

# EXPLORE

NUMBER 96

JULY 1997

Newsletter for  
the Association  
of Exploration  
Geochemists



## PRESIDENT'S MESSAGE

Membership of the AEG in Israel increased by 50% between 1992 and 1996. This would be a major achievement in those countries that are heavily populated with exploration geochemists, but Israel does not quite fall into that category — at least, not yet. We all know that statistics can be used as much to obscure as to illuminate and, to paint a more accurate picture in this case, that 50% increase merely reflected a swelling of our numbers from two AEG members to three. Now who, in their right mind, would have the audacity to put forward a proposal to host the 18th International Geochemical Exploration Symposium (IGES) in Jerusalem when there were so few exploration geochemists in the country? Well, the Israelis did and I think I may now have a slightly better understanding of that expressive Yiddish word, *chutzpah*. What's more they delivered a thoroughly professional symposium, together with field trips to northern and southern Israel, that blended good science with good friends — both old and new — in a fascinating and unique part of the world. The test of a successful meeting is that it seems to be over almost before it starts and that is what happened in the last week of May 1997. Our thanks go to many people — to the professional congress organisers (Kenes) who were ever-present and always helpful; to the Renaissance Hotel which provided an excellent setting for the symposium; to the sponsors, and in particular to the Geological Survey of Israel for its support and for its commitment of staff and resources; but above all to committee, so ably and energetically led by their co-chairmen, Ron Bogoch and Moshe Shirav, who made it all happen.



David Garnett

Without a large home-grown population of exploration geochemists to swell the numbers the 18th IGES was always going to be smaller than some of its predecessors. Nevertheless it is a great credit to the organisers that they managed to attract more overseas participants than we have had in many recent symposia, and this despite the best efforts of CNN to convince the world that the country was going up in flames. It was a particular pleasure to see so many colleagues from eastern Europe and I hope we will see them participating in similar numbers in the future.

I wonder if any previous IGES has spanned quite the range of topics covered in Jerusalem. While there was a solid core of mainstream themes — Exploration Geochemistry, Hydrogeochemistry, Sampling Media, and Advances in Analytical Techniques — we were also reminded that exploration geochemists share many similar interests/problems with scientists in related disciplines. Sessions on Environmental Geochemistry and Mitigation of Geochemical Impact on the Environment broadened the range, but the final topic — Archaeology and Geochemistry — must surely have been a first in IGES history and must have gone a long way towards making the 18th IGES the most diverse ever held. It was

*Continued on Page 3*

## TECHNICAL NOTE

### Water: A Medium for Exploration in Northern Terrains

Eion M. Cameron, Christopher Marmont, Gwendy E.M. Hall

*This article is dedicated to Jack Henderson. Jack, born in the United States, represented the very best in GSC field geologists: tough, fit as a deer, imaginative, enthusiastic, supportive, generous. He is the author of the authoritative geological report on the Penrhyn Group and gave us the benefit of his considerable knowledge throughout the project. Jack died July 22, 1997.*

#### INTRODUCTION

Recent advances in analytical chemistry have made hydrogeochemistry the cost-effective method for exploration that some geochemists envisioned more than 50 years ago. While preparing the obituary for Herbert E Hawkes we were impressed that this pioneer's first choice for a sampling medium was stream water, but his application of the medium was stifled by the crude analytical methods in the 1940's. At that time, colourimetric methods were the only practical way to measure trace metals in waters. However, the sensitivity of colourimetry was not sufficient for the ppb concentrations of these metals. Thus, Herb "invented" stream sediment sampling as an alternative. This developed into the most important geochemical approach to exploration, resulting in hundreds of mineral discoveries.

In the years since Herb Hawkes' work, analytical technology has revolutionized geochemistry. Laboratory instruments, such as the ICP-MS, can rapidly measure dozens of elements, many to the ppt level. There has also been development of portable instrumentation for field analysis. Because of the widespread familiarity with exploration methods involving the analysis of solids, an appreciation of the benefits of surface waters as a sampling medium has been slow to develop.

The benefits of using waters are most apparent in countries with a climate similar to that of Canada. The first, and most obvious feature, is the abundance of water bodies. Figure 1 is an aerial photograph of the Melville Peninsula in the Northwest Territories, where the work described in this article was located. There is an abundance of small lakes, less than a kilometre in

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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:

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## NOTES FROM THE EDITORS

*Sherman Marsh and Tom Nash*

As you can see, or will see if you turn to page 11, this is a color issue — our second. One of our advertisers, Geosoft, has again purchased a full page color ad thus allowing us to have three additional pages for scientific illustrations. We would like to thank Geosoft for providing us with this opportunity. Color is especially useful in scientific illustrations where so much more information can be shown and understood by using color.

As Editors we would, of course, like to be able to present more issues in color and more pages in color. Unfortunately the budget for **EXPLORE** doesn't include color, so we have to depend on our advertisers to support this effort. In this issue of **EXPLORE** we present three Technical Notes that utilize color illustrations. Most of these illustrations would be difficult, if not impossible, to show in black and white and the use of color is really necessary to convey the message to the reader. Although we cannot promise color in the future, we anticipate that we will have additional opportunities. To that end, we would encourage you to think about color for your contributions. We would like to have some Technical Notes utilizing color illustrations well in advance of publication so we can plan our next color issue. Putting together a color issue of **EXPLORE** is not a trivial task (this issue is about a month "late") and the more lead time we have the better prepared we can be. So, if you have, or are planning to write, a short article that would be enhanced or requires the use of color, please send it to us. We will do our best to get it into the next color issue.

Our next issue will focus on the 18th IGES that was held in Israel that last week of May of this year, and on the West Africa field trip that was held just prior to the meeting. If you have any interesting photographs or a short write-up on a facet of the meeting or field trip we would appreciate hearing from you.

Sherm and Tom



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## President's Message

*continued from page 1*

also particularly appropriate, given the long history of human occupation of this part of the world, coupled with the fact that Jerusalem itself was celebrating its 3000th anniversary. It should come as no surprise that archaeologists use geochemical techniques to identify probable sources of their samples, the only difference being that in their case the samples are ballast-stones recovered from a sunken Phoenician vessel or galena that could have been used as a source of galena cosmetics in Ancient Egypt. Whatever the topic - exploration geochemistry or a related discipline - it was a pleasure to hear the vigorous debate which was stimulated by some presentations. This quality of communication was equally high for the posters, many of which were outstanding.

While the number of abstracts received from university and government research groups was only slightly down on those received for the 17th IGES, in Townsville, there was a noticeable reticence on the part of industry to tell us about their work. A quick count shows that at the 17th IGES there were twenty-one abstracts where the senior author was from a mining/mineral exploration group. At the 18th IGES that number had dropped to just two. While I accept that there is far more incentive for university and government research groups to publish their results it is absolutely critical that we hear from industry as well, and I hope that this shyness will prove to be a temporary phenomenon. Your time to prove this is at the 19th IGES in Vancouver in 1999, so start planning now.

It was not all geochemistry: tours of the Old City and the Israel Museum gave us a greater awareness of the complex history of Israel, and how it has arrived at its place in the world today. The AEG dinner, outside in a very pleasant setting at the Ticho House, gave us a chance to announce the winner of the student paper prize (congratulations to Tracey Delaney) and we were also able to acknowledge the efforts of Ron Bogoch and Moshe Shirav in bringing us all together. As a bonus I discovered a fellow wine-label collector in Ron Bogoch, so I am now not only an expert on kosher wine but I have a very fine label to add to my collection. Exploration geochemistry has many benefits.

What have we learned from the 18th IGES? The single most important conclusion must be that it is possible to promote exploration geochemistry successfully in areas that do not have a large indigenous population of exploration geochemists. While it is essential that we cater to the needs of the majority of our members - in Australia, Canada and the USA - it is equally important that we do not become too introspective. One

goal of AEG is to advance and promote exploration geochemistry and to do that we must be prepared to venture off the well-worn paths from time to time. The 18th IGES was a good example of this. It also proved to be an excellent opportunity to talk to geochemists in related fields; to learn from them and to have the satisfaction of discovering that there are times when they can learn from us.

To Ron and Moshe, and all who worked with them - it was great, we enjoyed it immensely and the time went all too quickly. Many many thanks from all of us who were in Jerusalem, and to those who were not - you should have been there. Next time, in Vancouver, in 1999. We hope to see you there.

**David Garnett**

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## Footnote: AEG West Africa Field Trip

This was run as an adjunct to the 17th IGES in Jerusalem, but was coordinated by the AEG. An account of it will appear in the next EXPLORE, but our acknowledgments cannot wait till then. Our thanks go to all who made it possible, but in particular we would like to express our gratitude to Eric Hanssen and his wife Fadila, and to Philippe Freyssinet who between them were largely responsible for the success of the trip.

**David Garnett**



## Technical Note

*continued from page 1*

length, their location controlled by lithology or faults. What the photograph does not show is the even greater abundance of ponds, puddles and seeps in this permafrost terrane, which provide a means for follow-up surveys.

The second feature that favours waters is the high rate of oxidation of sulphide minerals. When the glaciers covering much of Canada melted about 8,000-10,000 years ago they left behind fresh rock surfaces exposing unoxidized sulphide minerals or they left tills, which are comminuted fresh rocks. These materials have provided a rich source for the dissolution of metals. The concept that cold, glaciated terrains are not favourable for sulphide oxidation, which initially discouraged geochemical exploration in northern Canada, could not be more wrong. Sulphide minerals in permafrost oxidize rapidly. Water that is cold dissolves more oxygen and thin films of water around ice and mineral grains provide a means of conveying oxygen and removing the dissolved metals.

Logistical advantages are the third feature that favours the use of waters. Lake waters can be sampled very rapidly. Using a float equipped light helicopter, it is possible to sample 200 lakes in an eight-hour day. No sample preparation is required. Experience with northern waters has shown that there is no need for filtering and no need for acidification, provided that samples are analyzed reasonably promptly after collection.

## MELVILLE PENINSULA, EARLY SURVEYS

The Melville Peninsula is part of the Canadian Shield, north of the Arctic Circle (Color Plate 2, Figure 2). It contains the western portion of a Lower Proterozoic fold belt, the Foxe Fold Belt, which continues east across Baffin Island and becomes the Rinkian Belt in

*Continued on Page 4*

*Shea Clark Smith*  
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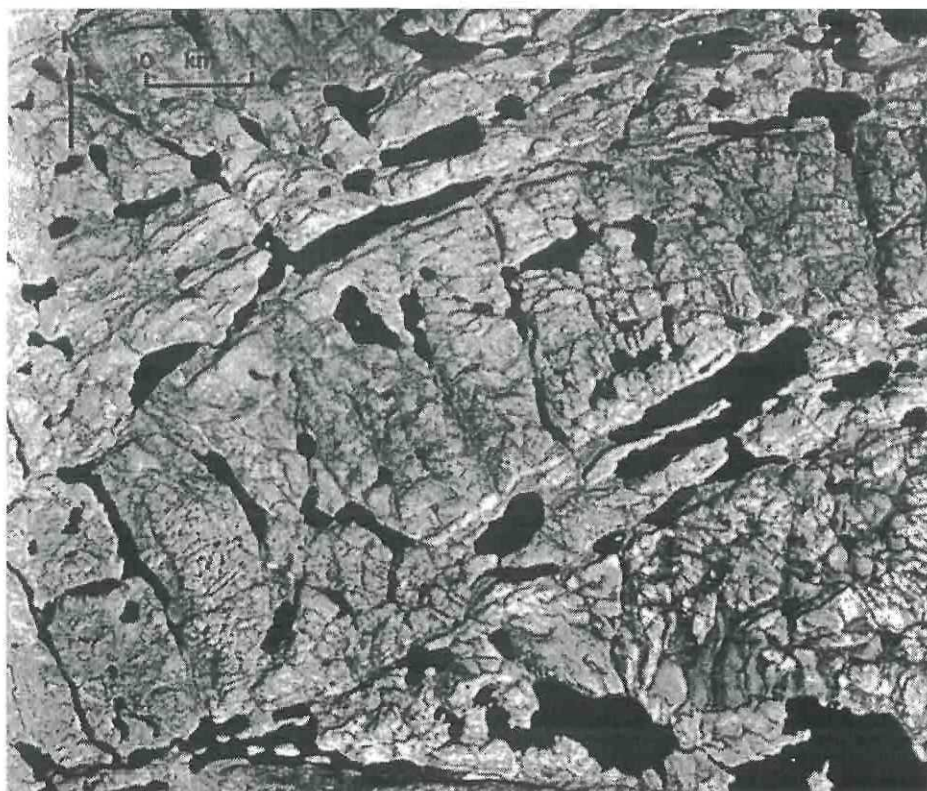
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## Technical Note

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*Figure 1. Vertical aerial photograph showing steeply dipping metasedimentary rocks of the Penrhyn Group, Melville Peninsula. The location of the abundant lakes is controlled by lithology and faulting.*

West Greenland (Greenland in Color Plate 2, Figure 2 is shown in its pre-continental drift position). The rocks of this belt appear to have good mineral potential, most notably demonstrated by the occurrence of the rich Black Angel Pb-Zn deposit in West Greenland. This encouraged the Geological Survey of Canada (GSC) to choose the fold belt for one of the earliest National Geochemical Reconnaissance (NGR) surveys, using lake sediments. The NGR survey of the Melville Peninsula, carried out in 1977, revealed extensive, strong, coincident Zn and Ni anomalies.

Rocks of the Foxe Fold belt on Melville Peninsula comprise the 1.86 Ga Penrhyn Group, resting unconformably on Archean basement (Henderson, 1983). Basal Penrhyn is thin orthoquartzite and rusty schist. These are succeeded by marble and biotite-quartz-feldspar paragneiss and schist and above this by calc-silicate gneiss, marble, schist and paragneiss. At the top are biotite-quartz-plagioclase schist and quartzite. In the lower part of the succession sulphidic, graphitic metasediments are common. Intense folding along east-northeast axes has produced broad, doubly plunging anticlinal zones of Archean basement, with narrow, tight, synclinal infolds of Penrhyn rocks. Metamorphism is upper amphibolite grade, ending at about 1.7 Ga, and foliated granitic rocks, including abundant pegmatites, intrude the Penrhyn.

In 1978, Cameron and Hall carried out experimental lake water surveys to interpret selected anomalies defined by the 1977 lake sediment surveys. The work was based in the Inuit community of Repulse Bay and used a Bell 206-B helicopter fitted with a specially designed sampling system (Cameron, 1978). This permitted rapid rates of collection, 30-40 lakes per hour. In a field laboratory, "total" heavy metals, pH and conductivity were measured. The heavy metals test, which principally measures Zn, is the dithizone method, using Bloom's buffer. The detection limit

of 1 ppb was more than adequate given the threshold of 5-10 ppb Zn. Waters were re-analyzed later in a laboratory for Zn, Cu and Ni using an atomic absorption spectrometer.

Results showed that most samples were typical northern Shield waters, weakly acidic, with <2.5 ppb of each of the three base metals (Cameron, 1979). Mineralized areas were outlined by tight clusters of metal-rich, often acidic waters. Zinc is the most abundant metal, with a 95 percentile of 193 ppb, followed by Ni and Cu. Soils from the mineralized areas are acidic and are partly leached of metals (which, of course, is why the metals are in the waters). Thus ponds and seeps were used for more detailed follow-up and several contained several thousand ppb Zn and Ni. Drilling was not carried out, but rock samples showed that the source of the base metals was paragneiss, often graphitic, which contained pyrrhotite, sphalerite, pentlandite and chalcopyrite. The anomalies occurred very extensively over much of the Penrhyn basin. It was suggested (Cameron and Hattori, 1992) that in this and some other Lower Proterozoic basins in the Shield, base metal rich fluids were originally exhaled into sulphur-poor anoxic waters. In the absence of H<sub>2</sub>S, the base metals were widely dispersed through the basin, rather than precipitating near the vent.

### BHP SURVEYS

BHP Minerals Canada Ltd. came to the area with a different perspective. Several of the geological features of the Penrhyn Group suggested that there might be potential for Broken Hill type (BHT) mineralization. BHT deposits are stratabound Pb-Zn-Ag deposits hosted by high-grade metamorphic sediments, with or without volcanic rocks, of middle Proterozoic age. The massive Pb-Zn-Ag mineralization does not respond to magnetic or electromagnetic exploration techniques; although responses from associated magnetic iron formations, amphibolite and pyrrhotite bodies may provide an indirect indication of adjacent BHT deposits. In the Penrhyn Group, previous workers had identified dozens of magnetic-electromagnetic and lake sediment geochemical anomalies; many tens of kilometres of gossans had been mapped; sphalerite had been discovered by Aquitaine Canada at two locations-DUC and BAR-in 1970; and geological reasoning suggested other parts of the Penrhyn Group were also prospective for BHT deposits. The exploration problem was how to evaluate and prioritize so many anomalies within such a large area.

Following literature research, the decision had been made by BHP to carry out a grassroots exploration program in the Penrhyn Group before contact was made between BHP (Marmont) and GSC (Cameron and Hall). Following this meeting, it was concluded that hydrogeochemistry afforded a means of addressing the exploration problem, and a cooperative program was established to carry out a regional hydrogeochemical program as the basis of the BHP investigation.

Work started in the summer of 1994 from a base camp near the centre of the Penrhyn outcrop. Sampling by BHP was from a Bell 206B helicopter with floats using a simple sampling device. This consisted of an aluminum pole with holders for three 125-ml Nalgene bottles. The bottles were pushed below the lake surface and retrieved, requiring the aircraft to spend only a few seconds on the lake.

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## Technical Note *Continued from Page 4*

At base camp a laboratory was established and equipped with two portable anodic stripping voltammetry (ASV) units, the PVD 2000, made by Chemtronics of Australia and staffed by one analyst. (A second analyst determined conductivity, pH and fluoride ion concentration of the waters). The method used to measure Zn in the waters is described in Explore (Hall and Vaive, 1991). Analysis of the waters was able to keep reasonably in pace with the sampling rate of approximately 150 per day. This was important, because it permitted immediate follow-up in areas of anomalous results. Logistical costs are high in remote areas such as the Melville Peninsula and the immediate availability of the geochemical data permitted more than the usual activities to be condensed into the first year. Samples were later analyzed for a wide range of elements by ICP-MS at ERI Ltd., Vancouver and at the GSC. The quality of results obtained in the field laboratory can be judged by the comparison of ASV and ICP-MS analyses of waters with >1 ppb Zn (Figure 3).

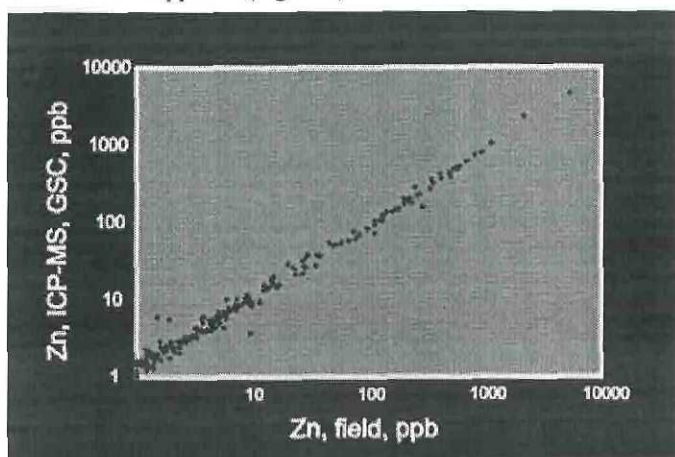


Figure 3. Comparison of analyses for Zn in lake water by anodic stripping voltammetry (ASV) in field laboratory and by ICP-MS, GSC laboratory.

The summer season is relatively short so far north. However, during 6 weeks in 1994, 4,929 lake water samples were collected covering the entire area of the Penrhyn Group, which comprises almost 12,000 km<sup>2</sup>. Anomalous samples, defined as waters containing <sup>35</sup> ppb Zn, occur in distinct clusters. There are 25 of these clusters, or anomalous areas (Color Plate 2, Figure 4). Beginning in 1994, but mainly in 1995, all anomalies were visited on the ground and follow-up investigations were carried out on selected areas. Follow-up methods included geological mapping, geophysics (magnetics, electromagnetics, gravity) and geochemistry (soil geochemistry, lithogeochemistry, surface waters), which will not be discussed further.

## INTERPRETATION

The large number of anomalies defined by the 1994 reconnaissance samples presented a challenge. Could the reconnaissance samples be used to classify and prioritize the 25 anomalies shown in Figure 4? One approach was the Se/S ratio, with both elements analyzed by ICP-MS. The basis for using this ratio is our metallogenic interpretation (Color Plate 3, Figure 5), which considers the Foxe Fold Belt to be a failed rift. Minor amphibolite within the Penrhyn sequence supports the presence of volcanism. Water pumped through volcanic rocks along the rift axis extracted base metals, which entered an anoxic basin in which carbonaceous shales formed. The anoxic waters were low in H<sub>2</sub>S, a consequence of sulphate-poor marine waters or, alternatively, non-marine or brackish water in a restricted basin. In the absence of high

concentrations of H<sub>2</sub>S, metals were widely dispersed in the anoxic waters, rather than primarily precipitating near the vents along the rift axis.

Studies of modern oceanic rifts show that Se has a strong tendency to precipitate with the vent sulphides, whereas relatively more S enters seawater. In addition, Se is strongly associated with sulphide of igneous origin, but not with sedimentary sulphides. The lack of Se in sedimentary sulphides results from the adsorption of selenite ions by iron oxides and clays. Thus when bacteria reduce marine sulphate there is no Se in the water to enter the sulphide. These observations suggested that anomalous water samples related to metal-enriched black shale should have low Se/S ratios, whereas anomalies related to vents along the rift, of potentially greater economic interest, should have higher ratios. The availability of S data made it also possible to calculate the Zn/S ratio. Figure 6 is a plot of the median Zn/S ratio versus the median Se/S ratios for each of the anomalous areas shown in Figure 4. Most such areas plot near the origin, with low values for both ratios. Low Zn/S values indicate rocks rich in pyrrhotite, not sphalerite, and low Se/S, sedimentary not igneous sulphide, both characteristic of metal-rich black shale of minimal economic value. Anomaly 7, the DUC claims, is different, with much higher Se/S and Zn/S. This evidence was taken to indicate that DUC might be at, or close to, a submarine vent. The use of ratios is essential. Amounts of S, Zn and Se vary widely within and between anomalous areas, with S being an index of how much oxidized sulphide is in the lake water. Other anomalies had higher Zn contents than DUC.

Ground follow-up work went ahead independently of studies of prioritizing anomalies. This follow-up work also suggested that

*Continued on Page 6*

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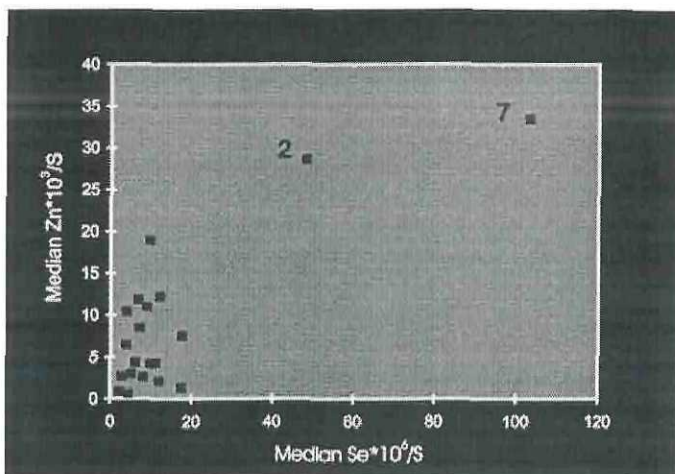


Figure 6. Plot of median values of  $Zn \cdot 10^3/S$  versus median values for  $Se \cdot 10^6/S$  for each of the anomaly clusters shown in Figure 4.

DUC was the most promising target. DUC was one of nine lake water anomaly clusters selected for detailed ground surveys on the basis of Zn-water anomalies, initial prospecting (which discovered minor amounts of sphalerite at five of these areas) and geological setting. Detailed mapping of DUC by Sean Whiteford (BHP) revealed a mineral assemblage including vesuvianite, scapolite, fluorite, epidote and goldmanite (green vanadian garnet) in an isoclinally-folded synformal sequence of psammo-pelite, calc-silicate, calcitic marble, graphitic schist, tourmalinite and minor gabbro. Pyrrhotite-bearing calc-silicates and graphitic units form conspicuous gossans. Up to 7% sphalerite was found in the

(locally massive) graphitic units. This assemblage suggested the presence of a significant exhalative hydrothermal system. Mapping and soil geochemistry reveal anomalous Zn over a strike length of more than 6 kilometres.

Drilling at DUC in 1996 revealed uneconomic grades of base metal mineralization, averaging 1-2% Zn in sphalerite, associated with up to 35% pyrrhotite-pentlandite (0.25% Ni in whole rock assays), minor chalcopyrite, trace galena, with conspicuous gold-manite and dravite gangue, hosted by calc-silicate gneiss and graphitic gneiss. A vent complex is suggested by: (a) V-rich min-erals and flat, MORB-type REE patterns in metamorphosed "shales"; (b) evidence of syn-sedimentary slumping in tourma-linite and massive graphitic units, perhaps associated with growth faults; and (c) pods of massive graphite, presumably the remains of bacteria that fed on the vent fluids (and which oxidized some of the igneous sulphide that might otherwise have precipitated metals).

### FUTURE RESEARCH

Modern methods of analysis present the geochemist with the opportunity and challenge of using data taken from across the periodic table. Until recently, it was not possible to dream of using ratios of Se and S in waters. We have not described here the rare earth element (REE) data that even at the ppb and ppt levels produce smooth chondrite-normalized curves that helped confirm the interpretation of DUC as a vent complex. Rare earth data from waters will find a particular application in the search for kimberlites with their distinctive REE patterns. Although this study relates to the northern Canadian Shield, the techniques are, in part, an outgrowth of studies of stream and river hydrogeochemistry in British Columbia and are thus of broader application.

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## Effects of Geology and Mining Activity on the Sediment Geochemistry of the Arkansas River Drainage Basin, Colorado

S. M. Smith, S. E. Church and G. N. Green

### ABSTRACT

The distribution of major, minor, and trace elements in stream sediments is controlled by the exposure of specific rock types and mineralized areas within the Arkansas River drainage basin. Mining activities and industry contribute elements to the

*Continued on Page 7*

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## Technical Note *Continued from Page 6*

environment that overprint this natural geochemical background. Regional geochemical maps showing the distribution of copper, lead, and zinc in almost 9,800 stream-sediment samples demonstrate the relationship between sediment chemistry and geology, and indicate several potential source areas of these metals in the basin. River-sediment samples show that the Leadville mining district is a major contributor of copper, lead, and zinc to the Arkansas River. At least two additional areas contribute zinc-rich sediments to the river. This study demonstrates the value that regional geochemical data, originally collected for mineral exploration purposes, can have in evaluating the impact of mining and mineral processing on the geochemistry of the riparian environment at a drainage basin scale. The process of dispersion reduces the concentration of copper in river sediment to crustal abundance values within 30 km below the Leadville mining district. In contrast, lead and zinc are not diluted to near crustal abundance values until the addition of sediments derived from the Mesozoic sedimentary rocks that crop out just above Pueblo Reservoir 235 km below Leadville, Colorado.

The methods outlined in this paper describe geochemical map products that can readily be developed from regional geochemical data to demonstrate the dispersion of metals from historic mining districts and their downstream impact on aquatic and riparian habitats. The derivative color ribbon maps are particularly useful in conveying the downstream impacts of historic mining activity to the lay audience.

## INTRODUCTION

Historic mining activity near Leadville, Colorado, has contributed metals to the sediments of the Arkansas River, resulting in environmental degradation of aquatic and riparian habitats along reaches of the river. High concentrations of metals in sediments from Pueblo Reservoir have been attributed to contamination from mining in the Leadville mining district, 235 km upstream (Callender et al., 1989). Several mining districts and mineralized areas in addition to the Leadville mining district also contribute sediments containing elevated concentrations of metals to the Arkansas River.

In 1993, we began a study of metal distributions in the Arkansas River drainage basin of Lake County, Colorado. The existing geochemical data base was supplemented by collecting large composite samples of minus-80-mesh sediment from various river reaches. Samples of active stream sediments and cores of recent lake and river sediments were collected to evaluate the contribution of metals from potential sources near Leadville (Church et al., 1993, 1994). Lead was used as an isotopic tracer to identify specific source areas. Stream sediments from the Leadville mining district contain lead, silver, bismuth, cadmium, zinc, arsenic, and copper at concentrations 2 to 215 times the crustal abundance concentrations. Lead shows the highest enrichment factors and copper the lowest. Pre-mining concentrations of these elements in Arkansas River sediments adjacent to the district, were below normal crustal abundance; except for lead and zinc which were enriched by factors of 2 to 3 (Church et al., 1993). Stream sediments from the Leadville mining district have lead-isotope signatures that match published lead-isotopic data from the ores (Thompson and Beaty, 1990). In contrast, lead-isotope signatures of samples from stream sediments collected from tributaries outside the district, or from the Arkansas River above the district do not match those of the Leadville ores. The study was expanded in 1994 to include the entire Arkansas River drainage above the Pueblo Reservoir. This report describes the methods used to assess concentrations and sources of metal contamination in river sediments and evaluates the distribution of

copper, lead, and zinc in the basin.

## GEOLOGIC SETTING

The geologic data from the Arkansas River drainage basin indicate that the oldest rocks exposed in the basin are a series of Precambrian gneisses and schists developed from the metamorphism of 1.7 to 1.8 billion year (B.Y.) old sedimentary and volcanic rocks. Several zinc-copper-lead sulfide deposits occur in and are genetically related to these Precambrian metamorphic rocks

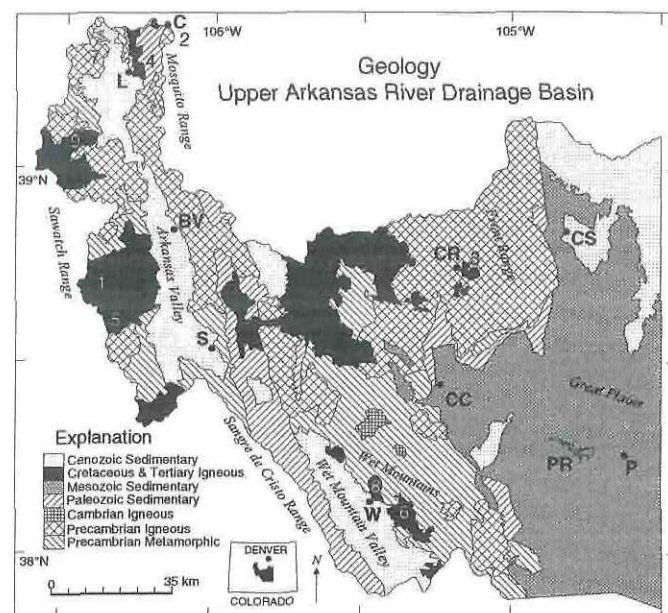


Figure 1. Simplified geologic map of the Arkansas River drainage basin modified from Green (1992). Localities: BV, Buena Vista; C, Climax; CC, Cañon City; CR, Cripple Creek; CS, Colorado Springs; P, Pueblo; PR, Pueblo Reservoir; L, Leadville; S, Salida; W, Westcliffe; physiographic features are indicated in italics. Mining Districts: 1, Chalk Creek; 2, Climax; 3, Cripple Creek; 4, Leadville; 5, Monarch; 6, Rosita Hills; 7, St. Kevin; 8, Silver Cliff; 9, Twin Lakes.

(Sheridan and Raymond, 1984; Sheridan et al., 1990). Large Precambrian granitic batholiths were emplaced into the metamorphic rocks during three intrusive episodes (at 1.7, 1.4, and 1.0 B.Y.). The crystalline Precambrian rocks are exposed primarily in the cores of the mountain ranges.

In the Wet Mountains, Cambrian alkalic igneous rocks and associated carbonatites have intruded the Precambrian metamorphic and igneous rocks north of Westcliffe (only the larger plutons are shown on Fig. 1). These intrusive rocks are enriched in niobium, thorium, rare earth elements, and phosphorus, and locally contain small deposits of copper, nickel, silver, and lead (Parker and Sharp, 1970; Armbrustmacher, 1979).

Lower Paleozoic sedimentary rocks form a series of pre-Pennsylvanian marine carbonates and sandstones that generally crop out in narrow belts along the edges of mountain masses (not distinguished from upper Paleozoic sedimentary rocks in Fig. 1). Near Leadville, extensive outcrops of these lower Paleozoic marine carbonate rocks host the silver, zinc, lead, and gold deposits which have been mined since circa 1860 (Tweto, 1968). During the Pennsylvanian and Permian Periods, sediments eroded from rising mountain masses were deposited as distinctive, red continental arkosic sandstones and conglomerates. Large exposures of these upper Paleozoic rocks are found along the east side of the Front Range between Cañon City and Colorado Springs, and in a belt on the east flank of the Sangre de Cristo Range trending north-

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northwest almost to Buena Vista.

Extensive and thick Mesozoic sedimentary rocks—sandstones, marine shales, and limestones—are exposed in the Plains Region east of the Front Range and Wet Mountains. Small exposures of Mesozoic rocks preserved in grabens west of Cañon City indicate that these rocks once cropped out over a more extensive area. During the Late Cretaceous and early Tertiary, volcanic and intrusive activity accompanied a period of mountain building during the Laramide orogeny. Several large plutons of this age (Fig. 1) are in the Sawatch Range, Mosquito Range, Wet Mountains, and Front Range. In the middle Tertiary, bimodal volcanic and plutonic activity produced volcanic fields of extrusive and intrusive rocks exposed between Cripple Creek and Salida, as well as several igneous stocks such as Climax (Bookstrom, 1990). Several base- and precious-metal mining districts are associated with these Late Cretaceous and Tertiary plutons including: Climax, Leadville, Cripple Creek, Rosita Hills, Silver Cliff, Monarch, Chalk Creek, and Twin Lakes (Fig. 1).

Erosion of the rising mountain masses elevated by block faulting in the early Tertiary spread extensive sedimentary deposits eastward over the Great Plains. Subsequent erosion by the Arkansas River and its tributaries have removed most of these sedimentary rocks from the area; however, a remnant of these lower Tertiary sedimentary rocks is exposed north and east of Colorado Springs (Fig. 1). Late Tertiary and Quaternary rifting created large valleys partially filled with Tertiary rocks and Quaternary sediments in the Wet Mountain and Arkansas Valley (Fig. 1).

### METHODS OF STUDY

Geochemical maps of the upper Arkansas River drainage basin were prepared from existing stream-sediment geochemical data (retrieved from the USGS National Geochemical Data Base, Hoffman and Marsh, 1994) to establish a strategy for the collection of new river-sediment samples. Stream-sediment data for a large region of central Colorado are from two large regional studies: data for 6,995 samples (minus-100-mesh) collected between 14 March 1976 and 11 October 1979 as part of the National Uranium Resource Evaluation program (NURE), and data for 2,796 samples (minus-80-mesh) collected between 1976 and 1982 for USGS mineral resource assessment studies of federal lands. The specific studies, sources of data, and the methodology used for compiling, gridding, and plotting these geochemical data are described in Smith (1994).

Data for copper, lead, and zinc were gridded and contoured using contour intervals selected as multiples (1, 3, 5, 10, and 20 times) of the crustal abundance of the element selected. Values chosen for copper, lead, and zinc—40, 20, and 75 ppm, respectively—fall between the crustal abundance value suggested for crustal rocks (Fortescue, 1992) and the average values derived for western U.S. soils (Shacklette and Boerngen, 1984). These values are also tempered by our experience with regional stream-sediment geochemistry.

Geochemical maps reflect the baseline concentrations for copper (p. 13; Smith, 1994), lead, and zinc (Color Plate 4, Figures 2 and 3) at the time the samples were collected (1976–1982). The distribution of each element is controlled primarily by the rocks exposed in the area. Mining districts, smelter sites, industrial sources of trace and heavy metals, and undisturbed mineralized areas are readily identified on geochemical maps by their elevated metal concentrations within the geologic framework.

On the basis of our regional geochemical maps, we collected composite river-sediment samples to determine the contribution of the major tributaries to the metal load of the sediments in the

Arkansas River. The results from the samples of river sediments are reported in Church et al. (1993, 1994). These twenty-two river-sediment sites are plotted on Color Plate 4, Figures 2–3 as filled diamonds. Between sites, the river was plotted as a “ribbon” and assigned a value on the basis of the metal concentration at the downstream site. The stretch above the Pueblo Reservoir was assigned the value for the most recent sediment in a core sample (locality T2B; Callender et al., 1989). By overlaying the ribbon maps on the regional geochemical maps, the effects of the geochemical composition of the rocks and the extent of dispersed metal contamination from mining districts, smelter sites, industrial sources, and undisturbed mineralized areas can be evaluated.

## INTERPRETATION AND DISCUSSION

### *Affects of Geology*

The concentrations of major, minor, and many trace elements in stream sediments are controlled primarily by the exposed rocks and their derivative soils. Within the upper Arkansas River drainage basin, the concentrations of lead in stream sediments from tributary basins (Color Plate 4, Fig. 2) are generally higher than crustal abundance (20 ppm) throughout the western two thirds of the area. On the east, there is a strong correlation with lead concentrations at or below crustal abundance and the outcrop pattern of Mesozoic sedimentary rocks. The Tertiary volcanic field between Cripple Creek and Salida, and the Cenozoic sedimentary rocks of the Wet Mountain Valley also contain lead concentrations in stream sediments that are below crustal abundance. Areas containing exposures of Precambrian metamorphic rocks, Precambrian igneous rocks, and Paleozoic sedimentary rocks are characterized by lead concentrations between 20 and 60 ppm. Stream sediments derived from the Precambrian granitic batholith between Cripple Creek and Colorado Springs contain average lead concentrations between 60 and 100 ppm. Quaternary basin-fill sediments in the upper Arkansas Valley are enriched in lead and reflect the high lead content of the rocks in the Sawatch and Mosquito Ranges.

The concentrations of zinc in samples of stream sediments from tributary basins (Color Plate 4, Fig. 3) are higher than crustal abundance (75 ppm) throughout the study area with the exception of the Paleozoic sedimentary rocks that crop out on the east flank of the Sangre de Cristo Range which are at or below crustal abundance. Stream sediments derived from the Precambrian metamorphic rocks generally contain slightly enriched zinc concentrations, between 100 and 225 ppm, when compared with other rocks in the basin.

### *Affects of Mining Districts*

Metal-enriched rocks formed during the original mineralization process are exposed at the surface at several places within the Arkansas River drainage basin. As these rocks weather, metals are released and dispersed in waters, soils, and stream sediments. The distance elements are dispersed from their original site depends upon several factors: climate, elevation, element concentration at source, geochemical behavior of the element, and the mineralogic or chemical form in which the element is transported.

Mining activities enhanced the relative concentrations of metals in the region and frequently increased the distance of element dispersion from the point source. Metal-rich soils are eroded at a faster rate when vegetation and soil are disturbed. Ore piles and mine waste dumps were often placed in or near streams, in flood plains, or on steep hillsides where they are readily eroded into streams. The exposure of additional sulfide-bearing minerals to water and oxygen caused increased acid generation, primarily as

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a result of the oxidization of pyrite, creating metal-rich acidic drainage and depositing soluble salt residues in the soils. Milling generally increases the rate of metal dispersion and acid generation because it increases the amount of surface area available for chemical reactions in the waste rock.

Several mining districts or known mineralized areas can be identified by metal enrichments on the geochemical maps for lead and zinc (Color Plate 4, Figs. 2-3). These include the Leadville, Climax, St. Kevin, Twin Lakes, Chalk Creek, Monarch, Cripple Creek, Silver Cliff, and Rosita Hills mining districts. Other mineralized areas can be identified between Westcliffe and Cañon City, on the east side of the Arkansas River between Buena Vista and Salida, and 35 km southeast of Westcliffe. Areas having anomalous metal concentrations found near Salida, Cañon City, Pueblo, and Leadville may also reflect metal contamination from historic smelters.

### *Distribution of Metal-Rich Sediments in the Arkansas River*

The primary source of copper, lead, and zinc in the river sediments of the Arkansas watershed is the Leadville mining district. Copper concentrations are elevated just down river from the district and show a simple pattern of dilution back to crustal abundance values over a distance of only 30 km downstream (p. 13; Smith, 1994). In contrast, lead and zinc concentrations do not decline to crustal abundance values in sediments of the Arkansas River above Pueblo Reservoir 235 km downstream (Color Plate 4, Figs. 2-3). The alteration halo surrounding the Climax porphyry molybdenum deposit is an additional source of molybdenum-, lead-, and zinc-rich sediments to the Arkansas River. However, Church et al. (1993) showed that concentrations of molybdenum, lead, zinc, and cadmium in river sediments derived from the Climax district are rapidly diluted to near crustal abundance values before the river reaches the Leadville mining district. Although other sources in the drainage basin also contribute lead and copper to the Arkansas River, they do not significantly change the dispersion pattern of these two elements derived from the Leadville mining district.

The concentration of zinc in river sediments remains at least 5 times greater than crustal abundance until just below Cañon City (Color Plate 4, Fig. 3). In this vicinity, large amounts of sediment derived from the erosion of the Mesozoic sedimentary rocks dilute the river sediments. An increase in zinc concentration occurs east of Cañon City where it cuts through the Precambrian metamorphic and igneous rocks. This zinc enrichment may be associated with zinc present in the Paleozoic sedimentary rocks that crop out just upstream in the drainage basin (Fig. 1). Zinc-rich sediments derived from mining districts in the Sawatch Range may also contribute to the zinc load of the Arkansas River.

### **ANIMAS BASIN, SOUTHWESTERN COLORADO**

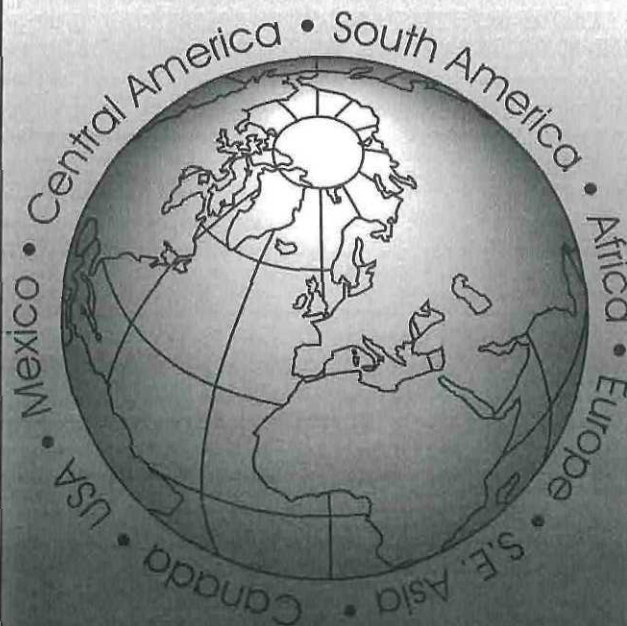
These same techniques have been adopted for use in the USGS Abandoned Mine Lands Initiative to demonstrate the impact of historic mining on watersheds (Church et al., 1997). In this report, the stream sediment, colloid, and water data were collected at the same time allowing for a complete interpretation of the chemistry and sediment transport dynamics of the affected river system. This study showed that the colloidal phase dominates the chemistry of the 0.45 micron filtered water, suspended sediment, and bed sediments. Water filtration at 10,000 Daltons is required to obtain dissolved concentrations of metals in waters affected by mining (Kimball et al., 1995). During low flow, these metal-laden colloids aggregate and settle into the bed sediments and reduce food-chain habitats for aquatic life. When these

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## Technical Note *Continued from Page 9*

sediments are remobilized at high flow, the concentration of zinc that desorbs from the colloids may exceed aquatic-life standards for trout for days to weeks.

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## Mineral Mapping by Remote Imaging Spectroscopy

*Gregg A. Swayze, Roger N. Clark, and K. Eric Livo*

Recent advances in infrared detectors and remote sensing technology are allowing minerals of interest to exploration and environmental scientists to be mapped from spectra obtained by high altitude aircraft. Color Plate 3, Figure 1 is an example of an application of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to help in the remediation of the California Gulch Superfund Site in Leadville, Colorado. The remotely sensed spectra are capable of locating sources of acid mine drainage and secondary iron minerals deposited from those waters.

The new airborne imaging spectroscopy instrument uses new infrared detector technology developed by NASA and the Jet Propulsion Laboratory in a high altitude NASA aircraft. Scientists at the U.S. Geological Survey have developed software to analyze the complex spectra and enhance desired features to produce maps depicting the distribution of iron minerals such as jarosite and goethite, specific clay minerals and carbonate minerals, and numerous rock-forming minerals. The new technology has a resolution of approximately 17 by 17 meters and has more than 200 channels in the visible and infrared region (0.38 to 2.50 microns) to allow reliable identification of hundreds of minerals.

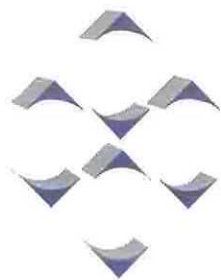
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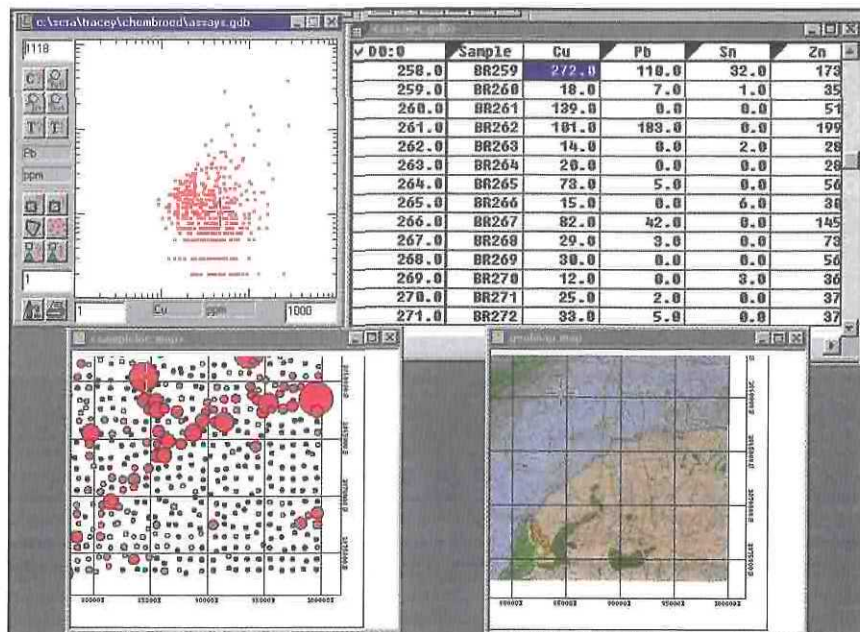
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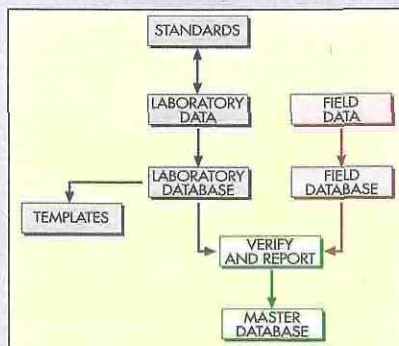
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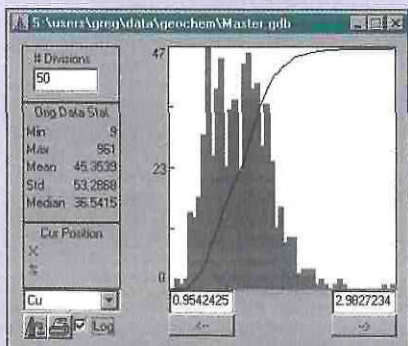
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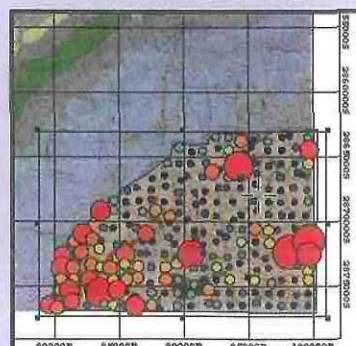
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## PLATE 2

Plate 2, Fig. 2: Map showing Lower Proterozoic Foxe and Rinkian belts. (Referenced on Page 3)

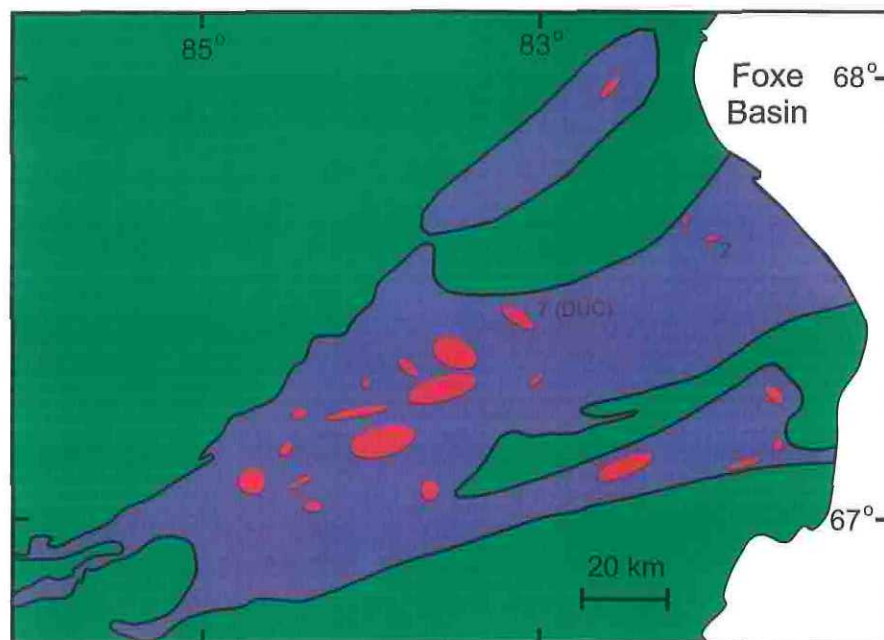
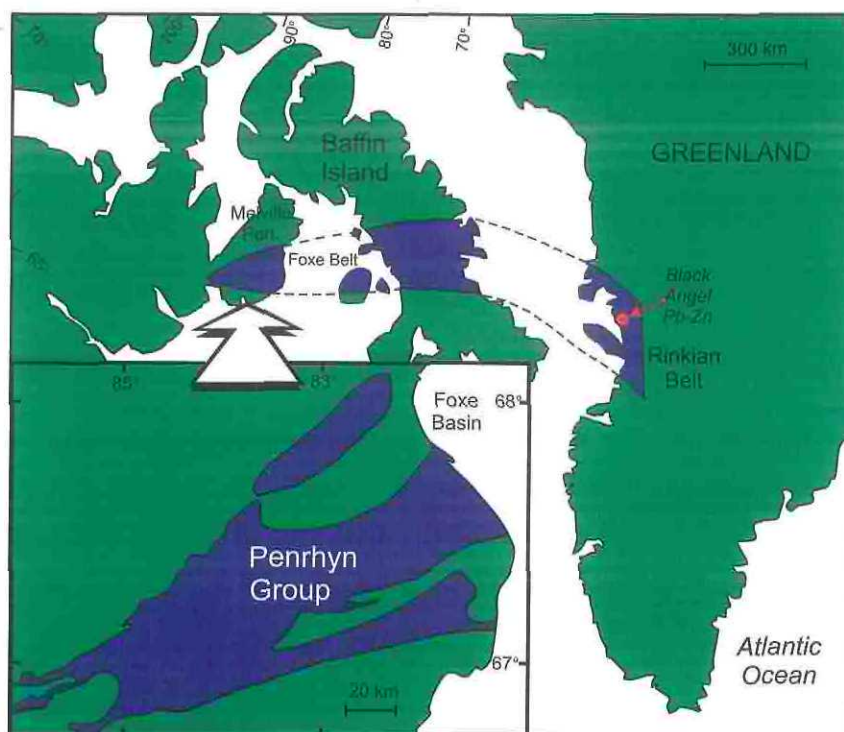


Plate 2, Fig. 4: Map showing clusters of anomalous samples with 5 ppb or greater Zn in lake water within Penrhyn Group. Clusters 7 (DUC) and 2 are identified. (Referenced on Page 5)

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# Foxe Basin

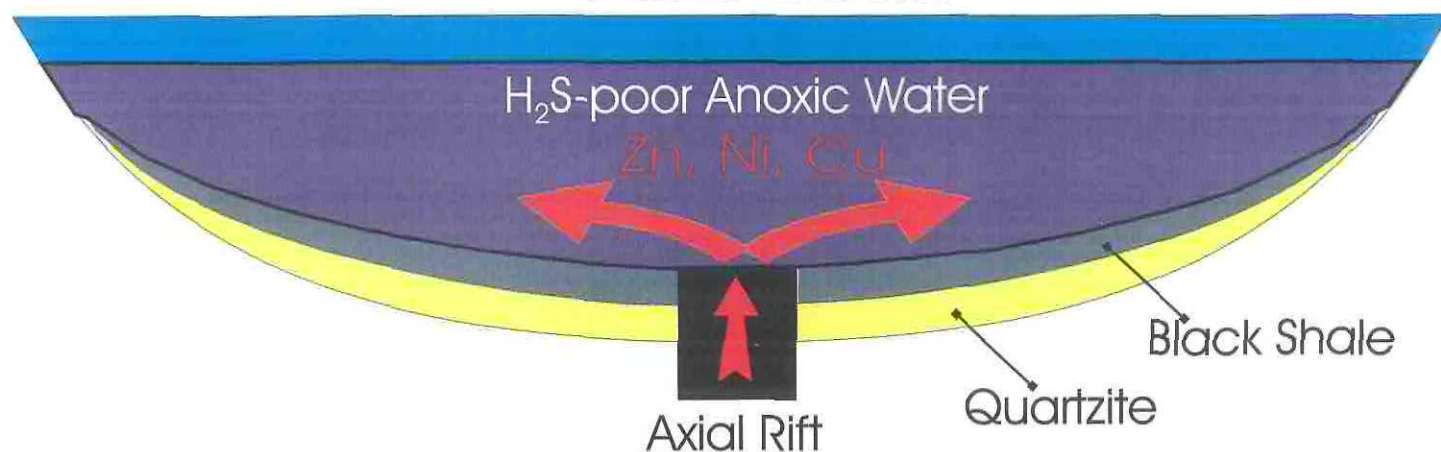


Plate 3, Fig. 5. Metallogenic model for base metal mineralization in Foxe Belt. (Referenced on Page 5)

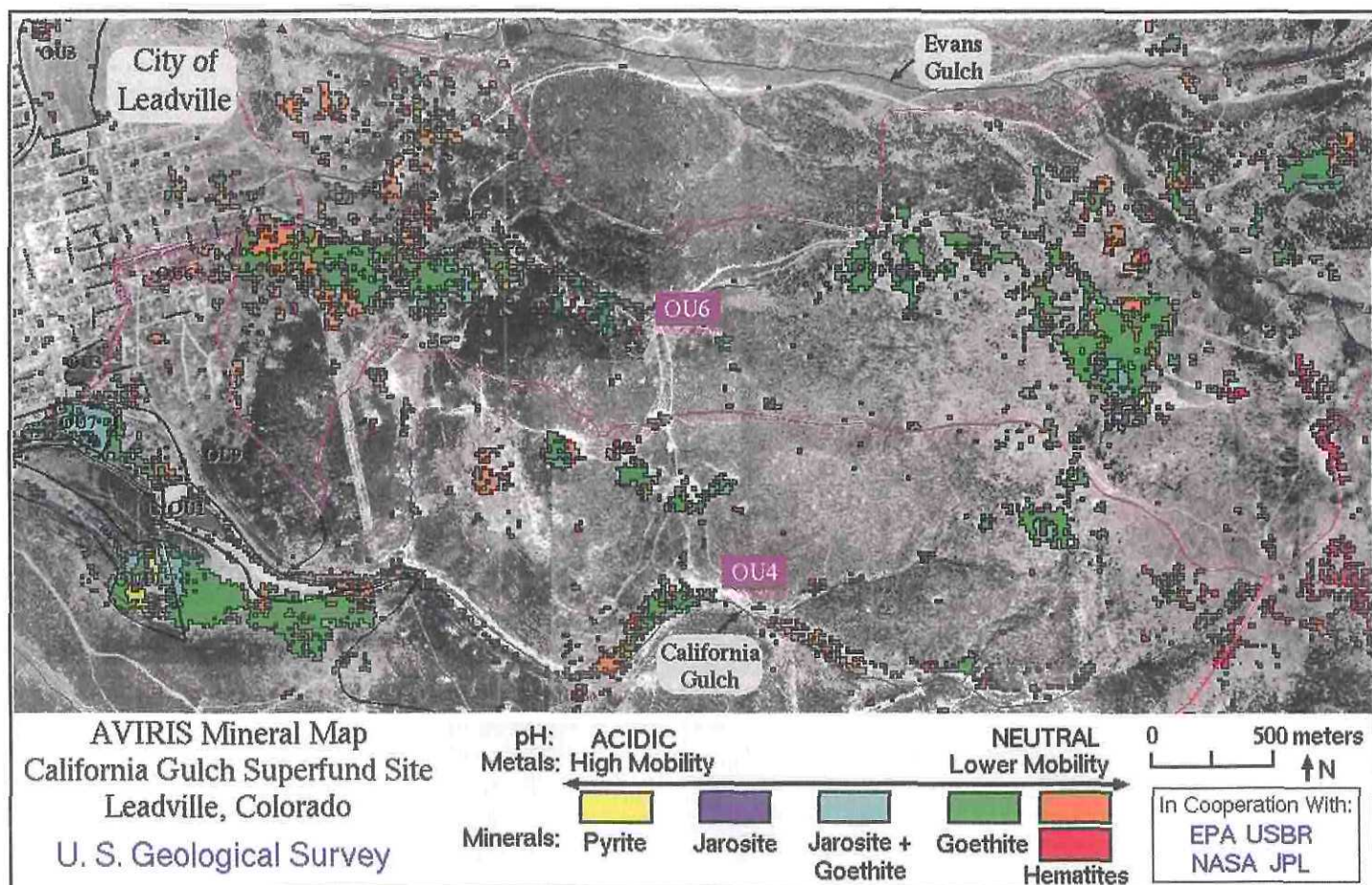


Plate 3, Fig. 1. Imaging spectroscopy map showing minerals at hazardous waste sites at the California Gulch Superfund Site, Leadville, Colorado. See Technical note **Mineral Mapping by Remote Imaging Spectroscopy** starting on Page 10.



## PLATE 4

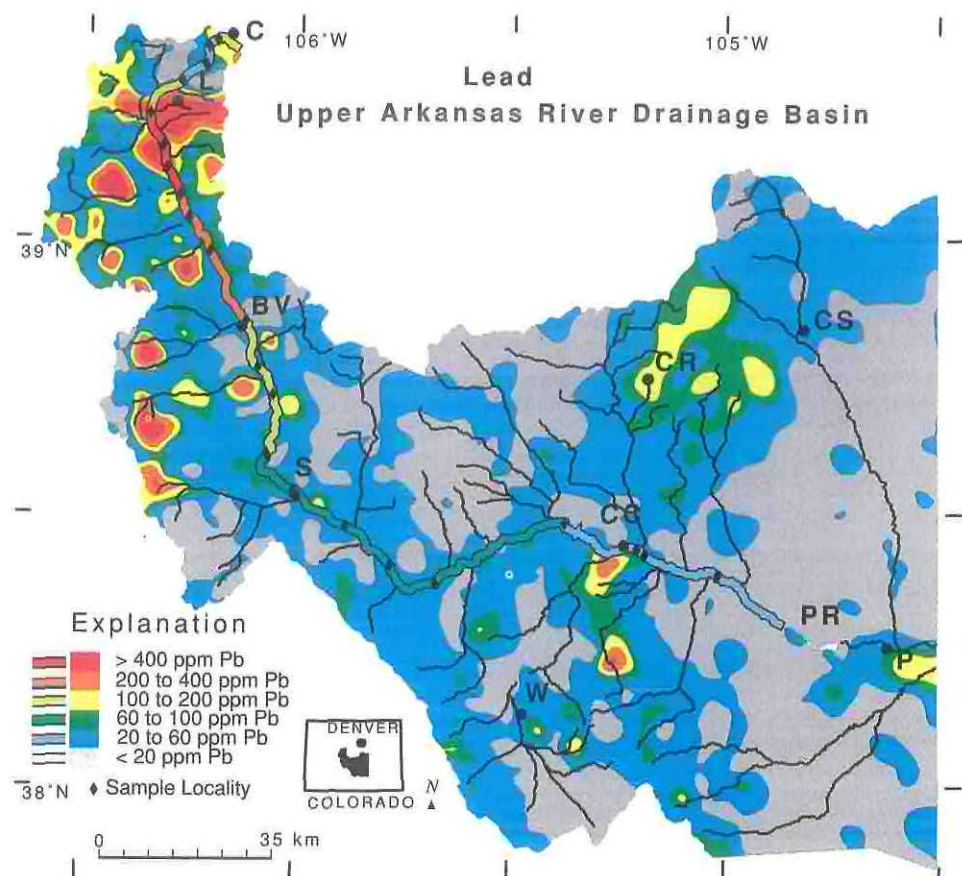


Plate 4, Figure 2. Distribution of lead in stream sediments from the Arkansas River drainage basin; abbreviations are listed in the caption for Fig. 1 (p. 7). Lead concentrations in river sediments are shown in the ribbon map overlaying the trace of the Arkansas River.

(Referenced on Page 8)

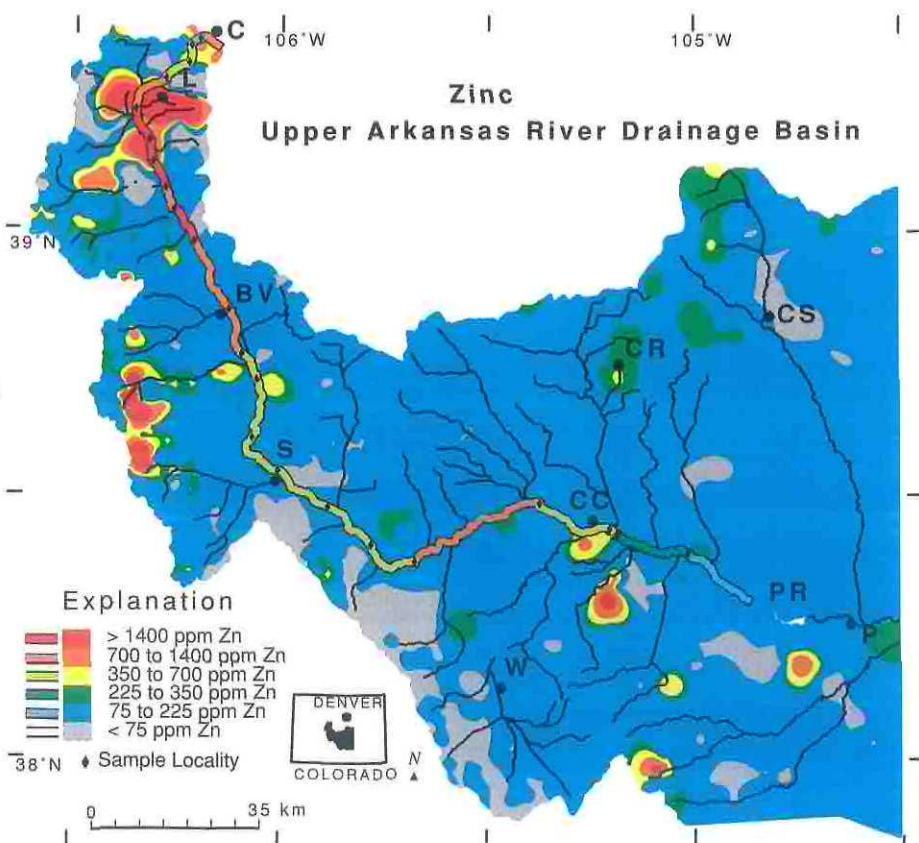


Plate 4, Figure 3. Distribution of zinc in stream sediments from the Arkansas River drainage basin; abbreviations are listed in the caption for Fig. 1 (p. 7). Zinc concentrations in river sediments are shown in the ribbon map overlaying the trace of the Arkansas River.

(Referenced on Page 8)



## STUDENT PAPER PRIZE

The Association of Exploration Geochemists and XRAL Laboratories, a Division of SGS Canada, take pleasure in announcing the 1996 Student Paper Competition Award. This is awarded for the best paper in a refereed scientific journal by a student, on work performed as a student, published within five years of graduation which addresses an aspect of exploration geochemistry. The student must be the principal author and nominations may be made by anyone familiar with the student's work.



Tracy Delaney

Entries closed at the end of 1996 for the Association's eleventh biennial Student Paper Competition. There were eleven entries from nine entrants from as far afield as Canada, China, USA, Australia and the UK. They were all of a very high standard and the choice was difficult. The winner, this time, was Tracy Delaney, now a Project Geochemist with Steffen Robertson and Kirsten, in Denver. Her winning paper was based on research for her M.Sc. Thesis, at the University of British Columbia, supervised by Prof. W.K. Fletcher, which she completed in 1993.

Tracy obtained her B.A. in Geology at the University of Colorado in 1984. Since then she has built varied experience in geology and geochemistry with the USGS (Denver) investigating the mineral potential of wilderness areas in the USA and Alaska, exploration in Nevada, Colorado and New Mexico with Atlas Precious Metal and Placer Dome. She has worked as a geochemical consultant, investigating trace elements in bedrock, tills, soils and stream sediments and in environmental geochemistry in monitoring acid mine drainage and in developing mine closure plans with the Environmental Geochemistry section of the Ministry of Energy, Mines and Petroleum Resources of British Columbia and with Steffen Robertson and Kirsten. She is a member of the Canadian Institute of Mining, the Association of Exploration Geochemists, the Association for Women Geoscientists and she is a registered Professional Geoscientist in British Columbia.

She receives a \$500 cash prize from XRAL, a two year membership in the Association, together with the Journal and Explore, a certificate of recognition and \$500 towards expenses to attend an AEG-sponsored meeting, where the award will be presented. Unfortunately she was unable to attend the 18th IGES in Jerusalem.

Her award-winning paper is entitled "Size distribution of gold in some soils associated with selected gold mineralization in Canada and the United States of America" which was published in 1993 in the Journal of Geochemical Exploration Volume 48 and was co-authored with Prof. W.K. Fletcher. A copy of the abstract follows:-

"Samples were collected near known gold mineralization from anomalous and background soils developed on glacial till in British Columbia and Ontario, and in residual soils in Nevada, Utah and the Yukon Territory. After wet sieving to five size fractions finer than 2000  $\mu\text{m}$ , and separation of heavy minerals (S.G.>3.3) for the -212+106  $\mu\text{m}$  and -106+53  $\mu\text{m}$  fractions, gold concentrations in each fraction were determined by fire assay-atomic absorption.

In all cases more than 60% of the gold resides in the -53  $\mu\text{m}$  fraction. For the residual soils most of the remaining gold is associated with the light mineral fractions and only a negligible proportion resides in the heavy minerals. Estimates of the numbers of gold particles and subsampling variability suggests that gold, in both heavy and light mineral fractions, is largely present as inclusions of fine gold. For exploration purposes, optimum sample representativity would be obtained with the -53  $\mu\text{m}$  fraction. How-

ever, because this fraction is a major component of the soils, use of a coarser size fraction (e.g., -212  $\mu\text{m}$ ) will only slightly reduce sample representativity. Also, because most of the gold is associated with the -53  $\mu\text{m}$  and light mineral fractions, use of heavy mineral concentrates offers no significant advantage and in some cases would result in anomalous conditions being overlooked."

The Association of Exploration Geochemists would like to thank XRAL Laboratories for, once again, supporting this worthy cause, which encourages young geochemists to publish their research.

I.D.M. Robertson

Chairman, Student Paper Competition Committee

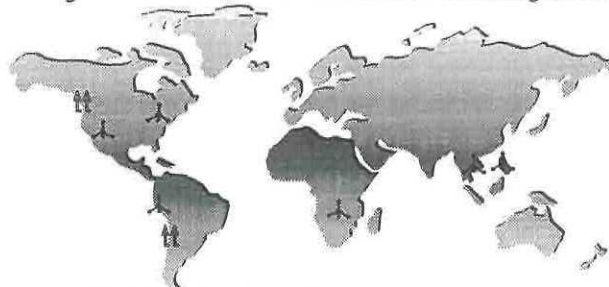
## CALENDAR OF EVENTS

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

- August 10-15, 1997, **Gordon Research Conference on Inorganic Geochemistry: Ore Deposits**, New Hampton, New Hampshire. INFORMATION: Mark Reed, Dept. of Geological Sciences, University of Oregon, Eugene, OR 97403-1272, TEL 541-346-5587, FAX 541-346-4692, mhreed@oregon.uoregon.edu or Kevin Shelton, Dept. of Geological Sciences, University of Missouri, Columbia, MO 65211, TEL 573-882-6568, FAX 573-882-5458, geosckls@showme.missouri.edu.
- August 11-13, 1997, **4th Biennial Society for Geology**

Continued on Page 16

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• Group 4A Whole Rock ICP.....	\$14.00	\$10.80
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## Calendar of Events

*Continued from Page 15*

**Applied to Mineral Deposits**, Turku, Finland. INFORMATION: Congress Office/SGA Meeting 1997, University of Turku, Lemminkäisenkatu 14-18B, FIN-20520 Turku, Finland, TEL 358-21-333-6342.

■ August 19-20, 1997, **IMA Working group in mineral equilibria and data bases**, Helsinki, Finland. INFORMATION: Pentti Holtta, Geol. Survey Finland, SF-02150 Espoo, Finland. TEL. 358-0469323-12, FAX. 358-0-462205, e-mail: pentti.holtta@gsf.fi.

■ September 1-5, 1997, **Challenges to Chemical Geology, 10th Meeting of the European Geological Societies**, Carlsbad, Czech Republic. INFORMATION: Dr. Martin Novak, Czech Geol. Survey, Geologická 6, 15200 Prague 5, Czech Republic, TEL 422-581-71-20, FAX 422-581-87-48, Novak@cgu.cz

■ October 5-10, 1997, **4th International Symposium on Environmental Geochemistry**, Vail Colorado. INFORMATION: R.C. Severson or L. P. Gough, USGS, Denver Federal Center, Box 25046, MS 973, Denver, CO 80225, TEL 303-235-5514 or 5513, iseg@helios.cr.usgs.gov.

■ October, 20-23, 1997, **Annual Meeting of the Geological Society of America**, Salt Lake City, Utah. INFORMATION: TEL 1-800-472-1988.

■ December 8-11, 1997, **Fall American Geophysical Union meeting**, San Francisco, Calif. INFORMATION: AGU meetings department, 2000 Florida Ave. NW, Washington D.C. 20009. TEL. 202-462-6900, 1-800-966-2481, FAX. 202-328-0566, e-mail: meetinginfo@kosmos.agu.com.

■ January 27-30, 1998, **Exploration methods '98-Pathways to Discovery**, Vancouver, B.C., Canada by Society of Economic Geologists and British Columbia and Yukon Chamber of Mines. INFORMATION: Jack Patterson, British Columbia and Yukon Chamber of Mines, 840 W. Hastings St., Vancouver, B.C. V6C 1C8, Canada. TEL. 1-604-681-5328, FAX 1-604-681-2363.

■ March 30-April 3, 1998, **9th International Symposium on Water/Rock Interactions**, Taupo, New Zealand. INFORMATION: B.W. Robinson, Wairakei Research Centre, Institute of Geological and Nuclear Sciences, Private Bag 2000, Taupo, New Zealand, TEL 64-7-374-8211, FAX 64-7-374-8199, wri-9@cns.cri.nz.

■ April 13-17, 1998, **The Seventh International Kimberlite Conference**, Cape Town, South Africa. INFORMATION: Department of Geological Sciences, University of Cape Town, Private Bag, Rondebosch, 7700, South Africa, 7IKC@GEOLOGY.UCT.AC.ZA, FAX: +27 21 650 3783, TEL: +27 21 650 2931. Secretary/Treasurer: James Gurney +27 21 531 03162 FAX: +27 21 531 9887.

■ May 18-20, 1998, **Geological Association Canada/Mineralogical Association Canada**, Quebec, Canada. A Morin, Dept. Geologie et de genie geologique, Universite Laval, Pavillon Adreïn-Pouliot Sanite-Fay, Quebec, G1K 7P4 Canada. TEL. 418-656-2193. FAX 418-565-7339.

■ August 10-14, 1998, **General meeting of the International Mineralogical Association**, Toronto, Canada. E. Schandl, Dept. of Geology, University of Toronto, Toronto, Canada M5S 3B1. TEL 416-978-7084, FAX 416-978-3938.

■ October 26-29, 1998, **Annual Meeting of the Geological Society of America**, Toronto, Ontario, Canada. INFORMATION: Pierre Robin, Dept. of Geology, 22 Russell St., Toronto, ON M5S 3B1, Canada, TEL 416-978-3022, FAX 416-978-3938.

■ October, 25-28, 1999, **Annual Meeting of the Geological Society of America**, Denver, Colo. INFORMATION: TEL 1-800-472-1988, meetings@geosociety.org.

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

**Virginia T. McLemore**

*New Mexico Bureau of Mines and Mineral Resources*

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FAX: 505-835-6333

e-mail: ginger@gis.nmt.edu



## 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,

*Continued on Page 17*

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## New Members

*Continued from Page 16*

recommendation by the Admissions Committee, review by the Council, and publication of applicant's names in the newsletter remains unchanged.

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## RECENT PAPERS

This list comprises titles that have appeared in major publications since the compilation in **EXPLORE** Number 96. 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 (USG OFR); Geological Survey of Canada Papers (GSC Paper) and Open File report (GSC 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 new references to Dr. Closs, not to **EXPLORE**.

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Cu, Fe, Ni, Pb, V, and Zn) and sulphur in terrestrial moss samples as indication of airborne pollution in a 188, 000 km<sup>2</sup> area in northern Finland, Norway, and Russia. *J. Geochem. Explor.* 58(2/3): 269-281.

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*Continued on Page 19*

## 20<sup>TH</sup> INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM, 2001

The Association of Exploration Geochemists is looking for a venue for the 20<sup>th</sup> IGES. The Association will consider all proposals for hosting this event. Proposals must include the following:

- Location
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- Suggested outline for meeting
- Suggested field trips and short courses
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## Recent Papers

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## Technical Note

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mineral assemblages related to mine dumps and tailings rich in pyrite, the major source of acidic drainage. Field checks confirm that highly acidic waters form in the pyritic tailings and waste rocks and is gradually neutralized as it spreads. The acidic waters are neutralized and a consistent sequence of iron minerals is deposited. The iron minerals jarosite, goethite, and hematite are diagnostic in the AVIRUS spectra, and the spatial patterns permit identification of sources of acidic drainage and document the fate of the acidic waters. This technology also is useful for mapping of clay and carbonate minerals that may provide natural mitigation of acid mine drainage.

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