

## Finally, a correlation coefficient that tells the geochemical truth

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### Introduction

Geochemists have long been aware of the problems surrounding estimating correlation coefficients for their analytical data sets. Very often they just don't make sense on the basis of the mineralogy of the sample material and our knowledge of mineral stoichiometry. The problem lies in the nature of geochemical analyses, they are relative measures reported in such units as weight %, parts per million (mg/kg),  $\mu\text{g/L}$ , etc., the sum of the parts, individual measures, add to a constant. Because of the relative units it does not matter whether all the parts have been determined in the analysis, the problem remains whatever the number of parts determined, even just two. The problems related to correlations were recognized by Pearson as long ago as 1897. The first geoscientist to study the problem systematically was Felix Chayes (1960) a research petrologist who worked for the Carnegie Institution's Geophysical Laboratory and for the Smithsonian Institution. The true information in a geochemical data set lies in the ratios between the parts, and Tom Pearce (1970) was the first geoscientist to promote the use of ratios in petrology, leading to a number of diagrams that are effective in classification and genetic studies. The mathematical groundwork for properly handling compositional data was laid out by John Aitchison (1984, 1986) with his exposition on the use of log-ratios. Since then numerous papers and books have been published on compositional data analysis, see for example Pawlowsky-Glahn *et al.* (2015) and the references in Reimann *et al.* (2017). Today a common approach in multivariate analysis, e.g., Principal Components or Factor Analysis, is to use a centred log-ratio (clr) of the data set prior to carrying out the analysis (e.g., Fig. 1). It might seem apparent then to also calculate the correlation coefficients on the clr-transformed data. However, this does not lead to consistent results, because clr variables are driven by their zero sum constraint. As a consequence, a negative bias occurs when correlation analysis in clr variables is performed. It is quite natural that different sub-compositions, i.e. subsets of the parts, for a data set do not yield the same correlation coefficients for the two parts of interest. The reason for this is the computation of the clr-transform involves dividing the value for each part (variable) by the geometric mean of all the parts in the subset for an individual sample; and different subsets for a sample will have different geometric means. One can also express each clr variable as a (scaled) sum of all pairwise log-ratios with the respective compositional part – a kind of intuitive result, when all information in compositional data is contained in log-ratios. A careful choice of parts, involved in the analysis, is thus always necessary.

A solution to the problem of negative bias of correlation analysis in clr variables has been proposed by Kynčlová *et al.* (2017) and involves the computation of symmetric coordinates, an extension of isometric log-ratios (Egozcue *et al.*, 2003). The symmetric coordinates are computed as weighted log-ratios that take the total number of parts into consideration. This procedure has been demonstrated with two large sets of geochemical (environmental) soil data by Reimann *et al.* (2017). The purpose of this article is to demonstrate the procedure and discuss the results for a small set of petrochemical data whose mineralogy will be familiar to readers. As such, this article is a tutorial rather than a contribution of original science. The data set of 16 'averages' for common plutonic rocks was published by Nockolds

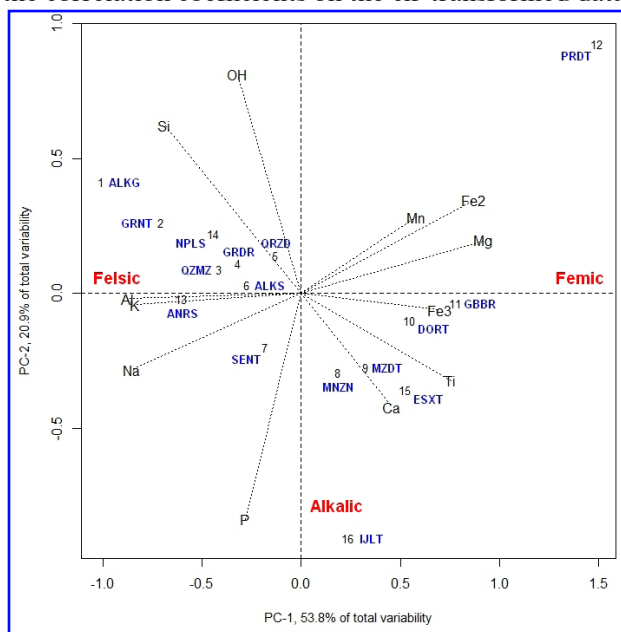


Figure 1. Principal Components Analysis for the clr-transformed Nockolds data set. Lithologies: 1 - Alkali Granite; 2 - Granite; 3 - Quartz Monzonite; 4 - Granodiorite; 5 - Quartz Diorite; 6 - Alkali Syenite; 7 - Syenite; 8 - Monzonite; 9 - Monzodiorite; 10 - Diorite; 11 - Gabbro; 12 - Peridotite; 13 - Anorthosite; 14 - Nepheline Syenite; 15 - Essexite; 16 - Ijolite

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# EXPLORE

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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.geolosc.org.uk/template.cfm?name=geea\\_instructions\\_for\\_authors](http://www.geolosc.org.uk/template.cfm?name=geea_instructions_for_authors)

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Submissions should be sent to the Editor of EXPLORE:

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## Notes from the Editor

EXPLORE issue 176 includes two technical articles. The first is written by Bob Garrett, Clemens Reimann, Karel Hron, Petra Kynčlová and Peter Filzmoser and demonstrates a solution to the problem of negative bias of correlation analysis using a small set of petrochemical data. The second article by Colin Dunn and Rick McCaffrey describes the use of seaweed as an exploration medium with an example from the west coast of Canada.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue: Steve Adcock, Steve Amor, Dennis Arne, Al Arsenault, Steve Cook, Peter Filzmoser, Bob Garrett, Karel Hron, Kate Knights, Petra Kynčlová, Chris Lawley, David Leng, Rick McCaffrey, Paul Morris, Ryan Noble, and Clemens Reimann, Dave Smith, Pim van Geffen, and Peter Winterburn.

Beth McClenaghan

Editor





## President's Message

My first President's Message in Explore (March 2016) was a bit of an introduction, but also highlighted my path into service for the AAG and the collaborative benefits that I had gained from being a student member. I benefited greatly from being a student AAG member and I encourage all of you that interact with students of applied geochemistry to encourage them to join. The AAG has a smaller, collegiate-feel for applied geochemistry and we are keener than ever to build our student members. I will review a few of the perks of being an AAG student member. Firstly, it is only \$10 US and includes subscriptions to our journal, *Geochemistry: Exploration, Environment, Analysis*, our newsletter **EXPLORE** and a number of student focused awards and programs including one for analytical support. It is less expensive than a pint of beer (in Perth) and you get a full year of value. The AAG offer some valuable student funding and support services. These include:

- 1) Analytical support (in-kind)
- 2) Conference travel funding
- 3) Conference presentation and publication awards
- 4) Abstract fee funding

The analytical support program enables some research samples to be analysed at our participating laboratory partners (Actlabs, ALS, Bureau Veritas Minerals Acme, Bureau Veritas Minerals Ultratrace, Intertek Genalysis, and LabWest). These analyses are performed for free or significantly reduced cost to the student. The AAG facilitates deserving students to get the needed analyses done and our committee also assists in getting this research published in our journal *GEEA* or the **EXPLORE** newsletter at a later time. A full list of supported research is shown later in this issue authored by Paul Morris.

Conference travel funding is offered to support student attendance primarily at our International Applied Geochemistry Symposia (IAGS). The next symposium is in Vancouver in June 2018 as part of the Resources for Future Generations major conference (RFG2018 <http://rfg2018.org/>) and we hope to support a number of students for their conference fees and potentially some travel/accommodation costs to a set value. The AAG is also offering student paper and poster prizes at the upcoming IAGS in Vancouver thanks in part to our sponsors SGS Minerals.

Finally, the AAG expects to reimburse students for all abstract fees incurred by submitting to the RFG2018 if the student is presenting in an IAGS affiliated session. Full details and more are available on our website or will be updated shortly as the RFG program develops. <https://www.appliedgeochemists.org/>

You can see it is worth your time as a student to join the AAG and become involved. As a member of the AAG, if you know any applied geochemistry students, please pass this information on to them. They are the future of the AAG and I would

like to see a big increase in students and early career researchers at the next IAGS in Vancouver. I will be encouraging the conference organisers to give preference to student presentations if spots are limited. I hope to meet many more students prominently presenting their research in Vancouver and developing the necessary collaborations for a strong future career in applied geochemistry.

**Ryan Noble**  
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(1954) as oxide percentages. More recent compilations have been made, but the Nockolds data suffices for the demonstration. The original oxides have been converted to cation percentages and H<sub>2</sub>O+ to OH, see Appendix 1 (see digital version of Appendix 1 on the AAG website).

### Data Analysis

For all the following computations and graphical presentations version 1.1.14 of the R (2017) package ‘rgr’ (Garrett, 2017) was employed. To graphically illustrate the interrelations between the geochemical data and the lithology a Principal Components Analysis (PCA) was undertaken following a centred log-ratio transformation (function ‘gx.mva.closed’), see Figure 1 (function ‘gx.rqpc.plot’), which was annotated (coloured text) with the lithological abbreviations outside ‘rgr’. The end members and outliers in Figures 2 to 4 were similarly annotated. Functions in ‘rgr\_1.1.14’, ‘xyplot.tags’ in conjunction with function ‘gx.symm.coords.mat’, can directly display plots tagged by text, such as lithological names.

The first principal component, PC-1, explains 74.7% of the total variability in the data set. High Si, Al and alkali metal felsic, quartzo-feldspathic, rocks are characterized by negative PC-1 scores, while femic, ferromagnesian mineral-rich, rocks high in Mg, Fe<sup>3</sup>, Fe<sup>2</sup>, Mn and Ti are characterized by positive PC-1 scores. In contrast, alkalic rocks with higher Ca, Na and P contents are characterized by negative PC-2 scores. The path from felsic intrusives, e.g., generally granitic, to femic rocks (gabbros and diorites) follows a ‘NW’ to ‘SE’ trend. Two Si deficient rocks, olivine- and pyroxene-rich peridotite, and nepheline- and alkali pyroxene-rich ijolite both plot as ‘outliers’ off-trend. The essentially mono-mineralic rock anorthosite, with dominant plagioclase feldspar, plots proximal to Al, K and Na close to the main trend in the data.

The default procedure in function ‘gx.symm.coords.r’ calculates Spearman correlation coefficients for the symmetric coordinates derived from the input data. Spearman ranked coefficients are preferred over Pearson product moment coefficients as they provide better estimates of correlation for data pairs that vary monotonically, i.e. the data points vary sympathetically or antipathetically, but not necessarily linearly. Furthermore, any monotonic transformation, e.g., logarithmic, has no impact on the Spearman coefficient as the ranks remain the same. For Exploratory Data Analysis (EDA) any systematic data relationship is of interest, even if it is curvilinear; should modelling be required linearizing transformations can be sought.

The correlation matrix (Table 1) contains two sets of Spearman coefficients, the upper triangle contains those based on the symmetric coordinates computed after Kynčlová *et al.* (2017), and the lower contains those based on the input data. Alternatively, Pearson coefficients may be selected, and the further option exists to apply a logarithmic transformation to the input data, which has been common practice amongst applied geochemists.

Table 1. Spearman correlation coefficients for the Nockolds data set. Upper triangle based on symmetric coordinates, lower triangle based on raw data

	Si	Al	Fe <sup>3</sup>	Fe <sup>2</sup>	Mg	Ca	Na	K	Ti	Mn	P	OH
Si		0.87	-0.58	-0.38	-0.66	-0.55	0.56	0.74	-0.79	-0.40	-0.16	0.71
Al	-0.44		-0.54	-0.67	-0.82	-0.44	0.77	0.75	-0.80	-0.42	-0.27	0.60
Fe <sup>3</sup>	-0.79	0.36		0.45	0.54	0.22	-0.22	-0.13	0.46	0.84	0.08	-0.19
Fe	-0.74	-0.04	0.80		0.93	0.51	-0.88	-0.59	0.67	0.41	-0.06	-0.23
Mg	-0.76	0.00	0.76	0.98		0.71	-0.86	-0.77	0.92	0.44	0.11	-0.30
Ca	-0.78	0.54	0.63	0.57	0.64		-0.32	-0.76	0.82	0.10	0.09	-0.30
Na	-0.13	0.77	0.20	-0.28	-0.30	0.21		0.64	-0.68	-0.25	0.01	0.47
K	0.66	0.06	-0.30	-0.56	-0.63	-0.63	0.29		-0.74	-0.30	0.47	0.41
Ti	-0.79	0.37	0.94	0.84	0.83	0.71	0.13	-0.36		0.41	0.15	-0.35
Mn	-0.77	0.19	0.84	0.76	0.70	0.37	0.06	-0.37	0.78		-0.21	-0.01
P	-0.40	0.40	0.75	0.49	0.50	0.62	0.30	0.00	0.79	0.37		-0.62
OH	-0.51	0.23	0.41	0.50	0.52	0.34	0.10	-0.48	0.54	0.53	0.17	

### Discussion

Silicon (Si) is the dominant part in the data set with cation percentages varying from some 20%, ijolite and peridotite, to 34.5%, alkali granite (see Appendix 1). Reading down the first column of Table 1, the Spearman coefficients are all negative, but for K. As the dominant part (Si) increases most of the remaining parts have to decrease to maintain constant sum. Yet from the mineralogy of these rocks we know that Si, Al, Na and K increase together in felsic rocks as the amounts of quartz, and alkali feldspar increase, together with white micas (OH), at the expense of less Si-rich ferromagnesian minerals rich in Fe, Mg, Ti and Mn, such as dark micas and amphiboles that are more abundant in femic rocks.

This mineralogical reality is reflected in the Spearman coefficients based on the symmetric coordinates displayed across the first row of Table 1. The negative symmetric coordinate correlations for Mg, Fe<sup>2</sup>, Fe<sup>3</sup>, Ti, Mn and Ca reflect the sympathetic relationship between these elements in ferromagnesian minerals from amphiboles, through pyroxenes to olivines, as they increase in abundance in femic rocks. This increase is at the expense of quartz (Si), albitic (Na) and orthoclase (K) aluminosilicate feldspars, and is reflected in positive symmetric coordinate correlations between Si, Al, Na, K and OH, and, as a group, their negative correlations with Mg, Fe<sup>2</sup>, Fe<sup>3</sup>, Ti, Mn and Ca.

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Data inspection and interpretation is often facilitated and improved by graphical presentations, function 'gx.symm.coords. plot' undertakes that task. The classic example of problems with compositional data is the Harker diagram, which dates back to 1909, for plotting various oxides against silica. Silicon (Si) and Al are the dominant cation pairs for each of the lithologies in the Nockolds data except peridotite (Mg & Fe replace Al), and Al-rich ijolite and nepheline syenite. The plot for Si and Al is presented in Figure 2.

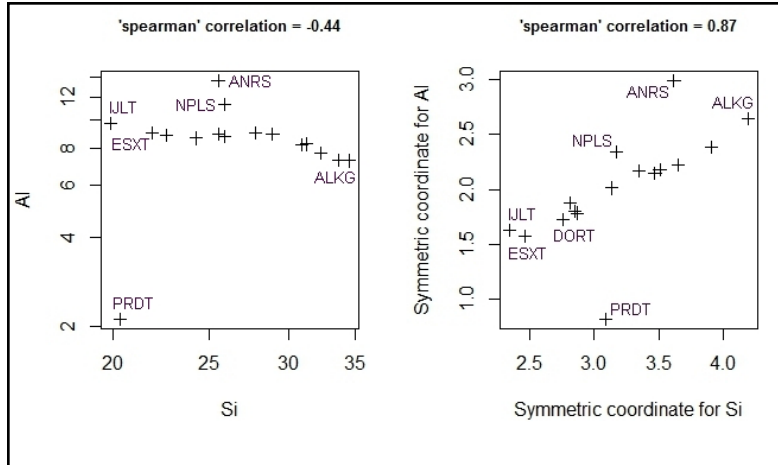


Figure 2. Plots of the Nockolds data for Si and Al as a pseudo Harker diagram (left) and as symmetric coordinates (right)

tion) for the Harker plot, however, this is due to the influence of the high leverage outlier peridotite, and in view of the graphic (Fig. 2, left) totally misleading. The Pearson correlation for the symmetric coordinates is 0.69, essentially unchanged.

A similar reversal can be demonstrated with Ca and Na, the two cations in the anorthite-albite plagioclase solid solution series (Fig. 3).

The Harker plot on the left shows the familiar negative relationship imposed by the compositional form of the data, with the mineralogical and geochemical outliers, peridotite in the lower left, and nepheline syenite and anorthosite at the top with highest Al. In contrast, the plot based on symmetric coordinates (Fig. 2, right) demonstrates sympathetically increasing Si and Al, with the ultramafic peridotite remaining an outlier at the bottom of the plot. The other two upper outliers are of interest, the most extreme is Al-rich anorthosite, and the less is nepheline syenite, which lies in the felsic to femic trend observed in the PCA (#14 in Fig. 1). The difference between the two plots is summarized in the differences between their Spearman correlations, -0.44 for the Harker plot and 0.87 for the symmetric coordinate plot, a convincing reversal. In this case the Pearson correlation is of interest. It is surprisingly positive 0.18 (with a logarithmic transformation

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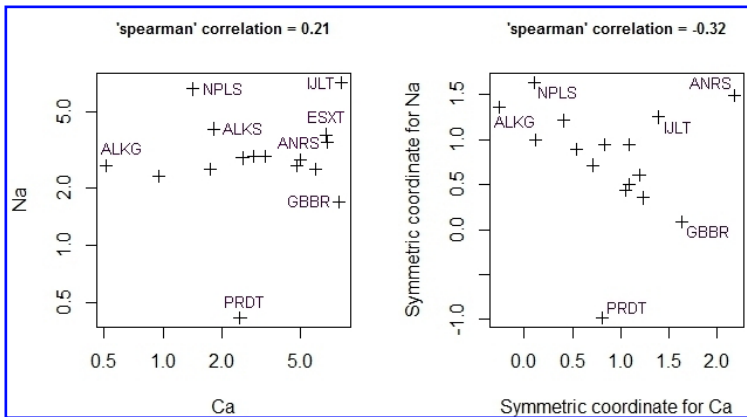


Figure 3. Plots of the Nockolds data for Ca and Na (left) and as symmetric coordinates (right).

the less extreme is ijolite. Summarized numerically by the Spearman coefficients, the untransformed data are positively correlated, 0.21, and the symmetrically transformed data are negatively correlated, -0.32, as should be expected on geochemical grounds.

A final example is one involving K and Ti, a minor element, i.e. between 1 and 0.1% in the composition, which clarifies their relationship, Figure 4.

The standard plot on the left shows a generally antipathetic relationship between K and Ti. As to be expected as K-rich felsic rocks are poor in Ti bearing minerals such as biotite, ilmenite and rutile and femic rocks are rich in Ti-bearing biotites, amphiboles, and other ferromagnesian minerals, but poor in K-rich minerals. There are two outliers, low Ti alkali granite and high Ti essexite, a Si under-

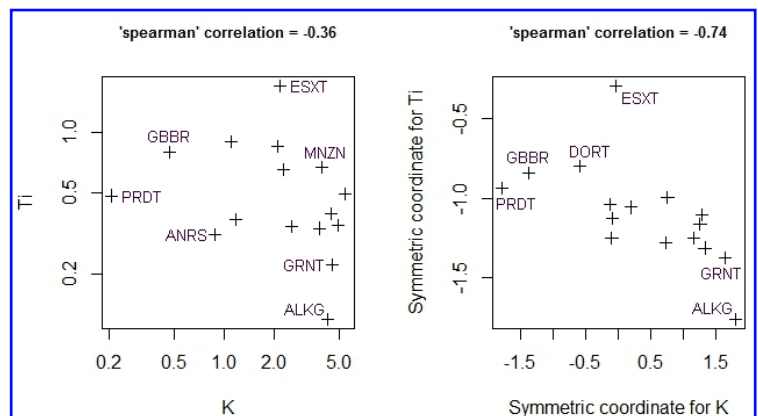


Figure 4. Plots of the Nockolds data for K and Ti (left) and as symmetric coordinates (right).

saturated rock dominated by plagioclase feldspar and pyroxene. The plot based on symmetric coordinates (Fig. 4, right) is much tidier, the main mass of the data plots within a more confined band due to the reduced influence of all the remaining parts in the total composition. The high Ti symmetric coordinate outlier, -0.30, is essexite which has the highest Ti cation percentage; the lithology in the lower right corner is alkali granite, which from its mineralogy of abundant orthoclase (K) and minimal biotite (Ti) plots as expected. Summarized numerically, the raw data Spearman coefficient of -0.36 has been improved to -0.74 through the symmetric coordinates removal of the effect of the competing parts in the composition on a part that is a minor/tracing contributor to the composition.

The Nockolds data set contains only major (Si, Al, Fe, Mg, Ca, Na & K) and minor (Ti, Mn & P) elements. It is used here as an example because of the ease of its interpretation. Many researchers are under the wrong impression that compositional data effects only exist when working with major elements. It has often been assumed (including by the senior author in the past)



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that a simple logarithmic transformation of minor and trace element data is sufficient. The example of Ti above demonstrates that the effect is not restricted to major element concentrations. The dominantly trace element study of Norwegian soils by Reimann *et al.* (2017) demonstrates that equally strong effects are exhibited for trace elements. Compositional effects are present in water analyses where the concentrations are usually reported in  $\mu\text{g/L}$ , three orders of magnitude lower than ppm ( $\mu\text{g/g}$ ), and they must be treated appropriately in order to obtain a correct representation of the interrelationships between the parts (Flem *et al.*, submitted). It is of no importance whether or not major elements are determined, the effect is inherent in the data – in their relative units.

### Conclusions

It has been demonstrated how the use of symmetric coordinates leads to correlation coefficients that ‘tell the truth’ and provide numerical expression to our observations of the mineralogy of the igneous rock and the stoichiometry of their minerals. Furthermore, the graphical display of the symmetric coordinates greatly improves the ability to interpret the results in a geoscientific context. The example of Si and Al clearly demonstrates the advantage of Spearman correlations over Pearson correlations in this kind of exploratory (EDA) investigation by the reduction of the influence of high leverage outliers. Importantly, the results presented go beyond correlation analysis. They demonstrate that simple bivariate scatterplots are not ‘simple’ at all when working with compositional data. The true relations between two parts only becomes clear when their symmetric coordinates are studied.

The Nockolds data are simple in structure and the underlying petrology and mineralogy are well understood and this is the reason they are used here. Interpretation of the Reimann *et al.* (2017) exposition for C- and O-horizon soils from a Norwegian survey is far more complex, and compounded by major variability introduced by varying ratios of minerogenic and organic fractions within the individual soil samples.

Correlation coefficients are sometimes inferred to imply causal relationships between the variables, or parts for compositional data. This can be dangerous as both measures may be unrelated directly, but through a third measure, ‘a lurking variable’, that may, or may not, have been measured. The result of this is that the inferred causation can be false and conclusions drawn erroneous. Given this, it is even more important for scientists working with compositional data to numerically estimate and display bivariate relations without the influence of the compositional nature of their data.

It is to be hoped that this procedure of working with symmetric coordinates will be incorporated into the common software packages used by geochemists and other users of compositional data. To facilitate their use the R scripts for the three symmetric coordinate functions are included in digital Appendix data files 3, 4, and 5 on the AAG website and an example of their use in Appendix 2; and if R is unavailable or inappropriate the processing flow and logic can be translated into a more convenient language for the user.

### Acknowledgements

The authors gratefully acknowledge the constructive suggestions of Chris Lawley and Pim van Geffen for improvements to the article.

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## Finally, a correlation coefficient that tells the geochemical truth... continued from page 9

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### Appendix 1

The Nockolds igneous plutonic data set as used in the report

Lithology	Si	Al	Fe <sup>3</sup>	Fe <sup>2</sup>	Mg	Ca	Na	K	Ti	Mn	P	OH
ALKG	34.53	7.28	0.55	0.88	0.16	0.51	2.60	4.26	0.120	0.039	0.061	0.444
GRNT	33.70	7.33	0.60	1.30	0.31	0.95	2.29	4.53	0.222	0.046	0.079	0.500
QZMZ	32.33	7.74	0.85	1.76	0.60	1.75	2.49	3.80	0.336	0.046	0.087	0.510
GRDR	31.27	8.29	0.93	2.01	0.95	2.54	2.85	2.55	0.342	0.054	0.092	0.614
QRZD	30.93	8.23	0.95	2.66	1.17	3.32	2.89	1.18	0.372	0.062	0.092	0.651
ALKS	28.92	8.95	1.62	2.04	0.58	1.82	4.05	4.91	0.348	0.085	0.083	0.500
SENT	27.77	9.06	1.53	2.20	1.22	2.90	2.91	5.42	0.497	0.062	0.166	0.595
MNZN	25.88	8.77	1.80	3.56	2.21	4.83	2.60	3.88	0.671	0.101	0.192	0.566
MZDT	25.55	8.99	2.28	4.18	2.38	5.00	2.79	2.29	0.653	0.108	0.188	0.566
DORT	24.24	8.68	1.91	5.42	3.69	6.00	2.49	1.10	0.899	0.139	0.153	0.755
GBBR	22.61	8.91	1.78	6.16	4.86	7.91	1.68	0.46	0.791	0.139	0.105	0.604
PRDT	20.35	2.11	1.76	7.65	20.52	2.47	0.42	0.21	0.485	0.163	0.022	0.717
ANRS	25.50	13.61	0.58	1.13	0.50	6.88	3.46	0.88	0.312	0.015	0.048	0.595
NPLS	25.89	11.27	1.69	1.55	0.34	1.42	6.56	4.43	0.396	0.147	0.083	0.906
ESXT	21.92	9.03	2.53	4.62	2.93	6.78	3.78	2.19	1.684	0.124	0.209	0.916
IJLT	19.91	9.77	2.80	3.26	1.94	8.13	7.09	2.12	0.845	0.155	0.663	0.528

ALKG - Alkali Granite; GRNT - Granite; QZMZ - Quartz Monzonite; GRDR - Granodiorite; QRZD - Quartz Diorite; ALKS - Alkali Syenite; SENT - Syenite; MNZN - Monzonite; MZDT - Monzodiorite; DORT - Diorite; GBBR - Gabbro; PRDT - Peridotite; ANRS - Anorthosite; NPLS - Nepheline Syenite; ESXT - Essexite; IJLT - Ijolite

### Appendix 2

Example scripts for use with symmetric coordinates functions

It is taken that the data table in Appendix 1 (see digital version of Appendix 1 on AAG website) has been converted to a .csv file and imported into R as a data frame. Note that there can be no missing entries in the data table, if a value is missing the column must be deleted, or a suitable value imputed:

```
> nockolds <- read.csv("D:\\my data\\nockolds.csv")
```

To generate the correlation matrix with Spearman coefficients, upper triangle based on symmetric coordinates, lower triangle based on untransformed data, Table 1, the default:

```
> gx.symm.coords.r(nockolds)
```

To generate the correlation matrix with Pearson coefficients, upper triangle based on symmetric coordinates, lower triangle based on log transformed data:

```
> gx.symm.coords.r(nockolds, method = "pearson", log = TRUE)
```

To generate the Si-Al plots in Figure 2, note that Si is in the second column of the data frame and Al in the third:

```
> gx.symm.coords.plot(nockolds, 2, 3)
```

Similarly, for the Ca-Na plots in Figure 3, with Ca in the seventh column and Na in the eighth:

```
> gx.symm.coords.plot(nockolds, 7, 8)
```





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# Seaweed as an exploration medium along inlets on the west coast of Canada. Part 1: Methods and results from Jervis Inlet

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Seaweeds are marine macroalgae of which more than 40,000 species are known (Vinogradov 1953); approximately 650 species are found in northeast Pacific ocean waters (Gabrielson et al. 2000). They can be classified into three main groups according to their habitat and colour: 1) green seaweeds (Class Chlorophyceae), mostly from the upper tidal zone; 2) brown seaweeds (Class Phaeophyceae), mostly in the mid-tidal zone; 3) red seaweeds (Class Rhodophyceae), mostly from the low tidal zone. Along the fjorded inlets of western Norway, Greenland and Canada, by far the most common seaweeds in the intertidal zone are the brown rockweeds (*Fucus spp.*), also known as wrack or bladderwrack. Along the southwestern coast of British Columbia (BC), Canada the most common species is *Fucus gardneri* (Fig. 1). It grows to 40–50 cm with irregularly dichotomous branches and is attached, generally to rock, by a discoid holdfast. This holdfast is purely physical and does not access the composition of the underlying rock. Colour variation is from pale to dark yellowish green, getting darker as it dries out between tides. It commonly has pale olive air bubbles (bladders) near the frond tips.



1a



1b



1c



1d

Figure 1: Rockweed (*Fucus gardneri*) in intertidal zone off the south-east British Columbia coast and collecting samples for analysis.

## Rockweed chemistry applied to mineral exploration and environmental monitoring

Various researchers have examined the chemical composition of rockweed, including general studies by Black & Mitchell (1952) and Bollinberg (1975); and local studies from Greenland (Bollinberg & Cooke 1985), Wales (Fuge & James 1973, 1974), Ireland (Cullinane & Whelan 1982), Sweden (Forsberg *et al.* 1988), England (Bryan & Hummerstone 1973; Morris &

*continued on page 14*



## Seaweed as an exploration medium along inlets on the west coast... continued from page 13

Bale 1975), Norway (Sharp & Bølviken 1979) and USA (Yang 1991). A comprehensive guide to seaweeds of BC is given by Scagel (1967).

Experimentation on the element absorption of rockweed and many other species of seaweed from the coast of southern BC, was conducted by the Geological Survey of Canada in the early 1990s (Dunn 1990; Dunn *et al.* 1993) and an overview published as a chapter in a book on metal hyperaccumulator plants (Dunn 1998).

The rugged coastline of BC with its steep cliffs into the mountainous hinterland and many incised streams that drain into the sea provide a challenge to mineral exploration. However, where streams cut into the rocks they inherit the chemical signature of those rocks. If a stream cuts through mineralization, the waters become slightly enriched in elements associated with such mineralization. The stream waters emerge into the sounds where their metal contents can be readily taken up in the nearby rockweed. With these principles in mind, a sampling program was devised to collect rockweed just seaward from where the streams meet the sea. The rationale being that if the seaweed is relatively enriched in a commodity metal (and/or its pathfinder elements) this would generate a focus for more detailed follow up into the mountains to look for the source – using other prospecting methods such as stream sediments, stream moss mats or the stream waters themselves.

To date, three areas have been sampled – along the shores of much of Jervis Inlet; around the shores of Texada Island; and around Howe Sound (Fig. 2). Samples from the latter area collected in 1990 included coastal areas down-drainage from the former Britannia Cu mine and were found to contain dramatically higher concentrations of Cu and Zn than samples from the same sites collected in 2015, attesting to the efficiency of the steady clean-up efforts over the past quarter century. This article deals with Jervis Inlet; subsequent articles will focus on the other areas at a later date.

### Sample Collection and Analysis

A 45 foot ocean-going yacht gave relatively fast transport along the coast to the proposed sample sites. On approaching a planned sample station, a rubber ‘Zodiac-style’ boat with a 10 HP motor and a two-person crew launched from the moored yacht to the shore. A suitable site for collecting a seaweed sample such as a cliff face (Fig. 1, bottom right) or a flattish rocky promontory (or beach) was visually identified. Cutting the motor enabled the boat to drift up to the sample site, or (if needed) the crew to get on shore (Fig. 1, top left). A fresh sample weighing about 100 g was plucked from the rocks (avoiding the small holdfast structure at the base). Barnacles, mussels or other small shellfish were removed; the sample was placed in a Hubco “New Sentry” spun bound polyester sample bag (7” x 12.5”), and the drawstring pulled closed.

Samples were oven-dried at 80°C resulting in up to 80% mass reduction due to water loss with variation directly related to exposure time in sunshine between high-tides. Each dried sample was reduced to fine powder in a coffee mill prior to digestion of a 0.5 g aliquot in modified aqua regia (1:1:1 HCl – HNO<sub>3</sub> – H<sub>2</sub>O) at 95°C for 1 hour and analysis by ICP-MS and ICP-ES for 65 elements (method VG101-EXT+REE at Acme Labs/Bureau Veritas, Vancouver). A separate aliquot was also reduced to ash by controlled ignition in a furnace held at 485°C for 16 hours and element concentrations determined by the same analytical methods (method VG104-EXT+REE). The ash yield from the dry material was 15-20% with the median and means both close to 16.5%.

Analytical results showed that the ashing process resulted in no loss of most elements; total volatilization of Hg, moderate losses (up to 30%) of As, Fe and Se and minor losses (<10%) of Cd, Cr, Ge, Sb and Sn. Nearly all samples reported below the method detection limits for Be, Bi, In, Nb, Pd, Pt, Ta, Th, Tl, W and most of the HREE. Precision on blind control samples was extremely good with RSDs better than 10% for all elements except those with concentrations close to detection levels (Au, Be, Ge, Hf, In, Re, Se, Te, W, Zr and some of the HREE). Pb in dry samples had 28% RSD, largely because of some drift in the analytical sequence. Precision of field and laboratory duplicates was similar to that obtained on the blind controls. Of relevance to this study is that the naturally higher Re in the field samples generated better precision than the lower concentration control samples. Concentrations referred to in the following text and plots are from the analysis of dry tissues, since the ashing did little to enhance distribution patterns and so was discontinued for the succeeding surveys.

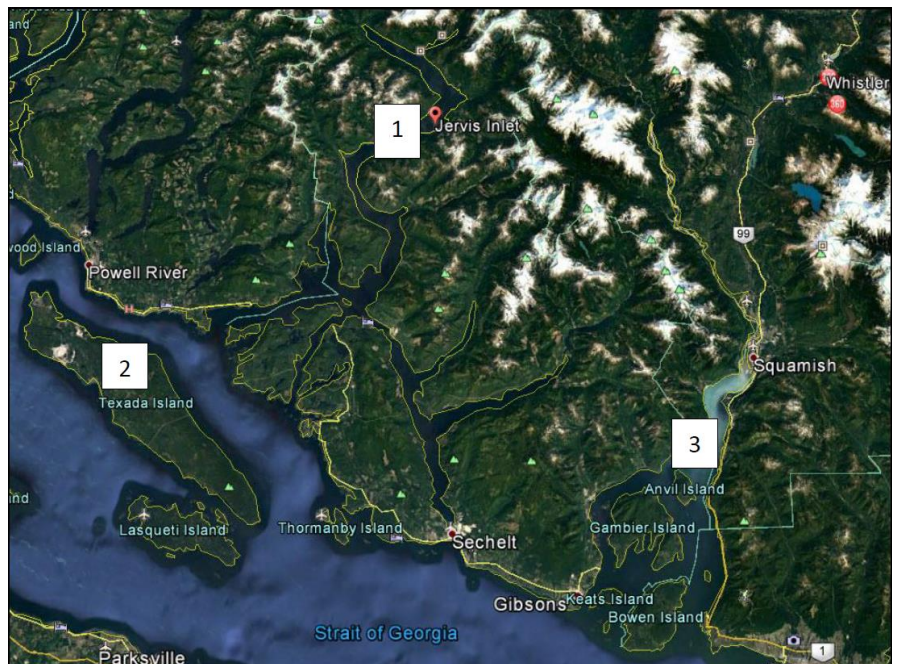


Figure 2: Survey areas - 1) Jervis Inlet; 2) Texada Island; 3) Howe Sound on the west coast of British Columbia (Google Map).

## Seaweed as an exploration medium along inlets on the west coast... continued from page 14

### Location

The southern end of Jervis Inlet is located about 100 km northwest of Vancouver and snakes northward from Saltery Bay for 75 km (Fig. 3). There is road access as far as Earls Cove at the southern end of the Inlet, but no roads or trails extend farther to the north, requiring boat access.



Figure 3: Location of Jervis Inlet. Source Google Maps <https://maps.google.ca>

### Geology

The lower Jervis Inlet area is in deeply dissected, mountainous country in which the main deep valleys have been invaded by the sea. For an extensive distance up the coast of British Columbia there is a system of inlets that penetrate the mountains for varying distances, resulting in typical fjords (Bacon 1957).

Bedrock is primarily Jurassic to Tertiary quartz-diorite and granodiorite of the Coast Plutonic Complex, overlain locally by basalts, andesites and volcanoclastic rocks and some Lower Cretaceous Gambier Group sediments. Quaternary deposits fill some valleys. For details of the bedrock geology map of British Columbia the reader is referred to [http://www.geosciencebc.com/i/pdf/Maps/NVI/NVI-1-1\\_geology.pdf](http://www.geosciencebc.com/i/pdf/Maps/NVI/NVI-1-1_geology.pdf)

Because of the extreme ruggedness, sometimes dense rainforest, and overburden of variable thickness, detail of the geology is poorly known, and to date little has been found to suggest that the granitic rocks of the survey area warrant further attention by prospectors. However, a few studies have shown that rocks of the Jervis Group contain small deposits of Cu, Zn, Pb and Au. Local occurrences of molybdenite are reported. Two adits into a small stock of gabbro-diorite on the west side of Upper Jervis Inlet intersected quartz veins and quartz-filled shear zones containing Au, Ag, Cu, Pb and Zn mineralization and a single 40 cm section yielded 0.72 oz/t Au with minor Co, Co and Bi (Laird 2008).

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

The Jervis Inlet survey was conducted in August of 2013. Samples were collected from 47 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 60 samples were submitted for analysis. The 7 splits of a rockweed 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, and Ge) that had concentrations close to the detection limits of the analytical method, yielding RSDs mostly better than 30%. Similarly, the reproducibility of the field and laboratory duplicates varied from good to excellent for almost all elements.

### Results

Table 1 summarizes the element concentrations in the 47 samples. Raw data are listed in a digital file (Appendix A) that is posted on the AAG website (<https://www.appliedgeochemists.org/index.php/publications/explore-newsletter>). Background



## Seaweed as an exploration medium along inlets on the west coast... continued from page 15

Google Earth images on which the data are plotted in Figures 4, 5 and 6 are intentionally provided at low resolution in order to show the contrast between land mass and water. Most elements exhibit a fairly normal distribution, with a few outliers of which the more notable is a single sample yielding 83.8 ppb Au which is more than 2 orders of magnitude higher than the median. Analysis of the ashed sample confirmed that the Au is highly anomalous. Its source is unknown.

Table 1: Element concentrations in dry rockweed.

		<i>D.L.</i>	Min.	Mean	Median	Max.
Ag	ppb	2	13	26	23	63
Al	%	0.01	0.01	<0.01	<0.01	0.23
As	ppm	0.1	8.3	15.9	15.7	26.5
Au	ppb	0.2	0.2	3.0	0.7	83.8
B	ppm	1	50	87	86	121
Ba	ppm	0.1	8.7	13.6	12.6	30.4
Be	ppm	0.1	<0.1	<0.1	<0.1	<0.1
Bi	ppm	0.02	<0.02	<0.02	<0.02	0.05
Ca	%	0.01	0.72	1.32	1.32	2.59
Cd	ppm	0.01	1.1	1.7	1.7	3.02
Ce	ppm	0.01	0.04	0.12	0.07	1.24
Co	ppm	0.01	0.32	0.74	0.56	3.19
Cr	ppm	0.1	1.6	3.1	2.1	18.1
Cs	ppm	0.005	0.022	0.039	0.037	0.149
Cu	ppm	0.01	0.97	1.74	1.54	5.58
Dy	ppm	0.02	<0.02	<0.02	<0.02	0.13
Er	ppm	0.02	<0.02	<0.02	<0.02	0.08
Eu	ppm	0.02	<0.02	<0.02	<0.02	0.03
Fe	%	0.001	0.009	0.027	0.014	0.37
Ga	ppm	0.1	<0.1	<0.1	<0.1	0.6
Gd	ppm	0.02	<0.02	<0.02	<0.02	0.13
Ge	ppm	0.01	<0.01	<0.01	<0.01	0.08
Hf	ppm	0.001	<0.001	<0.001	<0.001	0.008
Hg	ppb	1	2	5.9	5.5	12
Ho	ppm	0.02	0.02	<0.02	<0.02	<0.02
In	ppm	0.02	<0.02	<0.02	<0.02	<0.02
K	%	0.01	1.34	2.03	2.04	2.76
La	ppm	0.01	0.03	0.08	0.06	0.6
Li	ppm	0.01	0.15	0.35	0.28	2.36
Lu	ppm	0.02	<0.02	<0.02	<0.02	<0.02
Mg	%	0.001	0.525	0.663	0.661	0.881
Mn	ppm	1	23	40	35	122
Mo	ppm	0.01	0.08	0.14	0.13	0.39

		<i>D.L.</i>	Min.	Mean	Median	Max.
Na	%	0.001	0.459	1.502	1.455	2.82
Nb	ppm	0.01	<0.01	<0.01	<0.01	0.21
Nd	ppm	0.02	0.02	0.08	0.06	0.65
Ni	ppm	0.1	2.7	4.2	3.6	11.6
P	%	0.001	0.054	0.087	0.083	0.138
Pb	ppm	0.01	<0.01	0.10	0.07	0.67
Pd	ppb	2	<2	<2	<2	3
Pr	ppm	0.02	<0.02	<0.02	<0.02	0.18
Pt	ppb	1	0	<1	<1	0
Rb	ppm	0.1	5.3	8.7	8.9	10.7
Re	ppb	1	2	18	18	43
S	%	0.01	1.2	1.72	1.67	2.59
Sb	ppm	0.02	0.06	0.13	0.12	0.24
Sc	ppm	0.1	0.1	0.2	0.2	0.6
Se	ppm	0.1	<0.1	0.3	0.3	0.5
Sm	ppm	0.02	<0.02	<0.02	<0.02	0.14
Sn	ppm	0.02	0.02	0.07	0.05	0.19
Sr	ppm	0.5	345	535	521	886
Ta	ppm	0.001	<0.001	<0.001	<0.001	0.003
Tb	ppm	0.02	<0.02	<0.02	<0.02	0.02
Te	ppm	0.02	<0.02	<0.02	<0.02	<0.02
Th	ppm	0.01	<0.01	<0.01	<0.01	0.13
Ti	ppm	1	<1	10	2	158
Tl	ppm	0.02	<0.02	<0.02	<0.02	0.02
Tm	ppm	0.02	<0.02	<0.02	<0.02	<0.02
U	ppm	0.01	0.49	0.9	0.9	1.66
V	ppm	2	<2	<2	<2	5
W	ppm	0.1	<0.1	<0.1	<0.1	<0.1
Y	ppm	0.001	0.056	0.132	0.102	0.749
Yb	ppm	0.02	0.02	<0.02	<0.02	0.06
Zn	ppm	0.1	9.1	18.3	16.5	46.5
Zr	ppm	0.01	0.06	0.11	0.10	0.24

Figure 4 shows that Ag and As are more concentrated toward the southern end of the inlet than in the northern arm suggesting a source of metal enrichment to the east – perhaps from the valley indicated.



## Seaweed as an exploration medium along inlets on the west coast... continued from page 16

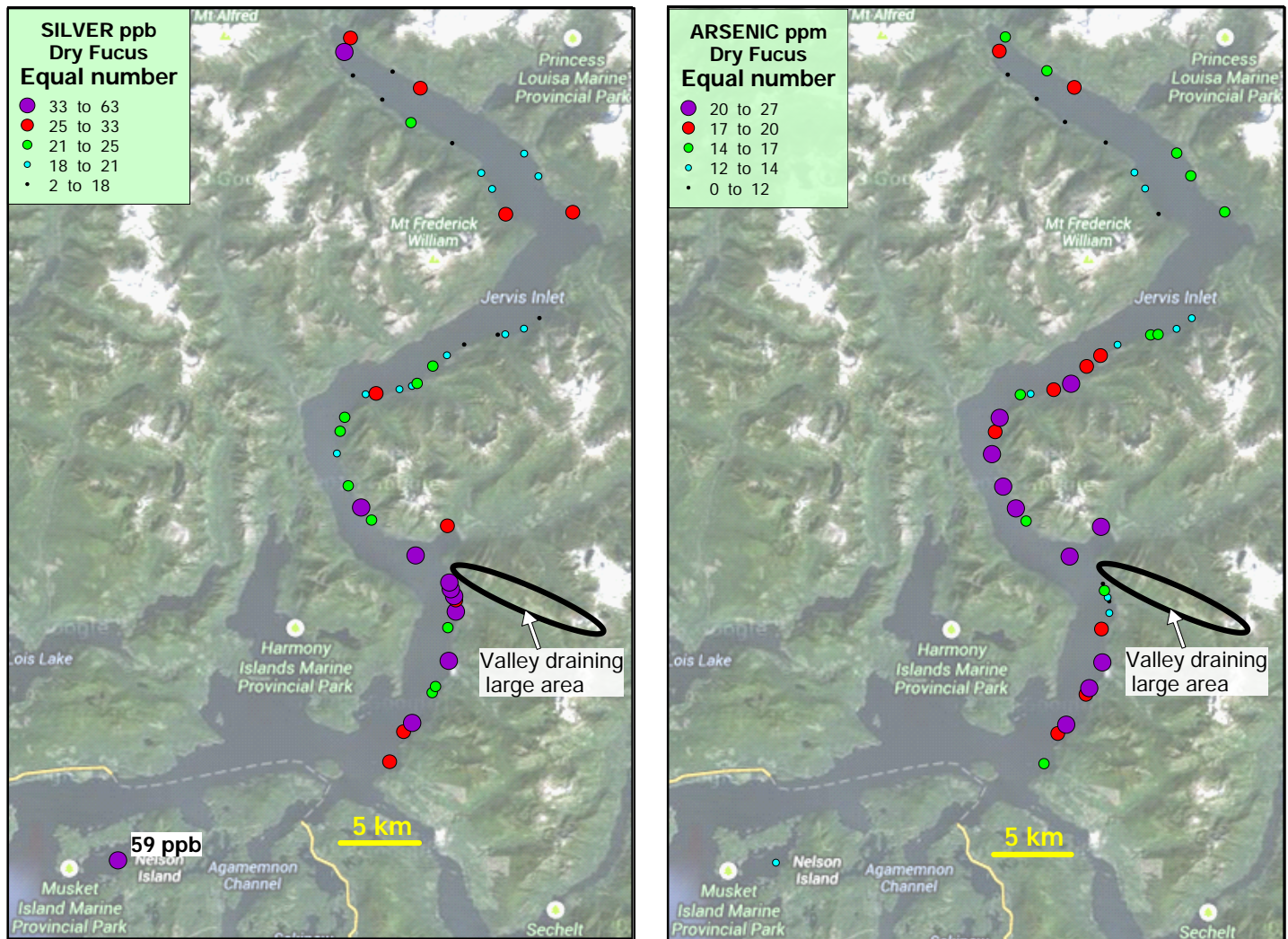


Figure 4: Ag and As contents in oven-dried rockweed determined by ICP-MS.

At the north end of the inlet, where there is an abundance of water and sediment draining from two large streams that extend to the north and northeast there is a relatively strong signature, compared to the rest of the inlet, of Cu, Mo, Ni, Co (Fig. 5) with associated Fe, REE and U suggesting a possible mineralized source upstream. Although the evidence is scant for predicting the type of mineralization, a similar suite of elements occurs in iron oxide copper gold (IOCG) deposits. However, Au levels are low in the seaweed from this area. The other area of relative enrichment is in the south, coincident with sites of Ag and As enrichment south of the valley indicated on Fig. 4.

Rhenium concentrations in vegetation are typically <1 ppb Re, but in brown seaweed they can be much higher. High enrichments (thousand-fold) of Re relative to seawater have been reported along the California coast, and it was concluded that brown algae acts as a biological sink of Re in oceans (Yang 1991). The highest concentrations of Re (up to 43 ppb Re) are at the southern end of Jervis Inlet. It is surmised that a higher concentration of fresh water from stream meltwaters draining from the mountains in the northern part of the inlet results 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. Similar patterns are exhibited by S and K.

### Summary and Conclusions

The brown rockweed *Fucus* grows in abundance in the intertidal zones of the northwest shores of Canada and the USA, and is easy to collect by boat. Where a stream flows over or through mineralized bedrock, the waters can become slightly enriched in elements associated with such mineralization, and many streams emerge into the sounds where their metal signatures can be readily detected in the rockweed close by. Seaweed anomalously enriched in a commodity metal (and/or its pathfinder elements) can provide focus for a more detailed follow up into the mountains to look for the source – using other prospecting methods such as stream sediments, stream moss mats or the stream waters themselves.



# Seaweed as an exploration medium along inlets on the west coast... continued from page 17

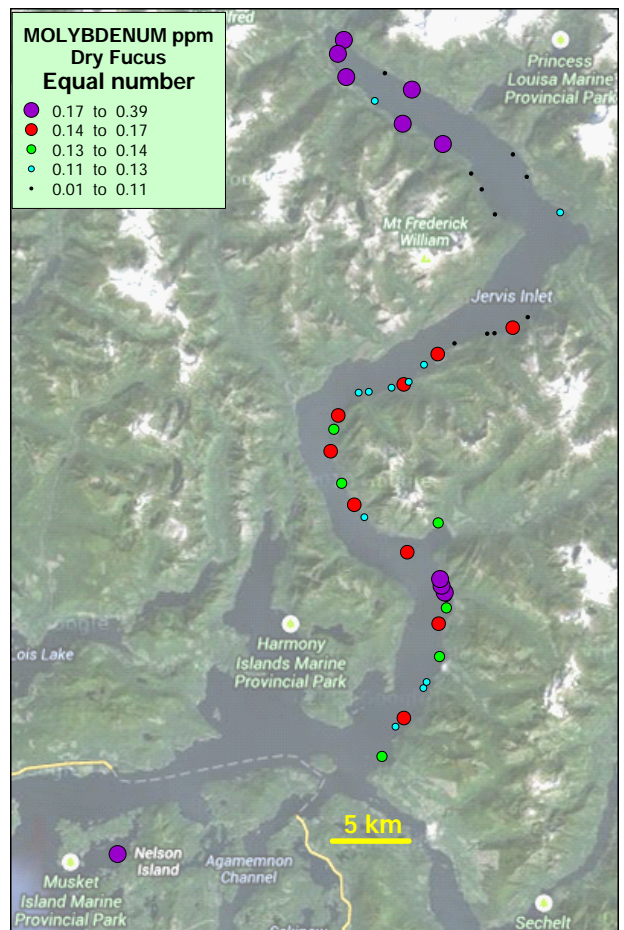
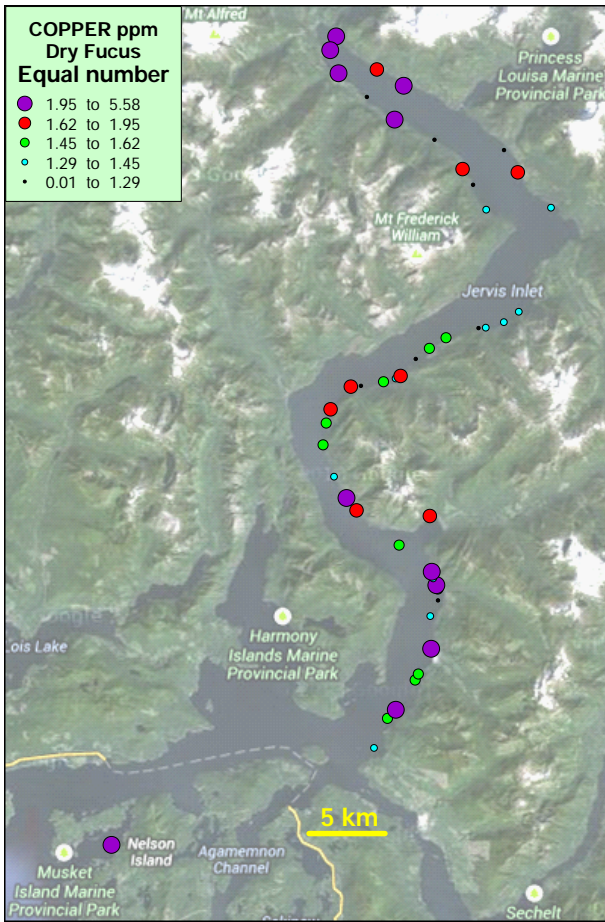
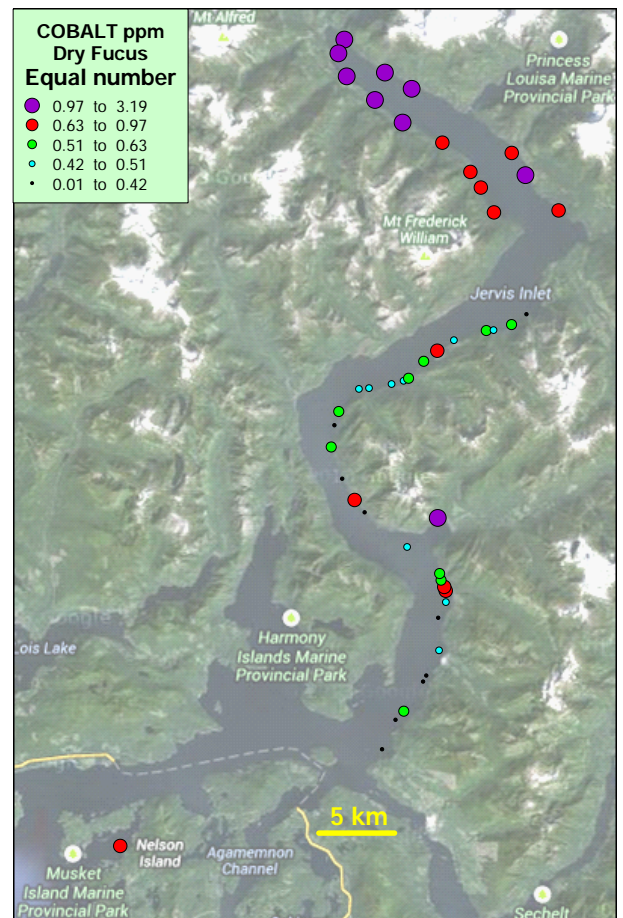
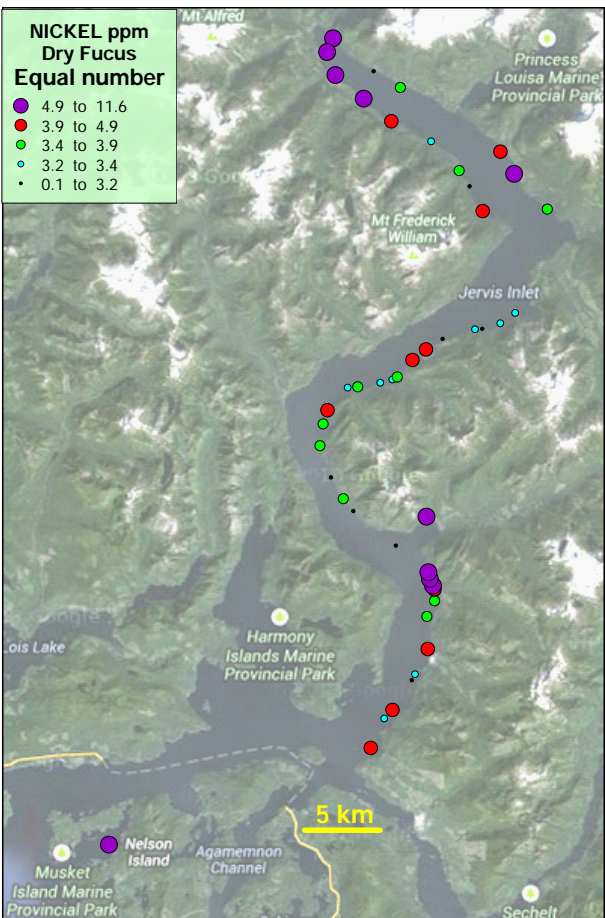


Figure 5: Cu, Mo, Ni and Co in oven-dried rockweed determined by ICP-MS.



continued on page 19



# Seaweed as an exploration medium along inlets on the west coast... continued from page 18

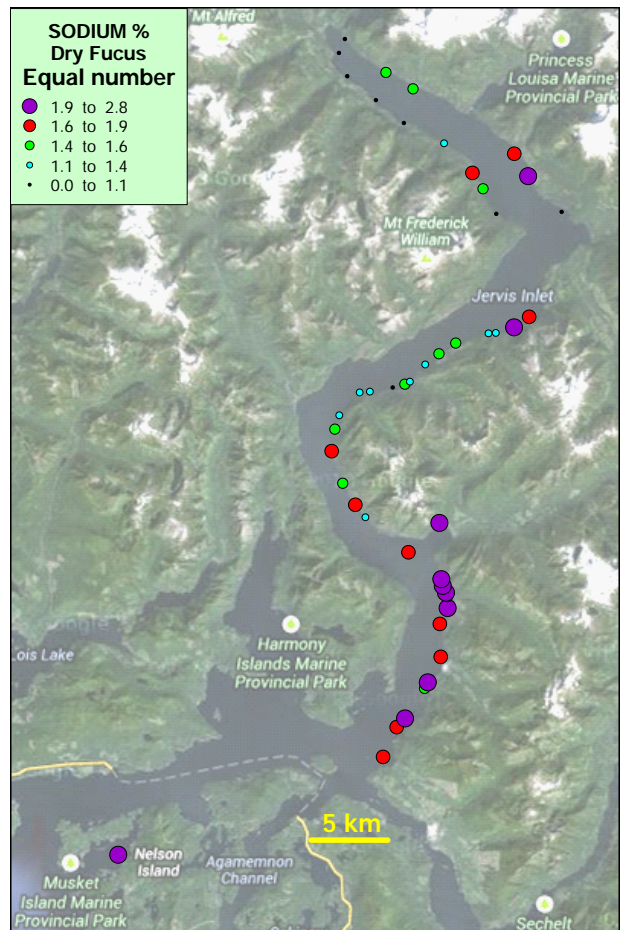
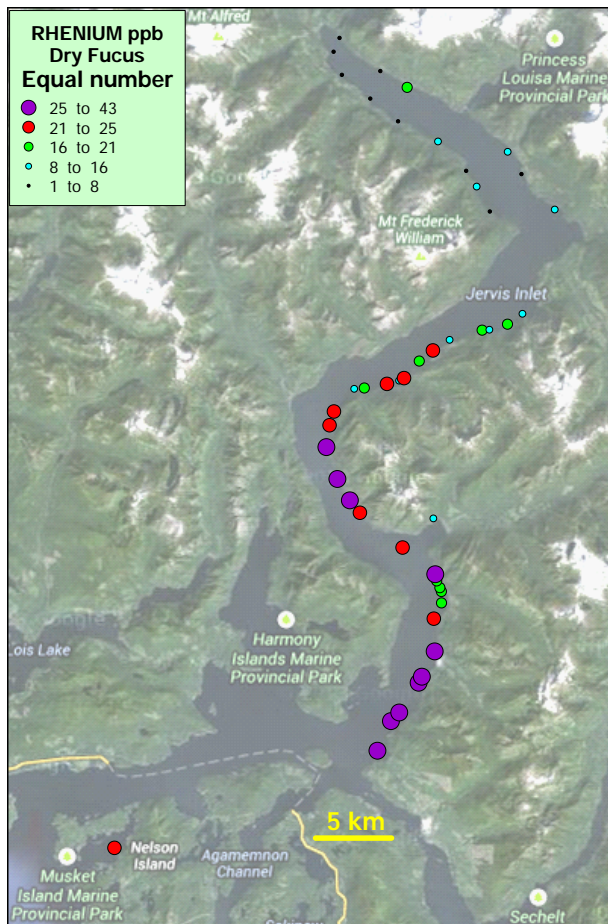
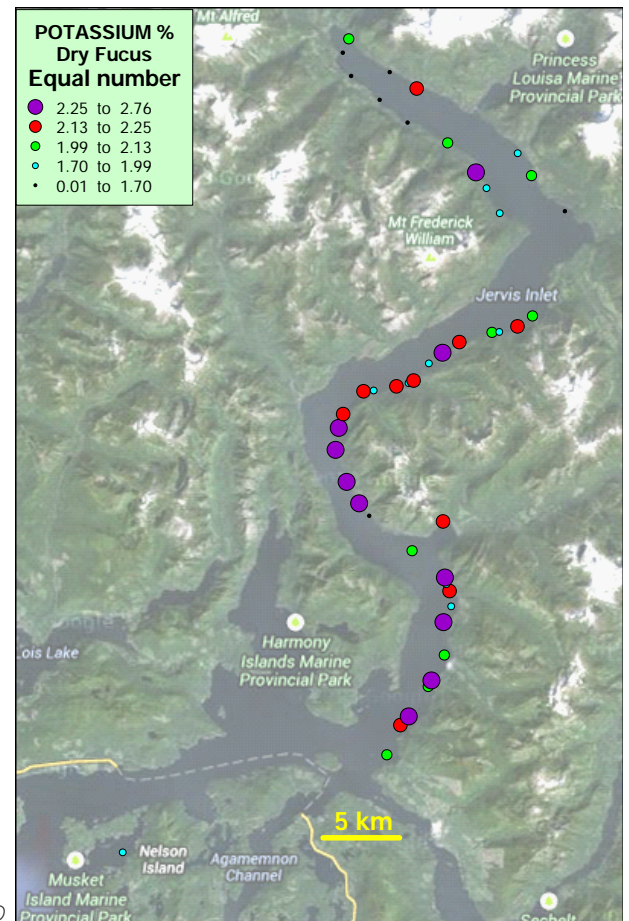
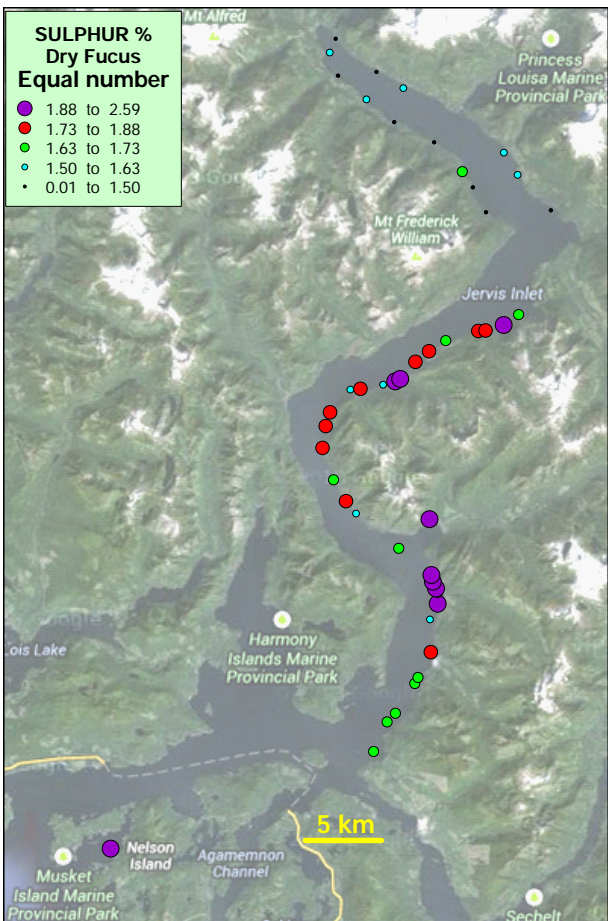


Figure 6: Re, Na, S and K oven-dried rockweed determined by ICP-MS.



continued on page 20



## Seaweed as an exploration medium along inlets on the west coast... continued from page 19

Forty-seven samples were collected from the shores of Jarvis Inlet from which distinct zones of relative metal enrichments were identified:

1. Ag, As and several other commodity and pathfinder elements on the eastern shores toward the south end of the Inlet;
2. Cu, Mo, Ni, Co with associated Fe, REE and U at the northern end of the Inlet, suggesting a possible mineralized source upstream;
3. High enrichments of Re (with coincident Na, S and K) that are probably related just to the water salinity, since brown seaweeds are known to be biological sinks of Re in the sea;
4. Local enrichments of Au with coincident pathfinder elements.

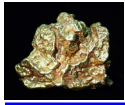
### Acknowledgements

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

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## Geochemical Nuggets

# Issues with Modern ICP-MS Gold Data

In recent years both the Yukon Geological Survey and Geoscience BC have undertaken the re-analysis of archived stream and lake sediment samples collected during the National Geochemical Reconnaissance (NGR) Program. This archived material has been analysed using a dilute *aqua regia* digestion followed by an ICP-MS instrumental finish. These programs have provided new data for a variety of important pathfinder elements at improved detection limits compared to when the original analyses were undertaken up to 40 years ago. These new data have allowed for a rigorous multivariate statistical analysis of the data to be undertaken within the context of drainage catchments (Mackie *et al.*, 2015) and have generated new exploration targets that are currently being actively explored.

Unfortunately, it is a common misconception that the new ICP-MS data are necessarily of superior quality to the historical data. While this conclusion is justified for the majority of elements included in the typical 51 element analytical suite, it is not true for elements such as Au, and partial results only are provided for other elements such as Zr and Ba. A judicious merging of both old and new analytical data from these historical samples is warranted.

Obtaining reproducible analyses of Au from stream sediment samples is particularly difficult (see the article by Arne and MacFarlane in **EXPLORE** No. 164 using an example from the Yukon). The ICP-MS re-analysis of samples in recent years used a 0.5 g aliquot of -80 mesh (<177 micron) sample material. The precision of the Au data is particularly poor, in spite of a lower limit of detection (LLD) of 0.2 ppb.

A recent review of ICP-MS data from the Yukon re-analysis program is provided by Mackie *et al.* (2017). Original reference materials, field duplicates and blind duplicates included in the original survey have also been re-analysed to provide a

comprehensive (albeit poorly documented) set of quality control data. The poor reproducibility of the ICP-MS Au data can be illustrated in several ways. The certified reference material (CRM) CANMET STSD-1 was included in many of the Yukon surveys re-analysed. It has a provisionally certified total Au content of 8 ppb, so well above the LLD of the analytical method. However, this suite of CANMET stream sediment reference materials (STSD-1 through 4) was likely never intended to provide reliable Au values and so probably was not pulverised and mixed in the fashion of a modern Au CRM. In this way it may be more analogous with a typical stream sediment sample collected from the field.

A total of 185 ICP-MS analyses of CANMET STSD-1 from the Yukon NGR program gives average and median Au values of 11.6 and 4

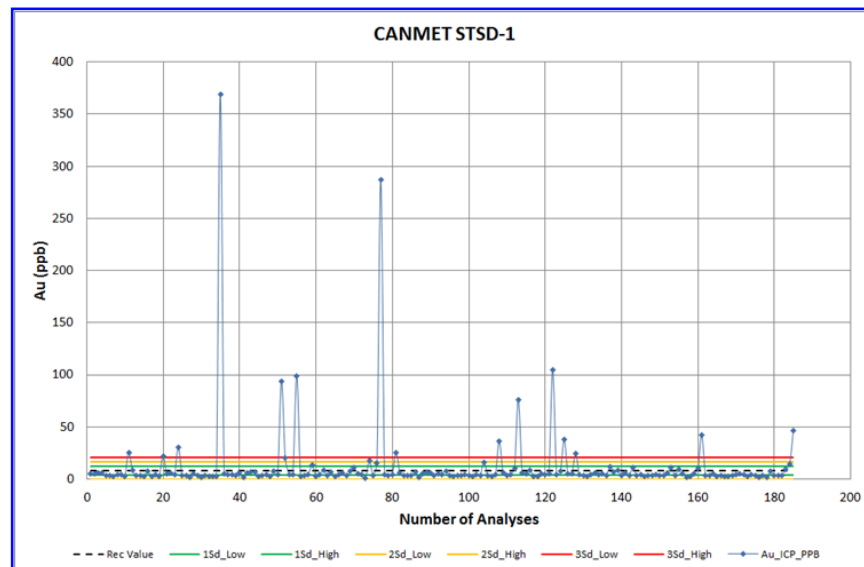


Fig. 1. Summary of *aqua regia* ICP-MS analyses of a 0.5 g aliquot of Canmet STSD-1 ppb, respectively. Figure 1 illustrates the extreme range of Au values obtained, from 1.1 to 368.7 ppb, with a coefficient of

variation (CoV) of 315%. Clearly not the sort of performance you would want from a CRM! Further, a simple scatter plot of original versus analytical (blind) duplicates (Fig. 2) shows a very poor correlation, with a root mean squared CoV of 64%. Both plots are indicative of the poor precision of the new ICP-MS Au data in general and emphasises the fact that the data should be used with caution. Even a sample with slightly elevated background Au values (e.g. STSD-1) can yield highly anomalous Au results and real Au anomalies may be missed. In this case the pathfinder elements will be more informative than the desired commodity in geochemical targeting.

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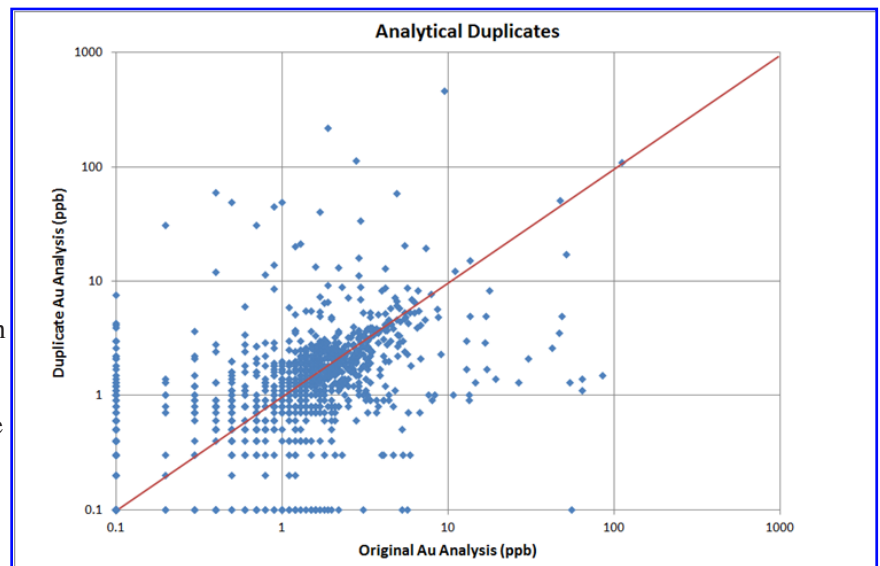


Fig. 2. Scatter plot of analytical (blind) duplicates for Au analysed by *aqua regia* ICP-MS using a 0.5 g aliquot of -80 mesh stream sediment.

continued on page 22

## Issues with Modern ICP-MS Gold Data... *continued from page 21*

Dawson Range, Yukon Territory, Canada. *EXPLORE*, No. 164, p. 1-10.

MACKIE, R.A., ARNE, D.C. & BROWN, O., 2015. Enhanced interpretation of regional stream sediment geochemistry from Yukon: catchment basin analysis and weighted sums modelling. Yukon Geological Survey, Open File 2015-10.

MACKIE, R.A., ARNE, D.C. & PENNIMPEDE, C., 2017. Assessment of regional stream sediment catchment basin and geochemical data quality. Yukon Geological Survey, Open File 2017-4, 29 p.

### Acknowledgment

The compiled quality control data shown here were kindly provided by Wayne Jackaman.

Dennis Arne, *CSA Global Pty. Ltd.*



## AAG Councillor Elections

Each year the Association of Applied Geochemists (AAG) needs motivated and energetic AAG Fellows to stand for election to the position of “Ordinary Councillor.” Fortunately, each year some of our most outstanding Fellows are ready, willing, and able to meet this challenge. However, this year I’m sending this to ALL MEMBERS, to encourage those Members that have the experience and enthusiasm to be involved, to convert your membership status and look to make a bigger contribution to the AAG (see the website for details).

This is the annual reminder to AAG Fellows (and Members that could become Fellows) that we need your participation on Council. It is our sincere hope that this email might entice more people to step forward for election to this important position.

If you are not eligible to become a Fellow, but want to be more involved, please send me an email message as we are looking to get more of our junior members active in the AAG and other opportunities will be coming available.

### Councillor Job Description

The AAG By-laws state that “the affairs of the Association shall be managed by its board of directors, to be known as its Council.” The affairs managed by Council vary from reviewing and ranking proposals to host our biennial Symposium to approving application for new membership to developing marketing strategies for sustaining and growing our membership. These affairs are discussed and decisions made at Council teleconferences usually held 3-4 times per year. Each teleconference lasts about 1 hour. In addition, there is often a running email discussion about a selected issue or two between each teleconference. So for a commitment of about 5 hours of your time per year, you can help influence the future of your Association. If you want to spend more than the minimum time required, there is plenty of opportunity to do so through committee assignments and voluntary efforts that greatly benefit the Association.

### Qualifications and length of term

The only qualification for serving as Councillor is to be a Fellow in good standing with the Association. Please note the difference between being a Member of AAG and being a Fellow. A Fellow is required to have more training and professional experience than a Member. Consult the AAG web site, Membership section, for further details. If you are not currently a Fellow and have an interest in serving on Council, please go through the relatively painless process of converting to Fellowship status in AAG.

Each Councillor serves a term of two years and can then stand for election to a second two-year term. The By-laws forbid serving more than two consecutive terms, although someone who has served two consecutive terms can stand for election again after sitting out for at least one year. Elections are usually held in Oct-Nov of the year for a term covering the following two years. Our next election will be in October-November 2017 for the term of 2018-2019.

### How to get on the ballot

If you are interested in submitting your name for consideration for election to AAG Council, simply express your interest to the AAG Secretary (Dave Smith, email: [dsmith@usgs.gov](mailto:dsmith@usgs.gov)) by October 15, 2017 and include a short (no more than 250 words) summary of your career experience. This summary should include the following:

- Your name
- Year that you became a Fellow of AAG
- Earth science degrees obtained, year of graduation of each, and institution of each
- Employment—list major employers and state years worked for each, e.g. 1980-1990, and type of work
- Position held as part of AAG or other past contributions to AAG
- 1-2 sentences about your professional experiences in applied geochemistry

All that is asked is that you bring energy and ideas to Council and are willing to share in making decisions that will carry the Association forward into a successful future. We look forward to hearing from you.

**Ryan Noble**, *President*,  
Email: [ryan.noble@csiro.au](mailto:ryan.noble@csiro.au)





## AAG Regional Report: Ireland and United Kingdom, June 2017

In Ireland the national Tellus programme, a combined regional baseline survey of surface geochemistry and airborne radiometric and traditional geophysics, is well underway. The Irish government is backing accelerated coverage of the whole country, and the regional-scale surveys of stream sediment, stream water and soil inorganic geochemistry are now complete across about one third of the country. Geological Survey Ireland are undertaking the surveys to recognised high standards, applying multi-element analytical techniques and rigorous quality control. The work is in conjunction with labs in Ireland and in the UK. The programme is concurrently funding external research projects in areas such as agricultural data applications, understanding prospectivity and deposit modelling, and is assisting survey geologists in revising the state geological maps. The project is releasing its data free of charge and freely to all, as it becomes available. See more at [www.tellus.ie](http://www.tellus.ie), including links to the book 'Unearthed' which stories some of the impacts felt from survey results to date.

The geosciences sector in Ireland has seen a huge boost in the last year, with the Irish Centre for Research in Applied Geosciences 'iCRAG' now supporting doctorate and post doctoral research in applied geochemistry. Early career scientists are working on traditional subjects such as energy, groundwater quality, critical raw materials and mineral deposits, as well as the social license to operate and public perception of the geosciences sector. In geochemistry the research areas include sediment and ore provenance and isotopic analytical applications. See [www.icrag-centre.org](http://www.icrag-centre.org) for more.

The British Geological Survey and University of Nottingham have launched their Centre for Environmental Geochemistry, a hub combining inorganic, organic and isotope geochemistry analytical facilities with domestic and international applied research projects. [www.environmentalgeochemistry.org](http://www.environmentalgeochemistry.org) details their work.

The geological surveys in Ireland and Britain are contributing to a European Union led consortium on critical materials and minerals databases, the Minerals4EU Project. Aiming to enhance minerals information and support European minerals development. See [www.minerals4eu.eu](http://www.minerals4eu.eu) for updates.

The UK and Ireland mining sectors are progressing a number of prospects. SRK Consulting UK Limited is currently assisting Dalradian Gold Limited with geochemical skills related to the development of the Curraghinalt gold project in Northern Ireland. SRK have been responsible for supervision of baseline sampling and geochemical assessment as well as laboratory and onsite testing of rock weathering. This work will be used in support of engineering and environmental studies. Drakelands Mine (formerly Hermerdon) for tungsten and tin in Cornwall is now reopened by Wolf Minerals Limited. This coincided with latest geochemical mapping completed by the British Geological Survey in southwest England. The Boliden Tara Mine in the Irish Midlands is actively expanding. Uptake of exploration licences in Ireland is going strong with lead-zinc, gold, copper, platinum and lithium targets.

### Kate Knights

*Geological Survey of Ireland; Email: [kate.knights@gsi.ie](mailto:kate.knights@gsi.ie)*



## Recently Published in Elements Volume 13, nos. 3 and 4

### Rock and Mineral Coatings: Records of Climate Change, Pollution, and Life

The June edition of Elements is an intriguing one that looks at rock and mineral coatings and how they retain a record of past climates, be used in archeology, or may hold evidence of life on Mars. The AAG news in this issue contains an update on GEEA by Kurt Kyser and introduces Co-editor-in-Chief, Benedetto De Vivo, as well as a summary of the article on "The use of automated indicator mineral analysis in the search for mineralization – A next generation drift prospecting tool" that appeared the March issue of Explore.

### Boron: Light and Lively

The August edition of Elements is dedicated to all aspects of the element boron. In this issue, AAG news consists of a message from the President and an abstract from the June EXPLORE article entitled "Evidence of Geothermal Activity Near the Nazko Volcanic Cone, British Columbia, Canada, from Ground and Surface Water Chemistry".

### Dennis Arne,

*CSA Global Pty Ltd; Email: [Dennis.Arne@csaglobal.com](mailto:Dennis.Arne@csaglobal.com)*



## Geochemistry: Exploration, Environment, Analysis

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The latest content is now available at: <http://geea.lyellcollection.org/content/current>  
May 2017; Vol. 17, 2

### Thematic set article: IAGS Tuscon 2015

Introduction to IAGS Tuscon 2015 volume

Robert Howell

Geochemistry: Exploration, Environment, Analysis, v. 17:61, first published on May 16, 2017, doi:10.1144/geochem2017-003  
<http://geea.lyellcollection.org/content/17/2/61.extract>

Lithochemical classification of igneous rocks using Streckeisen ternary diagrams

Cliff Stanley

Geochemistry: Exploration, Environment, Analysis, v. 17:63-91, first published on May 16, 2017, doi:10.1144/geochem2016-463  
<http://geea.lyellcollection.org/content/17/2/63.abstract>

Arsenic and mercury contamination related to historical gold mining in the Sierra Nevada, California

Charles N. Alpers

Geochemistry: Exploration, Environment, Analysis, v. 17:92-100, first published on May 16, 2017, doi:10.1144/geochem2016-018  
<http://geea.lyellcollection.org/content/17/2/92.abstract>

Assessment of supergene uranium-vanadium anomalies, Meob Bay deposit, Namibia

R.J. Howell and A.A. Davies

Geochemistry: Exploration, Environment, Analysis, v. 17:101-112, first published on April 4, 2017, doi:10.1144/geochem2015-406  
<http://geea.lyellcollection.org/content/17/2/101.abstract>

Geochemical prediction of arsenic attenuation from infiltrated heap leach drainage, Daisy Mine, Nevada

R.J. Howell, J. Declercq, R. Warrender, A. Prestia, J.V. Parshley, and J.R. Barber

Geochemistry: Exploration, Environment, Analysis, v. 17:113-123, first published on December 8, 2016, doi:10.1144/geochem2016-423  
<http://geea.lyellcollection.org/content/17/2/113.abstract>

Metal migration at the DeGrussa Cu-Au sulphide deposit, Western Australia: Soil, vegetation and groundwater studies

R.R.P. Noble, R.R. Anand, D.J. Gray, and J.S. Cleverley

Geochemistry: Exploration, Environment, Analysis, v. 17:124-142, first published on December 16, 2016, doi:10.1144/geochem2016-416  
<http://geea.lyellcollection.org/content/17/2/124.abstract>

Integrated studies of soil, termites, vegetation and groundwater to understand metal migration at the Kintyre U deposits, Western Australia

R.R.P. Noble, A.D. Stewart, G.T. Pinchand, T.C. Robson, and R.R. Anand

Geochemistry: Exploration, Environment, Analysis, v. 17:143-158, first published on February 16, 2017, doi:10.1144/geochem2016-439  
<http://geea.lyellcollection.org/content/17/2/143.abstract>

Urban geochemistry: Sisak in Croatia, a long - lasting historical, urban and industrial city

Ajka Šorša, Goran Durn, Josip Halamić, Stjepan Husnjak, Vesnica Garašić, and Marta Mileusnić

Geochemistry: Exploration, Environment, Analysis, v. 17:159-163, first published on August 23, 2016, doi:10.1144/geochem2015-395  
<http://geea.lyellcollection.org/content/17/2/159.abstract>

Dendrochemistry and soil clay geochemistry applied to exploration for deep U mineralization at the Halliday Lake Prospect, Athabasca Basin, Canada

P. Stewart, T. K. Kyser, D. Griffiths, and L. Lahusen

Geochemistry: Exploration, Environment, Analysis, v. 17:164-181, first published on December 13, 2016, doi:10.1144/geochem2015-386  
<http://geea.lyellcollection.org/content/17/2/164.abstract>





## AAG's Student Support Program

Initiated in 2011 and remodelled in 2015, the Association of Applied Geochemists' Student Support Program links applied geochemistry students with analytical laboratories to help students defray the cost of acquiring geochemical data associated with thesis work. AAG acts as an intermediary between applied geochemistry students and participating laboratories by assessing applications and recommending those with merit to supporting laboratories for in-kind support in terms of sample analysis. In turn, students are obliged to publish their results and include an acknowledgement to the Association and the supporting laboratory.

The program has gradually expanded, in terms of both the number of participating laboratories, and the number of students receiving support (Table 1). Six laboratories are now involved with the program, Actlabs, ALS, BV Minerals (Perth), BV Minerals (Vancouver), Intertek-Genalysis and LabWest. A check of laboratory websites shows that they offer a range of analytical services suitable to both mineral exploration and environmental assessment. The likelihood of an application receiving support from both AAG and any particular laboratory is increased if a reasonable amount of work is requested. In many cases, the in-kind support is a complement to data generated from other sources, rather than the complete analytical requirements of the thesis.

The capacity of laboratories to support this type of program is in part determined by the state of the mineral exploration industry. Accordingly, AAG accepts that the level of support for its program can fluctuate, with no guarantee that an application endorsed by AAG will result in work being carried out by a participating laboratory. However, the growth in the number of projects being supported (Table 1) shows that laboratories have committed to this program. The program now supports a diversity of research projects, in terms of geographical distribution of recipients, and diversity of thesis topics. Early recipients of support have fulfilled their obligations by publishing the results of their work with appropriate recognition to the supporting laboratory and AAG.

About 15 years ago, the AEG became the AAG, emphasising the Association's recognition of the environmental as well as the exploration application of geochemistry. Although the majority of supported applications are related to mineral exploration, a recent addition to the AAG's Student Support Program is Sonia Mulongo's MSc thesis work on the environmental chemistry of soils in Lubumbashi, Democratic Republic of the Congo.

This AAG program not only aims to foster the science of applied geochemistry, but also offers applied geochemistry students the opportunity to learn through personal experience about generating geochemical data. All participating laboratories are staffed by skilled analysts who can provide valuable advice on the most suitable analytical approach, itself a valuable contribution to the thesis work. The application form and conditions of support for this program can be found on the Students page on the AAG website ([www.appliedgeochemists.org](http://www.appliedgeochemists.org)).

**Paul Morris,**

*AAG Education Committee; Email: [paul.morris@dmirs.wa.gov.au](mailto:paul.morris@dmirs.wa.gov.au)*

Student	Institution	Country	Date	Degree	Thesis Title	Supporting Laboratory	Status	Publication
Xin Du	University of Western Australia	Australia	2011	PhD	Particle size fractionation and chemical speciation of REE in a lateritic weathering profile in Western Australia	Intertek-Genalysis	Completed	Chemical Geology, 330-331, 101-115 (2012); EXPLORE 157.
Andrew Lucas	University of Western Australia	Australia	2011	PhD	Evaluating the diffusive gradients in thin films technique for the detection of multi-element anomalies in soils	Intertek-Genalysis	Completed	EXPLORE 161, 1-15 (2013)
Marcus Phua	University of Melbourne	Australia	2014	MSc	Petrogenesis of the gabbroic intrusions hosting magmatic Ni-Cu-PGE sulphides at Melba Flats, western Tasmania	BV Minerals (Ultratrace)	Completed	SEG conference abstract, 2015
Enerst Tata	University of Buea	Cameroon	2014	PhD	Felsic plutonism, hydrothermal alteration and granite-related gold mineralization, Batouri gold district, SE Cameroon: geochronology and geochemical constraints	Intertek-Genalysis		Submitted to GEEA
Matthew Bodnar	University of British Columbia	Canada	2016	MSc	Mapping chemical dispersion above a buried VMS in a till covered terrain, Lara VMS deposit, Vancouver Island, Canada	ALS		
Victor Vincent	Modibbo Adama University of Technology	Nigeria	2016	BSc	Geological investigation of sediment hosted sulphide deposits of Azara-Akiri-Wuse Area, Northcentral Nigeria.	ALS		
Pradip Singh	Potosino Institute of Scientific and Technological Research	Mexico	2016	PhD	Nature of petrological, geochemical, geochronological settings and evolution of the Bundelkhand Greenstone Complexes, Bundelkhand Craton, India	ALS		
Hamid Zekri	Ifsan University	Iran	2016	PhD	Geochemical variation in regolith and anomaly detection over the Pitchi blind Pb-zn deposit	Actlabs		
Anthony Chukwu	University of Nigeria	Nigeria	2017	PhD	Petrology of Precambrian basement rocks and Ta-Nb pegmatite mineralization in Akwanga areas, northcentral Nigeria	Intertek-Genalysis		
Chinedu Ibe	University of Nigeria	Nigeria	2017	MSc	Geochemical studies on Precambrian basement complex rocks around Katchuan Ode, southeast of Ogoja, southeastern Nigeria	BV Minerals (Ultratrace)		
Sonia Mulono	University of Lubumbashi	Dem. Rep. of the Congo	2017	MSc	Mining exploitation impact on the soil of Lubumbashi city: an environmental approach	BV Minerals (Ultratrace)		

## AAG New Members

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### Fellows

Fellows are voting members of the Association. AAG members and non-members may become Fellows at any time. See the AAG website to download a membership conversion form.

Helen Waldron  
40 Griffith Way  
Thornlie, WA  
AUSTRALIA 6108  
Membership number #3347

Dr. Yulia Uvarova  
CSIRO: Principal Research Scientist  
26 Dick Perry Ave.  
Kensington, WA  
AUSTRALIA 6151  
Email: yulia.uvarova@csiro.au  
Membership # 4318

### Members

Members are non-voting members of the Association. Members must be 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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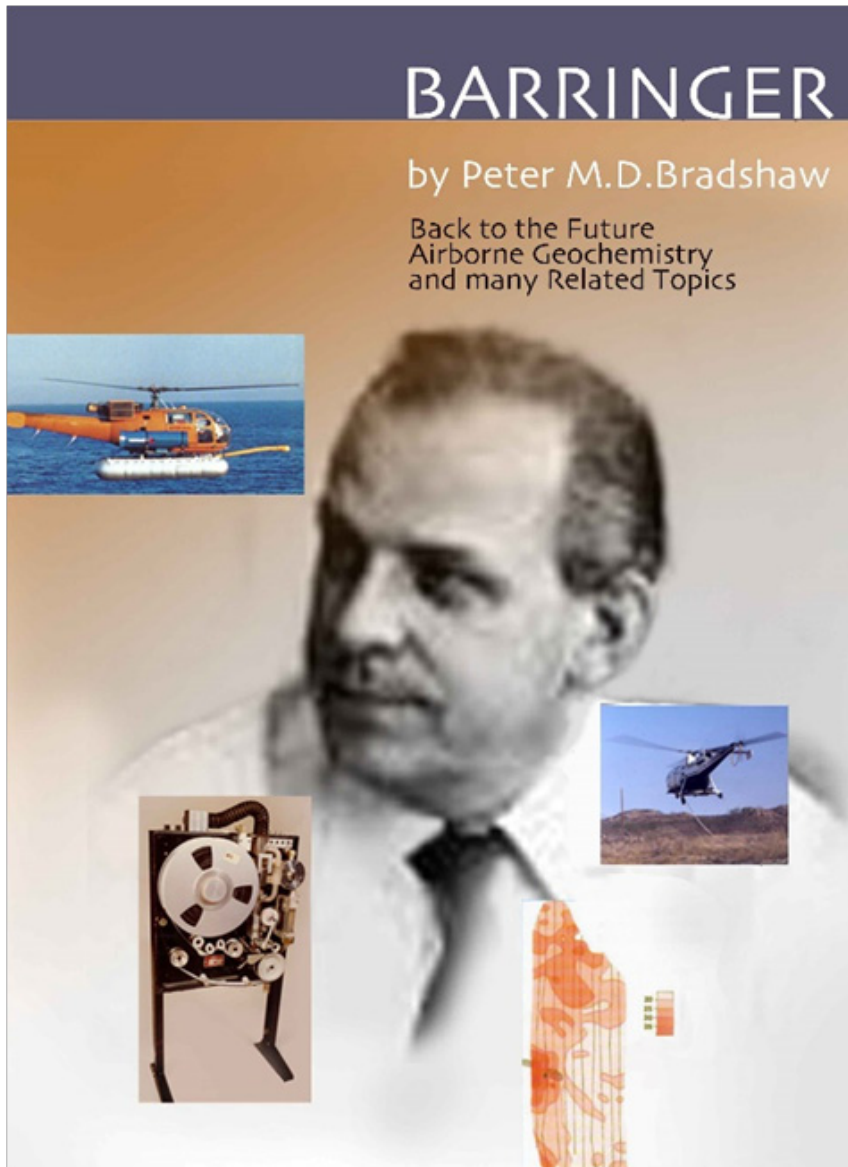
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## BARRINGER - THE BOOK

### Exploration, Remote Sensing, Environment, Analysis, Security

The 1960's and 70's were marked by an explosion in mineral exploration and remote sensing technology. A leader throughout this period was Dr. Anthony (Tony) Barringer and his team at Barringer Research Ltd. (BRL). The highly successful airborne geophysical methods created at BRL are well known while the contributions to exploration geochemistry and many other fields are not. This book documents the many advances in geochemical theory, as well as the ground, airborne and remote sensing techniques plus analytical methods that were conceived and developed under the leadership of Tony Barringer. Innovative concepts backed by pioneering research funded by BRL on the movement of metals in rock, soil and vegetation remain important areas of investigation. Tony Barringer's ability to bring together a diverse team including geologists, geochemists and physicists with electrical, optical and aeronautical engineers under one roof, provide leadership, a highly stimulating environment and financial support, was truly remarkable. This led to ground breaking advances in a number of different fields, including: exploration geochemistry for minerals and oil and gas; environmental monitoring from the ground, aircraft and space; and civilian and armed forces security. The underlying scientific principles for many of the inventions, now upgraded with modern electronics, are still considered state of the art. One of the many inventions from the BRL "incubator" described in this book is Ionscan, the drug and explosive screening device used in most airports today, which was conceived and developed by BRL in conjunction with technology for the detection of mineral deposits.

*Hard Cover book, including shipping US\$ 68.00\*, \*\**

*Soft Cover book, including shipping US\$ 58.00\*, \*\**

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\*Note, for US\$48 and US\$38 or \$C65 and \$C55 respectively (to avoid shipping charges) there will be limited number of both the hard and soft cover books available the MDRU booth at Roundup in Vancouver (first come first served) or directly available in Vancouver for a limited time from Pbradshaw@firstpointminerals.com

\*\*Note there will also a very limited number at the MDRU both at the PDAC. To reserve your copy for pick up at the MDRU booth please email Pbradshaw@firstpointminerals.com at the latest by Feb 22nd.

#### HOW TO ORDER:

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## 28th IAGS and Resources for Future Generations 2018

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 more than 5,000 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.

Eleven specific AAG applied geochemistry sessions will be chaired by AAG members. Details of the sessions are provided below. It is anticipated that the call for abstracts will open on August 1, 2017 and will close on January 15, 2018. Submissions of abstracts to the AAG sessions, as well as registration, short course, and field trip selection, will be handled through the RFG2018 website at <http://rfg2018.org>. The abstract submission process will allow the selection of the specific sessions for submissions. AAG members are encouraged to submit abstracts to the appropriate AAG sessions.

Registration at the conference will allow AAG members full access to the complete RFG18 technical sessions. A series of Short Courses and Field Trips are also being compiled by AAG for inclusion in RFG18; further information will be provided in the near future.

### AAG Sessions at the RFG18 Conference:

**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 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 practices** - 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 AMI-RA, CMIC). This session is intended to draw together key papers highlighting integrated models and their application to exploration.

**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.

## 28th IAGS and Resources for Future Generations 2018... *continued from page 28*

**Micro to Macro-biogeochemistry: Exploration, Processing, remediation and the Environment** - Biological systems play an 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 present 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 its 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.

**ARD in Mining and Civil Construction.** Acid rock drainage (ARD) and metal leaching (ML) are potential hazards that should be assessed at an early stage in planning major excavations for resource development or civil construction. Potentially acid generating materials can be predicted based on static and kinetic testing. This Session will present case studies both experimental and field, demonstrating practical mitigation and management of ARD in mining and construction.

**Peter Winterburn**

*NSERC/Acme Labs/Bureau Veritas Minerals Industrial Research Chair in Exploration Geochemistry,  
Mineral Deposits Research Unit  
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**WHAT ON EARTH IS  
YOUR PASSION?**

Call for Abstracts Opens  
August 1, 2017

#RFG2018 | [RFG2018.org](http://RFG2018.org)

## Hydrothermal Ore Deposits Course

The Departments of Earth Sciences at the University of Ottawa, Ottawa, Canada and Laurentian University, Sudbury, Canada are pleased to announce the 2017 Joint Modular Course in **HYDROTHERMAL ORE DEPOSITS**, which will be held at the University of Ottawa October 21-28, 2017.

The course will feature 4 two-day modules to be presented by Dr. Mark Hannington (University of Ottawa), Dr. Daniel Kontak (Laurentian University), Dr. Matthew Leybourne (Laurentian University), Dr. Richard Goldfarb (Consultant), Dr. Jeremy Richards (Laurentian University), Dr. David Burrows (Vale), Dr. J. Bruce Gemmell (CODES), Dr. Steve Piercey (Memorial University) and Dr. Robert Seal (USGS).

Oct 21 & 22 A Practical Guide to the Ore Elements, Minerals and Fluids  
Oct 23 & 24 Orogenic Gold Deposits and Porphyry-Related Systems  
Oct 25 & 26 Epithermal Systems and Iron Oxide-Copper-Gold Deposits  
Oct 27 & 28 Volcanogenic Massive Sulfides and Ores in Surficial Environments

The course is open to graduate students from any university as well as professionals in industry. Graduate students registered in the course may be eligible for credit toward their degree programs. Industry participants may receive credit toward professional training requirements.

More information is available at [https://science.uottawa.ca/earth/short\\_course](https://science.uottawa.ca/earth/short_course)

## Exploration '17

October 21 to 25, 2017, Toronto, Canada

Exploration '17 is the sixth of the very successful series of DMEC decennial mining exploration conferences, which have been held in the seventh year of every decade starting in 1967. The theme of the Exploration '17 conference is "Integrating the Geosciences: The Challenge of Discovery", featuring a multi-national, multi-disciplinary technical programme, exhibition, workshops and field schools.

[www.exploration17.com/About.aspx](http://www.exploration17.com/About.aspx)

### Program Schedule

Oral presentations are by invitation only  
<http://www.exploration17.com/Program-Schedule.aspx>





## 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](http://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](mailto:StephenAmor@gov.nl.ca) Tel: +1-709-729-1161

### 2017

- 17-20 SEPTEMBER SEG 2017. Beijing China. Website: [www.seg2017.org/](http://www.seg2017.org/)
- 17-22 SEPTEMBER 28th International Meeting on Organic Geochemistry. Florence Italy. Website: [www.houseofgeoscience.org/imog/](http://www.houseofgeoscience.org/imog/)
- 17-22 SEPTEMBER Applied Isotope Geochemistry 12. Copper Mountain Resort CA USA. Website: [www.iagc-society.org/AIG.html](http://www.iagc-society.org/AIG.html)
- 18-19 SEPTEMBER 19th International Conference on Gas Geochemistry. Rome Italy. Website: [www.waset.org/conference/2017/09/rome/ICGG](http://www.waset.org/conference/2017/09/rome/ICGG)
- 18-22 SEPTEMBER 11th International Kimberlite Conference. Gaborone Botswana. Website: [www.11ikc.com](http://www.11ikc.com)
- 24-29 SEPTEMBER 23rd International Symposium on Environmental Biogeochemistry. Palm Cove QLD Australia. Website: [www.iseb23.info](http://www.iseb23.info)
- 3- 5 OCTOBER William Smith Meeting 2017: Plate Tectonics at 50. London England. Website: [www.geolsoc.org.uk/wsmith17](http://www.geolsoc.org.uk/wsmith17)
- 9- 10 OCTOBER Annual International Conference on Geological & Earth Sciences. Singapore. Website: [www.geoeearth.org](http://www.geoeearth.org)
- 9-13 OCTOBER 14th International Symposium on Biomineralization. Tsukuba Japan. Website: [www.biomin14.jp](http://www.biomin14.jp)
- 21-25 OCTOBER Exploration '17. Toronto ON Canada. Website: [www.exploration17.com](http://www.exploration17.com)
- 21-28 OCTOBER Short course - Geochemistry of Hydrothermal Ore Deposits. Ottawa ON Canada. Website: [science.uottawa.ca/earth/short\\_course](http://science.uottawa.ca/earth/short_course)
- 22-25 OCTOBER GSA Annual Meeting. Seattle WA USA. Website: [www.geosociety.org/meetings/2017/](http://www.geosociety.org/meetings/2017/)
- 31 OCTOBER-  
2 NOVEMBER 10th Fennoscandian Exploration and Mining. Levi Finland. Website: [fem.lappi.fi/en](http://fem.lappi.fi/en)
- 6-7 NOVEMBER Janet Watson Meeting 2017: The Future of Contaminated Land Risk Assessment; stakeholder perspectives. London England. Website: [www.geolsoc.org.uk/jwatson17](http://www.geolsoc.org.uk/jwatson17)
- 6-11 NOVEMBER 9th International Conference on Geomorphology. New Delhi, India. Website: [www.icg2017.com](http://www.icg2017.com)
- 6-11 NOVEMBER Short Course: Fluids in the Earth. Naples Italy. Website: [tinyurl.com/yb6qf6o7](http://tinyurl.com/yb6qf6o7)
- 17-18 NOVEMBER 15th Swiss Geoscience Meeting. Davos Switzerland. Website: [geoscience-meeting.ch/sgm2017](http://geoscience-meeting.ch/sgm2017)
- 23-26 NOVEMBER International Conference on Computational Chemistry and Toxicology in Environmental Science. Taichung, Taiwan. Website: [theochem.wikispaces.com](http://theochem.wikispaces.com)
- 3-8 DECEMBER American Exploration and Mining Association Annual Meeting. Sparks/Reno NV USA. Website: [tinyurl.com/m99kskj](http://tinyurl.com/m99kskj)
- 7-8 DECEMBER 19th International Conference on Nuclear and Environmental Radiochemical Analysis. Sydney NSW Australia. Website: [tinyurl.com/jsh9gsu](http://tinyurl.com/jsh9gsu)

### 2018

- 8-13 JANUARY 2018 Winter Conference on Plasma Spectrochemistry. Amelia Island FL USA. Website: [tinyurl.com/mrvbqwa](http://tinyurl.com/mrvbqwa)
- 22-25 JANUARY Mineral Exploration Roundup 2014. Vancouver BC Canada. Website: [roundup.amebc.ca](http://roundup.amebc.ca)
- 11-16 FEBRUARY 2018 Ocean Sciences Meeting. Portland OR USA. Website: [osm.agu.org/2018](http://osm.agu.org/2018)
- 18-21 FEBRUARY Australian Exploration Geoscience Conference. Sydney NSW Australia. Website: [www.aegc2018.com.au](http://www.aegc2018.com.au)
- 4-7 MARCH Prospectors and Developers Association of Canada Annual Convention. Toronto ON Canada. Website: [www.pdac.ca/convention](http://www.pdac.ca/convention)
- 8-13 APRIL European Geosciences Union General Assembly 2018. Vienna Austria. Website: [www.egu2018.eu](http://www.egu2018.eu)
- 2-4 MAY International Conference on Geology & Earth Science. Rome Italy. Website: <http://geoscience.madrige.com>



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

- 16-21 JUNE Resources for Future Generations (Energy, Minerals, Water and the Earth). Vancouver BC Canada. Website: [rfg2018.org](http://rfg2018.org). See announcement in current issue of Explore.
- 8-13 JULY Geoanalysis 2018. Sydney NSW Australia. Website: [2018.geoanalysis.info](http://2018.geoanalysis.info)
- 12-17 AUGUST Goldschmidt 2018. Boston MA USA. Website: [goldschmidt.info/2018](http://goldschmidt.info/2018)
- 13-17 AUGUST 22nd General Meeting of the International Mineralogical Association. Melbourne VIC Australia. Website: [www.ima2018.com](http://www.ima2018.com)
- 28-31 AUGUST 15th Quadrennial IAGOD Symposium. Salta Argentina. Website: [www.iagod.org/node/76](http://www.iagod.org/node/76)
- 13-15 SEPTEMBER SIAM Conference on Mathematics of Planet Earth (MPE18). Philadelphia PA USA. Website: [www.siam.org/meetings/mpe18](http://www.siam.org/meetings/mpe18)
- 16-21 SEPTEMBER IWA World Water Congress & Exhibition 2018. Tokyo Japan. Website: [tinyurl.com/ybpmakrc](http://tinyurl.com/ybpmakrc)
- 14-18 OCTOBER Australian Geoscience Council Convention. Adelaide SA Australia. Website: [tinyurl.com/zqxc6n2](http://tinyurl.com/zqxc6n2)
- 25-26 OCTOBER Sampling 2018. Lima Peru. Website: [www.encuentrometalurgia.com/Sampling-2018](http://www.encuentrometalurgia.com/Sampling-2018)



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