



## Regional Geochemical Mapping Initiatives



When the Focus on Regional Geochemistry Mapping for this **EXPLORE** was proposed it was not known that a GEAA for 2005 has a similar theme. Clemens Reimann is the editor of and contributor to the GEAA and has kindly provided an introduction to this interesting issue of the Journal.

### Special GEAA issue on “Geochemical Mapping”

It was in 2002 during a trip as the Association of Exploration Geochemists’ (now the Association of Applied Geochemists, AAG) distinguished lecturer in the U.S. that Graham Closs suggested that I should write up my talk on geochemical mapping that I had just presented at the Colorado School of Mines. At that time I had not really thought about it, because these days most geochemical mapping is in colour, and colour figures in journals are still expensive to print. During a discussion with Gwendy Hall later on the same year the idea developed to prepare a special issue of Geochemistry: Exploration, Environment, Analysis (GEEA) dedicated to “Geochemical Mapping”, where all the papers would need colour printing, in the hope to somewhat reduce the costs. This special issue is now ready for printing and will appear as Volume 5, Part 4 of GEEA in November 2005.

A paper by Kaj Lax and Olle Selinus of the Swedish Geological Survey, summarises several decades of work of geochemical mapping in Sweden. A manuscript by Chris Johnson provides a good summary of more than 30 years of work by the British Geological Survey’s (BGS) baseline geochemical mapping program, the techniques used (from sample collection, preparation, analysis to data storage and map production) and its applications as well as an interesting discussion of future developments. Fiona Fordyce, also BGS, covers the topic of “geochemical surveys in urban environments” (GSUE) in Great Britain, geochemical mapping at quite another scale than the “usual” national surveys. In environmental studies, urban geochemistry has become increasingly important during the last ten years, no wonder since more than three quarters of the world’s population live in urban areas. Geochemists have vast experiences with regional scale surveys to offer to environmental urban mapping projects. A paper by Matthias Cornelius (CSIRO, Australia) is on a completely different topic: diamond exploration, and many colleagues may wonder about using regional geochemistry for diamond exploration. This paper demonstrates how regional scale geochemistry can be utilised for area selection for more detailed exploration in the search for diamonds.

My own paper “Geochemical Mapping – Technique or Art” is the one that Graham Closs wanted to see published.

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# EXPLORE

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Newsletter for the Association of Applied Geochemists



David Kelley

## AAG Presidential Address

If you were one of the 12,000 people attending the Prospectors and Developers Association of Canada (PDAC) Convention in Toronto this past March, you know how active the mining industry is going to be this year. Exploration spending is up again this year and since there is usually a strong correlation between spending and discoveries, this will hopefully produce some exciting new projects in minerals. Many predict that this upswing will last longer than previous ones, due to higher sustained metal prices. Although times are good now, the previous down-turn is still fresh in the minds of many, which begs the question of how the industry will respond to the next down cycle. John Dow of Newmont gave an excellent talk on this subject at the SEG 2004 meeting last September in Perth, relating the challenges of managing people and exploration programs with the ever changing business cycles. The supply of young talented geoscientists is critical to this issue and affects government, academia and industry. Discussions with exploration and human resource managers in several large companies indicate that there seems to be a strong focus in attracting and retaining young talent.

One way the AAG can respond to this challenge is to provide training workshops at diverse venues to help raise the general level of understanding in applied geochemistry. Graham Closs has been working with the SEG to put on a workshop in geochemistry at the SEG 2006 meeting in Keystone, Colorado, and Bill Coker has proposed another AAG-sponsored workshop to be held in conjunction with Exploration 2007 in Toronto, Ontario. While these are traditional venues for the AAG, we could offer similar workshops in the environmental and petroleum industries.

There was an excellent turn-out of AAG members at the PDAC and it looks like a similar number will be at the **Geological Society of Nevada’s** symposium “**Window to the World,**” May 15 - 18, 2005 in Reno, Nevada. The AAG will have a booth there so please stop by if you attend. Richard Glanzman has also graciously volunteered to represent the AAG at the 15th Annual Goldschmidt Conference: “A voyage of discovery”, to be held May 20-25 in Moscow, Idaho. Stop by and offer Dick a hand if you are at this meeting. Preparation for our own meeting, the IGES in Perth, Western Australia, September 19-23, 2005 is progressing well thanks to the hard work of Paul Morris, Nigel Radford and the Local Organizing Committee. Further information on this meeting appears in this issue of **EXPLORE**.

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## Focus on: Regional Geochemistry Mapping...continued from page 1



It discusses the multitude of mapping techniques that are nowadays used for preparing geochemical maps and highlights some of the shortcomings and advantages of certain techniques. Mapping needs training, however this is rarely given in university courses for geochemists at a time when software for mapping allows anyone to prepare maps that appear very pleasant at first glance but may be misleading. In that connection a book by Mark Monmonier: *How to lie with maps*; 2<sup>nd</sup> edition, University of Chicago Press, 1996, which I found on a recent trip to Bristol, needs to be recommended and should be a "must-reading" for any non-geographer attempting to construct maps.

A second paper in the same GEEA-issue summarises some of my experience with subcontinental-scale geochemical mapping in Northern Europe. It is an unusual paper in so far as it focuses on the thoughts behind the survey design more than on the results. Two geochemical atlases prove that these suggestions will deliver exciting and useful results from low-density geochemical mapping at the continental scale.

**Clemens Reimann**

*Geological Survey of Norway  
March 2005*



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## Element mobility in transported overburden — are we looking in the wrong direction?

I enjoyed the review of possible mechanisms of metal transfer through transported overburden by Aspandiar, Anand, Gray and Cucuzza (2004) in Explore 125, and have also been impressed by the outstanding work carried out by the Deep-Penetrating Geochemistry group in recent years in both North and South America (e.g. Cameron, Hamilton, Leybourne, Hall and McClenaghan, 2004). It is clear that we now have several elegant and plausible models for element transport through transported overburden. But before we rest on our laurels and accept that all has been explained, can I suggest that we have so far ignored at least two other potential sources of energy which could be capable of driving ions through the regolith to the surface, even though the driving forces come not from within the regolith but above it? These are electrically charged storm cells and tidal pull.

**Electrically charged storm cells** are common features over almost all landmasses. Around the world lightning strikes the Earth 50 to 100 times each second and at any given moment there are 1800 to 2000 thunderstorms in progress, almost all over land (Anon, 1986). Here in Australia we get between 0.5 and 2 lightning strikes to ground per square kilometre per annum over much of the continent (Australian Bureau of Meteorology, 2004). Such a strike density is not unusual elsewhere. Indeed, over large areas of India, Africa,

South and North America it is higher still (NASA, 2001). While fully developed thunderstorms represent the most intense electrical cells there must be many more cases where extremely powerful electrical gradients are generated within developing storm cells even though these do not get to the point of initiating lightning discharge. Consequently, over the course of no more than a few decades this should mean that the whole land surface of most continents will have been repeatedly exposed to the effects of these transient, but immensely powerful, phenomena. Evidence that this has at least some effect on the regolith comes from palaeomagnetic studies, where surface measurements may be unreliable due to the magnetic overprint induced by lightning strikes. Fulgurites, formed by fusion of soil by lightning strikes, have been traced up to 20 metres down into the regolith (Bouska, 1993), and there is even a report of tourists being injured by electrical discharges in a cave that was overlain by 300-400 metres of rock, with no artificial electrically conducting connections, when lightning struck the surface above them (Diendorfer and Schulz, 1997).

Storm clouds act like huge capacitors and the steep electrical gradients associated with them have been measured above ground over thousands of metres, so it would not seem to be unreasonable to argue that these forces could also penetrate a few tens or even hundreds of metres into the regolith below. They could therefore constitute a significant mechanism for mobilisation of elements. Figure 1 summarises some of these features. Typically a strong negative charge develops at the cloud base and this field

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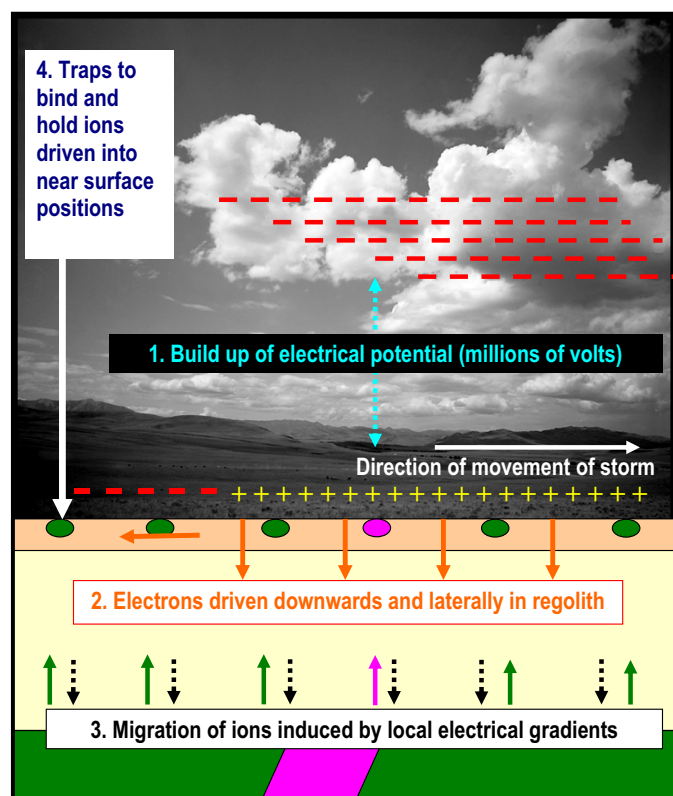
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## Element mobility in transported overburden — continued from page 3



**Figure 1.** Suggested mechanism of ion migration within regolith, driven from above by powerful atmospheric electrical gradients associated with storm cells.

becomes so intense that it interacts with the ground, often several thousand metres below it, driving electrons in the surface regolith away from it, both downwards and laterally. This results in the acquisition of a strong positive charge in the surface regolith immediately below the storm cloud. Under a mature storm the electrostatic field can achieve levels of between 10000 and 30000 volts per metre of elevation above the earth's surface (Carpenter and Tu, 2000).

The rate of movement of charged species in an electrochemical field can far exceed that of chemical diffusion, provided the voltage gradient is high enough. Hamilton (2000) has estimated that voltage differences as low as 10 - 60 millivolts would be sufficient to move ions

through a 30 metre thick electrolyte in 8000 years. This assumes the groundwater behaves as a perfect electrolyte, whereas in the real world many geochemical processes may affect the migration rate. Nevertheless, it does suggest that ions at least have the potential to move quite quickly through transported overburden if conditions are right, even with very small voltage gradients. A modest increase in voltage difference will speed up this process considerably, as demonstrated by recent research on electrokinetic remediation of metal contaminated soils. For example Reddy and Shirani, (1997) quote a study where electrodes were implanted in a clay-rich soil containing up to 500 ppm As, and potential gradients of between 20 and 40 volts per metre were applied. After three months 75% of the site had been reduced to the target of 30 ppm As. If gradients of a few volts per metre can achieve this kind of ion mobility in months how long would it take to move ions through significant thicknesses of regolith if they were exposed to local storm cells where – at least for short periods of time – electrical gradients are orders of magnitude greater?

What might happen in the regolith as a storm cell moved over it, assuming there was sufficient moisture in the vadose zone to allow movement of ions in solution? In the area immediately under the cell, where the regolith surface carries a strong positive charge, a reduced cation such as  $\text{Fe}^{2+}$  could be expected to be driven up towards the surface where it would lose an electron to become  $\text{Fe}^{3+}$ . It might then be available to scavenge other cations which could migrate to the surface under the influence of the negatively charged trailing edge of the storm footprint as it moved across the earth's surface. Such suitable near-surface chemical traps, which could immobilise ions once they had been driven up in the weathering profile, would probably be an equally important part of this model – otherwise ions could be just as easily driven down in the regolith as driven upwards.

Storm cells are complex things and many factors could come into play. If there was a lightning discharge this would result in a sudden local rush of surface charge to the lightning stroke channel (Carpenter, 2000) and this could in turn act as an engine to mobilise ions in the regolith, perhaps inducing different dispersion patterns from those generated by the storm cell itself. No doubt such factors as moisture content, resistivity and mineralogy of the regolith would also influence behaviour of ions. In an appreciable minority of cases the charge is reversed with a positive charge developing at the cloud base while a negative charge develops at the surface of the regolith. This could generate very different dispersion patterns from those generated under 'normal' storm cell conditions. It would be interesting to measure vertical voltage gradients in the regolith as a storm cell approaches, passes overhead (or nearby) and then moves on. How long can an effect be measured; how intense is it and how does it change as the cell moves on?

The above is pure speculation. I simply make the point that these electrically charged juggernauts rumbling across the landscape could prove to be an enormously powerful driving force, capable of inducing perhaps extremely rapid migration of ions through the regolith. Why invoke millivolts to move ions when we have millions of volts at our disposal?

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### Mobile Metal Ion Geochemistry

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## Element mobility in transported overburden — *continued from page 4*

As a footnote it is worth noting that the effects of these storm cells linger long after the cells themselves have dissipated. A portion of their electrical activity feeds into telluric currents which flow at or near the earth's surface. These currents can be modified, and at times intensified, by interactions between the solar wind and the ionosphere. Perhaps they too play a role in element dispersion in the regolith.

**Tidal pull.** Ocean tides are obvious. So obvious that we tend to forget that the same gravitational forces that cause the oceans to rise and fall are also operating on the air and solid landmasses. Although the movement is much less in the land than in the sea it can amount to a metre of vertical shift (UK National Maritime Museum), although it is normally probably of the order of 15 – 30 cm. If such a movement is happening twice a day across a land surface, is it too fanciful to speculate that this rising and lowering of the land surface may act as a driving force for movement of ions, either in gaseous form or in solution, rather like the action of a giant pump or set of bellows? Perhaps every geochemist should be issued with a set of tide tables.

**David Garnett**

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### Coming soon in the AAG EXPLORE newsletter:

Technical articles and letters to the editor are encouraged as submissions for discussion within the newsletter. Each issue of **EXPLORE** contains a series of short discussion papers which provide either an update on a particular geochemical topic, or present current debates about issues of interest. Suggestions for future "Focus" topics may be forwarded to the editor,

Chris Benn (Email: [Chris.Benn@BHPBilliton.com](mailto:Chris.Benn@BHPBilliton.com))

#### Issue: Focus topic and Contact:

128 Geochemical Data Processing

**Contributor Deadline** June 30, 2005

**Publication Date:** August 2005

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## President's Message... *continued from page 1*

The Focus Topic of this issue of **EXPLORE** is on regional geochemistry and geochemical mapping. This topic has broad application to natural resources and the environment, as indicated in the two articles by Dr. Wang Xueqiu and Reijo Salminen. Clemens Reimann is also editing a special issue of GEEA on this topic, which will appear as Volume 5, Part 4 of GEEA in November 2005.

You will also notice the lively debate on sampling between Dominique François-Bongarçon and Cliff Stanley/Barry Smee. This is an important issue for many of us in the mining industry and I think it is great for these debates to surface in **EXPLORE**. I would like to thank each of these gentlemen for taking the time to contribute on this issue for the greater good of our members. Their passion for this subject is obvious in their replies. Please comment on this debate and keep the discussion going.

I would like to point out that **EXPLORE** is an excellent place to publish ideas or work in progress. Since **EXPLORE** is not a formally referenced journal, articles do not go through rigorous editing, giving you the opportunity to publish relevant work quickly and in color. I encourage all of our members to take advantage of this. We now have a new Webmaster for our website. Andrew Ransom, with BHP Billiton, has agreed to take on this responsibility. I look forward to Andrew's contributions. If you have any comments or ideas for the website, please contact Richard Carver and Andrew. I would also like to thank Mike Scrimgeour for all of his efforts with the website. Mike tackled the complicated task of enabling on-line payment of dues for new members and membership renewals.

On a personal note, I have recently joined Newmont Mining Corporation, based in Denver. I look forward to working with Owen Lavin, Nigel Radford and the rest of the Newmont explorers. At the same time, I will miss all of my colleagues at WMC. I wish them all the best of luck, especially Phil Baker and Sarah Coker.

I hope to see many of you at the GSN meeting in May.  
Sincerely,

### David Kelley

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## Shea Clark Smith

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## CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry.

■ April 24-29, **2nd General Assembly of the European Geosciences Union (EGU 2005)**, Vienna, Austria.  
Website [www.copernicus.org/EGU/ga/egu05/index.htm](http://www.copernicus.org/EGU/ga/egu05/index.htm)

■ April 24-27, **Canadian Institute of Mining & Metallurgy CIM-AGM, Toronto 2005**.  
Website [www.cim.org/mce/toronto2005/](http://www.cim.org/mce/toronto2005/)

■ April 23-24, **CIM Exploration Geochemistry Workshop**, Metro Toronto Convention Centre,  
Website [www.cim.org](http://www.cim.org)

■ May 1-4, **I Brazilian Symposium on Metallogeny**, Gramado, Serra Gaucha, Hotel Serra Azul.  
Website [www.ufrgs.br/sbm](http://www.ufrgs.br/sbm)

■ May 7-8, **Irish Association for Economic Geology (IAEG) - Weekend Course on Copper Deposits: Genetic Studies and Case Histories**. Email Vincent Gallagher at [vincentgallagher@asi.ie](mailto:vincentgallagher@asi.ie). Website [www.iaeg.org](http://www.iaeg.org).

■ May 10-12, **Second World Conference on Sampling and Blending**. Sunshine Coast, Queensland, Australia.  
Website [www.ausimm.com](http://www.ausimm.com)

■ May 15-18, **Geological Society of Nevada Symposium 2005** Sparks, Nevada USA, Geological Society of Nevada. Email [gsnsymp@unr.edu](mailto:gsnsymp@unr.edu)

■ May 20-25, **15<sup>th</sup> Annual Goldschmidt Conference – A Voyage of Discovery**. University of Idaho, Moscow, Idaho, USA. Email [gold2005@uidaho.edu](mailto:gold2005@uidaho.edu). Website [www.uidaho.edu/gold2005](http://www.uidaho.edu/gold2005).

■ June 12-17, **Acid Rain 2005**, 7<sup>th</sup> International Conference on Acid Deposition, Prague, Czech Republic. Email [info@acidrain2005.cz](mailto:info@acidrain2005.cz).  
Website [www.acidrain2005.cz](http://www.acidrain2005.cz)

■ July 31-August 5, **2005 Gordon Conference**, Proctor Academy, New Hampshire. Attendance by invitation. Email [Steve.Garwin@geoinformex.com](mailto:Steve.Garwin@geoinformex.com)

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## CALENDAR OF EVENTS

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■ August 8-11, **Earth System Processes 2**, Co-convened by Geological Association of Canada and GSA, Calgary, Alberta, Canada.

Website [www.geosociety.org/meetings](http://www.geosociety.org/meetings)

■ August 29-2 September **STOMP 2005** – International Conference on Structure, Tectonics and Ore Mineralization Processes. Townsville, Australia.

Email [Stewart.Parker@jcu.edu.au](mailto:Stewart.Parker@jcu.edu.au).

Website [www.es.jcu.edu.au](http://www.es.jcu.edu.au).

■ August 30-September 13, 2005. **Modular Course in Structure, Tectonics, and Mineral Exploration**, Sudbury, Ontario, Canada.

Email: [blafrance@laurentian.ca](mailto:blafrance@laurentian.ca), Website <http://earthsciences.laurentian.ca>.

■ September 5-19 2005 **GEOCHIM 2005**, Prague, Email [pasava@cgu.cz](mailto:pasava@cgu.cz) or [masek@cgu.cz](mailto:masek@cgu.cz)

■ September 5-7, 2005 **9th IMWA (International Mine Water Association)** Oviedo, Spain. Email [imwa@innova.uniovi.es](mailto:imwa@innova.uniovi.es). Website [www.uniovi.es](http://www.uniovi.es)

■ September 19-23 **22<sup>nd</sup> IGES** Perth Western Australia – see this **EXPLORE** . [www.aeg.org](http://www.aeg.org)

■ September 20-23 **Mineral Deposits of South America: New Visions**, XVI Congreso Geológico Argentino, La Plata, Argentina. Website: [www.congresogeologico.ar](http://www.congresogeologico.ar)

■ October 25-November 5 **10th Brazilian Geochemical Congress and 2nd Geochemical Symposium of the Mercosul Countries**, Porto de Galinhas, Recife, Brazil

Email: [valderez@ufpe.br](mailto:valderez@ufpe.br)

Website: [www.ufpe.br/xcbgq](http://www.ufpe.br/xcbgq).

■ December 8-17. **Modular Course in Exploration Geophysics**, Sudbury, Ontario, Canada. Email:

[mlesher@laurentian.ca](mailto:mlesher@laurentian.ca),

Website: <http://earthsciences.laurentian.ca>.

■ April 5-16, 2006. **Modular Course in Exploration for Magmatic Ore Deposits**, Sudbury, Ontario, Canada. Email: [mlesher@laurentian.ca](mailto:mlesher@laurentian.ca),

Website: <http://earthsciences.laurentian.ca>.

Please check this calendar before scheduling a meeting to avoid overlap problems. Let this column know of your events.

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## New Members

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AUSTRALIA

Membership # 3830



## Focus on: Continental-Wide Geochemical Mapping in Europe

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### Introduction

The need for high quality, multi-purpose environmental geochemical baseline data for Europe was justified by the first European Working Group on Regional Geochemical Mapping immediately after the Chernobyl accident in 1986, when it was realised that a baseline for radioactive and other polluting elements could not be defined (Bølviken *et al.* 1990, 1993, 1996). Subsequent compilation of inventories of existing regional geochemical databases in Europe revealed the existence of some 120 separate geochemical databases based on up to seven different sample media. Although a wide range of element concentrations were determined by 13 different analytical methods, many environmentally essential elements were, however, not measured. (Plant and Ridgeway, 1990; Plant *et al.* 1996, 1997). Because it was impossible to compile a homogeneous data set for the whole of Europe from these data, it was clear that the establishment of a harmonised European wide geochemical database was essential to satisfy the needs of present day national and European Union legislation. Plant *et al.* (1997) made the case thus:

*“Throughout Europe public concern about the environment is growing. In response, national governments and the European Union (EU) are attempting to develop policies, legislation and infrastructure, such as the European Environment Agency (EEA). Attempts are also being made to establish ‘Safe Levels’ of Potentially Harmful Elements and Species (PHES), but these are often based on limited and/or inadequate information.*

*The available data on environmental geochemical baselines and radioactivity are not systematic in coverage or quality and, therefore, are not of the standard required to quantify the distribution of potentially harmful elements and species at the European scale as a basis for policy-making and monitoring future change to the environment.*

*In general, there is a failure to recognise that the natural geochemical background is highly variable and the natural levels of potentially harmful elements and species (such as As, Cd, Pb, NO<sub>3</sub>, the radioactive elements and organic pollutants) can be as high or higher than those caused by man-made sources of pollution. Even where synthetic pollutants are concerned, it is the natural geology and geochemistry which frequently exert the fundamental controls on the distribution of the potentially harmful elements and consequently determine their potential to create hazards.”*

Data on geochemical baselines are urgently needed, not only in Europe but also all over the world, because environmental authorities in most countries are defining limits for contaminants in soils and waters for different land

use purposes. The Commission of the European Union (EU) is preparing the Soil Protection Strategy and Directive for Europe. As geochemists know, the natural concentrations of elements are different in the different constituents of overburden, and vary markedly between geologically disparate areas. State authorities, however, are not always aware of these significant natural variations, which should be taken into account in defining action limits. There are already examples of action limits that are lower than natural concentrations.

Older national geochemical data sets in Europe, as it has already been pointed out (Plant and Ridgeway 1990; Plant *et al.* 1996, 1997), are not in a form that can be readily used for this purpose. It is not possible to define the present day European geochemical baseline for a single element on the basis of old geochemical data. Therefore, the data produced by the projects such as FOREGS Geochemical Baseline Mapping programme (Salminen *et al.* 2005) and the The Ecogeochemical Mapping of the Eastern Barents Region (Barents Ecogeochemistry) project (Salminen *et al.* 2004) should make a significant contribution to the European wide soil and water protection legislation, especially as a basis for defining action limits. Thus, systematic baseline environmental geochemical data are necessary to inform policy makers and to provide a sound basis for legislation. According to Plant *et al.* (1996), for this purpose such data are required to be:

1. *Standardised across national boundaries.*
2. *Available in digital form for use in GIS so that they can be viewed interactively with other datasets, such as those for land use and for animal and human morbidity and mortality data.*
3. *Comprehensive, to include the majority of potentially harmful elements and ideally as many harmful chemical species as possible, including synthetic compounds.*
4. *Based on a full suite of sample types including soil, stream sediment, surface water, groundwater and off-shore marine and estuarine sediment in the coastal zone.*

Worldwide, the aim of the International Union of Geological Sciences (IUGS) and the International Association of Geochemistry and Cosmochemistry (IAGC) Working Group on “Global Geochemical Baselines” is to compile a respective data, based on the Global Terrestrial Network sampling (GTN) - also called the Global Reference Network (GRN) - as recommended by the UNESCO International Geological Correlation Programmes IGCP 259, “*International Geochemical Mapping*”, and its successor, IGCP 360, “*Global Geochemical Baselines*” (Darnley *et al.* 1995) covering the whole Globe. In Europe, the FOREGS programme was originally planned to be the European contribution to that Global data, and also a practical example of how to carry out such an international survey. Geochemical mapping, which applies different sample media and analytical methods, has already been widely used in Nordic countries (Koljonen, 1992; Salminen, 1995; Lahermo, *et al.* 1996; Reimann, *et al.* 1998; Ottesen *et al.* 2000).

In the Barents Ecogeochemistry project, the project area is likely to be the focus of increased human activity in the near future, linked to further exploitation of natural resources such as the large hydrocarbon fields on land in



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the Timan-Pechora basin and the gigantic gas fields offshore, in the eastern Barents Sea. Development of such fields will, in all probability, necessitate building new pipelines on land, and new port facilities. These developments will, to a significant extent, take place in areas that have already experienced a human impact of various kinds (from earlier oil/gas and coal exploitation and other anthropogenic sources). A geochemical baseline study in the region gives the authorities and other involved interests a basis for assessing the existing state of the environment and for distinguishing impacts due to new developments from those

of an older date. Thus the environmental status of the whole region can be documented before the planned exploitation of new large oil and gas deposits.

### Methodologies applied in the large-scale geochemical surveys in Europe

The FOREGS Geochemical Baseline Mapping Programme was approved in 1996 by the Forum of European Geological Surveys' Directors (FOREGS). In 1996, the Working Group representatives were nominated by each country and by the end of 1997 the principles of field and analytical methodologies were agreed. To this group belonged the representatives of 26 European countries (see Table 1.).

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**Table 1.** A summary table of the Foregs Geochemical Baseline Mapping programme and the Barents Ecogeochemistry project

	Foregs	Barents
Survey area	4.2 mill. km <sup>2</sup>	1.55 mill km <sup>2</sup>
Participating organisations	Geological surveys of Austria, Albania, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Latvia, Lithuania, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and UK; and from Italy Università' di Napoli "Federico II", University of Padova, and Università degli Studi di Siena	Geological surveys of Finland and Norway, Finnish Nuclear Safety Organisation, S/C Mineral, St.Petersburg, Russia, ZAO Arkhangelskgeolrazvedka, Arkhangelsk, Russia, ZAO Mireko, Syktyvkar Komi Republic of Komi, Russia
Number of sampling sites	808	1384
Sample media		
Stream water	808 samples	1334 samples
Minerogenic stream sediment	801 samples	None
Floodplain sediment	749 samples	None
Organic soil layer (humus layer)	367 samples	1409 samples
Minerogenic top-soil	845 samples	None
Minerogenic sub-soil	789 samples	1415 samples
Terrestrial moss	None	1316 samples
Analysed elements and other parameters		
Soils	Ag, Al, As, Ba, Be, Bi, Ca, Cd, C, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, I, In, K, La, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, pH, Pr, Rb, S, Sb, Sc, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, TOC, Grains size	Al, As, B, Ba, Be, Bi, C, Ca, Cd, Cl, Co, Cr, Cs, Cu, F, Fe, Ga, Hg, I, K, La, Li, LOI, Mg, Mn, Mo, N, Na, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Si, Sr, Te, Th, Ti, Tl, U, V, Zn, and Zr
Organic soil	Ba, Cd, Co, Cu, Ga, La, Hg, Ni, Rb, Sr, and Zn	Al, Ag, As, B, Ba, Be, Bi, Br, C, Ca, Cd, Co, Cr, <sup>134</sup> Cs, <sup>137</sup> Cs, Cu, Fe, Hg, K, LOI, Li, Mg, Mn, Mo, N, Na, Ni, P, Pb, Rb, S, Sb, Se, Sn, Sr, Th, Ti, Tl, U, V, and Zn
Sediments	Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, S, Sb, Sc, Se, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, and TOC,	
Water	Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, I, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, pH, Pr, Rb, Sb, Se, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, EC, HCO <sub>3</sub> <sup>-</sup> , Br <sup>-</sup> , Cl <sup>-</sup> , F <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , and DOC	Ag, Al, Alkalinity, As, B, Ba, Be, Bi, Br, Ca, Cd, Cl <sup>-</sup> , Co, Cr, Cs, Cu, EC, F <sup>-</sup> , Fe, Hg, I, K, La, Li, Mg, Mn, Mo, Na, Ni, NO <sub>3</sub> <sup>-</sup> , P, Pb, pH, Rb, Sc, Sb, Se, Si, SO <sub>4</sub> <sup>2-</sup> , Sn, Sr, Th, Ti, Tl, U, V, Zn, Y, and Zr,
Moss		Al, Ag, As, B, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Na, P, S, Mo, Ni, Pb, Rb, Sb, Se, Sn, Sr, Th, Tl, U, V, and Zn
Time period	1996 (1986) – 2005	1999 (1998) – 2004
Number of participating countries	2 (6)	26

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The fieldwork was carried out in each country independently according to the published field manual (Salminen, Tarvainen *et al.* 1998). Special sub groups did the interpretation of the data where the group members willing to do such a work participated. The national teams varied much according to the local conditions and financial possibilities.

In the Barents project, the project organisation was based on permanent national groups from Finland, Russia, and Norway. These groups were in charge of planning and carrying out the fieldwork in their countries and doing the interpretation of results from their countries. In Finland three field teams (two persons in each) and in Russia twelve teams (three to four persons in each) carried out the regional phase sampling. The fieldwork in Russia was a huge effort, because some 70% of sampling sites were accessible only by helicopters.

### Sample Media

The geochemical data of both of these projects are based on the analysis of various sample media such as of stream water, stream sediment, floodplain sediment (or alluvial soil), residual minerogenic soil, organic soil layer (humus), and terrestrial moss. High quality and consistency of the data were ensured by using standardised sampling methods (Salminen, Tarvainen *et al.* 1998; Gregorauskiene *et al.* 2000), and by applying rigorous, harmonised quality assurance measures during chemical analysis and subsequent data handling stages. The choice of sampling media has been made in accordance with the recommendations of the IUGS/IAGC Working Group on Global Geochemical Baselines (Darnley *et al.* 1995). These media, described below, are considered to be the most representative of the Earth's surface environment, and are the most commonly used in past and current environmental geochemical investigations:

- Stream water (filtered and unfiltered);
- Stream sediment – mineral sediment (<0.150 mm);
- Residual soil, top soil – upper 0–25 cm horizon without the top organic layer (<2 mm);
- Residual soil, sub soil – lower C horizon, a 25 cm layer within a depth range of 50–200 cm (<2 mm);
- Organic soil layer (humus, where present);
- Overbank sediment – upper 0–25 cm horizon (<0.150 mm, optional);
- Overbank sediment – bottom layer (<0.150 mm, optional);
- Floodplain sediment – upper 0–25 cm horizon (<2 mm);
- Floodplain sediment – bottom layer (<2 mm, optional); and
- Terrestrial moss – the uppermost three shoots of *Hylocomium Splendens* or *Pleurozium Schreberi* species

*Stream, floodplain and overbank sediment* samples generally reflect the average geogenic composition of the whole catchment basin for most elements, although they are sensitive to pollution.

*Stream waters* reflect the interplay between geosphere/hydrosphere and pollution. At the same time, they can be a major source of drinking water.

*Soil samples* reflect variations in the geogenic composition of the uppermost layers of the Earth's crust. Because of this, it is important to avoid soil sampling at locations that had visible or known contamination.

Comparison of topsoil and subsoil data gives information about enrichment or depletion processes between the layers. One such process is anthropogenic contamination of the top soil layer. The <2 mm fraction is taken according to environmental standards. The <0.18 mm and finer fractions have been widely used in mineral exploration programmes. *Humus* samples can be used to determine the atmospheric (anthropogenic most cases) input of elements to the ecosystem. To reach this aim, samples should be collected in forested areas. To reflect the atmospheric input, the uppermost few centimetres of the organic layer are collected immediately under the green vegetation and litter (max. 3 cm).

*Terrestrial moss* samples are taken to reflect the atmospheric input (anthropogenic or geogenic) of elements over a limited time span. It has no roots and lives predominantly from the element input via the precipitation. Due to its large surface area it will also collect local (geogenic) dust. It has ion exchange properties and can enrich many elements over time. Moss is collected as a bio-monitor, reflecting variations in the regional composition of the atmosphere rather well for a limited time segment.

### Sampling Strategy

The FOREGS sampling grid was based on GTN grid cells developed for the purpose of Global Geochemical Baseline mapping (Darnley *et al.* 1995). This grid divides the entire land surface of the Earth into 160 km x 160 km cells. The cells have their origin on the equator at the 0° (Greenwich) meridian. European cells have identifiers such as N36W01, which is defined as the 36th cell north of the equator and the first cell west of the meridian of Greenwich, each cell having a size of 160 km in north-south direction and on average 160 km in east-west direction

In the FOREGS programme, a list of the GTN cells, with five randomly generated, numbered points which should be sampled, was produced beforehand by the Geological Survey of Finland (GTK). Since some of the GTN cells in coastal areas consist of mostly water, it was agreed that in order to obtain as perfect coverage as possible these cells could be included in the sampling programme, but at least three sites should be sampled in order to fulfil the specifications of the IUGS/IAGC "Global Geochemical Baselines" mapping programme.

The given randomly generated points were used to select the five nearest small drainage basins of <100 km<sup>2</sup> in area. From the selected small drainage basins the site for stream water (filtered and unfiltered) and stream sediment sampling was chosen close to the confluence point with the main stream. The residual soil (top and subsoil), and humus samples were collected from an appropriate site, within the area of the small drainage basin, representing the dominant residual soil type.

From the larger drainage basin (area 1000-6000 km<sup>2</sup>), to which the small drainage basin is connected, the floodplain

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sediment samples, the uppermost 25 cm, and the optional lowermost were collected, either from a suitable point near its outlet with the sea or the confluence point with another major river system. If no suitable large size drainage basin was available, the floodplain sediment samples were taken from a smaller drainage basin of minimum size >500 km<sup>2</sup>. In the Barents Ecogeochemistry project, the pre-labelled sample bags and bottles were mixed and then distributed in a random order to the organisations in charge of the fieldwork in each participating country. Thus the sampling proceeded in random order of site numbers. For site selection, all existing information on geology (bedrock and Quaternary deposits), soil types, morphology, and vegetation zones were used. The area was divided into drainage basins covering approximately 1000 km<sup>2</sup> each. These drainage basins were subdivided into drainage basins covering approximately 100 km<sup>2</sup> each. The sample site was located in that one of the 100 km<sup>2</sup> drainage basins that was thought to be the most representative for the whole area. A respective method was recently adopted generally in Russia (IMGRE, 1998). In the selection of the drainage basins first priority was given to the most pristine catchment. The dominant landscape conditions in the selected catchment guided the final site selection.

### Field training

In the FOREGS programme, the field methodology was according to the first draft of the field manual tested and modified during a two days' field course in the Slovak Republic in June 1997. After the experiences from that field course were carefully analysed the "FOREGS Geochemical Field Manual" was published in early 1998 (Salminen, Tarvainen *et al.* 1998).

In the Barents project, after the experiences from the FOREGS programme a much stronger effort was put on training the field personnel and harmonising the field methodology. One aim being that after the project, the methodologies, which are widely accepted and standardised in western countries, were adopted in the Russian organisations and institutions participating in and responsible for the project. During the 1999 field season some 30 persons including all team leaders and people in response of practical work spent five weeks together in the field collecting more than one thousand samples from catchment areas representing different geochemical landscapes in the Barents region (Salminen, 2000).

### Photographs

From each sampling in both Barents Ecogeochemistry project and FOREGS programme a suite of photographs were taken in order to document the local landscape and the sampling site. These photos are organised in special photo archives, which are or will be accessible via internet.

### Analytical methods

In the FOREGS programme (Sandström *et al.* 2005), the analytical work was carried out in the laboratories of

nine geological surveys in such a way that all samples of one particular sample media was analysed by one particular method in one laboratory. In the Barents Ecogeochemistry project the responsibility of all analytical work was only in one laboratory, the laboratory of Geological Survey of Finland, and only a minor part of the analytical work was done in other laboratories in Norway and Russia.

A regional large-scale geochemical project with low sampling density sets some special requirements for the analysis. The methods must be sensitive enough to reach the background levels, the precision must be acceptable, and additionally the accuracy must be better than in normal geochemical exploration surveys. The data is planned to be extensively used for environmental purposes, such as the assessment of natural element concentrations in different materials as a basis to establish or refine national or European maximum contaminant levels. The FOREGS programme is considered to be a pilot project for the IUGS Global Geochemical Baseline Programme, which aims and methodological requirements are described by Plant *et al.* 1996. For this reason the methods used in the FOREGS programme will have a standard operation procedure character and should thus be reproducible in various laboratories all over the world. However, considering the requirements for the sensitivity and elemental coverage, the most sophisticated instrumental methods have to be utilised which may exceed the capabilities of some skilled, but poorly equipped, laboratories to participate the global project in the future.

The total concentrations are relevant for geochemical interpretation of data. This means, that the silicate matrix is either decomposed before instrumental analysis or methods for solid samples such as X-ray fluorescence are used. However, to address the needs of national and European level environmental authorities, the information on leachable concentrations of the elements was considered of high importance. In the environmental chemistry a slightly unscientific and unspecific term, "near total" is used to describe the absolutely maximum concentrations, which can be liberated from the materials in nature. Normally *aqua regia* leach or digestion is used for this purpose. Unfortunately almost every laboratory has its own procedure for *aqua regia* leach and the standardised but laborious methods are rarely used. In both FOREGS and Barents Ecogeochemistry projects *aqua regia* leach was adopted to analyse the leachable concentrations of the elements in minerogenic samples. The problem of diversity of leaching procedures was avoided by having only one laboratory perform the analyses.

### Quality assurance

The sampling locations of both FOREGS and Barents project were randomised so as to randomly distribute minor errors in the analytical results. This approach minimizes their effect on the anomaly patterns on the maps.

### Quality control samples

In the Barents Ecogeochemistry project, at every 15<sup>th</sup> sampling site, a full set of all materials were collected as

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duplicate samples. The whole sampling procedure was duplicated, e.g. a new pit at the distance of some metres was dug for sampling the C-horizon. During the water sampling, a blank sample was prepared from distilled and deionised water. It was acidified and handled in the same way as the normal samples. A blank water sample was prepared after every fifteenth sample (normally at the same site as a duplicate sample was collected).

Two different sets of project standard samples of moss, organic layer and C-horizon material were included in the sample set at the same rate as the duplicates. One set was collected from southern Finland and the other one from the Leningrad region. All samples were thoroughly homogenised and divided to sub samples, which were then used as project standard samples.

In the FOREGS programme, from each country at least one GTN cell was randomly selected for duplicate sampling. Countries with nine or more GTN cells collected duplicate samples from 2 or more cells. Duplicate samples of each material were taken from one geologically representative small catchment of the selected GTN cell, and its corresponding floodplain. The procedure of collecting the duplicate samples was identical with that of the normal samples. For residual soil sampling, a duplicate composite sample was collected from 3 to 5 new pits dug not further than 10 metres from the original soil sampling pits, and for floodplain sediment sampling a new pit was dug not further than 10 metres from the original floodplain sediment sampling pit.

### Quality control in laboratory

Sampling and sample preparation may be considered the most critical steps influencing the overall quality of the process. To maintain consistent quality assurance and control, all the sample logistic control and preparation was conducted in the laboratory of the Geological Survey of Slovak Republic. In this way any confusions in sample identification, deviations in sample bags and bottles etc. could be assessed at the same level. Because sample splits were sent to analytical laboratories, the homogeneity of the processed samples was of major concern. A thorough homogeneity test scheme was implemented before submitting the samples for analysis. The protocol is described in more detail in the analytical manual (Sandström et al 2005)

Another quality assurance measure was to analyse all samples of particular type and method in one nominated laboratory. The benefit of this is to avoid undetectable bias between laboratories even when using the same documented method. The drift control is also better arranged within one laboratory. The methods, which were decided to be used, were routine methods of the particular laboratories, which allowed utilising the history of the quality control records and the human experience of the laboratories. All the participating laboratories had their own quality control system.

The accuracy of the methods has been based on the existing validation data of the particular laboratory. In order to control the long-term stability of the methods and also to compare the methods with each other, two monitoring samples were regularly analysed with the unknown samples. In order to assess the precision of the analytical methods and compare that to the sample bias, duplicate sampling and duplicate analysis methods were used. The duplicates were analysed randomised along with the normal samples. Both members of the duplicates were analysed in duplicate and sampling uncertainty evaluated by the ANOVA statistical interpretation method.

### Results

The results of both Barents Ecogeochemistry and the FOREGS Projects are published as atlas books, which include the maps (the Barents Ecogeochemistry atlas 190 maps and the FOREGS atlas 360 maps), description of the methodologies, and some background information. In the Barents Ecogeochemistry project (Salminen *et al.* 2004), a brief interpretation of the element distribution patterns is included, element by element, in the atlas book. In the case of the FOREGS atlas (Salminen *et al.* 2005), a larger interpretation will be published separately later. The main distribution way of the FOREGS atlas is via internet (<http://gsf.fi/publ/foregsatlas>). The Barents Ecogeochemistry atlas is also available via internet, as a service of its commercial publisher (Elsevier BV). The release of the original analytical data will probably be done in the near future. As an example of the published maps of both projects, the distribution of As concentrations in stream waters are shown in Figures 1 and 2.

Initial results show that the distribution patterns of both water and solid samples are related to such factors as large-scale tectonic provinces, geologic provinces such as areas of glaciated terrain, pollution reflecting industrialized areas, and areas of intensive agriculture. Because of different sampling density, the element distribution patterns of Barents Ecogeochemistry and the FOREGS programme describe source areas whose dimensions are different. In the Barents project, the distribution patterns of solid sample media can be connected to lithological units better than in the FOREGS programme where they preferably describe continent wide structural geological units.

### Discussion

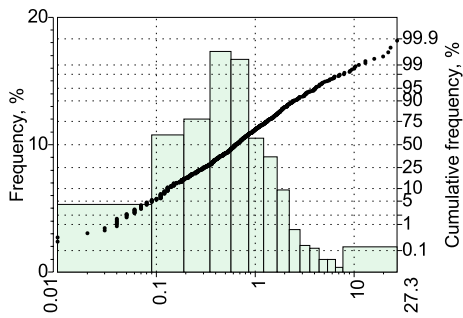
In the international survey projects, in order to guarantee the homogeneity of sample quality, it is important that all necessary equipment and other materials needed for collecting all samples are purchased and delivered from one source only to all parties. These include the complete field equipment such as GPS device, pH/Eh meter, camera, tools needed in sampling, all sample bags and containers (preferably beforehand numbered and labelled), syringes, filters, drip bottles, acids and other chemicals; in short absolutely everything necessary to take all samples at each site.

Training of the field-teams from various countries proved to be important in order to harmonise the

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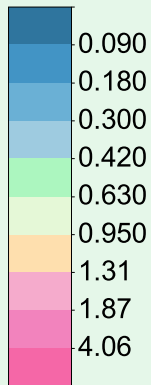


As  
ICP-MS, detection limit 0.01 µg l<sup>-1</sup>  
Number of samples 807  
Median 0.630 µg l<sup>-1</sup>

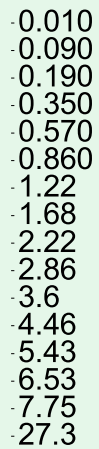
**Arsenic  
Stream water**



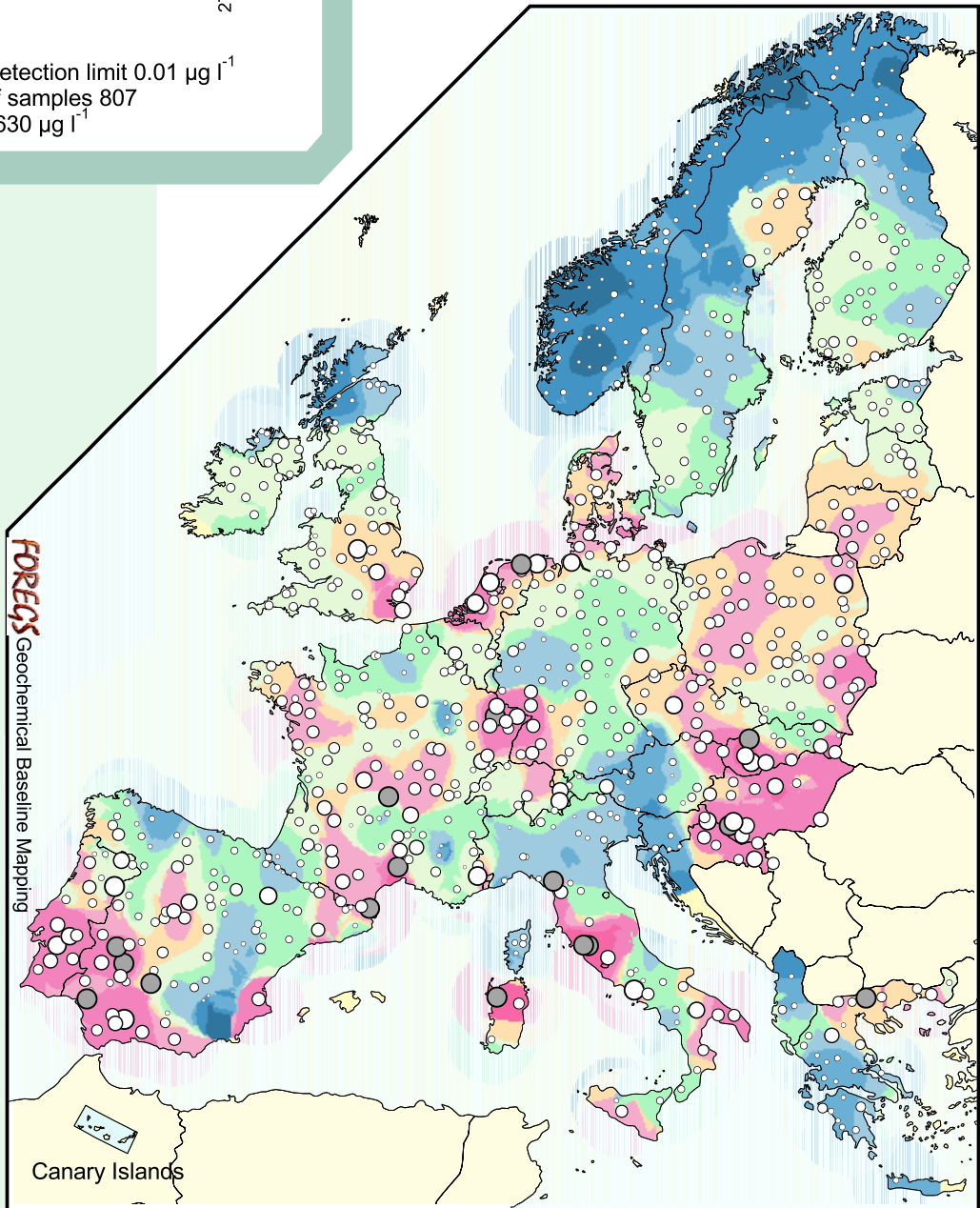
0 500 1000 Kilometers



As µg l<sup>-1</sup>



FOREGS  
Geochemical Baseline Mapping

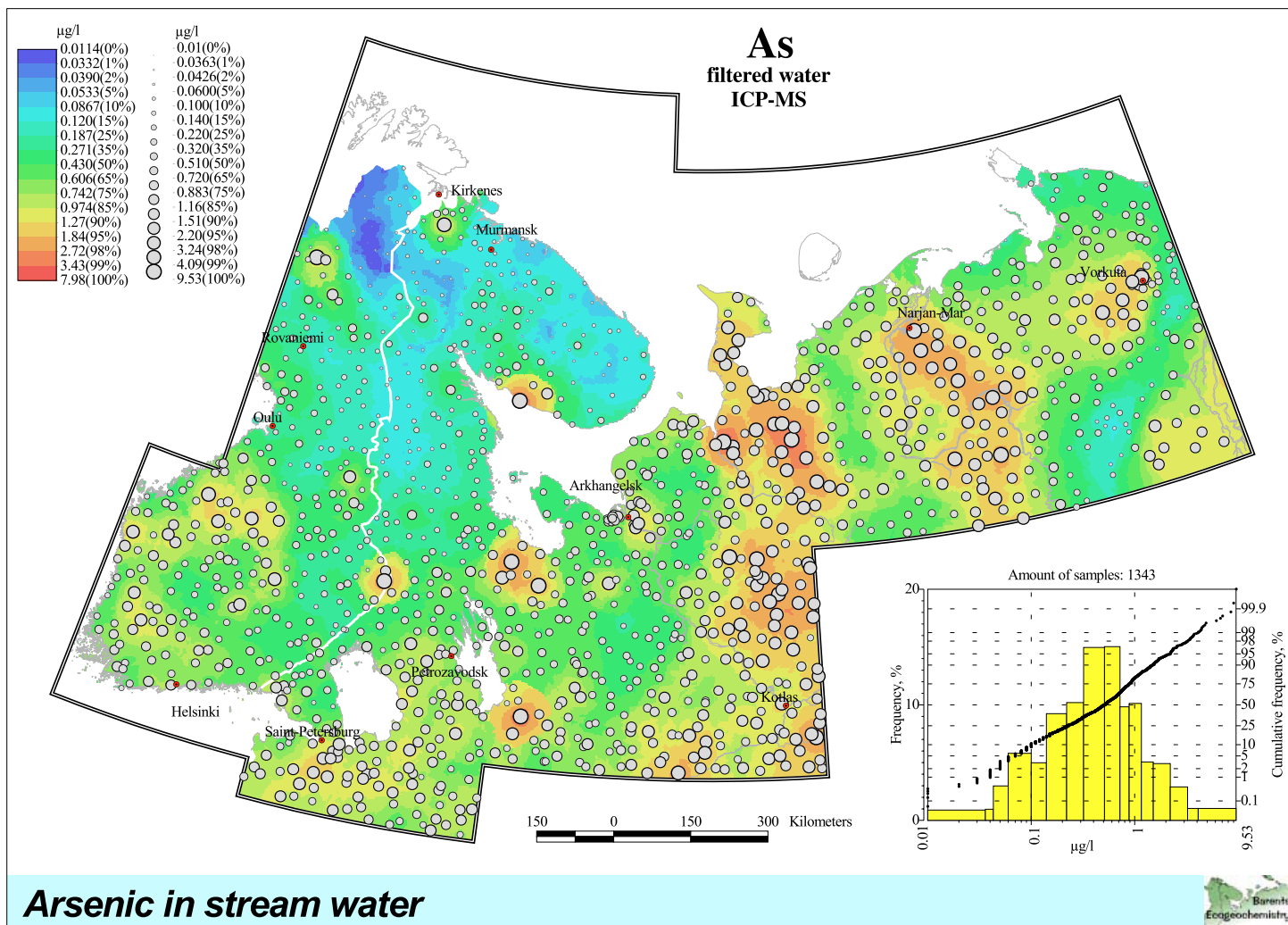


Canary Islands

As

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### Arsenic in stream water

understanding of the field manuals. This was clearly proved by the more effective and longer field training period of the Barents Ecogeochemistry project which followed a year later the short field training of the FOREGS programme. This proved to be necessary to ensure the methods and the aim of the whole project were understood by all participating scientists in a similar way.

According to these experiences we can strongly recommend that a relatively long and also expensive training phase should be always included in respective projects. Such a field-training course actually becomes also a pilot phase of the whole project, and experiences collected during this phase improve much the practices and quality of samples in the regional phase field work and laboratory procedures.

It is a challenging and ambitious task to compile a global geochemical database as was proposed by Darnley *et al.* 1995. The data collected from the Barents region will be added later to a pan European database, which is a part of Global Geochemical Baseline program. Thus, it will be possible to compile the worldwide geochemical survey data, although there are big risks in compiling different data sets.

These large-scale geochemical surveys have not only scientific interest, but they can also be used for political purposes and developing legislation. For instance, the

Barents Ecogeochemistry project was considered as an example of the political concept 'the Northern Dimension of European Union'. Respectively the FOREGS data are used as a baseline data in developing the EU soil and water protection directives.

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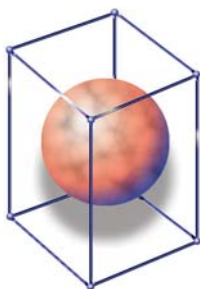
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## **22<sup>nd</sup> International Exploration Geochemical Symposium, Perth (Western Australia), 19 – 23 September 2005 • an update**

It is now only 6 months until the 22nd International Geochemical Exploration Symposium — the first International Applied Geochemistry Symposium — begins in Perth, Western Australia. We would like to take this opportunity to bring our Applied Geochemistry friends and colleagues up to date with our plans.

### **Technical program**

First and foremost, the technical program is now taking shape. We have been very fortunate in receiving more than twice the number of abstracts necessary to fill all the speaking slots for the 4 days of technical sessions. Likely sessions are:

- Geochemical exploration's brave new world. Seeing through transported overburden, mechanisms of metal mobility.
- Discovery case histories and geochemical exploration in tropical, temperate and glacial terrains.
- Environmental Geochemistry: its interaction with exploration.
- Geochemistry of mineral deposits: isotope and hydrothermal geochemistry.
- Data, our raw materials: analysis, QAQC, data management, data processing.

Given the excellent response, we anticipate varied and informative oral and poster sessions.

### **Field Trips.**

Four field trips are planned, two before the conference and two afterwards.

Pre-conference field excursions will be held in New Zealand, and the Kalgoorlie region of Western Australia. The New Zealand field trip, which requires 20 registrants to make it viable, will be led by Dr Stuart Simmonds of the

University of Auckland, and will visit the geothermal expressions of the Taupo Volcanic Zone in New Zealand's North Island. The likely cost is around \$A1500. This is a fascinating opportunity to get up front and personal with hydrothermal geochemistry! The trip will start and finish in Auckland and will ideally suit conference delegates who can stop off in New Zealand on the way to Perth at little or no extra cost.

The Kalgoorlie field trip will be run by the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC-LEME). The excursion will include examples of regolith evolution, and regolith and bedrock mineralization, in one of the world's oldest cratonic regions. The trip will run from Perth, with airfares included and will cost in the order of A\$ 1500.

Post-conference excursions include a visit to the Southwest of Western Australia, led by Dr Alan Mann; no visit to this area would be complete without visiting some of the excellent vineyards in the Margaret River region! This trip will run ex Perth and cost in the order of A\$ 800. The second post-conference excursion will visit parts of New South Wales, led by Dr David Cohen, and include examination of typical regolith exposures as well as mine visits. This excursion will run ex Sydney, and cost in the order of A\$ 1000. Its location and timing will especially suit delegates flying home over the Pacific Ocean.

### **Workshops and short courses**

Six one- or two-day workshops or short courses are on offer, split between before and after the meeting. Final costs for individual workshops or shortcourses have yet to be finalised, but they should range between \$A200 and \$A400 each:

1) Viewing and visualising geochemical data.

*Course Leader: Mark Arundell*

*Presenters: Simon Gatehouse, and Paul Agnew*

2) Regolith mapping

*Course Leader: Steve Hill*

*Presenters: Ravi Anand and Mike Craig*

3) Mineral Exploration Using Groundwater Geochemistry

*Course Leader: Patrice de Caritat*

*Likely presenters: Dave Gray, Bear McPhail, Mark Pirlo, Sue Welsh*

4) Environmental Geochemistry — towards mine closure

*Course Leader: Rob Bowell*

5) Selective extractions as applied to Exploration and Environmental Geochemistry

*Course Leader: Gwendy Hall*

*Likely presenters: Stew Hamilton, David Cohen, and others*



## 6) Data management

*Course Leader: Marianne Broadgate*

*Presenters: Paul Agnew, Andy Dent, Craig Morley, Rob Freeth*

### Social Program

We plan to hold a busy social program starting on Sunday 18<sup>th</sup> September with an Ice Breaker at the conference venue, the Sheraton Hotel. Drinks and light refreshments will be served in an informal atmosphere where you can meet old friends and make new ones. The cost is included in the registration fee.

On the Monday night, a sunset cruise down the Swan River to Fremantle, Perth's port city, is followed by a moonlight visit to Fremantle Jail, a significant part of Perth's convict past. The jail was built in the 1850's, and last housed prisoners in the early 1990s. After dinner at the jail, and trips round the cells and even the gallows, coaches will return you to Perth. The indicative cost will be A\$ 140.

On the Tuesday evening, we are very privileged to be able to hold the Conference Dinner at Western Australia's Government House, the official residence of the State Governor. This fine colonial building is set in magnificent gardens in the centre of the city only a short walk from the Sheraton Hotel. The dinner will cost in the order of A\$ 110.

Wednesday is a free day. After two days of technical sessions, with two days still to come, it's time for a short break! Whilst you are free to make your own plans, our conference organiser can help arrange whatever recreation you may want to undertake. Many visitors to Perth enjoy spending a day on Rottnest Island, some 20 km off the coast from Fremantle, and just 30 minutes from Fremantle by ferry. This delightful island refuge has no cars, so you can hire a bicycle to visit the sandy beaches and swim in the blue waters. For those of you more adventurously inclined (and if there is enough interest), Ian Robertson has offered to organise a day SCUBA diving trip for qualified divers to Rottnest Island to view some of the best temperate coral reefs in Australia. For a more relaxed break, Perth's Swan Valley hosts some world-class wineries.

On the Wednesday afternoon, Genalysis Laboratories (one of our 3 Platinum sponsors along with IO Geochemistry and Newmont Mining) invite you to visit their state-of-the-art laboratory complex in Perth, followed by dinner at the Royal Perth Yacht Club.

On the Thursday evening, a visit to Perth Zoo for dinner includes a starlit visit to the Australiana section of the zoo, where guides will be on hand to explain the unusual features of Australian wild life. The price for this evening will be in the order of A\$ 110.

### Accompanying persons program

Many people bring their partners to the IGES, and a program of entertainment for them is now being put together by several of the local geochemists' partners, many of whom have enjoyed the hospitality of previous IGES events in other countries. There are many interesting places to visit around Perth, and the spring weather in September is usually warm and pleasant.

### Trade displays

The conference venue has room for plenty of trade displays where you can meet your customers in a unique environment. This is unquestionably the largest single gathering of applied geochemists anywhere in the world, and if your business includes geochemistry, you can't afford not to be there! Information about the trade display layout, and costings are available from our conference organiser's website at [www.promaco.com.au/conference/2005/iges/](http://www.promaco.com.au/conference/2005/iges/).

### Sponsorship

There are still spots available for sponsors to secure exposure to conference delegates. Details can be found at the conference organiser's website, listed above.

### Registration

The final details of the events (registration, field trips, workshops, social events etc) are being prepared now. We envisage a registration cost of about A\$ 750, although exact prices are soon to appear with the electronic registration form on both the conference website

[www.promaco.com.au](http://www.promaco.com.au)  
and the AAG website  
[www.appliedgeochemists.org](http://www.appliedgeochemists.org)

If you require a hard copy of the registration documents, please contact Promaco Conventions, the conference organiser for the 22<sup>nd</sup> IGES:

Promaco Conventions  
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Western Australia 6153  
Facsimile: 61 08 93322911  
Email [promaco@promaco.com.au](mailto:promaco@promaco.com.au)

We encourage you to check the conference website [www.promaco.com.au/conference/2005/iges/](http://www.promaco.com.au/conference/2005/iges/) for updates on the 22<sup>nd</sup> IGES, and we look forward to seeing you in Perth in September.

**Nigel Radford and Paul Morris**  
*Co-Chairmen, 22<sup>nd</sup> IGES*

# Readers' Forum



**From Dominique Francois-Bongarcou, PhD**  
**AGORATEK International - dfbgn@attglobal.net**

It is with keen interest I started to read the technical note "Sample Preparation of 'nuggety' samples: Dispelling some myths about sample size and sampling errors".

However, shortly into the text, I realized the paper was misguided for a number of technical reasons. While one can easily agree with the overall conclusion that 3 kg pulverizers are not the best tool to use<sup>1</sup>, it is obviously not acceptable to think one should not be concerned with the size of the coarse split! Nor does this article make a valid point of it, as the following critical errors can easily be spotted:

- Poisson statistics can only apply assuming the gold grains are freed from their gangue (liberated ores), which is rarely the case just after crushing. This makes all the precision calculations and what-if scenarios in the note invalid. Gy's formula should be used down to liberation size, and even below as Poisson formulas fail to account for the size distribution of the gold grains whereas Gy's formula does.
- While primary sampling at the RC rig is a true sampling operation (which therefore contributes a variance component), core splitting is not. In the first case, a

smaller mass (sample) intends to represent the larger mass of whole interval cuttings. In the second case, the 1/2 core represents only itself. The variance attached to core splitting is not entirely a sampling<sup>2</sup> variance, which invalidates the two examples and their conclusions<sup>3</sup>.

- As a result, only the case of RC chips can be considered for the reasoning described in the note, but then, the primary sampling variance *can* indeed be controlled by adequate sample mass, as is the one for the coarse split. All the stages of the protocol are important, no one less than the others, and they must all be balanced with each other, which implies adjusting the coarse split mass as well on a case by case basis.
- The graphs are unrealistic: it is well known that the sampling variance depends not only on sample mass and crush size, but also on the size of the gold grains, which has been shown to vary with grade in most gold deposits. The sampling standard deviations have no reasons whatsoever to ever increase, nor to do so linearly with grade, and such general conclusions as the one pursued in this note are over-simplistic and do not take advantage of the many advances of Pierre Gy, founder of modern sampling theory.

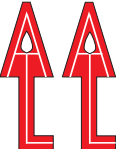
A more fruitful approach based on the work of Pierre Gy<sup>4</sup> and my experience developing sampling protocols over the past 15 years consists of:

1. characterizing the heterogeneity of the ore (i.e. Gy's formula parameters),
2. studying the gold grain size variations as a function of gold grade,
3. finding the grade at which the sampling characteristics of the ore are worst,
4. using this worst-case scenario to assess and correct the protocol for primary RC cuttings, crushed ore and pulp sampling stages.
5. The protocol is then optimized to make sure all these steps have as similar precisions as practically possible.

The overall preparation precision result is shown to be driven by the worst step(s). Either these poor steps can be improved, or if not practical, the other, better steps could be relaxed, as they cost money without fixing at all what makes the overall result poor (interestingly, this relaxing of better


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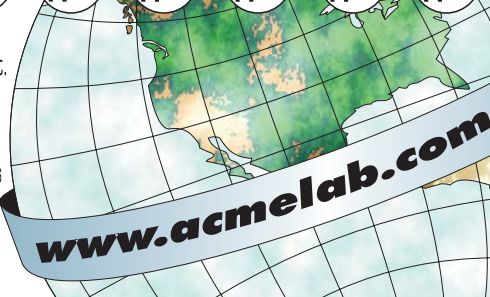
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## Readers' Forum

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steps sometimes paradoxically results in the acceptance of coarser pulverization).

The important point to remember is that this methodology can only be applied on a case by case basis, and that there is not such a thing as a universal, optimal coarse split mass or crushing size.

As far as myths are concerned, the latter, which goes back to the gold rushes, would be the one well worth eradicating.

### Footnotes

<sup>1</sup> The large pulverizers described in the note were designed with the aim of allowing for a larger coarse split after crushing, when it became clear the usual protocols (splitting 500 g at 10 mesh) were inadequate for medium to coarse gold. In reality, in many instances, the usual effect was to reduce the primary sample to 3 kg and skip coarse crushing, with often disastrous consequences.

<sup>2</sup> Sampling is defined as taking a smaller mass expected to represent the characteristics of interest of the whole lot. It is unfortunate the word is also used for the extraction of specimens or measurement supports.

<sup>3</sup> One would argue that the other core half could have been selected, therefore their grade difference is important. This, however, is a classical misconception: in fact, the drill hole could have been drilled 10 cm further to the right, so what about that other difference? And what about 10 m to the left? Where do we stop seeing this difference as a measurement error? The truth is we made a decision to measure the grade at a given location in space along a half cylinder. We could have chosen the full cylinder (usually with little geostatistical gain, in ultimate analysis) but we did not. The difference between the two half cores is why we interpolate the grade between drill holes, thus proving we should never consider/expect the ½ core to be representative of a larger volume of material. Spatially interpolating grades between measurement points, however close to each other, belongs to the domain of geostatistics, a discipline that is separate from sampling theory. In other words, the assumption that the two ½ core samples are sample duplicates, and can be analyzed as such, is simply invalid. Spatial components require different kinds of analysis (e.g. variography) not addressed

by the authors. The only, very rare case where it may make sense to process such data is when one of the two components (natural nugget effect and measurement error) has a variance known to be negligible in front of the other. In all other cases, their separation is not possible and useful conclusions cannot be derived.

<sup>4</sup> The reader wanting to know more about it will be interested in a cycle of international conferences on sampling and bed-blending which started in 2003 and will hold its next instance in Brisbane in May 2005 under the auspices of AusIMM and CSIRO.

### Reply to Dr. Dominique François-Bongarçon:

**Dr. François-Bongarçon takes issue with a number of points in our EXPLORE contribution entitled: "Sample Preparation of 'Nuggety' Samples: Dispelling Some Myths about Sample Size and Sampling Errors". We disagree with much of what he says and discuss his principle points below.**

(1) Dr. François-Bongarçon first suggests that Poisson statistics cannot be used to model sampling error in gold ores because the gold is typically not liberated. This comment ignores the work of Clifton *et al.* (1969), that has long formed the basis of sampling protocols for rare grains in applied geochemistry. This U.S.G.S. Professional Paper details how the *effective* nugget size and the *effective* number of nuggets can be calculated from the relative error of replicate samples of a given size, and how these can be used to estimate the relative error of samples of different sizes. Clifton *et al.*'s (1969) approach makes no attempt to exactly mimic non-ideal sample characteristics (such as full liberation, or constant grain size and shape), but rather employs an ideal 'equant grain model' that exhibits exactly the same variance structure of the material under examination. Using this Poisson-based model, predictions regarding the magnitude of sampling error can be made for samples of different size.

A follow-up publication, Stanley (1998), describes freeware; available for download from the website <http://ace.acadiau.ca/~cstanley/software.html> to undertake these calculations.

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## Readers' Forum

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These papers present compelling evidence, both theoretically and empirically, that the sampling error in material containing nuggets is essentially controlled by the largest nuggets (with examples from a range of deposit types: gold and platinum deposits, diamondiferous kimberlites, and rare earth element-bearing pegmatites). These illustrate that the size distribution of nuggets in the sample is generally of subordinate concern when considering sampling error. Rather, it is the largest nuggets that exert the most influence on the sampling error magnitude.

Instead of a Poisson model, Dr. François-Bongarçon suggests that the well-known sampling formula of Pierre Gy (1982) should be used because he claims that it, unlike Poisson statistics, accounts for grain size distribution. If one examines Gy's formula in detail, one will find that it employs a parameter called a 'granulometric factor' ( $g$ ) which is supposed to accommodate the effect of a range in grain sizes on sampling error. This factor is merely the ratio of the diameter of the largest (nominal) spherical grain in a particulate material that fits through a given mesh, to the diameter of the average grain in the material, raised to the power of three. As a result, this factor is merely used to convert grain volume described in terms of a mesh that passes a certain percentage of particles to the

average particle volume in the particulate material. In fact, this 'average grain size' is equivalent to the 'effective grain size' originally described and used by Clifton *et al.* (1969) in his model. Clifton *et al.* (1969) calculates this effective grain size by the formula:

$$d = \sqrt[3]{\sum_{h=1}^p \frac{m_h}{m_t} d_h^3}$$

This formula determines the volume-weighted mean diameter of particles in a sample, where the  $m_h$  are the masses of each of the  $p$  grain size ranges that a particulate sample has been sieved into, the  $d_h$  are the average diameters of these grain size categories,  $m_t$  is the total mass of the sample, and  $d$  is the 'effective grain size' or 'average grain size' of the nuggets. This formula is used in the Poisson-based approach of Clifton *et al.* (1969) and Stanley (1998) to model sampling error in materials with rare grains. Clearly, both Gy's (1982) formula and the Poisson-based approach of Clifton *et al.* (1969) accommodate, in exactly the same way, the grain size distribution of the material.


However, Gy's formula is based on and derivable from the binomial theorem. Consequently, Gy's formula doesn't apply to samples containing very low concentrations of elements contained in rare grains (e.g.,

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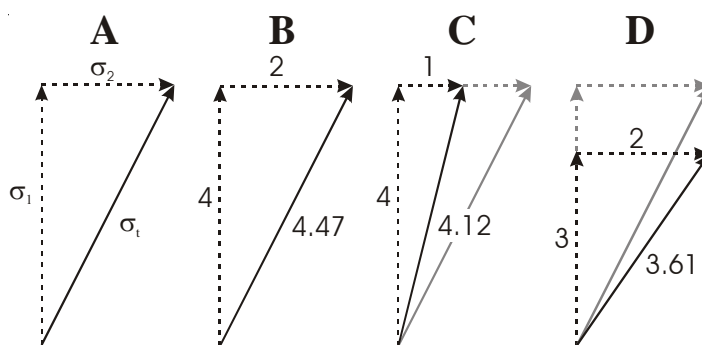
Au, PGE, diamonds, *etc.*), where a Poisson relation is applicable. Our avoidance in referencing Gy stems directly from the fact that we consider samples containing nuggets a scenario that is inconsistent with Gy's approach.

- (2) Dr. François-Bongarçon also claims that core splitting is not a sampling operation. Whereas some might consider this a semantic argument, it is not. If a whole material (the core) is divided into halves and one part is collected, it is sampled. The core halves could be obtained by dividing a vertically oriented core along N-S or E-W (or any other cut or broken) planes, or by dividing the core into one cm thick vertically stacked cylinders and collecting every other piece in the sample. Some of these formats may produce better samples than others, but in all cases, the core is sampled. One could easily also collect the remaining half of the drill core, and this would represent a second, 'duplicate sample'. The variation observed between the grades of the two duplicate samples thus estimates the 'sampling error'.

Dr. François-Bongarçon then carries his argument further, referring to drilling in a slightly different location (10 m to the left or right) to obtain a different piece of drill core and a different grade. This is not the problem (spatial variation) we are addressing, and is irrelevant to the discussion.

- (3) In his comments, Dr. François-Bongarçon indicates that "primary sampling variance *can* indeed be controlled by adequate sample mass". Although this is true in theory (a larger sample will most-often reduce sampling error), it is often times not achievable in practice. This is because geologists do not normally have access to infinite sample masses. Economic, logistical and physical constraints limit the size of sample that can be obtained and sampled, and oftentimes the available sample mass remains inadequate (mostly because of the 'nugget effect'). As a result, sometimes geologists have problems controlling sampling variances.

Dr. François-Bongarçon goes on to indicate that "all stages of the (sampling, preparation and analysis) protocol are important, no one less than the others." This is true, but only in the most general sense, as some stages of a sample treatment protocol introduce errors that are much larger than do other stages. The largest sources of errors are the most important to any sampling effort from a practical point of view, because their reduction can most expeditiously reduce the total error. Reducing a lesser error can never be as efficient. This is illustrated by the drawings in Figure 1, which demonstrate that a reduction in the error with the smaller standard deviation reduces the total error less than a similar reduction in the error with the larger standard deviation.



**Figure 1** – Graphical illustration of the effect of component error reduction. (A) Pythagorean relationships between component ( $\sigma_1$  &  $\sigma_2$ ) and total ( $\sigma_t$ ) errors, (B) initial component and total error magnitudes

$$(4.47 \approx \sqrt{4^2 + 2^2} = \sqrt{20}),$$

(C) component and total error magnitudes after reduction of smaller component error by 1 unit

$$(4.12 \approx \sqrt{4^2 + 1^2} = \sqrt{17}),$$

and (D) component and total error magnitudes after reduction of larger component error by 1 unit

$$(3.61 \approx \sqrt{3^2 + 2^2} = \sqrt{13}).$$

The maximum reduction in total error occurs when the largest component error is reduced.

Hence the emphasis in our original **EXPLORE** communication addressing the measurement and reduction of the field component of measurement error, the largest error in our two examples and at most other mineral deposits we have evaluated. In order to measure the error related to selection of the initial sample (effectively caused by the geology of the sample), the error introduced at each step of the subsequent sample size reduction process in the laboratory also must be measured. The difference between the laboratory errors and the total error measured by the field duplicates is the error related to 'geology'. It is this error that we hope to quantify, and ultimately reduce. This is, after all, the point of the whole process: to obtain an estimate of (and limit the) risk on the analyses being generated.

- (4) Dr. François-Bongarçon claims that "the graphs presented are unrealistic", and that "sampling standard deviations have no reasons whatsoever to increase (with grade)". The Thompson and Howarth approach (Thompson & Howarth 1973, 1976a, 1976b, 1978; Thompson 1973, 1982; Fletcher 1981; Stanley & Sinclair 1986; Stanley 2003) that we used to make our graphs and estimate measurement error was an empirical, valid and convenient method for our purposes. Thompson and Howarth's approach employs a linear model to characterize measurement error (sampling, preparation, analysis, whatever) as a function of grade. A linear model was used by Thompson and Howarth for two reasons: (1) because the poor estimates of error from duplicates do not allow one to legitimately employ a more

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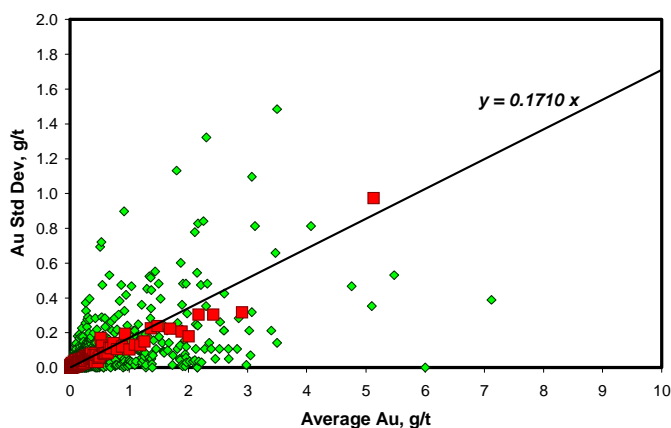
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complicated non-linear model, and (2) because, on empirical grounds, a linear model seemed to fit the analytical data that they were generating and for which they were using to describe the errors. We have used the identical linear model on our data, precisely because it also fits our data (Figure 2). We would be the first to use an appropriate non-linear model (e.g., a Poisson curve) if the data warranted, but because the relationships are demonstrably linear, it would be inappropriate to try to fit a curve to these data.

### Sampling Duplicates

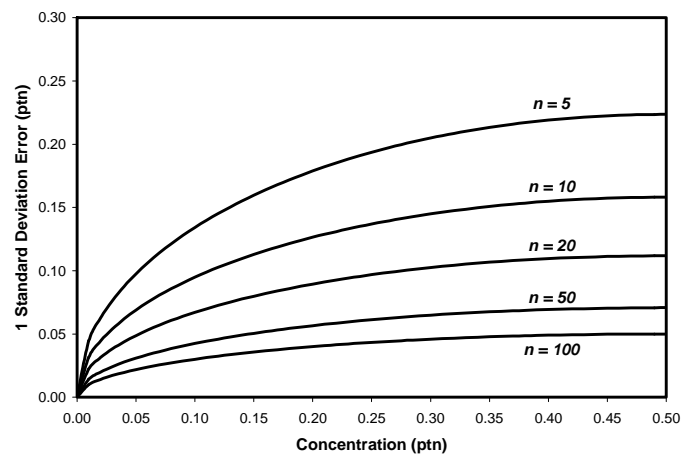


**Figure 2** – Modified Thompson-Howarth replicate error plot illustrating 3488 duplicate Au determinations from rotary reverse circulation samples (diamonds), and mean averages and standard deviations of groups of 11 duplicates (squares) for samples from an anonymous intrusion-related gold deposit. The grouped data define a linear relationship between concentration and error.

Dr. François-Bongarçon's contention that the standard deviations shouldn't increase with concentration is also inconsistent with his preference to use Gy's sampling formula (1982) to model sampling error. This inconsistency derives from the fact that the binomial theorem, on which Gy's sampling model is based, defines a sampling variance that increases with concentration according to the formula:

$$\sigma_c = \sqrt{\frac{c(1-c)}{n}}$$

where  $c$  is the element concentration (expressed as a proportion),  $n$  is the total number of grains in the sample, and  $s_c$  is the standard deviation of the concentration (expressed in proportion units). This formula describes a curve in concentration-error space that starts at the origin, rises steeply at low concentrations, and then shallows at higher concentrations (Figure 3). As a result, if Gy's (1982) sampling formula were to be applied to these case histories, the sampling error modeled would increase with concentration.



**Figure 3** – Examples of binomial sampling error models with different sampling parameters ( $n$ ). Values are expressed in proportions (ptn). Maximum sampling error occurs at a concentration of 50%.: Larger  $n$  define binomial sampling error models with smaller errors. At low concentrations, sampling error increases in a curvilinear fashion with increasing concentration.

(5) That Dr. François-Bongarçon is a major proponent of Gy's sampling theory is clear. Unfortunately, although Gy's sampling formula is applicable in ores that do not suffer from a nugget effect, the high regard that Dr. François-Bongarçon holds for this theory is not ample justification for its use to model sampling error in 'nuggety' materials.

Sincerely,  
**Cliff Stanley**  
**Barry Smee**

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## Focus on: National and Global Scale Geochemical Mapping for Mineral Exploration and Assessment in China



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### Abstract

Geochemical mapping projects in China have provided or are providing a huge amount of information for mineral resources and have made a significant contribution to mineral discoveries due to the high-quality, consistent, and informative data. In this paper, the author takes 3 geochemical mapping projects in China as examples to describe the ideas, methods and roles of geochemical mapping in mineral exploration and assessment: (1) China's National Geochemical Mapping Project (Regional Geochemistry - National Reconnaissance Project, RGNR project) has covered 6 millions of km<sup>2</sup> of China's outcropping regions during the past 25 years mainly using stream sediment samples at a sampling density of 1 per km<sup>2</sup> with analysis for 39 elements. It is one of the most successful geochemical mapping projects for mineral exploration. (2) Deep-penetrating geochemical methods are developed for hidden deposits in the remaining concealed terrains in China, which the RGNR project using stream sediment samples is limited. In order to quickly and cheaply delineate broad geochemical patterns for metallogenic belts or giant ore deposits in large diverse concealed terrains, wide-spaced sampling at a density of 1 sample per 100-800 km<sup>2</sup> was used. In the past 10 years approximately 800 000 km<sup>2</sup> have been covered and new large-scale geochemical patterns favorable for giant ore deposits have been delineated in concealed terrains. (3) Global geochemical mapping in China has been conducted since 1993 as part of the International Geochemical Mapping Project (IGCP259) and the Global Geochemical Baselines project (IGCP360). Five hundred flood-plain sediment samples were collected in large river catchments that cover China and 51 elements were determined according to the IGCP259/360. Some large

geochemical anomalies such as Pt and Pd have been delineated that were entirely unknown before. This shows the great potential role of global geochemical mapping in evaluation of the world mineral resources and prediction of the most favorable regions for discovering new large to giant ore deposits.

### Introduction

Hawkes and Webb in the 1960s emphasized that geochemical mapping is the aspect of geochemistry of most importance in geochemical prospecting (Hawkes and Webb, 1962). Since the late 1970s, many regional and national geochemical mapping projects with areas of thousands to millions of km<sup>2</sup> were carried out and geochemical maps or atlases have been compiled at various scales. However, many geochemical mapping projects have not played significant roles in mineral exploration. The reasons are that: (a) Many key mineralization elements were not analysed due to analytical problems, (b) The information for trace and sub-trace elements such as Au, Ag, Hg, W, Mo etc. is insufficient due to the high detection limits, (c) The results are not comparable due to the lack of quality control using standard reference samples and standard methods.

Chinese geochemical mapping projects have made the most significant contribution to mineral exploration and new discoveries in China due to the high-quality, consistent, informative and national comparable data. In this paper, the authors will take 3 geochemical mapping projects in China as examples to describe the ideas, methods and roles of geochemical mapping in mineral exploration..

### 1. China's National Geochemical Mapping Project

China's National Geochemical Mapping Project (Regional Geochemistry - National Reconnaissance Project, RGNR project) was initiated in 1978. It has covered 6 millions of km<sup>2</sup> of China's territory during the past 25 years. It has proven to be one of the most successful geochemical mapping projects in the world, not only because of the immense coverage area and the magnificent contribution to mineral exploration in China, but also because of its creative ideas about obtaining more consistent, informative and national comparable data (Xie et al., 1997).

Different sampling methods have been developed for different landscape and topographic environments in China. Stream sediment samples were used as a sampling medium

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## Obituary for Joe Brummer

On January 17, 2005 the world of Applied Geochemistry lost a strong supporter and good friend.

Johannes Jacobus (Joe) Brummer was born in Graaff Reinet, Cape Province, South Africa on September 2, 1921. He was an economic geologist (although he would frequently refer to himself as just a prospector). He obtained degrees in mining engineering (1943) and mining geology (1945) from Witwatersrand University, South Africa and his doctorate from McGill University (1955), Montreal.

Joe was probably one of the most successful mine finders ever. He was responsible for finding Cu mines in Zambia, Ni and Cu-Zn deposits in Manitoba as well as Zn and U deposits in Saskatchewan.

His early work as a geologist in Zambia between 1947 and 1953 on the Zambian Copper belt is well known. He created with W.G. Garlick the unconformity/strata bound model for the Copper Belt contrary to the commonly held notion at that time that these orebodies were hydrothermal.

Subsequently his findings were successfully applied to the discovery of new deposits along the belt. During this same period, less well known but just as significant, was Joe's support of exploration geochemistry research at a time when the Western world was just learning about the subject. Most geochemists who graduated from the Royal School of Mines during that time were guided and supported by Joe Brummer in the application of geochemistry to mine finding in the Zambian Copper belt. Subsequently such discoveries as the deeply buried Kalengwa Mine (see World Mining, June 1972) would be found using geochemical techniques developed under Joe's tutorship.

With this background in sedimentary ore deposits he arrived at McGill University in 1953 to pursue his PhD and to study and research the Gaspé Copper ore bodies. He mapped and described for the first time the alteration aureole about the deposits and classified the Aiguille Mountain ores as replacement deposits and the Copper Mountain zone as a later staged porphyry-type ore body. To this day this study is still the bible for exploration geologists searching for these deposits in the Appalachians.

While employed by Kennco Explorations Ltd. (1955-61) he initiated the first reconnaissance geochemical stream sediment surveys in the Cordillera and he carried out the first-geochemical stream sediment survey in the Canadian Shield, (Seal Lake). In reporting on the latter J.J. Brummer (CIM Bull., April 1960) remarked "*The project, which was primarily aimed at evaluating the copper potential of the area, had, by the use of geochemistry, finished up discovering lead, zinc, thorium and columbium mineralization*". The Cordillera studies were also successful in indicating the presence of a variety of mineralized areas and occurrences (eg. Huckleberry, Galore Creek, Sam Goosly). In addition to the above geochemical work Joe found time to study and publish on the copper-uranium mineralization in the Carboniferous sandstones of Nova Scotia.

By his bold, aggressive and at all times unconventional approach to mineral exploration Joe laid the ground work for systematic reconnaissance geochemical surveys in

Canada. The subsequent impact of this exploration tool on economic geology is well known.

His record of successes continued after he joined Falconbridge Nickel Mines Ltd (1961-70). He applied geological concepts, geophysical methods (E-M and seismic) and deep drilling techniques to the Manitoba Nickel Belt, which resulted in the discovery of such nickel deposits as Manibridge, Bowden Lake and Bucko Lake. At Stall lake, Manitoba, he and his team succeeded where others had failed, they found the down plunge extension of the Rod Cu-Zn deposit. Also, in Saskatchewan, Joe successfully applied boulder tracing and a study of the Pleistocene geology to locate the George lake zinc occurrence.

In 1970 he joined Canadian Occidental Petroleum and headed up their mineral division. In 1976 he was responsible for the first reconnaissance Alphameter survey carried out in the Athabasca uranium province. In 1979 under his leadership a vertical drill hole through the center of an a Alphameter-EM anomaly intersected ore grade uranium mineralization beneath 162 meters of Athabasca sandstone-the McClean Lake uranium mine was born.

Joe's superb record of discoveries did not come about by chance. They resulted because he was a knowledgeable economic geologist with extensive experience and interest in many commodities. He was willing to try the untried, to encourage and support applied research in mineral exploration, to be straightforward in his approach, to use every aid at hand, to act quickly and to be very supportive of his geological staff. He was thorough in his research and exploration efforts. He led in the development and applications of new or relatively untried techniques especially in the search for deeply buried deposits and the evaluation of mineral belts.

Unlike many mineral exploration geologists he managed to publish accounts of much of his work and has authored or co-authored 41 papers dealing with a variety of subjects including: mineral deposits geology, geochemical exploration, diamond exploration, gemology, as well as review papers on exploration geochemistry in Canada and diamonds in Canada.

He was the recipient of the Barlow Gold Medal (CIM) in 1978 and in 1984 the GAC awarded him the Duncan R. Derry medal for his major contributions to economic geology.

Not only was Joe an explorationist par excellence, he was also a sincere, honest and forthright person – his equal will not be soon seen.

Joe leaves his ever loving wife and indispensable partner, Eve as well as his sons Douglas and William and grandchildren Katherine and Nicholas.

God bless you Joe.

February 8, 2005

**Chris Gleeson**

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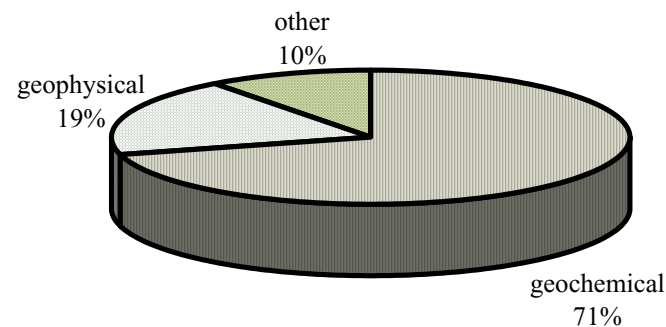


for the mountainous and hilly terrains in China at a sampling density of 1 sample per km<sup>2</sup>. Sampling of lag materials or rock debris was developed for desert and semi-desert terrains in northern China. Fine stream sediments and pond sediments or soils were used as sampling media in karst terrains in southern China. Very low-density sampling of stream sediments taken from the mouth of large tributaries was developed for mountainous areas in southwestern China. Analytical problems are a major issue in geochemical mapping. Taking into account issues with geochemical mapping projects in other parts of the world, general guidelines were developed for multi-element analysis (Xie, 1978; Xie, 1995). These include: (1) Detection limits of trace and sub-trace elements must be lower than their crustal abundance values. (2) The analytical data must be inter-laboratory or nationally comparable. (3) Multi-method and multi-instrument approaches should be used.. (4) Analytical quality control procedures have to be established using standard reference samples to monitor the inter-laboratory and within-laboratory bias.

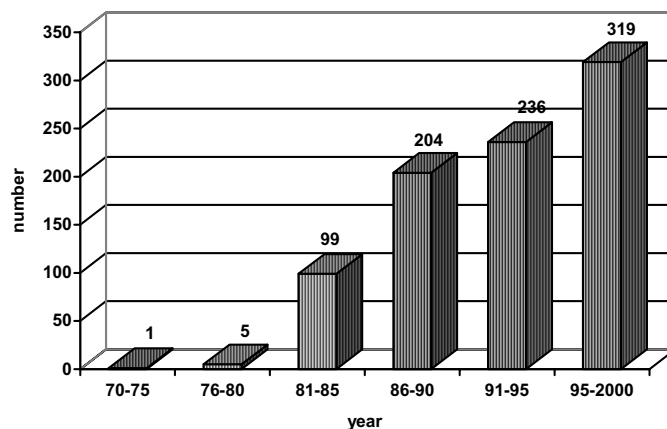
A multi-element analytical system using XRF as the main technique with AAS, GFAAS, AF, ES, POL, COL, ISE and LF was developed to determine 39 elements by following the above principles.

Up to 2004, the project has covered all hilly and mountainous terrains of China, an area of more than 6 million km<sup>2</sup>. Approximately 850 geochemical map sheets at a scale of 1:200 000 with 39 elements have been compiled.

Statistics show that 71% of the total mineral ore deposits have been discovered by geochemical methods, 19% by geophysical methods, 10% by other methods during the period 1981-2000 (Figure 1). Among the new discoveries by geochemical methods, precious metal deposits make up over 70%. Figure 2 shows the number of gold deposits discovered by geochemical methods from 1970-2000. The number of gold discoveries has increased by leaps and bounds since 1980s as result of RGNR project which started in 1978. The most exciting of them is the discovery of two world-class gold camps with gold reserves in excess of 500 tonnes. One occurs in the greenstone belt located at Xiaoqinling on the boundary of Henan and Shaanxi Provinces. Another occurs in carbonate terrains of southern China and has become the second largest Carlin-type gold camps in the world. The



**Figure 1:** Geochemical methods have played an important role in the discoveries of 817 new deposits in China during the period of 1981-1995.



**Figure 2.** Number of gold deposits discovered by geochemical methods from 1970 to 2000.

reasons of success in gold exploration in China were described in Xie and Wang (1991) and Wang and Xie (2000).

### Case history 1.1: Discovery of Shanggong gold deposit, Henan province, central China

The Shanggong gold deposit located at Xiaoqinling-Xiongershan hilly to mountainous terrane on the boundary of Henan and Shaanxi province is the first successful case history of gold discovery by using regional stream sediment survey. In the region, Mesozoic granite intrudes Archean metamorphic greenstones. These geological settings are favorable for gold mineralization. However, no economic ore body has been found by geological exploration for many years.

In 1978 a regional stream sediment survey which was as an orientation study for the RGNR Project was conducted across an area of 1470 km<sup>2</sup> at Shanggong area (Figure 3) at a sampling density of 4-5 samples / km<sup>2</sup> (Gong and Wang, 1984). Two to three hundred grams of a fine fraction from the stream sediments was collected at the mouth of the first order of streams. The samples in each square kilometer were mixed together to make a composite sample for analysis. The composite samples were ground to -200 mesh. A 10 gm sub-sample was taken for Au analysis by using chemical pre-concentration emission spectrography with a detection limit of 0.3 ppb.

A regional anomaly with an area of approximately 1000 km<sup>2</sup> was delineated by a threshold of 2 ppb Au (Figure 3). The anomaly is distributed along the boundaries of greenstones and granites and volcanic or sedimentary rocks. Within the regional anomaly, there are 4 strongly anomalous areas delineated by a 3 ppb contour. The largest anomalous center with an area of 150 km<sup>2</sup> occurred at Shanggong with a highest value of 1100 ppb at the center. In 1980 a detailed soil survey was conducted at the center by using a sampling grid of 100 m by 50 m. Three Au anomalous belts associated with As and Ag were delineated and alteration along NE trending faults was found. Large ore bodies were proven by 15 drill holes after a trenching program across the anomalous belts in 1982.

It was due to this successful discovery that a regional stream sediment survey was carried out on two 1:200,000 sheets totaling an area of approximately 15000 km<sup>2</sup>.

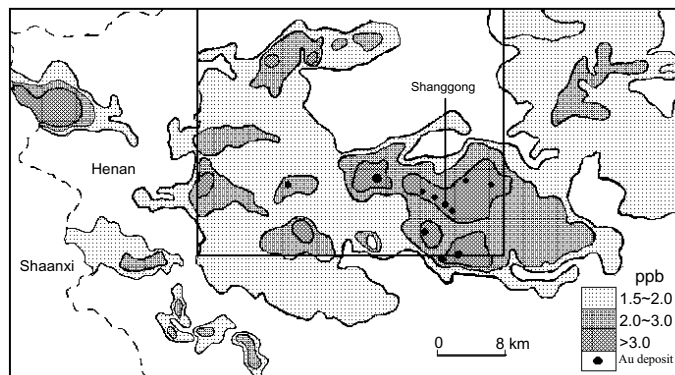
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## Focus on: National and Global Scale...

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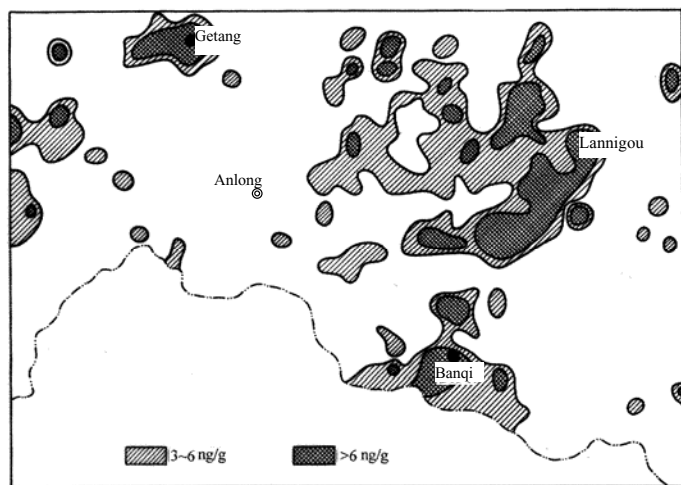
Hierarchically nested geochemical patterns have been delineated. A number of gold deposits with gold reserves of more than 500 tonnes were discovered by a follow-up and detailed survey (Figure 3).



**Figure 3:** Hierarchically nested geochemical patterns. A geochemical province with an area of approximately 15000 km<sup>2</sup> delineated by a threshold of 1.5 ppb, regional anomalies delineated by a threshold of 2 ppb. A number of gold deposits with gold reserves of more than 500 tonnes were discovered by a follow-up and detailed survey.

### Case history 1.2 Carlin-type gold deposit, carbonate terrain, Guizhou, southwestern China

In 1984 as part of the RGNR project a regional geochemical survey was conducted on the Anlong 1:200 000 sheet over carbonate terrain in Guizhou province, southwestern China. Three regional geochemical anomalies of Au with a threshold of 3 ppb and As, Sb and Hg were delineated (Figure 4). The largest one covers an area of 800

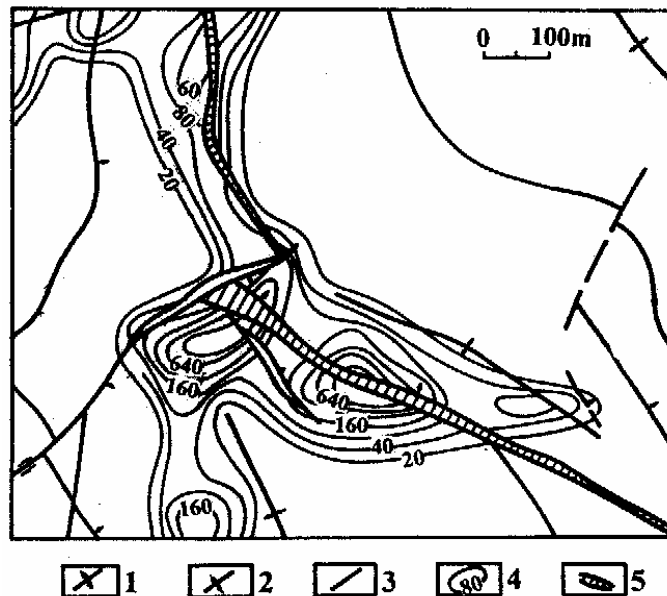


**Figure 4:** Regional geochemical anomalies of Au delineated by stream sediments in Anlong map sheet at scale of 1:200,000

km<sup>2</sup> and contains a large concentration center with a contour of 6 ppb.

In 1986 a follow-up stream sediment survey and geological mapping at a scale of 1:50000 was carried out. Mineralization of realgar and cinnabar in rocks was discovered and 51 rock samples were analyzed for gold. Twelve samples had gold values over 1.5 g/t. A detailed soil

survey was conducted and a concentration center was delineated. A large gold ore body with gold reserves of more than 100 tonnes was evaluated by drilling program at Lannigou (Figure 5).



**Figure 5:** Gold ore bodies discovered within the concentration centers delineated by detailed soil survey (modified from Zhou et al., 1996). Gold in ppb.

This successful discovery led to a series of discoveries of Carlin-type gold deposits in carbonate terrains of southern China, which has become the second largest Carlin-type gold belt in the world next to that in Nevada of the USA.

### 2. Deep-penetrating geochemical survey for large ore deposits in concealed terrains

The China's National Geochemical Mapping Project mainly using stream sediments has covered all the outcropping or thinly overburden terrains and totals approximately 6 millions km<sup>2</sup>. The remaining large diverse concealed terrains in China still remain to be covered by geochemical mapping. However, geochemical methods using conventional stream sediment survey are not suitable or have limited application in searching for deposits hidden under thick cover of transported overburden or thick sequence of post-ore volcanic or sedimentary rocks.

Recently, deep-penetrating geochemical methods including Selective Leaching of Mobile Forms of Metals in Overburden (MOMEQ) and Collection of Nanoscale Metals in Earthgas (MAMEG) have been developed (Wang et al., 1997; Wang 1998; Wang et al., 1999; Xie et al., 1999). The methods have been studied in detailed and regional surveys. The research is focused on geochemical mapping using wide-spaced sampling at a density of 1 sample per 100-800 km<sup>2</sup> in order to delineate broad geochemical patterns for giant ore deposits in diverse concealed terrains. The sampling methods and analytical procedures have been developed for desert terrains, alluvial plain, grassy and forestry lands (Wang et al., 1997). In the past 10 years, approximately 800 000 km<sup>2</sup> has been covered. Large-scale geochemical patterns consistent with or favorable for giant ore deposits or large metallogenic belts have been delineated in concealed terrains.

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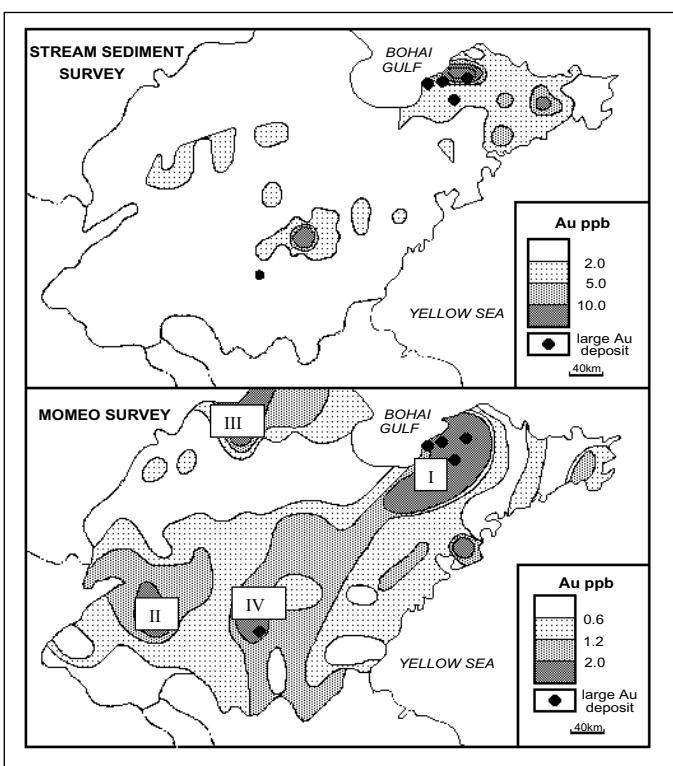
## Focus on: National and Global Scale... *continued from page 26*



### Case history 2.1: Wide-spaced sampling in alluvial terrain, eastern China

As a part of the Circum-Pacific Rim metallogenic belts, Eastern China has attracted researchers and exploration activities for many years. Many mineral deposits have been discovered in the region. The largest gold field in China is in the northeastern Shangdong province, located in the easternmost part of the study region. However, the transported alluvial overburden prevents assessment of the mineral potential. Cost-effective regional geochemical methods for penetrating through the alluvium and delineating geochemical provinces generated from large ore metallogenic provinces have been applied.

A deep-penetrating geochemical survey at a sampling density of 1 sample per 400km<sup>2</sup> was carried out on an area of 160 000 km<sup>2</sup>. Figure 6 shows distribution of Au by using the Selective Leaching of Mobile Metals method. It clearly shows that four large regional anomalies (I, II, III and IV) with gold values of more than 2.0 ppb have been delineated in the study region. Among them, the largest one (I) approximately 6 000 km<sup>2</sup> in the northeastern region, is not only consistent with the distribution of the known large and giant gold deposits but also extends further south into the transported overburden areas. This will facilitate the search for new concealed deposits. The Regional Geochemistry - National Reconnaissance (RGNR) project using stream sediment surveys analysed the <0.2 mm fraction and failed to give any response in this transported overburden region. The southern anomaly (II) of more than 2.0 ppb has been delineated around another known large gold deposit, which



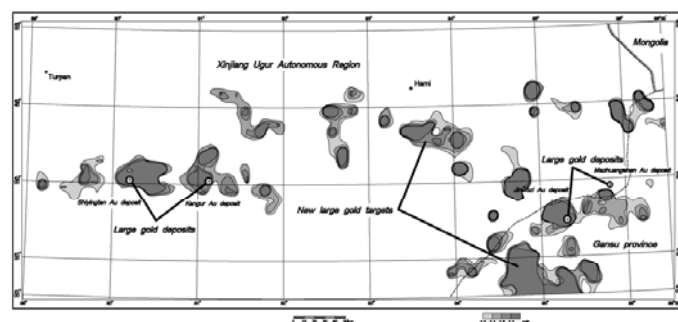
**Figure 6:** Comparison of gold distribution patterns delineated by using stream sediment survey and deep-penetrating survey.

the stream sediment data also failed to indicate because of the transported cover. The other two large regional anomalies (III) and (IV) in the NW and SW concealed regions are unknown and still remain to be further investigated. A geochemical province delineated by the content contour of 1.2 ppb is distributed along the Tanlu deep fault system, but the concentration centers delineated with higher values are distributed in the secondary faults on both sides of the deep fault system.

### Case history 2.2: Wide-spaced geochemical survey in arid desert terrains, northwestern China

Northwestern China is a large unexplored or under-explored terrain. Substantial areas are extremely arid and covered by regolith sediments concealing prospective bedrock sequences. More recently, interest was rekindled by the discovery of a large porphyry copper deposit with copper reserves of more than 10 millions of tons in the desert terrain of the Eastern Tianshan, Xinjiang, northwestern China.

In order to quickly get an overview of the mineral potential of covered terrain, wide-spaced sampling was carried out in an area of approximately 150 000 km<sup>2</sup> at a density of one sample per 100 km<sup>2</sup>. Fine fractions of regolith samples were collected from the weakly-cemented sandy horizon at a depth of 20-40cm. The soil samples were subjected to analysis for 33 elements as determined by ICP-MS/OES, GF-AAS, HG-AFS and CP-AES. Geochemical maps and interpretation maps using GIS were generated. Figure 7 shows that the results not only give prominent expression to the known large gold deposits but also delineate new large-scale targets of gold. New occurrences of gold have been discovered by a preliminary follow-up survey within these new geochemical anomalies.



**Figure 7:** Gold anomalies delineated by wide-spaced deep-penetrating geochemical survey in desert terrain, northwestern China.

### 3. Global Geochemical Mapping in China

Research on global geochemical mapping in China has been conducted since 1993 as part of the International Geochemical Mapping Project that commenced in 1988 (IGCP259) and the Global Geochemical Baselines project (IGCP360) that commenced in 1995. The aims of the IGCP259 are to establish a common primary database at an international level and to provide a framework for the adoption of standardized methods for national mapping. The aims of the IGCP360 are to cover the whole land surface of the earth with approximately 5000 sampling cells and to

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determine 71 elements of the composite samples collected from these cells (Darnley, et al., 1995). The results obtained from the two projects could provide geochemical maps and natural geochemical background values of our planet, a network for monitoring the earth's environment and a frame of reference for more detailed national geochemical mapping.

There has been much controversy and debate about the selection of sampling media with representative average values of elements for each 160 km×160 km cell. The Environmental Geochemical Monitoring Networks Project (the EGMON project) (Xie and Cheng, 1997) was launched in 1993 as a pilot study for the IGCP360 trying to find a suitable universally available sampling medium that represents a very large area. Five hundred flood-plain sediment samples were collected in large river catchments over the whole country (Fig. 8) and 51 elements were determined according to the IGCP259 recommendation. The geochemical maps produced by such wide-spaced sampling are surprisingly similar with the maps based on the RGNR project data (Figure 9). Although the original purpose was for environmental monitoring, some large geochemical anomalies such as Pt and Pd have been delineated (Figure 10). The gigantic Pt-Pd endowment in this block shows great promise for discovering economic Pt-Pd mineralization. An exploration strategy of progressive reduction of the target area and stepwise increase of the sampling density was undertaken. This example shows the great potential role of global geochemical mapping in evaluation of the world

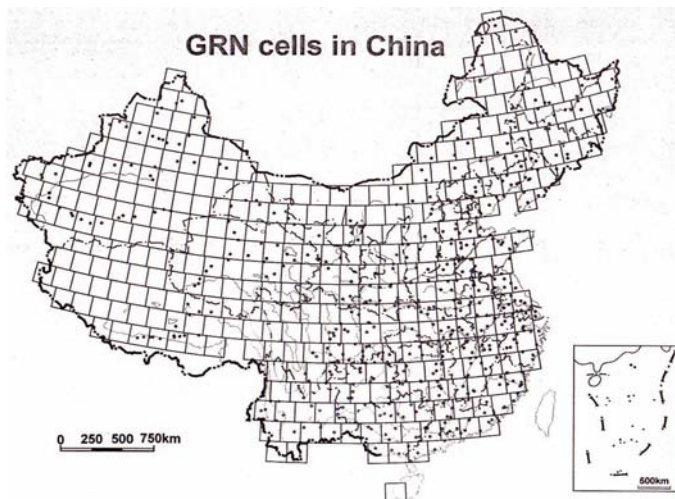


Figure 8: Global geochemical sampling sites with the GRN cells in China.

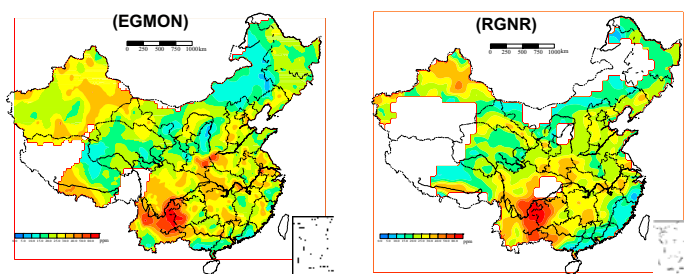


Figure 9: Comparison of copper geochemical maps in China by the RGNR project and the EGMON project. EGMON: 500 flood-plain sediment samples in whole of China, RGNR: 1 stream sediment sample per sq.km and approximately 1,500,000 samples in whole of China. Both maps are produced using average values taken from each 160km by 160km cell.

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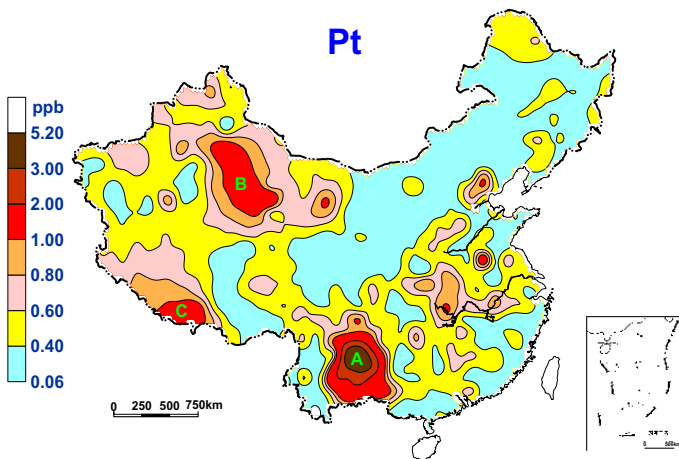


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## Focus on: National and Global Scale...

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**Figure 10:** Geochemical distribution of Pt in China.

mineral resources and prediction of the most favorable regions for discovering new large to giant ore deposits.

#### 4. Conclusions

Geochemical mapping at various scales can provide a huge mass of information for mineral resources. It enables geochemists to delineate geochemical patterns at local, regional, to even global scales. The huge mass of direct information and broad geochemical patterns will reduce uncertainty and risk in mineral exploration. Geochemical mapping has greatly extended the ability of the naked eye to recognize direct signals from mineral resources by sensitive analytical methods. This makes it practical to find “micro ore outcrops” which were not observable with the naked eye even in outcropping or sub outcropping terrains. We are underway in detecting extremely faint signals from deeply concealed deposits using ultra-sensitive deep-penetrating geochemical methods. These methods will make a great contribution to mineral exploration in large unexplored or under-explored covered terrains in the future.

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