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# Seaweed as an Exploration Medium along the inlets of British Columbia – Part 2: Chemical variations and long-term changes - Howe Sound

***Colin Dunn[1] and Rick McCaffrey[2]***
*[1]Colin Dunn Consulting Inc., North Saanich, BC (colindunn@biogeochemistry.ca);*
*[2]Vancouver, BC - formerly Acme Labs, Vancouver, BC (mccaffrey.rick@gmail.com)*

In a previous article we described the chemical variations of seaweed from the intertidal zone of Jervis Inlet, western Canada, focusing on the use of the brown rockweed known as wrack *(Fucus gardneri)* as a potential geochemical exploration medium that preserves the chemical variations of the surrounding coastal mountains (Dunn & McCaffrey 2017). A similar seaweed collection was made around Howe Sound from many of the same sites sampled 24 years earlier (Dunn *et al.* 1992), including the area down-drainage from the former Britannia Cu mine, 12 km south of Squamish (Fig. 1).

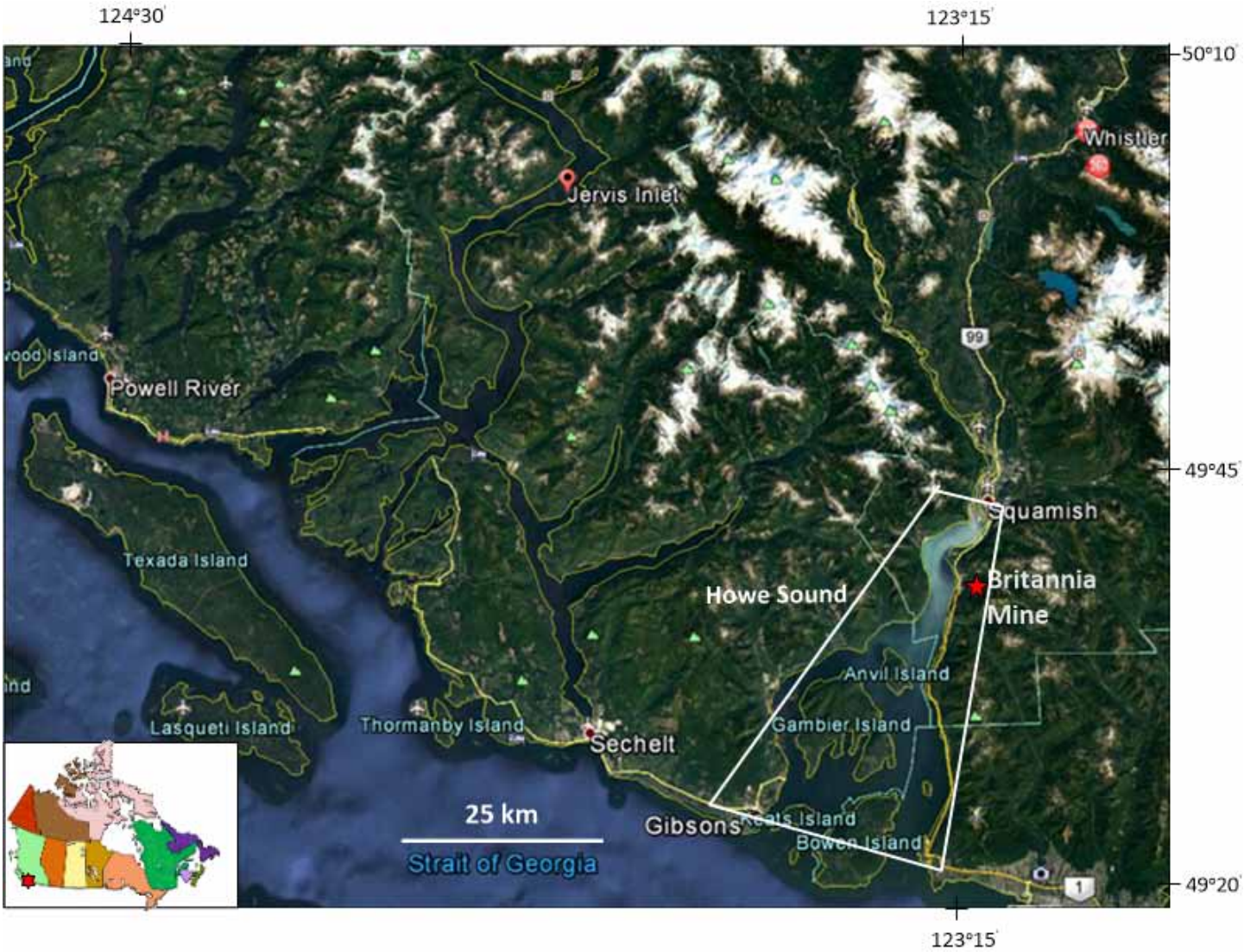


*Figure 1. Location map, including Howe Sound, Jervis Inlet, and Britannia Beach on the west coast of Canada.* Map base is from Google Earth.

## Location

Horseshoe Bay, opposite Bowen Island, lies 15 km west of downtown Vancouver, at the southeastern end of Howe Sound. The Sound terminates at Squamish 40 km to the north where the Squamish River drains from the north, and is up to 40 km wide in the south and narrows to 3 km for the last 20 km. Of the several islands in the Sound, Bowen, Gambier, and Anvil are the largest. Highway 99 follows the eastern shore, passing through the small communities of Lions Bay and Britannia Beach (Fig. 1).

*continued on page 5*


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Editor:
Beth McClenaghan (beth.mcclenaghan@canada.ca)
Business Manager:
Pim van Geffen 1-604-681-6765 (explorenewsletter@gmail.com)
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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: http://www.geolsoc.org.uk/template.cfm?name=geea_instructions_for_authors

In addition to the technical article, authors are asked to submit a separate 250 word abstract 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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# TABLE OF CONTENTS

Seaweed as an Exploration Medium along the inlets of British Columbia – Part 2: Chemical variations and long-term changes - Howe Sound ..... 1
Notes from the Editor ..... 3
President's Message ..... 4
The Search for Gold in Greenland ..... 13
AAG Councillors 2018-2019 ..... 18
Frank Arnott Award ..... 20
Resources for Future Generations 2018 Short Courses and Field Trips ..... 21
Gala Dinner Invitation ..... 26
Mentoring Benefits Everyone ..... 27
Recently Published in Elements ..... 27
Geochemistry: Exploration, Environment, Analysis ..... 28
Chapter Review ..... 30
Calendar of Events ..... 30

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Overburden Drilling Management ..... 10

# Notes from the Editor

Welcome to the first issue of 2018. **EXPLORE** issue 178 includes one technical article that describes part 2 of the use of seaweed as an exploration medium along the inlets of British Columbia, Canada, and was written by Colin Dunn and Rick McCaffrey. A second article describes the search for Viking gold in Greenland by Denis Schlatter, Joshua Hughes, and Ole Christiansen.

**EXPLORE** thanks all those who contributed to the writing and/or editing of this issue: Steve Adcock, Steve Amor, Dennis Arne, Al Arsenault, Ole Christiansen, Steve Cook, Travis Ferbey, Mike Gadd, John Gravel, Joshua Hughes, David Leng, Colin Dunn, Rick McCaffrey, Mike Parkhill, Denis Schlatter, Dave Smith, Wendy Spirito, Pim van Geffen, and Peter Winterburn.

**Beth McClenaghan**
*Editor*

# President's Message

In beginning my term (2018-2019) as President of the Association of Applied Geochemists (AAG), I want to first thank my predecessor Ryan Noble for his hard work and capable leadership at the helm of the Association over the past two years. Ryan has been a strong proponent of student funding and research support and has been instrumental in the AAG's embracing new technology such as social media and digital publications. He will be a difficult act to follow, but he will continue on the Executive Council as Past President along with Gwendy Hall and Dave Smith. Dennis Arne of CSA Global is now the new Vice-President of the AAG for the coming term and I look forward to working with such an experienced and capable group over the next two years. It will be a pleasure to continue working with Al Arsenault in the AAG business office, with our regional councilors around the world and with the elected members of the AAG Council. I thank outgoing councilors Paul Morris, Mel Lintern, Romy Matthies and Dennis Arne for their contributions work and welcome continuing councilor Erick Weiland and new councilors Maurizio Barbieri, David Murphy, Graham Sylvester and Yulia Uvarova to the 2018-2019 Council.

A few words about myself: I received my B.Sc. and M.Sc. degrees in geology from Carleton University and the University of British Columbia, respectively and for the past 11 years I have been Chief Geochemist with Teck Resources in Vancouver, British Columbia, Canada. Prior to that I held a number of different positions in private practice, industry and government; as a consultant, with Anglo American, the British Columbia Geological Survey and before that with the Geological Survey of Canada. During this time, I have seen the practice of applied geochemistry evolve considerably from its traditional field-based approaches to encompass rapidly developing fields of mineral chemistry, big data, and genomics, among others.

Without question the big event of 2018 will be our 28th International Applied Geochemistry Symposium (IAGS 2018) to be held June 16-21 in Vancouver, Canada. Unlike previous IAGS symposia however, in this case the AAG has partnered with the Resources for Future Generations (RFG 2018) conference, which will bring together many individual associations and societies under a single roof at the Vancouver Convention Centre. More than 5,000 people are expected to attend the four-day event. The AAG's local organizing committee, under the direction of Peter Winterburn of the University of British Columbia, is putting together exciting technical sessions, field trips, and short courses for the meeting. As always, the symposium will provide a venue for applied geochemists to meet, present their ideas, and generate new ones. The eleven applied geochemistry sessions organized by the AAG will showcase advances in both exploration and environmental geochemistry, while field trips will look at surficial geochemical methods, laboratory procedures and the lithogeochemical footprints of porphyry copper deposits in British Columbia and Nevada. The short courses will cover a wide range of topics from regolith characterization to lithogeochemistry, data interpretation and mineral chemistry. The AAG banquet is a long-standing tradition of IAGS Symposia. This year the dinner will be held at a truly unique location, the Vancouver Aquarium in Stanley Park. Full details of the RFG meeting and all AAG events are available at: http://rfg2018.org/, and on our newly-redesigned website at https://www.appliedgeochemists.org/. The Annual General Meeting (AGM) of the Association will also be held at RFG 2018 in Vancouver, and I would encourage all members to attend and take part. Finally, I wish to take a moment to remember our friend and colleague Kurt Kyser of Queen's University, who passed away prematurely in 2017. Kurt was an active member of the AAG, editor of GEEA and a highly regarded scientist. He was a regular contributor to AAG symposia and we shall miss him.

**Steve Cook,**
*AAG President*
*Email: Stephen.Cook@teck.com*

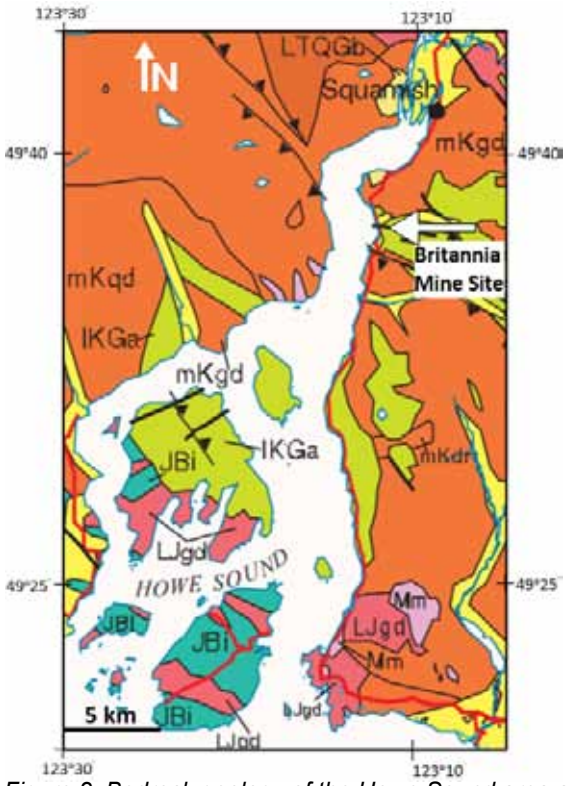


## 2018 AAG Dues Reminder

Reminder that AAG membership fees for 2018 are now due.

Membership fees can be paid on AAG's website (www.appliedgeochemists.org).

## Seaweed as an Exploration Medium… *continued from page 1*




### Environmental Setting and Geology

Howe Sound is located within the wet maritime forest (Coastal Western Hemlock Biogeoclimatic Zone) with steep mountains on either side. Water depth of the fjord averages 280 m south of a submarine ridge (14-61 m deep – "Porteau sill") north of Anvil Island located half-way up the Sound, and 240 m deep farther north. The bedrock geology of the sound area is shown in Figure 2.

In 1888, Cu was discovered in the mountains around Britannia Creek, 10 km south of Squamish, and in 1905 mining began. By 1929 it was the largest Cu mine in the British Empire. Mining continued until 1974, by which time it had produced 500,000 t Cu, 122,000 t Zn, 15,000 t Pb, 14,000,000 g Au, and 84,000,000 g Ag (Smitheringdale 2011). During the operations, a considerable amount of metal-rich sediment was discharged into Howe Sound and considerable efforts have gone into environmental remediation.

### Seaweed (Rockweed *[Fucus]*) Survey

The seaweed survey was conducted in August of 2015 (applying the same sample collection and analytical procedures as those described in Part 1) collecting samples from 34 stations, mostly at intervals of 2-5 km along the shore, with additional samples where streams were seen draining into the sea. Including controls, a total of 43 samples were submitted for analysis. The four splits of a rockweed

*Figure 2. Bedrock geology of the Howe Sound area and location of the Britannia Mine. Yellow Quaternary sediments including LTQGb (Garibaldi Gp volcanic rocks); mKgd Middle Cretaceous granodiorite; mKqd Middle Cretaceous quartz diorite; IKGa Lower Cretaceous Gambier Gp, metavolcanics and metasediments; JBI Jurassic Bowen Island Gp, mostly metavolcanic rocks; LJad Late Jurassic andesite; LJGd Late Jurassic granodiorite; Mm Mississippian metamorphic rocks. Geology from http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Maps/GeoscienceMaps/Documents/GM2005-03_South.pdf (after Armstrong 1990).*

*continued on page 6*

## Seaweed as an Exploration Medium… *continued from page 5*

control sample showed that analytical precision was very good with RSDs mostly better than 10%, except for a few elements (e.g. heavy REEs, Au, Hg, Mo, Sb, Th, and Ge) that had concentrations close to the detection limits of the analytical method, yet yielded RSDs mostly better than 30%. The data for Mo exhibited poor accuracy so are omitted from this summary. The reproducibility of the field and laboratory duplicates varied from good to excellent for almost all elements. Analytical data are reported in Appendix A.

### Results

Table 1 summarizes the element concentrations in the 34 samples and compares concentrations to the suite of 47 samples from Jervis Inlet, collected 2 years previously (Dunn & McCaffrey 2017). The highlighted median values show that Ag, Au, Ba, Ce, Co, Cu, La, Nd, Ti, and Y have concentrations more than 4 times higher in Howe Sound than Jervis Inlet; similar magnitudes of relative enrichment are shown for the maximum values.

| HOWE (n=34) | | *D.L.* | Median | Max. | JERVIS (n=47) | Median | Max. | Median Howe:Jervis | Maximum Howe:Jervis |
|---|---|---|---|---|---|---|---|---|---|
| Ag | ppb | *2* | 100 | 128 | Ag | 23 | 63 | 4.35 | 2.03 |
| As | ppm | *0.1* | 27.65 | 44.8 | As | 15.7 | 26.5 | 1.76 | 1.69 |
| Au | ppb | *0.2* | 14.25 | 23.5 | Au | 0.7 | 4.6* | 20.36 | 5.11 |
| B | ppm | *1* | 75 | 106 | B | 86 | 121 | 0.87 | 0.88 |
| Ba | ppm | *0.1* | 68.7 | 187.2 | Ba | 12.6 | 30.4 | 5.45 | 6.16 |
| Ca | % | *0.01* | 1.3 | 5.71 | Ca | 1.32 | 2.59 | 0.98 | 2.20 |
| Cd | ppm | *0.01* | 2.02 | 3.04 | Cd | 1.7 | 3.02 | 1.19 | 1.01 |
| Ce | ppm | *0.01* | 0.51 | 5.67 | Ce | 0.07 | 1.24 | 7.29 | 4.57 |
| Co | ppm | *0.01* | 3.385 | 6.11 | Co | 0.56 | 3.19 | 6.04 | 1.92 |
| Cr | ppm | *0.1* | 3.65 | 32.4 | Cr | 2.1 | 18.1 | 1.74 | 1.79 |
| Cs | ppm | *0.005* | 0.056 | 0.268 | Cs | 0.037 | 0.149 | 1.51 | 1.80 |
| Cu | ppm | *0.01* | 7.895 | 88.16 | Cu | 1.54 | 5.58 | 5.13 | 15.80 |
| Fe | % | *0.001* | 0.032 | 0.476 | Fe | 0.014 | 0.37 | 2.29 | 1.29 |
| K | % | *0.01* | 2.905 | 3.92 | K | 2.04 | 2.76 | 1.42 | 1.42 |
| La | ppm | *0.01* | 0.405 | 3.11 | La | 0.06 | 0.6 | 6.75 | 5.18 |
| Li | ppm | *0.01* | 0.6 | 2.74 | Li | 0.28 | 2.36 | 2.14 | 1.16 |
| Mg | % | *0.001* | 0.928 | 1.114 | Mg | 0.66 | 0.88 | 1.40 | 1.26 |
| Mn | ppm | *1* | 136.5 | 252 | Mn | 35 | 122 | 3.90 | 2.07 |
| Na | % | *0.001* | 2.6195 | 3.892 | Na | 1.455 | 2.82 | 1.80 | 1.38 |
| Nd | ppm | *0.02* | 0.415 | 3.02 | Nd | 0.06 | 0.65 | 6.92 | 4.65 |
| Ni | ppm | *0.1* | 8.1 | 15.5 | Ni | 3.6 | 11.6 | 2.25 | 1.34 |
| P | % | *0.001* | 0.128 | 0.198 | P | 0.083 | 0.138 | 1.54 | 1.43 |
| Pb | ppm | *0.01* | 0.21 | 1.27 | Pb | 0.07 | 0.67 | 3.00 | 1.90 |
| Rb | ppm | *0.1* | 12.8 | 16.8 | Rb | 8.9 | 10.7 | 1.44 | 1.57 |
| Re | ppb | *1* | 18 | 47 | Re | 18 | 43 | 1.00 | 1.09 |
| S | % | *0.01* | 3.395 | 3.77 | S | 1.67 | 2.59 | 2.03 | 1.46 |
| Sb | ppm | *0.02* | 0.115 | 0.35 | Sb | 0.12 | 0.24 | 0.96 | 1.46 |
| Sc | ppm | *0.1* | 0.2 | 1 | Sc | 0.2 | 0.6 | 1.00 | 1.67 |
| Se | ppm | *0.1* | 0.5 | 1 | Se | 0.3 | 0.5 | 1.67 | 2.00 |
| Sm | ppm | *0.02* | 0.06 | 0.63 | Sm | <0.02 | 0.14 | | 4.50 |
| Sr | ppm | *0.5* | 711.2 | 934.8 | Sr | 521 | 886 | 1.37 | 1.06 |
| Ti | ppm | *1* | 12.5 | 283 | Ti | 2 | 158 | 6.25 | 1.79 |
| U | ppm | *0.01* | 1.12 | 4.08 | U | 0.9 | 1.66 | 1.24 | 2.46 |
| Y | ppm | *0.001* | 0.45 | 2.931 | Y | 0.102 | 0.749 | 4.41 | 3.91 |
| Zn | ppm | *0.1* | 34 | 214 | Zn | 16.5 | 46.5 | 2.06 | 4.60 |
| Zr | ppm | *0.01* | 0.21 | 1.07 | Zr | 0.10 | 0.24 | 2.10 | 4.46 |

Mo omitted - v. poor accuracy at Howe Sound

*Less 1 high Au value that was not reproduced by resampling in 2017

*Table 1. Element concentrations in dry rockweed – Comparison of Howe Sound with Jervis Inlet.*

*continued on page 8*

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## Seaweed as an Exploration Medium… *continued from page 6*

Figure 3 shows the relatively high levels of Cu and Zn in samples from close to Britannia Beach. Lead values are elevated, but quite low, whereas Ag values show a stronger dispersion toward the southwest. The pattern for Ag has closer similarities to Au than base metals, perhaps indicating relative Au enrichment from a source on the west side of the Sound

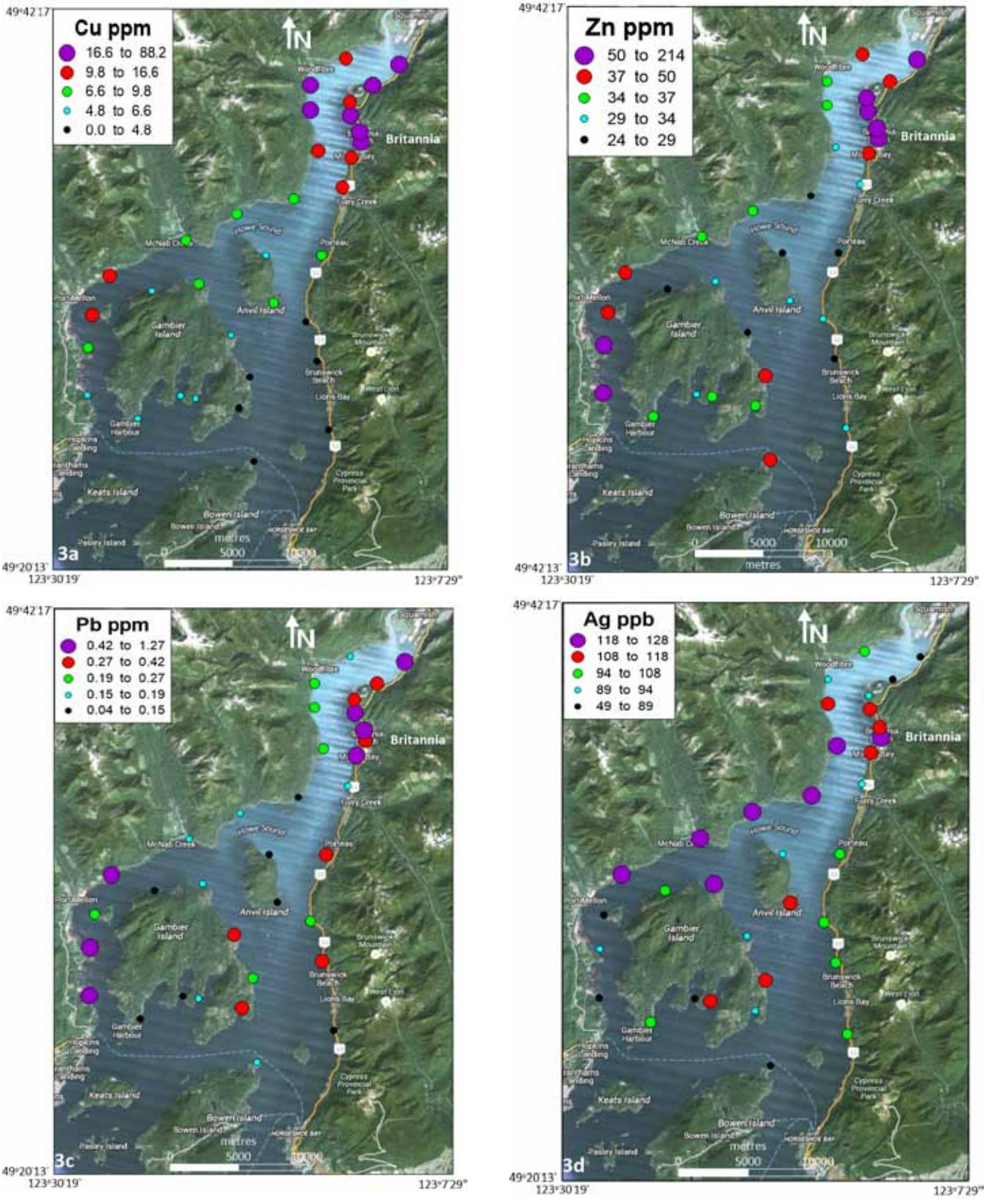


*Figure 3. Cu, Zn, Pb, and Ag concentrations in dry rockweed determined by modified aqua regia/ICP-MS.*

*continued on page 9*

## Seaweed as an Exploration Medium… *continued from page 8*

(Fig. 4) – e.g. McNab Creek (north of Gambier Island). Arsenic exhibits a similar pattern to Au, but shows more dispersion down the eastern channel.

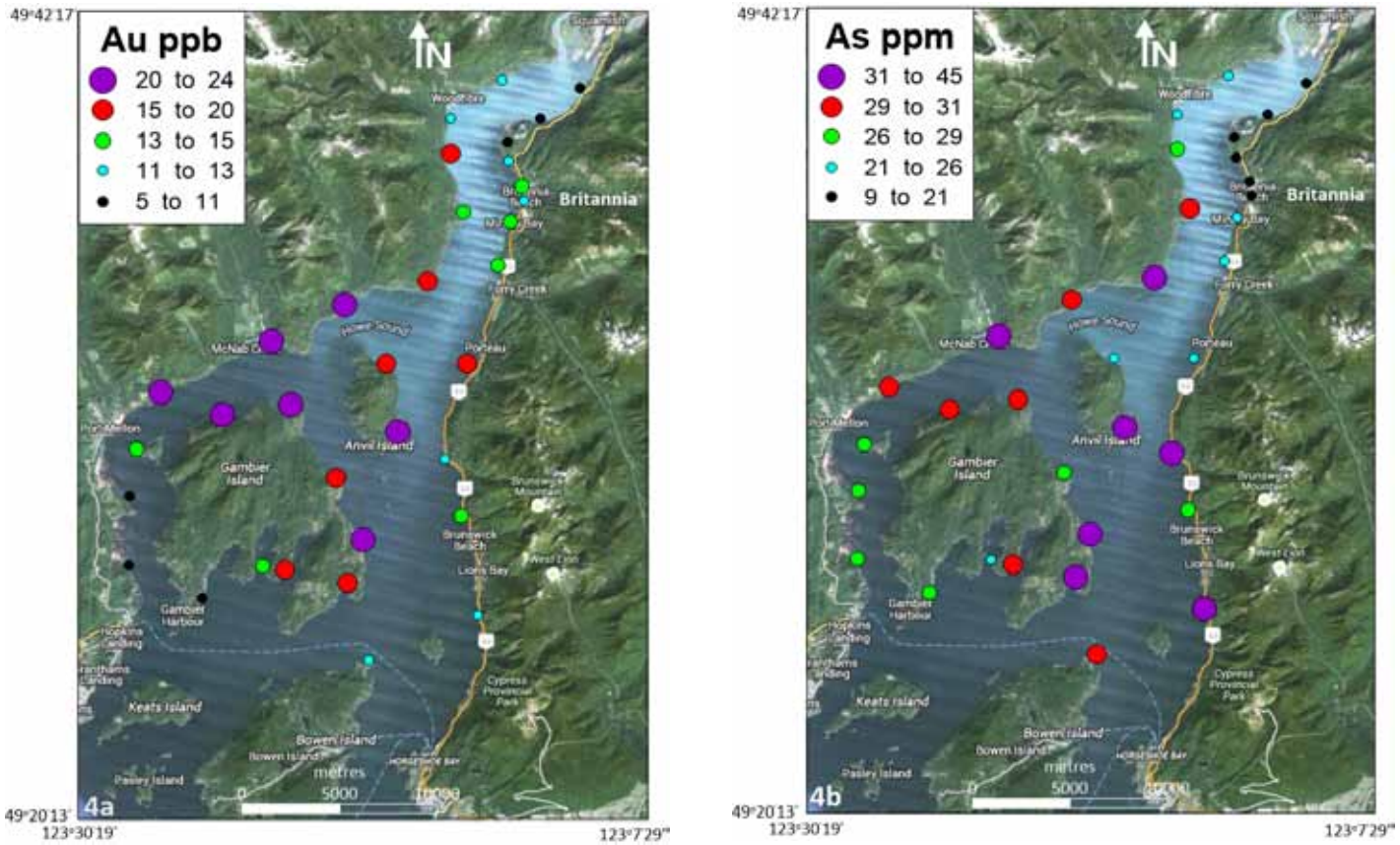


*Figure 4. Au and As concentrations in dry rockweed determined by modified aqua regia/ICP-MS.* *continued on page 10*

## Seaweed as an Exploration Medium… *continued from page 9*

At the north end of the Sound, where there is an abundance of water and sediment draining from the Squamish River, there are relatively high concentrations of Co and Cr (Fig. 5) with associated Ba, Fe, Ni, REE, Hg, and U (not shown) indicating a possible mineralized source upstream. However, a similar suite of elements was noted in the upper reaches of Jervis Inlet (Dunn & McCaffrey 2017) suggesting that this might be related to a higher influx of fresh water compared to farther south.

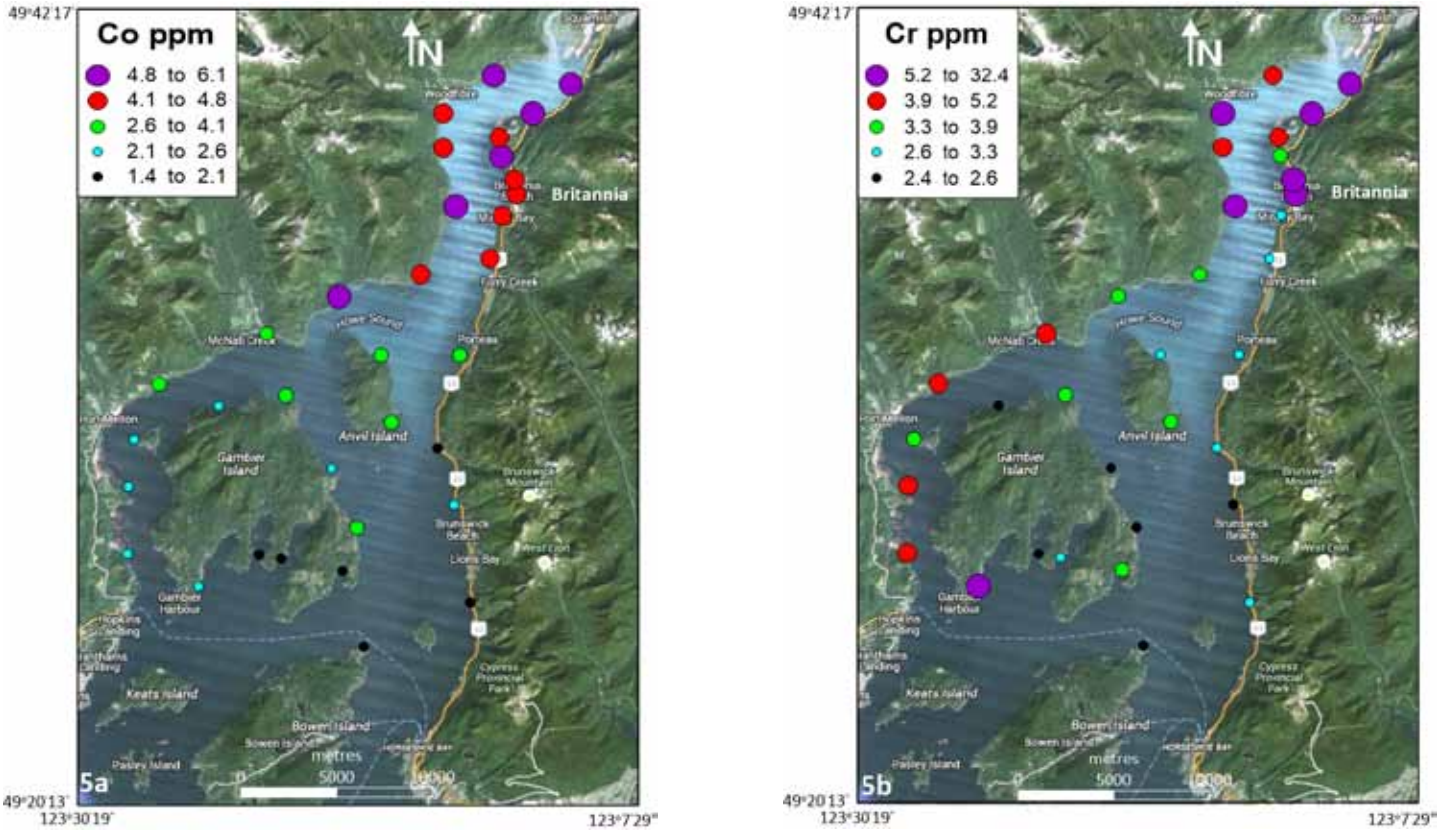


*Figure 5. Co and Cr concentrations in dry rockweed determined by modified aqua regia/ICP-MS.*

Rhenium concentrations in vegetation are typically <1 ppb re, but in brown seaweed the saline environment results in much higher levels. The highest concentrations of Re are mostly at the southern end of Howe Sound and, as at Jervis Inlet, it is surmised that the low concentrations in the north may be because that area has a higher concentration of fresh water from stream meltwaters draining from the mountains, resulting in stratification of fresh water over the denser seawater. The similar distribution pattern shown by Na is further indication that the northern waters are less saline than those to the south (Fig. 6). This may be a consistent pattern in the coastal fjords.

*continued on page 11*

## Seaweed as an Exploration Medium… *continued from page 10*

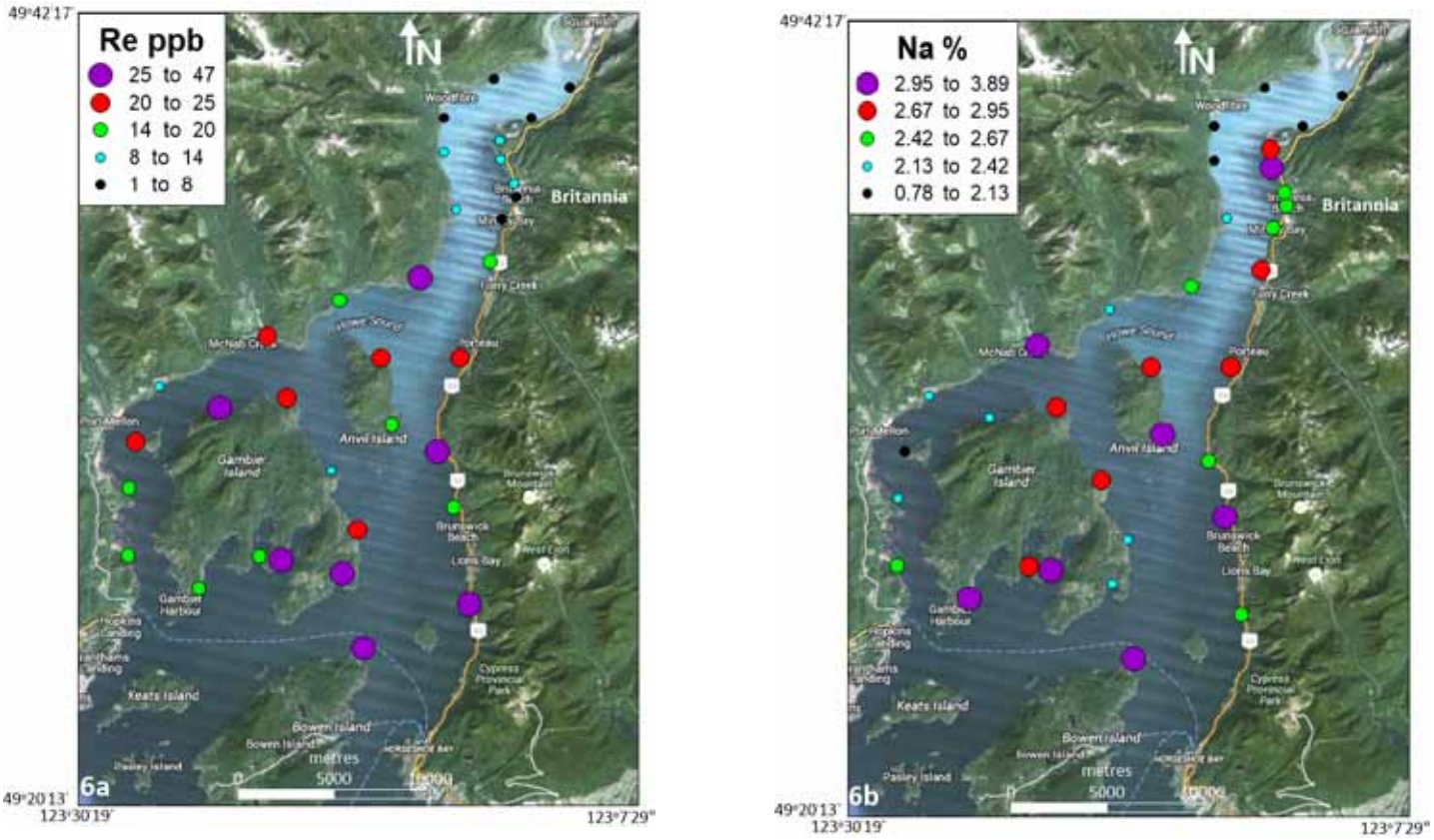


*Figure 6. Re and Na concentrations in dry rockweed determined by modified aqua regia/ICP-MS.*

### Long-term changes in seaweed chemistry

Figure 7a shows the Britannia Mine Museum. The mine site was to the left of the museum, and drainage down the valley carried metal rich sediments for many years, with the result that shoreline rocks on either side of the stream became heavily stained and no seaweed grew for a distance of 1.5 km to both the north and south of Britannia Beach (Dunn et al. 1992) – Fig. 7b.

Where the seaweed first appeared in 1991, it was stunted and contained 540 ppm Cu and 300 ppm Zn (Table 2).

| Year | Copper (ppm) Median | Max | Zinc (ppm) Median | Max |
|---|---|---|---|---|
| 1991 | 120 | 540 | 160 | 300 |
| 2015 | 7 | 88 | 35 | 210 |

*Table 2. Long term changes in concentrations of Cu and Zn in dry rockweed – same location resampled in 2015.*

Although the rock staining persists to today, the seaweed now grows in the previously barren zone and concentrations of both Cu and Zn are substantially lower in samples collected near the former mine site in 2015, presumably because of the extensive environmental remediation that had taken place over the previous quarter century. Cadmium (~2 ppm) and Hg (~10 ppb) had similar low concentrations in 1991 and 2015.

*continued on page 12*

*Figure 7. a) Britannia Mine Museum, drainage is down the valley to the left of the mine building; b) 1 km north of Britannia in 1991 - high-tide staining of rocks from effluents in Britannia Creek that drained into Howe Sound.*

## Seaweed as an Exploration Medium… *continued from page 11*

### Summary and Conclusions

The brown rockweed *Fucus* grows in abundance in the intertidal zones of the western shores of Canada and the USA, and is easy to collect by boat. Where a stream cuts through mineralization, the waters can become enriched in elements associated with the mineralization. Many streams drain into the abundant sounds along the northwest coast of the USA and Canada where their elevated metal signatures can be readily reflected in the rockweed close by. Therefore, if seaweed is relatively enriched in a commodity metal (and/or its pathfinder elements) a focus is provided for more detailed follow up into the mountains to seek the source.

Thirty-four samples were collected from the shores of Howe Sound. Distinct zones of relative metal enrichments were identified:

1. Notably Cu and Zn close to Britannia Beach, and undoubtedly derived from the former Britannia mine;
2. Pb and Ag also moderately enriched near Britannia Beach, but with Ag exhibiting similar enrichments along the western shore, opposite Gambier Island;
3. Highest Au levels were at similar sites to the highest Ag, suggesting an area of slight precious metal enrichment north of Gambier Island and possibly introduced into Howe Sound from McNab Creek. Arsenic dispersion, commonly associated with Au, extends from this area to the southeast;
4. Co and Cr present a different picture with highest levels (associated with Ba, Fe, Ni, REE, Hg, and U) in the north, suggesting drainage from a mixed source dominated by mafic rocks north of Squamish;
5. High enrichments of Re and Na are probably related to water salinity, since brown seaweeds are known to be biological sinks of Re in the sea (Yang, 1991);
6. Samples collected in 1991 from sites near Britannia Beach were resampled in 2015 and found to contain significantly lower concentrations of Cu and Zn than previously, attesting to the efficiency of the steady clean-up efforts over the past quarter century.

It is concluded that the rockweed *Fucus* can be a useful sample medium for providing focus to exploring for sources of metal enrichments, and can be used for long-term environmental monitoring.

### Acknowledgements

We thank Beth McCaffrey for her assistance in the collection of samples, and reviews of this article by Beth McClenaghan and Steve Adcock. We gratefully acknowledge the assistance of Terri-Lynn Ferguson and the analytical support provided by Acme Laboratories/Bureau Veritas, Vancouver, BC.



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# The Search for Gold in Greenland

***Denis M. Schlatter[1], Joshua W. Hughes[2], Ole Christiansen[3]***
*[1] Helvetica Exploration Services GmbH, Carl-Spitteler-Strasse 100, CH-8053, Zürich, Switzerland*
*[2] Department of Earth Sciences, Durham University, Science Labs, Durham, DH1 3LE, U.K.*
*[3] Kommune Kujalleq, Postboks 514, 3920 Qaqortoq, Greenland*

## Introduction

Gold is one of the first metals that was worked by humans and has been exploited and intensively used for more than 5000 years. Today gold is an increasingly important mineral resource, with over half of the global annual mineral exploration budget spent on the pursuit of gold deposits. More than half of the global gold production is used in the production of jewellery, whereas the remainder is used for financial reserves or for industrial applications such electronics, medicine, and space technologies. The main producers of this precious metal are China, Australia, the U.S.A., Russia and South Africa. However, gold can be found worldwide and, notably, in Greenland.

Gold occurrences have been discovered throughout Greenland in Archaean, Paleoproterozoic and Paleozoic terranes. However, it is fair to say that although mapping and sample collection in the known gold belts in Greenland were performed systematically, targeted exploration and applied research is lacking and the genesis of known deposits remains poorly understood and this in turn has resulted in a lack of identified gold resources (Kolb *et al.* 2017). Despite the clear potential, to date only one gold deposit in Greenland has commercially produced gold. The Nalunaq mine is located in the middle of the Napasorsuaq valley in south Greenland, about 30 km northeast of the village Nanortalik (Fig. 1). The mine was in production from 2004 to 2013, and produced approximately 713,000 tonnes of ore with an average gold grade of 15 g/t, corresponding to 10.67 tonnes of gold (Bell *et al*. 2017).

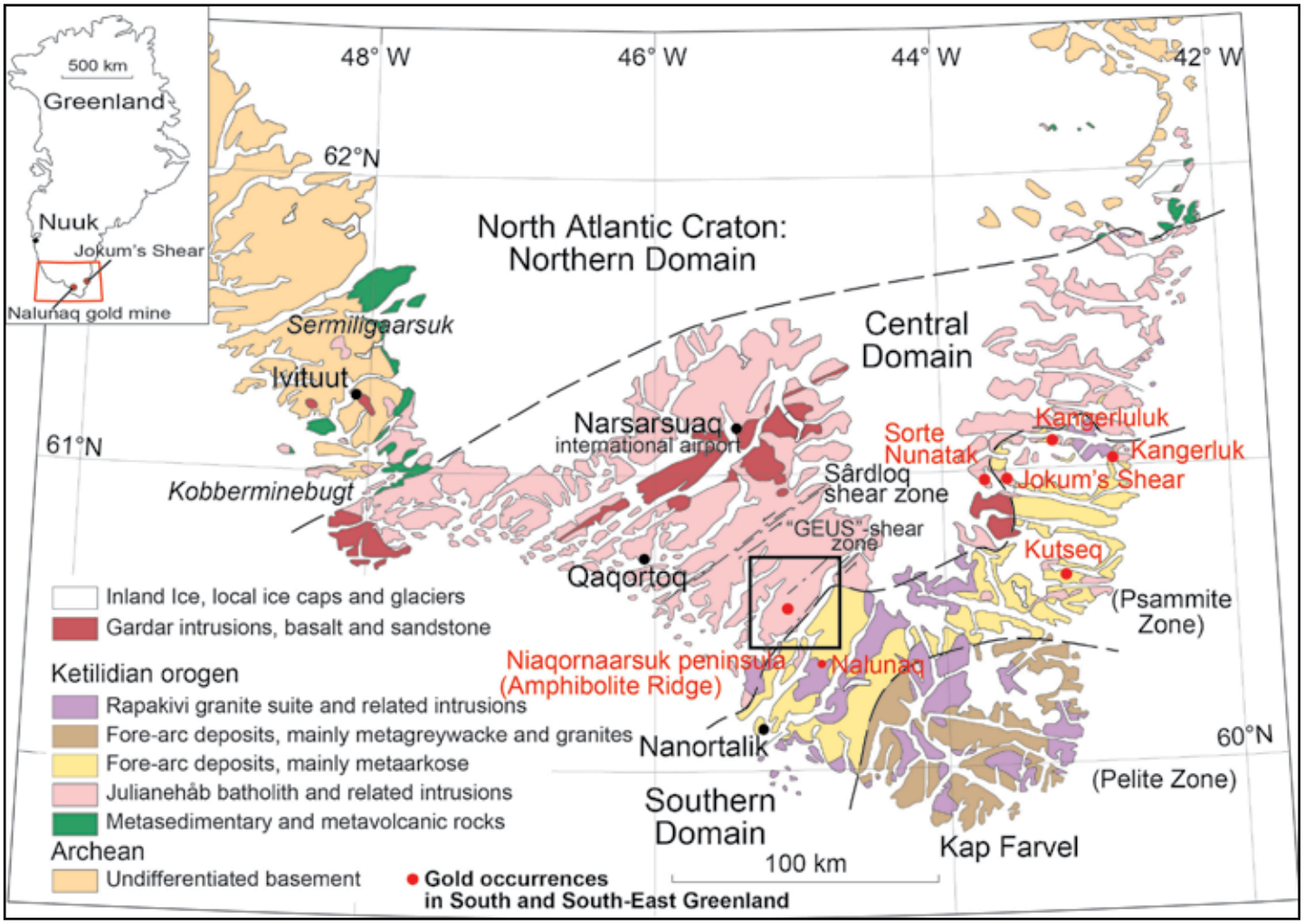


*Figure 1. The geological map of south Greenland showing in the north the Archean North Atlantic craton and in the south the Paleoproterozoic granites, metavolcanics and metasediments. Gold occurrences are indicated with red dots and define the Nanortalik gold belt. The black box shows the area where in Figure 4A a detailed map is provided (Illustration: Denis M. Schlatter, after Chadwick and Garde 1996)*

*continued on page 14*

## The Search for Gold in Greenland… *continued from page 13*

### What did the Vikings know?

The Vikings inhabited south and west Greenland between 985 and 1450 A.D. Viking knowledge of the presence of gold in Greenland is recorded in the Icelandic Sagas, although the accuracy of this source is debated among archaeologists. One likely candidate for the gold mentioned in the Sagas could be the gold occurrences of the Napasorsuaq valley where the Vikings maintained settlements connected to farms and some hunting shelters located on the slopes of the valley. These conclusions are supported by the archaeological structural remains and radiocarbon dating of recovered textiles to 1380 to 1400 A.D. Further interesting discoveries are reported by a Greenlandic field assistant that has apparently found some pieces of wood and a small metal shell with three suspension holes in the rim that the Vikings possibly used as a gold scale. It can be speculated that the Vikings extracted gold by panning stream sediments in the nearby river, and in smaller creeks higher up the valley, although the only Viking gold that is found so far comprises two gold rings from Igaliku that is a larger Viking settlement about 75 km northwest of the Napasorsuaq valley. In 2017, the archaeological remains of the Vikings settlements (an area totalling 35,000 ha) in south Greenland were inscribed on the UNESCO World Heritage List under the title “Kujataa Greenland - Norse and Inuit Farming at the Edge of the Ice Cap”. The gold projects described here, however, are located outside of the areas protected under the Kujataa Greenland UNESCO site.

### Geology of the Nanortalik Gold Belt

The Nalunaq gold deposit was formed about 1.77 Ga (Bell *et al.* 2017) at temperatures of 580°C and at a pressure of about 3 Kilobars, which corresponds to a crustal depth of about 10 km (Kaltoft *et al.* 2000). Nalunaq is located in the recently recognised “Nanortalik Gold Belt” which extends for more than 150 kilometres from south to south-east Greenland (Schlatter & Hughes 2014). Only the coast of south Greenland and some small areas in south-east Greenland are not covered by the Greenland Ice Sheet. However, the rest of the Nanortalik gold belt is covered by the massive inland ice sheet, which covers about 80 percent of surface of Greenland.

Geologically, the Nanortalik gold belt forms part of a Paleoproterozoic orogeny that resulted from northward oblique subduction of oceanic crust below the Archean North Atlantic craton (Kolb 2013). The gold occurrences and anomalies are grouped in clusters along the southwest-northeast trending southern margin of the Julianehåb Igneous Complex. South Greenland is characterized by high relief and the topography is generally very steep with some near vertical cliffs rising from sea level to over 2500 metres elevation. The rocks in south Greenland are mainly granite, gneiss, metasediments and metavolcanics metamorphosed to amphibolite facies. In southeast Greenland, glaciation is intense with outcrops largely restricted to nunataks.

The gold of the Nanortalik gold belt mainly occurs in quartz veins with some of the auriferous quartz having exceptionally high gold content (Fig. 2), including samples grading above 1000 g/t gold. Samples


*Figure 2. Quartz with visible gold from the Nalunaq mine in South Greenland. (Photograph credits: Sven Monrad Jensen, H.B. Madsen and Jakob Lautrup)*

*continued on page 15*

## The Search for Gold in Greenland… *continued from page 14*

from the auriferous Main Vein at Nalunaq mine have yielded up to 5240 g/t gold (Kaltoft et al. 2000). Common accessory minerals are pyrrhotite, arsenopyrite, sheelite and biotite.

### The long-lasting search to the discovery of the Nalunaq-deposit

Geologists started to investigate the ground of south Greenland in the 1980's for potential gold occurrences. Early regional exploration consisted of panning for gold in stream sediments. Numerous panned samples contained gold grains, most notably samples from Napasorsuaq. Based on these encouraging results, the prospecting efforts were intensified and scree and additional stream sediments were sampled to assess the gold content. Systematic geological mapping and outcrop sampling finally led to the discovery of the auriferous quartz vein at Nalunaq in 1992. This vein contains abundant visible gold and is located in a zone of sheared metavolcanics and metadolerites. It was precisely this single 0.2 to 2 meter thick quartz vein that was afterward exploited in the Nalunaq underground mine.

Once the known ore resources had been mined the Nalunaq mine was closed at the beginning of 2014, although efforts are now being made by Canadian junior exploration company, Alopex Gold Inc. (CVE:AEX), to add new resources through an ongoing exploration program.

Now the question remains: which other exploration models and methods could be applied to find new gold occurrences with commercial interest in south and in southeast Greenland? For example Bell *et al.* (2017) suggest

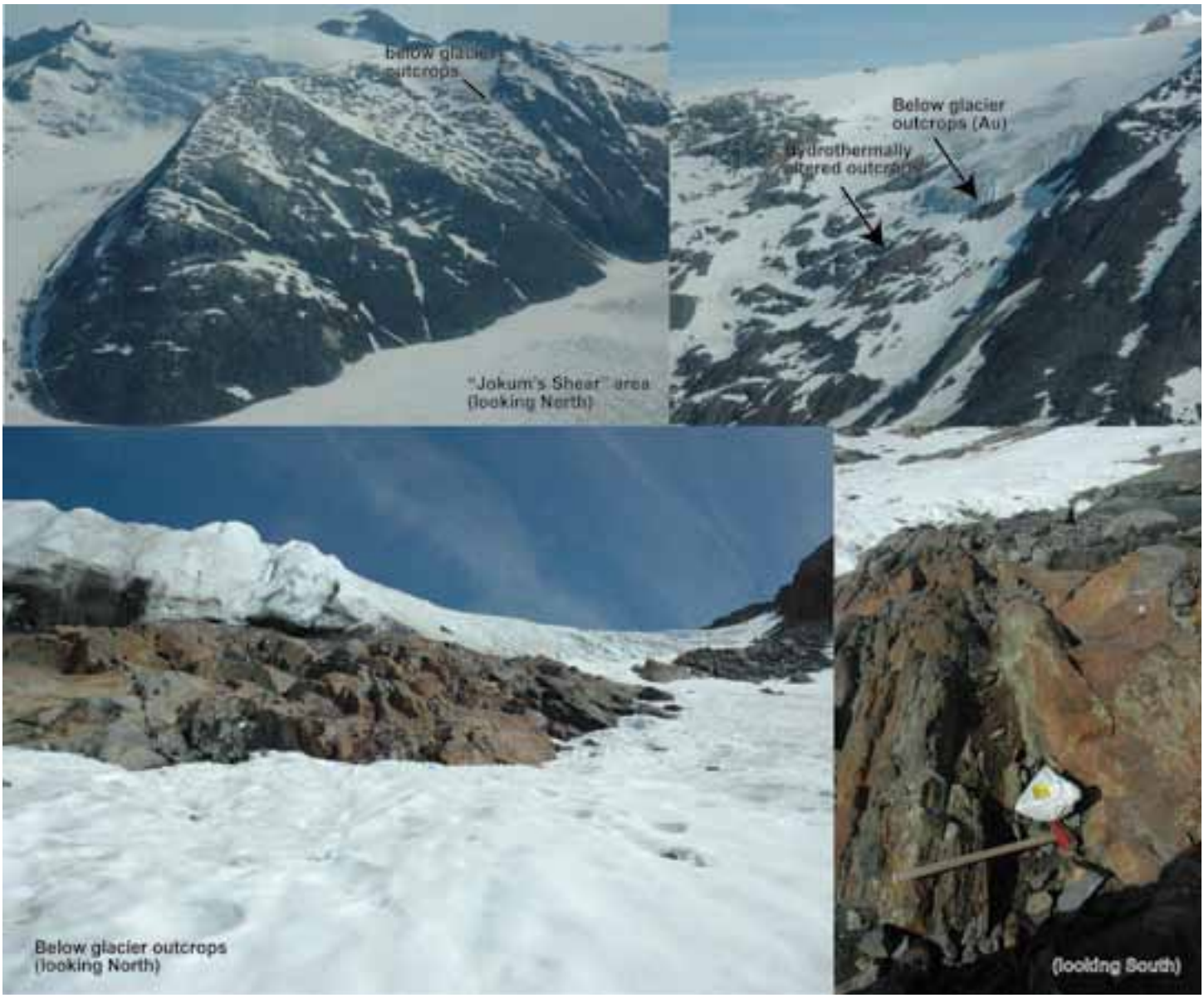


*Figure 3. "Jokum's Shear" area in remote South East Greenland. The arrow shows the gold mineralized outcrops at the "below glacier outcrops" where 3.1m long channel samples possess 9.3 g/t gold.*

*continued on page 16*

## The Search for Gold in Greenland… *continued from page 15*

that reactivated shear zones are where the Au mineralization occurs in the Nalunaq mine – and this represents a type of exploration model worth investigating. The Swiss consulting firm Helvetica Exploration Services GmbH has been involved for numerous years in Greenlandic gold exploration. Experts from Helvetica Exploration Services GmbH and NunaMinerals A/S carried out systematic geochemical sampling of scree sediments and stream sediments on the Niaqornaarsuk Peninsula between 2012 and 2014. NunaMinerals A/S was the national and partially state-owned mineral exploration company of Greenland, until the company went bankrupt in 2016. The NunaMinerals A/S - Helvetica Exploration Services GmbH team identified areas with high gold contents over 15 km$^2$ at Niaqornaarsuk with scree sediments of up to 1.4 g/t gold. Surface samples also yielded extraordinarily high gold contents up to 2533 g/t gold in grab samples. Even in remote areas of southeast Greenland the experts found new gold prospects, such as the "Jokum's Shear" (Fig. 3); from which channel samples yielded up to 3.1 metres at 9.3 g/t gold (Schlatter & Hughes 2014).

### Gold occurrences in 18 sub-areas

There are currently 18 target areas on the Niaqornaarsuk Peninsula (Figs. 1 & 4A). A cluster of gold targets centre around to so-called "Amphibolite Ridge" (Fig. 4B). Initial diamond drilling at Amphibolite Ridge has shown that gold is contained in both quartz veins and in hydrothermally altered granitic rocks (Bradley 2013; Schlatter et al. 2013). Channel

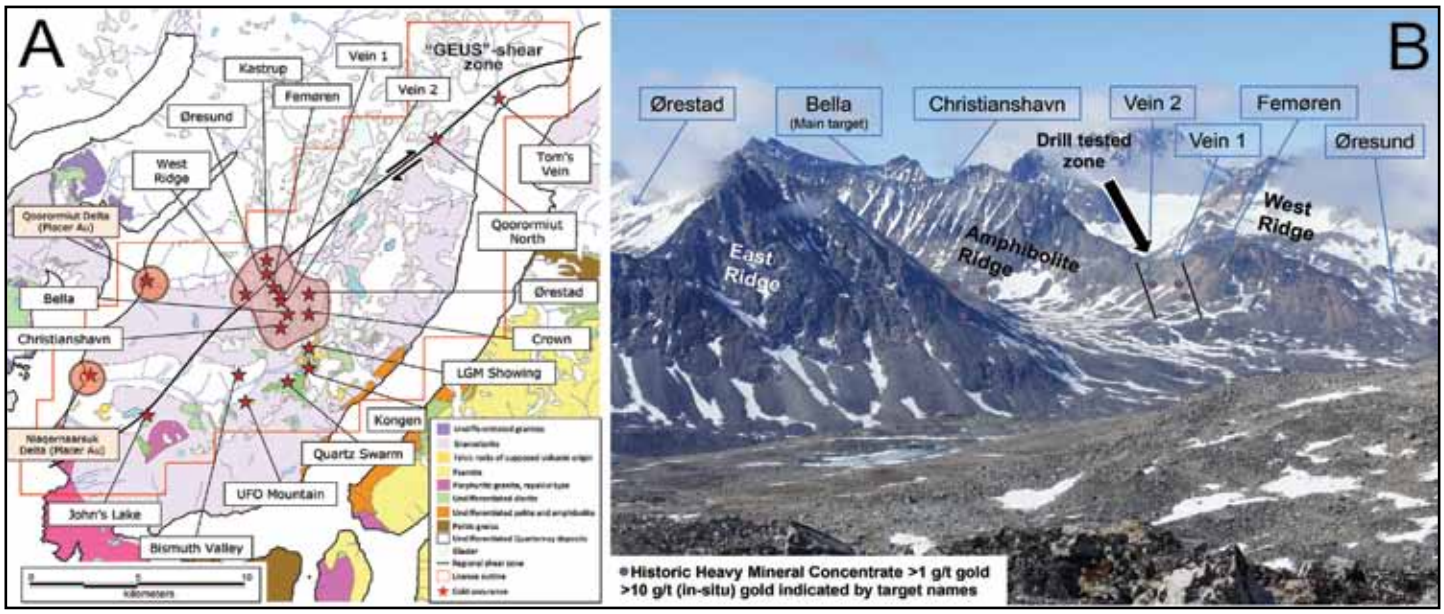


*Figure 4. (A) Areas on the Niaqornaarsuk peninsula that are favourable for future gold exploration with 18 subareas where in situ gold values are higher than 10 g/t and heavy mineral concentrates are higher than 1 g/t gold. The location of the detailed map of Fig. 4A is shown in a black box on the regional map of the Fig.1. (B) Photograph showing some of the targets with in situ gold > than 10 g/t; the arrow indicates the drill tested zone of the "Amphibolite Ridge".*

sampling profiles, carried out with rock saws, yielded up to 11 meters with 82.6 g/t gold. The majority of channels began or terminated in gold mineralisation, hence the true extent is yet to be confirmed and future work aims to refine the extent of gold mineralization since this has not yet been accomplished.

The next steps comprise the exploration and sampling of the remaining exploration target areas with the aim of identifying the most promising of all the targets in terms of the potential to host a future economic gold deposit. The salient goal is to demonstrate the existence of a significant gold belt and to infer the existence of significant gold occurrences in the nunataks and in the non-glaciated coastal areas of east Greenland. This is best done by finding numerous gold mineralized outcrops along the Nanortalik gold belt, and these outcrops can be located by recognizing favourable altered shear zone that can be tested for their gold contents. However it has to be kept in mind that a future mine not only needs to be profitable, but also that the environment remains protected and that workers are sourced from the local area.

At a recent Mineral Resource Assessment workshop in Copenhagen co-hosted by the Geological Survey of Denmark and Greenland and the Government of Greenland an expert panel has assessed the potential of undiscovered orogenic gold deposits very favourably. The panel comprised geoscientists with knowledge on orogenic gold mineralisation and/or Greenland geology and has assessed all data, literature, former work, map, etc. and discussed and assessed the possibilities of undiscovered orogenic gold deposits within predefined areas. They concluded that four gold deposits with

*continued on page 17*

## The Search for Gold in Greenland… *continued from page 16*

a 90 percent probability occur in south Greenland and that two gold deposits with 50 percent probability exist in southeast Greenland (Kolb 2015).

### Acknowledgements

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# AAG Councillors - 2018 - 2019

## Maurizo Barbieri

Maurizo Barbieri has been a Fellow of the Association of Applied Geochemists since 2013. He has over 15 years of postgraduate experience in geochemistry. Since 2006, he has been Associate Professor of Hydrogeochemistry and Environmental Geochemistry, since 2001 geochemistry laboratory manager, and a member of the Board of Directors at Sapienza University of Rome between 2009-2016. He is an Environmental Advisor (Hydrogeochemistry) for the International Project (2016-2019) SECOSUD II - Conservation and equitable use of biological diversity in the SADC region. The project is financed by the Italian Agency for Development Cooperation and implemented through Eduardo Mondlane University, South African National Park and Sapienza University of Rome.

Maurizo was a scientific coordinator for the Water Unit of the International Project that provides institutional support to the management of Protected Areas in Albania, funded by the International Union for Conservation of Nature (IUCN, 2012-2014) and for the Geochemical model of the Vico Lake (Lazio, Italy), funded by the Regional Agency for Environmental Protection of Lazio, Italy (2014-2016).

Currently he is focusing on the application of the geochemistry methodologies for the characterization of environmental problems, distribution of elements and isotopes in the Earth systems with emphasis on water-rock interaction, water quality, hydrogeochemical anomalies of natural origin, hydrogeochemical surveys, Ion chromatography, ICP-MS, water, soil and geological mapping, univariate and multivariate analysis of geochemical datasets, and isotope analyses of Sr, H, O and B.

He has been on the editorial board of: Chemie der Erde, Environmental Geochemistry and Health, Arabian Journal of Geosciences, Euro-Mediterranean Journal for Environmental Integration, Water, Geosciences, and Journal of Chemistry. He was a guest editor for a Water Special Issue "Isotopes in Hydrology and Hydrogeology".

*Email: maurizio.barbieri@uniroma1.it*

## David Murphy

David holds a BSc (Hons) degree from the University of Edinburgh (1986), a MAppSc from Curtin University (1993), both in geology, and a PhD from the University of Western Australia (2009). After an early career as an exploration geologist (Geopeko – North Ltd, 1988 – 1994; Helix Resources NL, 1994 – 1996; Plutonic Resources Ltd, 1996-1997), David joined Normandy Mining Ltd (now Newmont; 1997 - 2009), where Nigel Radford instilled a love of geochemistry. This was cemented by Cliff Stanley, who supervised, along with Bob Gilkes, an eclectic thesis involving lithogeochemistry, clay mineralogy, and linear algebra.

In 2010, David joined Barrick as regional geochemist, then in 2012 his current employer, AngloGold Ashanti, where he is the geochemist for the Global Greenfields Exploration group, with responsibility for the geochemical aspects of projects in Australia, North and South America, and Africa. He is also involved with data management and the interfaces between databases and data consumers. David is interested in fine-fraction geochemistry, X-ray diffraction, mathematical applications, and data analysis. Outside work he enjoys learning ever more abstract programming languages and manages a few endurance runs between injuries.

*Email: davidmkmurphy@gmail.com*

## Graham Sylvester

Graham obtained his BSc in Geology from the University of New South Wales in 1967, his MSc from the University of Toronto in1973, and then an MA from the University of Western Australia in 2013 and a PhD from the University of Western Australia in 2017.

*continued on page 19*

## AAG Councillors… *continued from page 18*

Between 1971 and 1972, Graham worked as an exploration geologist for Rio Tinto Canadian Exploration in Canada and the USA. From 1973 to 1974, he was the Exploration Manager for Consolidated Morrison Exploration, Toronto, conducting mineral exploration in Canada. From 1977 to 1980, he worked as a senior geologist for CRA Exploration conducting mineral exploration and research. Graham worked as an exploration geologist from 1969-1970 exploring for diamonds for Anglo-American Corporation in East Africa. Between 1980-1985, he was the District Geologist and State Manager, for Noranda Australia, working on mineral exploration projects and as business manager. From 1985 to1987, he worked for Western Biotechnology Ltd, as Managing Director biotechnology for the start-up company.

He was Senior Resource Manager for Porter Western Stockbrokers providing mining and exploration stock broking advice between 1987-1991. From 1991-1993, Graham was a business manager for CSIRO in the Mineral Exploration Division. He worked between 1993-2009 as an independent geological/geochemical consultant on mineral project evaluations, mainly in Australia, Russia, and Asia. From 2009 to present, he has been conducting research and evaluation of the use of geochemical techniques in geoarchaeology and archaeology.

Graham has spent the majority of his professional life working as a geologist/geochemist in the minerals industry around the world. Currently, he is actively involved in expanding the role that geochemistry can play in providing greater understanding of archaeological sites and researching the processes of formation of soil geochemical anomalies. He has not previously held any positions within AAG.

*Email: sylvestergc@gmail.com*

### Yulia Uvarova

Yulia obtained her B.Sc. in Geology from Moscow State University in 2001 and her Ph.D. in Geology from the University of Manitoba in 2008. From 2000-2002, she worked at the Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia as a Research Assistant. From 2003-2008 she was a teaching assistant at the University of Manitoba. From 2008-2012, Yulia worked at Queens' University, in the Queen's Facility for Isotope Research, where her research focused on geochemistry, mineralogy, petrology and genesis of economic mineral deposits, uranium in particular; development of new exploration tools for search of U deposits; behaviour of HFSE in high-temperature systems; geochemistry of non-traditional isotopic systems and application of these systems to elucidate processes responsible for deposit formation.

Yulia Uvarova holds a Research Scientist position in CSIRO Mineral Resources, Perth and works in a team of researchers developing new workflows and techniques for mapping the distal footprints of metalliferous mineral systems through drilling and sampling and developing the science of understanding large geochemical footprints of mineral systems and their detection on the surface.

*Email: Yulia.Uvarova@csiro.au*

### Erick Weiland

An internationally respected geochemist with over forty years of professional experience and technical knowledge across multiple disciplines, Mr. Weiland has successfully completed projects in fourteen (14) countries. Expertise includes: mining/mineral geochemistry, rock/waste characterization, environmental impact assessments, water quality and soil remediation investigations, material characterization, geochemical evaluation of surface water, groundwater, and mineral interactions, and assessing the acid generation potential (acid rock drainage) with associated leaching of potentially

*continued on page 20*

## AAG Councillors… *continued from page 19*

hazardous constituents from natural materials. He is an expert in the application of geochemistry supporting exploration, engineering, and environmental projects including site characterization, feasibility studies, permitting, remediation, water quality, soil remediation, evaluation of acid mine drainage, waste rock dumps and tailings dam engineering/design, and mine closure activities.

Mr. Weiland has successfully designed, implemented, and evaluated field and laboratory investigations related to geochemical processes in the surface and sub-surface environments. Projects include: attaining and maintaining compliance with federal and state permits; environmental assessment, safe recharging of surface and waste waters to groundwater aquifers, monitoring and cleanup; CERCLA emergency clean-up actions; risk assessment; fate and transport analysis of metals and non-metals within the natural environment; hydrological modeling; geochemical and contaminant transport modeling; and environmental analysis.

Mr. Weiland is currently the Manager of Source & Migration Control projects within the Freeport-McMoRan Environmental Technology / Life Cycle Analysis Team. This team identifies, evaluates, develops, and deploys emerged or emerging technologies that can be applied to risk and liability management at existing mining and processing sites, closure and reclamation of mining operations, and remediation of legacy sites.

Mr. Weiland joined the Association in 1978 and has been an active member ever since. He has participated as an AAG Councilor, President, Database Chairman, Editorial Board member, Canadian and Australian Geosciences Council representative, Symposium Chair, and other miscellaneous duties over the past 37 years.

*Email: eweiland@fmi.com*

## Frank Arnott Award, Exploration ’17

This short note is summarized from an article written by Ken Witherly in the SEG Newsletter No. 104, (2016). Frank Arnott was a pioneer in data integration, both in developing the software GeoExpress 2000 and promoting the value of data integration. His software was one of the first 3D data visualization packages developed explicitly for mining exploration applications and was the most powerful package of its kind at the time. Frank died in early 2009, but in 2012 his friends decided to honor him as a visionary and promote the importance of data integration to the exploration community. They organized a contest to encourage data integration and visualization https://www.frankarnottaward.com/. The contest was centered on five project areas representing a range of data types, geological deposit styles, scales, and terrains globally: (1) Olympic Dam area (Woomera Withdrawn Area), (2) South Australia; the Broken Hill area, New South Wales; (3) Yukon plateau, Yukon Territory; (4) Quesnel trough, British Colombia, and (5) Kevitsa mine, Finland. Exploration geochemistry data, in addition to geophysical and geological data, were provided to the contestants.

The contest opened in mid-2015 and ran until the end of 2016 and had two categories of entrants: (1) Apprentice – for those with <5 years industry experience and aimed at students and recent graduates, and (2) Experienced – for those with >5 years industry experience. Awards were determined by an independent group of judges that evaluated the entries based on technical innovation, exploration significance, impact, and the level of collaboration between the contestants. The finalists attended the Exploration ’17 conference (hosted by Decennial Mineral Exploration Conferences) in Toronto, Canada in October 2017, where they gave oral presentations on their submissions and the winners were announced.

The winner in the category (1) Early Career – Apprentice was “ Team on the Rocks”, second place was awarded to “Team University of Saskatchewan”, and third place was awarded to “Team Macquarie”. The winners of category (2) Experienced was “Team Logan’s Legends”, a team of young professionals based largely at the Geological Survey of Canada. Second place was awarded to “Team Deep on Data” from International Geoscience Services, and third place was awarded to “Team Uncover Australia” comprising staff from the Geological Survey of South Australia, Deep Exploration Technologies CRC, and Geoscience Australia.

# Resources for Future Generations 2018 Short Courses and Field Trips

The AAG has partnered with the Resources for Future Generations (RFG) 2018 Conference to be held in Vancouver, BC, Canada between 16-21 June, 2018 to hold the 28th IAGS Symposium as an integral component of the RFG18 conference. The 4-day conference covering Energy, Minerals, Water, and the Earth is expected to attract in excess of 5000 people to Vancouver to attend the conference. This will provide the AAG with the opportunity to showcase through specific AAG sessions, the advancements and applications of geochemistry in the spheres of exploration and environment.

Details about the sessions, short courses, and field trips organized by AAG are provided below. Registration at the conference will allow AAG members full access to the complete RFG18 technical sessions.

Further Information: Visit the RFG2018 website (http://rfg2018.org), or contact Dr. Peter Winterburn (pwinterburn@eoas.ubc.ca) NSERC-Bureau Veritas Minerals Industrial Research Chair in Exploration Geochemistry, University of British Columbia

## AAG Technical Sessions at RFG

**Analytical Technology in the search for minerals: Space to the Lab to the field**. - Recent, experimental and proposed developments in technology as applicable to the discovery of new mineral deposits and environmental studies with a particular emphasis on chemical, mineralogical, isotopic and spectral analytical techniques including remote sensing, laboratory analysis and field analysis.

**Big-Data: Integration, Management and Regional Scale Surveys** - Exploration companies, geological surveys and mining companies typically own gigabytes to terabytes of geochemical information with associated attributes, much of which is poorly examined beyond simple numerical treatments for limited components. Recent advances in the treatment of datasets using advanced techniques, including Hyper-cube amongst others will demonstrate through case studies and research examples, how to extract maximum value from regional scale and detailed mine scale datasets.

**Exploration Case studies - Out of the Box Concepts, methodologies and practises** - Case studies of mineral exploration, both positive and negative, with an emphasis on application of geochemistry. In particular those employing out-of-the-box concepts, models or methodologies that demonstrate new advances in mineral exploration, discovery, risk abatement and cost reduction.

**Exploration Undercover - Techniques, Technology and Strategy -** Demands for mineral resources continue to affect society with high metal prices, skill shortages, governmental policy changes, and billions of dollars in resource investment. The discovery of new mineral resources requires increasing risk, increasing costs, and increasingly effective exploration techniques. Exploration activity itself is increasingly focused in difficult localities such as those that lack outcrop, are covered by transported surficial materials or are deeper in the crust. As a result, the demand to develop new and improved geochemical exploration techniques and strategies is higher than ever. This session will include papers reviewing state of art progress, new concepts, technologies, case histories and exploration strategic paths aimed at discovery.

**Footprints of giant orebodies - Mineralogical, Spectral and Geochemical vectors to Discovery -** Across the globe there has over the last 5 years been several major research initiatives directed at developing fully integrated geological, mineralogical, chemical and geophysical footprints of large orebodies beyond visible alteration to so called cryptic effects (e.g AMIRA, CMIC). This session is intended to draw together key papers highlighting integrated models and their application to exploration.

*continued on page 21*

## Resources for Future Generations 2018… *continued from page 21*

**Geometallurgy: Exploration-Evaluation-Exploitation-Environment -** This session will examine the roll of Geometallurgy and geochemistry through the complete birth-cradle-grave cycle of an orebody, documenting how it's use can effectively reduce risk and cost an an early stage of exploration through evaluation and mining through to the impact of geometallurgy on waste disposal and mine closure. The session will comprise a keynote plus selected case studies of the application of geometallurgy, in particular novel or unconventional applications in natural resources.

**Hydrocarbons in the exploration for metaliferous and none-metaliferous deposits -** Hydrocarbons have shown considerable potential as an exploration tool for the discovery of mineral deposits, however not without controversy. Through case studies and recent technological advances, this session will present recent results on the application of hydrocarbons in mineral exploration.

**Hydrogeochemistry: Environment and Exploration -** Application of water geochemistry as both a tool to search for water resources and mineral resources in addition to the geochemistry of contaminated waters and their mitigation. The session will cover research and development of new techniques and technologies in addition to application case histories of hydrogeochemistry in exploration and remediation.

**Micro to Macro-biogeochemistry: Exploration, Processing, remediation and the Environment** - Biological systems play a increasing significant role in mineral exploration, mineral processing and site remediation exploiting natural interactions and processes between geological materials and biological processes. This session will review recent progress and new innovations in the utilisation of natural processes in resource development.

**Mineral Exploration in Extreme Environments -** Exploration Geochemistry in hyper-arid, tundra, tropical, high altitude, sub-oceanic and extra-planetary requires it's own techniques and technologies. This session will be devoted to research, development and case-histories of mineral exploration in these diverse, significantly more important, yet problematic environments with an emphasis on applied geochemistry.

**Stable and radiogenic Isotope systems: Applications in Exploration and the Environment -** Modern analytical technology has substantially reduced the cost of isotopic analysis to the level of routine analysis, in addition new systems have become commercially viable and the knowledge base and understanding of a range of isotope systems is now well documented. This session will demystify the application of isotopes in exploration and the environment through solid case studies demonstrating their value added benefit integrated with other information in the decision process.

## Short Courses at RFG

**Costs:** One day short courses are priced at CAN $350 for professionals and CAN$175 for students. The cost includes course notes (memory stick), coffee breaks, and lunch. Short courses are subject to a minimum participation and may be cancelled if the minimum is not achieved.

***Preconference: Sunday, June 17th, 2018***

**Mineral Chemistry: Applications to Mineral Exploration -** Mineral chemistry methods have long been routinely and successfully employed in diamond exploration, and over the past decade have also been increasingly utilised in base and precious metal exploration. Some of these methods promise great potential to improve assessment of metallogenic fertility and vectoring to mineralisation, and will undoubtedly see much wider application in exploration programs in the years to come. This one-day short course is intended to introduce exploration geologists and geochemist to the state of the art of key mineral chemistry methods used in the exploration for diamond, porphyry copper, epithermal gold and orogenic gold deposits. The short course will be presented by a high-calibre team from industry and academia, and will focus on exploration-relevant applications and case studies, while also providing an adequate understanding of the scientific and analytical fundamentals. ***Facilitator: Dr. Christian Ihlenfeld.***

*continued on page 23*

## Resources for Future Generations 2018… *continued from page 22*

**Exploration Geochemistry: From fundamentals to the field -** Geochemistry remains one of the fundamental tools used in mineral exploration along with geology and geophysics, however, underlying fundamentals that govern the behavior of chemical elements in the environment is often poorly understood by geologists leading to inappropriate application. Modern analytical techniques often provide a wealth of trace element information for 50 plus elements at sub ppm level, however, few organisations maximise the value of this information in the context of target selection, prioritisation and geochemical-geological mapping. This short course is intended to introduce the geologist / geochemist to simple fundamental concepts that govern the distribution and dispersion of chemical elements in mineral deposits and the natural environment and apply the principles to the design of surveys, analytical methodology/technology, target selection/prioritisation and lessons to be learnt from survey post-mortems. ***Facilitator: Dr. Peter Winterburn.***

***Post Conference: Friday, June 22, 2018***

**Lithogeochemistry: Theory and application from project generation to operation -** Lithogeochemical studies form a central component of many exploration and research initiatives, however are often poorly understood and applied. Lithogeochemistry has applications ranging from regional mineral exploration to around mine and deposit extension studies in addition to geometallurgy and mine waste management. A proper understanding of its application can provide fundamental insights into the chemistry and mineralogy and trace-element-mineralogy associations often buried in complex whole rock datasets. This short course will introduce applications of lithogeochemical interpretation from early stage mineral exploration and our understanding of ore deposits through to linking lithogeochemistry to geometallurgical studies. This short course provides an insight into how industry leaders and researchers are applying lithogeochemistry to answer some of the many questions facing the exploration and mining sector today. The short course will be a full day comprising discussions from both industry leaders (Teck, Anglo American, BHP and First Quantum), consultants and academics and is designed with practical examples of real world application beyond theory. ***Facilitator: Dr. Ian Dalrymple***.

**Regolith in deeply weathered terrains -** Deeply weathered landscapes occur over wide areas in a range of present-day climatic conditions, from rainforest to semi-arid and from tropical to temperate. They include many highly weathered prospective regions in Australia, South America, Africa and SE Asia and present both problems and opportunities for exploration. The challenge is to explore these areas effectively. Effective geochemical exploration can only be achieved by understanding the regolith and landscape and metal dispersion processes that have occurred within it in different climatic regions. The course will provide an introduction to the nature and formation of regolith and landscapes of these terrains, comparing and contrasting them across regions, including recommendations for a suitable terminology. Geochemical dispersion will be discussed within the context of regolith-landscape evolution in different regions and illustrated with numerous case studies based on research and exploration experience. ***Facilitator: Dr. Ravi Anand.***

**Integration of Exploration Geochemical and Mineralogical Data -** Geochemical and mineralogical data are now routinely collected on the same sample material, but the interpretation of these data sets is often done separately. Geochemical data may include assays or multi-element data collected from crushed rock or from surficial material. Mineralogical data may include hyperspectral analyses, semi-quantitative XRD or heavy mineral separates. Integration of complementary data sets such as these on a single interpretive platform allows for a better understanding of geochemical and mineralogical processes associated with hydrothermal mineralisation and secondary dispersion. The short course will enable the interpretation of geochemical and mineralogical data collected on the same samples by various means including fp-XRF, XRD, hyper-spectral, and conventional geochemical techniques. This short course will require participants to bring a laptop computer and download a demonstration copy of ioGAS interpretative software in the week prior to the course if they do not already have a license. Participants will undertake interpretation of published data sets following lectures to provide background on expected geochemical and mineralogical responses from some common hydrothermal mineral deposit types. ***Facilitator: Dennis Arne.***

*continued on page 24*

## Resources for Future Generations 2018… *continued from page 23*

**Advanced Concepts in Evaluating and Interpreting Geochemical Data -** Over the last decade there has been a rapid growth in the application of data analytics for data-driven business decisions in virtually every industry. It is our belief that over the next 10 years the mining industry will have to rapidly adopt and apply the power of data analytics to the ever-growing volume of geochemical data sets. However, geochemical data have unique mathematical properties and should not be analyzed without consideration of its structure. Geochemical data are reported as a composition; by definition it will sum to a constant and therefore none of the components (elements/oxides) are free to vary independently. This special property of geochemical data makes the application of standard data analytics methodologies flawed. The workshop will introduce several methods to circumvent problems arising from the compositional nature of geochemical data. Classical raw elemental ratios resolve the constant sum problem and are useful to model stoichiometrically controlled processes. However, these raw ratios restrict geochemical data to positive numbers which limits the application of most data analytics methods; typically developed for variables that are free to range in the positive and negative space of the real numbers. Alternatively, log-ratios of compositional data solve the constant sum problem and range across the entire real number space. The log-ratio transformations make geochemical data amenable to an arsenal of data analytics tools available to unlock the valuable information contained in data sets, allow for process discovery and subsequent process validation. Participants of this workshop will learn methods for data analytics in geochemistry. The workshop will cover the application of; applying ratios and logratios to compositional data; molar element ratio methods; multivariate methods including principal component analysis, cluster analysis, discriminant analysis, classification and regression trees, multi-fractals, and linear/non-linear geostatistics. ***Facilitator Dr. Eric Grunsky.***

**Exploration Geochemistry: Field analysis and characterisation -** On-site geochemistry and mineralogy underwent a fast development with mineral exploration and mine site management in the last decade. This brings field teams the opportunity of immediate decisions and dynamic targeting, with significant benefits in time and costs. Systematic field measurements can provide reliable information for lab sample screening and for target selection, prioritisation and geochemical-geological mapping. However, discrepancies between field measurements and laboratory analyses may happen and cast doubt on the former. This cannot be solved without good analytical practice and QA/QC, and with a sufficient geochemical knowledge. This short course is intended to provide the geologist / geochemist an up to date overview of field analytics, how to make profit of them and apply them to the design of exploration surveys, drilling monitoring, ore and waste management and site closure.
***Facilitator: Dr. Bruno Lemière.***

**Analytical Quality Control: Data Integrity for the Advancement of Science -** Regardless of the field of study, accurate information is essential to maintaining the integrity of research and making correct business decisions. A wide range of technical data is collected for geological, environmental and mining projects and in all cases the accuracy and precision of the information must be measured and understood. Poor quality data results for a research project may result in the inability to repeat and validate the study. For mineral exploration and mining applications, distorted findings can result in wasted resources. This short course will introduce participants to the basics of quality control with an emphasis on collection of geochemical data. Fundamental concepts such as contamination, analytical drift and precision will be introduced using case histories. The methods to monitor and control data quality, such as the insertion of barren materials, reference materials and duplicates will be explained as well as the statistics and graphs necessary to identify quality control failures. Exercises, primarily using Excel spreadsheets, will provide participants with hands-on learning and tools to use in the workplace. The afternoon session will concentrate on the lessons learned since 1999 when the Canadian security exchanges mandated the use of assay quality control in the mining industry. Whereas, the mining industry has generally implemented systematic quality control procedures, questions still arise for practitioners. Common questions around fit for purpose data, correct control limits, application of precision information and legal requirements will be addressed.
***Facilitator: Lynda Bloom.***

*continued on page 25*

**Resources for Future Generations 2018…** *continued from page 24*

## Field Trips at RFG

**Navigating a porphyry Cu hydrothermal system: Alteration and geochemical dispersion mapping - Yerington, Nevada, USA**

***Friday, June 22 to Sunday, June 24, 2018, $470.*** Includes: transportation, luncheons and accommodation; ex-Reno, Nevada. This 2.5-day field trip will examine the geology, hydrothermal alteration mineralogy, and geochemical dispersion around Yerington, Nevada. Yerington is a classic locality where porphyry Cu deposits, high level Fe-oxide deposits, and volcanic and plutonic complex have been tilted 80° on to their side so that a complete 3-D picture of a zoned magmatic-hydrothermal system is exposed. Day 1 of the field trip will focus on the geology of the porphyry Cu system beginning 3 km beneath to the level of copper precipitation. Day 2 will focus on the upper 3 km of the porphyry Cu system. Each day will link the geology of the tilted system with the alteration mineralogy together with the whole rock major and trace element geochemical changes in rocks that can be mapped using modern exploration methodology. Short hikes of up to 2 hours in duration are involved each day. ***Facilitated by: Richard Tosdal and John Dilles***

**Highland Valley Porphyry Copper Deposits: District-Scale Footprints - Merritt, British Columbia**

***Friday, June 22 to Sunday, June 24, 2018, $600.*** Includes: transportation, luncheons, accommodation and guidebook. This 2.5 day post-conference field trip (June 22-24) will examine the magmatic evolution, mapped alteration, hyperspectral response, and the lithogeochemical and C isotope footprints around the Highland Valley Porphyry Cu (HVC) deposits hosted in the Guichon Creek batholith in southcentral British Columbia. The review of the district will focus on the integration of the disparate data sets to better define the extent of the porphyry related hydrothermal alteration. Additionally, we will visit some key surficial geology sites and discus the composition and mineralogy of till and its relationship to dispersion from the porphyry centers.

The volume of hydrothermally altered rocks outboard of economically significant concentrations of Cu-Fe sulfide minerals is termed the porphyry footprint. An understanding of the fluid types that can be present during porphyry Cu formation, how they manifest in the footprint and their spatial distribution with respect to Cu-mineralized portions of the system is critical to developing better exploration tools. Four major porphyry Cu (± Mo) systems, hosted in various intrusive facies of the Late Triassic calc-alkalic Guichon Creek batholith, occur in the HVC district. Exposure and airborne magnetic data indicate that the batholith has an oval shape, elongate to the northwest, with a long axis of approximately 60 km and a short axis of 25 km. Due to its size and low degree of exposure (~3%), the HVC district is a realistic natural laboratory in which to investigate the large-scale footprint of porphyry Cu deposits and has been the subject of recent detailed mapping and sampling by the NSERC-Canadian Mining Innovation Council Footprints project. The field review of the district-scale footprint will consist of a traverse of representative outcrops, with accompanying data-sheets, from the margins of the batholith towards Cu mineralization associated with the actively mined porphyry centers. The focus will be on the regional alteration footprint and will not include a mine tour. ***Facilitated by: Kevin Byrne, University of Alberta; Guillaume Lesage, Mineral Deposit Research Unit; Alain Plouffe, Geological Survey of Canada; Robert Lee, Mineral Deposit Research Unit.***

**Geochemical Field Techniques - Mt Washington, Vancouver Island, British Columbia**

***Friday, June 22 to Sunday, June 24, 2018, $1050***. Includes: transportation, meals, accommodation and guidebook. All successful geochemical surveys begin with collecting good samples, that in turn, rely on in-the-field recognition of appropriate sample media. The explorationist must identify the landforms (especially in glaciated terrains) from which the media are drawn to accurately interpret source provenance of any anomalous results. This field trip is targeted to geoscientists who want to learn more about interpreting glacial landforms and the sampling of soils, tills, sediments and vegetation from leading industry experts in quaternary geology, biogeochemistry, exploration geochemistry and analytical chemistry. The field trip will visit two mineral deposits (an active massive sulphide mine and a porphyry Cu-Au prospect) on Vancouver Island. In situ analyses using field portable instruments (e.g. pXRF) combined with subsequent lab analyses of collected samples will give the participants a full appreciation of discovering geochemical anomalies and tracing these to mineralization. ***Facilitated by John Gravel.***

# To all RFG2018 Participants


The Association of Applied Geochemists invites you to a **Gala Dinner** on **Wednesday, June 20**, 2018 for a truly one-of-a-kind experience, dining amongst the 50,000 inhabitants in the halls and galleries of the spectacular Vancouver Aquarium. The evening will include travel by private coach to scenic Stanley Park. A welcome reception drink and tour of the aquarium's outdoor exhibits or participating in the AAG awards ceremony. Dinner prepared by executive chef Ned Bell while enjoying BC Okanagan wine. Then touring the aquarium's interior exhibits or taking in presentations by the aquarium's science staff on research conducted in the high-arctic and the Pacific Northwest. Private coaches will return our guests to the Conference Centre.


Tickets are CDN $120 and can be ordered on-line from the RFG2018 Registration site. When ordering, please select your choice of meal from the Sea, from the Farm or from the Garden. If you purchase more than one ticket, then please select your guest's meal choices. Seating is arranged so please indicate who you wish to sit with (other than your guests) and we will do our best to arrange seating.

## We hope you will join us!

Please direct any questions to John Gravel: john.gravel01@gmail.com

An IUGS Event

RFG2018
RESOURCES FOR FUTURE GENERATIONS

PREMIERE INTERNATIONAL CONFERENCE ON
ENERGY · MINERALS · WATER · THE EARTH
June 16-21, 2018
Vancouver Convention Centre, BC, Canada

## Mentoring Benefits Everyone

Mentoring is a critical component for any industry to ensure transfer of knowledge and to provide guidance to other professionals in their careers. Mentoring programs are well established in other professions (ie: medicine, law, engineering, etc) that date back decades, however, formal mentoring programs within geoscience are a comparatively new phenomenon. In Canada, professional associations (ie: APGO, etc) and industry organizations (ie: PDAC, etc) have established formal mentoring programs in the last few years.

Mentoring allows experienced professionals (mentors) to share their knowledge and provide guidance with others (mentees). Although the role of mentor has traditionally been filled by an older person and the mentee by a younger person, it is now common to see experienced professionals mentoring other established professionals.

The demographic of geochemists reflects the industry at large – a bimodal distribution – a large population of experienced professionals nearing retirement age and a sizeable population of early career professionals. Mentoring plays an important role to ensure that the brain trust of experienced professionals gets passed down to those entering the field of geochemistry.

Formal mentoring programs are structured to ensure a proper match between the mentor and mentee. At the outset of a mentoring relationship, both mentor and mentee agree to rules of engagement, an agenda and a schedule. Once a relationship has been formalized, the program is self-directed and allows for a high degree of flexibility (i.e., modifying session times, program duration, etc). Mentoring programs require an investment of time that is compatible with everyone's schedule – which typically can be as little as 1 hour per week.

As an active mentor, I find great satisfaction in working with mentees and seeing careers flourish. I encourage fellow professionals interested in mentoring to contact organizations that offer such programs to get involved as either a mentor or mentee and to contact your local professional geoscientist association or industry organization to find out more. For example, the Prospectors and Developers Association of Canada (PDAC) has a mentoring program that can be accessed through this web link: http://www.pdac.ca/members/students/mentorship

Enrolling in a mentoring program is an investment in the future of the participants and our industry. Our industry is in a state of transition and the need for mentors is stronger now than ever before. Mentoring is a rewarding experience for everyone and the learning goes both ways. The essence of mentoring is captured in a famous phrase from Sir Isaac Newton who wrote, "If I have seen further it is by standing on the shoulders of giants."

**David M. Leng, P. Geo.**
*Email: dleng@rgcinc.ca*

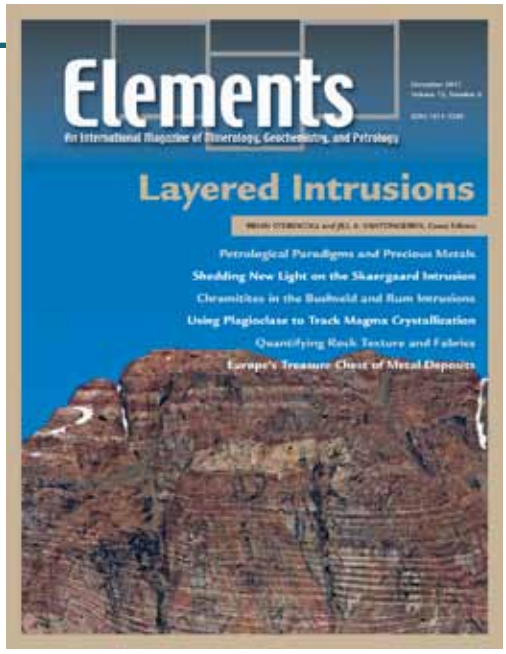
## Recently Published in Elements

*Volume 13, no. 6, Layered Intrusions*

The December 2017 issue of Elements deals with various aspects of layered intrusions. The AAG news in this issue contains a memorial to Professor Kurt Kyser and abstracts for two articles published in **EXPLORE** issue 176.

The first issue of Volume 14 will include messages from both the past and in-coming AAG presidents, along with an abstract for the technical article that appeared in **EXPLORE** issue 177.

**Dennis Arne**



# Geochemistry

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)*




## CONTENTS - Volume 17, No. 4


**Obituary, T. Kurtis Kyser (1951–2017)** 277

**Geochemical and isotopic characteristics of stream and terrace sediments of the Harsit Stream, NE Turkey**
Çiğdem Saydam Eker 279

**Indicator mineral and geochemical signatures associated with the Sisson W–Mo deposit, New Brunswick, Canada**
M. B. McClenaghan, M. A. Parkhill, A. G. Pronk, A. A. Seaman, M. W. McCurdy & M. I. Leybourne 297

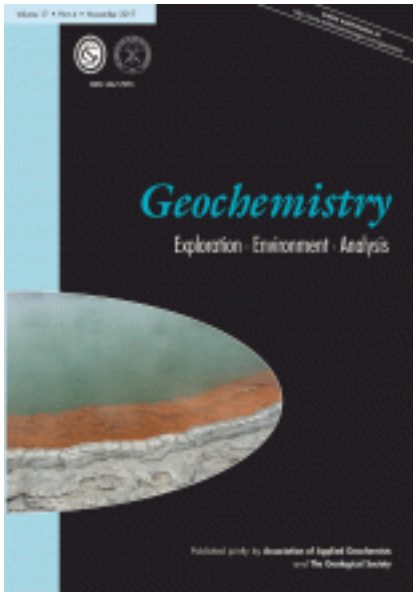
**Vibrational spectroscopy of epidote, pumpellyite and prehnite applied to low-grade regional metabasites**
Alistair J. R. White, Carsten Laukamp, Mark A. Stokes, Monica Legras & Bobby Pejcic 315

**Geochemical and mineralogical characterization of tailings of the Dexing copper mine, Jiangxi Province, China**
Hanjiang Pan, Zhizhong Cheng, Guohua Zhou, Rong Yang, Binbin Sun, Ling He, Daoming Zeng & Jing Wang 334

**Enhancement of stream-sediment dispersion trails using R-mode factor analysis: an example from Wadi Kamal layered complex, NW Arabian Shield**
Ahmad M. Al-Saleh 345

**Dendrochronology in mineral exploration: developing tools to see through anthropogenic impacts**
Madison Schmidt, Matthew I. Leybourne & T. Kurt Kyser 357

**Study of particles from the Kafang copper deposit in Gejiu city, Yunnan**
Dewei Li, Jianjin Cao, Hongling Ke, Chang Liu & Xiaojun Wei 367

# Geochemistry

EXPLORATION, ENVIRONMENT, ANALYSIS

*Co-Chief Editor:* **Benedetto De Vivo**, Università di Napoli Federico II, Italy (bdevivo@unina.it)

*Associate Editor:* **J. Carranza** (University of KwaZulu-Natal, South Africa)

*Production Editor:* **Jessica Pollitt**, Geological Society Publishing House, Bath, UK (jessica.pollitt@geolsoc.org.uk)

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## CONTENTS - Volume 18, No. 1


**Integrating petrogenesis and weathering to understand regolith chemistry: examples from the Palaeoproterozoic Carson Volcanics, north Kimberley, Western Australia**
Paul Morris **1**

**Development of partial extraction methods to estimate abundance of copper-iron sulphide minerals in the Escondida Norte porphyry copper deposit, Chile**
Richard K. Preece, Martin J. Williams & Jonathan M. Gilligan **13**

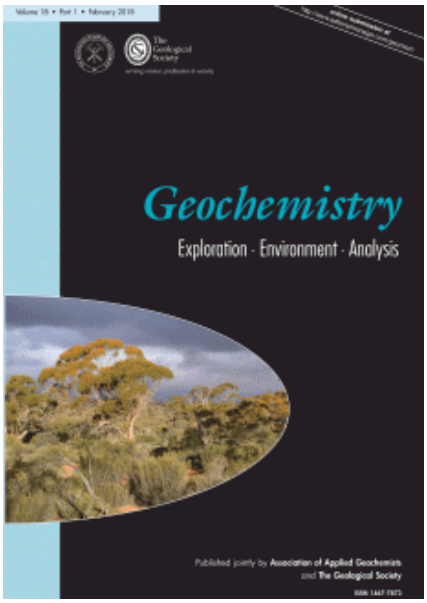
**Soil-gas and weak partial soil extractions for nickel exploration through transported cover in Western Australia**
R. R. P. Noble, D. M. Seneshen, M. J. Lintern, R. R. Anand, A. Pagès & G. T. Pinchand **31**

**Heavy metal contamination and health risk assessment in Critical Zone of Luan River Catchment in the North China Plain**
Rong Ma, Xiaoni Zhou & Jiansheng Shi **47**

**MMI partial extraction geochemistry for the resolution of anthropogenic activities across the archaeological Roman town of Calleva Atrebatum**
Graham C. Sylvester, Alan W. Mann, Samantha R. Cook & Clare A. Wilson **58**

**Assessment of sulphate and iron reduction rates during reactor start-up for passive anaerobic co-treatment of acid mine drainage and sewage**
Peter M. Smyntek, Jeffrey Chastel, Rebecca A. M. Peer, Evan Anthony, Jacob McCloskey, Emily Bach, Rachel C. Wagner, Joel Z. Bandstra & William H. J. Strosnider **76**

**Determination of carbonate vein chemistry using portable X-ray fluorescence and its application to mineral exploration**
Benjamin S. Andrew & Shaun L. L. Barker **85**

## *Chapter Review:* Application of till mineralogy and geochemistry to mineral exploration

*Authors: M.B. McClenaghan and R.C. Paulen*
*In:* Past Glacial Environments (Second Edition) *Edited by:* John Menzies and Jaap J.M. van der Meer
Published by: Elsevier, 2017

In the second edition of Past Glacial Environments, McClenaghan and Paulen (Research Scientists, Geological Survey of Canada) contribute a chapter devoted to applying till mineralogy and geochemistry to mineral exploration in glaciated terrain. Appreciating the importance of understanding how till forms and how sediment is dispersed, they set the stage for establishing how till can be used to track up-ice to a bedrock source by reviewing Quaternary glacigenic processes and ice sheet reconstructions. They continue by addressing subglacial till sampling methods, and items of importance for geochemical determinations, including how different size fractions and analytical methods can influence results.

I found the treatment of indicator minerals in subglacial tills to be the highlight of the chapter. McClenaghan and Paulen emphasize how the now-familiar methods used to discover diamonds in Canada's Arctic are being applied to explore for base (Cu, Mo, Pb, Zn, Ni), precious (Au, Ag, PGE), and specialty (REE, Li, Nb, Ta, Zr) metals. They discuss selected mineral deposit types (volcanogenic massive sulfide; sediment hosted Pb-Zn; Au; magmatic Ni-Cu-PGE; rare metals; porphyry Cu-Au-Mo; porphyry Sn-W; U) and how indicator minerals can be used for exploration. Included are a go-to table summarizing ore and pathfinder elements, common indicator minerals, reviews and case studies, high-quality colour photos of selected indicator minerals, and size fractions and density separations that target specific minerals. The reader is also briefly introduced to modern chemical and isotopic techniques that can link individual sand grains from the matrix of a till to a specific bedrock source.

This chapter will appeal to practicing geochemists and exploration geologists wanting to learn how surface sediments can be used effectively to explore in drift-covered areas. It will also appeal to graduate and upper-level undergraduate students. The reference list is extensive and is a useful catalogue of work on till survey design and implementation in different scenarios, and on interpreting results. The chapter is well written, the illustrations are well conceived and drafted, and the tables well executed. A recommended read.

**Travis Ferbey**
*British Columbia Geological Survey*

## 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**
Geological Survey of Newfoundland and Labrador
P.O. Box 8700, St. John's, NL, Canada, A1B 4J6
Email: StephenAmor@gov.nl.ca Tel: +1-709-729-1161
**Or** Tom Meuzelaar, AAG Webmaster,
Email: Tom_Meuzelaar@golder.com

### 2018

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|---|---|
| 17-19 MARCH | 4th International Conference on Geographical Information Systems Theory, Applications and Management. Funchal Portugal. Website: www.gistam.org |
| 19-23 MARCH | Lunar and Planetary Science Conference. Woodlands TX USA. Website: www.hou.usra.edu/meetings/lpsc2018 |
| 26-28 MARCH | 14th Australasian Environmental Isotope Conference. Wellington New Zealand. Website: www.confer.co.nz/aeic2018 |
| 4-6 APRIL | Mongolia Mining 2018. Ulaanbataar Mongolia. Website: www.mongolia-mining.org |
| 8-13 APRIL | European Geosciences Union General Assembly 2018. Vienna Austria. Website: www.egu2018.eu |
| 9-10 APRIL | Lithium: From Exploration to End-User. London UK. Website: www.geolsoc.org.uk/lithium18 |
| 23-24 APRIL | 20th International Conference on Earth Science and Climate Change. Boston MA USA. Website: tinyurl.com/yccmclcs |
| 2-4 MAY | International Conference on Geology & Earth Science. Rome Italy. Website: http://geoscience.madridge.com |
| 20-23 MAY | VIII Brazilian Symposium on Mineral Exploration. Ouro Preto Brazil. Website: www.adimb.com.br/simexmin2018 |

*continued on page 31*

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

| | |
|---|---|
| 21-25 MAY | The Solomon Meeting - A Forum for Advancing Mineral System Science. Clare Valley SA Australia. Website: solomonmeeting2018.com |
| 4-7 JUNE | 5th Annual International Conference on Geology and Earth Science. Athens Greece. Website: www.atiner.gr/2018geology |
| 5-6 JUNE | International Uranium Conference. Adelaide SA Australia. Website: uranium.ausimm.com |
| 10-13 JUNE | 4th International Congress on 3D Materials Science. Helsingør Denmark. Website: tinyurl.com/yahh2uxb |
| 16-21 JUNE | Resources for Future Generations (Energy, Minerals, Water and the Earth). Vancouver BC Canada. Website: rfg2018.org. **See announcement in current issue of Explore**. |
| 16-21 JUNE | GAC/MAC Annual Meeting. Vancouver BC Canada. Website: rfg2018.org |
| 26-28 JUNE | 3rd European Mantle Workshop. Pavia Italy. Website: emaw2018iggpavia.unipv.it |
| 30 JUNE – 6 JULY | 13th International Platinum Symposium. Polokwane South Africa. Website: 13ips.com |
| 1-6 JULY | 7th International Congress on Arsenic in the Environment. Beijing, China. Website: www.as2018.org |
| 2-7 JULY | 34th SEGH International Conference on Sustainable Geochemistry. Livingston Zambia. Website: segh2018.org |
| 7-8 JULY | Gordon Research Seminar — Ocean Biogeochemistry. Hong Kong China. Website: tinyurl.com/y98s7dwe |
| 8-13 JULY | Geoanalysis 2018. Sydney NSW Australia. Website: 2018.geoanalysis.info |
| 10-13 JULY | Granulites and Granulites 2018. Ullapool UK. Website: tinyurl.com/yc53c23z |
| 21-28 JULY | 27th Colloquium of African Geology. Aveiro Portugal. Website: cag27.web.ua.pt |
| 22-25 JULY | 11th South American Symposium on Isotope Geology. Cochabamba Bolivia Website: tinyurl.com/yd2wzrz9 |
| 5-10 AUGUST | Gordon Research Conference - Gordon Research Conference - Geochemistry of Mineral Deposits. Waterville Valley NH US. Website: tinyurl.com/ybnhv8mv |
| 5-9 AUGUST | Microscopy & Microanalysis 2018 Meeting. Baltimore MD USA. Website: tinyurl.com/yc9alqdk |
| 6-10 AUGUST | 2018 IGU Regional Conference. Quebec City QC Canada. Website: igu2018.ulaval.ca |
| 12-17 AUGUST | Goldschmidt 2018. Boston MA USA. Website: goldschmidt.info/2018 |
| 12-17 AUGUST | 21st World Congress of Soil Science. Rio de Janeiro Brazil. Website:www.21wcss.org |
| 13-17 AUGUST | 22nd General Meeting of the International Mineralogical Association. Melbourne VIC Australia. Website: www.ima2018.com |
| 19-21 AUGUST | 8th International Conference on Environmental Pollution and Remediation. Madrid Spain. Website: tinyurl.com/yburvkck |
| 22-24 AUGUST | 3rd Virtual Geoscience Conference. Kingston ON Canada. Website: virtualoutcrop.com/vgc2018 |
| 28-31 AUGUST | 15th Quadrennial IAGOD Symposium. Salta Argentina. Website: www.iagod.org/node/76 |
| 2-8 SEPTEMBER | 19th Annual Conference of International Association for Mathematical Geosciences. Olomouc Czech Republic. Website: www.iamg2018.org/ |
| 3-7 SEPTEMBER | 4th Annual World Multidisciplinary Earth Sciences Symposium. Prague, Czech Republic. Website: www.mess-earth.org |
| 3-7 SEPTEMBER | International Conference on Magmatism of the Earth and Related Strategic Metal Deposits. Moscow Russia. Website: magmas-and-metals.ru |
| 9-12 SEPTEMBER | Fourth International Symposium on Ethics of Environmental Health. Budweis Czech Republic. Website: iseeh.org |
| 10-13 SEPTEMBER | XXI Congress of Carpathian Balkan Geological Association. Vienna Austria. Website: cbga.sbg.ac.at |
| 13-15 SEPTEMBER | SIAM Conference on Mathematics of Planet Earth (MPE18). Philadelphia PA USA. Website: www.siam.org/meetings/mpe18 |
| 16-21 SEPTEMBER | IWA World Water Congress & Exhibition 2018. Tokyo Japan. Website: tinyurl.com/ybpmakrc |
| 17-25 SEPTEMBER | 13th International Symposium on Nuclear and Environmental Radiochemical Analysis: ERA13. Cambridge UK. Website: tinyurl.com/y9tbav7m |

*continued on page 32*

# CALENDAR OF EVENTS... *continued from page 31*

| | |
|---|---|
| 22-25 SEPTEMBER | SEG 2018. Keystone CO USA. Website: www.seg2018.org |
| 23-27 SEPTEMBER | 10th International Conference on Environmental Catalysis. Tianjin China. Website: tinyurl.com/yazebbz5 |
| 14-18 OCTOBER | Australian Geoscience Council Convention. Adelaide SA Australia. Website: tinyurl.com/zqxc6n2 |
| 25-26 OCTOBER | Sampling 2018. Lima Peru. Website: www.encuentrometalurgia.com/Sampling-2018 |
| 4-7 NOVEMBER | GSA 2018 Annual Meeting. Indianapolis IN USA. Website: tinyurl.com/yb859e9n |
| 12-15 NOVEMBER | XIII Latin American Symposium on Environmental Analytical Chemistry. La Serena Chile. Website: tinyurl.com/yc92c5jk |
| 4-8 DECEMBER | American Exploration & Mining Association (AEMA) Annual Meeting. Reno NV USA. Website: www.miningamerica.org/2018-annual-meeting |
| 10-14 DECEMBER | AGU Fall Meeting. Washington DC USA. Website: tinyurl.com/yclg7sut |
| 13-14 DECEMBER | ICGG 2018 : 20th International Conference on Gas Geochemistry. Bangkok Thailand. Website: tinyurl.com/ycw4ma8v |

## THE ASSOCIATION OF APPLIED GEOCHEMISTS

**P.O. Box 26099, 72 Robertson Road, Ottawa, Ontario K2H 9R0 CANADA • Telephone (613) 828-0199**
**www.appliedgeochemists.org**

### OFFICERS

January - December 2018

**Steve Cook**, *President*
Teck Resources Limited
Suite 3300, 550 Burrard Street
Vancouver, BC
Canada V6C 0B3
TEL: +1 604 699 4329
email: stephen.cook@teck.com

**Dennis Arne**, *Vice-President*
Principal Consultant
CSA Global Pty Ltd
17 Church Street
Yackandandah, Vic, Australia 3749
TEL: +61 407 300 605
email: Dennis.Arne@csaglobal.com

**David B. Smith,** *Secretary*
U.S. Geological Survey
Box 25046, MS 973
Denver, CO 80225, USA
TEL: (303) 236-1849
email: dbsmith13@gmail.com

**Gwendy E.M. Hall,** *Treasurer*
110 Aaron Merrick Drive
Merrickville, ON K0G 1N0
Canada
TEL: +1-613-269-7980
email: gwendyhall@gmail.com

### COUNCILLORS

2017-2018
Dave Cohen
Ray Lett
Tom Meuzelaar
Juan Carlos Ordóñez Calderón
Renguang Zuo

2018-2019
Maurizo Barbieri
David Murphy
Graham Sylvester
Yulia Uvarova
Erick Weiland

### REGIONAL COUNCILLORS

*Brazil*
João Larizzatti
joao.larizzatti@cprm.gov.br
*Chile*
Brian Townley
btownley@ing.uchile.cl
*China*
Xueqiu Wang
wangxueqiu@igge.cn
*Northern Europe*
Pertti Sarala
pertti.sarala@gtk.fi
*Southern Europe*
Benedetto De Vivo
bdevivo@unina.it
*Southeast Asia*
Iftikar Malik
malik.iftikhar@gmail.com
*Southern Africa*
Theo Davies
theo.clavellpr3@gmail.com
*UK and Republic of Ireland*
Kate Knights
kknights@hotmail.com

### AAG COMMITTEES

**New Membership**
Nigel Radford,
nradford@iinet.net.au

**Admissions**
Nigel Radford,
nradford@iinet.net.au

**Awards and Medals**
Ryan Noble
ryan.noble@csiro.au
Chris Benn
Pertti Sarala
Romy Matthies

**Education**
Paul Morris,
paul.morris@dmirs.wa.gov.au

**Symposia**
David Cohen,
d.cohen@unsw.edu.au

### AAG COORDINATORS

**AAG Student Paper Prize**
David Cohen,
d.cohen@unsw.edu.au

**AAG Website**
Gemma Bonham-Carter,
webmaster@appliedgeochemists.org
*Coordinator:*
Tom Meuzelaar,
tom_meuzelaar@golder.com

**Geoscience Councils**
David Cohen,
d.cohen@unsw.edu.au

**GEEA**
To be announced

**EXPLORE**
Beth McClenaghan,
beth.mcclenaghan@canada.ca

**ELEMENTS**
Dennis Arne,
dennis.arne@csaglobal.com

**AAG Regional Councillors**
Dennis Arne,
dennis.arne@csaglobal.com

### AAG BUSINESS MANAGER

**Al Arseneault**
P.O. Box 26099, 72 Robertson Road, Ottawa, ON K2H 9R0 CANADA,
TEL: (613) 828-0199 FAX: (613) 828-9288,
email: office@appliedgeochemists.org