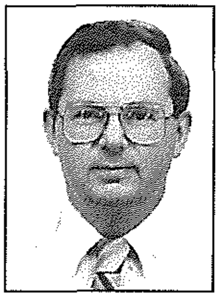
EXPLORE

Newsletter for the Association of Exploration Geochemists

NUMBER 93 OCTOBER 1996

PRESIDENT'S MESSAGE


Bill Coker

While this year has been a relatively quiet one for the Association of Exploration Geochemists (AEG), our membership has been very active preparing for next year, which will see us involved in a number of major meetings. First and foremost among them is the 18th **International Geochemical Exploration Symposium** (IGES) to be held in Jerusalem, Israel, May 25-29, 1997. You all should by now have received the "First Circular and Call for Papers" which outlines the session themes, workshops and field trips planned for the meeting. If you have not done so, please take time to look over this material and to reply to the organisers to let them know of your plans—as an attendee, as the presenter of a talk or poster, or as a participant on a field trip.

Our members are also heavily involved in organising the **4th International Symposium on Environmental Geochemistry** (ISEG) to be held in Vail, Colorado, USA, October 5-10, 1997. You should have received the "Second Circular and Call for Papers" for this meeting. In addition, several of our members are involved in organising and will be giving presentations at **Exploration '97** to be held in Toronto, Canada, September 14-18, 1997. Other meetings and workshops, several of which our members are involved with, are listed in the Calendar of Events within **EXPLORE**.

The current membership of the AEG is around 1,050 and shows healthy growth with new members around the world. However, we are finding ourselves in a situation where we are starting to not have enough exploration-oriented papers for the Journal of Exploration Geochemistry. Symposium Volumes and several Special Issues have helped fill the shortfall, but as of next year we could see a problem. It appears that this is due to a number of factors among which include: the major cut backs at many of the national and provincial/state geological surveys and government-funded research institutions which has affected the exploration geochemistry groups therein; cut backs, and loss or retirement of people teaching exploration geochemistry at universities, resulting in a real lack of students studying exploration geochemistry and hence writing papers; the need for all of these organisations, as a result of the aforementioned, to seek funds for research elsewhere, which in many cases produces research results which remain confidential for varying periods of time; and, the fact that most industry exploration geochemists are pretty stretched and do not have a lot of time, and in many instances permission, to publish the results of their research and work. On the other hand, there appears to be no shortage of environmentally-oriented geochemical papers out there as witnessed by the outstanding submission

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SPECIAL COLOR MAPS

Personal Computer (PC)-Based Methods for Integrating, Processing and Visualizing Multivariate Data: Review of Geology, Till Geochemistry, Lake Sediment Geochemistry, and Airborne Geophysical Data from the Beardmore-Geraldton District, Ontario, Canada

by Greg Hollyer and L. Harvey Thorleifson

Multivariate data collected from geological, geochemical and geophysical sources historically have not been managed and evaluated in a single PC-based environment. This tendency is, in part, due to the lack of techniques for integrating, processing and visualizing high-volume datasets from different sources. In this short discussion, the objective is to review the methodologies used to integrate, process and visualize a multivariate dataset originally acquired by the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS) in the vicinity of the Beardmore-Geraldton Greenstone Belt in Ontario. Although some methodologies, such as geostatistical kriging, that were employed are quantitative, this exercise was primarily qualitative in nature and was intended to illustrate practical techniques that can help set the stage for more detailed numerical and statistical analysis.

Multivariate Data Overview

The geochemical data available for this exercise included raw Excel and Lotus format spreadsheet data from a 1989 lake sediment survey and a 1991 till geochemistry survey conducted by the GSC and the OGS. High-quality geochemical data were acquired using rigourous sampling and

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Information for Contributors to EXPLORE

Scope This Newsletter endeavors to become a forum for recent advances in exploration geochemistry and a key informational source. In addition to contributions on exploration geochemistry, we encourage material on multidisciplinary applications, environmental geochemistry, and analytical technology. Of particular interest are extended abstracts on new concepts for guides to ore, model improvements, exploration tools, unconventional case histories, and descriptions of recently discovered or developed deposits.

Format Manuscripts should be double-spaced and include camera-ready illustrations where possible. Meeting reports may have photographs, for example. Text is preferred on paper and 5- or 3-inch IBM-compatible computer diskettes with ASCII (DOS) format that can go directly to typesetting. Please use the metric system in technical material.

Length Extended abstracts may be up to approximately 1000 words or two newsletter pages including figures and tables.

Quality Submittals are copy-edited as necessary without re-examination by authors, who are asked to assure smooth writing style and accuracy of statement by thorough peer review. Contributions may be edited for clarity or space.

All contributions should be submitted to:

EXPLORE
c/o J.T. Nash, Box 25046, MS973, Denver Federal Center
Denver, CO 80225, USA

Information for Advertisers

EXPLORE is the newsletter of the Association of Exploration Geochemists (AEG). Distribution is quarterly to the membership consisting of 1200 geologists, geophysicists, and geochemists. Additionally, 100 copies are sent to geoscience libraries. Complimentary copies are often mailed to selected addresses from the rosters of other geoscience organizations, and additional copies are distributed at key geoscience symposia. Approximately 20% of each issue is sent overseas.

EXPLORE is the most widely read newsletter in the world pertaining to exploration geochemistry. Geochemical laboratories, drilling, survey and sample collection, specialty geochemical services, consultants, environmental, field supply, and computer and geoscience data services are just a few of the areas available for advertisers. International as well as North American vendors will find markets through **EXPLORE.**

The **EXPLORE** newsletter is produced on a volunteer basis by the AEG membership and is a non-profit newsletter. The advertising rates are the lowest feasible with a break-even objective. Color is charged on a cost plus 10% basis. A discount of 15% is given to advertisers for an annual commitment (four issues). All advertising must be camera-ready PMT or negative. Business card advertising is available for consultants only*. Color separation and typesetting services are available through our publisher, Network Graphics, Inc.

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EXPLORE

Newsletter No. 89 OCTOBER 1995

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President's Message

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of papers, 150 or so, for the 4th ISEG at Vail. If there is no change in this situation there will be the inevitable shift towards more environmentally-oriented papers in the Journal. So, if we want to see exploration geochemistry continue to flourish, I urge all of you exploration geochemists out there to get busy and submit more exploration-oriented papers to the Journal.

Please feel free to contact me or any member of the Executive or Council on any matter concerning the AEG: we definitely seek you input and participation in *your* AEG.

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ELECTIONS

We are in the process of electing the 1997-98 Councillors for the AEG. All Fellows of the Association should have received their ballots by now and if you haven't already done so, please vote and return the ballot to the Secretary. Voting is one of the privileges of being a Fellow and we would like to see as much participation in the election process as possible. So, if you haven't sent in your ballot yet, please DO IT NOW! If you have sent in your ballot, thanks for your continued support of The Association of Exploration Geochemists.

Sherman P. Marsh, Secretary
U.S. Geological Survey
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Denver, CO 80225-0046

Deadlines for the Next Four Issues of EXPLORE

Contributors's deadlines for the next four issues of EXPLORE are as follows:

Issue	Publication date	Contributor's Deadline
94	January 1997	November 30, 1996
95	April 1997	February 28, 1997
96	July 1997	May 31, 1997
97	October 1997	August 31, 1997

NOTES FROM THE EDITORS

Sherman Marsh and Tom Nash

This issue contains an historic first use of full color for technical illustrations in EXPLORE. We are excited by this opportunity to bring this glimpse of new technology to you, and we hope that it can become a regular feature. This full-color centerfold comes to you at no extra cost because it accompanies the color advertisement. Many of us in geoscience have become painfully aware of a technical paradox in the mid-90's: color graphics are now commonplace in our daily work, yet publication costs for these illustrations have been prohibitive. We see graphs and maps in colors on our computer monitors, and can plot them easily on several types of color printers or plotters. Indeed, we have come to rely on colors to enhance graphics; the color is far superior to the black and white 'zipatone' patterns of years gone by. But the smiles collapse when we face the prospects of publishing those effective color maps and figures. There is good news, however. Costs of printing color pages is decreasing, and the technology of preparing color separates (required for the printing process) is now routine. For this publication, the extra cost for the full color is about $1 per copy for four pages of color. (The printing process handles one 11 x 17 inch sheet, thus the four pages are a maximum utilization of the printing run). If an advertiser is interested in a full color ad, the cost is roughly twice that of conventional black and white—and the reader can be treated to three pages of color illustrations at very little added cost.

The color illustrations printed herein were pulled together on less than 4 weeks notice for this experiment, and obviously are only a part of ongoing work. We think that these illustrations show the power of publishing in color. Future publications could be planned at an early date to include color illustrations, and appropriate text and interpretation written to enhance the impact of the illustrations. We could possibly attract manuscripts that would be directed to other journals, or perhaps never published effectively. In addition to seeking good scientific manuscripts and illustrations, we need to convince advertisers that the use of color will be of benefit to them as well.

Also in this issue are two less flamboyant messages that address environmental geochemistry. John Fortescue gives us some suggestions on the scientific linkage between traditional geochemical exploration technology and currently needed geochemical expertise in environmental studies; John encourages AEG to be a leader through its publications. President Bill Coker warns us of the decline in number of exploration geochemistry manuscripts submitted to our **Journal of Exploration Geochemistry**, and notes the increase in environmentally-oriented manuscripts submitted elsewhere. Discussion of the role of AEG in environmental geochemistry has been inconsistent and inconclusive to date. Here in Denver, we see synergy, not competition, between the two branches of geochemistry. We encourage members to use EXPLORE to discuss the issues and disseminate opinions, as John Fortescue has.

Sherm and Tom

TECHNICAL NOTE

Composition of White Micas in Weathered Rocks : Indicators of Rock Type and Proximity to Gold Mineralisation, Western Australia

by Keith Scott

INTRODUCTION

White micas are commonly present in the alteration assemblages surrounding structurally controlled Archaean gold mineralisation. In Western Australia, such gold deposits usually occur within sequences of mafic and ultramafic volcanic rocks which have undergone regional greenschist metamorphism (Groves and Phillips, 1987). In such regions, the abundance of hydrothermal muscovite may be useful as an indicator of mineralisation, particularly as muscovite is relatively stable under the lateritic and subsequent arid weathering conditions which affect the region (cf. Butt, 1989). Furthermore, mica composition can reflect proximity to mineralisation and/or the rock type prior to weathering. These micas have the general formula $X_2Y_4Z_8O_{20}(OH)_4$, where X = large ions in 12-fold coordination (K, Na, Ba, Ca, Sr), Y = octahedrally coordinated ions, mainly Al but also including Fe, Mg, Cr, V, Ti, Mn, and Z = tetrahedrally coordinated ions, Si and Al.

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Technical Note

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MICA ANALYSES

More than 300 wavelength-dispersive electron microprobe analyses have been carried out on white micas for major and trace components. By using extended counting times, detection limits of 100 ppm were achieved (Ramsden and French, 1990). Micas ranging in composition from muscovite to paragonite and margarite and illite to brammallite from mafic volcanics, felsic intrusives and shales about two Archaean gold deposits in Western Australia were analysed. The deposits are Panglo (570 km ENE of Perth) within mafic volcanics and shales of a rift-phase basin and Mt Magnet (480 km NNE of Perth) in platform-phase basin mafic volcanics and felsic intrusives (Hancock et al., 1990; Wilson, 1990).

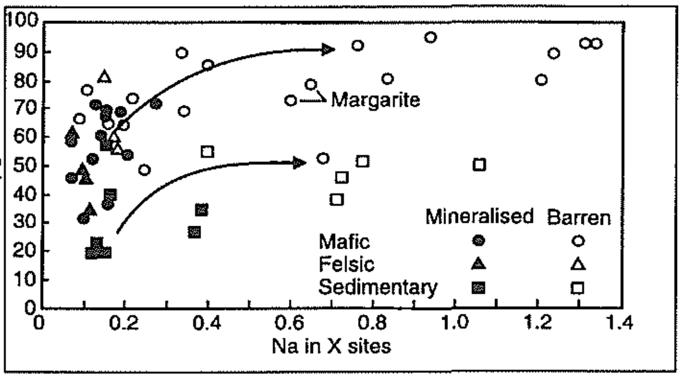

Fig. 1 Distribution of muscovite and paragonite relative to mineralisation in Section 3938N Star Gold deposit, Mt Magnet.

In gold alteration systems the mica compositions reflect proximity to mineralisation, with muscovite close to mineralisation and paragonite (and margarite) more distant (Fig. 1). The change from Na-rich to K-rich is not however simple substitution in the large ion sites but also involves both octahedrally and tetrahedrally coordinated ions of the micas. The mechanism $Na_x Al_{oct} Al_{tet} = K_x R_{oct} Si_{tet}$ (where R = divalent ions Mg and Fe in octahedral coordination) indicates that as Na enters the structure, Al is gained in both the octahedral and tetrahedral sites (Fig. 2), i.e. the mica becomes less phengitic. Such major changes in the structure of the mica make it likely that minor element contents also change with Na-K variations.

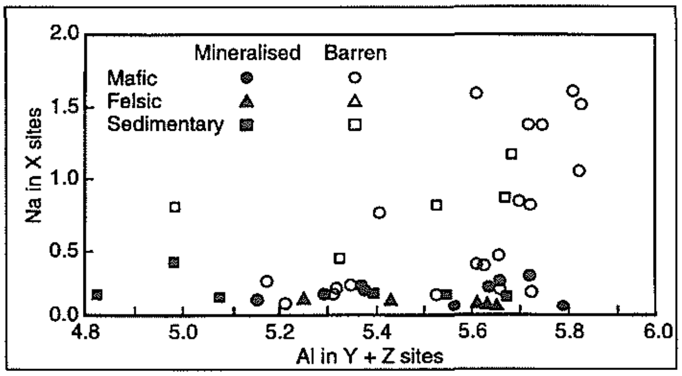

Fig. 2 Relationship between Na (in large ion sites) and Al (in tetrahedral and octahedral sites).

RESULTS AND DISCUSSION

Strontium concentrations >200 ppm are present in many micas, especially in shales peripheral to mineralisation. In shales Sr is directly related to Na content, i.e. barren shales contain Na-muscovite or paragonite with elevated Sr contents. Although Sr varies sympathetically with Ca in shale-hosted mica, the Ca-mica (margarite) has low Sr contents.

Barium contents up to 6200 ppm are present in micas with Ba being directly related to K and inversely related to Na contents, especially in shales. Margarite has low Ba contents.

Chromium contents >300 ppm often occur in micas of mafic volcanics but micas in shales and felsic intrusives have Cr <250 ppm. Consistently higher Cr contents in the micas from mafic volcanics from the platform basin than in those from the rift basin may reflect original genetic differences in the host rocks. The Cr contents of micas within a particular rock type do not appear to give any indication of proximity to mineralisation despite the presence of fuchsite in many of the Archaean gold deposits of Western Australia.

Nickel and Zn contents in micas are generally <100 ppm. Copper contents are often >100 ppm, especially in margarite and hence do not necessarily reflect an association with mineralisation.

Titanium varies between 200 and 1900 ppm in muscovite but it is always <600 ppm in paragonite and Na-muscovite, i.e. higher Ti contents occur in micas associated with mineralisation.

Iron contents of the micas are depleted relative to Mg close to mineralisation (Fig 3).

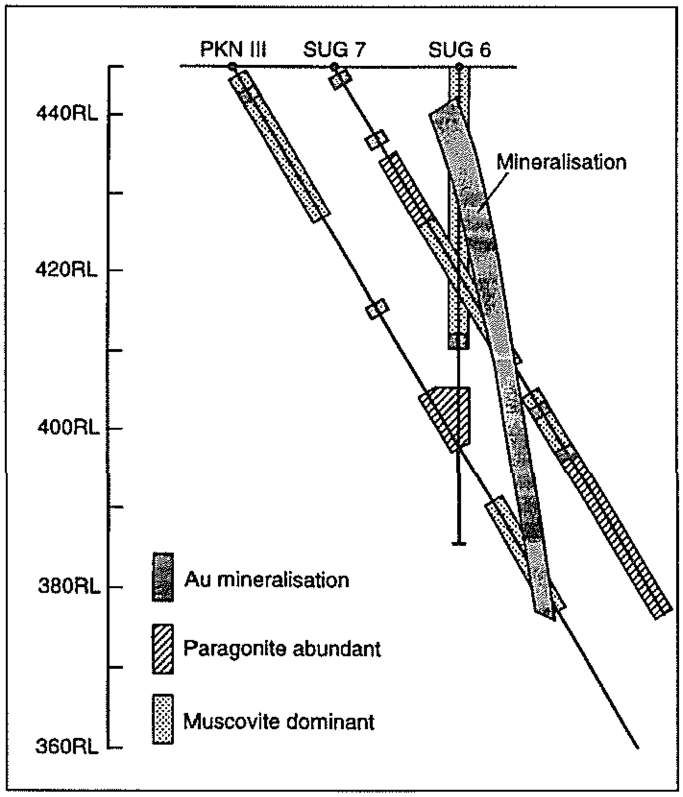

Fig. 3 Fe = Fe/(Fe+Mg) vs Na content of mica. Upper trend for mafic and felsic rocks, lower trend for sediments.*

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These features suggest that close to mineralisation the Sr, Na, Ca and Fe contents of micas are depleted and K, Ba and Ti contents elevated. The Cr content of mica was found to be a good lithological discriminant but not a good guide to mineralisation.

Because paragonite is readily differentiated from muscovite in the infrared region using hand-held field spectrometers such as the PIMA II, it may be possible to recognise areas of alteration even in weathered material using the PIMA. This area of research is currently being further addressed by AMIRA project 435 ("Mineral Mapping with Field Spectroscopy for Exploration").

Acknowledgements

Much of the work reported above was carried out in collaboration with the mineral exploration industry within AMIRA Project 241 "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia". The assistance and support of the project sponsors are gratefully acknowledged. Thanks are also due to Ken Kinealy and David French who assisted with the electron microprobe analyses.

A shorter version of this note appeared in Exploration and Mining Research News 5 (published by CSIRO Division of Exploration and Mining).

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REGIONAL COUNCILORS' NEWS

We welcome several new Regional Councilors. Clemens Reimannn has taken over from Agnete Steenfelt in the Northern Countries; Boudewijn de Smeth has taken over from Gunther Matheis in Europe and Charles Ukujeni has taken over from Cecil Begley in southern Africa. Our thanks to Agnete, Gunther and Cecil for their efforts in the past and we wish Clemens, Boudewijn and Charles well for the future.

With the elevation of Peter Simpson to the position of Vice- President we now have a vacancy for Regional Councilor in the UK and Republic of Ireland. Please contact David Garnett or Sherman Marsh if you would like to volunteer for this position.

David Garnet
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COMMENT

Dear Sirs;

The work and claims made in **EXPLORE** No. 91 (pages 15 and 16) must all be ascribed to Dean Butler and I am somewhat embarrassed to find myself listed as a co-author.

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Comment

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My role was merely to make some brief background comments and to document these claims, and I would be extremely surprised if they were substantiated. I find it difficult to believe that two such dissimilar techniques as neutron activation analysis and fire assay can come up with very similar gold contents on well-prepared international standards, yet both techniques are claimed to have underestimated the gold content substantialy.

I hope that, now we have enough detail on one of these "no-see-um" gold techniques, laboratories will try to replicate the results and in the process explain how we arrive at such inflated apparent gold values. However, there is one important correction to be made to the method, as summarised in Explore No 91: Point No 1 following `Extraction of gold is done in the following steps' should start `1. Size the ore sample to +38 micrometres (up to about 200 micrometres is acceptable, but ideally it should be mainly close to 38 micrometres). The gremlins got into the version that went to print and turned micrometres into millimetres. I hope that nobody has spent too much time attempting to leach what could be quite sizeable rocks!

David Garnett
Becquerel Laboratories

[The gremlins originally delivered to us a manuscript with only David Garnett as reporter. We tried to clarify the situation by adding Dean Butler as co-reporter. Sorry for the confusion, David. *Eds.*]

Dear Sirs;

Regarding "BLEG Sampling in Gold Exploration" by Nigel Radford (**EXPLORE** No.92), the author should remove Gosowong as a deposit in which BLEG played a significant role in discovery. The discovery resulted from follow-up of a -80 +200 mesh stream-sediment sample gold anomaly of 0.564 g/t, and of quartz vein float at the same location which assayed up to 0.73 g/t Au. The BLEG result at this location was 1.0 ppb Au—a background level. Later BLEG samples taken above and below the small stream which drained the deposit assayed around 2 ppb Au.

How many other deposits on the list compiled by Radford were really discovered partly as a result of BLEG sampling?

Grant Davey
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TECHNICAL NOTE

Suggestions for a Conceptual Bridge between Exploration and Environmental Geochemistry

by John Fortescue

Introduction

Bill Coker and Gwendy Hall have recently written in **EXPLORE** on the 'gap' between exploration geochemistry

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and environmental geochemistry. Gwendy Hall (1995; **EXPLORE** No 89) reported on a Canadian inter-agency meeting on the 'environmental mercury problem'. She noted a lack of common ground for discussion of this issue between geochemists of the Geological Survey of Canada and 'environmental geochemists' from other scientific disciplines. Bill Coker (1996; **EXPLORE** No.90) stressed the need for a strong, commonly accepted, geoscientific background for all who carry out geochemistry in the environment. The 'gap' between two natural sciences often results from the different historical development of the sciences concerned. This note explores reasons for the 'gap' between exploration geochemistry and environmental ecology from the historical viewpoint and suggests ways the AEG might bridge this gap utilizing the geochemical mapping experience of its members.

Summary of the Development of Exploration Geochemistry

The exploration geochemistry of today has evolved from the very effective methods of geochemical prospecting developed in the 1950s and 1960s. These simple, reliable, and quick geochemical methods were relatively cheap to apply almost anywhere in the world. Many 'geochemical anomaly patterns' derived from these maps were later utilized to assess and discover mineral deposits. Exploration geochemistry today continues the tradition of a 'successful science'. Compared with other environmental sciences, it is very practical and has methods based on a minimum of complex theoretical concepts and a lack of jargon.

Around 1970, methods of geochemical prospecting began a gradual paradigm shift which widened and deepened the scope of geochemical mapping. These innovations included: 1) multi-element geochemical mapping; 2) complex statistical analysis of single and multi-element data; and 3) broadly-based interpretation of regional map patterns for mineral resource appraisal. In the 1980s, this broadening continued with the addition of: 4) the concept of environmental baseline geochemistry; 5) image processing methodology (often combined with other geoscience data in a GIS); and 6) the routine determination of 50+ elements by complex instruments with strict quality control of chemical-analytical data and some element detection limits in the single digit ppt range.

As a result of these developments, government agencies, (and other organizations) in various parts of the world, began to publish regional geochemical atlases designed for use by the 'geo-' and 'enviro-' sciences. By the end of the 1980s over 38 regional drainage based geochemical mapping projects of areas greater than 5,000 sq.km. had been completed. Many of these studies were published in a geochemical atlas format. Originators of these atlases felt that they were making substantial contributions which would be enthusiastically accepted by environmental scientists. Unfortunately this was not the case and, as Gwendy Hall discovered, even today many environmental scientists are largely unaware of the potential environmental importance of regional geochemical maps.

Summary of the Development of Environmental Ecology

Traditionally, the training of ecologists included little exposure to geoscience and/or geochemistry. This omission can be traced to the origin of plant and animal ecology over 60 years ago. At that time, ecology was an academic science usually based on: 1) details of the behaviour of plants and/or animals; (2) the development of plant and/or animal communities; and/or (3) regional mapping of vegetative cover in terms of ecosystems. Traditionally, plant and animal ecological research was developed by small groups of students led by a professor who was a specialist in a particular aspect of the subject. In these groups academic excellence was stressed in: 1) planning; 2) field data collection; 3) laboratory data collection; 4) statistical data analysis; and 5) result reporting and interpretation. Results were reported at the highest academic level of the day and many learned discussions were reported concerning the details of ecology. There was not much emphasis on practical problems of environmental science.

In the mid-1960s, largely a result of the publication of Rachael Carson's book *The Silent Spring* (and related works) an 'environmental revolution' occurred which dramatically and rapidly placed ecology in the world scientific spotlight. As a result, the academic tradition of ecology was expanded overnight to become 'big science.' It was thought that 'ecology' would soon solve major environmental questions posed by the leaders of the environmental revolution. Environmental managers demanded of ecologists firm advice for the preparation of long-term plans for a 'sustainable environment.' Well-funded, multi-disciplinary, multi-year ecological research programs - such as the International Biological Program (IBP)- were organised by ecologists to provide this information. Many of these programs were based on the new (and untried) methods of 'systems ecology' that utilized a 'holistic' approach to ecosystem study.

In retrospect, from a practical viewpoint, the results of these programs fell well short of expectations. This failure has recently been discussed by several ecologists critical of the 'big science/ traditional ecology' approach. For example, the book *Method in Ecology* by K.S.Shrader-Frechette and E.D.McCoy (1993; Cambridge University Press, 328 p.) includes an analysis of the past, and current, role of ecology in environmental science. These writers' conclusions are summarised as follows: 1) Ecological data can be used to exercise control over some, but not all, environmental phenomena; 2) Ecological data can provide additional ways to think about scientific problems and can delineate the prohibited from the possible; 3) Because of its conservative nature, the scientific and ethical rationality underlying ecology as applied to environmental problems can provide a basis for its use in many practical situations.

Similarly, in his book *A Critique for Ecology* (Cambridge University Press, 366 p.) R.H Peters (1991) suggested that ecological theories are useful in environmental science only when they are: 1) empirical, because only empiricism allows realistic estimates of the uncertainty associated with unconsidered factors; 2) holistic and simplistic because complex, or mechanistic, theories seem inapplicable to many environmental problems and, 3) practical, because 'theories are often inspired by pressing questions about nature rather than the scholasticisms of academia.' Peters (1991) p.304.

Probably not all ecologists would agree fully with these criticisms of ecology. However, they do indicate the nature of the recent reappraisal of environmental ecology. By doing so they provide a useful starting point for building a conceptual bridge between exploration geochemistry and environmental ecology.

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A Conceptual Bridge Between Exploration Geochemistry and Environmental Ecology

The comments of Shrader-Frechette and McCoy (1993) and Peters (1991), summarised above, can be used as guides for bridging the gap between exploration geochemistry and environmental geochemistry. Exploration geochemists should now take advantage of this opportunity to use these ecological role statements for the description of the accumulated experience of exploration geochemistry. In this way, the traditional optimism of exploration geochemistry can be harnessed to bridge the gap between the sciences. For example, exploration geochemistry can show: 1) ways to exercise control over environmental phenomena using geochemistry; 2) additional and novel ways to think about inter-disciplinary environmental problems; 3) ways to utilize its conservative rationality to resolve practical environmental situations, and 4) ways to predict environmental change based on empirical, holistic, and practical experience. In theory, the conceptual bridge could be based on geochemical mapping experience and/or exploration geochemistry in relation to landscape ecology. The remainder of this paper deals exclusively with the geochemical mapping aspect.

To interest environmentalists in geochemical mapping, the myth must be dispelled that exploration geochemists "only map the tops of geochemical hills" (geochemical anomalies due to mineral deposits). It must be made clear at the outset, that, although this criticism is valid for **some** geochemical mapping in the vicinity of mineral deposits, it is certainly not valid for current, environmentally oriented, regional geochemical mapping

Four basic themes of geochemical mapping might be used for conceptual bridge-building. They are: 1) **Element abundance**: geochemical mapping is usually based on estimates of the abundance of one, or more, elements in the environment. As an aid to the understanding of geochemical map patterns, the exploration geochemists could provide a table of element abundances estimated for the Earth's Crust for world-wide utilization in all kinds of environmental-geochemical work. 2) **Standardised geochemical map legends**: a series of posters and/or short reports, to explain basics of geochemical mapping methodology applied at different map scales to environmental problems using one standard legend would simplify application of geochemical maps to a range of environmental problems (pollution, nutrition, and health of plants, animals and man). 3) **The methods of geochemical mapping**: a series of posters and/or short reports could explain individual facets of geochemical mapping such as: sampling plans, sampling methods, analytical methods, statistical analysis, map presentation, and spatial interpretation. 4) **Recent advances in geochemical mapping**: a series of posters and/or short reports might describe recent developments such as: multi-element analytical methods, digital mapping techniques, integrated studies utilizing geographical information systems (GIS), International Geochemical Mapping (IGM) and progress toward a global geochemical map. Publications in Journal of Geochemical Exploration and EXPLORE could communicate these and other aspects of our geochemical mapping expertise to environmental scientists.

Summary

The broad goals of environmental ecology and environmental geochemistry are quite similar. Communication would be improved if exploration geochemists would use the language of environmental ecology as a basis. Expertise in geochemical mapping and monitoring is clearly of vital importance in the development of a self-sustaining environment. Exploration geochemists are in a unique position to guide and educate environmental scientists in geochemical mapping.

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Special Color Maps

Continued from Page 1

analysis techniques documented in the reports included as References.

Briefly, lake sediment data were analyzed for 42 elements plus loss on ignition. Analysis methods included AAS, HY-AAS, NADNC, CV-ASS, GRAV and INAA techniques. For this exercise, a partial suite of elemental data including analyses for Au, As (AAS and INAA), Cu and Sb was used. In the case of the till geochemistry data, the elemental analysis was based on analysis of the <63 micron fraction, the <2 micron fraction and the non-ferromagnetic heavy mineral concentrates. For this exercise, an extensive set of data from 34 elemental analyses was made available, including fire-assay, ICP-AES and INAA data from the <63 micron fraction and <2 micron till fractions.

Available geophysical data included raw total field and gradient magnetic grids from airborne surveys flown on behalf of the OGS in 1991. Geological data included a comprehensive description of glacial and Precambrian geology, and report-sized geological maps. Figure 1 shows a geological map, geochemical sample locations from both geochemistry surveys and geophysical total-field magnetic data.

Data Import, Location and Integration

The initial problem in working with multivariate data from different sources is determining how to import, locate the data spatially (i.e. georeference) and integrate it so that it can be displayed, processed and visualized. The strategy in this exercise was to use a commercial PC-based geoscience data processing and analysis system with multiple database and map window functionality.

For the lake sediment survey, located data were provided so that the import process was trivial. Spreadsheet data were exported in ASCII format, manipulated in a word processor to remove blank values and the ASCII data were then imported into a designated database. For till data, the process was similar except that <63 micron and <2 micron data were identified by sample numbers only. Therefore, an additional step was required — namely to import location data (Easting and Northing) into designated <63 micron and <2 micron databases and then import elemental data into the corresponding databases.

Importing, locating and integrating geological data required manipulation of a scanned black and white image. An image was first scanned at 1200 X 1200 resolution and stored in a standard bitmap format. It was then imported into a map window and georeferenced semi-interactively by selecting points on the image and assigning them to known UTM coordinates. Next, the bitmap was warped to transform all points to UTM coordinates and saved in a grid format. For geophysical data, the data was provided in grid format and therefore the import, location and integration process required a single step.

As a result of the import process, all data were integrated into a single workspace containing location, <63 micron and <2 micron databases; a geological grid and two geophysical grids.

Initial Data Review and Selection

For elemental data from the till survey, a methodology was required for quickly selecting data for further analysis. In

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Regional distribution of heavy metals in humus and till near a base metal smelter at Flin Flon, Manitoba, Canada (see page 11)

Isabelle McMartin and Penny J. Henderson

Humus and till samples were collected in the Flin Flon-Snow Lake area, northern Manitoba and Saskatchewan, as part of a regional surficial geological mapping and geochemical prospecting program conducted by the Geological Survey of Canada under the Shield Margin NATMAP initiative. The study area is situated in the vicinity of a remote point source of anthropogenic pollution, the base metal smelter complex at Flin Flon, Manitoba. Particulate emission tests in the smelter stack have indicated that various amounts of Zn, Cu, Fe, Pb, As, Cd, Ag and Hg particles are discharged into the environment. The purpose of the study is to determine the regional distribution of heavy metals in surface soils, the relative contribution of these metals from natural and anthropogenic sources and the storage sites for emissions. The adjacent color figure illustrates the regional distribution of copper in humus and till in the Flin Flon-Snow Lake area. The results of the geochemical analysis and regional distribution maps for all elements are available in McMartin et al. (1996).

On a regional basis, till was sampled from 1 m deep pits or exposed sections spaced 1 to 5 km apart over 36 000 km2 (2223 samples). Humus was collected from directly over or near the till sampling site (1639 samples). The < 0.425 mm fraction of humus and the < 2 µm fraction of till was analyzed geochemically for a number of major and trace elements using inductively coupled plasma atomic emission spectrometry (ICP-AES), following nitric aqua regia digestion.

The proportional dot map of Cu in humus exhibits a "bull's eye" dispersal pattern, centered in the vicinity of the smelter. Maps of As, Cd, Hg, Pb and Zn, metals also known to be emitted from the smelter, reflect this general pattern. For these elements, concentrations are anomalously high at the centre of the contaminated area, and decrease with distance from the smelter according to an inverse curvilinear relationship, thus implicating the smelter as the source. The relationship is such that the log-concentration of the emitted metal decreases directly with the log-distance from the stack until background values are reached. Distance to background varies from about 70 to 104 km (average 85 km), depending on the airborne behaviour and stability in humus of the metal (90 km for Cu), the long-term result of variations in wind direction and speed, and the background value determined for that element. In till, concentrations of smelter-related elements show no direct relationship to distance from the smelter, but appear to be related to the variation in bedrock composition and the effects of glacial transport.

Based on results from the regional survey, a suite of humus and till samples collected at varying distances from the smelter, as well as from several soil profiles, were subjected to detailed analysis, including organic content determination and mineral composition, sequential extraction techniques, and SEM examination. Results from this detailed study indicate that downward leaching of metals from humus does not exceed 45 cm and that no relationship exists between organic content of humus and total metal concentrations (Henderson and McMartin, 1995). The forms of the various elements in humus and till will be presented in a second paper (Henderson et al., in prep.). The regional distribution of metals and evaluation of geochemical background is the subject of a third paper (McMartin et al., in prep.).

Henderson, P.J. and McMartin, I. 1995: Mercury distribution in humus and surficial sediments in the vicinity of Flin Flon, Manitoba, Canada; Water, Air and Soil Pollution, vol. 80, p. 1043-1046.

Henderson, P.J., McMartin, I., Hall, G.E.M., Walker, D., and Percival, J.B. in prep: The chemical and physical distribution of heavy metals in humus and till in the vicinity of the base metal smelter at Flin Flon, Manitoba, Canada; Environmental Geology.

McMartin, I., Henderson, P.J., Nielsen, E., and Campbell, J.E. 1996: Surficial Geology, Till and Humus Composition Across the Shield Margin, North-Central Manitoba and Saskatchewan: Geospatial Analysis of a Glaciated Environment, Geological Survey of Canada, Open File 3277, 101 p. (Appendices available on diskette).

McMartin, I., Henderson, P.J., Nielsen, E. in prep: Impact of a base metal smelter on the geochemistry of soils of the Flin Flon region, Manitoba and Saskatchewan; Canadian Journal of Earth Sciences.

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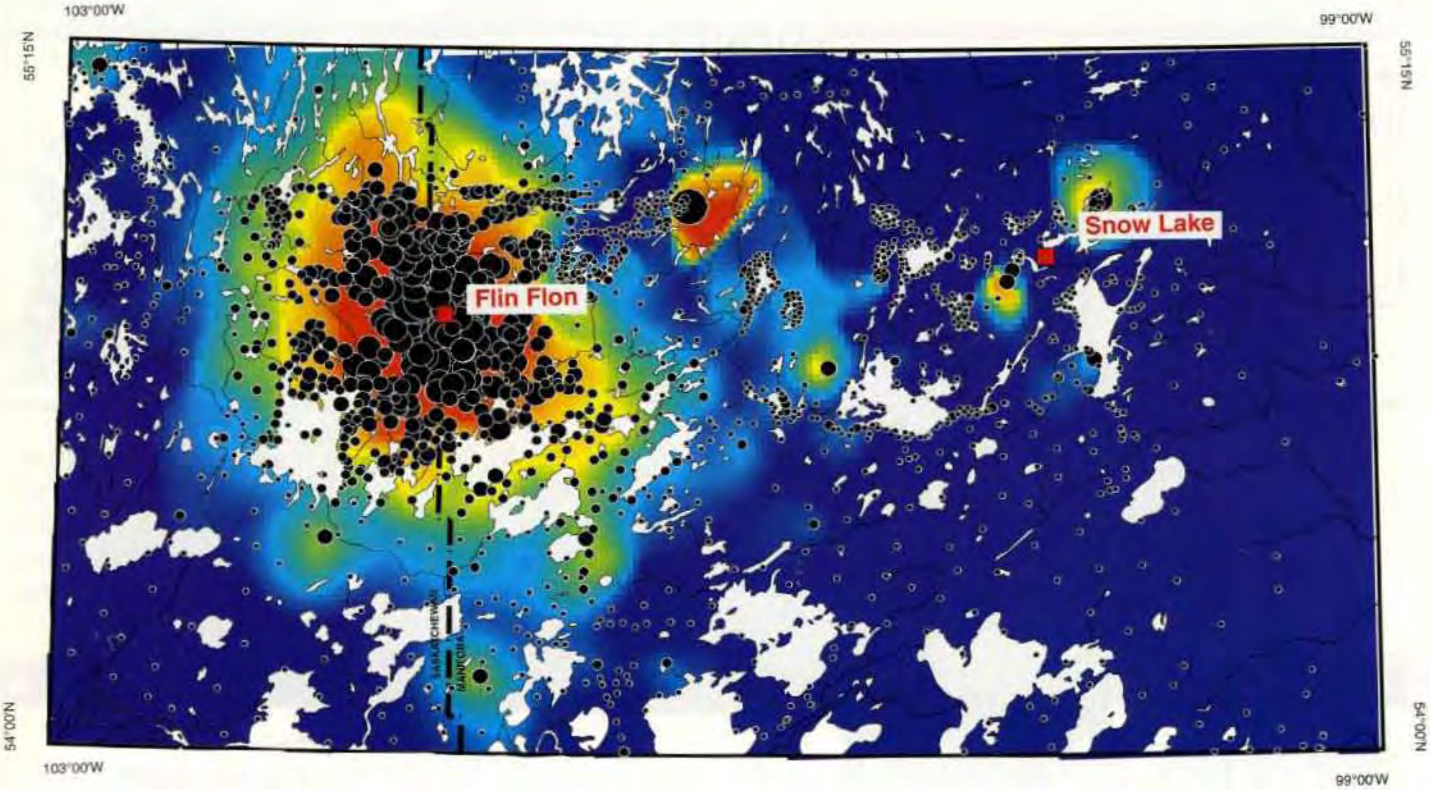
Geoenvironmental Assessment of Montana (see figure page 12)

Greg Lee

The U.S. Geological Survey Mineral Resource Program has been studying the relative potential for acidic, metal-rich drainage in the State of Montana. This effort has relied heavily on geographic information systems (GIS) technologies to not only assemble and query a substantial variety of multidisciplinary information, but to also statistically and empirically examine relationships among these data and produce models reflecting the relationships. Collaborators on this project include H. Alminas, V. Bankey, J. Elliott, D. Frishman, D. Knepper, D. Kulik, G. Lee, S. Marsh, A. McCafferty, J. Phillips, J. Pitkin, S. Smith, R. Tysdal, and B. Van Gosen. Digital information sources have included U.S. Geological Survey (Geologic, Water Resources, and National Mapping Divisions), digital Montana geology (G. Raines and B. Johnson, USGS), U.S. Bureau of Mines, Montana State Bureau of Mines and Geology, Montana State Library, U.S. Forest Service, Environmental Protection Agency, and Oregon State University.

The general approach to model-building has been to calculate the significance of spatial association of different levels of the various data layers with respect to "prototype" areas within the state and to then combine the correlative layers according to weights which reflect the levels of significance. To formulate the prototype, that is, identify areas within the state which typify the situation to be modeled, areas known to be relatively high in acid- and metal- generating potential and relatively low in acid-buffering capacity were selected. The various data layers, including geochemistry, geology, geophysics, remote sensing,

Continued on Page 20



MIN.	MAX.	%TILE	#SAMP
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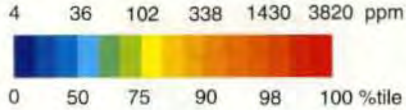
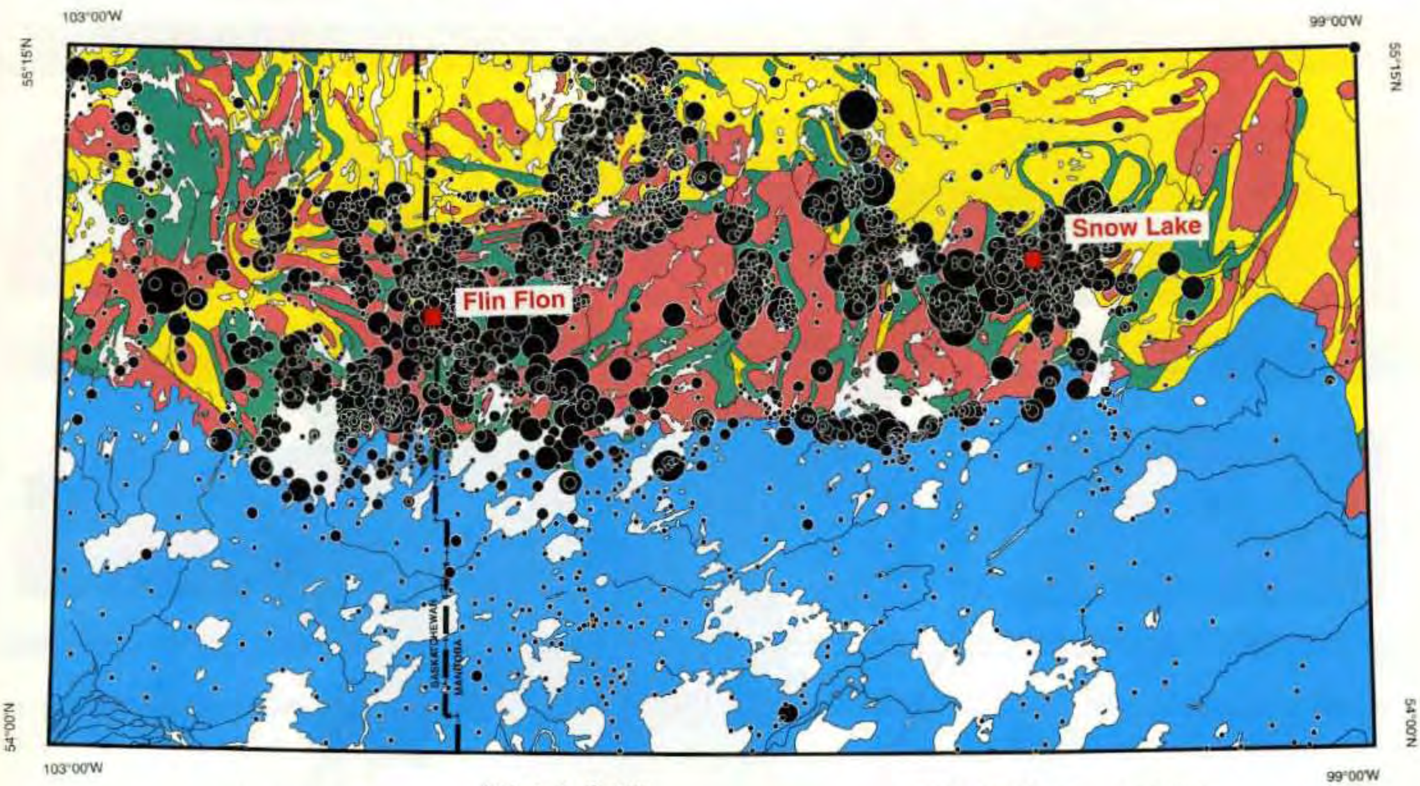
50	120	77.5	313
120	300	89.1	190
300	1100	96.8	126
1100	2000	99.2	39
2000	3820	100	13

Km 5 0 5 10 15 Km

1 : 1 500 000

Cu (ppm) in humus





MIN.	MAX.	%TILE	#SAMP
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125	200	83.2	602
200	400	97.5	318
400	900	99.7	50
900	3274	100	6

Km 5 0 5 10 15 Km

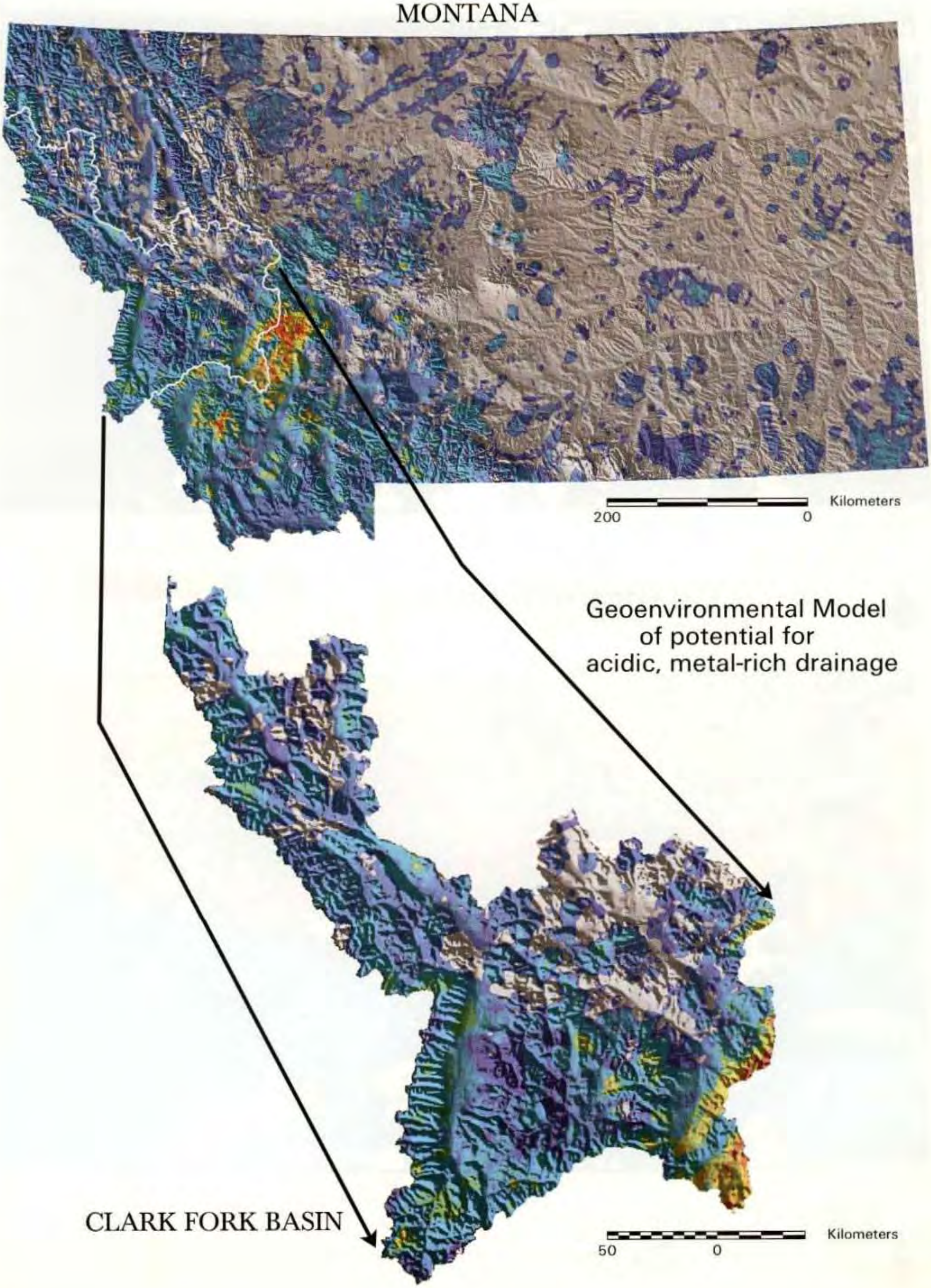
1 : 1 500 000

Cu (ppm) in till

BEDROCK LEGEND

PALEOZOIC
- Dolostone; minor sandstone, mudstone and shale

PRECAMBRIAN
- Intrusive rocks
- Metasediments
- Metavolcanics


MONTANA
Kilometers
200
0
Geoenvironmental Model
of potential for
acidic, metal-rich drainage
CLARK FORK BASIN
Kilometers
50
0

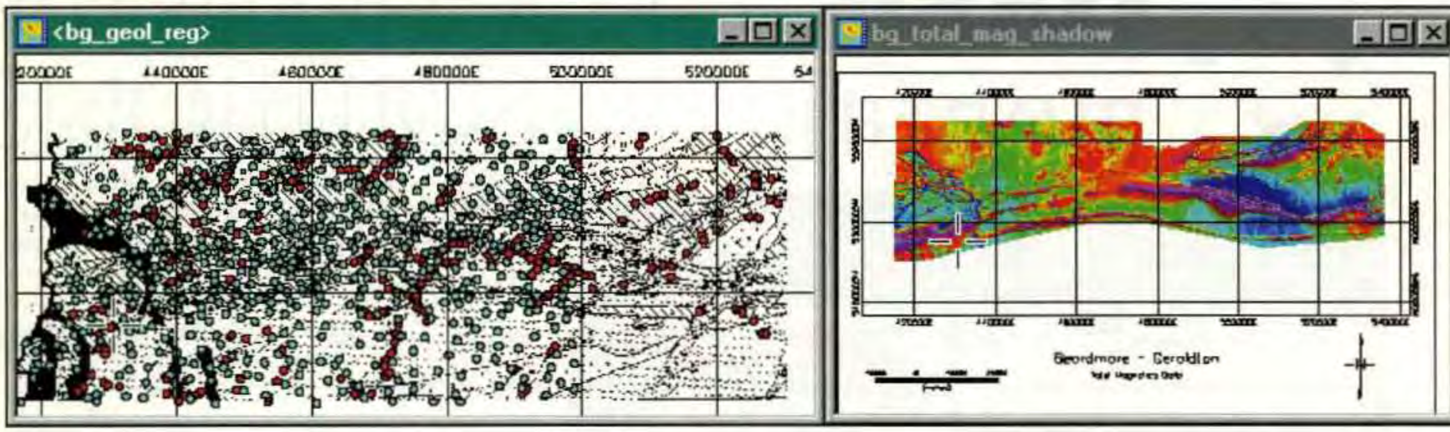


Figure 1: Integrated Geology, Geochemistry and Geophysics from the Beardmore-Geraldton area, Ontario. Map on left shows scanned, geo-referenced geology layered over regional till geochemistry (cyan) and lake sediment/water geochemistry (red) survey sample locations. Map to right shows shadowed total-field magnetic geophysical data. The dynamic link cursors (crosses) provide a local reference (Beardmore, ON). *Raw data and grids courtesy of the Geological Survey of Canada and Ontario Geological Survey.*

Figure 2: Till and Lake Geochemistry Images for Beardmore-Geraldton. Maps bg1, 2, 4 and 7 show geostatistical kriging (selected elements) and error (Au) grids from the <63 micron fraction of C-horizon till samples. Maps bg1 and 2 have proportional Au symbols (<63 micron fraction) superimposed. Maps bg3, 5, 6, 8 and 9 show geostatistical kriging (selected elements) and error (Au) grids from the lake sediment survey. Maps bg3 and 9 have proportional Au symbols (<170 micron fraction) superimposed. Maps bg1, 3, 7 and 9 also have scanned geology superimposed (not resolvable at this scale).

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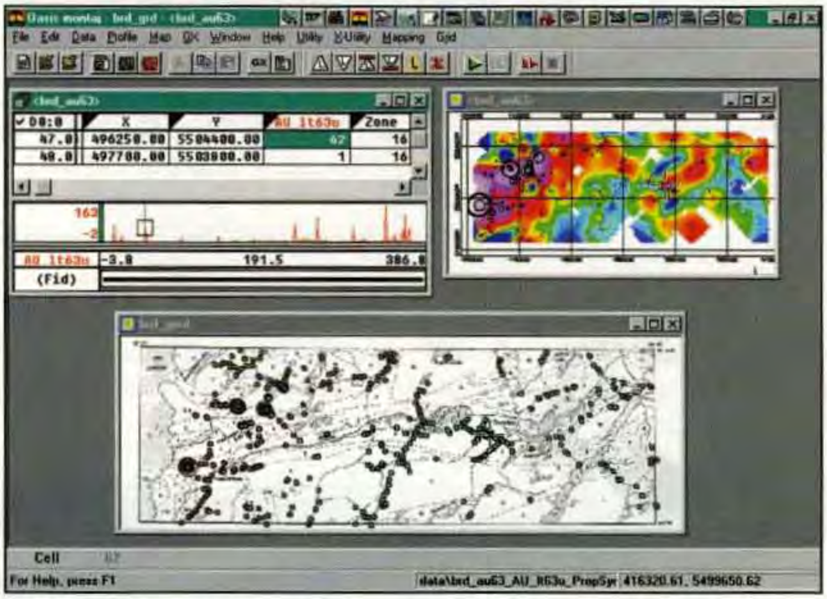

Gold values from the <63 micron fraction of C-horizon till in the Beardmore-Geraldton area, Canada. In the database, fire assay values are displayed numerically and graphically. To the right, proportional symbols overlay kriged Au values to show broad anomaly north and northeast of Beardmore to west and isolated high near Geraldton to east. The geology map depicts zone-coloured Au symbols and the till sampling pattern.

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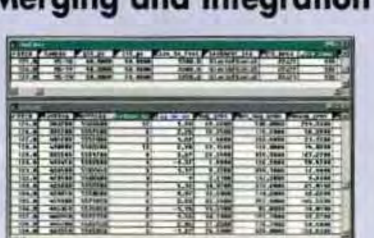

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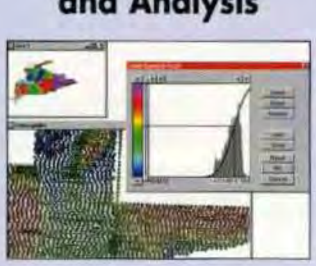

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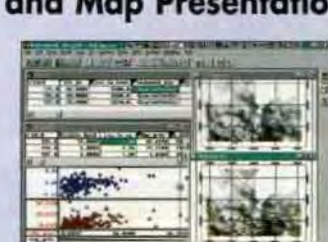

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Special Color Note

Continued from Page 9

this case, data were evaluated visually by displaying random line data in profile format in the PC workspace and visually looking for problems related to inadequate detection limits. This first-look procedure resulted in the identification of 18 of 34 elements for further processing. A second step was to plot groups of elements to visually identify relationships between precious metals and indicators (Au, As and Pt), base metals (Cu, Pb, Zn) and heavy metals (Cr, Co, Fe and Ni). This heuristic approach led to the selection of Au, As, Cu, Cr and Co for gridding and visualization. For lake sediment data and geophysics, all parameters were included in the exercise since only specific data were available.

Geochemical Data Processing

Statistical gridding employs the method of kriging to determine a value at each grid node based on the data. The routine used here first calculates a variogram of the data which shows the correlation as a function of distance. The farther apart the points become, the less is the correlation expected between points. The variogram shows this phenomena for a particular dataset and based on the variogram, the model that best defines the variance of the data can be selected.

For each set of geochemical data (till and lake sediment), data were gridded using a geostatistical kriging method and a power model was assumed for the variogram. This resulted in the series of till and lake geochemistry images for Beardmore-Geraldton shown in Figure 2. Maps **bg1_** and **bg4_** show the kriging and error grids for Au in the <63 micron fraction of till and maps **bg3_** and **bg6_** show the kriging and error grids (containing the standard deviation of the estimates at each grid node) for Au in lake sediments. Sample locations are overlain for illustrative purposes.

Multivariate Data Visualization

For this exercise, grids were shadowed — creating a three-dimensional appearance that helps in recognizing systematic trends in images. Another visualization technique consisted of adding related data layers consisting of proportional size symbols, sample locations, geologic maps and basemaps. For space reasons, only selected elements, sample maps and geophysical data are displayed in Figure 2.
In practice, each available image was displayed interactively, and expanded or contracted to view data in detail. Dynamic links were also used to interactively georeference specific locations on multiple maps and evaluate relationships in different multivariate data images.

Brief Analysis of Multivariate Data

Analysis of data consisted of a qualitative review of kriging results from different geochemical surveys and a cursory interpretation of recognizable spatial trends in the integrated multivariate dataset.

In comparing kriging data from the till and lake sediment surveys, the images show the same general spatial relationships for Au in maps **bg1_** and **bg3_** and Cu in maps **bg2_** and **bg5_**. Visual evaluation identifies key characteristics of the kriging process related to the sampling pattern and sample density. In the case of the <63 micron fraction of till, the error grid assumes a "brain coral" appearance with the distribution of values with low errors concentrated in a pattern closely approximating the dendritic sampling pattern along roads. In the case of the lake sediment data, the error grid assumes a "pitted" appearance that reflects the influence of individual isolated samples. The effect of sample density is also apparent with the more highly sampled lake sediment data having a much tighter "focus" than their till counterparts.

In analyzing the complete set of multivariate data, certain spatial trends are apparent. Regional magnetics in map **bg_total_mag_shadow** correspond directly to the regional geology map **bg_geol_reg** — showing strong E-W oriented linear magnetic anomalies (red) delineate metavolcanic belts in this area. Comparison with map **bg9_** shows an E-W oriented anomaly in Sb in the vicinity of metasedimentary rock units (sandwiched between metavolcanic belts). Magnetic lows (blue) in the western portion of the map correspond to mafic intrusives (solid black) in the geology map.

For geochemistry data, the lake sediment Au data indicate a string of isolated Au anomalies along the central metavolcanic / metasedimentary contact. Other apparent relationships include the concentration of Co values in the vicinity of the mafic intrusives in the west of the map area and the increase of Cu values to the northeast of Beardmore (indicated by the dynamic link). Arsenic appears to be relatively uniformly distributed along the metavolcanics and within the metasediments.

Conclusions

With the development of new software technologies (such as PC-based geoscience data processing and analysis systems), true integration, processing and visualization of

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Special Color Note

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multivariate geochemical, geophysical and geological data is now possible in the personal computer environment. In this exercise, a variety of data from different sources were quickly imported, processed and visualized together. This type of qualitative approach can help set the stage for more comprehensive analysis of historical multivariate data from different sources that have not previously been integrated, processed and visualized together. By extension, this approach may represent a departure point for analyzing more recently acquired multivariate data. Finally, the approach described here is largely qualitative but can be readily refined to more rigourously apply numerical and statistical analysis procedures at any point in the process.

Acknowledgements

Sincere thanks are extended to Martin McCurdy (GSC) and Vinod Gupta (OGS) for making lake sediment and geophysical data, respectively, available.

References

L. H. Thorleifson and F. J. Kristjansson, 1993. Quaternary Geology and Drift Prospecting, Beardmore-Geraldton Area, Ontario. Geological Survey of Canada, Memoir 435.

Regional Lake Sediment and Water Geochemical Data, Ontario, 1990. GSC Open File 2177, NGR 139-189; Parts of NTS 42E, 42L and 52H.

In addition to these two sources, readers may be interested in referencing large-scale data compilations currently being conducted by the GSC and OGS. The GSC recently released regional Cu geochemistry data for the entire province of Ontario and is working on regional Hg, Zn, Ni and other data. In March 1996, the OGS released the first in a series of 20 large-scale geophysical datasets containing re-processed data flown in various locations in Ontario.

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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.

- Oct. 28-31, '96 **Geological Society of America**, Ann. Mtg., Denver (Becky Martin, GSA Meetings Dept., Box 9140, Boulder, CO 80301-9140; TEL: (303)447-2020, ext. 164; FAX: (303) 447-1133)
- Nov. 10-14, '96 **Society of Exploration Geophysicists**, mtg., Denver (AAPG Convention Dept., Box 979, Tulsa, OK 74101; TEL: (918) 584-2555)
- Nov. 21-22, '96, **Advances in Saskatchewan Geology and Mineral Exploration**, Saskatoon, Saskatchewan, Canada. Saskatchewan Geological Survey, MINEXPO '96, PO Box 234, Regina, Sask. S4P 2Z6, Canada; TEL: 306-787-9181; FAX: 306-787-2488; email: bill.simmon@sasket.sk.ca)
- Dec. 4-6, '96, **Northwest Mining Association 102nd Ann. Convention**, Short Courses and '96 Exposition, Spokane, Washington. (NWMA, 10 N. Post St., Suite 414, Spokane, WA, 99207; TEL: 509-624-1158; FAX: 509-623-1241.
- Mar. 23-26, '97, **SEGH** 15th European Meeting, Dublin, Geological Survey of Ireland
- Mar. 24-27, '97, 4th **All Portuguese Language Countries Geochemical Congress** and the **10th Portuguese Geochemical Week**, Braga, Portugal (Prof. Graciete Dias, Dept. Ciencias da Terra, Univ. Minho, Campus de Gualtar, 4709 Braga Codex, Portugal; FAX: +351 53 604 304; TEL: +351 53 604 305; E-mail: geoquimica@ci.uminho.pt, URL http://delta. ci.uminho.pt/ct/port/homepage.html)
- May 17-19, '97, **Europe's Major Gold Deposits**, conf. by Irish Assoc. for Economic Geology and the Inst. of Mining and Metallurgy, Down, No. Ireland (Kerr Anderson, TEL 353-46-22363; FAX 353-46-22372; email: navanr@iol.ie and Eibhlin Doyle, TEL: 353-1-4785656; FAX: 353-1-478-5660; email: BHP@iol.ie)
- May 19-21, '97, **Geological Association of Canada/Mineralogical Association of Canada**, joint mtg., Ottawa, Ontario (Secretariat, Geological Survey of Canada, Room 757, 601 Booth St., Ottawa, K1A 0E8; TEL: (613) 947-7649; FAX: (613) 947-7650; E-mail: ottawa97@emr.ca)
- May 25-29, '97, **18th International Geochemical Exploration Symposium**, Jerusalem, Israel (Organizing Committee, International Geochemical Exploration Symposium, P.O. Box 50006, Tel Aviv 61500, Israel; TEL: (972 3) 5140014; FAX: (972 3) 5175674/660325; E-mail: iges@mail.gsi.gov.il)
- June 1-5, '97, **GEOANALYSIS 97**, 3rd Int'l Conf. on the Analysis of Geological and Environmental Materials, Vail, CO (Belinda Arbogast, U.S. Geological Survey, Federal Center, Box 25046, MS 973, Denver, CO 80225; TEL: (303) 236-2495; FAX: (303) 236-3200; E-mail: geo97@helios.cr.usgs.gov)
- June 23-26, '97, 4th International Conference on the **Biogeochemistry of Trace Metals**, Berkeley, CA (Dr. I.K. Iskandar, US Army Cold Regions, Res. & Eng. Lab, 72 Lyme Road, Hanover, NH 03755; TEL: (603) 646-4198; FAX: (603) 646-4561; E-mail: iskandar@crrel.usace.army.mil.
- Aug. 11-13, '97, 4th Biennial **Society for Geology Applied to Mineral Deposits** meeting, Turku, Finland (Congress Office/ SGA Meeting 1997, University of Turku, Lemminkaisenkatu 14-18 B, FIN-20520 Turku, Finland; TEL:

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Calendar of Events

Continued from Page 16

358-21-333-6342; E-mail: ceson@utu.fi)

- Sept. 14-18, '97, Fourth Decennial International Conference and Exhibition on **Mineral Exploration** with a theme of **Geophysics and Geochemistry at the Millenium**, Toronto, Canada (Jon Baird, c/o CAMESE, 345 Renfrew Drive, Markham, Ontario, Canada, L3R 9S9; TEL: (905) 513-0046; FAX: (905) 513-1834; E-mail: 103214@compuserve.com)
- Oct. 5-10, '97, 4th International Symposium on **Environmental Geochemistry**, Vail, Colorado (4th ISEG, c/o USGS/CEGG, Federal Center, Box 25046, MS 973, Denver, CO 80225; FAX: (303) 236-3200; E-mail: iseg@helios.cr.usgs.gov)
- June 29-July 1, '98, **International Platinum Symposium**, IAGOD/CODMUR, Johannesburg, South Africa (C.A. Lee, Box 68108, Bryanston 2021, South Africa; TEL: (2711) 4112253; FAX: (2711) 6923693)

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

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The George Washington University
Department of Geology
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NEW MEMBERS

To All Voting Members:

Pursuant to Article Two of the Association's By-Law No.1, names of the following candidates, who have been recommended for membership by the Admissions Committee, are submitted for your consideration. If you have any comments, favorable or unfavorable, on any candidate, you should send them in writing to the Secretary within 60 days of this notice. If no objections are received by that date, these candidates will be declared elected to membership. Please address comments to Sherman P. Marsh, Secretary AEG, U.S. Geological Survey, Mail Stop 973, Box 25046, Federal Center, Denver, Colorado 80225, U.S.A.

Editors note: Council has decided that all new applicants will receive the journal and newsletter upon application for membership. The process of application to the Nepean office, recommendation by the Admissions Committee, review by the Council, and publication of applicant's names in the newsletter remains unchanged.

FELLOWS

Bettenay, Leigh F.
Principal Geochemist
MIM Exploration
Perth, WA, AUSTRALIA

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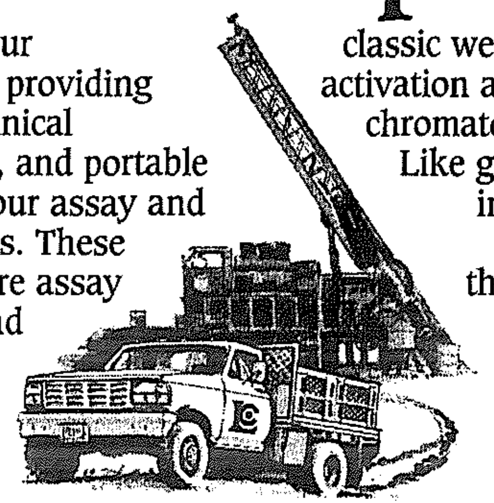

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Sexton, Alan J.
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WMC International
Nepean, ON, CANADA

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Santiago, CHILE

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Smyth, Dermot
Queen's University, Belfast
Newry, NORTHERN IRELAND

RECENT PAPERS

This list comprises titles that have appeared in major publications since the compilation in EXPLORE Number 92. Journals routinely covered and abbreviations used are as follows: Economic Geology (EG); Geochimica et Cosmochimica Acta (GCA); the USGS Circular (USGS Cir); and Open File Report (USGS OFR); Geological Survey of Canada papers (GSC paper); and Open File report (GSC

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Recent Papers

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OFR): *Bulletin of the Canadian Institute of Mining and* Metallurgy (CIM Bull); transactions of Institute of Mining and Metallurgy, Section B; applied Earth Sciences (Trans IMM). Publications less frequently cited are identified in full. Compiled by **L. Graham Closs**, Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401-1887, Chairman AEG Bibliography Committee. Please send references to Dr. Closs, not to EXPLORE

Alekseev, S.G., Dukhanin, A.S., Veshev, S.A., and Voroshilov, N.A., 1996, Some aspects of practical use of geoelectrical methods of exploration for deep-seated mineralization. J. Geochem. Explor. 56(1): 79-86.

Bowles, J.F.W., Gize, Vaughan, D.J., and Norris, S.J., 1995. Organic controls on platinum-group element (PGE) solubility in soils: initial data. Chronique de la Recherche Miniere 63(520): 65.

Calvert, S.E. and Pedersen, T.F., 1996. Sedimentary geochemistry of manganese: implications for the environment of formation of manganiferous black shale. EG 91(1): 36-47.

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Enzweiler, J. and Webb, P.C., 1996. Determination of trace elements in silicate rocks by X-ray fluorescence spectrometry on 1:5 glass discs: comparison of accuracy and precision with pressed powder pellet analysis. Chem. Geol. 130(3/4): 195-202.

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Legge, P.J., 1995. Geoscience 1994 and beyond: Thoughts on geology and exploration for world class deposits (Presidential Address). Aust. J. Earth Sci. 42(1): 1-.

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Continued on Page 20

Recent Papers

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Geoenvironmental Assessment of Montana

Continued from Page 10

and water pH, were considered as "candidates" to be incorporated as constituents of a model depicting relative favorability of acidic, metal-rich drainage within the state.

Using GIS methods, the qualifications of each of the candidates was measured by calculating the ratio of the percentage of the prototype areas occupied by the candidate to the percentage of the state occupied by the candidate. The computed ratio values were used to not only determine which levels of what layers should be included as constituents in the model, but also what weights should appropriately be assigned to these "submodels." A composite model image (page 12) was produced by combining the submodels using GIS (in this case, Erdas IMAGINE) functions. The "warmer" colors in the upper image on page 12 reflect higher combined weights of significance, which were draped over shaded relief for spatial reference. The lower image on page 12 was produced by "zooming in" on the statewide model, using the Clark Fork basin and its major tributary basins as a mask to make a map showing areas of relative favorability for acidic and metal-rich drainage.

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