborne scintillometry, was discussed; at the same time, it was recognized that other elements should be included. The Chernobyl accident on April 25–26, 1986, was the disaster that gave birth to the proposal for the multi-media geochemical baseline mapping of then-Western Europe by the Working Group on Regional Geochemical Mapping (1986–1993) of the Western European Geological Surveys (Stenestad 1990; Bølviken et al. 1993, 1996). This proposal led to IGCP 259 International Geochemical Mapping (Darnley et al. 1995), followed by IGCP 360 Global Geochemical Baselines, and finally to the decision in 1996 of the Directors of the Forum of European Geological Surveys (FOREGS) for the multi-media geochemical baseline mapping of Europe. Twenty-six countries participated in this project, resulting in the publication of the two-volume FOREGS Geochemical Atlas of Europe 2005 and 2006 (Salminen et al. 2005; De Vos et al. 2006).

The Task Group on Global Geochemical Baselines (1998–2016) of the International Union of Geological Sciences (IUGS) continued the work of the two IGCP projects, and with the harmonized FOREGS Geochemical Atlas of Europe, as an example, promoted the proposal for Global Geochemical Baseline Mapping. In 2016, the Task Group on Global Geochemical Baselines was elevated to a Commission (CGGB: Global Geochemical Baselines) by the IUGS Council, with the mandate to compile a comprehensive Manual of Standard Methods, which was published in 2022 (Demetriades et al. 2022; Ladenberger and Knight 2022). The methods described in the manual, besides their use for establishing the Global Geochemical Reference Network, can be applied in other geochemical surveys at any mapping scale.

The Workshop lectures were delivered in two parts, as shown in Table 1. The hands-on exercises, performed with Golden Software's Surfer and Grapher or with dedicated software programs compiled by CGGB members, were

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***Table 1.** Workshop lectures that, together with the hands-on exercises, can be freely downloaded by using the following pCloud hyperlink: https://u.pcloud.link/publink/show?code=kZG9bO0ZDA94k65fvy8erLL3aqGBqLeAR777.*

PART A

An introduction to the International Union of Geological Sciences Manual of Standard Methods for Establishing the Global Geochemical Reference Network

Global Terrestrial Network (GTN) grid cells, selection of sample sites, and sample types to be collected
- Hands-on exercise: Generation of random points in the GTN grid cells (He and Geng 2022)

Sampling methods: Introduction
- Rock sampling
- Residual soil and humus sampling
  - The soils of the world
  - Annotated soil profiles
- Stream water sampling
- Stream sediment sampling
- Overbank and floodplain sediment sampling

Cyprus: Where would you collect a sample? (*David Cohen*)

Sample preparation and storage

Development of reference materials for external quality control

PART B

Geoanalytical Methods and Requirements

Quality control: Introduction

Quality control procedures
- Laboratory reports hands-on exercise
- Estimation of practical detection limit hands-on exercise
- Duprepplot hands-on exercise
- Thompson & Howarth plots hands-on exercise
- ANOVA-RANOVA (Vassiliades 2022)
- Quality Control – The Cyprus soil geochemical atlas study (*David Cohen*)

Data conditioning methods: Generating time-independent geochemical data
- Levelling exercise

Data management and Map Production
- Map plotting exercise with Surfer using the FOREGS data set

Interpretation and usage of European multinational and continental-scale geochemical data sets

Global- to local-scale geochemical surveys

designed to be practical and applicable. These resources are available for downloading from the publication's webpage, empowering participants to apply their newly acquired knowledge in their geochemical mapping surveys (CGGB: Global Geochemical Baselines http://www.globalgeochemicalbaselines.eu/).

In total, 36 participants attended the workshop on the first day (Fig. 1a), 21 on the second day, and 23 joined the field training course (Fig. 1b, 1c, 2). Professor Hassina Mouri (2024–2028 IUGS President) also participated in the field course. The distinct difference in the number of participants on the first day, compared to the following two days, was that the conference organizers opened the registration for workshops relatively late, and most participants had already booked their return airline tickets to their home countries.

FIELD SAMPLING TRAINING COURSE

Planning a field sampling training course from a distance is difficult, even if there are local colleagues who volunteer to help. To begin with, it was crucial for the course to use a suitable drainage basin not far from Busan (Fig. 2). So, the planning comprised the following three stages:

i The planning of the field sampling training course was collaborative, underscoring the sense of community that the workshop fostered. The Google Earth image of the Busan area was studied, a potential drainage basin was

***Fig. 1. (a)** Workshop participants during the hands-on exercises, **(b)** stream water sampling site N24E76W2, and **(c)** field course participants recording field observations at soil sampling site N24E76T2.*

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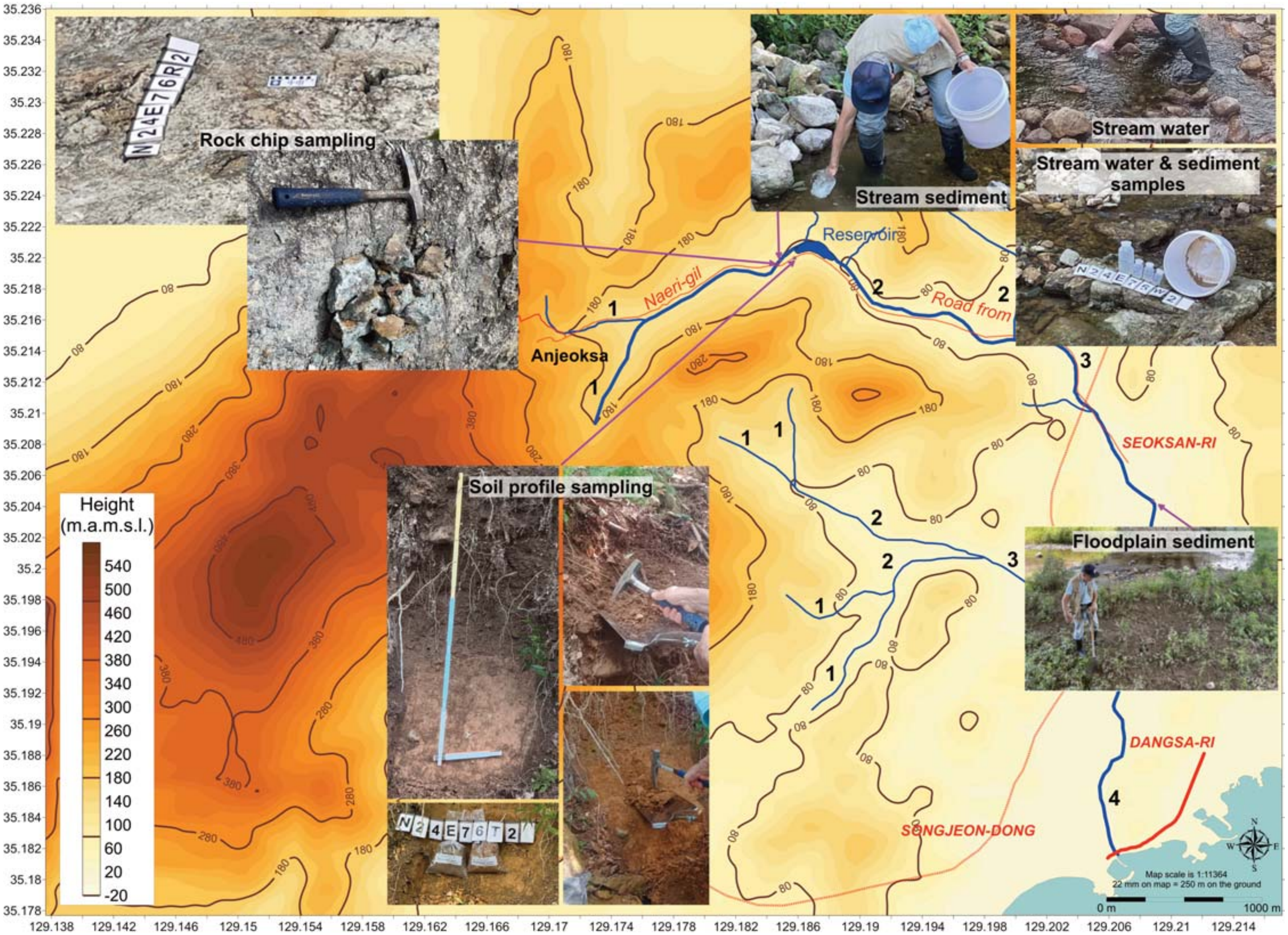

Fig. 2. *Topographical map of the Busan field training course area with sample sites and photographs. The black bold numbers 1, 2, 3 and 4 denote the Strahler stream order classification. Map plotted using Golden Software's Surfer v. 29 (https://www.goldensoftware.com/).*

located, and possible sample sites were marked. This information was then shared with Professor Jong-Sik Ryu (Pukyong National University, Busan), who, together with his Ph.D. students Hojin Park and Jeonghun Kim, after studying the sampling chapters in the Manual of Standard Methods (Demetriades et al. 2022), inspected the proposed sites and suggested alternative sites on the 3rd of July 2024.

ii For teaching purposes, a topographical map of the drainage basin was compiled using different software and tools, which are explained in a tutorial that will be available in 2025. On this topographical map, the potential sample sites were marked.

iii A preliminary survey was conducted on the 24th of August 2024 by Alecos Demetriades and Ariadne Argyraki with the assistance of a Pukyong National University Ph.D. student, Hojin Park. All potential sites and the road condition towards the residual soil site were examined during the preliminary survey. Since the road was very narrow, it was decided that a 25-seat coach could not reach it. Hence, an alternative site for the demonstration of soil sampling was selected; this site is situated on a mountain slope with an inclination of about 40º and is unsuitable for collecting a residual soil sample because there is evidence of soil creep, indicated by curved tree trunks. Similarly, the overbank and floodplain sediment sites could not be reached because of fenced private properties, and alternative sites were identified. Although these sites were not ideal, the problems of sampling residual soil, overbank and floodplain sediment could be explained and demonstrated in practice. The sites for collecting stream water, active stream sediment and rock samples were easily located (Fig. 2).

The field training course started by demonstrating stream water sampling, followed by rock, stream sediment, soil, and floodplain sediments, as almost described in the IUGS Manual of Standard Methods (Demetriades et al. 2022). The 'almost' refers to the stream sediment, soil and overbank/floodplain sediment sampling methods because the selected sites were not ideal but served to point out the specifications detailed in the IUGS Manual of Standard Methods and the sites that should be avoided. For example, (a) the stream sediment was coarse-grained, which meant that the active sed-

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iment should be collected from many traps to be able to reach the required minimum weight of about 1 kg of <0.150 mm grain size − ideally, another site downstream should have been selected; (b) this particular soil sampling site may be suitable for mineral exploration purposes, but not for the global geochemical baseline project, which requires the top (A horizon) and bottom (C horizon) soil to be developed on-site, and (c) the selected overbank/floodplain sediment site showed the mechanism of deposition of overbank sediment even in an artificially oriented river, stressing that nature always follows its course − suitable sites for the collection of overbank and floodplain sediments were shown, all of which were on private properties.

COMMENTS BY PROFESSIONALS AND STUDENTS ABOUT THE COURSE

After the workshop, participating university professors and Ph.D. students sent their comments and reflections, as detailed below:

- Ravi Ranjan Kumar, Assistant Professor, North-Eastern Hill University, Meghalaya, India (5/9/2024): "*It was a really good platform for us new people who are interested in the same type of work*."
- Basilios Tsikouras, Professor of Mineralogy and Petrology, University Brunei Darussalam (8/9/2024): "*It was an amazing experience for us and thank you for the flawless organisation of the workshop including the field trip. The material we received is invaluable.*"
- Youngsook Huh, Professor of Isotope Geochemistry, Seoul National University (27/9/2024): "Y*our workshop was both informative and fun, and I heard from some of the students that they are already incorporating some of what they learned into their own sampling trips, even though their research is most strictly geochemical baselines. So, your work is flowering in unknown places*."
- Eunje Oh, Ph.D. student, Seoul National University (5/9/2024): "*Thank you very much for your thorough and patient guidance throughout the workshop. I have not only learned of meticulous and precise sampling and data quality control measures but also have been inspired by your passion and attitude towards producing truly reliable data. Thank you so much for being such a great teacher and inspiration. I'm looking forward to learning more, both from the Commission and from the upcoming publication.*"
- Jena Jeong, Ph.D. student, Seoul National University (5/9/2024): "*I sincerely thank you for the insightful three-day workshop, including the field session. I especially appreciated the field session on the last day. It was an invaluable experience that helped me apply what we learned in a practical setting.*"

Apart from the e-mail messages sent after the workshop, Ariadne Argyraki (Commission's Public Relations Officer) sent an evaluation questionnaire to all participants, and 15 completed it. The results are presented in Table 2.

The participants considered the workshop "Excellent" (Table 2a). In Table 2b, with specific questions, the participants gave different answers depending on their interests, and at least one pointed out that too much information was provided in such a short time and was difficult to comprehend. The comments in Table 2c essentially support what we already knew, i.e., the workshop lectures and hands-on exercises were very difficult to elaborate in the required detail within the restricted time of two days. Sampling methods were emphasized because these are the most important step in any geochemical mapping survey, followed by sample preparation and quality control. The hands-on exercises needed more time. However, we informed the participants that they should try all the exercises upon returning home, and any questions they may have would be answered electronically or virtually.

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Table 2a. *The portion of the questionnaire enquires about the quality of the workshop.Fifteen participants answered the questions.*

QUESTIONS	RATING 5 = EXCELLENT TO 1 = POOR
How would you rate the quality of the workshop lectures?	5 (n=10); 4 (n=4); 3 (n=1)
How would you rate the quality of the workshop exercises?	5 (n=7); 4 (n=6); 3 (n=2)
How would you rate the quality of the workshop material in the USB memory stick?	5 (n=14); 4 (n=1)
How would you rate your experience during the field trip (please answer only if you followed the field trip)?*	5 (n=10); 3 (n=1)

* 4 people did not participate in the field course.

Table 2b. *This portion of the questionnaire enquired about the parts of the workshop that were most and least interesting to the participants.*

WHICH PART OF THE WORKSHOP DID YOU FIND MOST INTERESTING, AND WHICH PART WAS LEAST INTERESTING? Please provide your general comments.
The workshop was very useful in general, and the field experience was quite important in making the content of the workshop one's own. The most interesting part was quality control, and the least interesting part was sample site designation, but only because it wasn't readily applicable to my own field.
The discussions from the different participants.
Most parts of the workshop are interesting because I like to learn and hear the knowledge and speaker's experience during the class. It is only a little pity that the software for workshop exercises is expensive and cannot be used on Mac systems.
I experienced a well-prepared and standardised introduction, which supports the global geochemical baseline idea.
Had an absolutely enlightening time at the workshop! The wealth of knowledge shared and the engaging discussions with fellow participants were truly invaluable. A heartfelt thanks to the organisers and presenters for making this a good learning experience.
All parts of the workshop were good. The focus on hard rock should also be heightened.
The most interesting was the fieldwork; it is good to know there is a standardised way to collect samples.
The explanation of the analytical part was interesting.
Theory session.
Honestly, I'm not major in chemical mapping. So, I was so glad to be getting new information about the mapping.
I really enjoyed the fieldwork, especially because we learned what to be mindful of on-site. The lectures were also helpful and engaging, though covering so much over two days sometimes made it hard to stay alert.
Most interesting: field exercise, especially the soil sampling part. So many details are involved. Least interesting: Software dealing things. It's just a personal thought. My colleague found it interesting.
The most interesting part was the field trip, as well as the parts with the exercises on the 2nd day. Both offered hands-on experience to us. I cannot say anything was less interesting, but the Stream Sediment and the Floodplain Sediment sampling presenters were less prepared.
Most: Sampling

Table 2c. *This portion of the questionnaire asked for suggestions for improving the workshop.*

SUGGESTIONS FOR IMPROVEMENT
One of the reasons I joined the workshop was to learn the usage of Surfer in geochemical applications. Due to the lack of time, the workshop didn't cover this, which was understandable but disappointing nonetheless.
More exercises would be interesting.
I hope there is other substitute software that can be applied in the class. Maybe the class can be extended to more days because there is abundant information, and people would not be too tired to absorb it.
Keep up the good work.
To have a group folder to share pictures from the day of the workshops/fieldwork.
I was eager to learn the software, but we didn't get the chance to use it in class. Having more time for hands-on practice would be really beneficial!
A more proper field trip site would be good for the exercise, but I understand that there were some limitations regarding the location of the sampling sites.

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FUNDING

The International Union of Geological Sciences and the Association of Applied Geochemists co-sponsored the workshop. Both organizations are thanked for their generosity.

FUTURE WORKSHOPS

After two successful workshops, the first one in Athens on the occasion of the Society of Environmental Geochemistry and Health's conference in 2023 and the second in Busan (Republic of South Korea) in 2024 in conjunction with the 37th International Geological Congress, of two- and three-days duration, respectively, the next workshop, during the Goldschmidt2025 in Prague (July 2025), will extend over four days. The first two days will be devoted to lectures, the third to hands-on exercises, and the fourth day to a field course at sites used during the FOREGS Geochemical Atlas of Europe Project (Salminen et al. 2005; De Vos et al. 2006).

ACKNOWLEDGEMENTS

It is here proper to thank our South Korean colleagues Professors Youngsook Huh (Seoul National University) and Jong-Sik Ryu (Pukyong National University, Busan), and the Pukyong National University Ph.D. students Hojin Park, Jeonghun Kim and Minhxeok Park for their assistance in the organisation of the one-day field course. Special thanks go to Professor Youngsook Huh for her valuable help during the two-day workshop and to Hojin Park for organizing the pre-field visit for the location and preparation of the sampling sites. Golden Software (https://www.goldensoftware.com/) is thanked for providing free, gratis licenses for Surfer and Grapher to the workshop participants. David B. Smith is thanked for the thorough review of the original version of the article and his constructive comments.

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AAG Councillors 2025–2026

Pedro Acosta-Góngora

Dr. Pedro Acosta-Góngora is a researcher with the Geological Survey of Norway. His current area of research is focused on the application of geostatistical tools to ore genesis-related, predictive mapping (mineral potential and ecological) and geochemical anomaly identification studies. Derived from this work, Dr. Acosta-Góngora was part of the team that won the prestigious Frank Arnott Award (2018) given by the Prospectors and Developers Association of Canada (PDAC).

He holds a B.Sc. in Geology from the University of Costa Rica, a M.Sc. in Mineral Engineering with emphasis in mineral exploration from the New Mexico Institute of Mining and Technology, and a Ph.D. in Earth and Atmospheric Sciences from the University of Alberta, Canada. Dr. Acosta-Góngora has worked as a member of multidisciplinary research teams across all sectors, including the mining industry, academia, and government. He has extensive fieldwork experience that includes bedrock and various types of geochemical mapping surveys at local and regional scales across several countries. His early career was oriented to study the ore genesis of different of hydrothermal (IOCG, polymetallic vein-hosted and metasomatic uranium) and magmatic (Ni-Cu-PGE) deposit types using a wide range of geochemical tools (e.g. isotopic geochemistry, fluid inclusions, and concentration of major and trace elements in minerals and rocks).

He has been a short course instructor of applied geochemistry for mineral exploration at international conferences (PDAC and SGA). The results of his scientific contributions have been presented at national and international conferences and published principally as peer-reviewed papers (e.g. Economic Geology, Journal of Geochemical Exploration), book chapters, and open file reports (Canadian and Norwegian geological surveys).

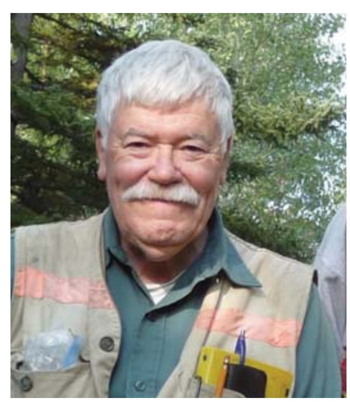
Aaron Baensch

Aaron is an executive geoscientist and technologist with 25+ years of international experience, spanning technology development, research, commercialization, global business development, strategy, investment, consulting, mining operations, mineral exploration and space. Aaron is also a strong advocate and promoter of sustainability, diversity and STEM pathways for the next generations entering the resources industry.

Aaron's passion is centred on deep engagement and collaboration with the Mining Equipment, Technology & Services (METS), Research and Space sectors. This draws on his deep domain experience in material characterization, sensors, IIoT, analytics, AI/ML, space, robotics and automation. This is combined with over a decade of direct exploration and mining operational experience. Aaron has spent the last 15+ years focusing on a wide range of technologies, including the adaption of analytical systems used by NASA on the Mars Curiosity Rover. He was also an embedded researcher and project manager at MinEx CRC and the Deep Exploration Technologies CRC where he holds several patents for novel technologies.

Professionally, Aaron is a proud graduate of the Western Australian School of Mines, Kalgoorlie (WASM) and holds a Bachelor of Science in Mineral Exploration & Mining Geology with 1st Class Honours. He is a Registered Professional Geoscientist, as well as a Fellow of the AusIMM, AIG, SEG and AAG. Aaron is also a qualified snowboard instructor and you can find him hitting up the slopes during the winter in the USA, Canada, New Zealand and Australia, as well as 4WD-ing, boating and fishing with his family and friends throughout the warmer months.

Ray Lett



Ray obtained a B.Sc. from University of London, UK, in 1968, an M.Sc. from University of Leicester, UK in 1970, and a Ph.D. from the University of British Columbia in 1979. He is a geochemical consultant and university sessional lecturer in geochemistry and economic geology at the University of Victoria, Canada. He was a laboratory supervisor and senior geochemist for the British Columbia Geological Survey between 1990 and 2010. Prior to that, he was a geochemist for Barringer Research/Magenta from 1980 to 1990 and an exploration geochemist/geologist for Amax Exploration/Fox Geological/BP Minerals in Vancouver, BC, between 1970 and 1979. Ray served as AAG Secretary from 1980 to 1985 and as a Councillor from 1990 to 1992, 1999 to 2000, 2006 to 2009, and 2015 to 2017. He has also served as a member of the AAG Education Committee between 2010 and 2022, as well as the Strategy Committee in 2016 and 2017. Ray retired after 20 years with the BC Geological Survey, and he now spends his time consulting, teaching (part-time) undergraduate university courses in geochemistry and economic geology, and serving on various geoscience committees.

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With more than 50 years of experience as a geochemist, Ray has been fortunate to see the development of applied geochemistry from the fairly simple methods used in the 1960s to the more varied and complex sampling and data analysis techniques available today. He is convinced that many technological advancements can be attributed to ideas generated from the Association's international symposia, from publications in the journal GEEA (Geochemistry: Exploration, Environment, and Analysis) and from articles in the EXPLORE newsletter. True, sources of information are valuable, but people are even more important, so it is even more vital today that Members and Fellows encourage younger geoscientists to consider a career in applied geochemistry and join the Association.

Ann Petts

Anna graduated from the University of Melbourne, Australia in 2002 with a B.Sc. (Hons) in Geology, and commenced a Ph.D. at the University of Adelaide in 2004 with support from the Cooperative Research Centre for Landscape Environment and Mineral Exploration (CRCLEME) with Dr. Steve Hill and Lisa Worrall as her supervisors. Anna received her Ph.D. in 2009 — final title of her research project was 'Termitaria as regolith landscape attributes and sampling media in northern Australia'.

Prior to commencing her Ph.D. studies, Anna worked as an exploration geologist with Iluka Resources (2003) in their Murray Basin Mineral Sands project; from 2008 to 2016 Anna was first an exploration geologist and then project geologist for Flinders Diamonds/Flinders Mines, primarily the Pilbara Iron Ore Project (mostly channel iron and detrital iron deposits plus hematite ore within basement) in the Hamersley Iron Province of Western Australia, plus also VHMS-style Ni and Cu exploration in the Windimurra Igneous Complex in Central Western Australia. In addition, Anna also has experience in diamond exploration in South Australia's Nackara Arc and Flinders Ranges. She has also worked as a contract geologist with Euro Exploration Services on projects that included Prominent Hill's IOCG exploration (then Minotaur), as well as later near mine exploration logging. Recently, her work with the Geological Survey of South Australia has included collaborating with CSIRO to undertake regional UltraFine+ soil and biogeochemical sampling and hydrogeological sampling. She has also collaborated with MinEx CRC to provide report-quality portable XRF downhole geochemistry for the National Drilling Initiative Delamerian and Northern Gawler projects.

Throughout her career, Anna has primarily been interested in the practical application of geochemical techniques to improve exploration outcomes in the field. Anna has designed and led portable XRF programs in the field and at the core library, and hopes to continue to promote sustainable and low-impact surface geochemical methods for better understanding the distribution of metals in the regolith and cover.

Sam Scher

Sam Scher is a geochemist with over 15 years of experience in mineral exploration, mining, and applied geochemistry. She holds Bachelor's and Master's degrees in Earth and Planetary Sciences from McGill University, Canada. Her master's research focused on high-sulphidation epithermal mineralization at the Kawah Ijen Volcano, Indonesia, and was published in *Economic Geology* in 2012.

Sam is the Director and Principal Geochemist at LKI Consulting Inc., where she designs and implements geochemical programs, integrating technologies like hyperspectral analysis and 3-D modeling to support exploration, mining, and geometallurgical projects. Her role encompasses training programs and geochemical technology implementations, as well as delivering tailored solutions to major, mid-tier, and junior mining companies.

Previously, she worked as a Senior Geochemist and Business Development Manager at Corescan, where she managed hyperspectral imaging projects and expanded client bases globally. She also served as a geochemist at a private exploration company in Chile, where she developed field programs and integrated geochemical and hyperspectral data into exploration workflows.

Sam is the founder and host of the *GeOCHemISTea* podcast, which provides a platform for geochemists to share experiences and insights. She is fluent in English and Spanish and proficient with geochemical, 3-D modeling, and geospatial software and technology. Sam is a member of the Society of Economic Geologists and Geologic Society of Washington, as well as a Fellow of the Association of Applied Geochemists.

Do you have a news item you would like included in the next issue of EXPLORE?

Send a note to the Editor!

Welcome New AAG Members

REGULAR MEMBERS

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

Dr Meabh Banrion
Geologist
160 Curlew Road,
Dublin 12
D12X927
Ireland
Membership #4575

Fernanda Castro
Exploration Geologistt
Geologica Servicios
Av Providencia 1650
Providencia
Region Metropolitana
Chile
Membership #4572

Dr David Lawrence
Principal Geologist
Barrick Gold Corp
37 Chapel Way
Epsom KT18 5TE
Great Britain
Membership #4578

Arnoldo Rudin
Chief Geologist, Mina Bellavista
1.5 Km Norte, Iglesia Miramar
Miramar P 60401
Costa Rica
Membership #4579

Dr Daniel Selles
Principal Geoscientist, BHP
Chile
Jose Zapiola 8021 Casa D
La Reina RM
Chile
Membership #4576

Steve Sheppard
Exploration Manager
Westar Resources Ltd
21 Bishopsgate Street
Carlisle, WA 6101
Australia
Membership #4574

Robert Theron
Exploration Superintendent
Gold Road Resources
12 Tareena Street
Nedlands, WA 6009
Australia
Membership #4577

FELLOWS

Fellows are voting members of the Association and are actively engaged in the field of applied geochemistry. They are Regular AAG Members who 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.

Pedro Acosta-Gongora
Research Geologist
Geological Survey of Norway
Leiv Erickssons vei 39
Trondheim 7040,
Norway
Membership # 4571

STUDENT MEMBERS

The Association also has student memberships. These members are students that are enrolled in an approved course of instruction or training in a field of pure or applied science at a recognized institution. Student members pay minimal membership fees.

Gabriel Cellier
Ph.D. Candidate
James Cook University
14 Leopold St, Townsville
Aitkenvale, QLD 4814
Australia
Membership #4580

Olivia Mejias
Ph.D. Candidate
University of Queensland
40 Isles Road, Indooroopilly
Brisbane, QLD 4068
Australia
Membership #4581

Max Lakanen
Queen's University
68 Gardiner St
Kingston ON K7M 1A7
Canada
Membership #4582

Gabriel Iklaga
Ph.D. Candidate
Enviro Geochemistry
12 Corvin Ter
Budapest 1011
Hungary
Membership #4583

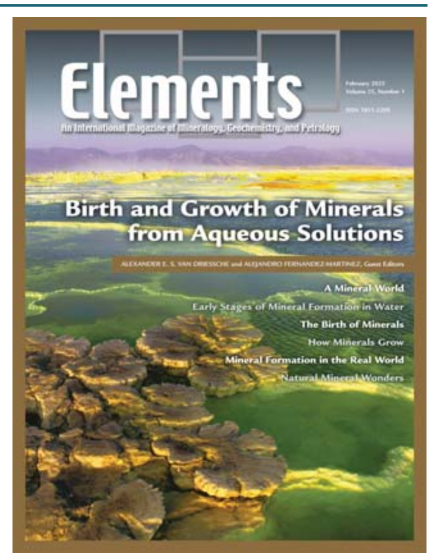
Mehran S Mamaghani
University of Tehran
Eskandari St
Tehran 021
IRAN
Membership #4573

Recently Published in Elements

February 2025, Volume 21, Number 1
Birth and Growth of Minerals from Aqueous Solutions

This issue of Elements offers a thorough synopsis of mineral formation by revising classical mechanisms and augmenting them with current insights about the nucleation and growth of minerals, particularly those regarding non-classical crystallization pathways.

There is one AAG news item in this issue of Elements, namely, profiles of AAG Councillors for 2024–2025: Mark Arundell, Patrice de Caritat, Alexander Seyfarth, Cliff Stanley, and Behnam Sadeghi.



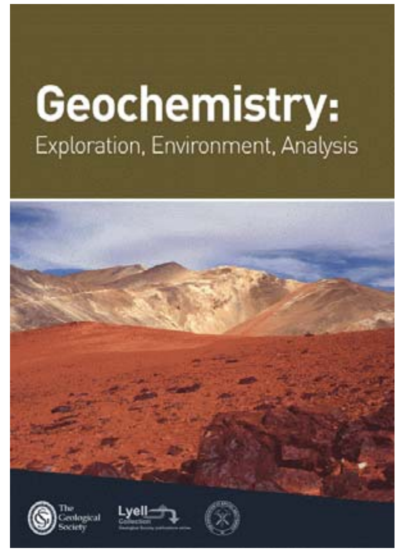
Reminder

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

Geochemistry: Exploration, Environment, Analysis

VOLUME 25, ISSUE 1, FEBRUARY 2025



A synthesis of the national-scale geochemical survey in the last 50 years in Brazil

M. Almeida, C. Couto Santos. C, J.H.Larizzatti, D. Eberhardt, S. Melo, and A. Moreira

At the end of the 19th century, classical geochemistry arrived in Brazil through Henri Gorceix, being primarily used in his studies of mineralogy and petrology. Meanwhile, exploration geochemical arrives later, in the mid-20th century. But it was only in the late 1960s that systematic survey at the national level began, starting with the creation of CPRM - Geological Service of Brazil, culminating in over 50 years of uninterrupted activities, providing coverage of the entire country at various scales: global (7.3%), national (6.2%), regional (22.7%), and local (2.3%). Throughout this period, 681 projects were carried out and a variety of sample matrices were collected, such as stream sediment (226,792), soil (122,202), heavy-mineral pan concentrate (107,959), rock (56,807), among others (8,258), totaling 522,018 samples so far. All this collection has been progressively recovered, compiled, and organized into a robust public database (open access), developed by CPRM - Geological Service of Brazil. More recently, high-density geochemical surveys were conducted in partnership with the China Geological Survey with the aim of comparing analytical and sampling methodologies. For the future (until 2050), two main actions are planned: 1) an expectation of an increase in the coverage of high-density prospecting surveys, ranging from 951,386 km^2 (restrictive scenario: 11.2% of Brazilian territory) to 2,204,778 km^2 (favorable scenario: 25.9% of Brazilian territory); 2) a forecast of Brazil's participation in the Global Geochemical Baselines Program, where sampling will be subdivided by regions – North (736), Central-West (225), Northeast (305), and South-Southeast (343) – totaling 1,609 sampling cells. (*reprinted from the journal website* https://jgsb.sgb.gov.br/index.php/journal/article/view/247)

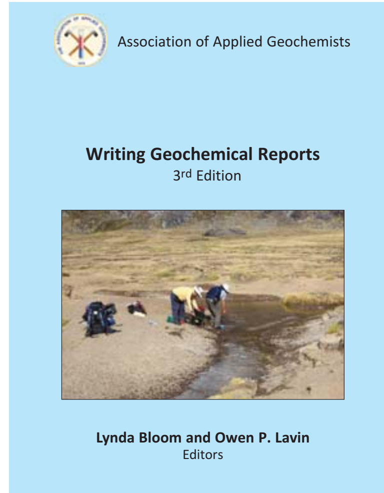
Almeida, M., Couto Santos, C., Larizzatti, J.H., Eberhardt, D., Melo, S., and Moreira, A. 2024. A synthesis of the national-scale geochemical survey in the last 50 Years in Brazil. Journal of the Geological Survey of Brazil, 7 (3), 263–75.

Free Publications Available from the Association of Applied Geochemists' Website

Writing Geochemical Reports, 3rd Edition

Guidelines for surficial geochemical surveys

Edited by Lynda Bloom and Owen Lavin



The Association of Applied Geochemists has developed international standards for writing geochemical reports that provide clear instructions for reporting geochemical results, together with the requisite supporting information to evaluate these results for accuracy, integrity and credibility.

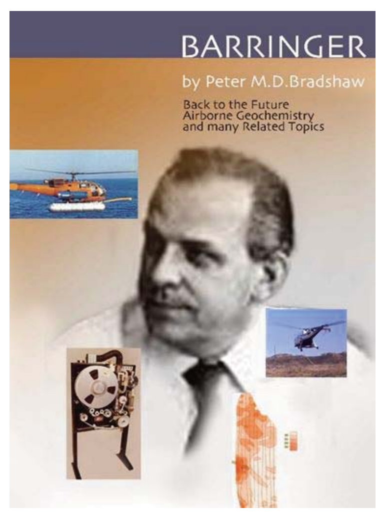
The target audience for these guidelines is anyone charged with reporting geochemical results, which includes, but is not limited to, company geoscientists, external consultants and contractors, government scientists, and university scientists and students.The guidelines focus on preparation of an electronic publication that provides a systematic and permanent record of the work performed and take into account the ability to bundle text, tables, figures, images, and oversized maps into one electronic file. The third edition of this guide was released in 2022 and expands the original mandate of Writing Geochemical Reports (1st and 2nd editions) to include multiple types of geochemical surveys with survey-specific recommendations.

The guide may be downloaded free of charge from the AAG website:
https://www.appliedgeochemists.org/publications

Barringer

Back to the Future: Airborne Geochemistry and many Related Topics

by Peter M.D. Bradshaw



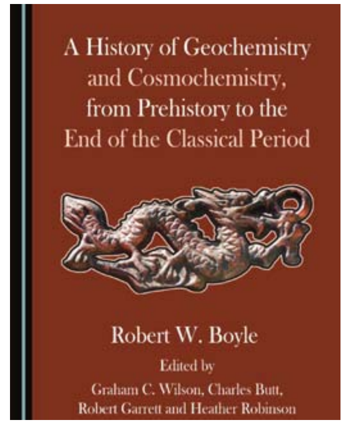
The 1960s and 70s were marked by an explosion in mineral exploration and remote sensing technology. A leader throughout this period was Dr. Anthony (Tony) Barringer and his team at Barringer Research Ltd. (BRL). The highly successful airborne geophysical methods created at BRL are well known while the contributions to exploration geochemistry and many other fields are not. This book documents the many advances in geochemical theory, as well as the ground, airborne and remote sensing techniques plus analytical methods that were conceived and developed under the leadership of Tony Barringer. Innovative concepts backed by pioneering research funded by BRL on the movement of metals in rock, soil and vegetation remain important areas of investigation.

Tony Barringer's ability to bring together a diverse team including geologists, geochemists and physicists with electrical, optical and aeronautical engineers under one roof, provide leadership, a highly stimulating environment and financial support, was truly remarkable. This led to ground breaking advances in a number of different fields, including: exploration geochemistry for minerals and oil and gas; environmental monitoring from the ground, aircraft and space; and civilian and armed forces security. The underlying scientific principles for many of the inventions, now upgraded with modern electronics, are still considered state of the art. One of the many inventions from the BRL "incubator" described in this book is Ionscan, the drug and explosive screening device used in most airports today, which was conceived and developed by BRL in conjunction with technology for the detection of mineral deposits.

The book may be downloaded free of charge from the AAG website:
https://www.appliedgeochemists.org/publications

Book release

A History of Geochemistry and Cosmochemistry, from Prehistory to the End of the Classical Period



Since Mendeleev outlined the modern periodic table in 1869, many new uses have been found for the 92 naturally occurring elements. This book travels back in time to describe the utilization of materials familiar (gold, copper, iron) and arcane (arsenic, boron, red ochre) and their practical history (mining, metallurgy, and crafts), with evidence from archaeology and geology. Together with the technological developments, author Robert Boyle portrays the advances in our understanding of materials science which led to modern geological and environmental sciences. It is a source book valuable to students of history and archaeology, mining and metallurgy, as well as to geologists, mineralogists and geochemists everywhere.

About the author, Bob Boyle (1920–2003)

Bob was a pioneer of the application of geochemistry to mining geology and mineral exploration. He was an eminent geochemist with a long career at the Geological Survey of Canada where he initiated the Geological Survey of Canada's regional geochemistry program in 1957. His publications spanned various mineral-deposit types and a wide spectrum of precious and base metals. Bob was a founding member of the Association of the Applied Geochemists in the 1970s, and was awarded the Association's highest honor, the Gold Medal, in 1999 in recognition of his lifetime of outstanding achievement in exploration geochemistry. Among Bob's many achievements and awards was his induction into the Canadian Mining Hall of Fame in 1997.

The book is available at: https://www.cambridgescholars.com/product/978-1-5275-7614-8

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.

2025

20–21 March	GEMS 2025 - International Conference on Geology Engineering and Marine Sciences. Wuhan, China. Website: gems.isgcpi.com/
23.–27 March	American Chemical Society Spring Meeting. San Diego, California, USA. Website: https://www.acs.org/meetings/acs-meetings/spring.html
1–4 April	GSA, 2025, Cordilleran Section Meeting. Sacramento, California, USA. Website: https://www.geosociety.org/GSA/Events/Section_Meetings/GSA/Sections/cd/2025mtg/home.aspx
27 April – 2 May	European Geosciences Union, EGU, EGU 2025, European Geosciences Union General Assembly. Vienna, Austria. Website: egu25.eu/
5–7 May	14th International Congress of Prospectors and Explorers, proEXPLO2025. Lima, Peru. Website: https://proexplo.com.pe
11–14 May	Geological Association of Canada, GAC-MAC-IAH-CNC, Annual Meeting. Ottawa, Canada. Website: https://event.fourwaves.com/ottawa2025/pages
11–15 May	EMAS 2025. 18th European Workshop on Modern Developments and Applications in Microbeam Analysis. Mataró, Spain. Website: https://www.microbeamanalysis.eu/
3–5 June	25th North American Workshop on Laser Ablation. Knoxville. Tennessee, USA. Website: https://www.nawlaworkshop.com/
16–21 June	Third IAGC International Conference (IAGC-3), Water-rock interaction 18 & Applied isotope geochemistry 15. Cagliari, Italy. Website: https://www.unica-wri-18.it/
6-11 July	Goldschmidt 2025 Conference. Prague, Czech Republic. Website: https://conf.goldschmidt.info/goldschmidt/2025/meetingapp.cgi
16–21 July	Third IAGC International Conference (IAGC-3). Cagliari, Italy. Website: https://www.unica.it/wri-18/
3–7 August	18th SGA Biennial Meeting, Golden, Colorado, USA. Website: sga2025.org
8–11 September	Australasian Exploration Geoscience Conference 2025. Perth, Australia. Website: https://2025.aegc.com.au/
8–12 September	Eurosoil 2025. Seville, Spain. Website: soilscience.eu/eurosoil-2025
26–29 September	Society of Economic Geologists, SEG 2025. Brisbane, Australia. Website: www.seg25.org
19–25 October	Geological Society of America Annual Meeting. San Antonio, Texas, USA. Website: https://community.geosociety.org/gsa2025/home

2026

26–29 January	Association of Mining and Mineral Exploration BC (AMEBC) Cordilleran Round Up Convention. Vancouver, British Columbia, Canada. Website: roundup.amebc.ca/
12-17 July	Goldschmidt 2026 Conference. Montreal, Quebec, Canada. Website: *forthcoming*

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.
- **Photos** (colour or black and white) should be submitted as separate high-resolution (minimum 300 dpi at the scale of reproduction) PNG, TIFF, JPEG or PDF files.
- **Figures** should be submitted as separate EPS, PDF or original software (e.g. CDR, AI) files.
- **Tables** should be submitted as separate digital files in Microsoft EXCEL® format (i.e. XLS).
- 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 the article. This abstract will be published in the journal *Elements* in the Society News page in the back of each issue.

Submissions should be sent to the Editor of **EXPLORE**:
Beth McClenaghan
Geological Survey of Canada 601 Booth Street, Ottawa, ON, CANADA K1A 0E8
Email: bethmcclenaghan@sympatico.ca