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Sinclair: Australia's First Caesium Deposit: Discovery and Exploration Implications

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INTRODUCTION

The Sinclair caesium deposit, discovered in 2016, delineated in 2017 and developed in 2018, is Australia's first mining operation to commercially extract the caesium-rich mineral, pollucite, and represents a globally important discovery. As commonly noted (e.g., Trueman *et al*., 2020), known economic caesium deposits are extremely rare with only three known mining operations having reported commercial quantities of pollucite; Bernic Lake Mine (Manitoba, Canada), Bikita Mine (Zimbabwe), and the Sinclair Mine (Western Australia).

The formation of pollucite only occurs in extremely differentiated, complex lithium-caesium-tantalum (LCT) pegmatites and given their size and rarity, caesium-rich deposits globally are either challenging to explore for or failed to form during the emplacement of the LCT pegmatite. The discovery and development of the Sinclair caesium mine, described in detail by Batt *et al*. (2020) has provided a rare opportunity to examine an extremely differentiated, complex LCT pegmatite with applied technologies to provide insight for future exploration and discoveries of economic caesium deposits.

DISCOVERY

The announcement of a significant caesium (Cs) intersection (6 m at 25.7% Cs_2O) associated with lithium-caesium-tantalum (LCT) pegmatites on the Pioneer Dome was reported by Pioneer Resources Ltd. on 17th October 2016 (Pioneer Resources Ltd. 2016a). Follow-up drilling delineated a cluster of pollucite lenses, named the Sinclair Caesium Deposit (Sinclair), with an initial Mineral Resource Estimate of 10,500 tonnes of the caesium ore, pollucite with a grade of 17.1% Cs_2O (Pioneer Resources Ltd. 2017). The commencement of mining operations was reported on 13th September 2018 (Pioneer Resources Ltd. 2018), less than 2 years from discovery.

Pollucite [$(Cs,Na)_2(Al_2Si_4O_{12})\ 2H_2O$] is a rare mineral with a high value attributed to its high caesium content (~29.66% Cs_2O), which forms in extremely differentiated LCT pegmatite systems. Global supply is very constrained and world resource estimations are unavailable (USGS 2020). Caesium chemicals are sold in limited quantities under confidential contracts so a true market price is unavailable.

Caesium is used in the production of photoelectric cells, energy conversion devices, such as fuel cells, magneto-hydrodynamic generators, and polymer solar cells; however its main use is in the manufacture of caesium formate brine, a heavy liquid (1.8 to 2.4 g/cm^3) used in high-pressure, high-temperature well drilling for oil and gas.

LOCATION AND GEOLOGICAL SETTING

The Sinclair caesium deposit is located 35 km north-northwest of Norseman in Western Australia (Fig. 1a). The mine is located within the Archaean-aged Yilgarn Craton of Western Australia, within the Coolgardie Domain of the Norseman – Wiluna Greenstone Belt, which contains several significant spodumene deposits, including Mt Marion and Bald Hill.

The Pioneer Dome is defined by a granitoid core that has intruded older Archaean-aged gneiss (Fifty Mile Tank Gneiss) and a greenstone sequence. The greenstone sequence comprises a mafic suite (black shale, ultramafic and mafic volcanics, and gabbro intrusions), which in turn has been stratigraphically overlain by a thick sedimentary sequence (Fig. 1b). Pegmatite bodies have preferentially intruded into the greenstone sequence. The Pioneer Dome and surrounding lithoscape has been metamorphosed to greenschist and lower-amphibolite facies and has been multiply deformed resulting in isoclinal folding (Griffin 1989).

At least 13 clusters of pegmatites, including LCT pegmatites, have been identified along a 20 km strike length on the eastern flank of the Pioneer Dome (Fig. 1c). The East Pioneer pegmatite corridor comprises a narrow (<1 km wide) mafic suite of rocks trending roughly north-south, faulted up against the Fifty Mile Tank Gneiss. This corridor is dominated by strong north-south cleavages and pegmatite dykes occur in both the gneiss and greenstones (Griffin 1990). To date the only available age determination is of the Fifty Mile Tank Gneiss dated at ≥ 2664 ± 5 Ma (Nelson 1997).

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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**:

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ADVERTISERS

Notes from the Editor

Welcome to the first **EXPLORE** issue of 2021. This issue features an article about the discovery of the Sinclair caesium deposit in Australia and the exploration implications. The article was written by Nigel Brand, David Crook, Stuart Kerr, Sophie Sciarrone, Naomi Potter, Christabel Brand, and Geoffrey Batt. A second article, written by Theo Davies, describes how recent applied geochemistry research in Africa contributes towards the understanding of causal cofactors of diseases of unknown aetiology. Bob Garrett has contributed a thoughtful note about minor elements.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue, listed in alphabetical order: Steve Amor, Dennis Arne, Al Arsenault, Geoffrey Batt, Nigel Brand, Christabel Brand, John Carranza, Steve Cook, David Crook, Theo Davies, Bob Garrett, Stuart Kerr, David Leng, Dave Lentz, Paul Morris, Naomi Potter, Jessey Rice, Sophie Sciarrone, and Dave Smith.

Beth McClenaghan
Editor

President's Report

The start of 2021 brings us five AAG Council members who will serve two-year terms, from 2021 to the end of 2022. They are:

Patrice de Caritat (2nd term)
Dave Heberlein (2nd term)
Ryan Noble (1st term)
Pim van Geffen (1st term)
Paul Morris (1st term)

I would like to thank Patrice and Dave for standing for another two-year term, and Ryan, Pim and Paul for agreeing to serve on Council. For Ryan and Paul this will be the 2nd time round, as well as having served as past Presidents. The important work of running the AAG is done by Council and its various committees. I would encourage Fellows to stand for nomination for the period 2022-2023, and Ordinary members to upgrade to Fellow status so that they can stand for Council and help determine the future direction of the AAG.

I would also like to congratulate Dr Robert (Bob) Garrett for being awarded an Honorary Fellowship following a formal nomination by his peers, approval by the Awards and Medals Committee, and ratification by Council. Bob is only the 8th AAG member to ever receive such an honour and joins Gwendy Hall as the only other current Honorary Fellow. Both are deserving recipients for their long service to our profession.

It is also my pleasure to congratulate Professor Cheng Qiuming as recipient of the AAG gold medal for 2020. Qiuming is the founding director of the State Key Lab of Geological Processes and Mineral Resources, China University of Geosciences (Beijing). The Gold Medal is awarded for outstanding scientific contributions and achievement in applied geochemistry.

The AAG and the International Association for Mathematical Geosciences (IAMG) have formally signed a Memorandum of Understanding between the two societies to foster cooperation. There is already some cross membership between the two societies and much to be gained through further interaction. One benefit is that each society can contribute to each other's newsletters, so if any AAG members have suitable content they should feel free to contact the editor, Katherine Silversides, at newsletter@iamg.org. Thanks goes to John Carranza for pushing this along.

In other news, the Society for Geology Applied to Mineral Deposits (SGA) has announced the postponement of their 16th biennial meeting in Rotorua, New Zealand from November, 2021 to a new date of March 28-31, 2022. The AAG is a co-host of the conference and has agreed to sponsor an exploration geochemistry workshop (Wahid Salama – coordinator) and a session on spatial data analysis for mineral exploration (Dr Arianne Ford and Dr John Carranza, co-convenors). We hope that international travel restrictions to New Zealand will have eased sufficiently by then for the conference to be well attended.

We have also submitted a proposal to the Australasian Exploration Geoscience Conference (AEGC) to conduct a 2-day short course in exploration geochemistry at their conference in Brisbane in September 2021. As the conference is of local interest and there is potential for a travel bubble between Australia and New Zealand later this year, we hope that this conference may proceed with a live venue and that the AAG will have several members there to contribute to the short course.

Which brings me to the IAGS scheduled for later in 2021. The local organizing committee (LOC), under the guidance of Brian Townley, has been keeping a close eye on the roll-out of vaccines in Chile. Vaccines are well advanced on a global scale, but there are concerns that international restrictions on travel and budgetary constraints will limit attendees in person. For these reasons, we are planning a hybrid model for the conference that would allow participants to join live sessions online. This is likely to be a model going forward for future IAGS given the advances in both the technology and our recent acclimatization to its use. The LOC has further suggested that we consider postponing the IAGS for another year, instead holding it in October 2022, to ensure that as many people as possible can attend. The AAG Executive are in favour of this suggestion and Council will discuss this at their March meeting. A formal announcement will be made in due course.

Dennis Arne
President

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The pegmatite wall zones typically consist of quartz, K and Na feldspars, and muscovite, while core zone minerals include biotite, lepidolite, petalite, pollucite (where present), tourmaline, and beryl. Less deformed pegmatites consistently cut more deformed pegmatites, which suggest that there were several episodes of pegmatite intrusion.

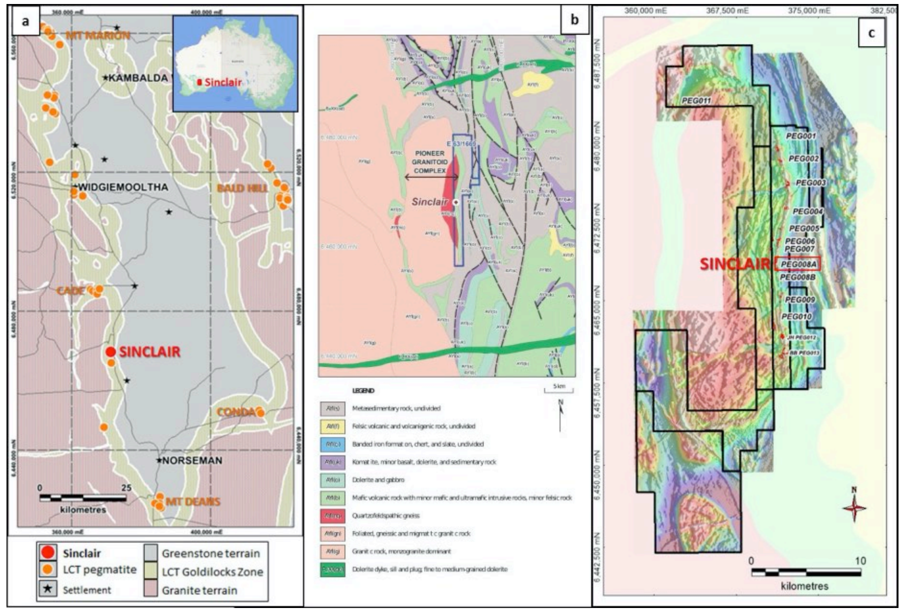

Figure 1. (a) Regional location map of the Sinclair deposit showing the granite-greenstone terrane and the known LCT-pegmatite occurrence located within the greenstone "Goldilocks Zone", (b) Regional geology of the Pioneer District, after Myers et al. (1998), (c) Distribution of Pioneer Dome pegmatite clusters.

EXPLORATION METHODOLOGY

Targeting spodumene-bearing pegmatites, conventional grid soil (-80 mesh) samples were collected over mapped pegmatite clusters within the mafic-ultramafic stratigraphy of the East Pioneer "Goldilocks" pegmatite corridor. Initial results obtained from standard geochemical analysis of soils by 4-acid digest confirmed the presence of coincident Li, Nb, and Rb anomalies over PEG06 and PEG09, with the latter body having lepidolite in surface float (Pioneer Resources Limited 2016c). All subsequent soil samples were initially analysed by field-portable X-ray Fluorescence Spectrometry (pXRF) instrumentation. This technology is commonly used in mineral exploration to provide instantaneous assessment of key element concentration, but is unable to resolve the concentrations of elements lighter than sodium, which has an atomic number of 11. Lithium (with an atomic number of 3) is thus not directly detectable by pXRF instruments. To address this limitation, correlation of observed Li content with a co-existing suite of 5 elements (Rb, Nb, Ta, Ga, and Cs) resolvable by pXRF in the initial round of geochemical results was used to derive an experimental algorithm (Li-Index) to estimate Li content by proxy. Where initial pXRF analysis returned an elevated Li-Index value, results were validated by conventional four-acid digest. Evaluation of the Li-Index against standard geochemical assays for lithium in these validation tests demonstrated a similar spatial distribution (Figure 2) with a correlation coefficient r^2 >0.84 (Brand & Brand 2017).

Data for over 7,200 soil samples were used to identify nine high priority targets including PEG008a, host to the Sinclair and 15 mid-rank targets within the 13 pegmatite clusters.

Following rock chip sampling and field mapping of PEG008a (Fig. 3), commencement of an inaugural 5000m RC drilling program in mid-2016 (Pioneer Resources Limited 2016b) identified both high grade lithium and caesium (Pioneer Resources Limited 2016a) with PDRC015 (6 m at 27.7% Cs_2O from a depth of 47 m) being the discovery hole for the Sinclair Zone Caesium Deposit.

During the delineation and development of the Sinclair Mine, in addition to conventional four-acid digest ICP-MS and fusion XRF assays, a range of both readily available and innovative technologies were applied in defining the deposit character including portable Raman spectroscopy (pRaman), short-wavelength infrared spectroscopy (SWIR), Fourier-transform infrared spectroscopy (FT-IR), portable XRF (pXRF), and micro-XRF (µXRF). The application of these technologies proved invaluable during the development of Sinclair as with a small resource of the pollucite and consequent short mining operational cycles, rapid assay turn-around and mineral confirmation was of paramount importance.

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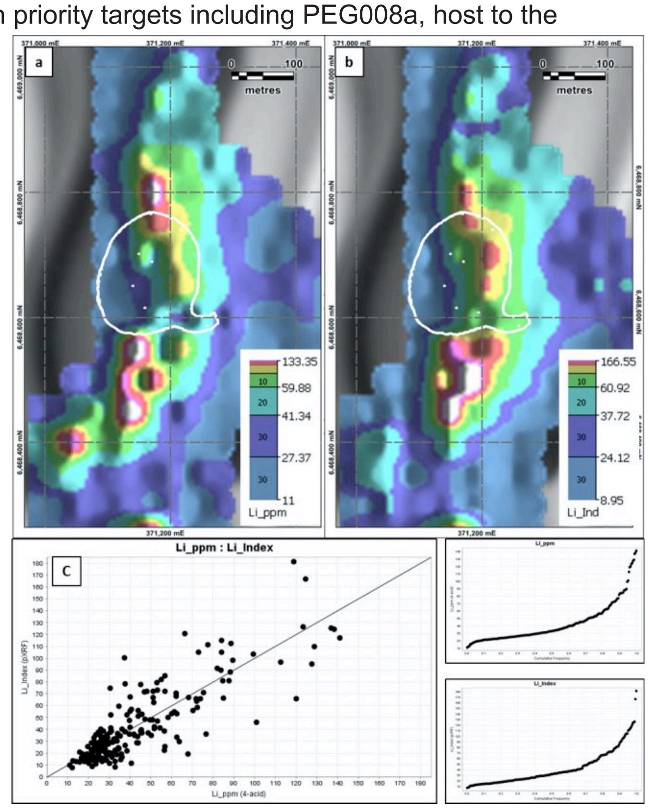

Figure 2. Image of lithium in soils over PEG008a (a) 4-acid digest ICP-MS, (b) pXRF Li-index with the Sinclair pit outline (white) for spatial context, (c) element probability plots and correlation (r^2 = 0.84) between Li and pXRF Li-Index.

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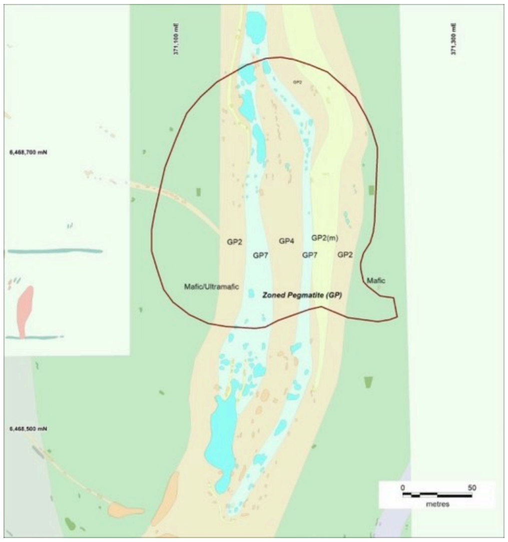

Figure 3. Detailed 1:1,000 mapping of PEG008 completed by Pioneer Resources Ltd. subsequent to the discovery of the Sinclair resource. Outline of final Sinclair pit rim shown by solid maroon line for spatial context. GP2, Pegmatite Wall Zone; GP4, Pegmatite Intermediate Zone (Microcline); GP7, Pegmatite Core Quartz Zone.

Grade control sampling during mine development was undertaken using a matrix-match Cs calibration on a countertop Bruker CTX XRF instrument. This instrument provided a comprehensive and virtually immediate geochemical monitoring capacity for sampled materials, which were confirmed by fusion XRF data post mining (Brand *et al*. 2019a).

To aid in the identification and mapping of mineralogical zones at Sinclair and in the surrounding Pioneer Dome LCT pegmatites, pRaman application was developed based on a spectral library of LCT-minerals prepared from the Sinclair system. Tested against 8,000 pRaman and FT-IR spectra collected from RC and diamond drill core and an additional about 2,000 grade control samples covering the economically important lower economic Li and Cs zones in the Sinclair Caesium Mine, this field-portable spectral methodology was able to provide rapid and robust identification of the key mineralogy present in the LCT pegmatite systems, including routine differentiation of pollucite and the key lithium silicates, eucryptite and petalite (Fig. 4), and reliable identification of the dominant components and corresponding mineralogical zonation of samples from the Sinclair system (Brand *et al*. 2019b).

Integrated results from pXRF and pRaman analysis of the Sinclair pegmatite are able to define the central core, being discrete pollucite pods (GP8), the flanking high-purity quartz (GP7), and discrete lepidolite (GP9) with the intermediate albite (cleavelandite), zinnwaldite, petalite, and eucryptite zone (GP6) occurring further outboard (Perring & Brand 2019).

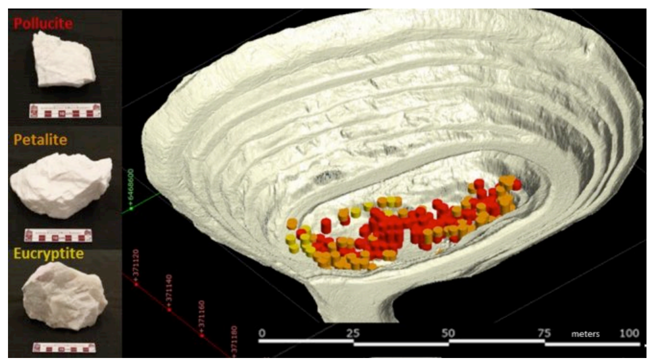

Figure 4. Distribution of pollucite (red), petalite (orange), and eucryptite (yellow) within the Sinclair Pit identified by pRaman spectroscopy during mine development.

SINCLAIR LCT PEGMATITE

Pegmatite lithogeochemistry

Benchmarked against known LCT pegmatite systems, the host pegmatite of Sinclair shows a unique chemistry of elevated Cs:K ratio, which is very distinct when compared with to petalite dominant and spodumene dominant pegmatite systems, reflecting it's extreme fractionation (Fig. 5).

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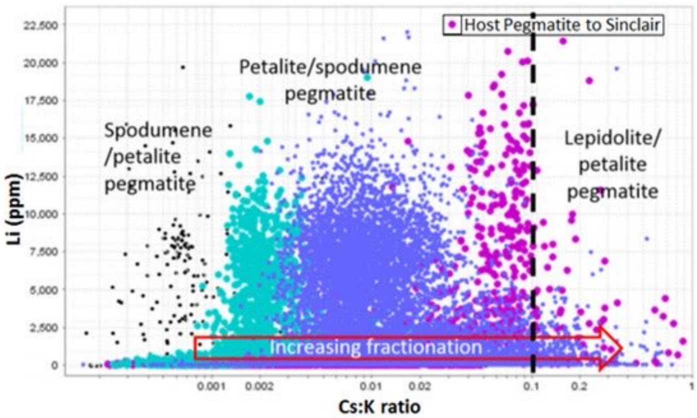

Figure 5. Plot of Cs:K ratio vs Li from three LCT pegmatites showing the extreme fractionation undertaken at Sinclair (purple).

As documented in literature (e.g. Černý *et al*. 1981), the K:Rb ratio is an efficient vector to map out the fractionation of an LCT pegmatite system. Plotting the Sinclair deposit data on to a Cs vs K:Rb scatter plot (after Breaks *et al*. 2003) graphically depicts the fractionation trend of the pegmatite (Fig. 6a) and the intimate relationship of Cs and Li. This is further emphasized by plotting the pegmatite zones from the discovery hole (PDRC015) on a Cs vs K:Rb scatterplot (Fig. 6b).

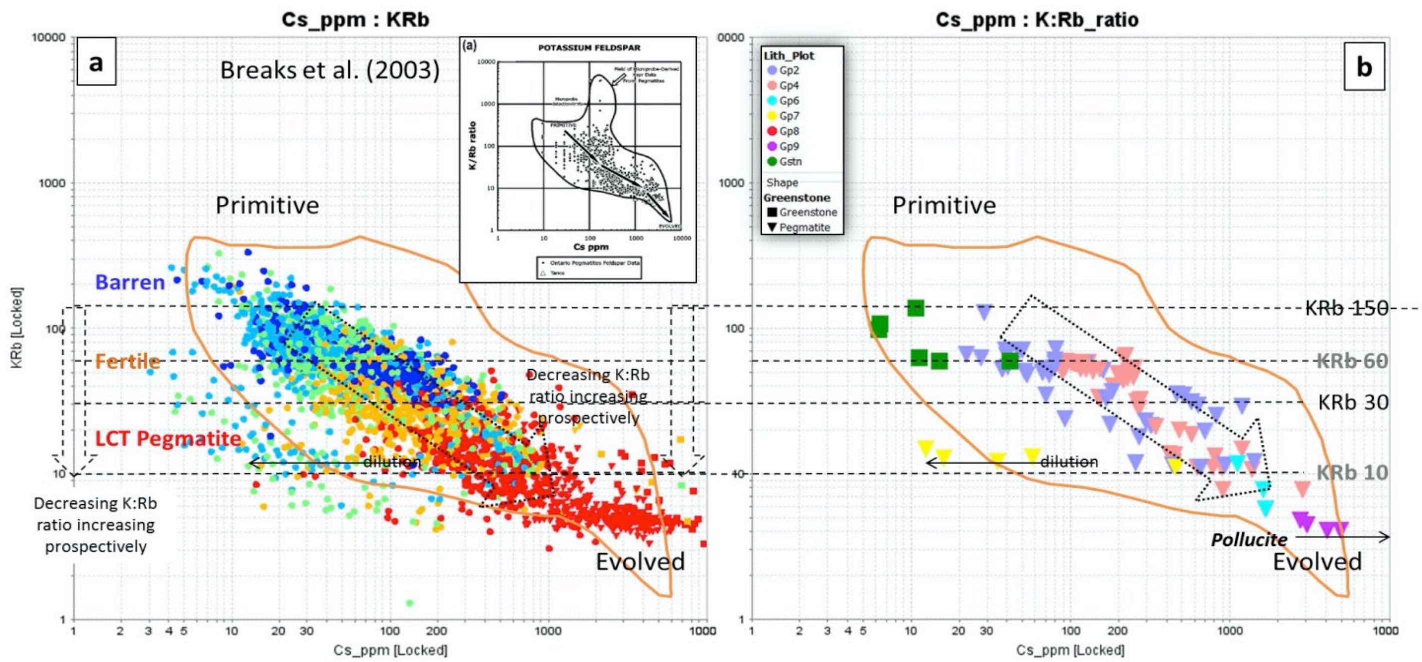

Figure 6. Plot of Cs vs K:Rb scatter plot showing general fractionation trends modified after Breaks et al. (2003) (insert); (a) all Sinclair drill data coloured by lithium (blue low, red elevated), (b) discovery hole, PDRC015 coloured by pegmatite zones (pollucite plots to the right of the diagram).

Down-hole plots of PDRC015 shows both the footwall (GP2) and hanging wall (GP4) having decreasing K:Rb ratio through their respective zones into the core of the mineralized pegmatite hosting pollucite – lepidolite (Fig. 7). Both Cs and Rb are significantly elevated within the GP4 - hanging wall and GP2 – footwall. Although there is a statistical relationship between these two elements, they are hosted by different mineral phases; Rb is hosted in microcline whereas the Cs forms a primary dispersion front associated with Mn (Potter & Brand 2019).

Geology and mineralogy

Common with the Bernic Lake and Bikita deposits, the Sinclair deposit's host LCT pegmatite consists of an outer pegmatite wall zone that is coarse grained, and dominated by plagioclase feldspar, muscovite, and quartz with accessory garnet, tourmaline, and beryl and an inner core zone composed of, in decreasing order, quartz, albite (cleavelandite), lepidolite, pollucite, petalite, zinnwaldite, eucryptite, beryl, amblygonite, and topaz. The core zone is 'capped' by a thick (~35-40m) monomineralic potassium feldspar zone (Fig. 8).

The pollucite mineralisation (GP8) is monomineralic, similar to the Bernic Lake deposit (London 2018), and forms small (~2-10m) discreet pods (Figure 9) spatially associated with albite (cleavelandite), lepidolite (GP9), petalite (GP5), and quartz (GP7). To date petalite (and eucryptite) are the key Li-silicate minerals present at Sinclair with only very rare instances of spodumene detected, unlike pollucite zones described from Tanco (Stilling *et al*. 2006) and Bikita (Dittrich *et al*. 2018).

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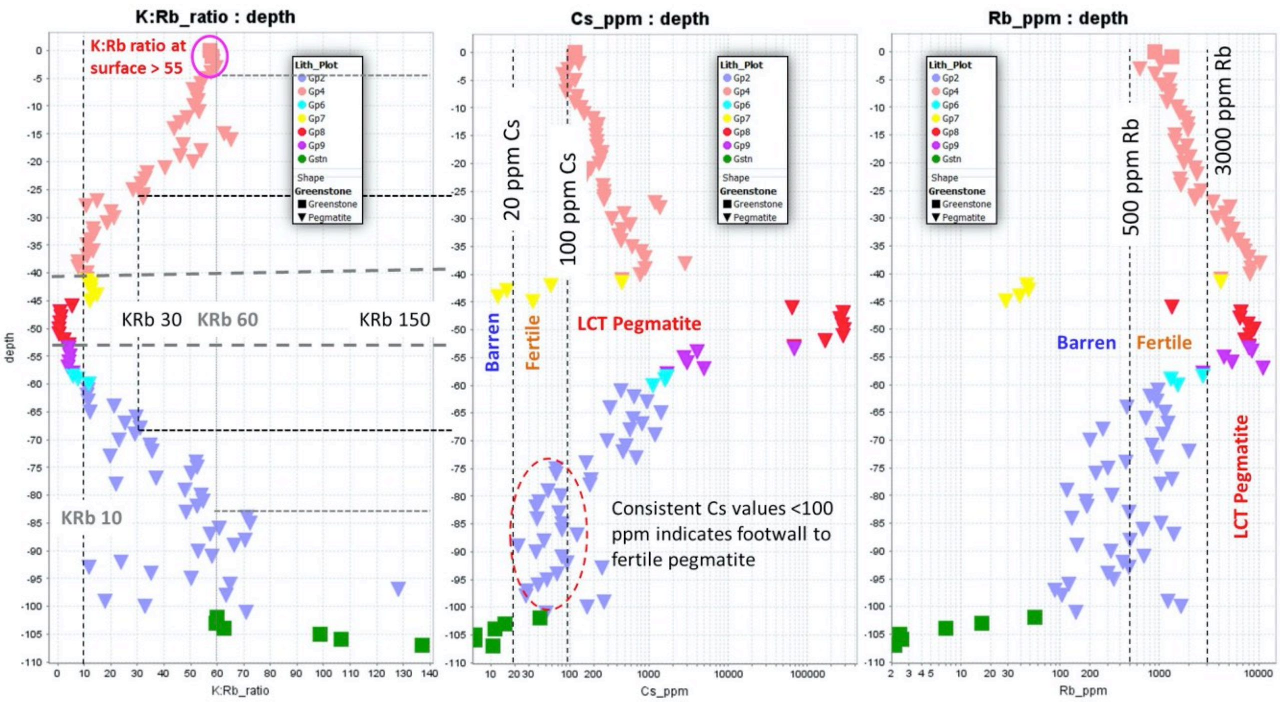

Figure 7. Down hole plots (depth in metres, m) from the discovery hole (PDRC015) showing deceasing K:Rb trend into the pegmatite core associated with increasing Cs and Rb concentrations.

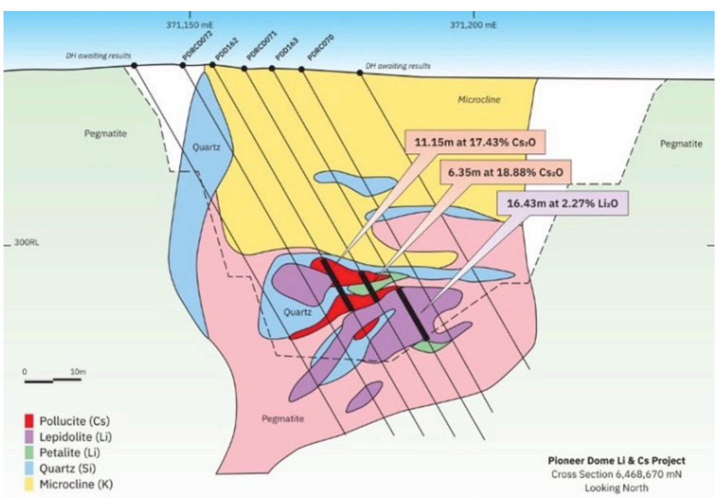

Figure 8. Geological cross section of Sinclair at 6468670m N with diagrammatic pit outline.

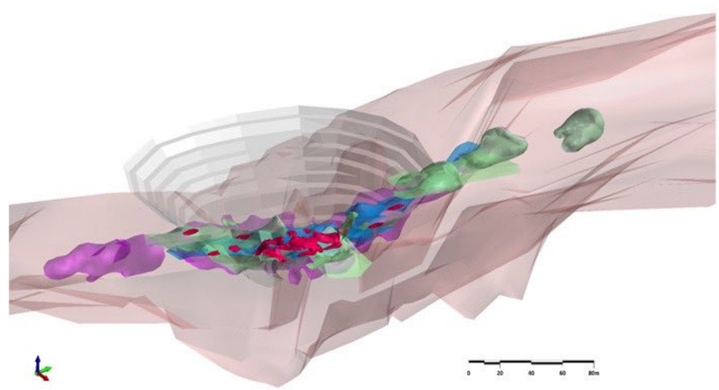

Figure 9. 3D model of selected mineralized domains within PEG008 prior to mining of the Sinclair Pollucite Zone. Pegmatite host body shown by peach-coloured envelope, with Core Pollucite Zone (GP8) shown in red, Core Petalite Zone (GP5) in green, Core Lepidolite Zone (GP9) in purple, and Core Quartz Zone (GP7) in blue. Final pit wireframe overlain for spatial context.

Chemical and mineral zonation in the pegmatite core

During the development of the Sinclair Mine, the use of the CTX pXRF instrument provided a comprehensive geochemical dataset and the pRaman, used to identify lithium silicate minerals (e.g., petalite, eucryptite), provided a comprehensive mineral data set.

Integrating the results, Figures 10a & 10b show a central core of discrete Cs pods (pollucite) associated with Si flanks (quartz) zoned by elevated Rb (lepidolite and microcline) with an outer flank of Mn (Zinnwaldite) and Ca (cleavelandite). Figure 10c, a long section through the deposit, shows the pollucite zone is capped by the overlying monomineralic potassium feldspar zone with basal Rb enrichment. Phosphorous-rich zones map out amblygonite, which has developed beneath the lepidolite (Rb) and appears to be breached by Cs (pollucite) potentially indicating deeper pods or a feeder conduit.

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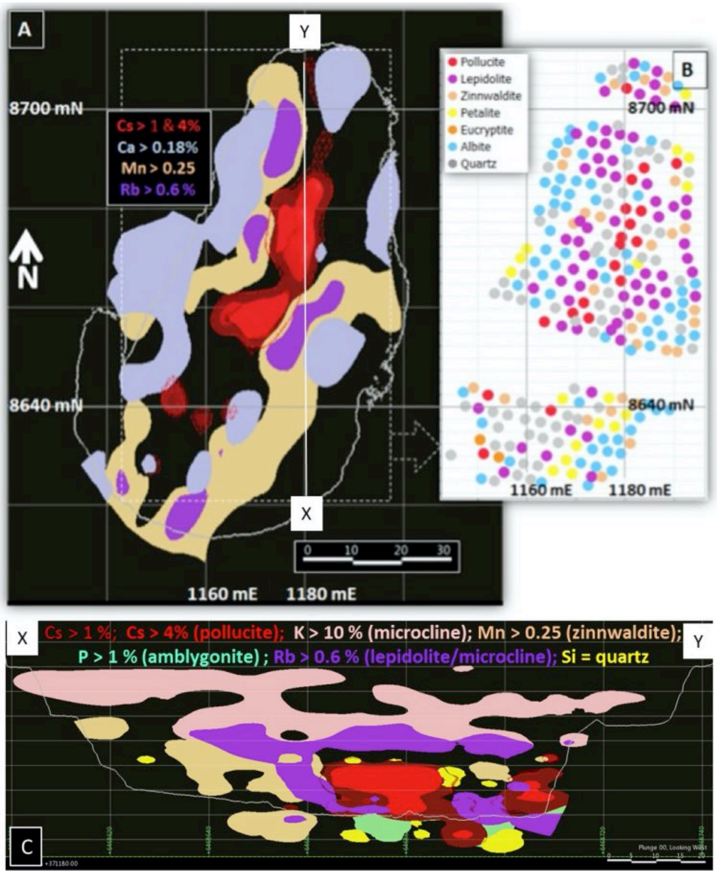

Figure 10. Chemical and mineral zonation in the pegmatite core; (a) plan section of Sinclair at 295 m RL showing selected element concentration analyzed by pXRF, and (b) dominant mineral phase identified by pRaman spectroscopy, (c) long section of Sinclair at 1180mE showing the zonation and monomineralic microcline cap enriched in Rb at its base.

Pegmatite weathering

Published data on pegmatite weathering, associated regolith development and landscape evolution is rare to non-existent; this is a sizable knowledge gap when exploring for LCT pegmatites in deeply weathered terrains such as the Yilgarn Craton.

During the development of the Sinclair Deposit, zones of weathered pollucite were encountered, typically associated with contacts and structures along which groundwater had penetrated. Weathered material collected during mining was investigated using X-ray diffractometry (XRD) and µXRF. The breakdown product of pollucite formed an inner white and outer pink phase (Fig. 11) both were confirmed by CSIRO as montmorillonite. The µXRF mapping shows the catastrophic loss (leaching) of Cs at the weathering interface with manganese associated with pink montmorillonite. Lepidolite veinlets remain unaltered, enriched in Rb and K. Had all the pollucite been converted to montmorillonite clay, an array of pods or miarolitic (clay filled) cavities (London 2018) would have formed along the Sinclair center line.

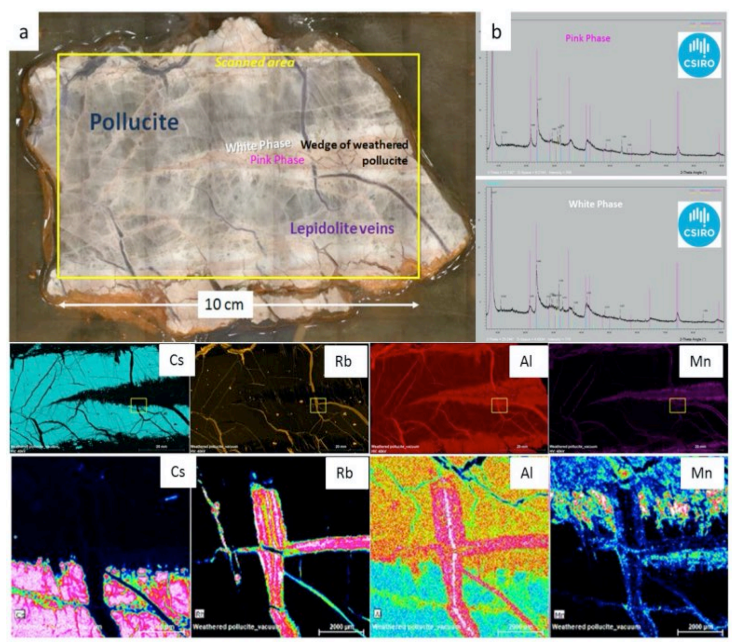

Figure 11. (a) weathering pollucite set in resin with XRD traces showing the montmorillonite as the weathered phases (b) µXRF element maps (Cs, Rb, Al, Mn) of the entire sample and zoomed in element concentration maps of Cs showing the weathering front and the catastrophic loss of Cs, Rb mapping out the lepidolite veinlets, Al mapping out the lepidolite vein, and montmorillonite and Mn front giving the pink colour to the montmorillonite.

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DISCUSSION AND EXPLORATION IMPLICATIONS

Initially routine soil sampling analyzed by conventional 4-acid digestion ICP-MS resulted in the development of the Li-Index pXRF calibration that enabled rapid screening of samples in the field to identify priority drill targets. Drilling of these targets resulted in the discovery of Cs at Sinclair. This discovery has provided an opportunity to investigate and thus improve our understanding of this style of mineralization utilizing extensive exploration and mining data sets to develop models for future discoveries.

The Sinclair surface soil results are low order (max Cs, 100 ppm; max Li, 141 ppm) producing a coherent and robust anomaly extending for over 450m (Cs > 20 ppm; Li >50 ppm) and are offset to the up-dip projection of the known mineralization (Figure 12).

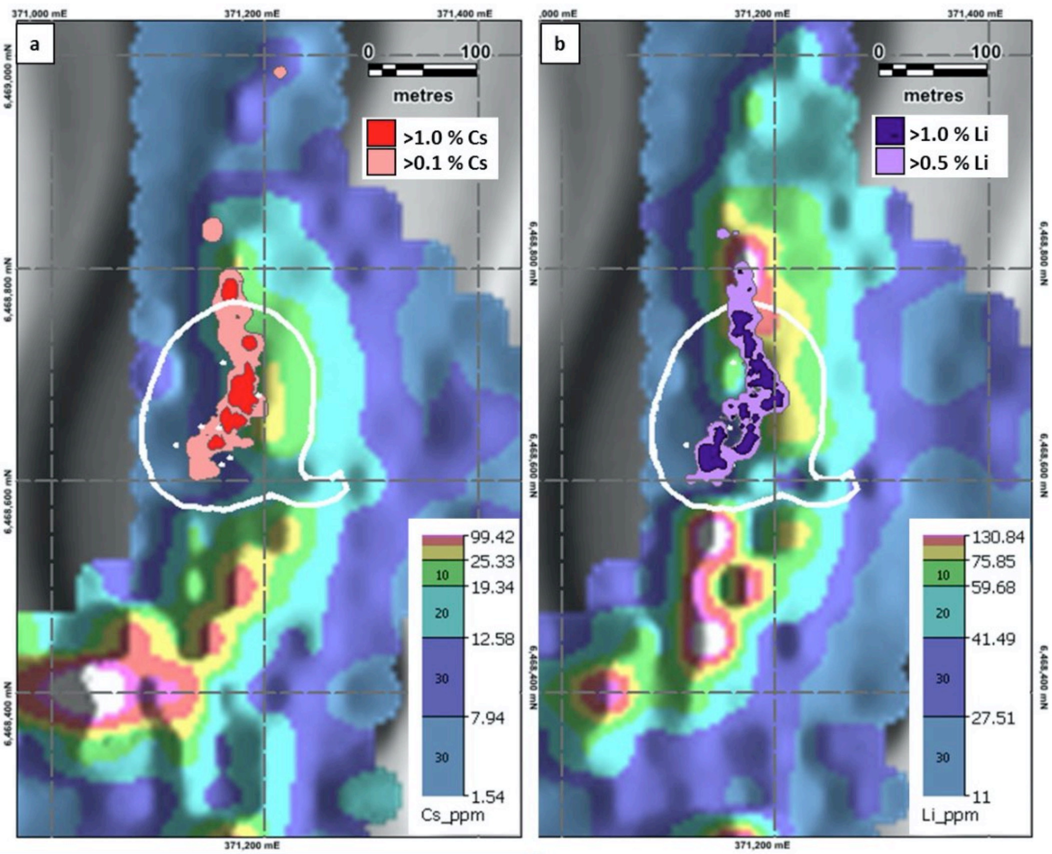

Figure 12. Image of surface soil response (4-acid/ICP-MS) and projection of the drill results (4-acid/ICP-MS) (a) caesium, (b) lithium with the Sinclair pit outline (white) for spatial context.

Lithogeochemistry enabled a precise understanding of which pegmatite zone was intersected and enhanced vectoring into the pegmatite core identifying "near misses", such as Rb enrichment in the outer zones. Although not undertaken, the leaching of Cs from pollucite during weathering would suggest water sampling could be utilized on a regional and local scale.

During the delineation of the resource a significant effort was undertaken to develop other field portable, rapid analytical systems (e.g., pRaman) that aided the development of the resource and will contribute to future exploration. Collaboration between Pioneer Resources and Portable Spectral Services (previously Portable XRF Services) to develop and calibrate field portable systems provided fit-for-purpose, "real time", and inexpensive chemical and mineralogical data which became invaluable during the short mining cycle of Sinclair. Following the mining of Sinclair, regional exploration continued utilizing the pRaman and Li-Index pXRF calibration resulting in the identification of the spodumene in Dome North (Pioneer Resources Limited 2019) and the discovery of Cade Spodumene Deposit containing 11.2 Mt at 1.21% Li_2O (Essential Metals 2020).

Acknowledgements

The authors wish to acknowledge the effort of Pioneer Resources Limited staff, consultants and contractors associated with the discovery, delineation, and development of Sinclair, Australia's first caesium mine, and the continued and ongoing support from Essential Metals Limited (previously Pioneer Resources Limited) Board of Directors. CSIRO is thanked for providing XRD data on the weathered pollucite. David Lentz is thanked for his review of the manuscript.

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Recent applied geochemistry research in Africa contributes towards understanding causal cofactors of diseases of unknown aetiology*

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SUMMARY

In the past few years, there has been increasing realisation of the importance of the possible role of geochemical variables as causality cofactors of diseases of unknown *aetiology (DUA) as well as occasional disease outbreaks in various geographical regions of Africa. This relationship has triggered a flurry of research initiatives on the Continent in understanding the geochemical fluxes of both nutritional and potentially toxic elements (PTEs) in the groundwater-soil-food crop continuum, that largely define the nutritional quality of the African diet, and hence the correct balance of micronutrients and vitamins in metabolic processes.

WATER, SOIL AND AIR POLLUTION

By far the largest volume of applied geochemistry research in Africa over the last 3 to 4 years (2017 - 2020) has centred around an understanding of the geochemical circulation of nutritional and potentially toxic elements (PTEs) in the water, soil and air environments (Table 1). This is consistent with the growing realisation of the important role of nutritional elements in shaping the diet, the criticality of their ‘‘optimal range’’ of intake in metabolic processes and hence, in warding off disease (e.g., Failla 2003). In the same way, knowledge of the fluxes of PTEs in the water, soil and air environments is essential for designing nutrient management strategies that would limit their (PTE) entry into the food chain.

Projects involving pollution studies of the water, soil and air environments have been conducted with respect to the source of pollutants - from agricultural activities, industrial activities, mining, leachates from dumpsites, and so on. These studies have been widely supported in recent years, thanks to a favourable shift in international funding policies. For example, results from the completed UNESCO/SIDA funded IGCP 594 and 606 projects on: ‘Environmental Health Impacts of Mining (on the water, soil and air environments) in Africa’ have been compiled in two Special Issues of the Journal of Geochemical Exploration (JGE): (Kribek *et al*. 2014, v. 144, Part C; and Toteu *et al*. 2019, v. 204/205), both of which have, since publication, experienced an extraordinary download rate.

Water Pollution

Groundwater obtained from wells and boreholes constitutes the main source of drinking water for many African communities; but this water is often of low quality since many of these wells are located close to sanitary facilities (Fayiga *et al*. 2018). Thus, much of the recent research on water chemistry and pollution in Africa has centered around the detection of unacceptably high values of PTEs in water bodies; in particular, those from which drinking water is tapped. The objective of these studies has been to decipher the health implications and proffer mitigative measures (e.g., Gilbert *et al*. 2017; Enitan *et al*. 2018; Adewoyin *et al*. 2019; Nwankwo *et al*. 2020; Ricolfi *et al*. 2020).

Soil Pollution

Identified sources of soil pollution in Africa include agricultural activities, mining, roadside emissions, auto-mechanic workshop effluents, leachates from refuse dumps and e-waste (Fayiga *et al*. 2018). Oil spills are a major problem in large oil-producing African countries such as Nigeria and Angola.

Soil micronutrient (B, Fe, Cu, Mn, Mo, Se, Zn, Cl, Co, etc.) deficiencies are a major problem for crops, livestock and people, and is a subject keenly researched at present (see e.g., Hengl *et al*. 2017). So also, are the consequences of an excess of PTEs in the soil. The last few years have therefore seen a substantial rise in research effort in understanding PTE fluxes in the soils, with the objective of assessing the health implications of unacceptably high levels of these elements (see e.g., Dalton *et al*. 2018; Nde & Mathuthu 2018; Odukoya *et al*. 2018; Kapwata *et al*. 2020; Kihara *et al*. 2020; Okereafor *et al*. 2020). The British Geological Survey (BGS) Project (2015 - 2020): “Strengthening African capacity in soil geochemistry to inform agriculture and health policies” (BGS, Updated 2020) clearly embodies these objectives.

Air Pollution

Despite the increasing awareness that has produced a surge in air quality research, there is still a dearth of air quality data in Africa. Air pollution in African cities stems largely from sources that include particulates and smoke from fossil fuel combustion, vehicular emissions, roadside dust containing pathogens and indoor radon concentrations in ambient air (e.g., see Davies 2015).

***** In the field of medicine, *aetiology* or *cause* is the reason or origination of a disease, or of a pathology (essential nature of disease) (Ross, 2018).

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Table 1. Breakdown and ranking of Africa's recent (2017 - 2020) applied geochemistry output (based on internet searches of 07.09.2020)

Rank	Area of Activity (Field Campaigns; Research; Publications; etc.)	Output (%)	Remarks
1	Water Quality	49.0	Proliferation of research on water chemistry and pollution has been a result of the need to understand health risks posed by unacceptably high levels of toxic elements in potable water supplies, as well as the realisation by all stakeholders that climate change would exacerbate the already dire water quality situation that currently exists on the Continent
2	Air Quality	33.3	The upsurge in research effort on air quality is in line with global activities in the area of atmospheric chemistry, to address climate change and health issues. In Sub-Saharan Africa where most of the Continent's mining activities are concentrated, the air quality situation is most serious, especially with regard to radon entry into homes, and its accumulation in deep underground mines
3	Soil Quality (Contaminated Land)	10.2	The main sectors responsible for soil pollution in Africa are mining, agriculture and waste disposal. A huge research effort supported by international funding has been mounted to address this, through measures such as phytoremediation. Much effort is being expended in understanding the processes and mechanisms of uptake of nutritional and PTEs from the soil through food crops, and their roles in mediating metabolic processes and influencing immune system functions
4	Climate Change Chemistry	4.1	A flurry of activities is taking place, in line with the trend of research on atmospheric chemistry and global change phenomena
5	Medical Geology (Environmental Geochemistry and Health)	1.5	As the link between geochemical cofactors and certain environmental diseases becomes clearer and more firmly established, we will continue to see a rise in research activities in this field
6	Isotope Geochemistry; inorganic and biogeochemical processes	0.4	A significant rise in the use of chemostratigraphy and isotopic dating is realised, as researchers begin to appreciate the potential of both stable and radiogenic isotopes to provide answers beyond the reach of geology
7	Geochemistry Aspects of Waste Disposal [Including Mine Wastewaters (AMD)]	0.3	The geochemical aspects of hazardous and non-hazardous waste disposal in Africa remain poorly researched. This is apart from the subject of acid mine drainage (AMD), which continues to be of immense environmental concern, particularly in South Africa - one of few African countries with established institutional structures for articulating waste disposal policies
8	Marine Geochemistry	0.3	The volume of research on marine geochemistry in Africa is very low. Surprisingly, little geochemistry is applied in exploration for offshore resources, despite the many petroleum discoveries made in the last few years
9	Geochemistry in Agriculture	0.3	Research continues to grow in the area of chemical technology, that would help farmers improve yields, while at the same time limiting fertilizer use
10	Geochemistry in Mineral/ (Ore) Exploration (GMOE)	0.3	Numerous geochemical exploration programmes were mounted or continued during the period under review, largely by mining companies. However, many geochemical and mineral target maps that are generated are not put in the public domain, for reasons of confidentiality, which, partly explains the unexpected low ranking of GMOE. Some geochemical exploration work is also carried out by government geological survey agencies and academics in universities; but this proportion, has declined significantly in recent years
11	Urban Geochemistry	0.2	Some data are available for the separate compartments of the water, soil and air environments; but this area of AG research in Africa is still very much in its infancy
12	Extraterrestrial Geochemistry	0.1	The volume of research on Extraterrestrial Geochemistry is low compared to work done in other continents; but awareness of its importance is growing [See below, Sections 2 and 3 of: The European Association of Geochemistry-The Geochemical Society (EAG-GS) Outreach Programme to Africa on 'Africa Initiative for Planetary and Space Sciences']
		100.0	

The following quote from a new (2019) UNICEF Report, appositely summarises the present situation regarding air quality: "Because air pollution is not monitored in Africa to the same extent as in other parts of the world, we are not only potentially underestimating the impact - we might also not know how bad it is until it is too late. … only about 6% of children [in Africa] live near reliable, ground-level monitoring stations that provide real-time data on the quality of air they are breathing - and it is likely that we are only scratching the surface in terms of understanding its full impact on children's health. This is compared to about 72% of children who live near reliable monitoring stations across Europe and North America. Increasing the base of reliable, local, ground-level measurements would greatly aid effective responses to this poorly-understood killer of children across the continent." Exposure to airborne radon progeny in the domestic environment, but also in deep underground mine settings, yields the largest source of exposure to ionising radiation of the population.

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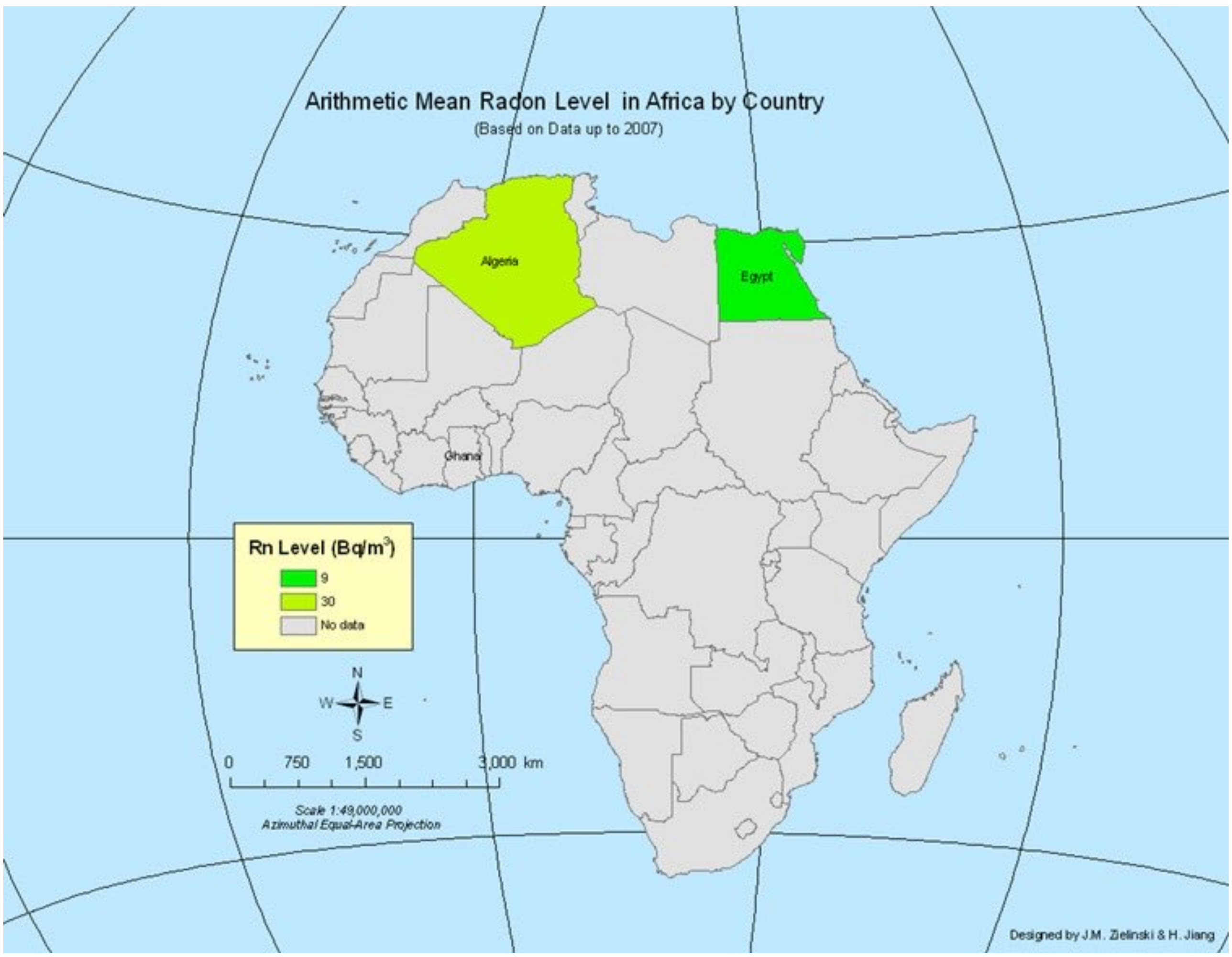
Radon research in Africa

There is a dearth of studies on radon concentrations and its fate in the African geosphere. This situation is well reflected in the data-deficient radon map (Zielinsky 2014; Fig.1) presented during a World Health Organisation project launch of 2017. However, greater awareness of the severity of the health consequences of radon exposure in homes and deep underground mines of Africa has brought about a rise in the number of studies on 'Radon in Africa' in the last 4 years (e.g., Botha *et al*. 2017; Kamunda *et al*. 2017; Masevhe *et al*. 2017; Botha *et al*. 2018; Bezuidenhout 2019; Herbst/CANSA 2019; Le Roux *et al*. 2019; Moshupya *et al*. 2019). Most of these studies address radon exposure situations and health effects in South Africa. Thus, a lot more needs to be done to tackle radon exposure problems in other African countries, especially in homes located in the neighbourhood of uranium and gold mining centres and over large areas of felsic intrusive rock.

Fig. 1. Africa: Arithmetic mean of radon, by country. Credit: Zielinsky & Jiang. Source Zielinsky 2014.



GEOCHEMICAL VARIABLES AS PLAUSIBLE CAUSALITY CO-FACTORS IN SUDDEN DISEASE OUTBREAKS AND OTHER 'DISEASES OF UNKNOWN AETIOLOGY' (DUA)

Sudden physical and/or chemical changes in soil, water or air composition as a result of some geological/geochemical/biochemical phenomena or some other geoenvironmental attributes such as latitude, altitude or seasonal variations at specific localities, ought to be considered more deeply by teams investigating the causes of enigmatic disease outbreaks whose aetiology cannot be immediately identified. Other categories of DUAs should also be considered in a similar vein.

Nodding disease, observed in Southern Sudan and *Noma*, observed in many parts of Sub-Saharan Africa, are examples of diseases for which the aetiological agents, until now, remain elusive. Some examples of DUA whose aetiology may well be linked with a geochemical or other geoenvironmental cofactor are described in Table 2.

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Table 2. Probable geoenvironmental co-factor(s) in some diseases of unknown aetiology (DUA)

DUA	Presentation	Geographical Distribution/Incidence	Geochemical (Including Trace Element Mediated Immune Response)	Geographical Patterns/ Climatic or Seasonal Variations	Remarks
Acrocyanosis	Acrocyanosis is a peripheral vascular disorder which presents as a persistent bluish or cyanotic discolouration of the extremities, most commonly occurring in the hands	Geographical locale (latitude; urban versus rural setting) uncertain - Kurklinsky et al. 2011	Chronic As toxicity- Tseng 1977; Mak 1988	Cold climate - Crocq, 1896; Carpentier 1998; Cold environments - Das & Maiti 2013; Kent & Carr 2020	"Diagnosis remains mostly clinical, and pathological mechanisms vary, suggesting that acrocyanosis may not be a single entity" (Kurklinsky et al. 2011) The association of As with metal sulphide ores, such as those containing Au, in African greenstone belt settings, is well known (See e.g., Davies, 2008). The greatest threat of As poisoning, especially in its inorganic form (WHO 2018), is posed to persons involved with the mining industry; but, the risk is also high among populations that depend on shallow or deep groundwaters for domestic purposes in and around the greenstone terrains (See e.g., Smedley & Kinniburgh 2001). Drinking water from these sources commonly contain As levels above the WHO provisional guideline value of 10 $\mu g l^{-1}$ (Ravenscroft et al. 2009)
Acute Febrile Illness	Acute febrile illness (AFI) is characterised by malaise, myalgia (pain in muscle or group of muscles) and a raised temperature that is a nonspecific manifestation of infectious diseases in the tropics (Bashkaran et al. 2019)	Sub-Saharan Africa; Tropics and Sub-Tropics	Viral respiratory tract infections - Crump et al. 2013; D'Acremont et al. 2014; Fe, Zn, Mg and Ca not significantly related to fabrile convulsion - Amouian et al. 2013	Clear seasonal trend - Kaboré et al. 2020	
Acute Severe Asthma	Asthma is characterised by chronic airway inflammation, resulting in periodic wheeze, cough and breathlessness (See Carlsson & Bayes 2020).	Worldwide	Respiratory tract infections - Johnston et al. 1995; Jackson & Johnston 2010; Air pollution - Guarnieri & Balmes 2014; Shmool et al. 2014	Cold weather - Hyrkäs et al. 2016; Weather changes - D'Amato et al. 2018	The mechanisms by which these environmental stimuli and viruses initiate asthma or cause worsening of the disease are still unknown - Kostakou et al. 2019
Alzheimer's Disease (AD)	Alzheimer's disease (AD) is the most common neurodegenerative disorder and the leading cause of dementia (i.e., the particular group of symptoms shown). It becomes worse with time (degenerative). The symptoms expressed are as a result of the damage or destruction of nerve cells (neurons) in parts of the brain involved in thinking, learning and memory (cognitive function)	By 2009, the global prevalence of dementia was estimated at 3.9 % in people aged 60+ years, with the regional prevalence being 1.6 % in Africa, 4.0 % in China and Western Pacific regions, 4.6 % in Latin America, 5.4 % in Western Europe, and 6.4 % in North America (Qui et al. 2009).	Significantly different (p less than 0.05) mean concentrations of Br, Cl, Ce, Hg, N, Na, P, and Rb were observed in AD bulk brain samples compared to controls - Ehmann et al. 1986; Varying trace element relationships with AD severity, with Al deposits greater in severely affected AD brain - Jagannatha Rao et al. 1999; Loef & Walach 2012; Bagheri et al. 2018; Liu et al. 2019; Anomalous concentration levels of metals in metal-binding proteins have growth inhibition functions on neurons - Constantinidis 1991; Richarz & Brätter, 2002; Trace metals and abnormal metal metabolism influence protein aggregation, synaptic signaling pathways, mitochondrial function, oxidative stress levels, and inflammation, ultimately resulting in synapse dysfunction and neuronal loss in the AD brain - De Benedictis et al. 2019	Long-term exposure to O_3 and $PM_{2.5}$ above the current US EPA standards are associated with increased risk of AD - Jung et al. 2015; Association between Alzheimer Dementia mortality rate and altitude - Thielke et al. 2015; Hu et al. 2016; Lall et al. 2019; Koester-Hegmann et al. 2019; Associations with seasonal temperature - Wie et al. 2019; Global warming and neurodegenerative disorders - Habibi et al. 2019	In 2019 Alzheimer's Disease International (ADI) estimated that there were over 50 million people living with dementia globally, a figure set to increase to 152 million by 2050 (ADI 2019). In both developed and developing nations, Alzheimer's disease has had tremendous impact on the affected individuals, caregivers, and society. Because developing countries are projected to see the largest increase in absolute numbers of older persons, their share of the worldwide aging population will increase from 59% to 71% (Qui et al. 2009). "Because occurrence of AD is strongly associated with increasing age, it is anticipated that this dementing disorder will pose huge challenges to public health and elderly care systems in all countries across the world" (Qui et al. 2009)
Chronic Kidney Disease of unknown aetiology (CKDu)	The predominant feature of CKD is tubular atrophy and interstitial fibrosis (thickening and scarring of the tiny air sacs and interstitial tissues in the lungs)	Reported in many parts of the world, especially among rural farming communities. High incidence in low- and middle-income countries over last two decades - Mills et al. 2015; Bikbov et al. 2020; "In 2017, the global prevalence of Chronic Kidney Disease (CKD) was 9·1% (95% uncertainty interval [UI] 8·5 to 9·8), which is roughly 700 million cases" - Cockwell & Fisher 2020	Synergistic reaction between Cd and diabetic-related hyperglycaemia - Edwards & Prozialeck 2009; Consumption of (polluted) well water suggested; need for investigating role of cadmium - Wanigasuriya et al. 2011; "Geographical mapping showed that villages with a high prevalence of CKDu are often related to irrigation water sources and/or located below the level of the water table" Jayasekara et al. 2013; Toxins/heavy metals - Jha et al. 2013; Groundwater geochemistry (high levels of F^-, Cd, As) - Wijetunge et al. 2015; High ionicity of drinking water due to fertilizer runoff - Dharma-Wardana et al. 2015; Rajapakse et al. 2016; Toxic metal exposure; water pollution - Lunyera et al. 2016; Synergistic reaction between F^- and water hardness - Sengupta 2013; Wickramarathna et al. 2017; Balasooriya et al. 2019	Altitude - Almaguer et al. 2013; Heat stress nephropathy due to global warming - Glaser et al. 2016	"There have been several global epidemics of CKDu. Some, such as Itai-Itai disease in Japan and Balkan endemic nephropathy, have been explained, whereas the aetiology of others remains unclear" (Gifford et al. 2017). "Those affected do not have common risk factors or underlying conditions that lead to CKD, such as diabetes, immune-mediated glomerulonephritis, or structural renal disease" (Caplin et al. 2019)
Geographic Tongue	Geographic tongue (also known as benign migratory glossitis) is an inflammatory disorder that usually appears in a map-like (geographic) pattern on the dorsum and margins of the tongue. Typically, affected tongues have a bald, red area of varying sizes that is surrounded, at least in part, by an irregular white border	A common condition, affecting 2-3% of the adult general population, worldwide (Ship et al. 2003).	Fe and Zn deficiency; Vitamin B12 - Ogueta et al. 2019; Nandini et al. 2016; Picciani et al. 2016, 2017		Some studies (e.g., Khayamzadeh et al. 2019) showed that patients with geographic tongue have lower levels of salivary Zn, compared to control groups
Kawasaki Disease (KD)	Kawasaki syndrome is an acute, self-limited vasculitis (inflamed blood vessels) of infants and children with unknown aetiology. Signs of KD include prolonged fever associated with rash, red eyes, mouth, lips and tongue, and swollen hands and feet with peeling skin. The disease causes damage to the coronary arteries in a quarter of untreated children and may lead to serious heart problems in early adulthood	KD occurs worldwide; most prominently in Japan, Korea, and Taiwan, reflecting increased genetic suscept-ibility among Asian populations (Rowley & Shulman 2018). The epidemiology of KD in Africa is very ill-defined, which inevitably leads to misdiagnosis and the reporting of very few cases. This gives the impression that the condition is rare in Africa - Badoe et al. 2011; Animasahun 2017; Noorani & Lakhani 2018. The presentation of KD is similar to that of measles (which is very prevalent in Africa), so the exact prevalence (of KD in Africa) is difficult to ascertain -See e.g., Badoe et al. 2011; Davaalkham et al. 2011	Environmental exposure to Hg - Orlowski & Mercer 1980; Mutter & Yeter 2008; Yeter et al. 2016; Portman et al. 2018; Airborne pathogens or toxins - Rodo et al. 2014, 2016	Decades of research have been unable to pinpoint the cause of the disease, but its distinct seasonality can hardly be in doubt - UCSDH, 2013; Lin & Wu 2017; Rypdal et al. 2018; Kim 2019; Elakabawi et al. 2020	(i) "Thus, these twin studies suggest that environmental factors contribute more to the development of KD than genetic factors among individuals with the same ethnicity." (Hara et al. 2016). (ii) The temporal association between the COVID-19 pandemic and the results of RT-PCR and antibody testing suggests a causal link between Kawasaki disease and COVID-19 (Toubiana et al. 2020)

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DUA	Presentation	Geographical Distribution/Incidence	Geochemical (Including Trace Element Mediated Immune Response)	Geographical Patterns/ Climatic or Seasonal Variations	Remarks
Multiple Sclerosis (MS)	Multiple Sclerosis is a demyelinating disease (a nervous system disease in which the insulating covers of nerve cells in the brain and spinal cord are damaged). This damage disrupts the ability of parts of the nervous system to transmit signals, resulting in a range of signs and symptoms, including physical, mental, and sometimes psychiatric problems (Compston & Coles 2002, 2008; Murray et al. 2012). Kister et al. (2013) list 11 specific symptom domains commonly affected in multiple sclerosis: mobility, hand function, vision, fatigue, cognition, bowel/bladder function, sensory, spasticity, pain, depression, and tremor/coordination	Distribution is worldwide. There is a striking latitudinal gradient in multiple sclerosis (MS) prevalence (Simpson Jnr. et al. 2011)	Metabolic imbalance of trace elements/metals - Rieder et al. 1983; Smith et al. 1989; Melø et al. 2003; Tamburo et al. 2015; Bredholt & Frederikson 2016; Janghorbani et al. 2017; Sarmadi et al. 2020	People who live in higher geographical latitudes may receive lower levels of sunlight, and therefore have lower vitamin D levels which could explain why there is a higher incidence of MS in countries with higher latitudes - MS International Federation, 2016	
Nodding disease	Nodding disease is characterised by an occasional nodding of the head, as in epilepsy, with seizures, stunted growth, and developmental disability sometimes occurring	This is an emerging disease in South Sudan, southern Tanzania, and northern Uganda. The exact prevalence and geographic distribution of the disease in the affected countries is unknown - Korevaar & Visser 2013	Deficiency of vitamin B6 (pyridoxine) and other micronutrients such as vitamin A, Se and Zn - GU/WHO, 2012	Climate change - Donnelly, 2012. cold weather - Kaiser et al. 2000; Nyugura et al. 2011; Living in the vicinity of fast-flowing streams, the breeding habitat of the black fly - Donnelly 2012	With Se and the other essential elements (micronutrients), we should note that there is a "critical range of intake" for them to perform optimally in metabolic processes (See e.g., Davies 2013)
Noma	Noma (cancrum oris or gangrenous stomatitis), is a severe and progressive gangrenous infection (body tissues die as a result of infection or inadequate blood supply) that affects the mouth and face	Mainly observed in tropical countries, particularly Sub-Saharan Africa. True global incidence unknown; but estimated incidence of 30,000 - 40,000 has been suggested by Srour et al. (2017)	Deficiencies of trace elements and amino acids influencing the efficacy of the immune system: Fe, Zn, cysteine, methionine, serine, and glycine - Baratti-Mayer et al. 2003; Malnutrition - Srour et al. 2017; Srour & Baratti-Meyer 2020		Patients generally live in extremely poor conditions, frequently located in remote rural areas
Parkinson's disease (PD)	Parkinson's disease (PD) is a progressive heterogeneous, multi-system and neurodegenerative nervous system disorder that affects movement. The cardinal features of Parkinson's disease are (i) tremor, mainly at rest; (ii) muscular rigidity, which leads to difficulties in walking, writing, speaking and masking of facial expression; (iii) bradykinesia, a slowness in initiating and executing movements; and (iv) stooped posture and instability (Sian et al. 1999). Parkinson's disease occurs when nerve cells, or dopamine-rich neurons in an area of the brain that controls movement called the substantia nigra. become impaired and/or die. But the complete series of steps leading to this cell death is still vague, and the underlying causes remain one of medicine's greatest mysteries	Worldwide occurrence. According to the 2016 Dorsey and GBD Collaborators Study published in 2018, 6.1 million (95% uncertainty interval [UI] 5.0 -7.3) individuals had Parkinson's disease globally, compared with 2.5 million (2.0-3.0) in 1990	Association with metal and trace element concentration in urine, serum, whole blood and cerebrospinal fluid - Bocca et al. 2004; Forte et al. 2004; Gellein et al. 2008; Zhao et al. 2013; Combination of Mo deficiency and purine ingestion - Bourke 2018; Significant association between the PD mortality rates and soil concentrations of Se, Sr, and Mg - Sun 2018; Adani et al. 2020; Lemelle et al. 2020	Existence of seasonality (related to temperature) in Parkinson's disease symptoms - Rowell et al. 2017; Improvement of PD symptoms at high altitude - Capcha et al. 2018; Thomas 2019	Regional maps depicting correlations between the distribution of PD and soil geochemistry which would be very helpful in this aetiological debate, are very rare in the published literature [See an example in: Sun (2018) for PD distribution in the United States]

THE AFRICA GEOCHEMICAL DATABASE PROJECT

The Africa Geochemical Database (AGD) project is the Africa component of a multi-stage global project, 'The International Geochemical Mapping', IGCP Project 259 (see Darnley *et al*. 1995), established to consider how best to provide quantitative data to portray the geochemical diversity of the Earth's land surface. A completed AGD would have a range of environmental applications, not least in the field of Medical Geology.

Between 2017 and 2020, large-scale geochemical activities involving sampling, analyses and data handling techniques related to the AGD were at a low ebb. Only a few geological survey institutions (e.g., Geological Survey of Namibia; Council of Geoscience of South Africa) recorded further work on regional geochemical database programmes. Reasons for the lowly position of the AGD in geoscience agendas of African countries are well articulated in the 2018 Annual Report of the International Union of Geological Sciences Task Group on Global Geochemical Baselines (IUGS-CGGB, 2019). A number of international workshops with significant African participation were held during the period under review, at which various technical aspects of the Global Geochemical Database Project, useful to the AGD campaign, were highlighted.

In 2017, the GEO Group on Earth Observations tabled for a second time, the Project Proposal (Activity ID77): "Africa Geochemical Baselines", analogous to the AGD Project, for support by EuroGeoSurveys, IUGS/IAGC and others (GEO 2016). The Project's aim was: "To develop a land base multi-element geochemical baseline database for mineral resource and environmental management". The Proposal also described a work programme for the period 2017 - 2019. The Project is within the vision of GEO: "To realise a future wherein decisions and actions, for the benefit of humankind, are informed by coordinated, comprehensive and sustained Earth observations and information" and "To develop a geochemical baseline database for the entire African continent through systematic sampling and chemical analysis according to the specifications of IGCP 259 International Geochemical Mapping (Darnley *et al*. 1995). We propose using only one sample

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medium, depending on terrain type, namely overbank or floodplain or catchment basin sediment, which is generally alluvial (or agricultural soil).”

Analytical Geochemistry

Among the reasons given for the low scientific output in the AGD Programme (geochemical sampling, laboratory analyses, data processing and data portrayal) is the problem of inadequate capacity in analytical instrumentation across Africa; so also is the lack of technical expertise for its operation. Problems associated with the poor analytical geochemistry performance of African laboratories are highlighted in the 2018 Annual Report of the IUGS Task Group on Global Geochemical Baselines (IUGS-CGGB 2019).

The European Association of Geochemistry-The Geochemical Society (EAG-GS): Outreach Programme to Africa

Under the auspices of the EAG-GS, the following events were held during the period under review:

1. EAG-GS 2017 – The Short Course: “Early Earth Life and Mineral Systems” (presented by Assoc. Prof. Axel Hofmann, University of Johannesburg, South Africa), explored the relationship between surface processes, evolution and habitat of life, and the formation of mineral deposits on the early Earth. It investigated the geochemical, mineralogical, environmental and biological evolution of the Earth’s surface and immediate subsurface from its volcano-sedimentary record 4.0 to 2.0 billion-years-old.
2. EAG-GS 2018 – “Africa Initiative for Planetary and Space Sciences” produced two International Workshops held in February, 2019 (First Africa Initiative for Planetary and Space Science Workshop, Addis Ababa, Ethiopia) and May, 2019 (Eastern Africa Global Navigation Satellite Systems and Space Weather Capacity Building, Pwani University, Kenya), respectively.

   The Workshops’ objectives were:

   - To connect African Planetary and Space Scientists with their international peers;
   - To build a road map for Planetary and Space Sciences in Africa, by identifying key research areas where African scientists can make significant contributions;
   - To solicit sponsors to support the development of this research domain in Africa;
   - To contribute to sustainable development in Africa through research, education, and public outreach in Planetary and Space sciences.

3. The 2019-2020 EAG-GS “Outreach Programme to Africa” (convened by Hasnaa Aoudjehane, Hassan II University, Casablanca, Morocco) took the form of a series of workshops and seminars on meteoritics and planetary sciences in universities and institutes across Africa during 2019 - 2020.

CONCLUSIONS

The trend in applied geochemistry research in Africa during the last few years has been towards determining the circulation of both nutritional elements and PTEs in the water-soil-food crop nexus, that enters the food chain. The prime motivator of this approach has been the increasing realisation of the significance of the entry - largely through the diet - of varying concentration levels of elements that may be bioavailable for negative interactions in metabolic processes that produce diseases, some of whose diagnoses are still ill-defined (DUA).

It is clear that most DUA’s are multifactorial diseases, caused by a complex interplay between genetic factors (polygenic), immunological mediators (trace elements/metals) and various environmental factors, none of which factors would cause the disease on its own. Based on an extensive literature survey on the subject, it is possible to proffer that trace element dynamics/imbalances in metabolic processes may one day be found to play a far greater role in unravelling the aetiology of DUA than has hitherto been realised.

It is suggested that correlation maps from a completed AGD [analogous to what exists for China (see Wang *et al*. 2007), England and Wales (see Rawlins *et al*. 2012), the USA (see Smith *et al*. 2019), and a few other countries] would, among other applications, enable the depiction of areas where *disease clusters* overlie *anomalous* element distribution (in water, soil or air), and so permit an evidence-based statistical assessment of the magnitude of any geochemical component in the disease causative web.

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Minor elements – the middle child beween petrochemistry and geochemistry

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INTRODUCTION

Some 30 years ago I wrote an article for EXPLORE titled 'A Cry from the Heart', then four years later, 'Another Cry from the Heart', both concerned the application of statistical procedures to geochemical data. I cannot write 'Another another ...', but that is what this is, and this time the cry concerns the data and how they are reported.

The Data

A colleague had requested help in visualizing geochemical data for 194 analyses of the <63 µm fraction of glacial tills from the Northwest Territories, Canada. In the study, three analytical procedures were employed. An Aqua Regia attack was selected to generate data to support base metal and gold mineral resource potential estimation; that attack preferentially solubilizing elements held in sulphides and loosely held on weathering products. A four-acid dissolution (HF-$HClO_4$-HNO_3-HCl) was chosen to generate data to support till provenance studies. A 'Total' Li-metaborate fusion procedure was undertaken to generate reliable rare-earth, and other, elemental data where the elements were held in minerals resistant to four-acid dissolution. Subsequently, element concentrations were determined in the solutes by ICP-OES or ICP-MS.

For the 'Total' determinations, concentrations of both major and minor elements were reported as oxides by the laboratory, based on the assumption that these data were going to be used for petrochemical studies, and possibly the calculation of normative mineral compositions.

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Discussion

Figure 1 presents the data for the minor element manganese (Mn), the MnO results reported in the 'Total' (LBF) determinations having been converted to elemental concentrations. Firstly, differences in the amounts of Mn liberated by Aqua Regia versus four-acid dissolutions are apparent in the displacement of the data into opposite quadrants about their 1:1 diagonals (Figs. 1A & 1a), predictably, the four-acid dissolution solubilizes more Mn than Aqua Regia. Secondly, the close agreement of the four-acid dissolution and 'Total' Lithium Metaborate Fusion data is reflected by the alignment of data around the 1:1 diagonals of their plots (Figs. 1C & 1c). The similar relationship between Aqua Regia and Lithium Metaborate Fusion data (Figs. 1B & 1b) as for Aqua Regia and four-acid dissolution data (Figs. 1A & 1a) is also exemplified in comparing Figures 1A and 1B (similarly, Figs. 1a & 1b), with displacements on the same sides if the 1:1 diagonals.

Figure 1. Mn (mg/kg) determinations of the <63 µm fraction of glacial tills by Aqua Regia (Mn-AQ), four-acid (Mn-4Acid), and Li-metaborate (Mn-LBF) procedures.

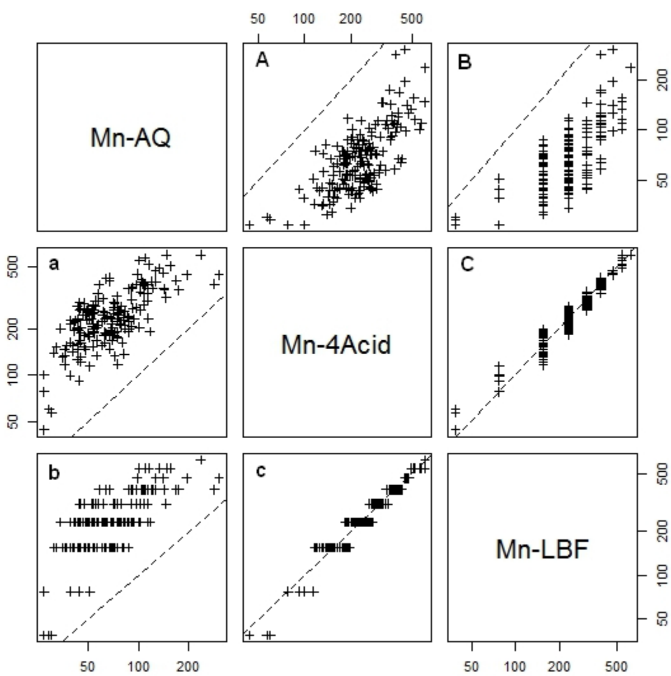
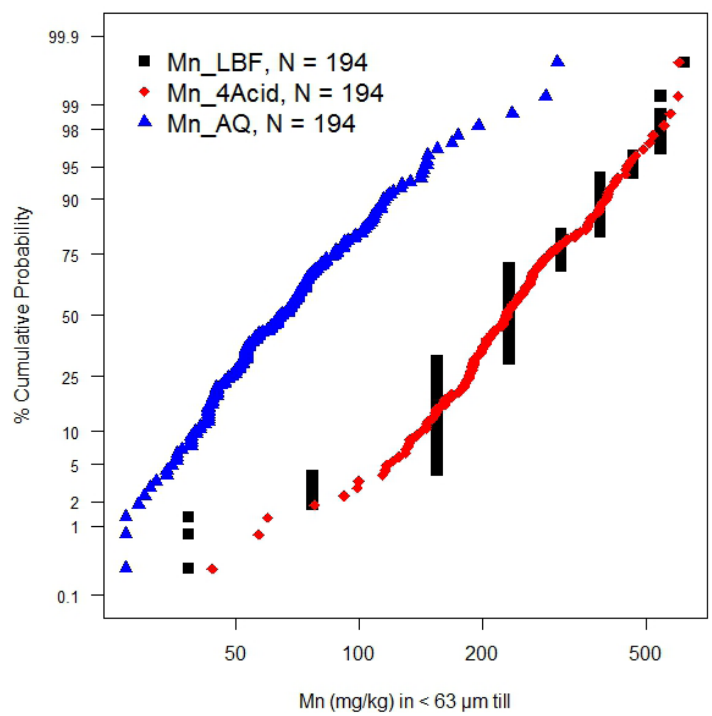


Figure 2. Cumulative probability plots for Mn (mg/kg) determined in the <63 µm fraction of glacial tills by Aqua Regia (Mn_AQ), four-acid (Mn_4Acid), and Li-metaborate (Mn_LBF) procedures.



These differences are clearly visualized in Figure 2, where the data are presented as probability plots. The displacement between Aqua Regia (blue triangles) and four-acid (red diamonds) reflects the different amounts of Mn liberated by the two acid-mixture dissolutions. The similar effectiveness of the 'Total' (black square) and four-acid (red diamonds) procedures in liberating Mn is exhibited by general overlap of the two cumulative probability plots. Comparison with the 'Total' analyses is complicated by the Mn data being restricted to only one of nine values by the reporting of the determinations as oxides to three decimal places – all of which have two leading zeroes! This carries little useful information for the geochemist, and prohibits any insightful data analysis.

Minor elements are defined as those with concentrations between 1,000 mg/kg (ppm) and one percent (10,000 mg/kg), a narrow one order of magnitude range (MINDAT 2020). In the instance of the 'Total' data discussed here, Ti, P, Mn and Cr were reported as percent oxides to two or three decimal places, often resulting in only one non-zero figure. Additionally, Ni and Sc were reported as elements with the major and minor elements. All the data for Ni were reported as less than a detection limit of 20 mg/kg, and the Sc to a useful two figures. The four-acid data for Ni show a range of 2.3 to 54.2 mg/kg, surely Ni could be determined in the Li-metaborate fusion solute by ICP-MS despite the dilution required to reduce the 'salt' content of the solute to workable levels.

The value of reporting high resolution in data, i.e. the absence of unnecessary rounding, is exemplified by studies such as Fabian *et al.* (2017) and Reimann *et al.* (2019a, b). They show that data reported with sufficient non-zero significant figures permits investigation of the relative roles of long-range diffuse contamination from industrial sources and local biogeochemical processes.

Some current data reporting practices, such as listing minor element concentrations as oxides in 'Total' analyses, can

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preclude any serious geochemical investigation. The conversion of elemental to oxide data, and *vice-versa*, is a trivial exercise, especially with ‘spread sheet’ software. Is there any purpose in retaining the way in which minor elements are currently reported in ‘Total’ analyses? They can be reported to the same standards as the trace elements resulting in no loss of information; then converted to oxides according to user requirements. Laboratories could even report the data in two tables, one for major and minor elements in percent oxides for petrochemical use, and the other for all data as mg/kg in up to four-figures for geochemical studies. The present practice of reporting minor elements as oxides is a failure.

Conclusions

It has been demonstrated that the reporting of minor element data in whole rock, ‘Total’, analyses is inadequate for geochemical studies. The frustration that this unnecessary inadequacy is the reason for this ‘Cry’, the ‘Another another …’. The minor elements are the awkward ‘middle child’ between the major and trace elements. Their reporting is torn between the needs of petrochemists and geochemists. This is unnecessary. There is no reason multiple reporting styles cannot be supported, and data not castrated by reporting with insufficient non-zero significant figures.

It is the hope of the author that this article will initiate a conversation between the scientists who use the data and the laboratories who provide them, so that no information is wasted.

Acknowledgements

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Note: The plot preparation was undertaken with R 3.4.3 (R-Project, 2020) and package ‘rgr’ (Garrett, 2020).

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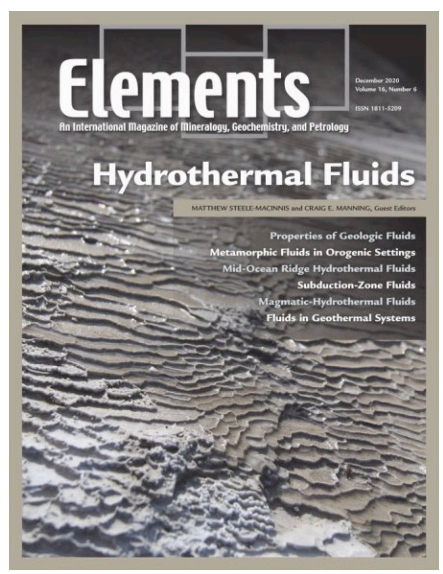
REIMANN, C., FABIAN, K., FLEM, B., & ENGELMEIR, P. 2019b. The large-scale distribution of Cu and Zn in sub- and topsoil: Separating topsoil bioaccumulation and natural matrix effects from diffuse and regional contamination. *Science of the Total Environment,* **655(1)**, 730-740.

Recently Published in Elements

December 2020, Volume 16, no. 6, Hydrothermal Fluids

This issue explores the physical and chemical properties of hydrothermal fluids and how they affect geologic processes, and it discusses our current understanding of the nature of hydrothermal fluids across a range of geologic settings; interactions between fluids and rocks; and the interrelationships between fluid-driven processes in different settings. Each article in this issue highlights both broad and specific overlaps between “normal” and ore-forming hydrothermal fluids and will describe how the features of hydrothermal systems reflect the specific properties of the fluids in each setting.

There are three AAG news items in this issue. First, citation for Benedetto de Vivo for his 2019 AAG Medal Award. Second, abstract of an article that appeared in issue 185 (December 2019) of the **EXPLORE** newsletter, namely “Why Minus 80 Mesh?” by R.G. Garrett. Third, abstract of an article that appeared in issue 186 (March 2020) of the **EXPLORE** newsletter, namely “Testing a Rapid Sampling and Analysis Workflow in the Remote Nullarbor Plain, Australia?” by R. Noble, N. Reid, K. Klump, J. Roberston, D.Cole, D. Fox, T. Pinchand, I. González-Álvarez, C. Krapf, I. Lau.



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

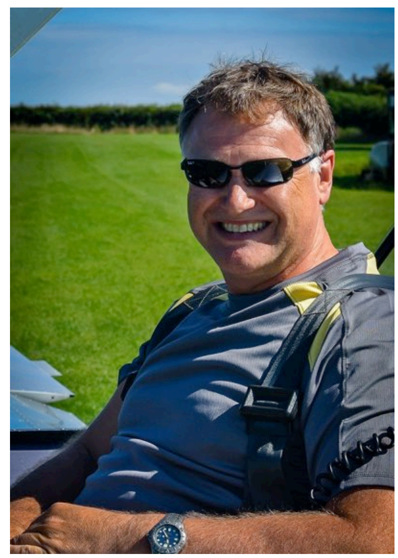
John Carranza

AAG Councillors 2021-2022

Patrice de Caritat

Patrice's university training is in geology, mineralogy and geochemistry, and his research interests include environmental and exploration geochemistry, hydrogeochemistry, isotope geochemistry, low-density geochemical mapping, and forensic geochemistry. Currently he is Principal Research Scientist at Geoscience Australia; Adjunct Professor of Applied Geochemistry at the University of Canberra; and Visiting Fellow at the Australian National University (ANU). Patrice has led and held senior research positions in a number of collaborative research programs, organisations and universities in Australia, Norway and Canada. Patrice has a *Lic Sci* (BSc Hons) degree from the University of Louvain (Belgium), and PhD from the ANU. Patrice was an International Association of GeoChemistry (IAGC) Councillor (2015-18) and Association of Applied Geochemists (AAG) Society News Editor for *ELEMENTS* (2011-15). Currently he is Associate Editor for *Applied Geochemistry* as well as for *Geochemistry: Exploration, Environment, Analysis.* Patrice is a Fellow of the AAG and AAG Councillor (2011-12, 2013-14 and 2019-20).

Dave Heberlein

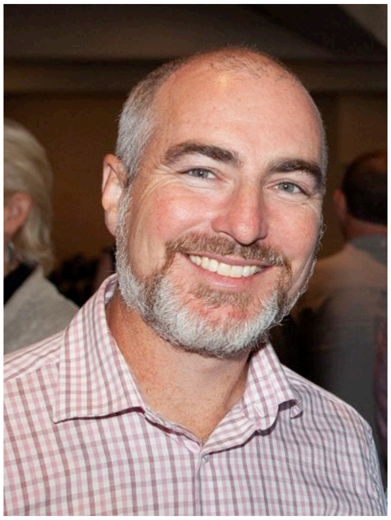


Dave has been a consulting exploration geochemist for 12 years (2008-present). Prior to that he was Chief Geochemist – Global Exploration for Barrick Gold Corp (2002-2007). He received his B.Sc. Honors degree from Southampton University in the UK and completed a bachelor's thesis on lithogeochemistry of VMS deposits in the Iberian pyrite belt. His M.Sc. (under the supervision of K Fletcher, Al Sinclair and Colin Godwin) involved lithogeochemical studies of leached capping and supergene enrichment at the Berg porphyry Cu-Mo deposit in Central BC. At Barrick, his main areas of focus were: a) development of a company-wide QA-QC program, b) investigation of deep penetrating geochemistry methods for covered environments globally; and c) in-house training of exploration geologists. In his current role, he provides consulting services in exploration geochemistry to the global mining industry. Working for both major and junior companies, he provides consulting services in QA-QC and laboratory auditing, geochemical survey design, sampling, analytical methods, data interpretation and GIS integration. He also provides training to industry in the form of public and private short courses. Recent research activities include participation in several Geoscience BC funded studies into deep penetrating geochemical methods applicable porphyry exploration in the glaciated regions of central BC. In collaboration with Colin Dunn, he has been involved in studies of the applicability of plant exudates as geochemical sampling media and the uses of halogens as pathfinder elements in organic-rich media.
He is a registered Professional Geoscientist in BC.

Paul Morris

Paul Morris was university educated in New Zealand at Otago University and Victoria University (Wellington), followed by stints at the University of Sydney, and Shimane University in western Japan. In 2018, he retired from a 30-year career at the Geological Survey of Western Australia, where he was Chief Geochemist for 22 years. He joined AAG (then AEG) in 1999 and has been a fellow since 2002. During his AAG membership he has held various positions including councillor, Symposium Coordinator, president, chairman of the Awards and Medals Committee and the Education Committee and is currently chairman of the New Membership Committee.

AAG Councillors… *continued from page 28*



Ryan Noble

Dr. Ryan Noble is a Senior Principal Research Scientist and the Group Leader of Predictive Mineral Systems Science with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Perth, Western Australia. He has been with CSIRO for 15 years working on geochemical research with application to the exploration industry. Ryan has a BSc and MSc in Soil Science from the University of Tennessee and a PhD in Applied Geology from Curtin University. Ryan has worked on numerous regolith and groundwater geochemistry projects related to Au, base metals, Ni and U mineral exploration. He is a Past-President and a Fellow of the Association of Applied Geochemists. Currently, Ryan serves on the Editorial Board for GEEA and as a Board member of the Australian Geoscience Council, Earth Science Western Australia and the Elements journal. Building on his earlier activities in the AAG, Ryan is keen to continue his involvement to strengthen the AAG and the benefits to its members.

Pim van Geffen

Dr. Pim van Geffen is a professional geochemist and consultant based in Vancouver. He obtained his PhD at Queen's University in Kingston, Canada, and his MSc from Utrecht University in the Netherlands. Since 2005, he has worked on a wide variety of projects in applied geochemistry and geochemical data analysis, ranging from soil- and biogeochemistry to lithogeochemistry and geometallurgical assessments. He currently works as a consultant with CSA Global, which is part of the ERM group of companies. In this capacity, he uses geochemical data analysis to solve metallurgical and environmental problems in mining operations and advanced projects. He was previously employed with Anglo American, Queen's University, ioGlobal, REFLEX (IMDEX), and as an independent consultant under Vancouver Geochemistry. He is a registered Professional Geoscientist with Engineers and Geoscientists of British Columbia, a Fellow of the Association of Applied Geochemists, a Fellow of the Society for Economic Geology, and serves on the Technical Advisory Committee of Geoscience BC.

The AAG-SGS Student Presentation Prize

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

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

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

The Rules

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

The Prize

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

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

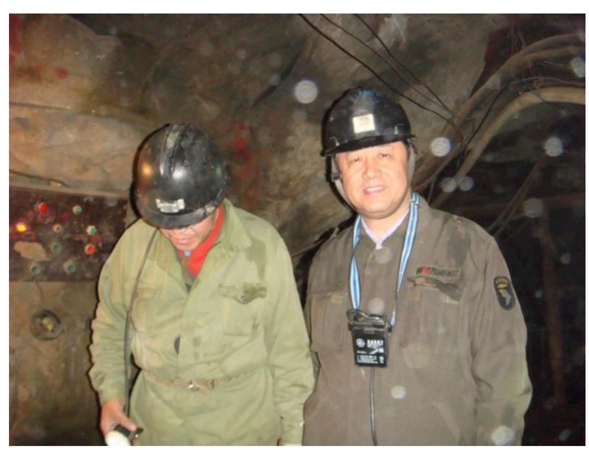
Qiuming Cheng, AAG 2020 Gold Medal

The Association of Applied Geochemists is pleased to announce that the 2020 Gold Medal for outstanding contributions to exploration geochemistry is awarded to Professor Qiuming Cheng, Sun Yat-sen University, Zhuhai City, and China University of Geosciences, Beijing, China.

Professor Cheng completed his Ph.D. in Earth Sciences at the University of Ottawa in 1994 following undergraduate and M.Sc. degrees at Changchun University of Earth Sciences, China. After a decade-long professorship at York University, Toronto, Canada, in 2004 he became a founding Director of a State Key Lab of Geological Processes and Mineral Resources at the China University of Geosciences in Wuhan and Beijing, China. Presently he is Professor, School of Earth Science and Engineering, at Sun Yat-sen University in Zhuhai City, and Faculty of Earth Science and Resources, at the China University of Geosciences, Beijing.

Professor Cheng is truly one of the top internationally leading scientists in quantitative geology and applied geochemistry. He has made fundamental contributions that have significantly advanced the theory of non-linear processes in geosciences and methods for modelling geochemical anomalies for mineral resources and environmental assessments. Professor Cheng's research contributions to exploration geochemistry have been exceptional in both the development of mathematical theory and the application of unique methods for recognizing mineralized environments across a range of geochemical landscapes, sample media and analytical methods. He has an exceptionally strong mathematical background and his research has resulted in a new paradigm for evaluating geochemical data through the use of non-linear mathematical methods combined with a deep understanding of geochemical processes.

Professor Cheng's methodology of fractal analysis of geochemical responses has resulted in the discovery of several mineral deposits in China, and his name is synonymous with the application of fractal analysis to geochemical data. More recent innovations are the local singularity analysis method for enhancing weak spatial signals in geochemical data, and a new multifractal inverse distance model. These new methods improve on the recognition of geochemical responses, and his research has influenced the way mineral exploration companies conduct their exploration programs. Professor Cheng has worked closely with both the academic and mineral exploration and mining communities to share and implement his research methodologies. His seminal 1994 paper on *The separation of geochemical anomalies from background by fractal methods* (Journal of Geochemical Exploration) has alone attracted over 860 citations. His productivity is reflected in his impressive publication record of some 280 journal papers, books and book chapters, generally as lead or as corresponding author, of which more than 44 have been published in AAG-associated journals. Professor Cheng received the Andrei Borisovich Vistelius Research Award from the International Association for Mathematical Geosciences (IAMG) as a promising young scientist and, more recently, the William Christian Krumbein Medal, the highest honour bestowed by the IAMG. He is also the first Fellow of the AAG to ascend to the Presidency of the International Union of Geological Sciences (IUGS). Significantly, he has been a mentor and supervisor to 55 graduate students at both York University and the China University of Geosciences.



Professor Cheng is a most worthy recipient of the Association's Gold Medal. His world-class accomplishments, his record of innovation, the international education of young scientists, and his service to the international scientific community have been remarkable. Presentation of the medal will take place at the upcoming IAGS in Chile this coming October 2021, or if the symposium is rescheduled, October 2022.

Stephen Cook
Chair, AAG Awards and Medals Committee

Robert G. Garrett - Honorary Fellow

The Association of Applied Geochemists is pleased to announce that Honorary Fellowship in the Association has been awarded to Robert G. Garrett, of the Geological Survey of Canada (GSC), Ottawa (emeritus), in recognition of his distinguished contributions to applied geochemistry during a career spanning more than 50 years. Honorary Fellows of the Association are granted this exceptional recognition for their contributions in generating and disseminating applied geochemical research at a high level and their long-standing commitment to the Association.

Robert Garrett has greatly influenced applied geochemistry during his 38 years as a Research Scientist and 15 years as an Emeritus Scientist (still active) at the GSC. Over his career he has authored or co-authored over 150 published papers, articles and government reports, a text book, and 5 book chapters, including 2 chapters in the *Handbook of Exploration Geochemistry*, volume 2, Statistics and Data Analysis in Geochemical Prospecting.

Robert is best known for his investigations and developments of statistical and mathematical methods for the interpretation of regional geochemical data and their application to mineral exploration. His research and resulting publications cover a wide range of topics including the design of geochemical surveys, management of geochemical data, geochemistry of organic lake sediments, drainage geochemistry, metals in the environment, and influence of geology on agricultural soils and crops. Robert was one of the very first to recognize early on the importance and power of exploratory data analysis (EDA) in geochemistry. He 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 data.

Robert has made consistent contributions to applied geochemistry in Canada and many other countries around the world. His GSC studies focussed on regional geochemistry, contributing to the design and implementation of Canada's National Geochemical Reconnaissance Program in the 1970s and the development of improved geochemical exploration methods and procedures for interpreting geochemical data. Internationally, he participated in Canadian International Development Agency exploration geochemistry projects in Brazil, Malaysia, and Jamaica. His geochemical interests involved international collaborations through COGEODATA, IGCP Projects 98, 259 and 360, the IUGS Global Geochemical Baselines working group, and the IUGS' Commission on Global Geochemical Baselines. He undertook regional geochemical studies in the Canadian Prairies to support diamond exploration that led to collaboration with soil and agricultural scientists in Canada and the USA concerning the phytoavailability of trace elements and their accumulation in food grains.

He contributed expertise to heavy metals and North America Free Trade Agreement meetings concerning policy initiatives for metals in the environment, Canadian CEPA risk assessment and regulatory related matters, Federal Toxic Substances Management Plan, Metals in the Environment (MITE), Toxic Substances Research Initiative (TSRI), and the North American Geochemical Soil Landscapes project with the United States Geological Survey, together with other US and Canadian federal departments.

Since retiring in 2005, Robert has continued to contribute to the GSC's scientific program as an Emeritus Scientist and to mentor younger scientists. Robert has also continued his ongoing development of the RGR package. The most recent update was released May 21, 2020.

Robert has been providing support and guidance to the Association since it was formed in 1970, in the early years as Councillor, Vice President and President and a member of the Bibliography Committee and the Awards & Medals Committee. In later years to the present, he further supported the Association by serving on the editorial boards of both of the Association's flagship journals, *Journal of Geochemical Exploration* and *Geochemistry: Exploration, Environment, Analysis,* and writing contributions for the newsletter EXPLORE.

M. Beth McClenaghan (Ottawa, Canada)
Gwendy E.M. Hall (Merrickville, Canada)
Clemens Reimann (Königstetten, Austria)

Welcome New AAG Members

Student Members

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

Mr. Matthew Morris
11 Mortimers Lane
Foxton
Cambridge, England
United Kingdom CB22 6RR
Member no. 4445

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.*

Mr. Morgan Wallace
USGS
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Great Falls, VA
USA 22066
Member no. 4435

Mr. Shaun Anderson
Chinova Resources
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Norman Park QLD
AUSTRALIA 4170
Member no. 4436

Prof. Marino Vetuschi Zuccolini
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Member no. 4446

Mr. Lindsay Craig
Exploration Manager
Gold Bull Resources Corp.
6980 Aspen Glen Road
Reno, NV
UNITED STATES 89519
Membership no. 4447

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 February 14th 2021, but further changes are likely, and users of the listing are strongly advised to carry out their own research as to the validity of an announcement.

Please let us know of your events by sending details to:
Steve Amor, Email: steve.amor2007@gmail.com
or
Tom Meuzelaar, AAG Webmaster, tom@lifecyclegeo.com

2021

Virtual Meetings

15-19 MARCH 52nd Lunar and Planetary Science Conference. Website: tinyurl.com/49zpujm8

23-25 APRIL 3rd International Conference on Geographical Information Systems Theory, Applications and Management. Website: www.gistam.org

25-30 APRIL EGU General Assembly 2021. Website: www.egu2021.eu

3-6 MAY Canadian Institute of Mining, Metallurgy and Petroleum (CIM) 2021 Convention and Expo. Website: convention.cim.org

3-4, 10-11 AUGUST International Uranium Digital Conference. Website: tinyurl.com/oxj7f1nw

In-Person Meetings (status as of February 14th 2021)

25-28 MARCH 27th International Mining Congress and Exhibition of Turkey. Belek Turkey Website: tinyurl.com/17ok9ys1

7-9 APRIL Mongolia Mining 2021. Ulaanbaatar Mongolia. Website: mongolia-mining.com

14-16 APRIL 4th International Conference on Geoinformatics and Data Analysis. Marseille France. Website: www.icgda.org

23-25 APRIL 3rd International Conference on Geographical Information Systems Theory, Applications and Management. Prague Czech Republic. Website: www.gistam.org

25-30 APRIL EGU General Assembly 2021. Vienna Austria. Website: www.egu2021.eu

9-14 MAY IWA World Water Congress & Exhibition 2020. Copenhagen Denmark. Website:tinyurl.com/y4s4u9fm

17-19 MAY GAC-MAC Joint Annual Meeting London ON Canada. Website: gacmac2021.ca

17-20 MAY Geological Society of Nevada 2021 Symposium. Sparks NV USA. Website: www.gsnsymposium.org

9-12 JUNE 2nd International Conference on Contaminated Sediments. Bern Switzerland. Website: tinyurl.com/4w483unc

13-18 JUNE Interior of the Earth (Gordon Research Conference). South Hadley MA USA. Website: tinyurl.com/yv84w8po

14-18 JUNE 9th International Workshop on Compositional Data Analysis. Toulouse France. Website: www.coda-association.org/en/codawork2021

20-25 JUNE Catchment Science: Interactions of Hydrology, Biology and Geochemistry. Andover NH USA. Website: tinyurl.com/y4vgl8eq

21-24 JUNE SIAM Conference Mathematical and Computational Issues in the Geosciences. Milan Italy. Website:www.siam.org/conferences/cm/conference/gs21

28-30 JUNE 2021 Australasian Environmental Isotope Conference. Ballina NSW Australia. Website: tinyurl.com/4ncq4pkt

4-9 JULY Goldschmidt 2021. Lyon France. Website: tinyurl.com/y869e3wo

12-15 JULY 8th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology

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CALENDAR OF EVENTS...

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18-23 JULY	Chemical Oceanography (Gordon Research Conference) - Chemical Tracers in the Sea. Manchester NH USA. Website: tinyurl.com/12k49dbn
25-30 JULY	12th International Symposium: Geochemistry of the Earth's Surface. Zurich Switzerland. Website: ges12.com
1-5 AUGUST	Microscopy & Microanalysis 2021 Meeting. Pittsburgh PA USA. Website: www.microscopy.org/MandM/2021
1-6 AUGUST	Atmospheric Chemistry (Gordon Research Conference). Newry ME USA. Website:tinyurl.com/17l5a027
1-6 AUGUST	Geoanalysis 2021. Freiberg Germany. Website: geoanalysis2021.de
8-10 AUGUST	28th International Conference on Geoinformatics. Nanchang China. Website: www.cpgis2021.com
16-20 AUGUST	34th International Geographical Congress. Istanbul Turkey. Website: www.igc2020.org/en
16-21 AUGUST	36th International Geological Congress, Delhi India. Website: www.36igc.org
23-27 AUGUST	Eurosoil 2021. Geneva Switzerland. Website: eurosoil2020.com
29 AUGUST-2 SEPTEMBER	3rd European Mineralogical Conference. Cracow Poland. Website: emc2020.ptmin.eu/
2-3 SEPTEMBER	Sampling 2020. Lima Peru. Website: tinyurl.com/y8ddlbxu
6-10 SEPTEMBER	Magmatism of the Earth and related strategic metal deposits. Apatity Russia. Website: tinyurl.com/1l3acg7p
9-10 SEPTEMBER	Discoveries in the Tasmanides - Mines and Wines. Orange NSW Australia. Website: tinyurl.com/yyodhxcl
9-11 SEPTEMBER	3rd International Conference on Tourmaline. Elba Italy. Website: www.tur2021.com
12-17 SEPTEMBER	30th International Meeting on Organic Geochemistry. Montpellier France. Website: eage.eventsair.com/imog-2021
13-17 SEPTEMBER	41st International Symposium on Environmental Analytical Chemistry. Regensburg Germany. Website: iaeac.com
14-17 SEPTEMBER	SEG 100 Conference. Whistler BC Canada. Website: www.seg100.org
15-20 SEPTEMBER	Australasian Exploration Geoscience Conference. Brisbane QLD Australia. Website: 2021.aegc.com.au
9-17 OCTOBER	28th Colloquium of African Geology (18th Conference of the Geological Society of Africa). Fez Morocco. Website: www.fsdmfes.ac.ma/CAG28
10-13 OCTOBER	GSA Annual Meeting. Portland OR USA. Website: community.geosociety.org/gsa2021
24-29 OCTOBER	29th International Applied Geochemistry Symposium (IAGS). Viña del Mar Chile. Website: iags2020.cl
Rescheduled	
1-3 NOVEMBER.	GAC-MAC Joint Annual Meeting. London ON Canada. Website:gacmac2021.ca
2-4 NOVEMBER	13th Fennoscandian Exploration and Mining. Levi Finland. Website: femconference.fi
25-28 NOVEMBER	Conference of the Arabian Journal of Geosciences. Istanbul Turkey. Website: www.cajg.org

2022

Rescheduled	
28-31 MARCH	15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Rotorua New Zealand. Website: confer.eventsair.com/sga2021
22-27 MAY	Geochemistry of Mineral Deposits (Gordon Research Conference). Castelldefels Spain. Website:tinyurl.com/yxtyprqc
31-MAY-2 JUNE	10th World Conference on Sampling and Blending. Kristiansand Norway. Website: wcsb10.com
24-29 JULY	15th International Conference on Mercury as a Global Pollutant. Cape Town South Africa. Website:www.ilmexhibitions.com/mercury2022
31 JULY- 5 AUGUST	World Congress of Soil Science 2022. Glasgow UK. Website: www.soils.org.uk/wcss2022

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CALENDAR OF EVENTS... *continued from page 35*

6-12 AUGUST	Geoanalysis 2022. Freiberg Germany. Website: geoanalysis2021.de/en
15-19 AUGUST	12th International Kimberlite Conference. Yellowknife NT Canada. Website: 12ikc.ca.
22-26 AUGUST	International Sedimentological Congress. Beijing China. Website: isc2022.scievent.com
13-15 SEPTEMBER	14th International Symposium on Nuclear and Environmental Radiochemical Analysis. York UK. Website: tinyurl.com/y989mvvz

2023

29 JANUARY-3 FEBRUARY	Winter Conference on Plasma Spectrochemistry. Ljubljana Slovenia. Website:https://ewcps2021.si