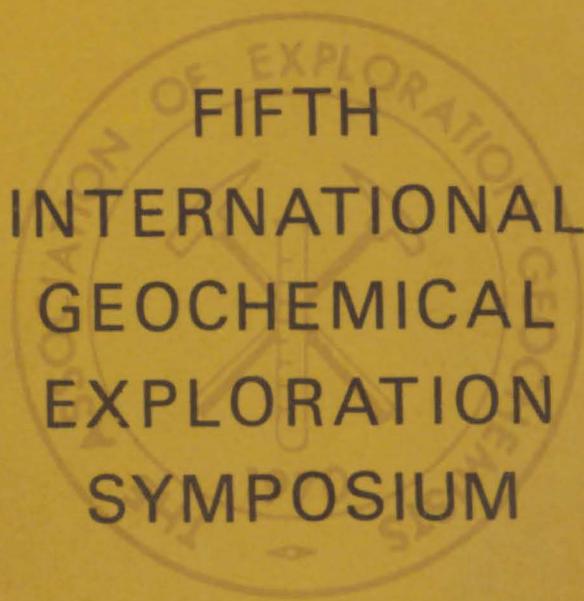


The Association of  
Exploration Geochemists

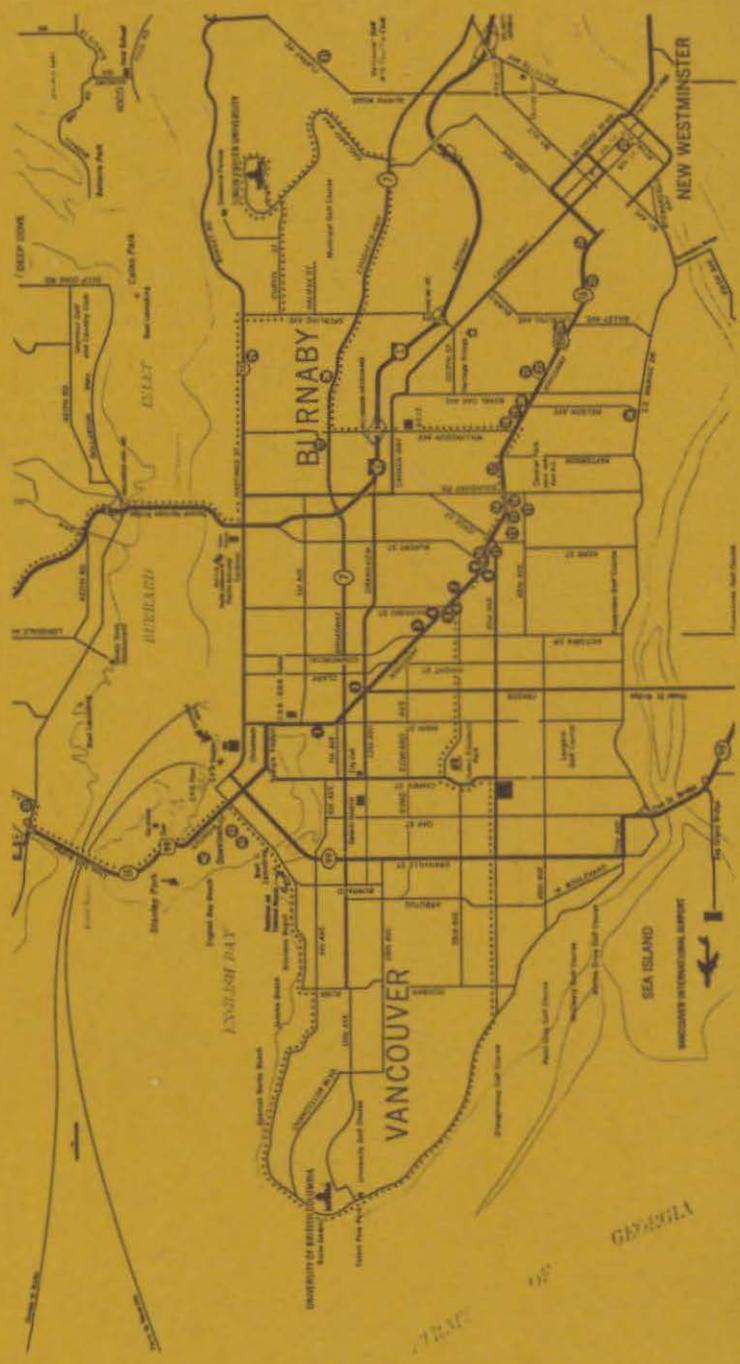


FIFTH  
INTERNATIONAL  
GEOCHEMICAL  
EXPLORATION  
SYMPOSIUM

April 1st-4th, 1974

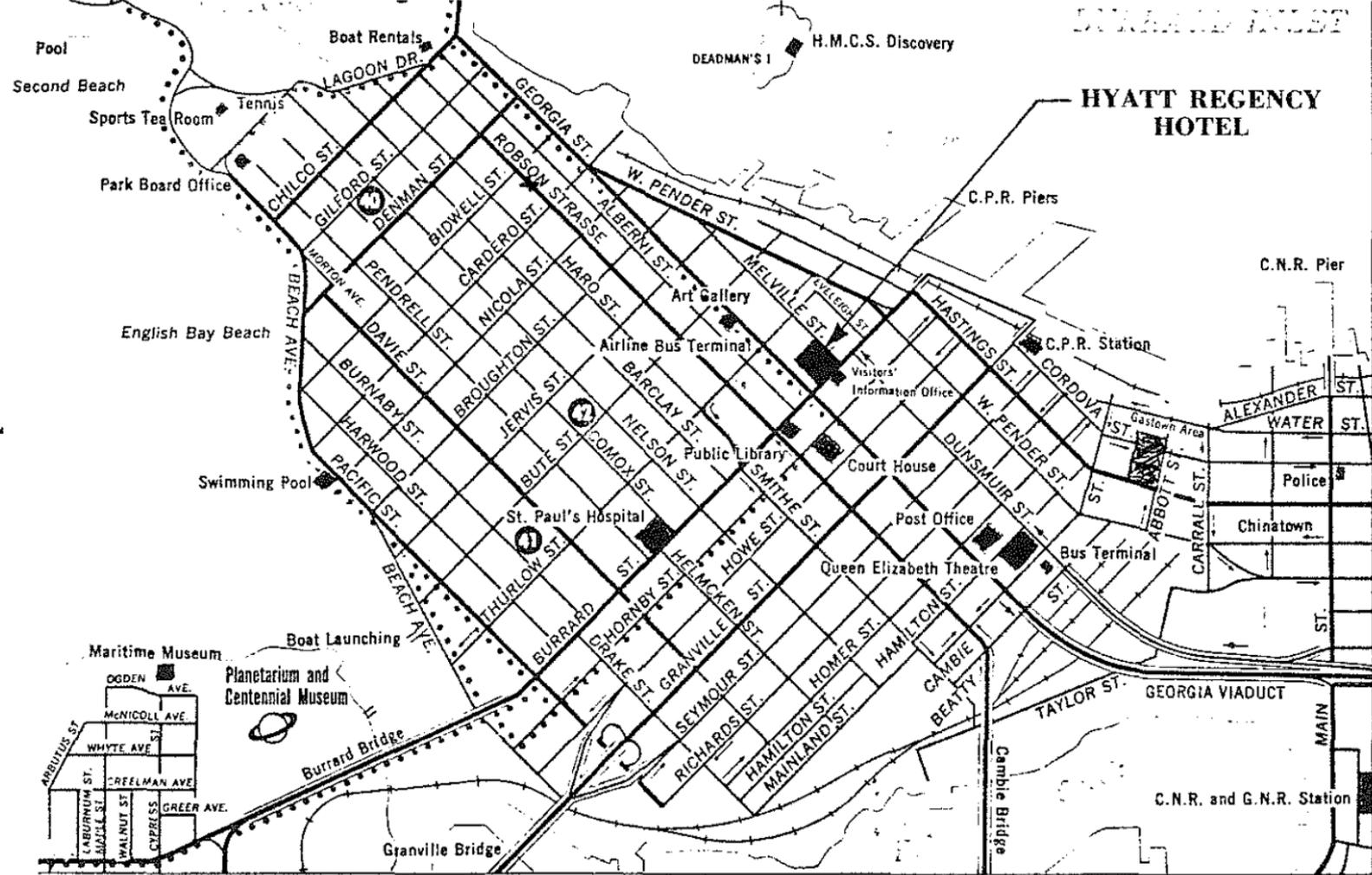
Vancouver  
British Columbia  
Canada

Handbook



MAP

GEORGINA



**HYATT REGENCY HOTEL**

C.P.R. Station

Queen Elizabeth Theatre

Planetary and Centennial Museum

Burrard Bridge

Granville Bridge

GEORGIA VIADUCT

C.N.R. and G.N.R. Station

C.P.R. Piers

C.N.R. Pier

Police

Chinatown

Bus Terminal

Court House

Art Gallery

Airline Bus Terminal

St. Paul's Hospital

Park Board Office

Second Beach

Pool

H.M.C.S. Discovery

Boat Rentals

LAGOON DR.

Tennis

Sports Tea Room

English Bay Beach

Swimming Pool

Maritime Museum

Boat Launching

TAYLOR ST.

Gambie Bridge

ST.

ST.

ST.

ST.

ST.

ST.

ABBITTS ST.  
LABURNUM ST.  
MADILL ST.  
WALNUT ST.  
CYPRESS  
WHYTE AVE.  
MCNICOLL AVE.  
OGDEN AVE.  
CREELMAN AVE.  
GREER AVE.

Planetarium and Centennial Museum

Burrard Bridge

Granville Bridge

TAYLOR ST.

Gambie Bridge

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# THE ASSOCIATION OF EXPLORATION GEOCHEMISTS

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Vice President .....	Dr. R. W. Boyle
Vice President .....	Dr. E. M. Cameron
Treasurer .....	Dr. M. B. Mehrtens
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B. M. Smee .....	Barringer Research Ltd.

## Ladies Committee

Mrs. I. L. Elliott

Mrs. J. D. Knauer

# ANNUAL GENERAL MEETING

## THE ASSOCIATION OF EXPLORATION GEOCHEMISTS

The Fourth Annual General Meeting of the Association will be held in the Prince of Wales Room at 7:30 p.m. on Monday, April 1st, 1974.

### PROCEEDINGS OF THE SYMPOSIUM

Prepaid orders for the volume of Symposium Proceedings may be placed at the desk in the Registration area.

Special reduced prices are:

Individual A. E. G. members

ordering prior to publication ..... \$25.00(U.S.)

Other delegates ordering prior to May 1st, 1974 ..... \$32.00(U.S.)

This price includes postage and packing to all parts of the world. We have been specifically informed by the publisher that the post-Symposium price will be substantially higher than that for orders placed now.

### SOCIAL PROGRAMME

#### Sunday, March 31st

8:00 p.m. - 10:00 p.m. .... No-host Wine and Cheese Party.  
(Regency Ballroom)

#### Monday, April 1st

12:30 p.m. - 2:00 p.m. .... Delegates' Beer Lunch.

1:00 p.m. - 4:30 p.m. .... Ladies' City Tour.

#### Tuesday, April 2nd

10:00 a.m. - 2:00 p.m. .... Ladies' tour of Chinatown followed  
by lunch and fashion show.

7:00 p.m. - 1:00 a.m. .... Delegates' and Ladies' evening in  
Gastown, including dinner.

#### Wednesday, April 3rd

12:20 p.m. - 2:15 p.m. Delegates' and Ladies' Harbour Cruise,  
including sandwich and beer lunch and band.

8:00 p.m. - 12:00 p.m. Delegates' and Ladies' Dinner and Dance.

#### Thursday, April 4th

9:00 a.m. - 2:00 p.m. Ladies' tour of Vancouver Waterfront and  
Simon Fraser University, with lunch in New Westminster.

9:00 a.m. - 11:30 a.m. .... Family tour of Stanley Park Zoo  
including a visit to the Aquarium.

**TECHNICAL TOURS  
BRITISH COLUMBIA PORPHYRY COPPER DEPOSITS**

**Highland Valley — Lornex and Bethlehem Mines**

*Thursday, April 4*

Fly to Kamloops. Overnight in Kamloops.

*Friday, April 5*

Drive to site of Afton Mines. Coffee at Logan Lake.  
Visit Rio Algom/Rio Tinto Lornex property.

Return to Logan Lake for lunch.

Visit Bethlehem Copper Corporation property.

Return to Vancouver.

Temperatures are likely to be in the low thirties  
so warm clothing should be worn.

*Cost — \$70.00 (Can.) excluding meals.*

**Island Copper Mines**

*Friday, April 5*

Vancouver to Port Hardy by boat.

Lunch and dinner on board.

*Saturday, April 6*

Bus to mine site. Tour of Island Copper operations.  
Lunch at mine.

Return to Vancouver arriving early Sunday morning.

Precipitation is probable so waterproof clothing  
should be worn.

*Cost — \$75.00 (Can.)*

**GEOLOGICAL SCIENCES CENTRE, UNIVERSITY OF BRITISH  
COLUMBIA**

Delegates are invited to visit the Geological Sciences Centre on the campus of the University of British Columbia between the hours of 10:00 a.m. and 5:00 p.m. on Friday, April 5th. Visitors will be able to see displays illustrating the Centre's activities. Transportation arrangements will be announced.

## TECHNICAL PROGRAMME

### Monday April 1

#### Morning — Opening Ceremonies

- 10:30 *Dr. I. Nichol*, President of the Association of Exploration Geochemists, will introduce *Dr. D. J. McLaren*, Director of the Geological Survey of Canada, who will welcome the delegates. *Dr. J. S. Webb*, Professor of Geochemistry at the Royal School of Mines and President of the Institution of Mining and Metallurgy of London will give the opening address — "Environmental Problems and the Exploration Geochemist".

### Monday April 1

#### Afternoon — General Technical Session

Chairmen — *H. E. Hawkes*, *H. V. Warren*

- X 1:55 *E. M. Cameron*. Methods of geochemical exploration for massive sulphide deposits in Canada.
- 2:25 *E. Buhlmann*, *D. E. Philpott*, *M. J. Scott*, and *R. N. Sanders*. The status of exploration geochemistry in southern Africa.
- 2:50 *M. Shiikawa*, *K. Wakasa*, and *N. Tono*. Geochemical exploration for the Kuroko deposits in the Northeast Honshu, Japan.
- 3:15 *J. Pokorny*. Geochemical prospecting for ores in the Bohemian Massif, Czechoslovakia.
- 3:40 Coffee
- X 4:05 *J. H. Montgomery*, *D. R. Cochrane*, and *A. J. Sinclair*. Discovery and exploration of the Ashnola porphyry copper deposit near Keremeos, B. C.: a geochemical case history.
- X 4:30 *G. J. S. Govett*. Soil conductivities: assessment of an electrogeochemical exploration technique.
- 4:55 *R. Salvadori*. Geochemical Exploration in Sardinia.

### Tuesday April 2

#### Morning — Application of Statistical Techniques

Chairmen — *A. W. Rose*, *D. Sampey*

- 8:55 *A. J. Sinclair*. Some considerations regarding grid orientations and sample spacing.
- 9:25 *S. Dijkstra*, and *K. Kubik*. Autocorrelation studies and geochemical data analysis.
- 9:50 *M. David*. Lakeview revisited: variograms and correspondence analysis, new tools for the understanding of geochemical data.
- 10:15 Coffee

- 10:35 *F. Cachau-Herreillat et al.* Towards a quantitative utilization of geochemical exploration: threshold problem, estimation of soil surveys.
- 11:00 *R. Sinding-Larsen.* A computer method for dividing a regional geochemical survey area into homogenous subareas prior to statistical interpretation.
- 11:20 *R. I. Dubov.* The choosing of functions for the geochemical data description.
- 11:40 *A. J. Bull, and R. H. Mazzucchelli.* Application of discriminant analysis to the geochemical evaluation of gossans.
- 12:00 *W. E. Sharp, and T. L. Jones Jr.* A topologically optimum prospecting plan for streams.

## Tuesday April 2

### Afternoon — Primary Dispersion

Chairmen — *R. W. Boyle, F. Cachau-Herreillat*

- 1:30 *R. L. Erickson, and S. P. Marsh.* Integrated geologic and geochemical studies, Edna Mountain, Nevada.
- 2:00 *R. J. L. Colvine.* Distribution of ore and related elements in the wallrocks, Broken Hill Mine, Kabwe, Zambia: a method of detecting significant aureoles in fractured carbonate country rock.
- 2:25 *J. A. Randall.* The Corral de Piedra molybdenite stockwork, Durango, Mexico.
- 2:50 *W. J. Wolfe.* Zinc abundance in early Precambrian volcanic rocks: its relationship to exploitable levels of zinc in sulphide deposits of volcanic-exhalative origin.
- 3:15 Coffee
- 3:40 *W. D. Goodfellow.* Major and minor element halos in volcanic rocks at Brunswick No. 12 sulphide deposit, N. B., Canada.
- 4:05 *J. E. Gunton, and I. Nichol.* Chemical zoning associated with the Ingerbelle-Copper Mountain mineralization, Princeton, B. C.
- 4:30 *I. R. Jonasson, and D. F. Sangster.* Variations in the mercury content of sphalerite from some Canadian sulphide deposits.
- 4:55 *J. Oyarzun. M.* Rubidium and strontium as a guide to copper mineralization emplaced in some Chilean andesitic rocks.

### Wednesday April 3

#### Morning Session 1 — Primary Dispersion

Chairmen — *R. I. Dubov, B. Bolviken*

- 8:55 *M. J. Al-Atia, and J. W. Barnes.* Rubidium: a primary dispersion pathfinder at Ogofau gold mine, southern Wales.
- 9:25 *G. M. Lawrence.* Rock geochemistry and radiometry as a guide to mineralization in the Galway granite, Ireland.
- 9:50 *R. G. Garrett.* Copper in Proterozoic acid volcanics as a guide to exploration in the Bear Province.
- 10:15 Coffee

### Wednesday April 3

#### Morning Session 2 — Exploration in Lateritic Terrain

Chairmen — *J. A. Hansuld, M. Shiikawa*

- 10:40 *C. R. M. Butt, and N. R. Sheppy.* Geochemical exploration problems in Western Australia, exemplified by the Mt. Keith area.
- 11:05 *J. R. Wilmshurst.* The weathering products of nickeliferous sulphides and their associated rocks in Western Australia.
- 11:30 *R. Cox.* Geochemical soil surveys in exploration for nickel-copper sulphides at Pioneer, near Norseman, Western Australia.
- 11:55 *P. M. Ong, and A. C. Sevillano.* Geochemistry in the exploration of nickeliferous laterite.

### Wednesday April 3

#### Afternoon — Exploration in Tropical Terrain

Chairmen — *P. R. Donovan, M. A. Chaffee*

- 2:20 *M. J. Scott.* Three case histories from a geochemical exploration program — Windhoek District, Southwest Africa.
- 2:50 *P. J. Goossens.* Geochemical behavior of galena under semi-arid climatic conditions in western Africa.
- 3:15 *D. E. Philpott.* Shangani, a geochemical discovery of a massive disseminated Ni-Cu sulphide deposit.
- 3:40 Coffee
- 4:05 *M. Saigusa.* Relation between copper contents in soil and copper grade of ore bodies calculated by drill core assay of some porphyry copper deposits in tropical terrain.
- 4:30 *V. A. Bugrov, and I. M. Shalaby.* Geochemical prospecting in the Eastern Desert of Egypt.
- 4:55 *P. B. Trost.* Interpretation of molybdenum content in ground-water utilizing Eh, pH and conductivity.

## Thursday April 4

### Morning — Exploration in Glaciated Terrain

Chairmen — *W. W. Shilts, M. B. Mehrrens*

- 8:55 *W. B. Coker, and I. Nichol.* Metal dispersion in lake sediments related to mineralization and its use in reconnaissance in northern Ontario.
- 9:25 *P. H. Davenport, E. H. W. Hornbrook, and J. Butler.* The use of lake sediments in a reconnaissance geochemical survey for zinc mineralization in western Newfoundland.
- 9:50 *R. C. Leake, and R. T. Smith.* A comparison of sample types in stream sediment geochemical prospecting in parts of upland Britain.
- 10:15 Coffee
- 10:40 *P. LaSalle, B. Warren, P. Gilbert, A. Louis Jacob, and Y. R. LaSalle.* Moraine sampling under varved clays in the Rouyn-Val d'Or area: general results.
- 11:05 *C. F. Gleeson, and E. H. W. Hornbrook.* Semi-regional and detailed exploration geochemical studies demonstrating the effectiveness of till sampling at depth.
- 11:30 *B. Bolviken, and O. Logn.* Electrochemical model for element distribution around sulphide bodies.
- 11:55 *E. M. Kujatkovskiy, N. F. Majorov, G. V. Sveshnikov, and A. V. Sinitzyn.* Geochemical methods of Cu-Ni ore deposits prospecting on the areas with glacial sediment cover.

## Thursday April 4

### Afternoon — Analytical Geochemistry

Chairmen — *H. Bloom, J. R. Foster*

- 1:30 *W. E. Hill, Jr.* The use of analytical standards to control assaying projects.
- 2:00 *G. H. Allcott, and H. W. Lakin.* The homogeneity of six geochemical exploration reference samples.
- 2:25 *W. Brown, and G. R. Hilchey.* Sampling and analysis of geochemical materials for gold.
- 2:50 *A. R. Barringer.* AIRTRACE — a new airborne biogeochemical technique.
- 3:15 Coffee
- 3:40 *A. W. Rose.* The mode of occurrence of trace elements in soils and stream sediments applied to geochemical exploration.
- 4:05 *Liberto de Pablo Galan.* Direct reading emission spectroscopy analysis of geochemical samples.
- 4:30 *I. L. Elliott.* Closing remarks.

**Rubidium: A primary dispersion pathfinder at Ogofau Gold Mine, southern Wales**

*M. J. Al-Atia and J. W. Barnes*

*Department of Geology and Oceanography*

*University College of Swansea, Swansea, U. K.*

Elements which are suitable as pathfinders to ore share certain characteristics, namely low melting points and high vapour pressures. Rubidium falls within these parameters and work on the primary dispersion aureole surrounding the ancient Ogofau gold mine in southern Wales suggests it has promising applications. At Ogofau the rubidium aureole in the shaley country rocks is better developed than the aureoles for lead, zinc, copper and mercury. The gold-pyrite mineralization is surrounded by a zone in which 90 percent of the 51 samples taken show rubidium enhancement greater than two standard deviations (20 ppm) above the mean background value for the area of 125 ppm, and 84 percent show enhancements greater than three standard deviations (30 ppm). There is no accompanying change in potassium content which might account for this enrichment. It is also significant that no rubidium aureole surrounds the low temperature pyrite-free lead and zinc ores at Rhydymwn, which occur only 7<sup>1</sup>/<sub>2</sub> miles away in similar rocks, but there is a well developed primary dispersion aureole of lead and zinc.

Rubidium has also been noted in the rocks surrounding the Braden porphyry copper deposit in Chile (Armbrust et al., 1971). The element may well be a selective pathfinder to certain types of mineralization but still requires further investigation. It has the advantage of ease of chemical determination in rock samples by simple X. R. F. procedures.

**The homogeneity of six geochemical exploration reference samples**

*G. H. Allcott and H. W. Lakin*

*U. S. Geological Survey, Denver, U. S. A.*

Analysts of the Branch of Exploration Research, U. S. Geological Survey, have made more than 46,000 determinations on six geochemical exploration reference samples for the purpose of furnishing data on the homogeneity of the samples. The samples are considered to be sufficiently uniform to be useful as geochemical ex-

ploration reference samples despite significant variance ( $\alpha=0.05$ ) in the data for some elements as revealed by a hierarchical analysis of variance. Statistical parameters based on analyses of 50 randomly chosen samples, where operator, technique, and instrumental variables were controlled, are presented.

A handout giving a summary of the results from many laboratories on a number of elements will be available.

## **AIRTRACE — A new airborne biogeochemical technique**

*A. R. Barringer*

*Barringer Research Ltd., Toronto, Canada*

The surface of the earth is a continual generator of organic matter that rises into the atmosphere. This occurs in all terrain including forest, tundra, grassland, desert, and over the oceans. The AIRTRACE system is a technique for collecting this matter whilst traversing in a mobile platform such as an aircraft, ship or motor vehicle and extracting the associated gases, vapours, metallo-organic compounds and organically chelated metals. Analysis is carried out by a variety of techniques including emission spectroscopy and mass spectroscopy. Providing that the system is operated under appropriate meteorological control, anomalies can be related to the underlying terrain and it is possible to detect certain classes of mineralization at high sensitivity.

The system relies upon the fact that the organic fraction in the atmosphere accumulates and concentrates metals and greatly enhances the geochemical contrast between adjacent source areas. A portion of the system responds to components in the ground such as mercury vapour that have travelled upwards in gaseous form prior to adsorption on organic constituents in the atmosphere, providing sharp anomalies 200 feet above the ground. This is in marked contrast to free mercury vapour which gives very poor results at more than a few feet above the ground. The list of adsorbed gases and vapours being detected by this technique is gradually being extended to facilitate detection of concealed mineralization. A further portion of the system operates on metals which are believed to have travelled ionically or as colloids in ground waters and have been chelated or biologically incorporated into organic source matter on the ground.

The distribution and character of metals carried in the organic constituents of the atmosphere do not appear to be the same as in conventional soil geochemistry. In some cases sensitivity for deposits beneath transported overburden is increased and research on possible

electrochemical causes is underway.

The AIRTRACE system has also shown considerable potential for hydrocarbon seep detection in both on-shore and off-shore surveys.

The system is covered by a comprehensive series of patents issued and/or pending on all manufacturing or resource countries.

## **Electrochemical model for element distribution around sulphide bodies**

*B. Bolviken*

*Geological Survey of Norway, Trondheim, Norway*

*O. Logn*

*A/S Sydvaranger, Oslo, Norway*

It is suggested that the upper lithosphere can be considered as a primary redox potential field, where the groundwater represents an electrolyte, and the silicious bedrock a porous dielectric in the electrolyte. The redox potentials of this primary field decrease from the surface towards the depth, a reason why electrical currents flow — positive (e.g.,  $H^+$ ) downwards and negative e.g.,  $OH^-$ ) upwards — in the lithosphere.

A body of electrically well conducting sulphide mineralization can be regarded as a dipole inert electrode in the electrolyte, the lower end constituting the anode and the upper the cathode. Secondary currents in addition to those of the primary field flow between cathode and anode; cations move upwards and anions downwards in the electrolyte, and electrons upwards in the electrode. In some places the direction of the currents are the same for both primary and secondary fields; in other places primary and secondary currents counteract each other. Consequently, patterns of varying current density and ion concentration develop around the electrode.

If the environment of the electrode is homogeneous, these patterns will be quite regular; at a vertical electrode the current density and the ion concentration will be highest in the vertical extensions of the electrode. For a sub-outcropping ore body the overburden represents an environmental heterogeneity, because the electrical conductivity of the overburden is higher than that of the country rock and lower than that of the ore. Thus, when adapted to surface conditions, the model suggests high current density and high ion concentration in the vicinity of the boundaries of the upper part of the ore, and low values for these parameters in the overburden above the ore.

Aspects of the possible influence of electrochemical dispersion on

element distribution in ore and country rock are discussed. Empirical data for self potentials, redox potentials, specific conductivity and pH in water in diamond drill holes, as well as contents of Li, Na, Cu, Zn, Pb, Cl and values for pH and specific conductivity of soil extracts at the Joma massive pyrite deposit are interpreted in view of the model presented above.

## **Sampling and analysis of geochemical materials for gold**

*B. W. Brown*

*Chemex Labs Ltd., North Vancouver, Canada*

*G. R. Hilchey*

*Sumitomo Metal Mining Canada Ltd., Vancouver, Canada*

Recent sampling, processing and analytical procedures for the determination of gold content in geochemical materials have been modified to provide meaningful data at much lower detection limits. Physical and chemical studies to determine optimum sample size and type have greatly improved the practical application of gold geochemistry in mineral exploration.

Gold was studied in several types of natural soils, silts and organic materials. Emphasis was placed on the sampling of these media and the preparation procedures best suited to provide consistent material for the determination of gold. Particle size determination, screen analyses and the pulverizing and homogenizing of test samples from gold bearing soil profiles and silts, provided sufficient physical data to identify the most practical sampling material and methods.

Analytical procedures employed the use of atomic absorption and carbon rod techniques. The gold bearing materials were subject to a variety of digestion and preconcentration techniques prior to analysis. A determination of volatile constituents and benzene extractables was used to evaluate the relationship between organic and inorganic gold content in the "B" soil horizon.

## Geochemical prospecting in the Eastern Desert of Egypt

V. A. Bugrov

*United Nations Development Project, Cairo, Egypt*

I. M. Shalaby

*Geology Survey of Egypt, Cairo, Egypt*

This paper describes the main results of the geochemical operations carried out by the UND Project "Assessment of the Mineral Potential of the Aswan Region" during 1968-1973. The first large-scale geochemical surveys were introduced into Egypt by the Project in 1968 within the framework of the rocky Eastern Desert, previously little studied geologically. The tasks facing the Project as well as the field conditions prevailing in the Project area produced various problems in selecting types and techniques of geochemical surveys, which had to be solved in the course of orientation work. Reconnaissance, regional and detailed geochemical surveys were carried out. Stream sediment, loose and bedrock sampling often supplemented by heavy mineral panning were combined depending on the physiographic and sampling conditions. Regional prospecting was found to be successful using stream sediment sampling of the argillaceous (minus 0.075 mm) alluvial fraction followed by analysis of the cold extractable heavy metal content, while the minus 1 mm alluvial fraction was found to be best for spectrographic analysis.

Panning of heavy concentrates was also applied with a fair degree of success, especially when prospecting for gold and heavy minerals resistant to weathering. (i.e., cassiterite, wolframite, columbite, etc.). Bedrock sampling was applied as a routine measure and produced good results. In the areas where there was some loose material, i.e., eluvium, colluvium, etc., this was sampled during detailed operations, mostly using the minus 1 mm fraction. In localities covered with a mixture of loose material and aeolian sand, sampling of the minus 1 mm plus 0.25 mm fraction was undertaken (after enrichment of the collected samples by sieving out the sand fraction minus 0.25 mm), especially for metals such as Cu, Mo, Sn, etc.

Major successes of the Project's geochemical prospecting program included the finding of several areas containing Ta-Nb albitite-type ores; Sn mineralization in greisens; stockwork-type Mo ores and sulphide Cu-Ni-Co ores in a gabbro-peridotite complex. The overall results of these operations drastically modified earlier views on the metallogeny and the economic promise of the Eastern Desert of Egypt.

## **The status of exploration geochemistry in southern Africa**

*E. Buhlmann and R. N. Sanders*

*Johannesburg Consolidated Investment Company Limited  
Randfontein, South Africa*

*D. E. Philpott*

*Prospects of Rhodesia, (Pvt) Limited, Salisbury, Rhodesia*

*M. J. Scott*

*B. & O. Minerals (Pty.) Limited, Windhoek, South West Africa*

Extensive application of geochemical techniques to "grassroot exploration" in southern Africa resulted in a number of significant discoveries, some of which are discussed in separate papers at this symposium.

The success of geochemical exploration under local conditions depends largely on the rapid turnover of large volumes of samples. Optimising routine procedures of sample collection, processing, assaying, data processing, interpretation and follow-up, permits the handling of large amounts of samples at low cost.

The role of geochemistry in geologically or geophysically orientated programs is discussed. Geological as well as geophysical programs become more effective if geochemical techniques are incorporated, because the latter tend to eliminate unmineralized targets (barren sulphide, eg.) while enhancing the mineralized ones.

For a wide variety of geological and geomorphological environments in southern Africa geochemistry offers not only the most effective but also the cheapest exploration techniques.

## **Application of discriminant analysis to the geochemical evaluation of gossans**

*A. J. Bull*

*Western Mining Corporation Ltd., Perth, Western Australia*

*R. H. Mazzucchelli*

*Western Mining Corporation Ltd., Kalgoorlie, Western Australia*

Many of the nickel sulphide orebodies discovered since 1965 in the Archaean Shield of Western Australia are characterized by gossanous outcrops. The search for, and evaluation of gossans has accordingly played a prominent part in subsequent nickel exploration programs and several discoveries have been attributed in large part to the successful identification of gossans.

In the ultramafic environments under consideration the causes of gossan-like ferruginous outcrops with high Ni abundance are several. Other than nickel sulphides, they include sulphide-bearing volcanogenic sediments, lateritized ultramafics and disseminations of non-nickeliferous sulphides and oxides. One of the most widely employed means of discrimination of nickel sulphide gossans involves analysis and interpretation of various trace elements. The interpretation of trace element data on gossans and pseudo-gossans is complicated by the fact that the abundance ranges for most elements overlap to the extent that a considerable area of doubt exists in the assignation of a given sample to the significant or non-significant categories. In an attempt to define more clearly the trace element parameters a suite of 270 gossans and pseudo-gossans was analysed for five elements, Ni, Cu, Co, Cr, Zn and subjected to discriminant analysis. The samples were initially categorized into the six groups below, based on the best available knowledge of their probable genesis:

- Group 1: Known to be related to nickel sulphide mineralization.
- Group 2: Probably related to nickel sulphide mineralization.
- Group 3: Probably related to sulphide-bearing tuff or sediment horizons within or adjacent to ultramafic rocks.
- Group 4: Probably related to lateritic weathering of ultramafic rocks.
- Group 5: Probably related to non-nickeliferous sulphide and/or oxide accumulations in ultramafic rocks.
- Group 6: Significance not known.

The application of discriminant analysis to the above data results in the development of discriminant functions in terms of the five elements analysed. These may be used to assign samples of unknown origin to any of the first five groups with a stated probability. Classification of new samples may be achieved most easily through a computer evaluation of the discriminant functions. However, to facilitate classification in the field, a single page chart was created by consideration of marginal distributions of the populations on two dimensional cross sections of the discriminant space. The chart proved to be easy to use, and a measure of its success may be inferred in that classification by the chart of the original samples in Groups 1 and 2 indicated that:

88% of the samples had been correctly assigned.

8% of the samples had been incorrectly assigned.

4% of the samples was unclassified.

Thus, only 8% of samples would not have been recognized as significant by this evaluation.

Among the advantages of the discriminant analysis scheme for gossan data are that it can be augmented and refined as new data become available, whether this be in the form of data for new gossans, or re-classification of samples as a result of improved understanding of the genesis of gossans previously included in the data file.

## **Geochemical exploration problems in Western Australia, exemplified by the Mt. Keith area**

*C. R. M. Butt*

*C S I R O — Wembley, Western Australia*

*N. R. Sheppy*

*Metals Exploration N. L., Kalgoorlie, Western Australia*

Exploration in Western Australia, particularly in the Archaean Yilgarn Block, is hindered by widespread deep weathering and an extensive mantle of transported overburden. The landscape is perhaps unique, and the weathering history long and complex, with relicts, such as the main drainage patterns, dating back to the Mesozoic. In the broadest terms, two main episodes of weathering are important.

- (i) Humid periods of lateritisation and peneplanation in the mid-Tertiary. During these, rocks were weathered to depths often exceeding 100 metres, giving rise to extensive chemical dispersion and redistribution of rock components.
- (ii) Subsequent periods of aridity, continuing to the present. Under these conditions, the old landscape has been dissected to expose and reweather various horizons of the pre-existing laterites, and valleys have been further infilled with alluvial and colluvial deposits.

The controls of element redistribution and of the development of enriched horizons during lateritisation are poorly understood. Thus, enrichments which, under favourable environments, can become of ore grade, such as nickel laterites, can also be considerable false anomalies. Consequently, the interpretation of geochemical data from weathered residuum, whether sampled at the surface or at depth by drilling, can often be difficult.

Exploration of the Mt. Keith claims of Metals Exploration N. L., 400 km NNW of Kalgoorlie, W. A., exemplifies some of the problems. The claims cover a strike length of some 27 km of a dyke-like ultrabasic

unit within a "greenstone" belt which is one of the most productive of economic Ni-mineralization in Western Australia. With the exception of massive sulphides at Perseverance, 65 km to the south, all the deposits are of disseminated sulphides within the serpentinized dunite core of the unit. At Mt. Keith itself, the main body has reserves of 263 million tons indicated, 27 million tons inferred, at a grade of 0.60% Ni.

All rocks have been lateritised and part of the belt subsequently eroded. The ultrabasic thus passes through a number of geomorphological situations, from complete laterite profiles often buried by transported material to truncated profiles exposing various horizons of the laterite. Fresh rock is nowhere exposed and surface expression is merely ferruginous and/or siliceous saprolite. The main body itself is a slight topographic low with a complete laterite profile preserved beneath about 25 metres of alluvium.

A limited orientation study of surface sampling by hand auger was conducted in an area of eroded residuum. This showed that Cu, Ni and Mn contents of whole samples from the greatest depth possible (usually 1 metre) gave the best definition between lithological units. The minus 80-mesh fraction gave poor results. However, this technique was of limited use since it is suitable for less than 30% of the strike length. Magnetometry is a more rapid discriminator of the ultrabasic rocks and was used to define these as initial target zones throughout the property.

For more detailed exploration, the sampling technique adopted was rotary drilling to an average depth of 30 metres, traversing the magnetic feature at 305 metre (i.e. 1000 ft.) intervals. To a large extent, this obviated a need for a careful appraisal of geomorphology and soils, and for more than a general appreciation of Ni-Cu distribution in the lateritic profile. Subsequently, diamond drilling demonstrated that economically significant bodies of disseminated pentlandite were centrally located within the ultrabasics, rather than at contact zones.

Orientation over the main body showed that disseminated sulphides were indicated by concentrations exceeding 4000 ppm Ni, 300 ppm Cu in the intensely weathered zone. (In the shaft, this 25-55 metre zone contains 660-36000 ppm Ni, mean 8450 ppm, and 14-1690 ppm Cu, mean 615 ppm.) These parameters proved to be about 75% effective in all geomorphological environments. However, situations occur where laterite Ni contents above 4000 ppm overlie ultrabasics containing less than 1500 ppm, and conversely, where weathered zones are depleted relative to fresh serpentinites containing 3000-4000 ppm Ni.

## **Towards a quantitative utilization of geochemical exploration: Threshold problem, estimation of soil surveys**

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In the recent considerable development of geochemical exploration, a striking feature is the fact that this continues to be devoted mainly to the location and description of geochemical surfaces and not to the quantitative estimation of the anomalies.

Firstly, the old debated problem of threshold level of anomalous values is reviewed: a theoretical discussion shows the arbitrariness of the usual rule of "two standard deviations" for the threshold level. A deconvolution solution is proposed to enable a probabilized estimation of cut-off values for regional surveys.

The insolvability of the problem in detailed surveys is demonstrated by the variable value of the ratio of the constant anomaly surface to the variable surface of the surveyed area.

The problem of quantitative estimation in detailed soil surveys is also examined by using A. P. Solovov's determination of "K" ratios between estimated quantities of metal in soils over estimated quantities of metal in bedrocks. Two estimations of this ratio in areas of France with continental or Atlantic climates lead to consistent values for this ratio: 1.2 to 1.5 for lead, zinc, copper, tungsten, titanium, etc. . . . in landscapes of mechanically displaced soils. These values are interpreted as showing a non-leaching process of dispersion or at least a leaching which affects with equal intensity the different element during the weathering of bedrock.

The determination of this ratio in different environments will be promising if conducted in strictly standardized conditions.

## **Methods of geochemical exploration for massive sulphide deposits in Canada**

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As a major source of zinc, copper, lead and silver, comprising more than one-third of the metallic mineral production of the country, massive sulphide deposits are a particularly important exploration target in Canada. By reason of their occurring mainly in Precambrian terrane, their search often demands a rather different approach than that appropriate to younger deposits of this type. Massive sulphides

are found in eugeosynclinal-type volcanic sequences, or in the related sediments. In Canada they are commonly associated with the more siliceous volcanic rocks. The lens-like bodies are usually aligned along a stratigraphic contact in the volcanic rocks, above a pipe-like alteration zone through which the mineralizing solutions passed.

These small rich bodies (a stratigraphic width of 50 feet or more is considered large) present a good target for the electromagnetic methods that have played a leading role in exploration of the Canadian Shield. However, a major problem with this and other geophysical techniques is that of discriminating between deposits containing useful, non-ferrous metals, and the much more abundant bodies of iron sulphides or other conducting materials. Recent research has pointed to the directions in which geochemistry will play a much greater part in exploration for massive sulphides. The author will present data from rock, soil and drainage sediment samples from a number of areas of Canada that help to evaluate the usefulness of various methods of geochemical exploration.

Data are given for sulphur, zinc and copper in host rocks that show that anomalous contents of ore metals are largely confined to the feeder pipe, to the deposit itself, and to the stratigraphic horizon on which it lies. This observation has two important consequences. Firstly, it is generally not practical to use the ore element content of the volcanic host rocks to discover the ore potential of a particular district or volcanic cycle. Secondly, secondary dispersion is from a point source, rather than from a more extensive area of rocks that have an anomalous metal content.

In the southern Shield many districts show only a very limited dispersion of metals. This is a consequence of thick glacial sediments and lack of deep weathering of sulphides. Combined with the point-source nature of the primary anomaly, this conspires to give a secondary anomaly of limited areal extent. These anomalies require close interval sampling, that is justifiable only as a follow-up to geophysical or geological surveys. In the permafrost areas of northern Canada a different situation prevails. Here, most areas have only a thin glacial cover and there has been fairly intensive weathering of sulphides since the ice sheet receded. In areas studied by the writer, there has been deep, selective weathering of sulphide bodies. The mobile elements, zinc and copper, have dispersed widely in the drainage system. Less mobile elements, such as lead, silver and arsenic, are largely retained in the soils and gossans that overlie mineralization. In these conditions geochemical methods are ideally suited to exploration for massive sulphides, using zinc and copper at the reconnaissance stage of exploration and lead, silver and arsenic for detailed soil sampling.

Litho geochemistry is likely to find increasing use in exploration for massive sulphides, particularly for concealed deposits in established mining camps. Here attention should be focussed on the ore element content of important stratigraphic horizons, on the composition of the feeder pipes, and on the dispersion of highly mobile components, such as halogens, out from the deposit and feeder pipe. The composition of the feeder pipe is very distinctive with major loss of calcium and sodium and gain of magnesium and iron. Compared to the dimensions of the pipe that are apparent from hand specimen examination of the rocks, rock geochemistry should expand the effective size of the feeder pipe target.

### **Metal dispersion in lake sediments related to mineralization and its use in reconnaissance in northern Ontario**

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In areas of glacial overburden with indefinite and disorganized drainage systems, such as exist in large regions of the Canadian Shield, conventional geochemical exploration techniques involving the sampling of stream sediments and soils have found limited application. In such areas lake sediment composition could be an indicator of mineralization if either the host rock or the mineralization itself has some diagnostic geochemical feature which is transmitted to lake sediments. If these conditions are fulfilled, lake sediment sampling would offer a convenient procedure for reconnaissance scale exploration in Shield areas.

The usefulness of the procedure has been previously demonstrated in permafrost areas of Canada. In the southern Shield, where organic activity is much greater, metal dispersion in lake sediments is controlled by a number of factors contributing to the existence of a complex relationship between lake sediment geochemistry and mineralization. Orientation surveys, carried out over four greenstone belts within the Superior Province, investigated the nature of metal dispersion in lake sediments associated with mineralization to evaluate the feasibility of utilizing lake sediments as a sample medium in reconnaissance surveys. These investigations indicated that the most representative and homogeneous sample of a single lake basin occurs in the centre and deepest sections of a lake. However, it was difficult, if not impossible, to distinguish a lake adjacent to mineralization from one in barren terrain on the basis of the single element analyses of the organic rich material from the lake centres. This feature is due to the various

dispersion processes operating in the surface environment which contribute to lake sediment composition.

Anomalous metal dispersion patterns are associated with the Cu-Ni mineralization at Shebandowan and the Cu-Zn deposit at the Mattabi Mine; these were detected using screening procedures to eliminate dispersion patterns attributable to causes other than mineralization. A reconnaissance survey based on the analysis of organic rich lake sediments from lake centres, and subsequent screening of the analytical data revealed the existence of prominent anomalous zones, one of which was comparable to that associated with the Mattabi Mines deposit. Follow-up investigations confirmed the reconnaissance anomalies to be associated with favourable geology. Further geological and geophysical investigations are currently underway to evaluate the significance of the anomalous zones.

Final assessment of the technique must await the results of the current program to evaluate the significance of the anomalies revealed by the reconnaissance. Provisionally, however, it is concluded that sampling and analysis of organic rich lake sediments followed by screening of the data may be a viable exploration procedure in the southern areas of the Canadian Shield in the search for Cu-Ni and base metal massive sulphide deposits.

**Distribution of ore and related elements in the wallrocks,  
Broken Hill Mine, Kabwe, Zambia:  
A method of detecting significant aureoles  
in fractured carbonate country rock**

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The distribution of lead and zinc in the dolomite wallrocks of the lead-zinc-vanadium deposit at Broken Hill Mine, Kabwe, Zambia, has been investigated by electron microprobe and heavy mineral studies. From these studies, sampling methods and sample treatment were adopted to show the presence of significant aureoles about the main orebodies.

The ore metals were dispersed outwards from the orebodies by flow of the hydrothermal solutions along fractures and joints in the wallrocks. This resulted in mineralization, consisting of sphalerite and galena or goethite, localized in veinlets. Close to the orebodies there was dispersion by diffusion of the ore metals through the massive dolomite between the fissures, giving enrichment of lead and zinc at

the boundaries and in the outer zones of dolomite crystals.

This type of aureole of lead and zinc in fractured carbonate wallrocks is very irregular, with erratic peaks of metal concentrations which bear no direct spatial relations to the presence of an orebody. Often there is no systematic enrichment with proximity to mineralization.

In order to reduce the effect of the erratic occurrence of mineralized material from minor fissures in the wallrock samples, a composite chip sample was taken over 5 ft. (1.53 m) of core and crushed samples were separated in heavy liquid. Separated wallrock samples were analysed by X-ray fluorescence for the ore metals, lead, zinc, vanadium and cadmium, and also iron, copper, strontium and silica.

The results show the presence of substantial aureoles, sometimes exceeding 40 ft. (12.2 m), round the major orebodies at the Broken Hill Mine. In addition, the erratic anomalous values, remote from mineralization, have been suppressed.

## **Geochemical soil surveys in exploration for nickel-copper sulphides at Pioneer, near Norseman, Western Australia**

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Nickel-copper sulphides at Pioneer are localized at or near to the base of a serpentinized ultramafic body forming part of the Norseman-Kalgoorlie "Greenstone Belt" of the Archaean Shield of Western Australia. Geochemical and petrographic investigations have shown that the ultramafic body consists of several repetitions of differentiated cycles, each cycle consisting of a basal layer of metadunite overlain by serpentinized peridotite passing upwards into metapyroxenite.

The sulphide bodies consist essentially of a pyrrhotite-pentlandite-chalcopyrite assemblage within structurally controlled loci. In situ alteration of pyrrhotite to marcasite and of pentlandite to violarite is associated with supergene processes. As a result of recent weathering these sulphides have been oxidized to a limonitic gossanous material, extending down to 40 m below surface. The gossans retain the geometrical form of the sulphide bodies, and also retain anomalous nickel and copper values.

Outcrop in this strongly dissected and flat terrain is essentially negligible and the only visible surface expression of the nickel-copper mineralization is the sporadic occurrence of gossan float.

Geochemical investigations have shown that the nickel-copper

mineralization is readily detectable by sampling and analysing the residual soils. Experience in this environment has shown that gossan searching and geochemical soil sampling are the most effective, rapid, and economical techniques for positively detecting sub-outcropping nickel-copper mineralization.

The typical soils of the area are solonized brown soils showing a characteristic profile development. Over mineralized ultramafic, mafic and metasedimentary rocks the distribution of nickel and chromium in these soils accurately reflects bedrock nickel and chromium distribution. In areas of sub-outcropping mineralization the soils show strong anomalies in the distribution patterns of nickel, copper, cobalt and nickel/chromium which are associated with secondary iron and manganese oxides.

This paper describes a case history of successful geochemical exploration at Pioneer in the Western Australian "nickel belt."

## **Lakeview revisited: Variograms and correspondence analysis, new tools for the understanding of geochemical data**

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This paper intends to show how two new statistical techniques can help to answer several questions raised in geochemical data interpretation. The variogram will show the interdependence of samples and possible trends. It will thus help to answer questions concerning sample spacing, sample size, and level of variation. It also helps to point out anisotropies in an environment. Correspondence Analysis is a new distribution free factorial analysis technique where both sample-space and variable-space are considered at the same time. It produces diagrams which can be thought of as generalized petrographic diagrams, showing both samples and variables, and from which geological factors can be extracted. Several examples will be discussed, and particular attention will be given to the Lakeview Pluton of Southern California, which was carefully sampled several years ago by Baird and McIntyre. Several examples of this technique applied to exploration geochemistry will be discussed, and it will be shown how factors can be mapped and anomalous areas detected.

# **The use of lake sediments in a reconnaissance geochemical survey for zinc mineralization in western Newfoundland**

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Lake sediment samples were collected over a 3000 square mile region underlain by lower Palaeozoic carbonate rocks in western Newfoundland. This belt of carbonate rocks contains a number of zinc and zinc-lead showings. An earlier pilot study over known zinc mineralization near Daniel's Harbour indicated that the zinc distribution in lake sediments closely reflects the presence of zinc mineralization in the local bedrock.

Samples were collected to achieve an approximately random pattern at a density of at least one sample per square mile where lake distribution permitted. The preferred sample location was at the lake-centre-bottom where the lake sediment composition is predominantly organic-rich. The samples were oven dried, sieved to minus 80-mesh ( $<177\mu$ ), and analysed for Zn, Pb, Mn and Fe by atomic absorption spectrophotometer. The organic content was estimated from the loss on ignition.

The lake sediment survey has permitted an evaluation of the zinc potential of the whole belt of lower Palaeozoic carbonate rocks, and has delineated areas of anomalous zinc values comparable to those associated with the zinc deposits of Daniel's Harbour. These areas are considered suitable targets for follow-up work by detailed lake and/or stream sediment sampling.

The following points will be discussed: the choice of sample type and location; the effects of surficial environment on zinc and lead distributions; and the relationship of anomalous zinc and lead distributions to mineralization.

## **Autocorrelation studies and geochemical data analysis**

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The efficiency of large scale, medium density geochemical surveys depends largely upon the development of appropriate methods of data

analysis. In this context, the current literature emphasizes the use of experimental moving average techniques, correlation studies, regression analysis, cluster analysis and factor analysis. In comparison, little attention is given to topics concerning the description and the study of spatial variations of trace element values in terms of autocorrelation or other concepts relating to the theory of random variables.

The paper describes the experience obtained with the application of a number of statistical techniques for separating trends from local effects, including the practical use of autocorrelation studies. Examples are given of subjects including: selection of sampling densities, smoothing techniques, semi-quantitative assessment of map accuracies and of criteria for defining threshold values.

### **The choosing of functions for the geochemical data description**

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During recent years several mathematical techniques have been applied to geochemical exploration data. It seems necessary to systematize these techniques with the objective of selecting the best techniques for the particular problem. In this way new insights into the data may be gained.

The aim of mathematical processing is to emphasize the most useful components of the geochemical data. The techniques employed can be arranged in order of their usefulness. Similarly the costs of processing the data (including assembly into a usable format) must be considered in order that the most economically beneficial technique is selected.

From the above considerations, regression analysis appears to have considerable advantage over other techniques.

The principal criterion is the return in useful information compared with the cost of the technique. The extent of the benefits arising from the use of regression analysis can only be estimated by having applied it to several well known situations, i.e., training or orientation exercises.

Since many data are already available on the relation of amount of mineralization and the size of geochemical halos, only small amounts of training material are required in this case. Even smaller amounts of training data are required to construct mathematical functions describing the zoning of aureoles. Examples of such functions are trend

analysis, element ratios, etc.

By ranking these functions with regard to their usefulness in previously studied examples the best function for a particular problem may be chosen using the "rank approximation."

All the functions obtained from calculations may be expressed visually with graphs, maps and sections.

## **Integrated geologic and geochemical studies, Edna Mountain, Nevada**

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Detailed geologic and geochemical studies of the Edna Mountain quadrangle, Humboldt County, Nevada, were undertaken to determine (1) the stratigraphic and structural history of this complex area, (2) the regional distribution and abundance of metals in rocks of the area, and (3) the factors that control the distribution and abundance of those metals.

Sedimentary rocks in the area range in age from Cambrian to Permian and include near-shore, transitional, and deep-basin clastic rocks telescoped by thrust faults related to at least four different orogenic episodes. Small plutons and dykes and sills of Mesozoic age intrude the sedimentary section, and volcanic rocks of Tertiary age locally conceal the section. The entire rock complex is repeatedly offset by later normal faulting.

Although no deposits of economic significance are known in the area, numerous occurrences of mineralized ground, along with a large variety of types of mineralization, abundance of altered rock, structural complexity, and abundance of intermediate to silicic igneous intrusive rocks suggest that concealed or heretofore unrecognized mineral deposits may exist in the area.

The geochemical studies to date have established the regional distribution and abundance of several metals in rocks in the area and identified broad target areas and guidelines for mineral exploration. Geochemical maps showing the regional distribution and abundance of copper, lead, zinc, molybdenum, silver, gold, mercury, arsenic, antimony, bismuth, and tungsten in rocks are presented on a generalized geologic and aeromagnetic base. Most samples are from shear or fault zones, fractures, jasperoid, breccia reefs, veins, and altered zones. Such selective rock sampling enhances the probability of detection of zoning patterns and leakage halos that help outline concealed target areas.

The distribution and abundance of metals is structurally controlled and crudely zoned. We recognize three episodes of mineralization, each characterized by a distinctive metal suite. In some places the same block of structurally prepared ground has been invaded by all three episodes. The earliest period of mineralization resulted in a stratabound vanadium deposit in black carbonaceous siltstone of Ordovician age. The second episode resulted in deposits of copper, molybdenum, and bismuth with satellite deposits of lead, zinc, and silver associated with Jurassic quartz monzonite and Cretaceous granodiorite plutons. The third episode of mineralization, probably late Tertiary, is characterized by the same metal suite that is associated with the Carlin-type gold deposit. These deposits have been emplaced by thermal-spring activity. Tungsten was mined from hot-spring deposits in this area during World War II.

All rock samples (about 3,500) were prepared and analysed in truck-mounted laboratories at Winnemucca, Nevada. Copper, lead, zinc, silver, gold, and mercury were determined by atomic absorption methods. Arsenic, antimony, molybdenum, tungsten, and bismuth were determined by semiquantitative spectrographic methods.

### **Direct reading emission spectroscopy analysis of geochemical samples**

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In geochemical exploration, direct reading spectroscopy has established itself as an ample, rapid, reasonable cost analytical method. However, the variety of rocks encountered in geochemical surveys may cause large errors due to matrix and inter-element effects that, if solved by using comparable standards, spiking or dilution, may result in the loss of the best advantages of the method. As a solution that would not require special sample preparation and allows very rapid analysis, the most commonly occurring volcanic and sedimentary rocks were classified as to their chemical and mineralogical composition, refractoriness, and behaviour in the arc, etc., into twelve average groups whose compositions can be defined in terms of the seven major components  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , and  $\text{Fe}_2\text{O}_3$ . These standard compositions were synthetically prepared, calcined, spiked with trace elements — from 1% to 0 ppm, mixed in a 20:30:50 ratio with graphite and lithium borate containing Pd as an internal standard in an amount equivalent to 500 ppm, and burned in a DC arc. The instrument was capable of simultaneously analysing up to 60 elements or 31 as in the present case. The volatilization pattern of each element, reproducibility of results, types of electrodes, response of measuring circuits, operating conditions, etc., are reported.

To calculate concentrations from measured intensities (voltages), these were divided by the intensity corresponding to the Pd internal standard and plotted against concentration. For the major components  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , and  $\text{Fe}_2\text{O}_3$ , intensity ratios were again divided by the concentration and plotted against concentration for each of the twelve matrices. A standard curve was drawn, the points falling outside which represented matrices whose composition included a major element affecting the intensity ratio of the analysed one. A series of simultaneous equations of type (1)

$$\left[ (I_{\text{Si}}/I_{\text{Pd}})/\text{SiO}_2 \right]_c - \left[ (I_{\text{Si}}/I_{\text{Pd}})/\text{SiO}_2 \right]_m = \alpha_{\text{Al}_2\text{O}_3} \left( \text{Al}_2\text{O}_3 \right) + \alpha_{\text{CaO}} \left( \text{CaO} \right) + \alpha_{\text{MgO}} \left( \text{MgO} \right) + \alpha_{\text{Na}_2\text{O}} \left( \text{Na}_2\text{O} \right) + \alpha_{\text{K}_2\text{O}} \left( \text{K}_2\text{O} \right) + \alpha_{\text{Fe}_2\text{O}_3} \left( \text{Fe}_2\text{O}_3 \right) \quad (1)$$

was set up for each element in each matrix. Solution by Gaussian reduction with positioning for size solved for the correcting function  $\alpha$ . A third group of actual working curves or equations of type (2)

$$(I_{\text{Si}}/I_{\text{Pd}})_c = (I_{\text{Si}}/I_{\text{Pd}})_m \left[ 1 + \text{SiO}_2 (\alpha_{\text{Al}_2\text{O}_3} \text{Al}_2\text{O}_3 + \alpha_{\text{CaO}} \text{CaO} + \alpha_{\text{MgO}} \text{MgO} + \alpha_{\text{Na}_2\text{O}} \text{Na}_2\text{O} + \alpha_{\text{K}_2\text{O}} \text{K}_2\text{O} + \alpha_{\text{Fe}_2\text{O}_3} \text{Fe}_2\text{O}_3) \right] \quad (2)$$

was computed correlating measured and corrected intensity ratios, correcting functions, and major element concentrations.

Trace elements were treated similarly. At the selected wavelengths and concentrations involved, inter-element effects are caused by major components. Intensity ratios were plotted against concentration for each matrix, one of which was selected as a reference and the others treated as deviations. For successive concentrations of the measured trace element, reference and deviated intensities were equated to composition of the matrices and correcting functions (equation type 1). Solution by Gaussian reduction calculated correcting functions which were now plotted versus concentration of the measured element. A polynomial solution to these curves found equations correlating the correcting function or the inter-element effect of each major component on the 23 trace elements analysed.

The procedure presented established a relatively simple but lengthy computational program which permitted instant analysis — in less than a minute — of a sample for 23 trace elements and 7 major ones, with matrix and inter-element corrections, for any of the 51 common rock types considered. Final checking with well known international

standards gave results within the deviations and errors admitted for optical emission spectroscopy.

## **Copper in Proterozoic acid volcanics as a guide to exploration in the Bear Province**

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A program to determine the regional mineral resource potential of the acid volcanics in the Wopmay sub-province of the Bear Province using lithogeochemical methods was undertaken in 1973. A variety of copper occurrences are known in the Proterozoic acid volcanics and a regional assessment of the copper potential of the area was considered desirable.

The field area lies in the northwestern part of the Canadian Shield; it is bounded by the Shield margin in the west and the Wopmay fault (a meridional fault, approximately  $116^{\circ} 30'W$ ) in the east, and latitudes  $63^{\circ}N$  and  $66^{\circ}N$  respectively at the south and north. A total of some 1,000 sites were sampled in duplicate and these samples have been analysed for 15 elements (Al, Fe, Mg, Ca, Na, K, Mn, Ba, Sr, Li, Rb, Cu, Pb, Zn, U). Atomic absorption spectrophotometry has been used almost exclusively, U was determined fluorimetrically, after a sample attack with either lithium tetraborate or an  $HF-HClO_4$  acid mixture. Additionally, partial Fe, Co and Cu have been determined after an ascorbic acid-hydrogen peroxide attack which preferentially leaches that fraction of the metals held in sulphide form in the rock.

The total Cu data has been interpreted with the major and minor elements being used to reflect significant changes in rock type across the field area. This approach requires the use of statistical and mathematical methods applied with the aid of computing facilities. The precise objective of the interpretation being firstly, to identify samples or areas where Cu appears to be abnormally concentrated or depleted in terms of the broad petrogenetic features of the rock as reflected in the major and minor element data, and secondly, to relate these samples or areas to known or suspected copper mineral occurrences. This interpretational procedure is contrasted with the direct assessment of the partial Cu in the rocks, revealing samples or areas of abnormal copper sulphide accumulation or depletion. The two interpretations of the copper mineral potential of the field area are then compared, contrasted and evaluated.

Whereas the analysis of samples for total amounts of elements is attractive to government and research agencies interested in the broader

aspects of exploration, geology and geochemistry, it may be time-consuming and uneconomic for industrial enterprises. The total data requires careful, often computer-assisted, interpretation to differentiate between patterns of metal distribution related to broad petrogenetic features and those patterns related to processes of sulphide accumulation. In contrast, the partial selective leach leads to data which can be handled without the use of a computer as a necessity and is directly interpretable in terms of sulphide accumulation, or depletion, at a lower cost. This latter procedure is, therefore, to be preferred if only an exploration mineral resource potential study is required.

### **Semi-regional and detailed exploration geochemical studies demonstrating the effectiveness of till sampling at depth**

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In Canada till sampling has been carried out by different techniques for many years primarily to detect and define metal dispersion halos associated with metallic sources.

The technique described in this paper involves the sampling of till at or near bedrock by the use of a light percussion drill and piston sampler. Successful studies were carried out in areas underlain by ultramafic bodies and gold occurrences in the Timmins-Val d'Or regions of Ontario and Quebec and over a base metal deposit in Newfoundland.

The following aspects will be discussed:

1. The equipment and operational procedures.
2. Operational problems under summer and winter conditions in glacial terrains containing plateau peat bogs, glacial lake clays and exposed tills.
3. Examples of semi-regional applications in outlining ultramafic bodies and gold-bearing zones.
4. Results of detailed sampling to outline specific drill targets.
5. Evaluation of geophysical conductors.
6. Comparisons between results obtained from lake sediments in a glacial lake clay terrain and the underlying till.
7. Sample composition and size fractions in relation to analytical and interpretive requirements.

## Major and minor element halos in volcanic rocks at Brunswick No. 12 sulphide deposit, N. B., Canada

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Work by the Exploration Geochemistry Group at the University of New Brunswick to develop rock geochemical exploration techniques capable of detecting deeply-buried sulphide deposits has shown that trace element halos can be recognized around such deposits. In an effort to increase the usefulness of rock geochemistry in exploration, studies of major and minor element variations in rocks around sulphide deposits have been undertaken. Preliminary data from the Brunswick No. 12 deposit show that there are significant variations in Ca, Mg, Na, K, Mn, and Fe which can be spatially related to the sulphide zone.

The Brunswick No. 12 deposit, located in northern New Brunswick, has at least  $82 \times 10^6$  tons of massive sulphides containing 9.69 percent Zn, 3.77 percent Pb, 0.29 percent Cu, and 2.46 ounces of Ag per ton; the main sulphide minerals are pyrite, sphalerite, galena, pyrrhotite, chalcopyrite, tetrahedrite, and bornite. The ore zone lies within a Cambro-Ordovician sequence of pyroclastic volcanic rocks, sedimentary rocks with associated sulphides and iron formation, and intermediate to basic volcanic rocks, all of which have been subjected to lower greenschist regional metamorphism. The hanging-wall rocks are iron formations, chloritic and sericitic siliceous sedimentary rocks, intermediate to basic volcanic rocks and pyroclastic acid volcanic rocks. The footwall rocks are chloritic and sericitic siliceous sedimentary rocks and pyroclastic acid volcanic rocks. The only alteration described in the literature consists of chloritization, sericitization and silicification of the sedimentary rock units immediately associated with the ore deposit and extending up to 200 feet into the footwall volcanic rocks. Mineralogical alteration extending laterally along the ore horizon is also localized to the immediate area of sulphide mineralization: this is referred to as the "intense alteration zone."

One hundred and eighty rock samples from 45 drill holes intersecting acid volcanic rocks 2,500 feet below and above the deposit and 8,000 feet south and 5,200 feet north of the deposit along the same stratigraphic horizon were taken. These were analysed for Ca, Mg, Na, K, Mn, Fe, and Al by atomic absorption spectrophotometry after a total digestion with hydrofluoric and perchloric acid.

The acid volcanic rocks below the deposit show the following distributions of major and minor elements in a halo zone up to 1,500 feet below the deposit and 1,600 feet laterally north and south of the

deposit.

- (a) Manganese, Mg, and Fe markedly increase in concentration in the halo zone.
- (b) Calcium and Na show a marked concentration decrease in the halo zone.
- (c) The concentration of K generally increases towards the deposit; it shows a relative decrease in the zone of intense alteration but even here is still higher than background. The K:Na ratio, however, consistently increases towards the deposit.
- (d) Aluminum shows no apparent variation with proximity to the sulphide deposit. Fluctuations in Al concentrations are attributed to sample variation.

Acid volcanic rocks above the deposit reveal no anomalous trends in major element distribution. They represent apparent background conditions.

The distribution of major and minor elements in the foot-wall and volcanic rocks associated with Brunswick No. 12 deposit suggests that these rocks have been subjected to hydrothermal alteration, probably from late-stage metal-bearing fumarolic fluids. In the zone of intense alteration near the deposit, chloritic and sericitic mineralogical alteration has been recognized; further from the deposit, subtle changes in the mineralogy due to hydrothermal alteration apparently have been masked by later greenschist metamorphism.

The recognition of a major and minor element halo in the footwall volcanic rocks of Brunswick No. 12 deposit suggests several applications useful to exploration in the Bathurst area. These are:

- (a) To determine the stratigraphic "up" direction from the volcanic rocks associated with massive sulphide deposits.
- (b) To outline significantly larger targets in geochemical exploration for massive sulphide deposits.
- (c) To establish a close genetic and spatial relation between the source of metals from late stage volcanic activity and the formation of massive sulphide deposits.
- (d) To locate favourable stratigraphic horizons in the exploration for unknown sulphide deposits and to locate extensions of the zones of mineralization around known ore deposits.

## Geochemical behavior of galena under semi-arid climatic conditions, in western Africa

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A small but high grade galena vein has been discovered by geochemical exploration in northwestern Upper Volta. The climate is transitional between north soudanian and sahelian, with an evaporation/precipitation ratio about 5:1. This unique western African mineralization occurs in an alluvial fan characterized by transported fragments of lateritic material in a clay matrix. The bedrock is formed by Precambrian (Birrimian) metamorphic schists and quartzites. Following the discovery of cerussite fragments in semipermanent stream-sediments a soil geochemical survey was carried out covering 1.2 square km area with sampling every 50 metres and every 10 metres in anomalous zones. The samples were analysed by A. A. S. for Pb, Cu, Zn, Ag, and Ni. Lepeltier's method and computer facilities were used for the statistical treatment of the chemical results.

The geochemical backgrounds for Pb, Cu, Zn and Ni are respectively 74, 86, 48 and 30 ppm; the thresholds are respectively 115, 230, 82 and 80 ppm. The area of anomalous Pb values is restricted to a narrow elongated zone where trenching led to the discovery of a massive, vertical argentiferous galena vein, one metre thick, a few metres below the surface. The vein found within the schist makes an angle of 50° with the schistosity.

Sampling on both sides of the vein, in deep trenches and in shallow drill-holes was carried out in order to trace the geochemical dispersion of the lead and other metals (Cu, Ag, Zn, Ni, Sb, Ti) contained in trace amount in the galena. The lead has been traced in the soil for a distance of less than two metres laterally from the vein. The silver is present within the lead zone but in very small amount. The copper can be traced for several hundred metres away from the galena vein. It must be pointed out here that the Cu background is unusually high for the kind of soil and climatic conditions when compared with the Cu background of only 50 ppm developed above the Goren porphyry copper located in the same climatic condition or the Cu background of 80 ppm for the Gaoua porphyry copper where evaporation/precipitation ratio is only 1:5. The zinc and nickel are sporadically distributed and apparently are not related to the lead mineralization. Bi, Sb and Ti have not been checked.

The presence of plumbogummite, quartz, hematite, goethite, clays, anglesite, cerussite, pyromorphite, pseudomalachite and covellite have been detected in the soil by XRD, UV spectrography and electron microprobe. An unidentified small prismatic and zoned mineral has

been detected; its composition (electron microprobe) is CaO 2% to 15%,  $P_2O_5$  22%, PbO 61.5 to 75.8%. The XRD and chemical composition suggest a lead-hydroxylapatite. The primary sulphide oxidation envelope shows a characteristic mineral zoning with development of covellite at the contact with the galena. The covellite is surrounded by an anglesite zone which is surrounded by a cerussite zone. The cerussite zone is surrounded by a lead and copper phosphate zone. This zoning (sulphides→sulphate→carbonate→phosphates) indicates an adjustment of the lead (and Cu) minerals to an increase of alkalinity in the soil.

The lead secondary dispersion pattern is too restricted to be used in regional soil geochemical exploration under such climatic conditions. However, the copper anomalies can indicate the proximity of lead mineralization (even if Cu is in trace amount in the galena) in transported lateritic overburden under semi-arid climatic conditions.

### **Soil conductivities: Assessment of an electrogeochemical exploration technique**

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A study of the relation between geochemical and electrochemical processes is part of a research program at the University of New Brunswick to develop geochemical exploration techniques capable of locating deeply buried deposits. As a result of this work it has been found that the electrical conductivity of water slurries of soil samples show anomalous values in the vicinity of both sub-outcropping and buried mineralization.

The determination of soil conductivities is simple and rapid. One gram of minus 80-mesh soil is weighed into 100 ml deionized water and stirred for one minute; the conductivity is then immediately measured by a dip-type conductivity cell and a conductivity bridge.

Soil slurry conductivity measurements and comparative trace element content are given for B-horizon soils in the vicinity of seven different sulphide deposits. These are massive Zn-Pb deposits in northern New Brunswick and Spain, a massive vein-type Sb deposit in south-central New Brunswick, massive and disseminated Ni-Cu-Co deposits in southern New Brunswick, and disseminated Zn-Pb deposits in northern New Brunswick and Greece. The New Brunswick deposits have three to 120 feet of glacial debris overlying them; some of the Ni-Cu-Co deposits have a zone of barren rock above mineralization. The

deposit in Spain has three to five feet of residual soil overlying it. Nevertheless, all these varied deposits give an anomalous soil slurry conductivity response at least as good as and, in some cases, better than the conventional geochemical trace element anomaly. Only the deposit in Greece — which has a very thin layer of rocky residual soils over mineralization — fails to give a marked response.

The form of a conductivity anomaly is not a simple peak. The form varies with depth and type of mineralization (i.e., massive or disseminated); apparently it does not vary with mineralogical composition of the deposit. Thus, the response over near-surface massive deposits is generally high-amplitude and short-wavelength peaks and troughs; over disseminated and more deeply buried deposits the amplitude decreases and the wavelength increases. There is an indication that anomalously high values persist for many thousands of feet from mineralization.

Although these results represent only a preliminary investigation, they are sufficiently encouraging to suggest that soil slurry conductivities could add another dimension to the interpretation of geochemical data.

### **Chemical zoning associated with the Ingerbelle — Copper Mountain mineralization, Princeton, British Columbia**

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Zoning of mineral assemblages reflecting alteration of the cooling intrusive phase and adjacent wall rocks has been shown to be associated with mineralization in many porphyritic intrusions. These alteration zones are normally broader than the mineralization and thus constitute a larger search target for porphyry-type mineralization. The delineation of these zones normally has been defined on a mineralogical basis but rarely on a chemical basis. The chemical zoning of major, minor and trace elements associated with the alteration zones adjacent to the Ingerbelle — Copper Mountain ore bodies is described. An evaluation is made of the extent to which these chemical alteration zones constitute a broader exploration target that may be useful in mineral exploration.

The mineral deposits in Nicola volcano-sedimentary stratigraphy associated with the Copper Mountain intrusion most closely resemble porphyry copper type deposits. Deposits of a similar type occur in the Intermontane Belt of British Columbia and thus there remains a cer-

tain potential for locating further deposits. The Nicola formations adjacent to the Copper Mountain Intrusions were sampled together with a background area of similar original lithology. The samples were analysed by X-ray fluorescence and atomic absorption for eighteen major, minor and trace elements. The most notable feature from a reconnaissance exploration viewpoint is the association of increased contents of phosphorous, rubidium and strontium and to a lesser extent soda and potash in the Nicola formations intruded by the Copper Mountain stock. These features constitute parameters for the recognition of potentially mineralized areas of altered Nicola rocks associated with alkalic igneous centres.

Considering more local chemical zoning associated with mineralization, the Nicola formations north of the stock, containing the Ingerbelle and Copper Mountain deposits, have higher copper contents than less intensely mineralized formations south of the stock. Variations in the nature of alteration associated with economic mineralization is indicated by a broad zone of soda enrichment related to the Ingerbelle deposit as opposed to localized zones of potash enrichment associated with the Copper Mountain deposits. This chemical zoning is considered to reflect varying degrees and types of metasomatism and mineralization. The distribution of the chemical zoning with respect to areas of discrete mineralization, in some cases constitute larger and thus more attractive exploration targets than the more localized areas of mineralization.

### **The use of analytical standards to control assaying projects**

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AMAX Exploration evaluated the Pima County, Arizona properties of Banner Exploration for acquisition purposes during the latter half of 1972. The NE orebody at Twin Buttes was the most intensive single evaluation, the orebody, and ore stockpiles at the Twin Buttes mill were drilled. Resulting in 4000 samples to be analysed for four assays each. A total of 16,000 assays were run and evaluated in a 14-week period. The primary assaying was done by a commercial laboratory utilizing AMAX Exploration's assay standards for quality control to eliminate systematic errors. The project was completed on time with better than a 95% confidence level that the assays were within 5% of the amount present. These data were contributory to the purchase of Banner by AMAX in 1973. The standards program and its application to quality assurance on assays are discussed.

## Variations in the mercury content of sphalerite from some Canadian sulphide deposits

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Mercury levels have been determined in sphalerites and zinc concentrates from some Canadian sulphide deposits primarily of the volcanogenic and "Mississippi Valley" (carbonate-hosted) types. Samples were collected from deposits in the Canadian Shield, Cordillera, Arctic Islands, and the Appalachian Region. Host rocks range in age from Archean to Mesozoic and contain ores of different compositions, e.g., Cu-Zn, Cu, Pb-Zn-Ag.

Based on preliminary data, mercury content appears to vary according to genetic type, regions in Canada, age of host rocks, and to a lesser extent, bulk ore compositions. In general, sphalerite in volcanogenic deposits contains more mercury than that in carbonate-hosted stratabound deposits. The Flin Flon — Snow Lake — Lynn Lake volcanic deposits contain sphalerite of higher mercury content (up to 450 ppm) than similar deposits elsewhere in the Shield. The mercury content of sphalerite in stratabound deposits of the Grenville Province, irrespective of their genetic type, is high (up to 160 ppm) relative to other tectonic provinces.

With respect to age of host rocks, mercury in sphalerite of volcanogenic type deposits varies in relative abundance as follows: Proterozoic (10-450 ppm) > Phanerozoic (10-120 ppm) > Archean (1-50 ppm). In carbonate-hosted deposits, the order of abundance is similar: Proterozoic > Phanerozoic. Carbonate-hosted deposits have not been recognized in the Archean.

Sphalerite in deposits which contain sulphosalt minerals (generally the Pb-Zn-Ag ores) were found to contain high mercury levels; also, the mercury content of sphalerite in Zn-rich deposits is generally higher than that in Cu-rich deposits.

Although these data are preliminary and further analyses may ultimately result in a revision of the trends noted above, some interpretation is proposed and the application of these data to the use of mercury as a geochemical prospecting aid is discussed.

# **Geochemical methods of copper-nickel ore deposits prospecting in areas with glacial sediment cover**

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This report sums up the results of geochemical prospecting for copper-nickel ore deposits that have been carried out for many years on the Cola peninsula. The basement of the region consists of multiple folded Archean and Proterozoic crystalline rocks which have been broken, by numerous faults, into blocks of different dimensions. Basic and ultrabasic intrusions are widely represented and copper-nickel and pyrite-pyrrhotite mineralization is genetically related to them. The relief is gentle; low-mountain, swells and swales being predominant. The climate is humid and mildly Arctic. Permafrost is absent. The vegetation is transitional from tundra to north-taiga types and peat bogs are common. The loose mantle mainly consists of glacial sediments varying in thickness from several metres up to many tens of metres. Ancient and recent crusts of weathering are absent or rather weak. Sulphide ore deposits reveal zones of oxidation that never exceed several tens of metres. Autochthonous friable sediments of eluvial and deluvial types are rather rare.

Ground and fissure water is weakly or very weakly mineralized and belongs to hydrocarbonate-calcium type. Ground water level is commonly high; the plains and areas of low relief are swampy.

Ore bodies reaching the level of erosion generate secondary lithochemical and hydrochemical aureoles (reaction rims) and dispersion trains which can be subdivided into following genetic types.

## **A. Lithochemical Aureoles:**

- (a) Mechanical train-like buried aureoles of dispersion in basal moraine.
- (b) Mechanical fan-like open boulder trains in ablation and terminal moraine.
- (c) Saline supra-ore diffusion and train-like aureoles in different moraine sediments.
- (d) Irregular saline dispersion trains in near-shore limnitic, swamp and recent alluvial sediments.

## B. Hydrochemical Aureoles:

- (a) Ground water dispersion aureoles in moraine deposits and fissure water in solid rocks.
- (b) Surface channel dispersion trains.

The main indicator elements of secondary aureoles and dispersion trains of copper-nickel ore deposits are found to be nickel, copper and sulphur; additional indicator elements are cobalt, silver, zinc and molybdenum. The mobility of the main indicator elements in the hypergene zone increases from nickel to sulphur. In hydrochemical aureoles and dispersion trains sulphur is in sulphate form and nickel and copper are in ionic form. In lithochemical aureoles and dispersion trains sulphur is mainly in epigenetic pyrite while other indicator elements more characteristically appear to be occlusions on finely dispersed clayey minerals and hydrous ferric and manganese oxides. The sorption processes are most intensive when a reducing barrier is encountered. Under such circumstance the aureoles and dispersion patterns of sulphur and other indicator elements, though differing in some details, coincide in space. The process of dispersion of indicator elements in films of ground water in moraine seems to play an important role in lithochemical saline dispersion. This last accounts for the limited extension of the aureole from an ore body even under conditions of high ground water filtration and rather thick (10-15 metres and more) overburden.

Prospecting for ore deposits is very effective when boulder-debris and heavy concentrate methods are used. Both of them belong to the group of geological-mineralogical methods and are beyond the topic of this report. When prospecting by lithochemical salt aureoles and dispersion trains, samples of loose mantle are taken from the depth of (a) 0.7-1.0 metre in areas of marked relief having a comparatively deep ground water level or (b) 0.1-0.2 metre in watercourses on lake shores and from underturf layers in swampy areas. When prospecting using hydrochemical aureoles and dispersion trains samples are taken from ground water spring along low-land bog margins and from first/second order surface-stream flows with a spring flow not exceeding 20 litre/second.

Different methods of analysis may be used for lithochemical samples. The best method is considered to be atomic absorption analysis of acid extractable nickel and copper combined with the determination of additional indicator elements in anomalous samples. In practice a field chemical laboratory may use acid decomposition of samples followed by rapid determination of nickel and copper in solutions. In addition, samples from anomalous areas ought to be roughly analysed for sulphur in a field laboratory and by atomic absorption or emissive

spectrographic analysis for additional indicator elements in the base laboratory. The use of emissive spectrographic analysis alone seems to be least efficient because of the possibility of missing weak low-contrast salt aureoles and dispersion trains.

In the field laboratory hydrochemical samples are analysed for nickel, copper, cobalt, sulphate-ion and general chemical composition. By means of co-precipitation with cadmium sulphide there may be extracted a vast number of indicator elements. The precipitated concentrates are analysed spectrographically in the base laboratory.

Large scale lithochemical prospecting programs (1:50,000-1:100,000) utilise sampling of the hydrographic net and the shore-lines of lakes and swamps. Sample density is about one sample per square kilometre with a sample interval of about 100 metres in streams and 50 metres along shorelines.

Detailed surveys (1:10,000) are conducted on 100 metre x 20 metre grids in combination with geophysical techniques. Their main purpose is to detect superimposed and train-like aureoles in moraine.

The detection of weak geochemical anomalies requires analysis of high accuracy and statistical treatment of analytical data. The reliability of detected anomalies may be substantially increased by the use of the so-called multiplicate parameters which are products of the contents of indicator elements in the samples.

Using elementary composition the anomalies may be subdivided into (a) rock-anomalies (caused by basic and ultrabasic masses), (b) pyrite-pyrrhotite anomalies (caused by vast pyrite-pyrrhotite mineralization), and (c) copper-nickel anomalies. A criterion for discriminating anomalies is the linear productivity ratio or weighted average ratios of copper, cobalt, chrome and silver to nickel. For swampy areas and surface drainage patterns the ratios of nickel plus copper to sulphur and of nickel to sulphur are used. The above criteria work reliably in cases of salt aureoles of dispersion but are less trustworthy for streams of dispersion.

The location, form and dimensions of the orebody may be determined geochemically only when supported by geological, geomorphological and hydrogeological data. Information about the genesis and thickness of loose cover is of special importance. Therefore special overburden-type maps of appropriate scale should be compiled for the area to be prospected.

Probable reserves of the ore bodies may be theoretically estimated using total areal productivity of salt lithochemical aureoles. The reliability of such estimations is, however, rather poor because of the complexity of the processes of aureole formation. Since the number of anomalies found during a survey is rather small the final assessment

must be based on drilling data accompanied by primary ore bodies aureoles research.

In the 1:50,000 scale stage of prospecting, lithochemical and hydrochemical sampling must be preceded by airborne geophysical surveys and are carried out before or simultaneously with geological surveys on the same scale. In the stage of detailed prospecting (1:10,000), lithochemical sampling is combined with surface geophysical methods usually using the same traverse lines. For areas where eluvial and deluvial sediments predominate spectrometallometric sampling proves to be most efficient. For territories when the moraine cover does not exceed 10-15 metres, acidic decomposition with in situ determination of nickel and copper in solutions is recommended. In cases of thicker moraine, atomic absorption and colorimetric analysis of weak acidic extracts of lithochemical samples should be used.

When the results of lithochemical and biochemical (phytochemical and soil geochemical) methods are compared it is obvious that under conditions of relatively simple geology they give much the same information. However, biochemical methods are appreciably more complicated and more labour-consuming.

A geological survey of anomalous areas, as a rule, is carried out only after their ore-bearing potential is confirmed but before beginning exploration prospecting.

Lithochemical research on primary aureoles is carried out by trench sampling and by logging the drill core.

### **Moraine sampling under varved clays in the Rouyn-Val d'Or area: General results**

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A project to employ miners laid off by the mines of the Cadillac area (in the Rouyn-Val d'Or mining belt) was started in July 1971. Ground moraine (lodgment till) or what was thought to be ground moraine was sampled along or between roads wherever access was possible. Most of the samples were collected under the varved clays with a piston sampler (Gleeson type). It is estimated that between 80-90% of the samples were collected at the contact with bedrock. The minus 80-mesh fraction was analysed for Cu, Zn, Ni, Pb, Co, Mn, Cd, Ag by the atomic absorption method. The coarse fraction was passed through bromoform, ground, and the minus 80-mesh fraction analysed for the

same elements.

Seven thousand samples were so collected, and the coarse fraction of samples showing anomalous chemical results was examined under a binocular microscopes.

Interesting results will be presented through various maps concerning the reflection of bedrock in the till samples, as well as anomalous results that may be interesting from the prospector's point of view.

### **Rock geochemistry and radiometry as a guide to mineralization in the Galway Granite, Ireland**

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Minor molybdenite mineralization occurs disseminated in a leucogranite facies of the Lower Devonian post-tectonic Galway Granite of western Ireland. The nature of the leucogranite has been investigated in detail over 10 km<sup>2</sup> of the southwestern margin of the pluton, where local erosive Pleistocene Ice has exposed extensive rock pavements and low crags, now interspersed with blanket peat.

Profiles showing variation of 10 major and 17 trace elements, determined in rocks by automatic X.R.F. analysis, are presented and related to mineralogical variation. The pluton is composed of a central granodiorite succeeded transitionally by an adamellite, with the leucogranite occurring marginally or in tectonically flat-lying zones. The leucogranite is identified as a silica-potassic rich fractionated end-product of the Granite magma.

The behaviour of the alkali metals usefully describes the magmatic differentiation sequence. Whole rock Rb/Sr ratios are demonstrated to be a particularly sensitive indicator of the magmatic fractionation. Ratios average 4.2 for the granodiorite, 6.0 to 6.3 for the adamellite, 35 for the leucogranite and up to 120 for the aplites. Mafic metals, including Cu and Zn, depend almost entirely on the distribution of hornblende, biotite and magnetite.

Rapid reconnaissance by scintillometry gives results corresponding closely to the petrographic and geochemical zones. The gamma-count varies between 0.018 and above 0.036 millirads/hour over the exposed granite, and is largely controlled by K<sub>2</sub>O variation.

## **A comparison of sample types in stream sediment geochemical prospecting in parts of upland Britain**

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A comparison is made between the minus 100-mesh sieved fraction, a water-suspended fraction and a panned concentrate of stream sediments collected from three geologically contrasting areas in northern England and Scotland, namely, the Cheviot Hills, parts of Kirkcudbrightshire in southwest Scotland, and the Shin district of Sutherland in the far north.

The methods of sampling and of chemical analysis and the physical characteristics of each of the sample types are described and compared. Both the minus 100-mesh fraction and the panned concentrate are obtained from total sediment samples, wet-sieved in the field through 0.25 inch and 0.10 inch mesh. The water-suspended fraction is recovered by decanting after mixing the raw sediment with water.

Consideration of the minus 100-mesh fraction and the panned concentrate shows the latter to be more effective and sensitive in the detection of vein mineralization in the areas studied. This is due to the release into the stream sediment of discrete mineral fragments which largely persist at a grain size too coarse to pass the 100-mesh sieve and which are too resistant to produce appreciable secondary metal accumulation in the chemically active fraction of the sediment. Though closer, the comparison between the two methods in the detection of disseminated mineralization in Kirkcudbrightshire shows the concentrate method to be more sensitive. It is comparatively less effective, however, in the detection of a leached vertical tabular copper-bearing structure in the same district. Here the minus 100-mesh and suspended fractions are more successful because of the relative scarcity of mineral fragments compared with friable gossan phases in the surface manifestation of the structure.

A close relationship exists between the minus 100-mesh and water-suspended fractions of sediments collected over a series of sedimentary rocks in southwest Scotland but in the area of crystalline rocks in Sutherland the water-suspended fraction shows greater contrast and sensitivity in the detection of molybdenum and copper mineralization. This is considered to be the result of greater dilution of the metal-rich fraction by quartz in the sieved fraction.

Of the three techniques the panned concentrate is generally but not invariably the most successful in the detection of base-metal mineralization; but it is the most time-consuming. The on-site detection of mineralization by an examination of the pan by a trained observer is also possible. The water-suspended fraction is quicker to

collect and prepare for analysis and is as effective or more effective than the minus 100-mesh sieved fraction in the detection of mineralization of the more mobile elements. The minus 100-mesh fraction is an effective compromise technique in the areas surveyed, being suitable for small-scale regional mapping the results of which have wide applications in several scientific disciplines.

### **Discovery and exploration of the Ashnola Porphyry Copper Deposit near Keremeos, B. C.: A geochemical case history**

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The Ashnola copper property is a typical porphyry copper deposit which was discovered by regional stream sediment sampling. Subsequent geochemical studies included additional stream sediment sampling, soil sampling of A and B horizons, biogeochemical sampling, and rock sampling. The results of the geochemical studies are compared to geology and geophysical expression of the deposit.

### **Geochemistry in the exploration of nickeliferous laterite**

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Applied geochemistry was used in prospecting and preliminary exploration of four nickeliferous laterite deposits in Western Palawan and Tawi-Tawi Island, Philippines.

Based on the evaluation of geochemical results from near-surface soil samples collected from a 300 by 300 metres grid, each laterite prospect was subdivided into: (a) highly anomalous areas, (b) anomalous areas, (c) slightly anomalous areas, and (d) background areas.

At the first laterite prospect (Long Point, Western Palawan) the geochemical subdivisions were proved by test pitting. The majority of test pits in the slightly anomalous to highly anomalous areas, particularly in the latter, penetrated possible nickel ore ( $\geq 0.9\%$  cutoff) in laterite and/or in the subjacent decomposed serpentinized ultramafic

rocks. By contrast, most of the test pits sunk to check the background areas revealed nickel deposits which are below the cutoff grade.

Using the resulting geochemical anomaly maps as guides in the exploration of the other three laterite prospects, test pitting was largely confined to the slightly to highly anomalous portions of the nickeliferous laterite prospects. Sinking of unnecessary test pits in areas containing low grade nickel was thus avoided resulting in substantial savings in exploration costs.

## **Rubidium and strontium as a guide to copper mineralization emplaced in some Chilean andesitic rocks**

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The value of Rb and Sr as guides to copper mineralization emplaced in andesitic and basaltic-andesitic volcanic rocks has been shown to be positive in the case of some porphyry copper (Braden, Rio Blanco) and stratiform-type deposits (Buena Esperanza).

Both elements follow the variation of major elements (Rb — K and Sr — Ca) added or subtracted during hydrothermal alteration associated with the copper mineralization. However, their higher sensitivity to hydrothermal processes, and the speed and precision of their analysis by X-ray fluorescence makes them better indicators than the major elements substituted.

In porphyry copper deposits emplaced in andesitic rocks, Rb is a very sensitive and semi-quantitative indicator of alteration (Armbrust et al. 1971, Oyarzun 1971). The absolute value of Rb content and that of the Rb/K ratio increases from the non-altered rock, via the propylitic zone to the potassic one, this being that zone usually associated with the primary mineralization. However, this effect apparently does not apply in the case of porphyry copper deposits emplaced in granitic rocks (El Abra, Page and Conn, 1973).

In stratiform copper deposits within Jurassic andesitic and basaltic volcanic rocks (Buena Esperanza, Losert, 1972), Sr is a good indicator of local alteration associated with copper mineralization, in that it decreases to 1/10 of "normal" content (200-300 ppm). This is considered a valuable guide in current exploration programs (Alfaro, 1973).

## **Shangani, a geochemical discovery of a massive/disseminated Ni-Cu sulphide deposit**

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Geological environments, favourable for Ni-Cu mineralization were selected in the Rhodesia Greenstone Terrain and subjected to systematic soil-geochemical exploration.

Sympathetic Cu-Ni-Co anomalies were encountered and follow-up work led to the discovery of substantial disseminated and massive Cu-Ni-sulphide mineralization comprising the Shangani orebody which is now being brought into production. Methods of systematic geochemical exploration, interpretation of data and subsequent priority rating, screening of priorities and elimination of targets are discussed.

The significance of sympathetic multi-element anomalies as opposed to mono-element anomalies is illustrated and explained using the Shangani example where barren ultrabasic rocks may give rise to soil-geochemical anomalies exceeding those over mineralized ultrabasic rocks.

## **Geochemical prospecting for ores in the Bohemian Massif, Czechoslovakia**

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Since 1952, geochemical methods have been applied to ore prospecting in Czechoslovakia. The main natural conditions controlling the working methods are a temperate climate, deep overburden connected with a long geological development of the Bohemian Massif, and a strong influence of anthropogenic effects on the landscape geochemistry (old mines, recent industry, dense population and agriculture).

Four stages of development can be distinguished in the short history of geochemical prospecting in Czechoslovakia: a period of method development and prospecting in the neighbourhood of known ore deposits (1952-1958), a period of broad field applications (1958-1964), a period of stagnation (1964-1969), and a recent period of a new activity, mostly an exploration for buried and hidden ore deposits (since 1969).

Successful geochemical exploration methods used in CSSR are as

follows: soil surveying, base-of-slope sampling, stream sediment surveys, hydrogeochemical and biogeochemical prospecting and rock-sampling surveys. These methods are very often used in combination with geophysical measurements or heavy mineral prospecting (panning).

Of the chemical techniques, emission spectrometry, atomic absorption spectrometry and radiometric methods are of special importance. Colorimetry, polarography and neutron activation analysis are uncommon. The use of selective ion electrodes, e.g., the fluoride electrode, seems to be promising.

In the last decade, methods for locating tin ores, including hidden deposits were developed. Soil surveying is a suitable method used in the search for greisen zones in granites, for chlorite-cassiterite-sulphide ores and tactite tin ores in phyllite complexes. Prognostic zones of hidden deposits in granites were predicted on the basis of detailed geochemical maps, e.g., trend maps of Li, F, Rb, Ga, Be, Sn. The primary dispersion patterns in overlying quartz porphyries characterized by anomalous concentrations of Sn, Rb, Mo, W indicate hidden tin ores in granitic elevations.

Most geochemical exploration activity is concerned with the search for lead-zinc deposits of the vein and stratiform types. A great deal of knowledge was gained in the Pribram ore district and in the Ceskomoravska vrchovina Highland. In the Jeseniky Mountains the primary dispersion patterns in rocks were investigated on a broad regional scale. This method is combined with hydrogeochemical exploration.

Ground-water and stream-water fluorine anomalies were found by using a selective fluoride electrode in direct field measurements. Several new fluorite veins and promising areas were discovered.

### **The Corral de Piedra molybdenite stockwork, Durango, Mexico**

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The Corral de Piedra molybdenite stockwork is located on the Rio Piaxtla in the barrancas on the western edge of the Sierra Madre Occidental some 900 kms. northwest of Mexico City and about 850 kms. south of El Paso, Texas. It lies 14 kms. northeast of the Minas de San Luis, S. A. silver-gold mine at Tayoltita. Corral de Piedra was first

recognized as a molybdenite stockwork in 1965 and staked shortly thereafter. Geochemical and geological studies have continued since that time and drilling was recently started on what is one of the largest molybdenum prospects in Mexico. As neither airphotos nor topographic maps were available, triangulation was used as a base for plane table mapping to locate geologic and sample points.

The gross structure of the area is a doubly plunging anticline best delineated by upper Tertiary ignimbrites and known as the Corral de Piedra Dome; its long axis trends northeast. The mineralized rocks, also Tertiary in age, underlie these rhyolite ignimbrites and form the core of the dome. These consist of acid, potassium-rich extrusives of the Socavon formation and slightly more sodic intrusives of the Piaxtla granodiorite batholith. The whole is cut by acid to intermediate dykes. Mineralization consists of massive silicification replaced by a network of northeast striking and northwest dipping MoS veinlets. Later molybdenite formed stringers with northerly strikes; the last MoS stage followed a northwest strike. Most veinlets are steeply dipping. Dykes and specularite veins are mostly post-molybdenite and formed in northwest-striking fractures with moderately steep southwest dips. The dykes sometimes carry minor copper, and the specularite is associated with most of the cassiterite in the region.

Rock samples were taken for geochemical analysis for Mo and in some cases for Sn, Cu,  $WO_3$ , Ag, and Au. Contouring of Mo values gives anomalies which agree closely with geologic mapping and indicate a mineralized zone about 2 kms. long and half a kilometer wide, striking  $N20^\circ E$ . Tin forms a negative anomaly in the molybdenite area and positive anomalies to the north; it is more abundant generally in this stockwork than in most Mo properties. Although some areas show strong chalcopyrite content, copper is present erratically in the molybdenum zone. Results of analyses for tungsten vary widely with different laboratories, and its distribution is unclear. Small amounts of silver are related to molybdenum-rich zones, but gold content is negligible.

Background for molybdenum in the region is very low, apparently less than 5 ppm; the geochemical gradient is normally very steep between 5 and 50-100 ppm Mo. Therefore, a threshold value of 100 ppm Mo is considered conservative for anomalies. The zone including all measurable indications of molybdenum coincides with the northeasterly strike of the rhyolite extrusives and intrusive granodiorite of the core of the dome rather than the  $N20^\circ E$  strike of the threshold anomaly.

## **The mode of occurrence of trace elements in soils and stream sediments applied to geochemical exploration**

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A knowledge of the mode of occurrence of trace elements in natural materials is necessary in order to apply chemical principles to the behavior of trace elements. Among the important modes are occurrence as a major element in a trace mineral, as a trace constituent in the lattice of a pre-existing rock mineral or a mineral formed during weathering, and as an adsorbed or exchangeable ion on the surface of a colloidal particle or in a clay. Techniques for distinguishing between these modes of occurrence are reviewed, and some results of experiments using selective chemical attacks are presented. In soils from the Stillwater complex, Montana, palladium is found to occur mainly in association with organic material and in the lattice of clays, whereas platinum tends to persist in primary minerals, leading to a separation of these elements. In stream sediments of Pennsylvania, major amounts of cobalt occur in iron oxides, and important amounts of zinc and copper occur in clays but very little in the organic fraction of most sediments. Soils over serpentinites contain most of their chromium in chromite and a lesser amount in iron oxides; nickel is concentrated in iron oxides and silt-size particles. These methods or simplified versions of them can be used to detect weak anomalies and to investigate the origin of puzzling anomalies.

## **Relation between copper contents in soil and copper grade of ore bodies calculated by drill core assay of some porphyry copper deposits in tropical terrain**

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Before conducting information and outline drilling on a porphyry copper deposit, it is most advisable that the grade of copper of the target be previously estimated by a detailed geochemical study of soil sampling results. To illustrate how this estimation may be carried out, geochemical data and copper contents of three porphyry copper deposits in tropical terrain, St. Nino (Philippines), Nungkok (Malaysia) and Chaucha (Equador), are compared.

The ratio of  $C_x\text{-Cu}/T\text{-Cu}$  may be one of the important factors affecting the calculation of ore grade, and this ratio may be influenced

by thickness of overburden. In the case of St. Nino where the overburden is very thin, the ratio is only 0.55 percent. On the contrary, at Chaucha where the overburden is very thick, the ratio is 35 percent. According to this ratio, the copper content of the ore body will be from 1.5 to 3 times the total copper value in the soil above the ore body.

## **Geochemical exploration in Sardinia**

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Ente Minerario Sardo is carrying out a complete inventory of the natural resources of Sardinia.

A geochemical reconnaissance forms an important part of the first stage of this exploration program.

The survey, begun in 1973, will last approximately two years and will eventually cover a surface of 14,000 km<sup>2</sup> or 2/3rds of the island of Sardinia.

A total of 20,000 stream sediment samples have been analysed by a fully automated atomic absorption method for eleven elements, Pb, Zn, Cu, Ag, Sb, Ni, Co, Cr, Mg, Mn, F .

All analytical results are being statistically interpreted with the use of a computer.

Our paper will cover the sampling methods, the preparation techniques, the analytical methods and the statistical interpretation. Some case histories will also be treated.

## **Three case histories from a geochemical exploration program — Windhoek district, South West Africa**

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Following a summary description of the semi-desert climate and the predominantly sedimentary geology of South West Africa a rapid, high volume, system of geochemical soil sampling appropriate to this environment is outlined.

This method contributed to the discovery and subsequent proving of one important and two minor ore-bodies in 1971. All three deposits are

of the copper-zinc-silver bearing massive sulphide type and are considered to be genetically related to volcanic activity during formation of the Damara geosyncline in the late Precambrian. The surface expressions, where exposed, take the form of (visibly) completely leached gossans and magnetite-bearing quartzitic rocks.

Local effects on dispersion due to the presence of weathering massive sulphides in the near-surface environment are discussed.

## **A topologically optimum prospecting plan for streams**

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Study of the branching network of streams suggests that an optimum sequential prospecting plan for a stream can be obtained by successive halving the basin at the centroid. This theoretical plan is designed for the case where a unique substance is being carried by the stream system from a single source. When this holds the modal number of sequential samples to locate the source of a substance is given by  $S = 1 + [\log_2 M_0]$  where  $S$  is the number of samples,  $M_0$  is the link magnitude of a stream at its outlet (number of source streams in the basin) and  $[ ]$  means the integral value (the closest integer less than the bracketed value). This sample design can serve as a model against which sampling efficiency of any practical program may be judged.

To illustrate the sampling procedure with a field example, a moderate sized drainage basin (approx. 109 km<sup>2</sup>) was chosen which drains the area surrounding the Brewer gold mine (South Carolina). This mine has an alteration halo with an unusual, abundant chert-like topaz. These pebbles are easily recognized visually and because of their high density they can be quickly verified using a heavy liquid.

Prior to actual sampling, a drainage pattern map was prepared from topographic maps (Scale of 1:24,000) of the area, and the magnitude of each channel section was determined. The basin has a total of 144 sources divided mostly into two dominant streams whose combined outlet discharges into the Lynches River.

Sampling was begun by testing the mouth of the drainage basin one hundred meters upstream of the Lynches River. Topaz (11 pieces/9.7 liters) was readily recovered using a hand sieve covered on the bottom with 6mm. screen ( $1/4$  in. hardware cloth). The basin was then sampled at the first centroid (magnitude-72) where no topaz was detected. Sampling was continued at successive centroids until all but two exterior

(source) links had been eliminated. At this point it must be realized that the source could occur on an interior link as well as on an exterior link. A sample was then taken upon an interior link such that one of the two remaining exterior links would be eliminated. A negative result here showed that the topaz source was either on the remaining exterior or the remaining downstream interior link. Sampling of this exterior link was negative.

The calculated theoretical number of sequential samples to search the basin is 7 if the source is on an exterior link or 8 if the source is on an interior link; because of a favourable division of the basin only 7 samples were actually required. Time to carry out the search required 4 hours for preliminary office work to set up the plan and 16 hours of field work using an automobile and foot travel to reach the sample sites.

## **Geochemical exploration for the Kuroko Deposits in the Northeast Honshu, Japan**

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The Kuroko deposits are strata-bound polymetallic sulphide deposits of Miocene age in Japan. These high grade lead-zinc-copper ores have been mined since the middle of the nineteenth century.

The genesis of Kuroko deposits has been the subject of much discussion, especially regarding whether the deposits are syngenetic or epigenetic.

The concept of genesis of the Kuroko deposits is one of the most important factors in exploration for them.

Our applied geochemical work has been carried out on the basis of the concept of a submarine hydrothermal and exhalative sedimentary origin for the Kuroko deposits.

Soil samples were collected from a mining area, about 200-300 m under which a blind ore body is known to occur.

The results demonstrate significant anomalies in the soils over the ore bodies.

Multivariate techniques of statistical analysis of the data from drill

cores around the ore body in selected areas can be used for identifying ore horizons and serve to forecast ore deposits.

## **Some considerations regarding grid orientation and sample spacing**

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Mineral potential of an area commonly is investigated by accumulating geochemical (and other) data in a regular or gridded pattern over the region of interest. Extensive reconnaissance studies of this type generally are preceded by an "Orientation" survey, results of which are used to optimize the broader scale survey. Among the types of information that can be obtained from many orientation surveys are certain geometric features of the target being sought directly, such as, shape, size, and anisotropism (elongation), all of which have important implications concerning grid orientation and sample spacing. Some consideration is given to the methods used to represent these geometric features and how their quantification is prerequisite to

- (1) determinign optimum grid orientation and sample spacing,  
and
- (2) recognizing the probability of success of an extensive survey.

## **A computer method for dividing a regional geochemical survey area into homogeneous subareas prior to statistical interpretation**

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This paper presents a computer procedure which has been used to divide a geochemically heterogeneous survey area into reasonably homogeneous subareas.

Humus ( $A_1$ ) soils from an area in central Norway (70 x 70 km) were sampled at the intersection of a 3 km square grid and 14 chemical elements were determined in each sample. The samples were considered scaled to unit variance, as axes. In this space, groups were isolated by applying the "K-means" algorithm which minimizes the mean square distance between samples within the same group. The samples were partitioned into an increasing number of groups and

Wilks's Criterion  $\Lambda$  (the ratio of the determinant of the within-group and total dispersion matrices) was determined for each partition. The number of groups ( $k$ ) corresponding to the partition with the minimum value of the product  $K^2 \times \Lambda$  was chosen as the number of geochemically homogeneous classes to be distinguished within the survey area.

Mapping these classes without considering geographic location produced maps with very fragmented subareas and irregular boundaries. A regrouping of the samples was therefore performed according to a mixed distance measure, taking into account both geochemical and geographical proximity, resulting in more continuous and compact subareas.

Statistical analyses of the regional geochemical exploration data, before and after regrouping of the samples into subareas, were compared and regrouping proved to be clearly advantageous.

### **Interpretation of Mo content in groundwater utilizing Eh, pH and conductivity**

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Geochemical exploration for porphyry copper targets in southeastern Arizona was conducted during the last two years utilizing groundwaters.

Samples of groundwaters were generally collected from wells which had been pumping for at least ten minutes. The pH and Eh were determined immediately at the sample site. Samples were then placed in two polyethylene bottles, one of which was acidified, and sent to a commercial laboratory for analysis of Mo, conductivity and other trace elements.

Both correlation diagrams and theoretical calculations utilizing Eh — pH diagrams suggest that the molybdenum content is not primarily controlled by the Eh — pH of the groundwaters.

Correlation diagrams of the conductivity, which is proportional to total dissolved solids, shows a much higher correlation between the molybdenum content and conductivity than between the molybdenum content and Eh — pH.

Case studies conducted near a known — but then unopened — porphyry copper deposit show little change in pH, Eh as the target is approached; however, the molybdenum content increases significantly. Thus, one might utilize a ratio of molybdenum content/conductivity to suggest the proximity of an oxidizing porphyry copper.

# The weathering products of nickeliferous sulphides and their associated rocks in Western Australia

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The essentially N-S trending Archean ultramafics of the Eastern Goldfields region of Western Australia carry some of the more recent discoveries of nickel-copper sulphides.

This area has presented a somewhat unique problem in exploration in that, unlike similar areas of Canada, the terrain is deeply and pervasively weathered. Further, the chemical, mineralogical and geological nature of the sulphide associated rocks was by no means fully understood.

In this present work we have been concerned with the recognition of the weathering products after nickel-copper sulphides: much of the study is related to the Spargoville property to the south of Kalgoorlie.

The problem might be taken in two parts, that involving the variation in the nature of the (fresh) rocks particularly in respect of the manner of occurrence of the sulphides, and that involving the "variability" of the weathering process.

It is now generally accepted that the majority of the "deposits" are magmatic with the sulphides tending to lens-like concentrations, toward the base of the unit. The sulphides within a lens may grade from massive through disseminated with occasional (massive) remobilized sulphide in country rock. Significant, and differing, out-crop may develop over each of these zones.

Weathered zones over "unmineralized" ultramafic sequences present somewhat of an initial problem; individual hard specimens may resemble closely those from rock carrying extensive sulphides. This is quite understandable in the light of a detailed study of the fresh rocks of such a sequence.

A very wide range exists for the significant levels of the primary chemical indicators Ni and Cu, as a result of variation in "type" of the weathered rock because of variation in the weathering process — from highly siliceous ( $\text{SiO}_2 \sim 90\%$ ) to highly ferruginous ( $\text{Fe} \sim 50\%$ ).

However, the mobility of nickel and copper, and their general abundance in the immediate environment limits their usefulness to quite an extent although zinc in particular may be used as a negative indicator against exotic copper. With this in mind we turned to the low-level trace elements Pt and Pd as possibly less mobile indicators. Both elements are readily analysed at the sub ppm level by a combined fire assay — atomic absorption method. The data for the weathered rocks for these elements was initially puzzling. Although Pd seemed to

correlate with the sulphide content of the indicated fresh equivalent, Pt was quite variable and not always present.

Analysis of the fresh rocks has shown an acceptable correlation for Pd and Ni, but Pt varies markedly with the type of the sulphide occurrence and with the position in the mineralized section.

Pd thus seems to be a useful indicator, being related to sulphide nickel and being reasonably persistent in outcrop.

Textural studies also provide a useful back-up to geochemical work or vice-versa, depending on one's persuasion.

Although massive sulphide tends to leach initially to a boxwork of minimally siliceous iron oxides, subsequent infilling with silica and iron oxides gives a more or less siliceous rock in which occasional textural pseudomorphs after "pentlandite" and altered pyrrhotite may be found, textures after secondary pyrite-marcasite may also be observed.

In the disseminated sulphides, massive oxidation of the sulphide grain is more common, apparently as the result of neutralisation of the nascent sulphur species by the magnesia carbonates and silicates. Sulphide textures may be well preserved. Siliceous replacement textures after silicates may also be recognized, in particular the amphiboles.

The emphasis on the use of copper was based originally on the common association of chalcopyrite with massive sulphides in the contact-type bodies known at the time (1969). Also, it was assumed that Cu was less mobile than Ni during weathering and hence less prone to form falsely anomalous concentrations during weathering. However, at Mt. Keith, the Cu/Ni ratio of 1:60 is much less than that for massive ores (1:11) so that Cu was of less importance than Ni during exploration. In addition, Cu tends to concentrate in the marginal pyroxenitic zones of the ultrabasics where there is less chance of mineralization and also where, in the weathered zone, there is often a poor contrast between the ultrabasics and the basic and intermediate volcanic country rocks.

## Zinc abundance in early Precambrian volcanic rocks: Its relationship to exploitable levels of zinc in sulphide deposits of volcanic-exhalative origin

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A survey of 2,700 published and unpublished chemical analyses of Early Precambrian tholeiitic and calc-alkaline volcanic rocks from the Abitibi, Wawa and Wabigon belts of the Canadian Shield has demonstrated certain regularities in the abundance and distribution of zinc. Zinc abundance ranges from 3 ppm to 200 ppm in background volcanic rocks remote from mineralization and much of this variation is accounted for by fractional crystallization processes represented by the variables  $\text{SiO}_2$  and total Fe.

The average zinc contents of sampled areas in the volcanic belts vary from 85 to 95 ppm and zinc frequency distributions closely approximate a normal form. Small differences in the statistical characteristics of zinc populations may be explained by systematic inter-laboratory analytical error and by lack of correspondence between the sampled and target populations caused by (1) non random sampling procedures and (2) the use of unweighted averages in large areas of unrepresentative surface exposure.

The chemical data have been compiled and plotted to develop mathematical expressions for Zn variability in unmineralized differentiated sequences of Early Precambrian volcanic rocks. Using a function of the type:  $\log \text{Zn} = 3.1014 - 0.2183 \text{SiO}_2 \pm 0.1875$ , components of regional background variability due to the silicate fractional crystallization process can be isolated from local anomalous Zn variation attributable to mineralizing processes connected with the localization of sulphide deposits of volcanogenic origin.

Zinc variation in Precambrian volcanic rocks has been mapped in detail in a 35 square mile test area situated in the central Abitibi belt, 30 miles west of Noranda and 21 miles north-east of Kirkland Lake. Data collected from sites spaced with a mean density of 30 per square mile, are used to illustrate regional and residual patterns of Zn variability related to normal differentiation processes and mineralizing processes respectively.

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$$K = \frac{2a_1}{b_1}$$

Series

$$\log k - \log l = \log \frac{2a_1}{b_1} - \log \frac{2a_2}{b_2}$$

$$\log \frac{2a_1}{b_1} - \log \frac{2a_2}{b_2} = \log \frac{a_1 b_2}{a_2 b_1}$$

$$\log \frac{a_1 b_2}{a_2 b_1} = \log \frac{a_1}{a_2} + \log \frac{b_2}{b_1}$$

$$K' = \log 2 - \log \frac{2a_1}{b_1}$$

$$d = d_1 2^{2n} + a_2 2^{2n}$$

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