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Exploring for laterally transported copper in gravels using radon detectors

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Preamble

This manuscript is based on an initial idea from the lead author, the late Peter Alan Winterburn as part of the Atacama Gravels Project, started under the MDRU Exploration Geochemistry Initiative in 2015. Thomas Bissig and Peter Winterburn discussed the preparation of this manuscript in May 2019 and Peter indicated that he would read over the first draft once more and provide additional input. His untimely death on June 21st, 2019 in Valparaíso, Chile has prevented this. However, based on his informal comments, we are confident that he would support the publication of this work, and we have therefore decided to continue in Peter´s honour. However, any potential errors and omissions are responsibility of the second and third authors.

Introduction

Copper is readily leached from acid generating sulfide ore during weathering and oxidation (e.g., Chavez 2000, Reich & Vasconcelos 2015). Copper-bearing solutions can be transported laterally for up to 6-8 km until the solutions are neutralized (or reduced) sufficiently to precipitate secondary Cu minerals (carbonates, silicates, oxides, halides, and sulphates). This process can form exotic Cu deposits (e.g., Munchmeyer *et al.* 1996; Mote *et al.* 2001; Sillitoe 2005). Copper-bearing solutions commonly follow the gravel-bedrock contact or permeable layers within the gravel beds (Sillitoe 2005), although Cu transport in surface runoff has recently been proposed for the Tesoro exotic Cu deposit in Chile (Fernandez-Mort *et al*., 2018). While exotic Cu deposits are attractive exploration targets for oxide Cu in their own right, elevated Cu content within gravel cover may serve to vector towards supergene enriched and primary hypogene porphyry Cu ore bodies up gradient. However, detection of oxidized copper mineral species under gravel cover by traditional geochemical or geophysical means remains challenging.

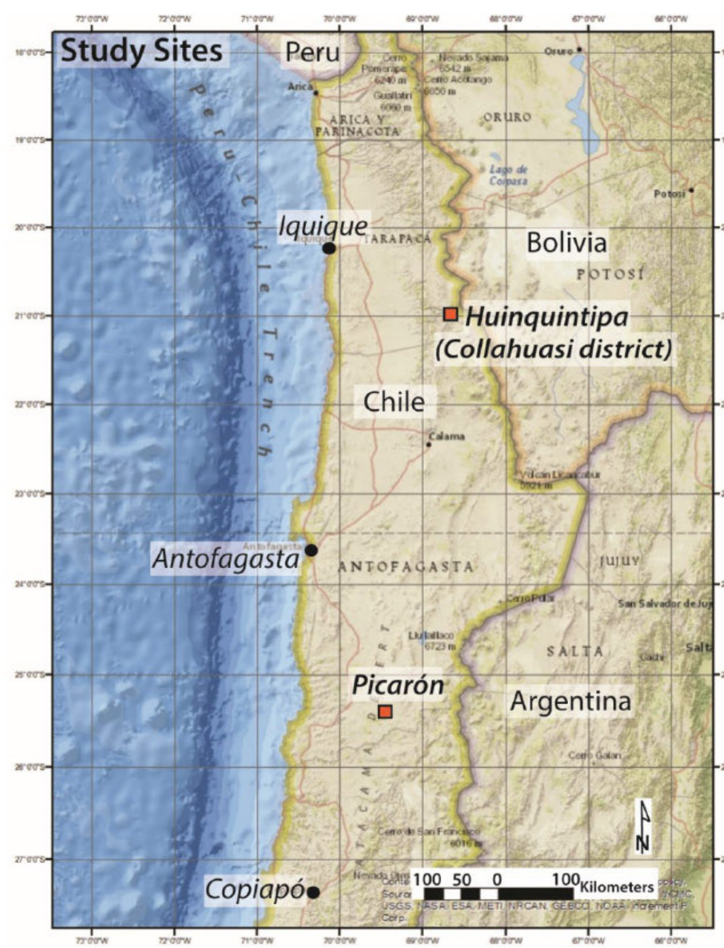

Figure 1. Location of Picarón and Huinquintipa in northern Chile.

Radon is an inert radioactive gas produced in the decay chain from the decay of ^{238}U and ^{232}Th to ^{206}Pb and ^{208}Pb respectively. The isotope produced from ^{238}U is ^{222}Rn (half-life 3.84 days) whereas ^{220}Rn (half-life 55.6 seconds) derives from ^{232}Th. The immediate parent of radon gas is the alkali earth element ^{224}Ra (half-life 3.6 days) for the ^{232}Th decay series and ^{226}Ra (half life 1,602 years) for the ^{238}U decay series.

Uranium can, together with Cu, be hydromorphically transported in oxidized and acidic meteoric fluids. Oxidized U^{6+} is easily transported over a wide range of pH conditions as different aqueous complexes (e.g., Krupka & Serne 2002), whereas reduced U^{4+} is generally immobile. Chrysocolla, a common mineral in exotic Cu deposits, has been found to contain significant quantities of U (in some cases more than 0.1 wt%: Barton 1956; Kahou, *et al.* 2020). Radon gas generated from the decay of U via Ra can ascend through permeable gravel deposits for distances up to 200 m or

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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.
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- 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 second EXPLORE issue of 2020. This issue features one article that describes exploring for laterally transported copper in gravels using radon detectors. It was written by Peter Winterburn, Thomas Bissig, and Alexandra Brown. The temporary new AAG logo in the top right corner of the front page of **EXPLORE** and on the AAG website was designed by my son to help commemorate the Association's 50th year in 2020. Happy Birthday AAG!

EXPLORE thanks all those who contributed to the writing and/or editing of this second issue in 2020, listed in alphabetical order: Steve Amor, Dennis Arne, Al Arsenault, Thomas Bissig, Alexandra Brown, John Carranza, Steve Cook, Bob Garrett, Jeff Jaacks, David Leng, and Peter Winterburn.

Beth McClenaghan
Editor

2020 AAG Dues Reminder

Reminder that AAG membership fees for 2020 are now due.

Membership fees can be paid on AAG's website at:
https://www.appliedgeochemists.org/membership/renew-membership

President's Message

Well, what a difference a few months makes! As I composed my inaugural President's message back in January of this year, our major concern regarding the 29th IAGS was the political situation in Chile. By March it became clear to the Local Organizing Committee (LOC) chaired by Brian Townley that it was not going to be possible to proceed as planned with the November meeting this year given the spread of Covid-19. It was therefore decided by the AAG executive to postpone the meeting until the second half of 2021. The LOC ultimately recommended the new dates of October 24 – 29, 2021 at the same venue in Viña del Mar, Chile. Our reasoning for such a delay included the uncertainties as to when international travel bans might be lifted and the difficulty some members might have obtaining permission, funding and insurance to travel to an overseas conference. Word here in Australia is that they do not expect to lift international travel bans until next year at this stage. Even Queensland has closed its borders indefinitely. The good news is that there is still time to submit an abstract for the IAGS!

That is not to say that the AAG has gone into hibernation. There are several initiatives underway. One of the more artistic flourishes has been the addition of a new 50th birthday logo to the home page designed by Beth McClenaghan's (EXPLORE editor) son Conner. Nice to have a graphic artist in the family! An example practical problem in applied geochemistry (stream sediment geochemistry from northern Vancouver Island, Canada) has also been posted on the AAG web site on a new page entitled "Case Studies". This will hopefully be the first of many practical problems in applied geochemistry to be added to this new section. Please take a look and use the contact button to provide me with feedback, suggestions or questions. In addition, we would like to start adding presentations and videos to the web site on a variety of topics to increase the content available to our members. Council will discuss further changes to the web site to host this content. The AAG web site is one our most effective tools to promote and support the field of applied geochemistry, especially during a time when professional and social interactions are restricted.

To that end several organizations have been moving to webinars to replace public seminars. The CSIRO in Australia has initiated a Discovery Covideo Series (https://events.csiro.au/Events/2020/May/8/CSIRO-Discovery-Covideo-Series) that has recently hosted a geochemical presentation by our AAG Past President Ryan Noble, as have Prospectors Earth Sciences and Coresafe, also based in Australia (https://thegeohug.com). There will be many more series out there. If you know of any with a geochemical focus, please pass on the links to Al at the Office of Applied Geochemists (office@appliedgeochemists.org) so that notifications can be sent to members and/or posted on the AAG web site.

While on the subject of webinars, the Executive has recently tested Zoom as a platform for meetings and has made the decision to use it at our next Council meeting in early June. This platform will replace our long-running conference telephone facility and should result in significant savings, as well as providing a more satisfying interaction for all involved.

In another sign of our changing world, The Geological Society, publishers of our journal Geochemistry: Exploration, Environment, Analysis, would like to stop the publication of hard copy journals and move to on-line publication only. The AAG has been asked to consider this request and the significant cost savings it will entail.

But enough of the virtual world. In the real world in which we work and live there have no doubt been many disruptions and job losses. If you have news of how industry is weathering the pandemic in your area, please pass that information on to your regional councilors for mention in their reports to Council. Some of our members may have been affected by illness, recently lost their jobs, had their hours reduced, or are struggling with working from isolation. The situation is improving in many jurisdictions, but the repercussions are likely to persist for months, if not years. Now is a good time to contact colleagues to see how they are doing and to offer support if needed. Fortunately, geologists and geochemists are not entirely averse to self-isolation and may fare better than many!

Please keep in touch through the AAG and IAGS (https://iags2021.cl/) web sites to follow progress with preparations for the conference next year. New key dates will be implemented for the 29th IAGS and new content will soon be appearing on the AAG web site. Now is also a good time to write that paper or article for GEEA or EXPLORE you've been planning but just didn't get around to. I'm sure Beth or Scott would be pleased to hear from you.

Dennis Arne
President

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more (Ramola *et al*. 1989) and serve as an indicator for secondary Cu minerals in exotic Cu deposits. Since Ra is much less mobile than U in the supergene environment (Ball *et al*. 1991), it is unlikely that significant quantities of Ra were removed from the areas enriched in U and Cu and elevated Rn counts are assumed to be directly related to elevated U concentrations.

Detection of Rn has long been used for U exploration (e.g., Gingrich 1984). Radon detectors, normally applied to monitor radon emissions in buildings, can be used to detect secondary U and, as a proxy, Cu mineralization under gravel cover. We tested the viability of this approach at the largely mined out Huinquintipa exotic Cu deposit, Collahuasi district and the buried Picarón prospect, Victoria district, both located in northern Chile (Fig. 1).

Methods

Radon emissions were measured using alpha decay testing devices (Accustar AT-100). The AT-100 device consists of a plastic cup which contains nitro cellulose film that records alpha decays of Rn as fission tracks. No distinction can be made between Rn derived from Th or U by this device but, based on typical concentrations in the rock types present at the study sites and the much longer half-life of ^{222}Rn, the detected Rn is assumed to be largely derived from ^{238}U via ^{226}Ra. The AT-100 devices were attached to the bottom of regular plastic cups and placed in Tyvek bags (Fig. 2). These bags then were buried in the soil, with the opening of the plastic cups downward, at about 30 cm depth (Fig. 2). The devices were left in the soil for 10-12 days. After removal, the Rn detection devices were sealed in Ziploc bags and sent for analysis to Accustar Labs in Ward Hill, Massachusetts, United States. The results are reported in bequerel per cubic meter (Bq/m^3) which is a measure of alpha decays per second and volume. According to the specifications given by Accustar, counting uncertainty is 12%. Field duplicates collected in the program are within this 12%. Blanks were used to establish background emission values of 30 to 81 Bq/m^3. For further specifications see http://www.accustarlabs.com/ or http://www.accustarcanada.com/.

A limited number of rock samples of exotic mineralization from Huiquintipa, as well as samples from reverse circulation (RC) drilling chip trays from Picarón were analyzed by the 4-acid digestion ultra-trace method (MA250) at Bureau Veritas Mineral Laboratory, Vancouver, Canada. The aim of these analyses was to measure the concentration of U present and its relationship to Cu, Mn and Fe concentrations. Sequential leach methods were not applied and therefore no inference on mineralogical association of U can be made. At Picarón, rock-fragments were collected from drillhole RC-11-17 every other 2 m interval from surface to 24 m depth and at every 2 m interval throughout the mineralized zone (24—46 m). Additional samples at approximately 10 m spacing were collected below the mineralized zone. From RC-11-12, samples were only collected from the mineralized zone (26-36 m) at every 2 m interval. Note that coarse rejects from RC drilling are no longer available. Thus, the type and amount of sample material is not fully representative for the drillhole intercepts due to the small amount of material, sample bias and repeated sample wetting for logging. The original aqua regia digestion multielement ICP-AES analyses from the drill campaign generally yielded U values below detection limit for that method (i.e. < 10 ppm), which is too high to resolve variations of U content associated with oxide Cu minerals in gravels.

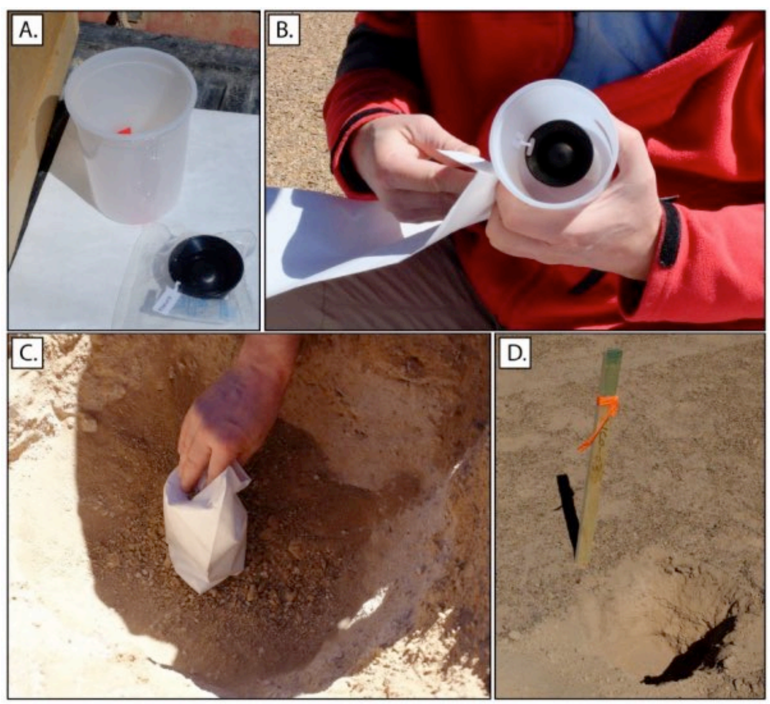

Figure 2. Radon alpha track test devices and method for Rn in soil testing. A) Accustar AT-100 device (black), plastic cup and Tyvek bag. B) AT-100 device attached to the bottom of the plastic cup to be inserted in a Tyvek bag. C) The Tyvek bag containing the plastic cup with the AT-100 in a test hole at ca. 30 cm depth, before being buried for 10 days. Note that the opening of the plastic cup is downward. D) Typical test site.

At Picarón, soil samples were collected at 5 and 30 cm depth from 26 sites from two transects across the exotic mineralization. Samples (n=52) were analyzed by ICP-MS following deionized water leach and aqua regia digestion at Bureau Veritas Mineral Laboratory, Vancouver, Canada. The aim of these analyses was to test whether traditional soil geochemical methods are capable of detecting oxide copper mineralization under cover and whether high Rn counts can be explained by near-surface accumulation of U.

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Huinquintipa study site and Rn detector results:

Huinquintipa is an exotic Cu deposit from which approximately 29 Mt at 1.07% Cu has been mined (Nelson *et al.* 2007). It is located to the west of the Rosario Porphyry (Fig. 3) and hosted within gravel deposits which have been partly eroded after the formation of exotic Cu mineralization. Copper is mostly hosted in chrysocolla and a variety of Mn-bearing oxides (Fig. 4). Most of the Cu has been mined out and the Cu-bearing manto is only locally preserved (Fig. 4).

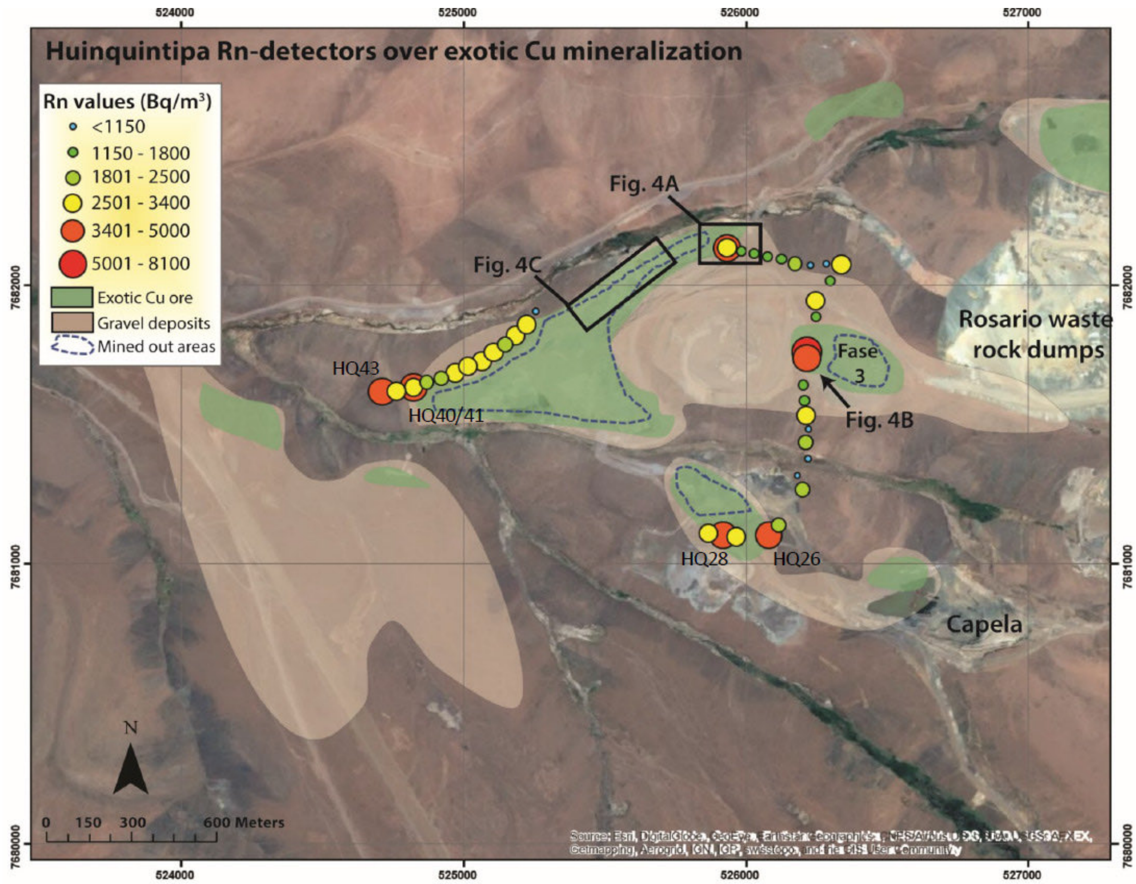

Figure 3. Radon detector results over Huinquintipa, Collahuasi. Locations illustrated on Figure 4 are indicated; additional sample locations mentioned in the text are labelled. Background imagery is from ESRI digital globe.

Figure 4. (below) Green dashed lines outline exotic Cu mineralization. Approximate locations of Rn detector sites and corresponding radon values (Bq/m³) relative to exotic Cu mineralization at Huinquintipa. A) Looking east at northern extent of main manto. B) Looking east at the exposed relict exotic Cu mantos of Fase 3. C) Main exotic Cu manto as it appears along strike to the southwest of area shown in A.

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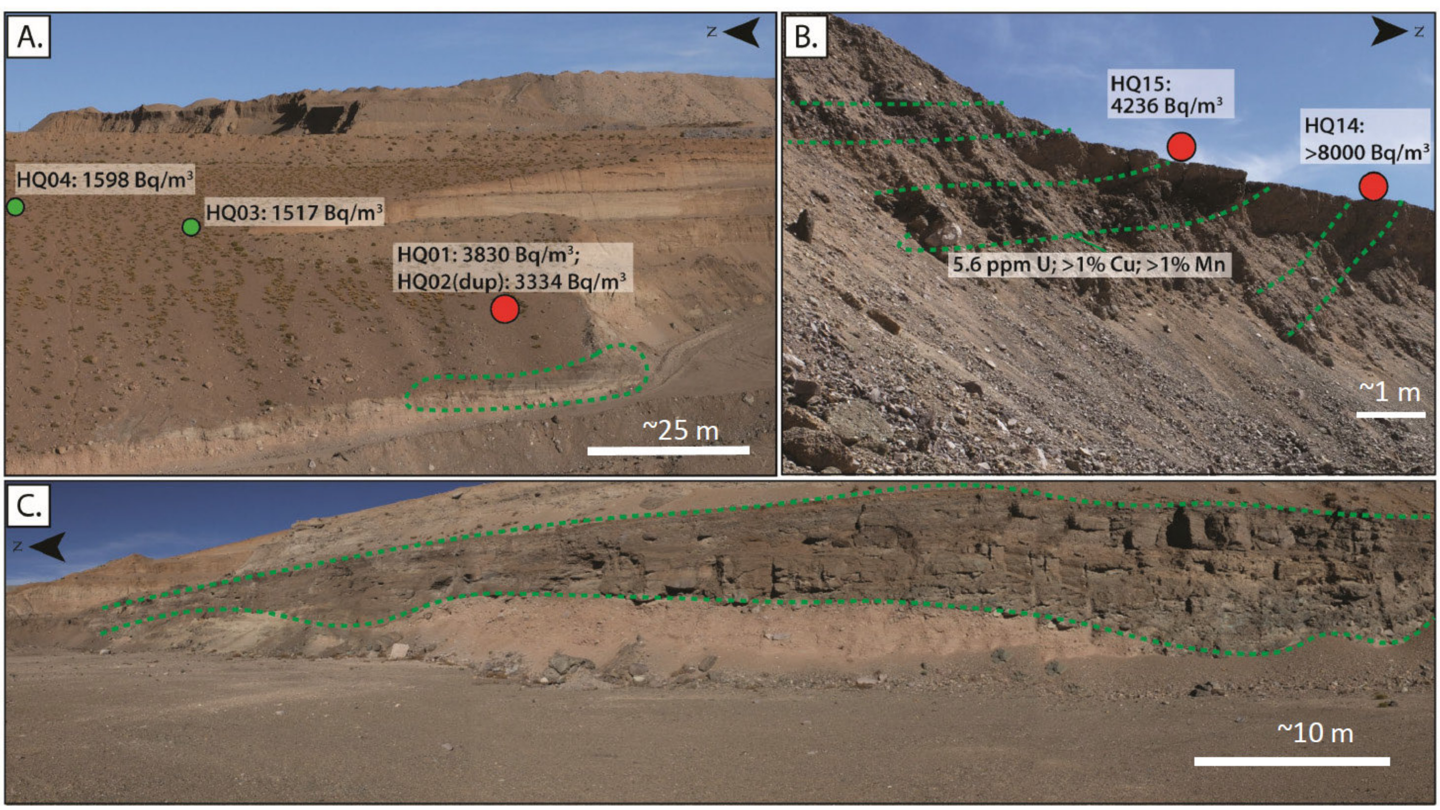

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A total of 42 Rn detectors were placed in a north to south transect across the Fase 3 zone with two short east to west oriented transects at either end (Fig. 3). An additional northeast oriented transect was sampled at the western limit of the deposit. The Rn counts range from 340 Bq/m^3 to 4850 Bq/m^3 with one detector registering alpha decays above the upper detection limit of 8000 Bq/m^3. A few of the detectors (HQ01, HQ14, and HQ15) were placed near and above exposed portions of Cu mantos (Figs. 3, 4) and recorded among the highest Rn counts (> 3400 Bq/m^3), in one case exceeding the upper limit of detection (HQ14). Additional high values were obtained from detectors placed above gravel-hosted exotic mineralization in the southern E-W transect (HQ26 and HQ28) and from those placed west of the known extent of exotic mineralization. The latter detectors were not placed above gravel deposits but over bedrock (HQ43) and at the bedrock-gravel contact (HQ40 and duplicate HQ41). Conversely, the lowest Rn counts came from several detectors placed where gravels were eroded south of Fase 3 zone (< 1150 Bq/m^3). Low values were also obtained from areas where mineralization has been mined out, and where detectors were located over bedrock except for those west of the known exotic mineralzation mentioned above.

The overall dataset demonstrates that Rn counts are high in detectors placed above known exotic mineralization and low in areas where gravels and possible exotic mineralization were eroded. Thus, high Rn counts are a good proxy for the presence of exotic Cu mineralization. However, the detectors placed at the far west of Huinquintipa are at odds with this interpretation because high Rn counts were detected over bedrock, albeit close to the gravel contact. Exotic Cu mineralization may not only be hosted in gravels but can also be hosted in fractures in the bedrock below gravel, such as described from e.g., Damiana in the El Salvador district (Mote *et al.* 2001). Whether bedrock-hosted exotic Cu mineralization is present in fractures at Huinquintipa remains to be confirmed.

Picarón study site and Rn detector results:

Picarón is an exotic Cu prospect, perhaps better described as a hydromorphically transported Cu anomaly, located some 4.5 km west of the small, historically mined Vaquillas epithermal deposit (Fig. 5). Modest Cu grades (generally <0.5 wt.%) are hosted in Mn-bearing oxides observed in RC drill chips near the contact between gravel and bedrock at approximately 32-38 m depth below surface. The bedrock is dominantly Jurassic limestone whereas the gravel

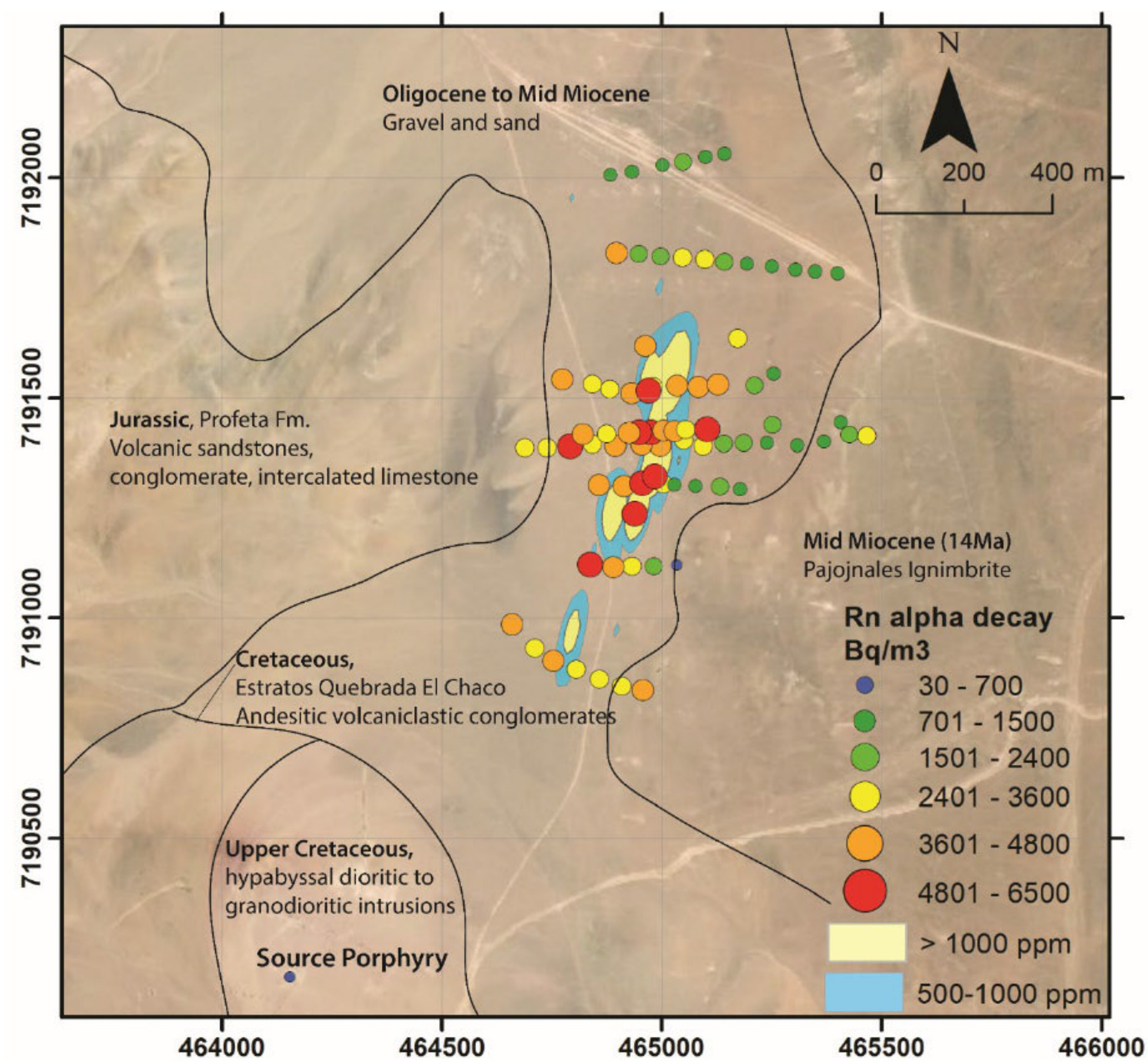

Figure 5. Radon detector results from Picarón. Copper grade contours are projected to surface from approximately 35 m depth. Geology from Venegas et al. (2017). Background imagery is from ESRI digital globe.

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sequence includes increasing amounts of intermediate to felsic volcanic and intrusive clasts from the bedrock upward. The mineralization is fully concealed by gravel deposits and has been defined by 6 RC-drillhole fences with 3 to 6 drill holes each. The likely bedrock source of Cu is a small porphyry prospect exposed about 1 km to the SW of the exotic mineralization.

A total of 86 Rn detectors were placed over the zone of oxide Cu and over nearby adjacent background (Fig. 5). An additional 12 detectors were deployed near Quebrada El Chaco (Fig. 6), some 7 km to the SE from Picarón, to test an area without exotic Cu mineralization in the gravel. The detectors of the background control survey all showed Rn values of less than 2312 Bq/m^3 (Fig. 6).

The Rn decay counts over Picarón range from about 300 Bq/m^3 to about 6500 Bq/m^3. Detectors placed over Cu mineralization in the gravels yielded Rn values of > 3500 Bq/m^3 (Fig. 5). The lowest Rn value pertains to a sample placed over bedrock where oxidized primary mineralization is exposed (PICO-18: 333 Bq/m^3), and areas to the east of the mineralized zone (Fig. 5).

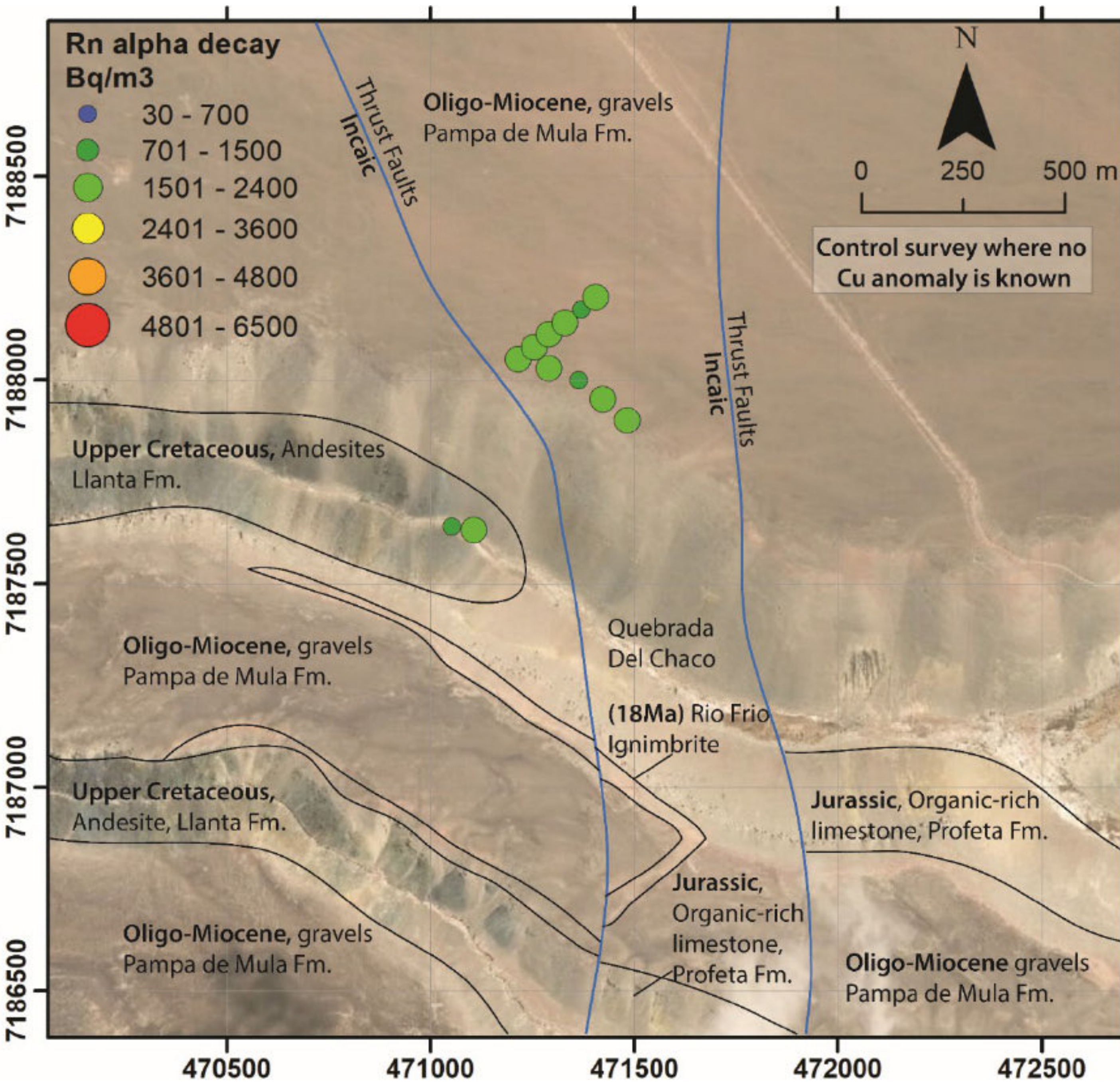

Figure 6. Radon detector results from the control survey at Quebrada del Chaco, located approx. 7 km to the SE from Picarón. Geology from Venegas et al. (2017). Location of thrust faults under gravel cover is inferred. Background imagery is from ESRI digital globe.

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Association of Cu with U

The use of Rn α-decay to detect anomalous U and by inference Cu is based on the assumption that exotic Cu mineralization is characterized by elevated U concentrations. This has been demonstrated as early as the 1950s (Barton 1956) and recently in the Atacama Desert (Kahou *et al.,* 2020). An attempt was made to investigate the presence of elevated U in Cu mineralization in this study as well. The ore samples from Huinquintipa all yielded more than 1% Cu (above upper LOD) and U concentrations between 5 and 21 ppm, whereas all samples analyzed from Picarón contained <5 ppm U and <0.35% Cu. From limited macroscopic observations, it is evident that the highest U contents pertain to those samples with chrysocolla as the dominant Cu mineral and not black Cu-bearing Mn-oxides. In a downhole diagram of Picarón drillhole RC-11-17, U, Cu and Mn show a co-variance through the mineralized zone (Fig. 7). However, the highest Cu values were obtained from a sample representing a depth of 50-52 m and this sample does not have elevated U. Conversely, the highest U value of 4.8 ppm was obtained from a sample at 82-84 m. This depth corresponds to a transition between dark grey and beige-grey limestone, which is interpreted as the redox boundary and therefore may explain the slightly elevated U.

Overall, the geochemical data indicate that exotic

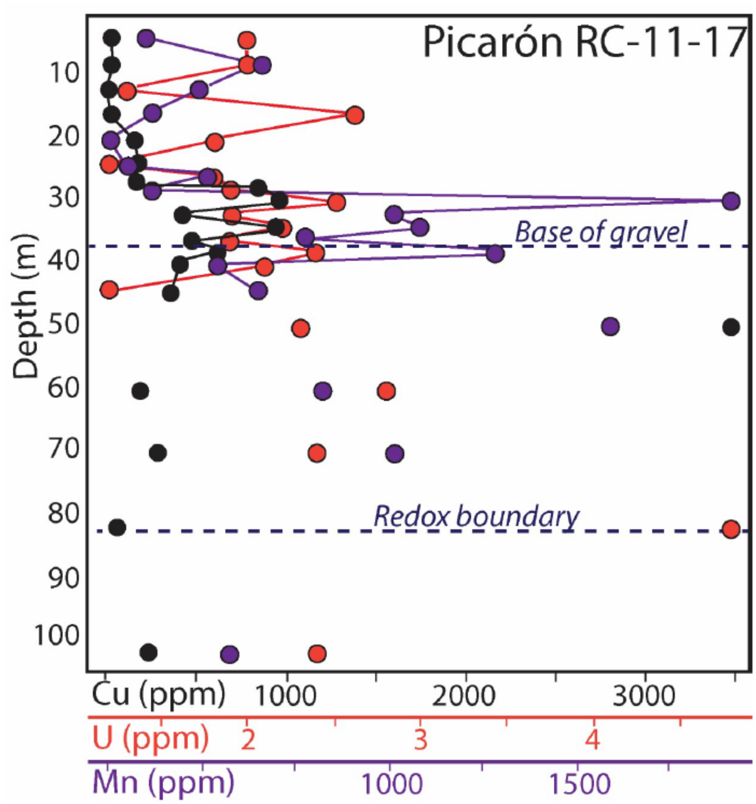

Figure 7. Total digestion data from rock chips taken from RC trays. Downhole plot of Cu, Mn and U concentrations from Picarón RC hole 11-17. Symbols are only connected where consecutive samples were analyzed. Note the co-variance of Cu-U and Mn through the mineralized zone immediately overlying the base of gravel/bedrock contact.

Cu mineralization at Huinquintipa contains U concentrations significantly above crustal abundance. However, additional sampling and sequential leach analyses would be required to elucidate the mineralogical associations of Cu and U and establish background U and Cu concentrations. Limitations of sample material accessible at Picarón does not allow establishing an association of Cu with U with confidence beyond the suggestion of a co-variance through the mineralized zone.

Selective leach geochemistry of surface materials above exotic Cu mineralization at Picaron

Soil samples were taken at the gravel surface, some 30-40 m above bedrock contact. The surface materials at Picarón are slightly alkaline with a soil-slurry pH range of 7.3 to 9.5, and a similar range of values from the samples taken at 5 cm and 30 cm depth. Soil conductivity at 5 cm depth ranges between 30 and 835 μS/cm^3 (15-440 ppm total dissolved solids (TDS)). At 30 cm depth, soils are substantially more conductive with values ranging from 76 to 2820 μS/cm^3 (38-1570 ppm TDS) with one outlier for which 5620 μS/cm^3 (3190 ppm TDS) recorded. There is no systematic difference between samples collected above exotic mineralization and those over background (Fig.8).

Chlorine and Na as well as Ca and S values from the

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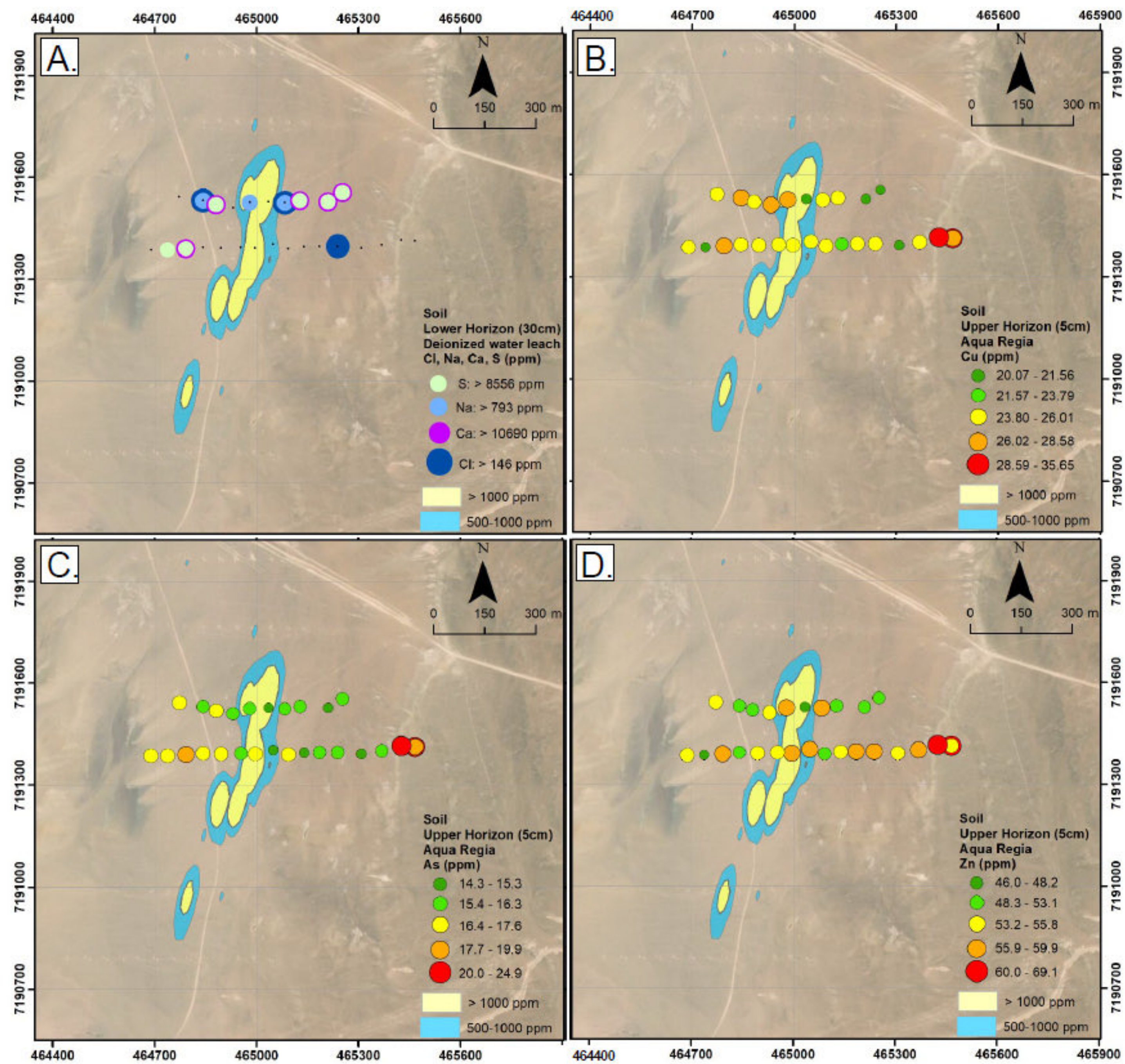

Figure 8. Soil analysis results for: A) Cl, Na, Ca, and S by deionized water leach ICP-MS from samples taken at 30 cm depth. Soil analyses results by aqua regia digestion ICP-MS of B) Cu, C) As and D) Zn from samples taken at 5 cm depth at Picarón. Copper grade contours are projected to surface from approximately 35 m depth. Background imagery is from ESRI digital globe.

deionized water leach of lower soil horizon samples spatially correlate with the conductivity results, indicating that much of the TDS can be explained by the presence of gypsum and salts in the soil (Fig. 8A).

Soil analyses by aqua regia digestion indicate that elements commonly used as pathfinder elements in Cu exploration (e.g., Cu, Mn, Zn, As, Mo, Ag, and U) have only a narrow range of values and are generally not elevated in the soil above the exotic mineralization (Fig. 8). Uranium ranges between 0.7 and 1 ppm, Cu between 20 and 36 ppm (Fig. 8B). Copper and As concentrations are highest in samples collected over an older gravel surface above ignimbrite to the east (Fig. 8). This pattern is interpreted as an effect of the age of the gravel plain and/or dominant rock units in the gravel, and not as an indication of underlying mineralization.

Soil analyses by deionized water leach reveal the presence of weakly bound or soluble ions. Elevated values of chalcophile elements in association with highly conductive material may indicate accumulation in surface material due

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to capillary transport or seismic pumping of metal-bearing fluids along structures above oxidizing sulfide ore bodies (Brown *et al.* 2019). At Picarón, there is no discernible systematic pattern of Cu anomalies over concealed oxide Cu mineralization, or a relationship between elevated Cu and high TDS values in association with structural trends. Copper values are < 40 ppb (Fig. 9). The upper soil horizon, however, has slightly higher Cu values than the lower horizon, which is consistent with published results from Spence, where Cu is elevated near the top of the soil and lower concentrations occur at depth (30 cm; Cameron & Leybourne 2005).

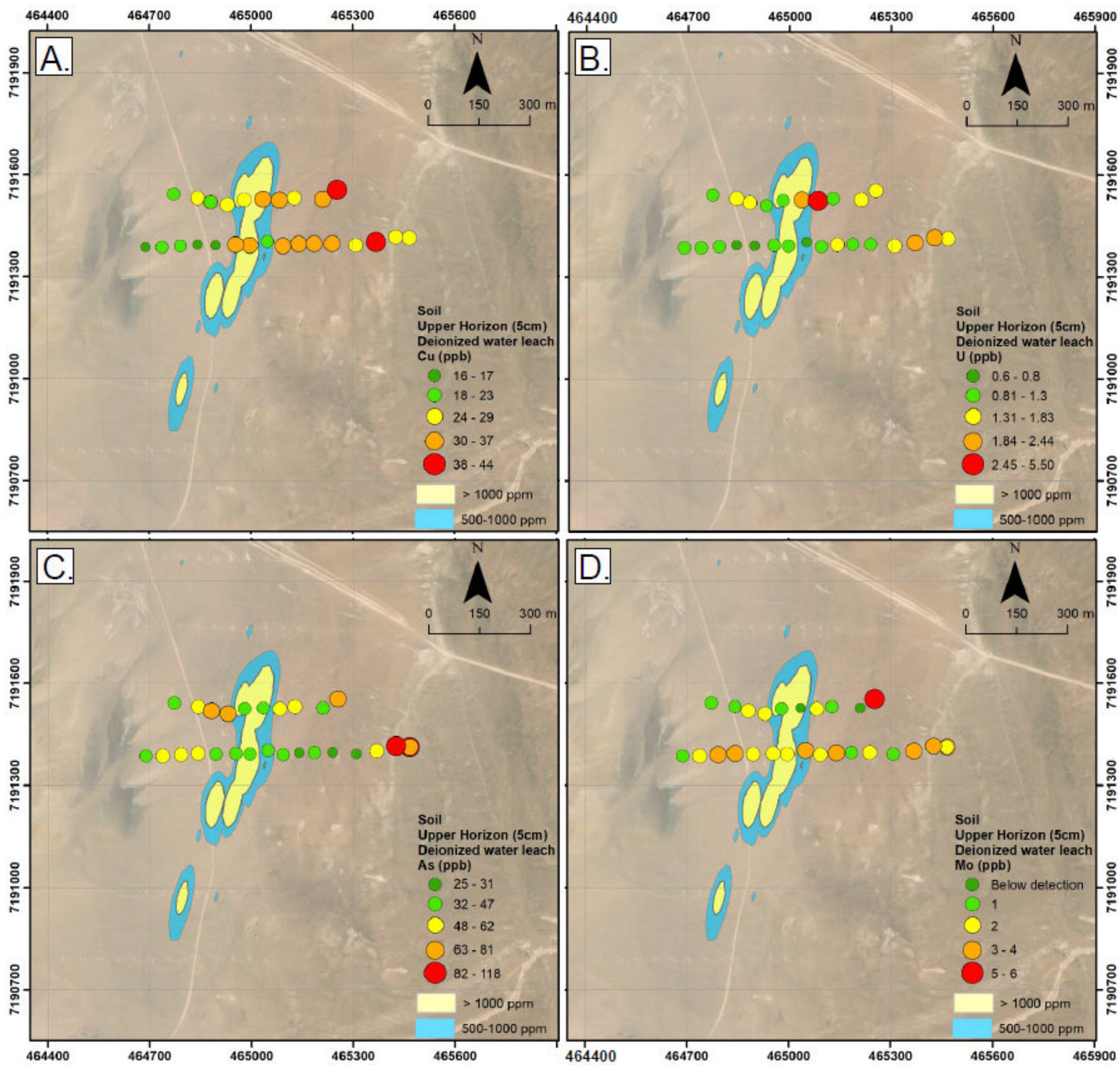

Figure 9. Soil analyses results by deionized water leach ICP-MS of A) Cu, B) U, C) As, and D) Mo from samples taken at 5 cm depth at Picarón. Copper grade contours (blue and yellow) are projected to surface from approximately 35 m depth. Background imagery is from ESRI digital globe.

Discussion

The results demonstrate an empiric spatial relationship of Rn counts above or near exotic Cu mineralization. However, additional research is required to better understand where elevated U is located within the gravels relative to exotic Cu mineralization. Likewise, the influence of Ra mobility and concentration on the Rn counts requires additional work. The

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soil data from Picraón indicate that elevated Rn counts cannot be explained by U transported along faults through gravel cover and precipitated or adsorbed to soil particles near surface. However, high Rn counts could theoretically also be explained by decay from Ra transported along permeable structures, adsorbed to soil matrices and concentrated near surface. Radium 226 is the immediate parent isotope of ^{222}Rn in the U-series decay chain and has a half-life of 1602 years which is long enough for such transport and accumulation to occur. Radium was not analyzed, but it is more easily transported in acidic fluids than under the mildly alkaline conditions observed currently at Picarón (Rachkova *et al.* 2010). Radon derived from Ra transported along faults and concentrated near surface is therefore an unlikely explanation for the Rn patterns at Picarón. Moreover, no evidence for faults intersecting the gravel surface has been observed. Conversely, it is possible that low Rn counts directly over bedrock, including over primary mineralization at Picarón, can be explained, in part, by poorly developed soil, limiting the possibility for Ra to accumulate.

Radon gas, on the other hand, can diffuse over 200 m or more in unconsolidated, dry gravels (Ramola 1989). The water table at Picaron is currently 60-80 m below surface and therefore below the exotic mineralization. Water saturation therefore did not limit the movement of Rn gas from the exotic Cu mineralization. What remains to be shown is to what extent atmospheric conditions (pressure and temperature) can influence the results.

The primary source of Cu is chalcopyrite from porphyry Cu mineralization, likely hosted in quartz-sericite altered rocks which contained enough pyrite to generate the acid required for Cu transport during supergene oxidation (cf. Chavez 2000). The acidic fluids generated during supergene oxidation were probably also capable of dissolving and mobilizing U (Tieh & Ledger 1981). In addition, hypogene sericitic alteration may have also played a key role in destabilizing primary U-bearing phases such as apatite, feldspars and zircon and making U available for aqueous transport (Bouzari *et al.* 2016; Geisler et al. 2007), enhancing the availability of U during supergene oxidation of porphyry systems compared to unaltered granitoids.

Conclusions

The results from Huinquintipa and Picarón suggest that Rn detecting devices are a potential low-cost exploration tool for buried oxide Cu mineralization. Anomalous Rn is detected near concealed oxide Cu mineralization transported laterally from its primary source at both Huinquintipa and Picarón. Radon detecting devices are useful not only for the exploration of exotic Cu ore bodies but can, as demonstrated at Picarón, detect Cu anomalies below ore grade level under the gravels, which then can be used as a vector towards primary Cu targets upstream. In these areas, traditional soil geochemistry fails to detect oxide Cu mineralization buried under cover.

Acknowledgements

Eric Araya and Victor Jara (Collahuasi) are thanked for their help with the work at Huinquintipa. We thank First Quantum Minerals Ltd. for field support and access to the Picaron study site, and AngloAmerican Chile for facilitating access to the Huinquintipa site. This project is part of the MDRU "Discovery Tools for Copper in the Atacama Desert"

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Exploring for laterally transported copper in gravels... continued from page 13

project, supported by First Quantum Minerals, AngloAmerican and Quantum Pacific Exploration (QPX). We extend our gratitude to EXPLORE reviewers Jeff Jaacks and Bob Garrett for their helpful and constructive reviews and to Beth McClenaghan for the editorial comments and oversight. This is MDRU publication 440.

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Benedetto De Vivo, AAG Gold Medal 2019

The Association of Applied Geochemists is pleased to announce that the 2019 Gold Medal for outstanding contributions to exploration geochemistry is awarded to Professor Benedetto De Vivo, University of Napoli Federico II (retired), Italy.

Professor De Vivo has had a distinguished career in applied geochemical research in Europe and around the world, beginning in the1970s and culminating in his long association with the University of Napoli Federico II in Naples, first as Associate Professor in Applied Geochemistry (1987-2000) and then as Full Professor (2000-2017). He graduated in Geological Sciences from the University of Napoli Federico II in 1971, and worked for private companies in ore deposits, mineral exploration and related fields in Italy, Africa and Central America for several years prior to joining the National Research Council (CNR), Rome as a researcher from 1976-1987. He has also served as a research fellow at the Colorado School of Mines (1978) and the U.S. Geological Survey (1982 and 1992), and as a visiting scientist at the Geological Survey of Japan (1990). His current appointments include Adjunct Professorships at Virginia Tech in the United States, and at both Nanjing University and Hubei Polytechnic University in China. Presently he is Full Professor of Exploration and Environmental Geochemistry at Pegaso On-Line University in Naples.

Benedetto's principal fields of research have been environmental geochemistry, fluid and melt inclusions in minerals, and geochemical prospecting applied to mineral exploration. His many contributions to geochemical research and teaching can only be briefly summarized here. Benedetto has been Chairman of the Working Group "Inclusions in Minerals" of the International Mineralogical Association. He was Editor-in-Chief of the Journal of Geochemical Exploration for a decade (2007-2016), and was Co-Chief Editor of *Geochemistry: Exploration, Environment, Analysis* (2016-2017), where he has been a member of the editorial board since 2004. He has also served on the editorial boards of other respected journals, including Mineralogy and Petrology and American Mineralogist.

One of Benedetto's most significant achievements, among many, was his prominent role in the execution of large European-scale geochemical mapping projects, particularly the FOREGS and GEMAS projects, and the Geochemical Atlas of Europe. Benedetto's impressive publication record includes more than 140 journal publications, as well as dozens of monographs and educational publications. His enthusiasm for teaching and the dissemination of knowledge has led to the supervision of some 30 PhD theses in Italy, the United States and China over the course of his career. He has been aptly described by his peers as an exceptional communicator and gifted teacher.

Professor De Vivo is presently the AAG's Regional Councillor for Southern Europe, and is a most worthy recipient of the Association's Gold Medal. With the postponement of this year's IAGS in Chile, the presentation of the Gold Medal will instead take place at the rescheduled Symposium in 2021.

Stephen Cook
May, 2020

Gwendy E. M. Hall – Honorary Fellow

The Association of Applied Geochemists is pleased to announce that Honorary Fellowship in the Association has been awarded to Gwendy E. M. Hall, of the Geological Survey of Canada, Ottawa (retired), in recognition of her distinguished contribution to applied geochemistry in a career spanning 50 years.

Her passion for science and the AAG, a high level of integrity, and a humility that has enabled her to communicate widely as well as encourage and mentor the research of others is well established. Her Honorary Fellowship is particularly noteworthy as she is the first recipient of this honor since Ian Nichol in 2005. Only seven eminent geochemists – all now deceased – have attained Honorary Fellow status over the entire 50-year history of the AAG and its predecessor, the AEG.

What is it that makes Honorary Fellowship so special, particularly given that Gwendy is already a recipient of the AAG's Gold Medal (2005) and Silver Medal (2013)? An Honorary Fellow shall have made a distinguished contribution to applied geochemistry that warrants exceptional recognition. The AAG Council has endorsed both criteria and process for conferring of Honorary Fellow status. The criteria span a broad involvement in generating and disseminating applied geochemical research at a high level, as well as a long commitment to the Association. A minimum of three Fellows must formally propose an individual to the AAG's Awards & Medals Committee. Their independent assessments are forwarded to the AAG Secretary, who then presents the results to Council. A unanimous endorsement by Council is required. Significantly, the number of active Honorary Fellows is capped at a maximum of 5% of AAG Fellows at any one time. Full details concerning Honorary Fellowship are available on the AAG website.

Gwendy Hall has had a prolific publication record over her long career, including 35+ years at the Geological Survey of Canada (GSC) as a research scientist. She has published over 200 papers in recognized scientific journals (>100 as lead author), over 45 GSC reports, and more than 10 book chapters (many as an invited author). Although she is perhaps best known for her work on selective leaches and their application to mineral exploration, her R&D work and resulting publications cover a wide range of topics, including hydrogeochemistry, the development and application of cost-effective approaches for analysis of a broad range of elements to ultra-low levels, environmental geochemistry, the development of specialized techniques to detect individual elements, evaluation of pXRF technology for real-time acquisition of geochemical data, and the application of geochemistry to detect past nuclear test explosions. She has been on the editorial board of prestigious scientific journals, including *Chemical Geology* and *Geochemistry: Exploration, Environment, Analysis*, and a scientific reviewer for several respected journals including *Analyst, Journal of Analytical Atomic Spectroscopy, Analytica Chimica Acta, Applied Geochemistry, Water Air Soil Pollution*, and *Geochemistry: Exploration, Environment, Analysis*. She was instrumental

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Gwendy E. M. Hall… *continued from page 16*

in the creation of the AAG's journal *Geochemistry: Exploration, Environment, Analysis* in 2001, serving as Editor in Chief from inception until 2015.

Throughout her career, Gwendy has made a consistent contribution to the transfer and dissemination of applied geochemistry knowledge, with a career-long commitment to presenting seminars, workshops, conference talks and posters. She has made more than 270 conference presentations, including at all AEG & AAG symposia since 1987. She has presented over 25 seminars to industry, government and academia, including the Canadian Institute of Mining and Metallurgy distinguished lecture series in 2005 and 2006. Gwendy was AEG Distinguished Lecturer in 1998. She has organized and chaired over 14 conference sessions, including four for IGES/IAGS, and was responsible for organizing and chairing the 'Geoanalysis 90' conference, which was the precursor for an ongoing conference series. She has been an invited lecturer at Canadian universities, an external examiner for postgraduate theses, and an advisor for university-based research proposals and theses.

Much of her innovative work at the GSC has been applied by laboratories, government and industry, and is widely available in the public domain due to a prolific and high-quality series of publications. Her successful approach to the technology transfer of her R&D research has resulted in the commercialization of media- and element-specific analytical techniques, and the optimizing of the use of applied geochemistry in the search for mineral deposits by exploration companies. This commercialization was recognized by a Government of Canada award for technology transfer in 1998.

Gwendy has been a long-serving member of the AEG and AAG since joining the Association in 1987, serving unselfishly and guiding its development. She has been an ongoing member of the AAG Council since 1989, led it as President in 1994-95, and was the AEG's Distinguished Lecturer in 1998-99. She is currently AAG Treasurer, a key executive position that she has filled since 1996. Her contributions to applied geochemistry were recognized by the Association with the AAG Gold Medal in 2005, and her commitment to the Association with the Silver Medal in 2013. She is the only person other than the late Eion Cameron who has received both medals. The scientific rigour that she demonstrated while at the GSC has continued since her retirement in 2005, again evidenced by a continued contribution to knowledge via publications, dissemination of her work at conferences, and collaboration with government and industry. She has, for example, continued her research on cost effective ways to detect mineralization, focusing on the use of field portable XRF through research funded by the Canadian Mining Industry Research Organization (CAMIRO).

Gwendy's Honorary Fellowship will be formally presented to her at the next IAGS in Chile, now rescheduled for 2021. Those wishing to read more about her many achievements can find her Gold Medal presentation citation made by the late Gerry Govett in **EXPLORE** No. 129 (Dec 2005), and her Silver Medal presentation citation made by Paul Morris in **EXPLORE** No. 162 (March 2014). Versions of both citations are also available on the AAG website, as are listings of all earlier AAG Honorary Fellows Bob Boyle, Eion Cameron, Alan Coope, Gerry Govett, Herb Hawkes, Ian Nichol, and John Webb.

Paul A. Morris
M. Beth McClenaghan
David L. Kelley
Stephen Cook

The Changing Role of Geological Surveys

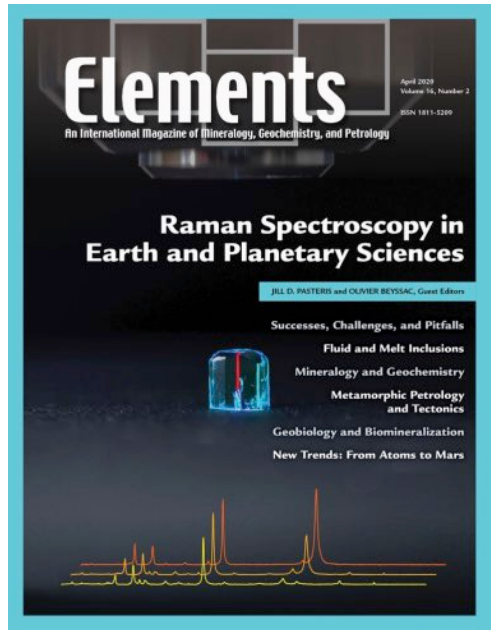
Geological Society of London Special Publication 499
https://sp.lyellcollection.org/online-first/499
Edited by: P.R. Hill, D. Lebel, M. Hitzman, M. Smelror and H. Thorleifson
Geological surveys provide research, mapping, publications and assessments of their jurisdiction's geology, resource vulnerability and investment potential for resources, while concurrently addressing issues like hazards and engineering. This volume examines how geological surveys are structuring their research environments to favour innovation for the public good and how geological surveys stay abreast of the sweeping technological changes and globalization of ideas.

Recently Published in Elements

April 2020, Volume 16, no. 2, Raman Spectroscopy in Earth and Planetary Sciences
This issue comprises six articles reviewing the application of Raman (microprobe) spectroscopy in the geosciences, which has deepened and broadened rapidly over the past four decades. The only AAG news in this issue is the first message of Dennis Arne as President of AAG.

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

John Carranza



Welcome New AAG Members

Fellows

***Fellows** are voting members of the Association and are actively engaged in the field of applied geochemistry. They are nominated to be a Fellow by an established Fellow of the Association by completing the Nominating Sponsor's Form.*

Regular Members

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

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EXPLORATION, ENVIRONMENT, ANALYSIS

The journal is abstracted and/or indexed in *AGI's Bibliography and Index of Geology, Chemical Abstracts, Current Contents, Engineering Index, GEOBASE, GeoRef, Mineralogical Abstracts, PASCAL/CNRS, GeoArchive, Thomson ISI database (SCIE, CC/PC & ES)*

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29th IAGS postponed until 2021

The AAG Executive and Local Organising Committee have unanimously agreed to postpone the 29th IAGS until **October 24-29, 2021** due to the uncertainty created by the coronavirus pandemic.
The submission of abstracts will commence November 1st, 2019.
We hope all AAG members, conference registrants and sponsors will navigate through this crisis safely and encourage you all to follow the directives of your local authorities to minimise its impact.

Website: https://iags2021.cl

29th IAGS Local Organising Committee
AAG Executive

CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry. These events also appear on the AAG web page at: www.appliedgeochemists.org.

Please let us know of your events by sending details to:

Steve Amor, Email: steve.amor2007@gmail.com
or
Tom Meuzelaar, AAG Webmaster, tom@lifecyclegeo.com

Unless otherwise endorsed, there has been no online notice of cancellation or rescheduling of the events below, in response to the Covid-19 pandemic, as of May 14th 2020. However, in the event of further interest, checking the conference websites is strongly recommended.

2020

21-26 JUNE	Goldschmidt 2020. Honolulu HI USA. Website: goldschmidt.info/2020
30 JUNE-1 JULY 7-9 JULY	International Uranium Conference. Adelaide, SA, Australia. Website: uranium.ausimm.com ***Virtual meeting***
13-16 JULY	7th Annual International Conference on Geology & Earth Science. Athens, Greece. Website: www.atiner.gr/geology ***Option of remote (online or pre-recoreded) presentation***
14-16 JULY	International Archean Symposium. Perth WA Australia. Website: 6ias.org
18-20 JULY	Third International Workshop on Environment and Geoscience. Chengdu China. Website: www.iwegconf.org
28-30 JULY	14th International Nickel-Copper-PGE Symposium. Marquette MI USA. Website: www.nmu.edu/eegs/symposium-2020
2-6 AUGUST	Microscopy & Microanalysis 2020. Milwaukee WI US. Website: www.microscopy.org/MandM/2020 ***Virtual meeting***
10-11 AUGUST	3rd International Conference on Earth Science & Geo Science. Atlanta GA USA. Website: tinyurl.com/vlc3ryf
19-21 AUGUST	10th International Conference on Environmental Pollution and Remediation. Prague Czech Republic. Website: icepr.org
Rescheduled	
31 AUG - 2 SEPT.	GeoConvention 2020. Calgary AB Canada. Website: www.https://geoconvention.com
Rescheduled	
2-6 SEPTEMBER	Euroscience Open Forum 2020. Trieste, Italy. Website: tinyurl.com/y2qq3knh
6-9 SEPTEMBER	11th International Conference on Environmental Catalysis. Manchester UK. Website: www.confercare.manchester.ac.uk/events/icec2020
7-11 SEPTEMBER	Multidisciplinary Earth Science Symposium. Prague Czech Republic. Website: tinyurl.com/y5a8gvlm
13-16 SEPTEMBER	Fifth International Symposium on Ethics of Environmental Health. České Budějovice (Budweis) Czech Republic. Website: iseeh.org
5-7 OCTOBER	20th Peruvian Geological Congress. Lima, Peru. Website: tinyurl.com/y8h9tu5u
10-18 OCTOBER	28th Colloquium of African Geology (18th Conference of the Geological Society of Africa). Fez Morocco. Website: www.fsdmfes.ac.ma/CAG28
18-23 OCTOBER	IWA World Water Congress & Exhibition 2020. Copenhagen Denmark. tinyurl.com/y8tpg3jt
22-23 OCTOBER	3rd Virtual Geoscience Conference. Marseille, France. Website: vgc2020.sciencesconf.org
25-28 OCTOBER	GSA 2020. Montréal QC Canada. Website: tinyurl.com/yyz3jgq2 ***May be Virtual***
25-29 OCTOBER	18th International Geological Congress on Heavy Metals in the Environment. Seoul, South Korea. Website: ichmet2020.org
Rescheduled	
9-14 NOVEMBER	36th International Geological Congress. Delhi, India. Website: www.36igc.org
20-26 NOVEMBER	10th South American Symposium on Isotope Geology. Viña del Mar Chile. Website: ssagi.science
23-24 NOVEMBER	International Conference on Geology & Geochemistry. Dubai UAE. Website: geochemistry.conferenceseries.com
30 NOVEMBER – 4 DECEMBER	American Exploration and Mining Association Annual Meeting. Sparks NV USA. Website: www.miningamerica.org/2020-annual-meeting

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CALENDAR OF EVENTS... *continued from page 30*

2021

18-21 JANUARY	Mineral Exploration Roundup 2021. Vancouver BC Canada. Website: roundup.amebc.ca
31 JANUARY-5 FEBRUARY	Winter Conference on Plasma Spectrochemistry. Ljubljana Slovenia. Website: ewcps2021.si
Rescheduled	
4-5 FEBRUARY	Sampling 2020. Lima Peru. Website: tinyurl.com/y8ddlbxu
9-12 FEBRUARY	Australian Earth Sciences Convention. Hobart TAS Australia. Website: www.aesconvention.com.au
14-18 MARCH	Minerals, Metals & Materials Society 2021 Annual Meeting & Exhibition. Orlando FL USA. Website: www.tms.org/tms2021
15-16 MARCH	International Conference on Chemical, Ecological, Environmental Science and Technology. London UK. Website: tinyurl.com/ybgp7sub
18-21 APRIL	Australasian Exploration Geoscience Conference. Brisbane QLD Australia. Website: 2021.aegc.com.au
17-20 MAY	Geological Society of Nevada 2021 Symposium. Sparks NV USA. Website: www.gsnsymposium.org
Rescheduled	
29 JUNE - 2 JULY	5th International Congress on 3D Materials Science. Washington DC USA. Website: www.tms.org/3dms2020
4-9 JULY	Goldschmidt 2021. Lyon France. Website: tinyurl.com/y869e3wo
11-16 JULY	15th International Conference on Mercury as a Global Pollutant. Cape Town South Africa. Website: www.ilmexhibitions.com/mercury2021
1-6 AUGUST	Geoanalysis 2021. Freiberg Germany. Website: geoanalysis2021.de
16-20 AUGUST	12th International Kimberlite Conference. Yellowknife NT Canada. Website: 12ikc.ca
Rescheduled	
29 AUGUST-2 SEPTEMBER	3rd European Mineralogical Conference. Cracow Poland. Website: emc2020.ptmin.eu/
12-17 SEPTEMBER	30th International Meeting on Organic Geochemistry. Montpellier France. Website: eage.eventsair.com/imog-2021
Rescheduled	
13-17 SEPTEMBER	41st International Symposium on Environmental Analytical Chemistry. Regensburg Germany. Website: iaeac.com
Rescheduled	
24-29 OCTOBER	29th International Applied Geochemistry Symposium (IAGS). Viña del Mar Chile. Website: iags2020.cl
15-18 NOVEMBER	15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Rotorua New Zealand. Website: confer.eventsair.com/sga2021

2022

31 JULY- 5 AUGUST	World Congress of Soil Science 2022. Glasgow UK. Website: www.soils.org.uk/wcss2022
Rescheduled	
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

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
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