9 th INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM

May 12-14, 1982, Saskatoon, Canada

PROGRAM WITH ABSTRACTS

Co-sponsored by Mineral Deposits Division
of Geological Association of Canada

9 th
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PROGRAM WITH ABSTRACTS

THE ASSOCIATION OF EXPLORATION GEOCHEMISTS

Co sponsored by Mineral Deposits Division of Geological Association of Canada

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Wine and Cheese	Sally Babcock
Western Barbeque	Judy Stoeterau, Linda Bloom, Fred Langford
Luncheons	Barry Cooper
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PROGRAM SUMMARY

REGISTRATION AND INFORMATION

Tues.	11 May	– 19:00 – 22:00 h.	Bessborough Hotel, Adam Ballroom
Wed.	12 May	– 8:00 – 16:00 h.	Centennial Auditorium
Thurs.	13 May	– 8:00 – 16:00 h.	Centennial Auditorium
Fri.	14 May	– 8:00 – 12:00 h.	Centennial Auditorium

TECHNICAL PROGRAM

Wed. – Fri.   12 – 14 May

Oral and Poster Presentations – Centennial Auditorium.

Thurs.   13 May (evening)

Core Display (from 18:00 h.) and tour of the analytical facilities of the Sask. Research Council – Sedco Centre (transport will be provided).

Fri. 14 May (evening)

Submarine Hydrothermal Systems (Films and Slides), from 18:30 h. – Holiday Inn.

(Annual General Meeting of the AEG – 16:45 h., Thurs. 13th – meeting room in the Centennial Auditorium).

SOCIAL PROGRAM AND LUNCHEONS

Tues.   11 May   – 19:00 – 22:00 h.

Complimentary Wine and Cheese – Bessborough Hotel, Adam Ballroom.

Wed.   12 May   – 12:15 h.

Luncheon (guest speaker Senator S.L. Buckwold) – Holiday Inn, Commonwealth Ballroom.

Wed.   12 May   – 20:00 h.

Western Barbeque (guest speaker D. Moroz, Deputy Minister, Sask. Mineral Resources) – Western Development Museum (transport will be provided).

Thurs. 13 May   – 12:15 h.

Luncheon (included in registration fee) – Centennial Auditorium.

Fri.   14 May   – 12:15 h.

Luncheon (included in registration fee) – Centennial Auditorium.

Fri.   14 May   – from 18:00 h.

Vesna Festival – Centennial Auditorium.

Details of the spouses' program and any remaining vacancies on field trips can be obtained from the registration desk.

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

WEDNESDAY 12 MAY - MORNING: URANIUM GEOCHEMISTRY

****

Chairmen: L.S. Beck, Sask. Min. Resources
           B. Bølviken, Norwegian Geol. Survey

8:30   OPENING ADDRESSES:

                    V. Sopuck .... 9th IGES General Chairman
                    K. Lovstrom ...... AEG President
                    L.S. Beck .... Executive Director, Saskatchewan
                                       Mineral Resources

9:00   NUMBER THREE OREBODY, RANGER ONE, AUSTRALIA. A CASE HISTORY.

         Sherrington, G.H., Browne, A.L.L., Duffin, R.H., and
         Danielson, M.J.

9:20   GEOCHEMICAL EXPLORATION FOR UNCONFORMITY - TYPE URANIUM DEPOSITS
         IN PERMAFROST TERRAIN - HORNBY BAY BASIN, NORTHWEST TERRITORIES,
         CANADA.

         Hoffman, S.J.

9:40   FAVOURABLE ENVIRONMENTS FOR POSSIBLE URANIUM MINERALIZATION,
         PENINSULAR MALAYSIA.

         Heng, C.L., Chand, F., and Ahmad, J.

10:00   Coffee

10:30   HYDROGEOCHEMICAL EXPLORATION FOR URANIUM WITHIN THE ATHABASCA
         BASIN, NORTHERN SASKATCHEWAN.

         Earle, S., and Drever, G.

10:50   ORIENTATIVE LITHOGEOCHEMISTRY OF THE ARCHEAN AND APHEBIAN BASEMENT
         IN THE KEY LAKE URANIUM DEPOSIT AREA, SASKATCHEWAN, CANADA

         Strnad, J.G.

11:10   USE OF LITHOGEOCHEMISTRY IN LOCATING UNCONFORMITY TYPE URANIUM
         DEPOSITS.

         Sopuck, V.J., de Carle, A., Wray, E.M., and Cooper, B.

11:30   GEOCHEMICAL ZONING AROUND THE McCLEAN URANIUM DEPOSITS, SASKATCHEWAN,
         CANADA.

         Golightly, J.P., Brummer, J.J., Saracoglu, N., and Gleeson, C.F.

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

WEDNESDAY 12 MAY - AFTERNOON: URANIUM GEOCHEMISTRY AND HYDROGEOCHEMISTRY

****

Chairmen: J.A. Hansuld, Amax, Toronto
D.C. Bruni, CPRM, Brazil

13:30   GEOCHEMICAL EXPLORATION FOR URANIUM AND OTHER METALS IN TROPICAL AND SUBTROPICAL ENVIRONMENTS USING HEAVY MINERAL CONCENTRATES.

Watters, R.A.

13:50   STREAM SEDIMENT GEOCHEMICAL PROSPECTING FOR URANIUM IN THE PALEOZOIC OF THE BELGIAN ARDENNES.

Martin, H., Lefin, J.P., Dejonghe, L., and Henry, J.

14:10   A URANIUM DISTRICT DEFINED BY RECONNAISSANCE GEOCHEMISTRY IN SOUTH GREENLAND.

Armour-Brown, A., Steenfelt, A., and Kunzendorf, H.

14:30   THE DISTRIBUTION OF URANIUM IN MANGANESE NODULES FROM THE DEPOSITS OF THE PACIFIC OCEAN.

Kunzendorf, H., Friedrich, G., and Plüger, W.L.

14:50   Coffee

15:20   GROUNDWATER GEOCHEMISTRY OF URANIUM AND OTHER ELEMENTS, MONTICELLO AREA, NEW YORK.

Rose, A.W., Wesolowski, D., and Smith, A.T.

15:40   RADIUM^{223}/RADIUM^{226} RATIO IN GROUNDWATER AS A URANIUM EXPLORATION TOOL.

Dean, J.R., Bland, C.J., and Levinson, A.

16:00   EVALUATING RADIOACTIVE ANOMALIES USING RADIUM^{223}.

Dickson, B.L., Meakins, R.L., and Bland, C.J.

16:20   GROUNDWATER GEOCHEMISTRY IN THE ABITIBI VOLCANIC BELT OF QUEBEC.

Lalonde, J.P.

16:40   THE APPLICATION OF HYDROGEOCHEMISTRY TO THE EXPLORATION FOR MISSISSIPPI VALLEY - TYPE DEPOSITS IN NORTHWESTERN OHIO.

Deering, M.F., Mohr, E.T., Sypniewski, B.F., and Carlson, E.H.

17:00   HYDROGEOCHEMICAL EXPLORATION FOR BARITE, OUACHITA MOUNTAINS, U.S.A.
Steele, K.F., and Wagner, G.H.

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

THURSDAY 13 MAY - MORNING: GEOTHERMAL ENERGY AND GENERAL PAPERS

****

Chairmen: A.W. Rose Penn. State Univ.
            A.J. Björklund, Geol. Surv., Finland

8:30   A METHODICAL AND REGIONAL CONTRIBUTION TO GEOCHEMICAL MULTI-ELEMENT
        PROSPECTING FOR CARBONATITES BY ENERGY DISPERSIVE X-RAY FLUORESCENCE.
        Kramar, U.

8:50   LABORATORY AND FIELD EVIDENCE IN SUPPORT OF THE ELECTROGEOCHEMICALLY
        ENHANCED MIGRATION OF IONS THROUGH GLACIOLACUSTRINE SEDIMENT.
        Smee, B.W.

9:10   SOIL AIR CARBON DIOXIDE AND OXYGEN DISEQUILIBRIA AS A GUIDE TO
        CONCEALED MINERALIZATION IN SEMI-ARID AND ARID REGIONS.
        Lovell, J.S., Hale, M., and Webb, J.S.

9:30   THE USE OF FLUID INCLUSION DECREPITOMETRY TO DISTINGUISH MINERALIZED
        AND BARREN QUARTZ VEINS IN THE ABERFOYLE TIN-TUNGSTEN MINE AREA,
        TASMANIA.
        Burlinson, K., Dubessy, J.C., Hladky, G., and Wilkins, R.W.T.

9:50   GEOCHEMICAL HYDROCARBON EXPLORATION - A NEW/OLD EXPLORATION TOOL.
        Duchscherer, W.

10:10   Coffee

10:30   THE ROLE OF MERCURY, ARSENIC AND BORON AS PATHFINDERS IN GEOCHEMICAL
        EXPLORATION FOR GEOTHERMAL ENERGY.
        Shiikawa, M.

10:50   Hg AND As SOIL GEOCHEMISTRY OF THE MEAGER CREEK GEOTHERMAL AREA.
        Openshaw, R.E.

11:10   SURFACE GEOCHEMISTRY AT ROOSEVELT SPRINGS KGRA, UTAH.
        Lovell, J.S., Meyer, W.T., and Atkinson, D.

11:30   GEOCHEMICAL INDICATORS OF A HIGH TEMPERATURE GEOTHERMAL SYSTEM.
        Moore, J.N., Capuano, R.M., and Christensen, O.D.

11:50   EXPLORATION FOR GEOTHERMAL ENERGY IN INDIA.
        Murty, K.S.

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

THURSDAY 13 MAY - AFTERNOON: GEOSTATISTICS AND GENERAL PAPERS

****

Chairmen: R.G. Garrett, Geol. Surv. Canada
           S. Hoffman, B.P. Minerals, Vancouver

13:20   ASPECTS ON THE PROBABILITY DISTRIBUTION OF ANOMALOUS VALUES IN
          GEOCHEMICAL DATA.
          Björklund, A.

13:40   SCORESUM - A TECHNIQUE FOR DISPLAYING AND EVALUATING MULTI-ELEMENT
          GEOCHEMICAL INFORMATION, WITH EXAMPLES OF ITS USE IN REGIONAL
          MINERAL ASSESSMENT PROGRAMS.
          Chaffee, M.A.

14:00   STATISTICAL EVALUATION OF THE SIGNIFICANCE OF CATEGORICAL FIELD
          PARAMETERS IN INTERPRETATION OF REGIONAL GEOCHEMICAL SEDIMENT DATA.
          Matysek, P., Sinclair, A.J., and Fletcher, W.K.

14:20   SAMPLING AND ANALYTICAL ERRORS IN GEOCHEMISTRY: THEIR VARIATION
          WITH THE METAL CONTENTS IN STREAM SEDIMENTS.
          Bølviken, B., Ekremsaeter, J., Ottesen, R.T., and Volden, T.

14:40   COMPUTER ANALYSIS OF MINERALIZATION WITHIN EVOLVING CALDERA AND SUB-
          VOLCANIC SYSTEMS, BONANZA AND BRECKENRIDGE MINING DISTRICTS, COLORADO
          MINERAL BELT, U.S.A.
          Pride, D.E., and Hasenohr, E.J.

15:00   Coffee

15:20   RECENT ADVANCES IN GEOCHEMICAL EXPLORATION IN CHINA.
          Xuejing, X., Zheng, Kang-Le

15:40   GEOCHEMISTRY OF TIN, TUNGSTEN AND MOLYBDENUM IN SWEDISH PROTEROZOIC
          GRANITOIDS: THEIR POTENTIAL USE IN REGIONAL MINERAL EXPLORATION.
          Drake, K.M.

16:00   DISTRIBUTION OF MERCURY COMPOUNDS IN ORE AND COUNTRY ROCK AT SIGMA
          GOLD MINE, VAL d'OR, QUEBEC.
          Aftabi, A., and Azzaria, L.M.

16:20   THE USE OF K/Tl and Tl/Sr RATIOS AS GUIDES TO MINERALIZATION.
          Ikramuddin, M., Nordstrom, P.M., Kinart, K.P., Martin, W.M.,
          Digby, S.J.M., Elder, D.D., Nijak, W.F., and Afemari, A.A.

(16:45   Annual General Meeting of the Association of Exploration Geochemists)

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

FRIDAY 14 MAY - MORNING: LITHOGEOCHEMISTRY IN AREAS OF MASSIVE
                             SULPHIDE DEPOSITS (MDD SESSION)

****

    Chairmen: J. Alan Coope, Newmont Expl., Toronto
               N.J. Allman, President, Geol. Assoc. Canada

8:30   OVERVIEW, PRESENTATIONS.

         Coope, J.A., and Plant, J.

8:45   CHEMISTRY OF THE HOT SPRINGS ON THE EAST PACIFIC RISE AT 21°N (350°C)
         AND THE GULF OF CALIFORNIA (315°C).

         Edmond, J.M.

9:10   HYDROTHERMAL DEPOSITION ON THE EAST PACIFIC RISE AT 21°N.

         Haymon, R.M.

9:35   SULPHIDE MINERALIZATION AND WALLROCK ALTERATION IN OPHIOLITES AND
         MODERN OCEANIC SPREADING CENTRES.

         Koski, R.A.

10:00   Coffee

10:30   ARCHEAN SEA-FLOOR HYDROTHERMAL SYSTEMS: THE THIRD DIMENSION.

         Ridler, R.H.

10:55   TUFFACEOUS EXHALITES AS EXPLORATION GUIDES FOR VOLCANOGENIC
         MASSIVE SULPHIDE DEPOSITS.

         Scott, S.D., Kalogeropoulos, S.I., Shegelski, R.J., and Siriunas, J.M.

11:20   LATERAL AND STRATIGRAPHICAL ZONATIAN OF CHALCOPHILE ELEMENTS ABOUT
         THE HOWARD'S PASS (XY) STRATABOUND Zn-Pb DEPOSIT, SELWYN BASIN, YUKON.

         Goodfellow, W.D., Jonasson, I.R., and Morganti, J.M.

11:45   DIFFERENTIATION OF DIAGNOSTIC ALTERATION TYPES IN THE WALLROCKS OF
         ARCHEAN VOLCANIC-EXHALATIVE MASSIVE SULPHIDE DEPOSITS.

         Amor, S.D., and Nichol, I.

TECHNICAL PROGRAM - ORAL PRESENTATIONS

****

FRIDAY 14 MAY - AFTERNOON: LITHOGEOCHEMISTRY

****

Chairmen: J. Plant, IGS, London
           G.L. Coetzee, AEG, S. Africa

13:20   LITHOGEOCHEMISTRY OF WAINALEKA Cu-Zn VOLCANOGENIC DEPOSIT, VITI LEVU,
         FIJI, AND POSSIBLE APPLICATIONS FOR EXPLORATION IN TROPICAL TERRAINS.
         Rugless, C.S.

13:40   ROCK GEOCHEMICAL EXPLORATION AT MOUNT MORGAN, QUEENSLAND, AUSTRALIA.
         Fedikow, M.

14:00   LITHOGEOCHEMISTRY AS AN INDICATOR OF URANIUM AND TIN MINERALIZATION,
         SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA.
         Muecke, G.K., and Chatterjee, A.K.

14:20   LITHOGEOCHEMISTRY OF HYPOGENE, SUPERGENE AND OUTCROP SAMPLES, BERG
         PORPHYRY COPPER DEPOSIT, BRITISH COLUMBIA.
         Heberlein, D., Fletcher, K., and Godwin, C.I.

14:40   COBALT AS AN EXPLORATION TOOL IN THE OUTOKUMPU ZONE, FINLAND
         Hakanen, P.

15:00   Coffee

15:20   THE USE OF THE "IMMOBILE" ELEMENTS Zr AND Ti IN LITHOGEOCHEMICAL
         EXPLORATION FOR MASSIVE SULFIDE DEPOSITS IN THE PRECAMBRIAN PECOS
         GREENSTONE BELT OF NORTHERN NEW MEXICO.
         Petersen, M.D.

15:40   A PROMISING USE OF MULTIVARIATE STATISTICAL ANALYSIS IN LITHOGEO-
         CHEMICAL PROSPECTING.
         Selinus, O.

16:00   NEW DATA ON PRIMARY AUREOLES OF RARE-METAL PEGMATITES.
         Shmakin, B.M.

16:20   LITHOGEOCHEMICAL DISPERSION ASSOCIATED WITH THE RIRIWAI ZINC-TIN
         LODE, NORTHERN NIGERIA.
         Imeokparia, E.G.

16:40   THE USE OF SILVER AND COBALT AS PATHFINDER ELEMENTS FOR LOCATING COPPER-
         GOLD BEARING QUARTZ VEINS IN TWO-MICA GNEISSES OF THE SERBOMACEDONIAN
         MASSIF, KILKIS PROVINCE, NORTHERN GREECE.
         Kelepertsis, A., Karamanou, E., and Polyzonis, V.

17:00   ROLE OF LITHOGEOCHEMISTRY IN DELINEATING THE WESTERN EXTENSION OF THE SINGHBHUM SHEAR ZONE, EASTERN INDIA.

            Talapatra, A.K., Battacharya, C., and Bose, S.s.

17:20   CLOSING REMARKS

(18:30   SUBMARINE HYDROTHERMAL SYSTEMS - Film and Slide Presentation by J. Edmond, at the Holiday Inn).

POSTER SESSIONS

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WEDNESDAY 12 MAY
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Posters will be on display all day in the Confederation Room, on the second floor of the Centennial Auditorium.

HYDROGEOCHEMICAL INVESTIGATIONS OF THE "MIDWEST" LAKE AND "CANDY" LAKE ENVIRONMENTS, NORTHERN SASKATCHEWAN.

Dyck, W.

GEOCHEMISTRY OF METAPELITES ASSOCIATED WITH URANIUM MINERALIZATION AT THE MIDNITE MINE, NORTHEASTERN WASHINGTON.

Ikramuddin, M., and Chou, G.

GEOCHEMISTRY OF BIOTITE FROM GRANITIC ROCKS AND ITS RELATIONSHIP TO URANIUM MINERALIZATION AT THE MIDNITE MINE, NORTHEASTERN WASHINGTON.

Asmerom, Y., and Ikramuddin, M.

EVALUATION OF THE URANIUM POTENTIAL OF PLIO-PLEISTOCENE TO RECENT SEDIMENTS OF WESTERN KANSAS.

Berendsen, P., and Hathaway, L.R.

DISPERSION AND MODE OF OCCURRENCE OF URANIUM IN STREAM SEDIMENTS.

Bloom, L.

INTERPRETATION OF SECONDARY DISPERSION PATTERNS AT KEY LAKE, NORTHERN SASKATCHEWAN.

Maurice, Y.T., Strnad, G.J., and Dyck, W.

HOST-ROCK ALTERATION GEOCHEMISTRY IN THE VICINITY OF THE MAURICE BAY URANIUM DEPOSIT (SASK.).

Mellinger, M.

LASER-INDUCED FLUORESCENE; A HIGH SENSITIVITY METHOD FOR URANIUM ANALYSIS IN THE FIELD OR LABORATORY.

Castledine, C., and Robbins, J.

GEOCHEMICAL EXPLORATION AT THE CARACOLES Ag DISTRICT ANTOFAGASTA, CHILE.

Cabello, J.

POSTER SESSIONS

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THURSDAY 13 MAY

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THE STREAM SEDIMENT GEOCHEMISTRY OF COPPER, MOLYBDENUM AND URANIUM IN
THE LATERITIC ENVIRONMENT AROUND DALAKURU, SIERRA LEONE.
Fode, D., and Martin, H.

THE USE OF SEM-EDS IN GEOCHEMICAL EXPLORATION.
Piispanen, R.

GEOCHEMICAL PROSPECTING DEVELOPED BY METAMIG IN MINAS GERAIS – BRAZIL.
Alecrim, J.D.

FLUID INCLUSION DECREPITATION MEASUREMENTS IN EXPLORATION FOR GOLD IN
WESTERN AUSTRALIA.
Burlinson, K.

EXPLORATION GEOCHEMISTRY IN NORTHEASTERN BRAZIL.
Goncalves, G.N.D., and Bruni, D.C.

GEOCHEMICAL SAMPLE DIGESTION BY HIGH PRESSURE ACID LEACH.
Hale, M., and Lovell, J.S.

ELECTRONIC GEOCHEMICAL DATA TRANSMISSION.
Blok, H., and Morse, R.D.

GEOCHEMICAL STUDY OF SOIL AND STREAM SEDIMENTS FROM GEBEL EL RUSAS AND
UM GHEIG AREAS, EASTERN DESERT, EGYPT.
Morsy, M.A., and Hassan, F.H.

REGIONAL GEOCHEMICAL AND PAN-CONCENTRATE EXPLORATION PROGRAMS IN PARAIBA
STATE, BRAZIL.
Pereira, L.C.B., and Correia de Oliveira, J.J.

PRACTICAL FIELD PORTABLE AA ANALYSER.
Castledine, C., and Robbins, J.

SOME RELATIONSHIPS BETWEEN GRANITOIDS AND TIN-TUNGSTEN MINERALIZATION
WITHIN NORTHERN PORTUGAL.
Oliveira, J.M.S., and Pereira, E.

APPLICATIONS OF A LITHOGEOCHEMICAL TECHNIQUE WITH EMPHASIS ON GOLD EXPLORATION.
White, M.V.W., and Verma, H.M.

PAPERS "BY TITLE ONLY"

In the event that speakers scheduled to give oral presentations are unable to attend, some of these papers may be presented in their place.

SUSPENDED MINERAL MATTER AS A STREAM SEDIMENT SAMPLE FOR GEOCHEMICAL PROSPECTING.
Siegel, R.

GEOCHEMICAL DISPERSION PATTERNS IN GLACIAL TILL OVER SULPHIDE ORES AT AVOCA, EIRE.
Moon, C.J., and Hale, M.

STATISTICAL ANALYSIS OF REGIONAL GEOCHEMICAL EXPLORATION DATA.
Brooke, J.P.

THE WOLLASTON URANIUM BIOGEOCHEMICAL ANOMALY - NORTHERN SASKATCHEWAN.
Dunn, C.E.

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EXTENDED ABSTRACTS - ORAL PRESENTATIONS

NUMBER THREE OREBODY, RANGER ONE, AUSTRALIA: A CASE HISTORY
by
G.H. Sherrington, A.L.L. Browne, R.H. Duffin and M.J. Danielson

Introduction

The Number Three Orebody at Ranger One in the Alligator Rivers province has a publicly-stated resource of 27 781 000 tonnes of ore at an average grade of 0.2% U_3O_8 using a cut-off grade of 0.05% U_3O_8 (E.R.A. 1980). The ore is classified as "possible plus probable" because insufficient drilling has been executed to allow use of "proven" by guidelines of the Australian Associated Stock Exchanges.

The body, with 58 000 tonnes of contained U_3O_8, is large by world standards. Although the geology has been described by others, public description of the response of the body to various geochemical and geophysical exploration methods has been brief. This is partly because the Number One Orebody, some 2 km to the south, was selected for first development and is now being mined by open-pit methods. The Number One Orebody has received most description. Each deposit sits in the same stratigraphic position in the Mine Series rocks of the Cahill Formation but there are some differences between them.

The Number Three body is little disturbed by the activities of man and it provides a useful testing ground for exploration methods. The main disturbance has been some costeaning and diamond drilling on a square grid of 100 m edge. A local grid has a baseline designated 10 000 m E aligned N-S. The traverse line at 11 800 m N intersects the approximate centre of the surface expression of the body, which plunges east at about 30°, roughly conformable with enclosing metasediments. The known depth of mineralization traversed ranges from surface to approximately 500 m.

Geology

The Ranger One deposits are within the Lower Proterozoic Cahill Formation, a metasedimentary sequence of schists overlying carbonates, which overlies the mixed Archean(?) - Lower Proterozoic migmatite-gneiss-schist terrain of the Nanambu Complex. The Cahill Formation here dips at about 30° to the east. The Carpentarian Kombolgie Formation unconformably overlies these older successions throughout the region, though not at Ranger One.

The Number Three Orebody mineralization sits in a structurally-disturbed zone in the Cahill Formation carbonates and schists, where block faulting has caused incorporation of a fragment of Kombolgie Formation sandstone in the west of the ore zone. Intrusive pegmatites, basic dykes, and massive chlorite rock occur through the succession.

There is virtually no outcrop of pre-Carpentarian lithologies; the known geology is interpreted from drilling. A laterite profile is regionally and locally developed. The depth of weathering of lithologies to lateritic clays ranges down to about 3 to 30 m, while the depth of occurrence of iron oxides on joint and foliation surfaces is from 20 - 90 m below the surface.

The 11 800 m N traverse crosses the whole of the local Orebody stratigraphy, including the down-faulted Kombolgie Formation fragment.

Remote Sensing Methods

Casual inspection of Landsat photographs does not indicate any feature

related to mineralization, although some regional matching of E-W linear features with known deposits is possible. Aerial photography shows no obvious correlation of any feature with mineralization. Airborne gamma radiometric surveys give a very strong response to the Ranger One complex of nine anomalies. Both One and Three Orebodies have mineralization intersected by the land surface. Airborne magnetic surveys do not delineate the bodies themselves, but clarify the concealed positions of the footwall complex and some magnetic schist units stratigraphically above the Cahill Formation.

Ground Exploration

Regional gravity surveys assist in definition of the Nanambu Complex boundaries. On a prospect scale, the gravity pattern in the vicinity of the two Orebodies is mildly disturbed.

The following summary lists ground exploration methods applied to the traverse 11 800 m N at Three Orebody, each of which is illustrated by original data in the paper. The symbols "+", "+", and "-" summarise (with qualification) the success of each method, from useful through equivocal to non-responsive.

Ground magnetics	(-)
Ground radiometrics	(+)
Gravity	(+)
V.L.F. electromagnetics	(-)
Transient electromagnetics	(-)
Self potential	(-)
Resistivity	(-)
Surface pea-gravel geochemistry	(+)
Soil geochemistry at 0.5 - 1 m deep	(+)
Soil geochemistry at 1 - 2 m deep	(+)
Soil geochemistry profiles 0 - 5 m deep	(+)
Soil and rock geochemistry profile 0 - 100 m deep	(+)
Radon gas	(+)
Helium gas	(+)
Biogeochemistry	(+)
Hydrogeochemistry	(+)
Stream sediment sampling	(+)

Differences Between Orebodies

In spite of the proximity of One and Three Orebodies, they have some differences. Number One has a higher grade, more chlorite, more intrusive dykes, more internal shearing, but less faulting than Number Three. However, the exploration methods noted above would be equally responsive on both bodies. This cannot be said of other known orebodies in the province (Jabiluka 1 and 2, Koongarra, Nabarlek). The large Jabiluka 2 body is essentially blind to all methods not involving drilling. It appears to be more distant from the footwall complex than Ranger 1, has more carbonaceous material, comparatively more gold and sufficient gross lithological differences to draw comment.

The differences between bodies within this province are enough to cause caution in the design of exploration programs based on any one body. While it is attractive to many to draw comparisons between the Alligator Rivers province and the Saskatchewan province, there are already significant differences in exploration approach based on the non-comparative features of the various bodies.

GEOCHEMICAL EXPLORATION FOR UNCONFORMITY-TYPE URANIUM DEPOSITS IN PERMAFROST
TERRAIN-HORNBY BAY BASIN, NORTHWEST TERRITORIES, CANADA
by
S.J. Hoffman

The Hornby Bay sandstone basin of the Northwest Territories represents one
of three geological environments in Canada favourable for the occurrence of
unconformity-type uranium deposits. The study area lies within perma-frost
terrain. Surficial deposits are typically water saturated and associated with
landscape features described as frost boils, solifluction lobes and 'grass
glaciers'. Topographic relief is in the order of 100 m over km distances but
locally may exceed 300 m in more rugged areas. Overburden comprises locally
derived tills except along former major glacial meltwater streams. Surficial
deposits are typically less than 20 m thick and bedrock exposure is high over
much of the survey area.
Geochemical case histories are presented for soil and lake sediment
surveys which illustrate the sequence: identification of a regional anomaly,
anomaly follow-up, discovery of radioactivity, and detailed geochemical
investigations. The relative degree of success of discovery of radioactivity
in bedrock or boulder trains by geochemical methods is high. Orientation
studies indicate that anomalous dispersion trains can be traced from their
source 20 to 200 m downslope. As a result of these studies an optimum sample
density was established to be a 50 m interval along lines 100 m apart. Soils
were selected in preference to frost boils by virtue of the more alkaline pH
associated with the latter medium and the enhanced solubility (leaching) of
uranium recognized to accompany basic pH conditions. Anomaly generation is
apparently favoured by active hydromorphic processes in an overburden
environment which contains a homogeneous and relatively low background of 0.5
ppm, 4N nitric acid-leachable uranium. Anomaly contrast is typically at least
2X to 3X this value and anomalous values exceeding 1.5 ppm are highly
reproducible.
Copper and radium anomalies appear to be useful pathfinders for uranium.
Determination of cold extractable copper by field tests such as the Bloom
total heavy metals or the Holman copper can effectively lead to discovery of
radioactivity. Radium anomalies tend to give a higher anomaly contrast to
background than uranium and results can be obtained by the field laboratory
using a simple procedure within a week of sample collection. By contrast,
turnaround of uranium and base metal data by a commercial laboratory is in the
order of three weeks.
Lead is present in anomalous concentrations in all mineralized rock
samples, but lead enrichment in overburden is not sufficiently diagnostic to
permit its use as a pathfinder element. Positive associations of uranium with
nickel, cobalt, or zinc are only noted for a limited number of radioactive
occurrences.
Radon geochemical surveys have been conducted on a regular basis with
limited success. Variability in overburden conditions related to sample
texture, site drainage, depth to permafrost, proximity to lakes and topography
have combined with poor analytical reproducibility and contamination to
mitigate follow-up of anomalous results; except under conditions where the
radon concentration is orders of magnitude greater than a survey average.
Methods requiring two visits to the sample site (for placement of the
instrument and subsequent measurement and retrieval) are very costly.
Analysis of soil samples for polonium-210, a radiogenic daughter of radon,
offers theoretical and cost advantages. Preliminary studies indicate very

reproducible results are possible on duplicate field samples and anomalies are defined in association with radioactivity and/or soil uranium anomalies.

The search for unconformity uranium deposits beneath a barren sandstone capping is hampered by the inability of the deposit proper to respond to geophysical surveys. Definition of geochemical anomalies near faults within the sandstone basin constitutes one of the four conditions elevating an area to drill target status. Methods for drill testing of geochemical targets are described. These are dependent on the topographic relationship between geochemical anomaly and source structure.

HYDROGEOCHEMICAL EXPLORATION FOR URANIUM WITHIN THE ATHABASCA BASIN, NORTHERN SASKATCHEWAN
by
S. Earle and G. Drever

Since 1978 the Saskatchewan Mining Development Corporation has analyzed ground water samples from almost 100 locations within the Athabasca Basin. The samples were collected from exploration holes drilled to test the uranium potential of geological and geophysical targets at the unconformity between the Helikian Athabasca Group sandstone and the underlying Aphebian and Archean basement rocks. The program was initiated to determine the nature and extent of hydrogeochemical anomalies around zones of uranium mineralization in the Athabasca Basin, and to develop equipment and procedures for sampling deep ground waters on a routine basis.

Samples are collected from 60 to 75 mm diameter diamond drill holes which are lined with plastic (PVC) pipe. The pipe is slotted adjacent to the zone of interest. Ground water from above this zone is excluded by the use of rubber sleeves between the pipe and the wall of the hole. Water introduced during drilling is removed during a period of decontamination pumping, at which time specific conductivity is monitored at surface. Oxidation potential is measured with a down-hole probe. A bailer sampler is used to collect samples for analysis of major anions and cations, important metals, uranium and its radiogenic daughters, and hydrocarbon gases.

Major element data are used to assist in the interpretation of ground water chemical evolution and flow patterns. Concentrations of total dissolved solids vary from 50 mg/l to over 50 000 mg/l. A general evolutionary trend is from HCO_3-Na-K dominant, to Ca-Mg-Cl dominant.

Uranium, radium and radon concentrations are very high in samples from most mineralized holes. Uranium concentrations range from less than 0.1 to over 2 000 μg/l, radium from less than 1 to 175 pCi/l and radon from less than 100 to more than 200 000 pCi/l. Anomalous concentrations have been observed several tens of metres away from areas of known mineralization, but further work is necessary in order to evaluate typical dispersion distances.

Helium concentrations are strongly dependent on ground water residence time, and even where helium isotope ratios are considered, it is difficult to distinguish ore related anomalies from those due to accumulation over long periods.

Because of differing radio-stabilities and chemical mobilities, uranium and its daughter products offer the possibility of distinguishing between near and distant sources. In the Athabasca Basin, where the typical ground water flow rate is probably less than 1 m per day, and possibly less than 1 cm per

day, radon levels can only be a reflection of local conditions. Uranium is also likely to be a local indicator because of limited mobility in a reducing environment. Ra-226, with a half-life of 1 600 y, may be a regional indicator where flow rates are relatively fast, or a local indicator where rates are slow. Ra-223, with a half-life of 11 days, is a local indicator with about 3 times the range of radon. Helium, which is stable and extremely mobile, reflects regional conditions with a proportionally small local contribution.

Athabasca Basin uranium deposits contain both solid and gaseous hydrocarbons, presumably derived from graphite-bearing pelitic rocks. Concentrations of methane, ethane and propane, are elevated in the vicinity of some mineralized zones. Elevated hydrocarbon levels are also characteristic of ground waters with high concentrations of dissolved solids, and may be associated with unmineralized graphitic zones.

ORIENTATIVE LITHOGEOCHEMISTRY OF THE ARCHEAN AND APHEBIAN BASEMENT IN THE KEY LAKE URANIUM DEPOSIT REGION (SASKATCHEWAN, CANADA)
by
J. Strnad

More than half of the proven uranium reserves in the Athabasca Basin are contained within the Key Lake U-Ni deposit at the basin's southeastern edge. The area studied comprises several orientatively explored areas within an intra-basin zone approximately 7 km wide, which extends from Blanchard Lake in the west to Wilson Lake in the east (45 km WNW and 10 km NE from the Key Lake deposit respectively). The uranium and nickel regional background of the Aphebian metasediments, covered by the Athabasca Basin platform sediments, has been studied on samples taken from vertical diamond-drill holes (DDH) cross-cutting elongated electro-conductive zones. Three clusters of DDHs, each located within specific lithostructural subunits of the ensialic Hudsonian mobile Cree Lake Zone, provided in total 502 samples of pelitic, mostly carbonaceous, metasediments and some of the commonly associated anatexites. Uranium concentrations follow a close-to-lognormal distribution with a median value of 3.0 ppm; 18 percent of the samples contain above 10 ppm and only one percent above 100 ppm. Nickel yields again a close-to-lognormal distribution with a median value of 33 ppm, and only 6 percent of samples above 100 ppm. To compare the regional background obtained from the orientatively explored areas with the mineralized environment, the Aphebian metasediments and Hudsonian anatexites hosting the primary halo of the Key Lake deposit have been selected as the local background from the mineralized vicinity. Fifty-seven composite samples, each representing a 10 m vertical section of the 50° dipping peri-basal Aphebian sequence, were collected from two deep DDHs drilled beneath the Gaertner orebody. The U values within this 220 m thick sequence range from 1 to 10 ppm with a close-to-lognormal distribution and median of 3.2 ppm. Nickel yielded a median of 46 ppm, with 7 percent of samples above 100 ppm.

The peri-basal sequence, grossly subdivided into three stratigraphic units displays a definite tendency to concentrate Th, K and U within the hanging wall; Ni, Co, As, Fe, S, Cr, V, Ti and Mg in the main graphite horizon; and Na, Ca and Mn within the footwall series. The graphite horizon of about 40 m thickness contains 2 percent organic carbon, 0.6 percent sulphur, a mean Ni value of 106 ppm, but a low average uranium content of 2.5 ppm. To compare

local Aphebian background with the potential <u>Archean source</u>, 10 samples from the nearest (to the Key Lake deposit) margin of the Zimmer Lake Archean inlier were assayed. The set is characterized by foliated highly potassic and low Q granitoids. Uranium ranges from 2.5 to 10 ppm <u>with an average of 6.0 ppm</u>. Ni shows a characteristically low average of 16 ppm. Several tentative conclusions can be drawn from the comparison of three main sets of data and from their internal variations:

1. <u>Archean rocks</u> display a <u>granitoid source</u> whose original composition probably became masked by introduced K during the Hudsonian event; 2. Local <u>Aphebian rocks</u> compared with local Archean indicate a tendency to be <u>more mafic</u> with enhanced concentrations of Mg, Fe, Ca, Ti, P, and S, and by <u>lower Th</u>. Such a bulk Aphebian composition is caused by the contribution of the graphitic lithology to the geochemical background; 3. All metallic elements except U (eg. Ni, Co, As, V), which are also concentrated in the Key Lake deposit, reach high concentrations within this lithology. There are no Archean rocks in the vicinity which might provide these Aphebian concentrations by simple sedimentation of the Archean detritus; 4. Contrary to the widespread assumption that the unconformity-related type of uranium deposit requires "hot" Archean in the vicinity and/or Aphebian "U-protores",the observations in the Key Lake area show that <u>the orebodies and their primary haloes are overprinted with a sharp U-gradient over the low-U environment.</u> Archean rocks contain only 6 ppm U and the immediate Aphebian sequence beneath the deposit yields a median of 3.2 ppm U, which fits the regional median of 3.0 ppm U. Low uranium and high nickel values are common to both regional and orebody-hosting Aphebian environments of the Key Lake region.

APPLICATION OF LITHOGEOCHEMISTRY IN LOCATING UNCONFORMITY-TYPE URANIUM DEPOSITS

by
V.J. Sopuck, A. de Carle, E.M. Wray, and B.R. Cooper

Lithogeochemical-mineralogical haloes around unconformity-type uranium deposits in northern Saskatchewan provide expanded drill targets five to fiteen times the size of the deposit. These deposits are located at or near the unconformity between Aphebian metamorphosed basement rocks in close proximity to Archean granitoids and overlying unmetamorphosed sandstones of the Helikian Athabasca Group. Deposits studied include Key Lake (Deilmann), Midwest and Eagle Point.

The bulk of the mineralization at the Midwest and Deilmann deposits is located at or near the unconformity. This polygenetic uranium mineralization consists mainly of pitchblende and coffinite along with gersdorffite, niccolite, rammelsbergite, millerite and bravoite.

Mineralization at Eagle Point extends to a depth of 200-300 m below the postulated unconformity and consists mainly of oxides of uranium with insignificant levels of arsenides or sulphides.

Deposits near the unconformity are associated with broad alteration haloes in the overlying sandstones and more restricted haloes in the basement rocks. The haloes in the sandstone are localized around steeply dipping fault structures which are characterized by zones of intense leaching of specular hematite and detrital heavy mineral layers and changes in chemistry related to clay mineral alteration and tourmalinization.

Clay mineral alteration haloes are common in the sandstone and basement

host rocks. Interstitial clays in the Manitou Falls Formation of the Athabasca Group consist mainly of kaolinite and illite with lesser amounts of chlorite. K_2O/Al_2O_3 ratios prove useful in delineating illite-kaolinite patterns in the sandstone and in upper portions of the paleoweathering profile in basement rocks. The Midwest deposit is characterized by a broad bell-shaped zone (500 m across strike) of high K_2O/Al_2O_3 ratios (> .15) in which illite is the dominant clay mineral. The sandstone above the Deilmann deposit, on the other hand , is characterized by silicification and kaolinitization with low K_2O/Al_2O_3 ratios (< 0.05). This kaolinite cap overprints a pre-existing illite zone.

Anomalous boron values are characteristic of all deposits considered in this study. Boron anomalies are similar in extent to the anomalous clay mineral alteration patterns. Altered sandstones are characterized by aggregates of radiating magnesium-rich dravite within the clay matrix. Problems arise however, with regard to the interpretation of boron patterns, mainly because of the detrital tourmaline component in sandstones and metamorphic tourmalines present in the Aphebian metasediments. Background values in hematite-rich sandstone at Key Lake are in the order of 300 ppm B, whereas at the Midwest property the background is approximately 40 ppm. Anomalously high magnesium contents are generally related to chloritization and tourmalinization in sandstones. At Key Lake dravite forms the dominant magnesium-rich phase in sandstones whereas chlorite is the dominant phase at Midwest.

In basement rocks the various layers of the paleoweathering profile are overprinted within 25-100 m of mineralization. The paleoweathering profile consists of the upper bleached layer (dominantly kaolinite and quartz in background drill holes), the hematite layer and the lower green layer. Bleaching related to illitization and chloritization overprints all three layers. This change is associated with enrichments in MgO, K_2O, B, S, U, As, Ni and P_2O_5.

Trace elements such as U, Ni, As, and Co are generally of little use in expanding targets in the sandstone as they are restricted to a few tens of metres horizontally from mineralization. These elements do, however, form anomalies along the steeply dipping mineralization-related fault structures.

Deposits with a large depth extension in the Aphebian metasediments, such as Eagle Point, have intense dravite-chlorite-illite alteration zones which are restricted to within a few metres of mineralization across strike. The complexity of basement rock inhibits the use of individual elements as alteration guides other than in the intensely altered zone. The application of multivariate statistical techniques to the geochemical data prove useful in identifying the mineralogical changes at Eagle Point where an alteration zone up to 200 m wide across strike can be identified. This alteration is related mainly to the breakdown of albite and biotite.

GEOCHEMICAL ZONING AROUND THE McCLEAN URANIUM DEPOSITS, SASKATCHEWAN, CANADA
by
J.P. Golightly, C.F. Gleeson, J.J. Brummer and N. Saracoglu

Some 3 400 drill core samples of the Athabasca Group and underlying regolith have been obtained by sampling 8 m sections from 55 diamond drill holes in the McClean Lake Area, Saskatchewan. Forty-eight holes are from

sections over six areas known to contain uranium mineralization and 7 are from unmineralized areas. The uranium zones are covered by 30 to 180 m of Athabasca sandstones and conglomerates.

The uranium mineralization of the McClean deposits can be described as belonging to two different facies; a more reduced sulphide-arsenide facies and a more oxidized hematite-"bleached" facies, superimposed on any one of three host rocks.

The sulphide-arsenide facies is probably older and, except in one deposit, it forms a patchy distribution of relicts. The principal pattern is an upwards increase in sulphur/arsenic ratio. The hematite-"bleached" facies appears to be younger and may represent a reworking of the earlier sulphide-arsenide facies mineralization under more oxidizing conditions.

The trace metals can be grouped according to their redox behaviour. V, Mo and U, occurring as oxides, form one group while Ni, Co, Zn, Cu and As, occurring as sulphides and/or arsenides, form intermediate and most reduced groups respectively. Iron is concentrated in the most oxidized facies as hematite or goethite and in the most reduced facies as pyrite-bravoite, siderite and chlorite. Manganese follows the distribution of siderite.

The ratio of oxidized to reduced minerals can be represented by the ratio of U/Ni. This ratio can be used to estimate the variation of redox potential in the deposit at the time of deposition or alteration. The principal pattern is one of systematic increase in U/Ni ratio or oxidation potential both upward and to the northeast in each of the hematite and bleached facies.

A generalized Eh-pH diagram is used to qualitatively describe the significance of each mineral facies.

The U/Ni ratio of the transition between the hematite and "bleached" facies increases upwards. The phase diagram suggests that a possible cause is an upward decrease in pH and increase in Eh.

The overall distribution is compatible with the origin of the deposits due to reduction at the interface between a plume of reductant emanating from fractures in the sub-Athabasca basement and an oxidizing aquifer moving southwestward in the sandstone. This model does not accurately predict the distribution of elements among the seven McClean Lake pods. However, it explains the overall pattern. Local variations in metal ratios in solution either in time or reflecting local provenance could be adduced to explain local deviations from the overall pattern.

Clay alteration, apparently largely contemporaneous with the earliest mineralization, is largely illitic but with sporadic occurrences of xenotime and goyazite. Thus K and to some extent P, Y and light REE's are also enriched to some degree in the deposits.

U analysis of the drill core shows that there is little movement of U into the overlying sandstones from basement rocks and regolith that contain no uranium deposits. U in the Athabasca sandstone from these areas averages less than 1 ppm. However, where uranium zones have been found in the basement rocks, regolith and lower Athabasca sandstone, U values greater than 2-3 ppm consistently occur in the overlying sandstones at or near surface.

There appears to be two types of U anomalies, those that flank the deposits and those that directly overlie them. Both types exhibit vertical and lateral continuity. They are associated with vertical to steeply dipping fracture systems that traverse the Athabasca sandstone from basement to surface. The fractures are thought to be related to diagenetic processes from compaction of the sedimentary rocks over basement irregularities as well as tectonic processes (i.e. readjustment along old basement structures).

These results suggest that target areas containing deeply buried uranium

deposits could be defined by U analyses of the Athabasca sandstone from quite widely spaced holes of limited depth. This conclusion can be compared to XRD and chemical studies of clay mineral distribution within the Athabasca sandstone about the deposits.

GEOCHEMICAL EXPLORATION FOR URANIUM AND OTHER METALS IN TROPICAL AND SUBTROPICAL ENVIRONMENTS USING HEAVY MINERAL CONCENTRATES
by
R.A. Watters

A general review of metals exploration via geochemistry is given with particular reference to uranium in a wet tropical environment. Many of the data are taken from the author's earlier work in Indonesia and more recent studies in Sri Lanka, which include base metals. These are complemented by results of various short projects undertaken whilst consulting during the last two years in North Queensland, New South Wales and in Timor.

The problems of carriage mechanisms have, for long, bedevilled the exploration geochemist. It is only quite recently that sequential analysis has indicated the relative weightings of these various mechanisms. There are still explorationists who are under the impression that clay minerals play an important part in transportation by some sort of "plating" process. The importance of coatings and heavy mineral species is illustrated with reference to existing literature, and to short case studies performed by the author. A variety of elements have been examined, notably Au, Sn, Ag, As and Cu, Pb, Zn and some of the more interesting behavioural characteristics have been reported.

These data indicate that a great enhancement of the anomalies for most of these elements can be expected from heavy mineral concentrates vis-a-vis the conventional minus 80 mesh fraction. In fact, U, Sn and Au anomalies may be lost in the sieving process. So-called failures of exploration geochemistry can be explained by referring to the role of heavy minerals. Resampling of areas which did not show anomalies with conventional methods has produced anomalies using heavy minerals. Hitherto unsuspected gold provinces have been shown to exist, and areas within historically gold-bearing regions have been found to be anomalous where no pre-existing workings occurred.

This means that much of the early work showing negative results might well be favourably resampled. There is no such thing as "geochemistry did not work" - only a sampling medium problem. The elements from a weathering deposit must go somewhere. It is the geochemist or unadvised geologist who neglects to choose the most suitable medium or the most appropriate or enlightened analytical technique who fails, not the principle.

Field procedures used in the past five years are described and a few practical hints are given, predominantly with reference to broad reconnaissance and early follow-up phases of exploration (the super strategique and strategique phases, to borrow an idea from Grimbert).

The step-by-step approach espoused by the author is detailed.

Finally, some recent research trends in Australia are described. It is suggested that combinations of techniques will produce the best understanding of the patterns which the elements make. No single approach can be adequate with the number of parameters - both known and unknown - which operate on the sampling medium.

It is concluded that the exploration geochemist has a long way to go in quantifying these variables. We have literally only scratched the surface.

STREAM SEDIMENT GEOCHEMICAL PROSPECTING FOR URANIUM IN THE PALEOZOIC OF THE BELGIAN ARDENNES
by
H. Martin, J.P. Lefin, L. Dejonghe, and J. Henry

During the years 1979 and 1980, a preliminary program of uranium exploration in the Paleozoic of the Belgian Ardennes was carried out under the sponsorship of the Commission of European Communities. The Laboratory of Mineralogy of the Polytechnic Faculty of Mons was charged with the radiometric section of the program, the Geochemistry Laboratory of the Free University of Brussels with the hydrogeochemical exploration, and the Geochemistry Laboratory of the University of Louvain with the stream sediment exploration. The Geological Survey of Belgium had the responsibility for coordinating the three programs, the statistical and computer treatment of the data, and the compilation of the different maps.

Orientation studies at the Geochemistry Laboratory of the University of Louvain showed that a positive geochemical response for uranium could be obtained with bank sampling, which consists of collecting colluvium and alluvium on both sides of the rivers. This necessitates a large sampling density of about one sample per km^2 (10 205 samples from an area of 11 000 km^2).

The frequency distribution of the values of uranium follows the lognormal law with a geometric mean of 1.06 ppm and a threshold of 2.36 ppm (P = 0.954). The anomalies (>3 ppm) fall into three main areas each in a different geological setting: (1) at the periphery of the Cambro-Silurian Massif of Stavelot; (2) within the transition beds between the Visean and Namurian; (3) in the lower Devonian of the central Ardennes.

The first two areas coincide with zones of known radiometric anomalies and of the occurrence of uraniferous minerals.

In the third zone, follow-up work has led to the discovery of a uraniferous mineral assemblage consisting of a weathered mass of iron oxide, leucoxene and phosphates.

Statistical analyses of the results indicate no significant relationship between U and both organic carbon and Mn, a negative correlation between U and both carbonate and pH, while a good positive correlation between U and Cu, V and Fe may indicate an association of U, V, and Cu with iron oxides formed during meteoric alteration.

A URANIUM DISTRICT DEFINED BY RECONNAISSANCE GEOCHEMISTRY IN SOUTH GREENLAND
by
A. Armour-Brown, A. Steenfelt and H. Kunzendorf

A reconnaissance exploration survey over 14 000 square kilometres of Precambrian terrain in South Greenland using stream sediment and stream water samples delineated some 2 000 square kilometres with enhanced uranium levels

in the centre of the field area and smaller anomalous zones in the south (see Figure). The area is underlain by Archean and Proterozoic gneisses and granites and metasediments all of which have been intruded by late Proterozoic alkaline intrusions (Gardar Province). The terrain is mountainous and the streams are either steep torrents or impeded drainages typical of glaciated terrains with boggy organic rich sediments. The sample density averaged one per 6.25 km^2. The water samples were analysed for uranium with a (Scintrex) UA-3 analyser in the field, along with conductivity and the pH. The fine sand, silt and clay fraction (-100 micron) of the stream sediment samples was analysed for uranium by delayed neutron counting, and 18 other elements by energy dispersive X-ray fluorescence.

The central area, or 'U-geochemical district', of some 2 000 km^2 was defined by a high uranium background in both stream sediments (5-20 ppm) and stream waters (0.5-1.0 ppb). This area also included a markedly higher occurrence of highly anomalous values in the order of 50-100+ ppm in the stream sediments and 1-10 ppb in the stream waters, which was reflected in the very high variance of uranium values of samples from this area. In addition, the south of the field area also has a relatively high uranium background (5-15 ppm) in both the sample media with some discrete anomalous areas, usually with slightly lower values than the central area, but still with a more than adequate anomaly contrast of 5-10 times.

An areal correlation in the central area of high pH with high uranium raised the question of possible secondary environmental controls. On the
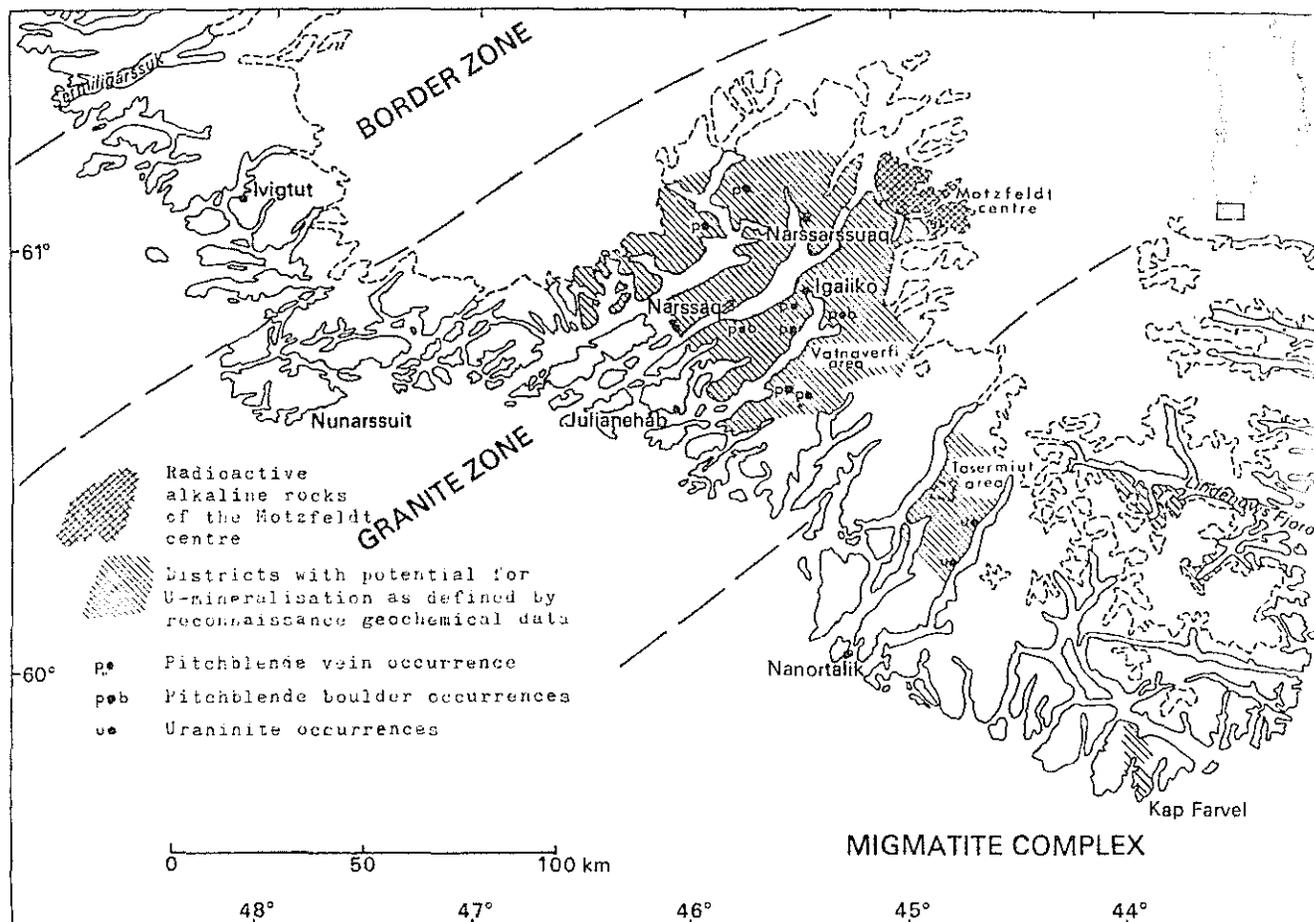

Figure illustrating field area, uranium district and anomalous zones.

other hand, an areal niobium and uranium correlation and the geographic proximity of this uraniferous district to the alkaline intrusions suggested a genetic relationship between the uranium mineralization and the alkaline intrusive events.

Limited follow-up work located eight pitchblende occurrences in this large district, and two occurrences of uraninite in the south. The pitchblende is in lenses within veins which contain quartz, calcite, fluorite and minor amounts of sulphides. Elements which are typically associated with alkali rocks, Th, Y, and Nb, are also present in the veins but in very varying amounts. The age of the pitchblende based on uranium and lead isotopes gives an average of 1 120 Ma ranging between 1 180-1 100 Ma which corresponds to the late stages of the alkaline intrusive activity. The uraninite in the anomalies in the south occurs as disseminated grains in migmatitic neosome. It is not associated with thorium. U:Pb isotopic ratios give an age of 1 728 Ma which corresponds to late thermal events in the area.

A combination of primary and secondary features have complemented each other in enhancing the uranium values of the stream sediment and to a lesser extent the stream water in the central area. The proposed mechanism for this enhancement is, firstly the presence of uranium in a soluble mineral form and secondly its association with carbonate minerals. The carbonate is dissolved by the ground and surface water; this is reflected in the high pH levels, facilitating both the solution and the transport of the uranium by the formation of the U-carbonate complexes. Thirdly, the impeded drainages and bogs, which had an acid environment, reduce the mobility of uranium by lowering the pH and the adsorption of uranium on organic material.

The mobility of uranium in the secondary environment of the central area has helped to enhance the reconnaissance geochemical results and brought attention to the mineral potential of the area. Geochemistry is not, however, so useful at the follow-up stage as it is difficult to locate the source of the anomalies whose concentrations do not bear any relation to the proximity let alone the economic significance of uranium mineralization. The southern area, on the other hand, which is more rugged and has less organic-rich stream sediment and does not have carbonate minerals associated with the uranium mineralization, has a slightly lower tenor of uranium compared to the central area. Geochemistry is expected to continue to play a useful part in localizing uranium mineralization in this area.

It is suggested that the wide distribution of uranium in South Greenland, as demonstrated by the reconnaissance geochemistry, may be part of a much wider uranium 'geochemical province' if it is joined with the uranium showings in Labrador. The present plate tectonic models suggest such a connection and the ages of uranium mineralization are similar. (e.g. 1 728 Ma for Kitts U-showing and 1 243 Ma for Michelin U-showing).

THE DISTRIBUTION OF URANIUM IN MANGANESE NODULES FROM THE DEPOSITS OF THE PACIFIC OCEAN
by
H. Kunzendorf, G. Friedrich and W.L. Pluger

During the past seven years large numbers of manganese nodules have been collected from deposits in the Pacific Ocean, particularly deposits from the equatorial North Pacific manganese nodule belt between the Clarion and

Clipperton Fracture Zones. Exploration of these and other deposits was carried out within the framework of oceanographic cruises aimed basically at the demarcation of economic nodule fields, their distribution within varying marine environments, and at an evaluation of growth mechanisms deduced from mineralogical and geochemical studies. Manganese nodules were mainly collected by free fall grab samples along grids of various sizes, but nodules were also recovered by box corers and with dredge hauls.

Because relatively few systematic data on uranium in manganese nodules exist, 1 386 bulk manganese nodules and 183 deep sea sediments from several areas of the North and South Pacific were analyzed for U by the delayed-neutron counting technique. The samples were recovered during the following cruises with the German research vessels Valdivia and Sonne: P, VA-04, VA-05/1, VA-08/1, VA-13/2 and SO-06/C (equatorial N. Pacific), SO-04/2 and SO-11/2 (Peru Basin), SO-06/A to I (N-S transect at 134º W), and SO-06/K (Southwest Pacific).

The variation of uranium in manganese nodules was studied within individual nodule layers and manganese crusts. Local and regional sampling programs were used to evaluate the distribution of U on these scales.

Compared to deep sea sediments and seawater, uranium in manganese nodules is generally enriched up to about an order of magnitude and about three orders of magnitude respectively. The uranium content of the terrigeneous (residual) phase of nodules composed mainly of aluminosilicates is usually more than an order of magnitude lower than that of the bulk nodule. Significant variations of U within nodules, and variations of U in manganese nodules on a local and on a regional scale were found. The principal factor controlling these variations appears to be the clear association of U with Fe in the nodules, suggesting that uranium is most probably coprecipitated with Fe from seawater in an iron-rich ferromanganese oxide phase. Nodules containing $\delta - MnO_2$ (iron-rich) as the principal manganese oxide phase commonly observed on seamounts, have therefore higher U contents (> 5 ppm) than those predominantly composed of the other major manganese oxide phase, 10 Å manganite.

Abyssal plain nodules, composed of both ferromanganese mineral phases, often show elevated U (and Fe) values in the upper nodule layers exposed to seawater but significantly lower U contents in the bottom layers presently resting in the sediment. Diagenetic supply of manganese from the sediments possibly acts as a diluent for the U contents of the bottom layers of the nodules.

On a local scale (within a few thousands of km^2), dense sampling around seamounts in an area of the equatorial N. Pacific suggests a directional deposition of U from seawater into ferromanganese oxides because high-U nodules were preferably collected on the northwestern flanks of seamounts. These deposition patterns are possibly caused by bottom currents generating well-oxygenated conditions at seamount areas opposed to the flow.

A regional variation of U contents in nodules on a N-S transect at 134º W was found between 20º N and 20º S. The biogenic productivity of surface waters is thereby greatly reflected, in that nodules farthest away from the equator with low biogenic surface production, have the highest U contents. In general, areas with economic-grade nodules (Mn/Fe >3, Ni+Cu $> 2\%$) have low U contents (~ 3.5 ppm), whereas nodules from topographical highs and manganese crusts have relatively high U contents (5 to 12 ppm).

GROUNDWATER GEOCHEMISTRY OF URANIUM AND OTHER ELEMENTS, MONTICELLO AREA,
NEW YORK
by
A.W. Rose, D. Wesolowski and A.T. Smith

Near a group of small Cu-U occurrences in the nearly flat-lying Devonian
Catskill Fm. near Monticello in southeastern New York, 500 well and spring
waters have been collected at a 1 km spacing and analyzed for major elements,
pH, conductivity, dissolved O_2, U, He, Rn and 31 other trace elements.
Factor analysis indicates important element associations termed "Dissolved
solids" (Ca, Na, Mg, pH, U, B, Li, Sr, Zn), "Immobile traces" (Th, Ce, Co, Cr,
Nb, Y, Zr), "Deep groundwater" (Na, As, B, Li, Sr, He, U, Br, Cl, Ba),
"Reducing conditions" (Fe, Mn, - dissolved O_2), "Brine" (Cl, K, Na, B, Ba,
-F), "Well contamination" (Cu, Zn, P), "As-Se-P", "Rare earths", and "Mo-U".
Relations of U and several other elements to conductivity suggest mixtures of
3 types of waters, but many elements show no clear relationship to
conductivity. A map of U values indicates only a slight tendency for high
values to cluster around known U occurrences, but sections showing samples
plotted according to aquifer show two strongly anomalous zones, one of which
contains the known U occurrences. Waters are highly undersaturated in U, and
saturation indices (-5 to -9) do not show useful patterns. The complex
$(UO_2)(HPO_4)_2^{2-}$ is the predominant form of U in most waters. Helium in
groundwater is clearly concentrated in deep waters of the mineralized area,
and furnishes the most distinctive anomaly; high Rn values are scattered
through the area. The groundwaters show more definitive patterns than stream
water and stream sediment, which furnish only weak and spotty anomalies, but
distinction of groundwater aquifers is needed for best results.

RADIUM^{223}/RADIUM^{226} RATIO IN GROUNDWATER AS A URANIUM EXPLORATION TOOL
by
J.R. Dean, C.J. Bland and A. Levinson

In the search for the exact location of uranium ore deposits, measurement
of relative amounts of the decay daughters of ^{238}U and ^{235}U dissolved in
groundwater can be a useful and valuable tool. Two such radionuclides are
^{226}Ra and ^{223}Ra.

By weight, ^{235}U is generally present in nature to the extent of only
0.7% relative to ^{238}U. However, because ^{235}U has a higher specific
activity (shorter half life) its disintegration rate is 4.6% of that for
^{238}U. Assuming that secular equilibrium exists, the thorium and radium
descendents from each series will be present in the same relative
disintegration rates. When subjected to groundwater leaching, those isotopes
(^{230}Th and ^{226}Ra in the ^{238}U series, ^{227}Th and ^{223}Ra in the ^{235}U
series) exhibit different solubility behaviour. For example, the thorium
isotopes are insoluble under all but very acidic (pH 2) conditions, whereas
the radium isotopes are considered to be much more soluble. Consequently, the
absolute and relative activities of the unsupported radium isotopes present in
the groundwater leachate begin to decrease upon separation from their thorium
parents. Since ^{223}Ra has a half life of 11.4 days and ^{226}Ra has a half
life of 1 600 years, ^{223}Ra will decay 50 000 times faster and be more than

99% depleted in 60 days. Over the same time period the ^{226}Ra decrease will be imperceptible. Each isotope will lose activity in proportion to the time elapsed since they were leached. As a result, measurement of the activity ratio (Ar) of ^{223}Ra to ^{226}Ra in drill hole groundwaters or in spring waters, coupled with a knowledge of groundwater flow direction and velocity (V), allows estimation of the distance (D) from the sample site to the uranium deposit. That relationship is given by equation (1).

$$D = -16.4 \times V \times \ln(Ar/0.046). \qquad (1)$$

where Ar refers to the radium activity at the time of sampling and D and V are in units of metres and metres/day, respectively.

Precise measurement of ^{223}Ra and ^{226}Ra activities in ground or spring water requires that the solutions to be analyzed contain at least 1 Becquerel/litre of each. Since such an activity of ^{223}Ra is seldom found in groundwater, preconcentration of radium from large (1 000-2 000 litres) volumes is usually required. This can be done in the field with portable equipment by adsorption on to manganese dioxide-impregnated filters which have been shown to exhibit strong attraction for radium. Desorption into a much smaller volume is made by acid wash. Within 10 to 12 days from field sampling, quantitative activity measurement of the radium isotopes must be made by high resolution alpha spectrometry. Peaks in the alpha particle spectrum identify the presence of ^{223}Ra, ^{226}Ra and in some cases, ^{224}Ra (from the thorium series).

Consideration has been given to the fact that the presence of certain concentrations of anions may cuase the solubility of thorium to increase markedly. Fortunately, ^{227}Th has a half life (18.2 days) of similar magnitude to that of ^{223}Ra. That, in addition to the knowledge that the precursors of both, ^{231}Pa and ^{227}Ac, are very insoluble under most normal circumstances, makes it possible to deduce the relative location of any observed ^{223}Ra activity.

Studies carried out in Saskatchewan, Canada, have demonstrated that the technique has application in either ground or spring waters. The most optimistic results have been seen in groundwaters obtained as a result of drilling. Most spring waters in this area are relatively young and rarely contain significant amounts of radium isotopes.

EVALUATING RADIOACTIVE ANOMALIES USING RADIUM-223
by
B.L. Dickson, R.L. Meakins and C.J. Bland

Radiometric anomalies are commonly caused by radium found in swamps, wet areas and around salt lakes in areas unsupported by its parent, uranium. These anomalies are often located during aerial surveys, but follow-up techniques to evaluate their significance are relatively undeveloped. As part of a research program into the use of decay products of uranium and thorium for uranium exploration, we have been investigating the measurement of radium isotopes in groundwaters as a means of evaluating the significance of these "radium anomalies".

There are four radium isotopes in the uranium and thorium decay series: ^{226}Ra (half life = 1 600 yr) in the ^{238}U series, ^{223}Ra (half-life = 11.4 days) in the ^{235}U series, and ^{228}Ra (half-life = 5.75 yr) and ^{224}Ra (half-life = 3.64 days) in the ^{232}Th series. Of these, all but ^{228}Ra

decay by alpha emission and may be determined in water samples by alpha spectrometry after chemical extraction and deposition in a thin layer. Where radium anomalies are found, detection of the ^{235}U daughter radionuclide ^{223}Ra may be a useful indication of nearby uranium mineralization.

In a uranium ore where secular equilibrium is established, the activity ratio of ^{226}Ra to ^{223}Ra is 22:1. If the radium from uranium mineralization enters moving groundwaters, the ^{223}Ra should decay to below a detectable limit in a period of less than 2 months. Hence it has been suggested that if ^{223}Ra is detected then a uranium source is nearby, and from the water flow rate some estimate may be made of how close the source is to the sampling point.

Application of the ^{223}Ra method has not proved so simple. Examples of radium analyses of water samples are given in the table. The samples described come from known uranium deposits, from radium anomalies, and from water supplies in areas containing no known uranium mineralization. The results given in the table suggest that ^{223}Ra is not uncommon in groundwaters. The ranges of measured activities of ^{226}Ra and ^{223}Ra cover four orders of magnitude. More surprising is that the ratio of activities of ^{226}Ra to ^{223}Ra tends to be less than the equilibrium value of 22:1 and in some samples almost equal amounts of ^{226}Ra and ^{223}Ra have been observed. Some of the highest ratios are from waters within known uranium deposits. One of the most resistant elements to leaching is protactinium, present as ^{231}Pa in the ^{235}U series. It is possible that low ^{226}Ra/^{223}Ra ratios arise after long periods of leaching by groundwater; a situation which is presumably attenuated wherever uranium mineralization is established.

Present results show no correlation between radium levels and water parameters such as pH and Eh. Within a given area the highest concentrations of dissolved uranium are usually associated with the highest concentrations of radium but between areas there is no general relationship between the absolute concentrations of the two species.

Combined with knowledge of the geology and form of the uranium mineralizations the results in the table suggest that the factors influencing the amounts of radium in groundwaters are:
1) the porosity of the uranium bearing formation;
2) the dispersion of the uranium in the formation;
3) the proximity of the uranium source to the water sampling location;
4) the level of salinity in the water;
5) the flow rate of the water;
6) the period of contact between the uranium bearing formation and the water.

Thus with a low porosity hard rock containing uranium mineralization, the amounts of radium found in solution may be quite low. On the other hand, in groundwaters contacting a roll front type deposit where the uranium is absorbed onto humate/pyrite layers on individual sand grains within an unconsolidated sediment, the amounts of radium isotopes can rise to extraordinarily high levels. Highly fractured rocks containing low levels of uranium may therefore be a source of quite high levels of radium in groundwaters.

The isotopic ratio of the radium isotopes will depend on the time of contact between the groundwater and the uranium bearing rocks. The short-lived ^{223}Ra (and ^{224}Ra from the thorium decay series) should accumulate faster than long-lived ^{226}Ra but as the water ages the amount of ^{226}Ra will grow relative to the ^{223}Ra (and ^{224}Ra). Hence, in quickly moving young waters used as water supplies or feeding into springs, quite low ^{226}Ra/^{223}Ra ratios are found. In some of the older, highly saline waters

TABLE OF RADIUM ANALYSES ON SOME AUSTRALIAN GROUNDWATERS

Sample	Type of Uranium Mineralization	Eh (mV)	pH	Salinity mg/l	U (ppb)	^{226}Ra pCi/l	$^{223*}Ra$ pCi/l	$\dfrac{^{226}Ra}{^{223}Ra}$	$^{224*}Ra$ pCi/l
(a)	Waters contacting known uranium mineralization								
KO3)	Pitchblende veins in quartz mica	156	7.35	115	219	27	2.4	11.2	13
KO5)	schist	343	6.71	109	112	94	4.7	20.0	23
KO13)		340	7.41	75	4	24.4	5.2	4.7	86
GD121)	Carbonaceous material in unconsolidated	267	7.0	14 200	nm	8 390	210	40	107
GD107)	sand sediments	-66	6.2	12 000	nm	940	1.4	670	nd
GD120)		280	6.9	13 700	nm	1 270	14	91	22
(b)	Waters contacting rocks containing elevated uranium								
TL7	Graphite schist containing 60 ppm U	204	5.9	34	0.8	0.3	0.1	3.0	0.2
SH21)		544	6.8	18 050	3 330	28.4	6.6	4.3	nm
SH30)	Uranium and thorium rich granite	294	6.65	19 050	16 490	35.7	5.2	6.8	nm
SH38)		269	6.93	17 485	nm	23.9	3.1	7.7	nm
(c)	Waters from radium anomalies								
TO7)		450	5.0	27	0.1	7.0	8.2	0.9	66
KO20)	Swamp anomalies	164	7.09	153	15.5	1.9	0.6	3.3	0.3
GP1)		nm	nm	nm	<3	1.6	0.1	13.5	1.7
AQ55)		475	3.6	48 720	142	2 070	585	3.5	nm
AQ61)	Salt Lake anomalies	nm	nm	177 070	6	360	1.0	360	49
LT 1)		nm	3.5	112 500	7	47	3.3	14.2	40
AQ21		154	4.5	116 000	6.5	263	200	1.3	269
(d)	Drinking Waters								
MW2		15	6.7	1 060	nm	9.8	0.7	14.0	6.1
MW3		232	6.5	1 480	nm	34.8	3.8	9.2	48
MW4		259	6.4	935	nm	12.4	0.5	25	6.6
BO3		nm	6.6	332	nm	0.1	0.03	3.0	0.2

$*^{223}Ra$ and ^{224}Ra corrected for decay between time of sampling and analysis

nm = not measured;   nd = not detected

very high ^{226}Ra and ^{223}Ra levels are found.

Thus, neither the presence of ^{223}Ra nor any particular level of the $^{226}Ra/^{223}Ra$ isotopic ratio is an unqualified indication of nearby uranium mineralization. High levels of ^{226}Ra and ^{223}Ra together are a strong indication of uranium mineralization in unconsolidated sediments associated with extremely saline waters. In hard rock situations the interpretation of the results is less certain. The results to date have shown no clear correlation between the radium results and presence of mineralization. Analyses of the thorium daughters ^{228}Ra and ^{224}Ra will possibly aid in separating waters draining mineralized areas from those from unmineralized areas. However, for hard rock areas further understanding of the means by which radium enters groundwaters will be needed before the measurement of ^{223}Ra will be a useful means of evaluating the uranium exploration value of a radium-bearing groundwater.

GROUNDWATER GEOCHEMISTRY IN THE ABITIBI VOLCANIC BELT OF QUEBEC
by
J.P. Lalonde

From 1974 to 1976, approximatly 5 000 water samples were collected from wells springs and drill holes over an area of about 20 000 km^2 in the Abitibi volcanic belt of northwestern Quebec. This important mining area, which is also extensively settled, is mostly covered by thick overburden consisting of glacial and glacio-lacustrine sediments which were considered by explorationists as geochemical barriers limiting the usefulness of surface geochemical exploration techniques. Thus, groundwaters in contact with till or bedrock were sampled routinely in order to obtain information indicating the possible presence of hidden deposits.

The samples were collected in polyethylene bottles, acidified with acetic acid and analyzed routinely for 20 elements (Cu, Zn, Pb, Cd, Ni, Co, Cr, Fe, Mn, Mo, Hg, As, U, Li, F, Cl, Na, K, Ca, Mg) by atomic absorption and atomic emission spectrophotometry, selective ion electrodes and fluorometry.

Four types of multi-element dispersion patterns have been identified: 1) regional patterns with areas varying from 15 to 100 km^2; these patterns often seem discordant with respect to the known geology; 2) geochemical belts in which high concentrations extend for distances ranging from 5 to 30 km; these belts usually follow certain lithological units; 3) local dispersion patterns (or anomalies) with areas ranging from 1 to 15 km^2; and 4) geochemical complexes which consist of groups of at least two of the preceding types. These complexes may or may not follow the mapped regional geological trends.

Empirical information resulting from the study of several case histories indicates that multi-element dispersions associated with known mineralization are generally local. The groundwater chemistry in northwestern Quebec changes very rapidly with changing geological environments, and it would seem that most multi-element dispersions from mineralized sources extend usually less than 2 km down the water gradient. Therefore, the local patterns should be of greatest interest to mining exploration since they are the ones which can best define mineralized zones.

In all, 240 local patterns (or anomalies) have been identified throughout the sampled area and these patterns can be classed into two categories (figure 1):

A

B

SUPERIMPOSED PATTERNS

C

D

ADJACENT PATTERNS

road.................. ....

APPROXIMATE SCALE
4   2   0   2   4   6   8
kilometres

ANOMALOUS DISPERSIONS

élément 1 ....
élément 2 .. .. ----
élément 3 . . ..

Figure 1: Types of superimposed and adjacent multi-
           element dispersion patterns forming local
           anomalies.

Figure 2   Geochemical signatures observed in 21 base metal
           and gold mines. (A strong signal requires that
           50% or more of the samples contain anomalous
           concentrations, a moderate signal requires between
           25 and 49% where as a weak signal requires 1 to 24%
           On average, about 7 samples were collected in each
           mine environment.

Base metal mines/Éléments	As	Ni	Cu	F	Mo	Li	Mn	Zn	Pb	Co	Mg	Ci	Ca	Cd	Na	Hg	Fe	U	K
New Insco	●	◉					●	●	◉	◉				●			●		
Louvem Manitou	◉	◉	◉	●	●	◉	◉	◉		◉	◉	◉		◉			◉	+	
Louvem	◉	◉	●	◉	●	●	◉	◉	●	●		●		●					
Lemoine	+		●	+	◉	●	◉						+						
Norita	◉	+	●		●		◉			+						●			
Orchan	●			●	◉	+		●	+		+				●				
Henderson	◉	+	●	●	◉	+				+		+		+					
Matagami Lake	+	+	+	+	◉			+	+		●								
Selco	◉			◉	◉			●						●		+			
Opemiska Perry	●	◉	+	◉	◉	●		+											
Patino Copper			+		◉	●		●			●			+					
Gaspé Copper	●	+	◉	●	◉	●		+	+				●	◉	●				+
Mines Madeleine	◉	◉	◉		◉	◉	●												
Mines d'or																			
Agnico Eagle	●	◉	+	◉			◉			+	+			+		↔	+		
Comflo	●	◉	+	◉	+	●			+	+			◉						
Darius	●	◉	◉	●	◉	●			+			◉							
Sigma	●	◉	+				◉			+	●	●		+	●	●			
Lamaque	◉	◉	+				◉	●	◉	◉	◉	◉		●	+	●			
Belmoral		◉	●				◉	●		●			●						◉
Chadbourne		◉	●		◉	●	●				◉					●			
Thompson-Bousquet		+	+	+	◉				+										

SIGNAL
◉ strong
● modéré
+ weak

a) superimposed dispersion patterns of several elements (targets);
b) groupings of adjacent dispersion patterns of several elements (zonations).

Although the dispersion of the elements in the groundwater may reflect their distribution in the primary environment, it is also possible that the two preceding categories of patterns are actually related to the distance from the source. Thus, the type of pattern observed could depend on where sampling intersects a multi-element dispersion. If the sampling is close to the source, a target could preferentially be obtained whereas if the sampling is distant, a zonation could well be observed.

The elements with the highest frequency of occurrence are As, Ni and U which occur in more than 30% of the 240 local dispersion patterns (anomalies); Co, Cu and Mo occur in more than 25% whereas Zn, Hg, Pb and F appear in more than 20%. This relative sequence of element occurrences is very similar to the one recently established for apparent element mobilities in the soils and overburden of the Abitibi clay belt. This latter sequence is: As>Ni>U>Hg>Zn Cu>Pb>Mo.

The correlation coefficients calculated for trace element pairs give us very limited insight into trace element associations. This situation is attributable to: 1) the diversity of geochemical environments in an area as large as the one covered; 2) the high analytical detection limits for most trace elements; and 3) the fact that the base unit for such calculations is the sampling site rather than the environment. However, if the percentage of occurrence of various element pairs in the local dispersion patterns is compiled, we find tht the most frequent element associations are Cu-Pb and Ni-Co which occur in more than 15% of the local anomalies and Cu-Zn, Pb-Ni, Ni-Cd, K-Mg and Mo-F which occur in more than 12.5%.

Lastly, groundwaters were sampled in 21 base metal and gold mines in an attempt to define certain characteristic signatures that would help to interpret the accumulated mass of data and to discriminate those local signals which are most probably associated with mineralization. The results of this study (figure 2) suggest that the suite of As, F and Mo is most important for defining base metal mineralization whereas As, Ni, (F or Cl) and Mn seem to characterize gold-bearing environments.

THE APPLICATION OF HYDROGEOCHEMISTRY TO THE EXPLORATION FOR MISSISSIPPI VALLEY-TYPE DEPOSITS IN NORTHWESTERN OHIO
by
M.F. Deering, E.T. Mohr, B.F. Sypniewski and E.H. Carlson

A cluster of minor Mississippi Valley-type deposits occur in the surface bedrock exposures of northwestern Ohio. The district, which forms a northeasterly trending belt that is draped across the Findlay Arch, extends from the Indiana border to the Lake Erie Islands. The deposits are of interest because they might be indicators of economic mineralization at depth. The deposits occur in flat terrain and bedrock is found mainly in quarries that are scattered across the area. The minerals of the deposits, chiefly celestite, fluorite and sphalerite with lesser amounts of barite and galena, show variation in both geographic and stratigraphic distribution in the district. Dolomites of Middle Silurian to Middle Devonian age, which are the host rocks for the deposits, also form an important aquifer system in the

area.

Mineral exploration by hydrogeochemical methods is suited ideally for northwestern Ohio due to the glacial cover and to the lack of surface exposure. Through a reconnaissance study, 100 samples from shallow wells (50 m deep or less) were collected across an area of about 19 000 km^2. Recharge takes place in the southern part of the area, the southern border being marked by a drainage divide, while groundwater flow is northward towards Lake Erie. Bicarbonate alkalinity (183-580 ppm), Cl (2-230 ppm), F (0.2-2.8 ppm), specific conductance (100-3 000 μmho), pH (6.9-8.6) and temperature were determined in the field. Ba (< 0.001-1.39 ppm), Ca (27-560 ppm), Fe (<0.02-11.2 ppm), K (1-34 ppm), Mg (14-192 ppm), Na (3-151 ppm), Pb (< 0.001-0.029 ppm), SO$_4$ (4-2 025 ppm), Sr (0.15-73.9 ppm), Zn (< 0.002-1.73 ppm) and hardness as CaCO$_3$ (127-2 144 ppm) were determined in the laboratory. A trilinear diagram of the major constituents was used to characterize the groundwater chemically and trend surface maps were utilized to establish chemical changes in the direction of flow. The majority of the samples are high in sulphate, the source of which is believed to be evaporites within the carbonate sequence. The remainder of the water samples are rich in carbonate and bicarbonate. As no distinct groupings of sample sites appear in the trilinear diagram, the groundwater of the region is believed to be well mixed. With the exception of bicarbonate alkalinity, trend surface maps of the major constituents show increasing concentrations in the direction of flow.

Trend surface maps for several of the trace and minor constituents reflect the geographic distribution of the minerals in the deposits. Correlations are weakened, however, due to the influence of geochemical barriers such as SO$_4$ on Ba and Sr, and possibly Ca and Mg on F. Trend maps for F and Sr, the most mobile of the indicator elements, are especially useful. The widespread distribution of fluorite across the district and the restriction of celestite to its eastern half are reflected in the trend surface maps for those elements. The map for Pb, however, follows the trends of the major constituents instead of the distribution of the mineralization. A closer correlation of the trace and minor element chemistry with the distribution of the surface deposits is being attempted through the application of solubility indices.

In a detailed study over one of the more intensely mineralized parts of the district, 46 samples from domestic wells were collected across an area of 78 km^2. As this area is underlain entirely by the Lockport Dolomite (Middle Silurian), ranges for the major chemical constituents show less variation than the regional values. Chemical data indicate that the concentrations of the major constituents are comparable to the regional values with the exception of SO$_4$ which is significantly lower. The dispersion of the trace and minor elements in this area is being examined at present. Although the mineral deposits near the surface in northwestern Ohio are not economic in value, the application of hydrogeochemical methods holds promise in exploring surrounding areas where potentially economic deposits of the Mississippi Valley-type may be present. The application of the method to deep wells in northwestern Ohio seems also to be justified.

HYDROGEOCHEMICAL EXPLORATION FOR BARITE, OUACHITA MOUNTAINS, USA

by

K.F. Steele and G.H. Wagner

Introduction

Ninety-three springs and eight surface-flow artesian wells were sampled as part of a general geochemical survey of the groundwater in a 130 x 140 km mineralized area of the Ouachita Mountains west of Hot Springs National Park, Arkansas to the Arkansas-Oklahoma border. However, only the results related to barite will be discussed here. The survey area was subdivided into two sub-areas based on mineralization and lithology.

The rocks of Area I are primarily of Paleozoic age with Arkansas Novaculite and Stanley Shale predominant with some sandstone and minor limestone. Manganese mineralization (including psilomelane) is widespread -- over 100 prospects. Three barite districts and active barite mines also are present. The barite occurs as the result of replacement or fracture filling in the first few metres of the lower Stanley Shale Formation. There are also small scattered Pb-Zn deposits throughout the area.

Area II strata are composed of Paleozoic rocks (Stanley Shale, Jackfork Sandstone and Atoka Sandstone); Cretaceous age limestone, gravel, siltstone and sandstone; and Quaternary alluvium. Three mineral districts (mercury, antimony and strontium) are present along with small, scattered Pb-Zn deposits. Barite is prevalent throughout much of the area as cement in the Cretaceous sandstones and gravels. The barite districts in Area I are much more areally restricted than the barite cement in Area II; therefore, the barite mineralization in Area I does not greatly affect the values in the table except for the upper range values.

Detection of Individual Deposits

Anomalous Ba values are extremely useful indicators of barite mineralization as can be seen from the table. Seventy-five percent of the known barite deposits (9 out of 12) in Area I are located by anomalous Ba concentrations in springs within 3.4 km of the deposits and 83% of those within 1.7 km. Of the three not detected, one is a thin veined deposit which may explain its non-detection.

Percent $BaSO_4$ saturation = $(a_{Ba^{++}} \cdot a_{SO_4^{=}})$/solubility product of $BaSO_4)_T$ x 100

where $a_{Ba^{++}}$ is the activity of Ba^{++} in the sample, $a_{SO_4^=}$ is the activity of $SO_4^=$ in the sample and T is the temperature of the water.

Comparison of Areas

The widely prevalent cement in the Cretaceous sandstones and gravels of Area II is reflected by higher median, upper range and threshold values of Ba concentrations, and also higher median and threshold percent $BaSO_4$ saturation values (see table). Because barite solubility can be affected by the ionic strength, temperature, and the pesence of $SO_4^=$ ions, the actual Ba concentration may not be as useful in detecting barite deposits as the ratio of the activity product from measured values to the solubility product for that temperature, that is, percent $BaSO_4$ saturation.

The nine false anomalies in Area I may actually represent undiscovered mineralization as all but one of these samples are located in a barite district. The prevalence of barite as a cement in Area II probably explains the false anomalies in this area. Yet, it is interesting to note that two of the three known deposits in Area II are detected.

Because Sr can substitute for Ba in barite, anomalous Sr or Ba/Sr values

were tested for detecting barite mineralization, however, the results were negative. The percent $BaSO_4$ saturation technique produced favourable results but does not appear to offer any advantage over the Ba threshold value because every site determined to be anomalous in terms of percent $BaSO_4$ was anomalous in terms of Ba.

Because the percent $BaSO_4$ saturation takes into account the ionic strength, temperature (for the solubility product) and $SO_4^=$ activity, this parameter should be useful in reducing the possibility of missing anomalous Ba values. For example, a particular spring near a barite deposit might have a high $SO_4^=$ concentration due to oxidizing sulphide minerals which would lower the Ba concentration. Therefore the spring may not be anomalous in terms of Ba, but could have an anomalous percent $BaSO_4$ saturation.

Conclusions

The location of barite deposits in the Ouachita Mountains and elsewhere using groundwater chemistry appears to be promising. The method would require Ba analysis and other major ion analyses (for calculation of ionic strength) for the determination of percent $BaSO_4$ saturation. The method is simple, quick and effective, with an approximately 70% success rate in detecting known barite mineralization.

Table of comparison of barium (ppb) and percent $BaSO_4$ saturation for groundwater for Area I and II.

	Median	Range	Threshold	Average Anomalous Value	Number (Percentage) of Anomalous Values
Barium					
Area I	11.5	<1-420	28	121	18(25%)
Area II	30.5	<12-930	36	214	12(40%)
% BaSO4 Saturation					
Area I	1.1	<0.2-96.0	2.2	32.2	13(18%)
Area II	10.0	0.3-96.7	62.0	71.9	4(13%)

A METHODICAL AND REGIONAL CONTRIBUTION TO GEOCHEMICAL MULTI-ELEMENT PROSPECTING BY ENERGY DISPERSIVE X-RAY FLUORESCENCE FOR CARBONATITES

by

U. Kramar

Carbonatite complexes are of high economic interest as potential deposits for elements such as Nb, REE, P, Ti, Fe, Mn, Cu, Ba and F.

The Kaiserstuhl carbonatite was explored and partly exploited for Nb_2O_5. Up to 1952 some 22 000 tons of carbonatite with niobium content in the range of 0.05 to 1.17% Nb_2O_5 were mined from the Schelingen deposit at

the Orberg.

Above the old quarries a geochemical soil survey was carried out in order to detect ranges of niobium and rare earth element mineralizations. A radionuclide-excited energy dispersive X-ray fluorescence analysis has been used as a field method for multi-element determinations.

From an area of about 0.1 km^2 some 500 soil samples were taken by a Purkhauer sampling device. The majority of the samples were residual soils from a depth of 10-60 cm below surface. The soil sample was collected from the lower 20 cm of the Pürkhauer sampling device if possible. The western part of the sample area is covered with loess up to 4 m thick. Here the samples were taken from a depth of 90 cm. Some additional samples were also taken in the loess covered area from a depth of up to 3 m.

All samples were dried at 130°C and sieved to -80 mesh, and the powder analyzed by energy dispersive X-ray fluorescence. Radioactive sources of 10 mCi ^{109}Cd and 10 mCi ^{241}Am were used to excite the characteristic X-rays of Zn, Cu, As, Pb, Rb, Sr, Nb, Zr, Ba, La and Ce. The detection limits for these sources are given in the table. The computerized X-ray fluorescence system consists of an Si(Li) detector (80 mm^2 active area, 3 mm thickness and an energy resolution of 165 eV at 5.9 keV), amplifier - electronics and a computer-coupled multichannel analyzer (PDP11/04 + Canberra 8 100). This system is able to analyze about 50 samples per day for all above mentioned elements.

The samples of some key traverses were prepared and analyzed directly in the field with the energy-dispersive X-ray fluorescence equipment mounted in a four wheel drive truck. The results obtained from these samples were used for
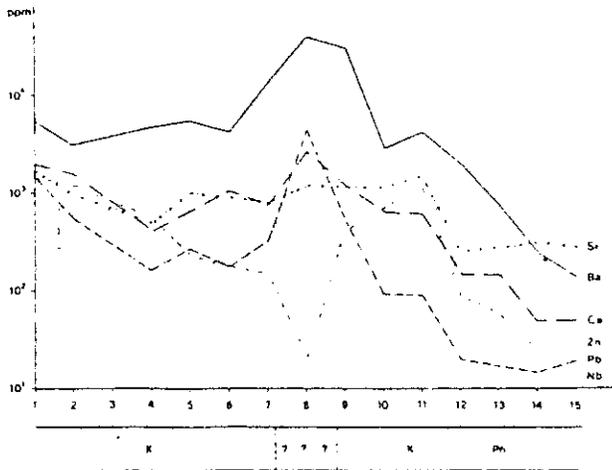

Fig. 3 Soil traverse on carbonatite-phonolite boundary in the Kaiserstuhl, southwest Germany (spacing of sampling points 5 m) A = carbonatite, Ph = phonolite

TABLE I

Compilation of counting parameters and detection limits

Elem.	X-ray line (keV)		Excitation	Detector	Interference	Detection limit (ppm)	count. time (sec)
Cu	K_α	8.05	^{109}Cd	Si(Li)	Zn K_α	30	400
Zn	K_α	8.64	^{109}Cd	Si(Li)	Cu K_α	30	400
As	K_α	10.54	^{109}Cd	Si(Li)	Pb L_α	10	400
Rb	K_α	13.34	^{109}Cd	Si(Li)		10	400
Sr	K_α	14.17	^{109}Cd	Si(Li)		10	400
Zr	K_α	15.78	^{109}Cd	Si(Li)	Sr K_α	10	400
Nb	K_α	16.62	^{109}Cd	Si(Li)		10	400
Sn	K_α	25.04 25.27	^{241}Am	Ge		10	100
Cs	K_α	30.97 30.63	^{241}Am	Ge	Ba K_α	10	100
Ba	K_α	32.19 31.81	^{241}Am	Ge	Cs K_α, La K_α	5	100
La	K_α	33.44 33.03	^{241}Am	Ge	Ba K_α, Ce K_α	10	100
Ce	K_α	34.72 34.28	^{241}Am	Ge	La K_α	10	100
Pb	L_{β_1}	12.62	^{109}Cd	Si(Li)	Rb K_α	20	400

planning further traverses. All other samples were analyzed in the base laboratory. From the results of this survey it is possible to identify the underlying rocks using the multi-element determinations of the soil samples. The early carbonatite intrusion and the later carbonatite veins show significant differences in the trace element patterns with very high contents of Nb, Ba, REE, Sr, Zn and Pb. The early carbonatites are characterized by the highest Nb concentrations (up to 1% Nb in the soils), Ba concentrations in the range of 5 000 ppm and about 1 000 ppm Ce. The later carbonatite veins show the highest concentrations of Ba (up to 10%), Pb and Zn (more than 2 000 ppm) but are low in Nb (less than 100 ppm). The surrounding rocks (i.e. phonolite, essexite) are much lower in most of the trace element concentrations. The Figure gives results of a traverse across a carbonatite-phonolite contact.

The loess cover of the western part causes a dilution and smearing of the rock-induced trace element patterns. However it seems possible to eliminate a part of the dilution effect due to the loess cover by use of inter-element correlations.

LABORATORY AND FIELD EVIDENCE IN SUPPORT OF THE ELECTROGEOCHEMICALLY ENHANCED MIGRATION OF IONS THROUGH GLACIOLACUSTRINE SEDIMENT
by
B.W. Smee

Ionic aureoles, overlying or contiguous to massive sulphide occurrences, have been postulated to have been emplaced as a result of natural galvanic forces. The occurrences of these galvanic forces, most commonly referred to as the self potential or spontaneous polarization phenomena, are well documented, but ionic migration in response to these electrical forces remained to be proven conclusively.

The purpose of this study was to attempt to document ionic migration attributable solely to electrogeochemical transport. Pleistocene glaciolacustrine sediments rich in clay-size particles was the geological substrate chosen to minimize migration processes other than those of electrogeochemical transport. These sediments are known to have low hydraulic conductivity, especially when not already desiccated, and at the same time posess a low resistance to the passage of an electric current.

Laboratory experiments which simulated a field situation utilized the radioisotope ^{65}Zn as a tracer and revealed a readily detectable diffusion of Zn^{2+} into glaciolacustrine clay; the distance of penetration of the Zn^{2+} being significantly increased by the application of a DC electrical potential, similar in magnitude to a natural self potential. The rate of diffusion was greatest around the margins of the cathodic electrode located at the base of the clay layers; the areas shown to have the greatest current density. The resulting pattern of Zn penetration into the clay, when viewed in a vertical section, showed a double-peaked increase in Zn concentration on either side, and a distinct decrease in Zn penetration directly above this cathode. Extrapolation of the average diffusion coefficient found for Zn^{2+} ($D_o = 6.3 \times 10^{-9}$ cm.s^{-1}) to other ions commonly associated with base metal deposits, revealed that only H^+ could be expected to move through appreciable thicknesses (> 20 m) of clay in the 8 000 years since sediment deposition.

The hypothesis that H^+ would diffuse through appreciable thicknesses of varved clay, and that the pattern of this diffusing ion would be predictably modified by a self potential field generated by an oxidizing sulphide body, was tested over the Magusi River volcanogenic massive sulphide deposits near Noranda, Quebec, Canada. The organic soil horizon (H) and top of the clay soil layer (C) were sampled and analyzed for conductivity, pH, and the pH sensitive major and minor elements. The mineral horizon revealed distinct changes in conductivity, pH, Ca, Mg, and Fe above the contacts of the hangingwall and footwall of the sulphide hoirzon, thus producing a double-peaked "rabbit-ear" anomalous pattern. The H soil horizon, when corrections for variable "total" element and carbon concentrations were applied, showed clear anomalies in Fe, Mn, Ca and Mg. A ratio of EDTA Fe/TOTAL Fe to total organic carbon revealed the best "rabbit-ear" anomaly above the sulphide horizon. The use of organic horizon geochemistry as a method of evaluating EM conductors overlain by water-saturated lacustrine sediments is recommended.

SOIL AIR CARBON DIOXIDE AND OXYGEN DISEQUILIBRIA AS A GUIDE TO CONCEALED MINERALIZATION IN SEMI-ARID AND ARID REGIONS
by
J.S. Lovell, M. Hale and J.S. Webb

Anomalous levels of carbon dioxide and oxygen in soil air have proven effective indicators of sulphide mineralization concealed beneath transported overburden in three semi-arid to arid localities in different parts of the world.

The carbon dioxide and oxygen concentrations in soil air can be measured in the field using a tubular steel sampling probe with an integral sliding hammer, a carbon dioxide analyzer which exploits the differing thermal conductivities of the principal gases which constitute soil air, and an oxygen analyzer which depends for its operation on the paramagnetism of oxygen. The probe is driven into the soil to a depth of about 50 cm, and a hand vacuum pump is used to extract soil air through sideports near the tip of the probe and introduce this into the measuring instruments connected in series. The results are expressed as the carbon dioxide and oxygen disequilibria of the soil air sample relative to atmospheric air. The equipment is easily carried and operated by one man and measurements can be made at about 40 sample sites per day.

At Johnson Camp, Arizona, three zones of low grade chalcopyrite and sphalerite mineralization occur as tabular pyrometasomatic deposits in metamorphosed Paleozoic limestones. The mineralization and host rocks lie beneath a transported overburden of alluvium and pediment gravels, within which layers of caliche have developed. The thickness of transported overburden in the area increases towards the northeast, so that the suboutcrop of the most southwesterly zone of mineralization is concealed beneath about 10 m of transported overburden, while the most northeasterly zone is concealed beneath more than 150 m of overburden. Soil air carbon dioxide and oxygen disequilibria anomalies were detected over each of the three mineralized zones. Anomalies range up to 0.9% CO_2 and 0.75% ΔO_2 compared to background measurements of 0.1 to 0.2% CO_2 and 0.1 to 0.3% ΔO_2.

At Witvlei, South West Africa (Namibia), chalcopyrite mineralization

CARBON DIOXIDE AND OXYGEN IN SOIL AIR. JOHNSON CAMP

$CO_2 - O_2$ IN SOIL AIR, WITVLEI
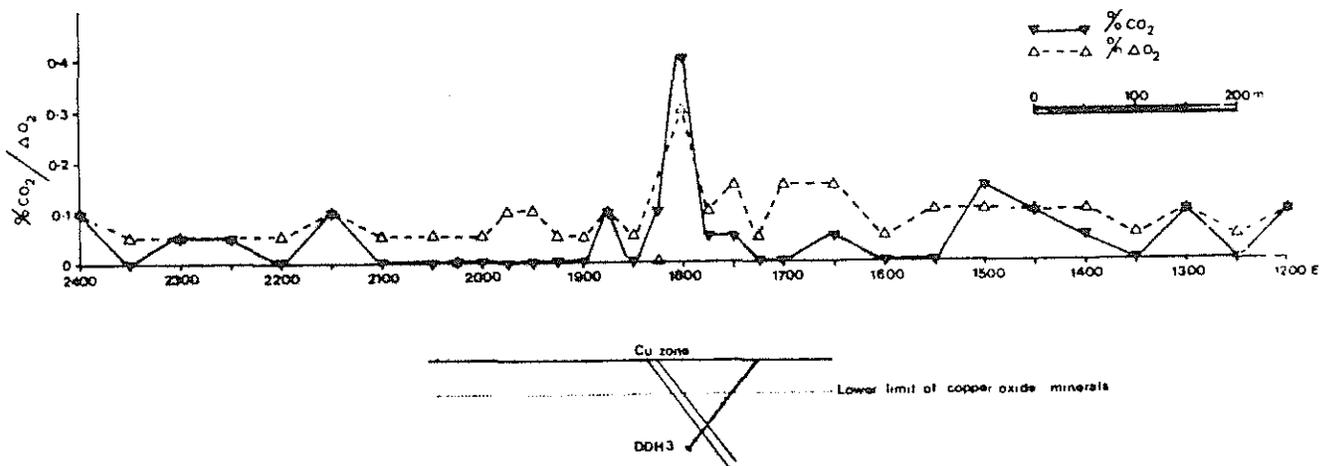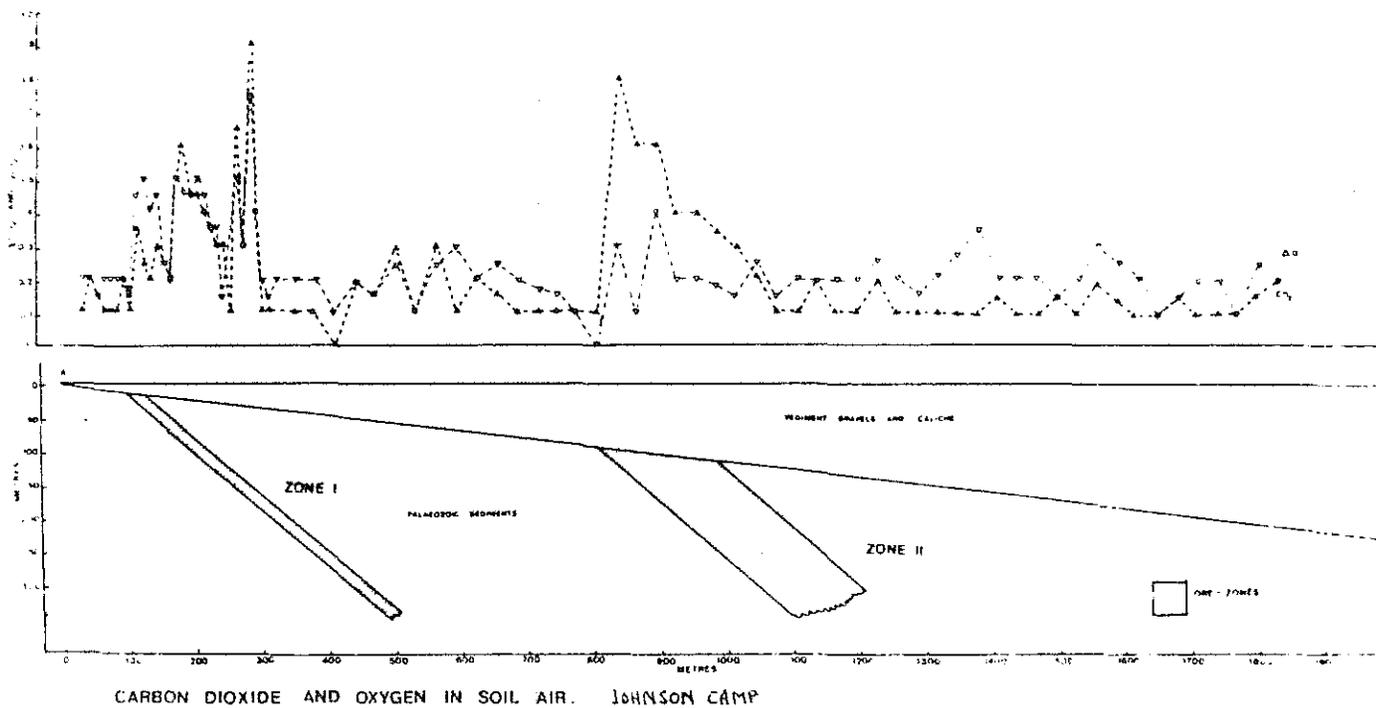
occurs within sandstones and siltstones which constitute part of a sequence of clastic, calcareous and argillaceous sediments. There is a surface covering of up to 2 m of transported Kalahari sand. Along two traverses soil air disequilibria anomalies reflect the concealed suboutcrop of the mineralization. Anomalies of up to 1% CO_2 and 0.5% ΔO_2 exhibit good contrast against background levels of 0.05 to 0.1% CO_2 and 0.05 to 0.2% ΔO_2.

At Ash Shaib, Saudi Arabia, a body of copper and zinc sulphides occurs within Precambrian amphibolites, hornfels, gneisses, calc-silicates and dolomites. The mineralization has some surface expression as an oxidized outcrop but to the west this is lost beneath a cover of unconsolidated wadi sediments up to 8 m thick. Two soil air traverses over the wadi sediments disclosed the position of the concealed suboutcrop of the mineralization by anomalies of up to 0.5% CO_2 and 0.25% ΔO_2. Background levels for both measurements were as low as 0.05%. A third traverse on the wadi sediments over an induced polarization anomaly, already proved by drilling to be due to a graphitic zone at depth, produced no soil air disequilibria anomalies.

The soil air disequilibria detected are attributed to active oxidation of the sulphide mineralizations at depth. The oxidation process creates an oxygen demand which is partly met from the soil air, and this is thus depleted in oxygen. The acid liberated by sulphide oxidation attacks carbonate gangue minerals and host rocks with the evolution of carbon dioxide. This migrates down the concentration gradient towards surface, so raising the carbon dioxide level in the soil air.

Several factors contribute to the development of the clear anomalies recognized in the case histories described here. First, semi-arid to arid climates promote a fairly rapid rate of sulphide oxidation. The transported overburden types of the areas studied are relatively porous, thus aiding the migration of gases through the overburden profile. Finally, the arid near-surface soil supports relatively little biological activity, and thus background levels of carbon dioxide and oxygen disequilibria in the soil air tend to be low and relatively uniform.

The detection of carbon dioxide and oxygen anomalies in soil air therefore appears to offer a simple, cost-effective and potentially reliable technique with which to explore for sulphide mineralization concealed beneath transported exotic overburden in semi-arid and arid regions.

THE USE OF FLUID INCLUSION DECREPITOMETRY TO DISTINGUISH MINERALIZED AND BARREN QUARTZ VEINS IN THE ABERFOYLE TIN-TUNGSTEN MINE AREA, TASMANIA
by
K. Burlinson, J.C. Dubessy, G. Hladky and R.W.T. Wilkins

Mineralization at the Aberfoyle mine in north-eastern Tasmania occurs in quartz veins within quartzite and shale host rocks. Typically, cassiterite and/or wolframite are found on the margins of the ore veins which are related to a cupola of an aplitic intrusive. This has been intercepted 320 m below the surface in the mine shaft. Barren quartz veins of the same or related hydrothermal systems are found within the area surrounding the mine, and barren pre-mineralization quartz veins also occur. Whereas the barren veins are invariably deformed, ore veins range from being undeformed to having undergone moderate ductile deformation.

In exploration for additional centres of mineralization nearby, it is necessary to distinguish between these vein types, but this can be difficult using geological criteria, particularly in drill core. This study has focussed on the use of fluid inclusions to distinguish between vein types. The technique of fluid inclusion decrepitometry was applied using a newly constructed microprocessor-controlled instrument. In this technique, samples, which are crushed and screened, are characterized by the sounds produced by leaking or bursting of fluid inclusions during heating. Quartz samples from 7 barren and 10 ore veins from the mine itself and surrounding areas were decrepitated (Fig. 1) and also submitted to extensive observations by conventional microscopic techniques.
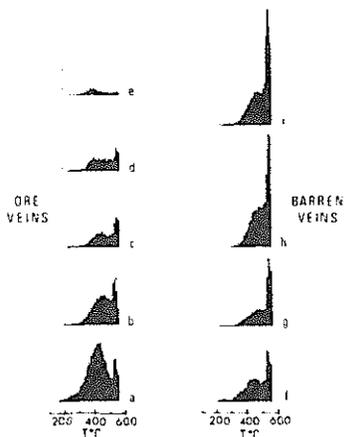
Fig. 1. Decrepigrams of quartz from Aberfoyle mine ore veins (a-e), an Eastern Hill vein (f) and pre-mineralization veins (g-l).
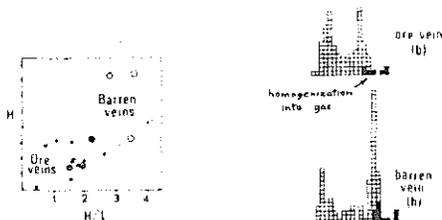

Fig. 2. Decrepigram high temperature peak height (530 across the ratio of high to low temperature peak heights of the Eastern Hill veins.
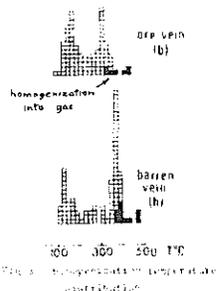

Fig. 3. Homogenization temperature distribution.

The decrepitometer output is a histogram of counts versus temperature, and the ore veins show distinctly bimodal histograms with peaks at 390–460°C and 530–540°C. The barren veins also give bimodal histograms but with the peaks overlapping to produce a shoulder at 460°C leading on to an intense peak at 520–540°C. Whereas the ratio of the heights of higher and lower temperature peaks for the ore veins was < 2.7, for the pre-mineralization barren veins this ratio was > 2.7 (Fig. 2). However, certain mildly deformed unmineralized veins from Eastern Hill also plot in the ore field suggesting the existence of hydrothermal mineralization at depth in this area.

The microscopic investigations reveal rather subtle differences between the fluid inclusions of the ore and barren veins. Inclusions in the ore vein quartz are of two major types –

(1) "CO_2-rich" with highly variable H_2O and CO_2 contents ranging from 3 to 72 mole % CO_2. The gas phase also has a highly variable density

at ambient temperature. Most of these inclusions homogenize about 300°C, and both liquid and gas phase homogenizations occur.

(2) Aqueous inclusions with a vapour phase of low density. Homogenization temperatures are usually relatively low (100-200°C) but they can be as high as 375°C, and these inclusions usually homogenize into the liquid phase.

A similar inclusion assemblage occurs in quartz of the barren veins, inclusions almost entirely filled with gas being common. However in contrast with the ore vein quartz, inclusions with visible liquid CO_2 at ambient temperature (21°C) are rare. In all samples of both ore and barren vein quartz, significant necking-down of the inclusions has widened the apparent range of fluid composition and increased the actual range of homogenization temperatures.

The gases of 18 inclusions in both ore and barren quartz were analyzed by laser Raman microprobe. All are CO_2-rich with all but one of the ore vein quartz inclusions having > 93 mole % CO_2. Minor amounts of N_2, CH_4 and H_2S were present in the ore veins, with greater amounts of these components, especially methane, in the barren veins. Inadequate data exist for firm conclusions to be drawn, but the compositions of gases (3 analyses) in the Eastern Hill veins appear to more closely related to those of the pre-mineralization veins.

As an aid in interpreting the decrepigrams, histograms of the homogenization temperatures were prepared (Fig. 3). These are bimodal for both the ore and barren quartz, with peaks at 100-200°C and 300-400°C. At first sight these would appear to correlate with the peaks on the decrepigrams, allowing for the expected displacement of decrepitation peaks towards higher temperatures. However, by heating samples at 50°C intervals from 250°C to 500°C it is shown that all inclusions of low homogenization temperature decrepitate by 250°C without detection by the decrepitometer. The decrepitation peak at 390-460°C for the ore quartz is correlated with the presence of CO_2-rich inclusions which homogenize into the liquid phase. These begin to decrepitate at approximately 300°C and are entirely destroyed by 500°C leaving only those gas-rich inclusions which homogenize into the gas phase, and any aqueous inclusions which homogenize at high temperature, to contribute to the higher temperature decrepitation peak. By 500°C all inclusions >3 μm diameter in the ore vein quartz are destroyed. In the barren quartz, gas-rich inclusions which homogenize into the liquid phase do so at temperatures ~50°C higher than those in the vein quartz. These inclusions give rise to the intense decrepitation peak at 520-540°C. However, even at 550°C about 20% of the inclusions >5 μm diameter remained intact. The origin of the 460°C shoulder in the barren quartz decrepigrams is not clear.

Counts of total visible inclusions per unit volume show that there is poor correlation between inclusion abundance and decrepimetric activity in these samples. Furthermore, calculations indicate that only about one in 10^5 visible inclusions give rise to an event which is recorded by the decrepitometer at the instrument settings used. This in part reflects the fact that a substantial proportion of the very small inclusions do not decrepitate in the experimental temperature range. More importantly, however, there must be a minimum inclusion size below which the noise of decrepitation does not rise sufficiently above background to be recorded as a discrete event. A random selection of 500 inclusions in thick sections of samples showing low (1 774 counts per gram) and high (18 836 counts per gram) decrepitation activities for the 420-600 μm particle size fraction, were measured to give the following distributions:

Inclusion size (µm)	Low activity sample	High activity sample
<3	92.9%	79.5%
3-6	6.3%	11.2%
6-9	0.8%	6.6%
9-12	rare	2.1%
>12	rare	0.6%
Total inclusions/gram	8.9×10^8	3.8×10^8

Total decrepitation counts would appear to depend primarily on the abundance of inclusions $>\sim 10$ µm diameter. This in turn depends on the degree of ductile deformation of the quartz, a smaller average inclusion size being associated with the more deformed samples. Thus the major influences on the form of the decrepigram are the inclusion size distribution and the fluid compositions of the different inclusion types in the sample.

In conclusion, fluid inclusion decrepitometry seems to be a useful method of classifying the quartz veins at the Aberfoyle mine despite the fact that the differences between their inclusions are rather subtle. The technique may be applied empirically, but the value of the information obtained is greatly enhanced by concomitant optical microscopic study of selected control samples.

GEOCHEMICAL HYDROCARBON EXPLORATION - A NEW/OLD EXPLORATION TOOL
by
W. Duchscherer, Jr.

The search for petroleum has evolved into an extremely highly sophisticated technology where today practically every scientific discipline known is being brought to bear upon the endeavour. Yet, the use of geochemical hydrocarbon exploration remains a peripheral exploration tool. The trend toward scientific integration has led the petroleum explorationist to the point of being a specialist. It would seem that our petroleum scientists have focussed their interests mainly on the investigation of principles and less on their ultimate purpose of discovering new and larger oil and gas reserves. So, it is not by chance, that leading geochemists have been speaking more and more freely of the necessity to integrate our tools of exploration and thus do a better job. The theoretical basis for hydrocarbon geochemistry is complex, and, as with all exploration tools, the problems and difficulties of interpreting the data will never be completely eliminated.

This article considers the importance of using the Δ C method in geochemical hydrocarbon exploration which has been employed successfully for over 40 years. The addition of carbon-isotope ratios to this method has added a new dimension to geochemical hydrocarbon exploration. The theoretical basis of the Δ C and $\delta^{13}C$ method has been presented earlier by the author and will only be touched upon briefly here.

Very simply, the basis of all geochemical hydrocarbon exploration is based on the much debated premise that the lighter hydrocarbon gases and their components migrate vertically from a trap through the overlying sedimentary pile to the surface. Upon reaching the surface, through oxidation and reduction, they leave their signatures in one form or another that can be detected by physicochemical methods. These physicochemical signatures are

discernable as "geochemical haloes".

From soil samples, collected from 2-3 m deep, what is measured is the result of absorption and adsorption by soil particles that are altered to CO_2 by oxidation and form a unique, stable, carbonate system with the surface and near-surface material. This is unlike other carbonate systems and when subjected to a differential thermal technique, dissociates into CO_2 within its own specific temperature range. This alteration of surface material is cumulative, therefore, and indicates where maximum hydrocarbon leakage has taken place over the life span of the material sampled. It is durable and unaffected by pressure and temperature variation or recent hydrocarbon contamination.

Values are expressed in terms of millivolts which are proportional to the CO_2 given off by the dissociation of the carbonate system under standard conditions. Frequency curves are constructed for all values for the determination of accurate contour levels for mapping.

After significant ΔC anomalies are located, they can be further verified by use of carbon-isotope ratios. As methane migrates to the surface from underlying hydrocarbon accumulations, there is a progressive selection or fractionation that causes enrichment of the carbon-13 isotope. The methane, thus reaching the near-surface, is isotopically ligher. When oxidized in accordance with the equation $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$, the carbon having been converted to carbon-dioxide, is taken up in the pore-filling carbonate cements that are found in the near-surface soils and sediments.

High carbon-dioxide values (ΔC) in the geochemical halo directly reflect the $\delta^{13}C$ carbon-isotope ratios from underlying hydrocarbon accumulations. This is observed over fields containing hydrocarbon accumulations where $\delta^{13}C$ values in the pore-filling carbonate cements become increasingly negative (lighter) toward the crests (i.e. exhibiting lower ΔC values). This indicates enrichment of ^{12}C relative to the PDB standard. Whereas, positive values of $\delta^{13}C$ indicate depletion in ^{12}C or enrichment in ^{13}C (i.e. exhibiting higher ΔC values).

The observed ΔC anomalies and $\delta^{13}C$ anomalies leave an indelible pattern in the near-surface sediments and soils which are herein referred to as geochemical hydrocarbon haloes.

Examples presented show that the combination of ΔC and ^{13}C data from near-surface soil sampling is a significant step forward in improving geochemical hydrocarbon exploration methods.

THE ROLE OF MERCURY, ARSENIC AND BORON AS PATHFINDERS IN GEOCHEMICAL EXPLORATION FOR GEOTHERMAL ENERGY
by
M. Shiikawa

In Japan we have about one hundred geothermal areas which occur in the following geological units: green-tuff areas including sedimentary basins, Neogene plutonic rock areas, Pliocene-Quaternary sedimentary basins and Quaternary volcanic areas.

Geochemical exploration for geothermal energy in the Onikobe basin in the vicinity of the Naruka geothermal area, Miyagi Prefecture, was carried out by the Geochemical Exploration Research Group of MMIJ.

The Onikobe basin is regarded as a caldera and is covered with lake

deposits composed of conglomerates, sandstones, mudstones, dacitic tuff and andesitic tuff breccia and lava flows.

In the southern part of the basin a Quaternary dacitic volcano and two fumaroles occur. Hotsprings also issue from the lake deposits in the southwestern part of the basin.

The tectonic line, including Naruko and Onikobe geothermal areas, extends into the geothermal areas in Ogachi region, Akita Prefecture. Geothermal manifestations in this area can be divided into three groups: acid type hotsprings, named Kawarage, containing hydrochloric acid; and neutral to alkaline type hotsprings called Oyasu, Ohyu and Takanoyu. Their host rocks are green-tuff and lake deposits of the basin in the green-tuff areas. These geothermal areas were also surveyed by the same research group of MMIJ.

Field Survey

Surveyed areas in the Onikibe basin and the Ogachi region were 10 km^2 and 20 km^2, respectively. Rocks, soils (A and B horizons) and stream sediments were sampled at a density of one sample per 1.0 km.

Chemical Analyses

The samples were analyzed by atomic absorption spectrophotometry, colorimetry and X-ray fluorescence methods for arsenic, boron, cadmium, cobalt, copper, iron, lead, manganese, magnesium, nickel, potassium, silver, sodium, titanium, vanadium and zinc.

Results

Results from the chemical analyses of the stream sediments are shown by means of average values from 200 samples as follows (all in ppm except where noted):
Ag 0.2, Al 6.9 (%), As 7.8, B 4, Cd 0.1, Co 21.0, Cr 5.6, Cu 8.4, Hg 0.05, Mg 6616, Mn 383, Ni 5.5, Pb 10.6, Ti 2010, V 272, Zn 144.

Results from the 97 soil samples (A-zone) are shown as follows:
Ag 0.2, Al 9.6 (%), As 7.0, B 13, Cd 0.8, Co 14.5, Cr 9.4, Cu 11.4, Hg 0.41, Mg 5186, Mn 385.3, Ni 8.7, Pb 23.7, Ti 1957, V 83, Zn 95.

Mercury, arsenic and boron contents in the altered rocks from the Onikobe geothermal area show 22.5, 69.4 and 1.5 ppm respectively.

The boron mineral Sassolite, H_3BO_3, occurs locally in and around geothermal manifestations such as hotsprings and fumaroles. The mineral has also been found around springs at Sasso, Italy. In Japan it was found as sublimates around the fumaroles at Iwo-Jima Island in Kyushyu, and at Showashinzan in Hokkaido.

Statistical Analysis of Geochemical Data

Statistical analysis was applied to raw and log transformed data for geochemical exploration of geothermal energy. Principal component analysis, Direct Varimax and Varimax methods were applied to the geochemical data. From these factor analyses, a factor showing geothermal character is composed of mercury, arsenic and boron. For example, the factor loadings showing geothermal character are shown as follows: Hg 0.943, B 0.583 and As 0.520 computed from the Direct Varimax method.

The factor scores computed from these factor loadings are the highest at the fumaroles Arayu-Jigoku and Katayama-Jigoku in the Onikobe area.

The results suggest that these volatile elements (Hg, As and B) are very useful pathfinders in geochemical exploration for geothermal resources.

Hg AND As SOIL GEOCHEMISTRY OF THE MEAGER CREEK GEOTHERMAL AREA
by
R.E. Openshaw

Introduction

The Meager Creek Geothermal Area (Fig. 1) is centred around the Meager Creek Volcanic Complex of Pliocene to Recent age. This volcanic complex is the most northerly volcano of the Garibaldi Volcanic Belt, an extension of the High Cascade volcanoes.

A primary target of about 6 km^2, termed herein the South Reservoir, has been identified on the south flank of the complex. Preliminary testing of the first deep test well, completed in November 1981 to a depth of 2 500 m, indicates equilibrium temperatures over 230°C and permeable structures at 1 350 m and 1 600 m. A second deep test well is in progress.

Broad targets in the northern part of the area correspond approximately to the resistivity anomalies in Figure 1. Four shallow gradient wells have been drilled to date and heat flows of the same magnitude as the South Reservoir (up to 670 MW/m^2) have been measured.

The most useful exploration techniques have been found to be water geochemistry, electrical resistivity, shallow thermal gradient drilling, and detailed geologic mapping and fracture analysis.

In this report we are concerned with the results of a survey of the Hg and As soil geochemistry carried out in the Meager Creek area during the 1981 field season. Mercury in soils has been found to show good correlation with high heat flow areas and to outline geothermally active structures . Arsenic soil geochemistry is highly complimentary to Hg soil geochemistry in that Hg is transported mainly in the vapour phase and As in the liquid phase.

Soils at 696 sites were collected along sample lines (Fig. 1) and 77 samples in 6 soil profiles. The survey focusses on the South Reservoir but reconnaissance lines have been run in other parts of the area. New water geochemistry and surface water electrical conductivity results complimentary to the soil geochemistry are discussed.

In a preliminary study of the Hg soil geochemistry in the Meager Creek Area most of the anomalously high values were associated with organic rich soils and the overall usefulness of Hg as an exploration guide was not conclusively demonstrated. The present work shows that Hg-As soil geochemistry can be successfully integrated with the ongoing exploration of the Meager Creek geothermal area at both the reconnaissance level and at more advanced stages of development.

Sampling and Analytic Techniques

Valley glaciers have left behind extensive deposits of glacio-fluvial material in the Meager Creek area and soil horizons are generally poorly developed. Only the organic rich A horizon is clearly distinguishable in most locations. Based on soil profile results 50 to 70 cm was established as the optimum sampling depth.

Samples were collected in 150 cc screw-capped plastic jars. Sample drying, preparation, and analyses were done at Chemex Labs Ltd. Both Hg and As soil contents were determined using atomic absorption techniques.

The sampling interval for the line survey was 100 m except in areas of particular interest where the interval was reduced to 50 m and in one case 20 m.

Results

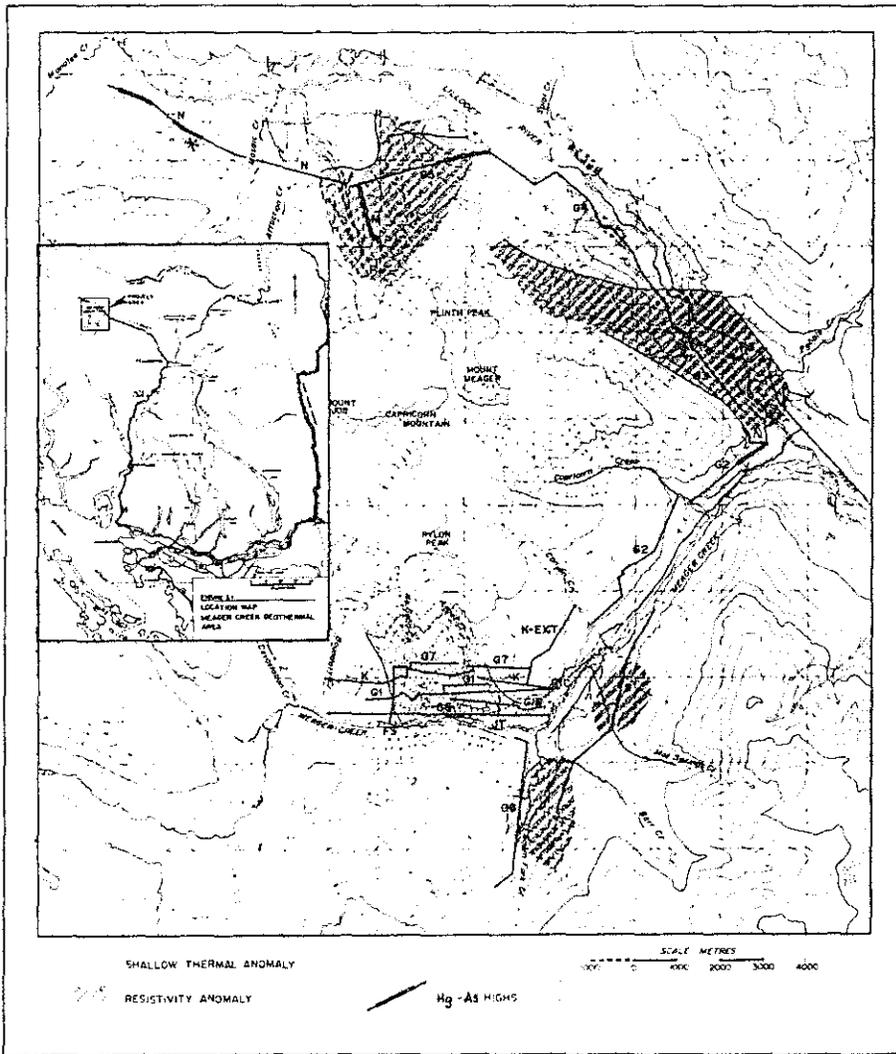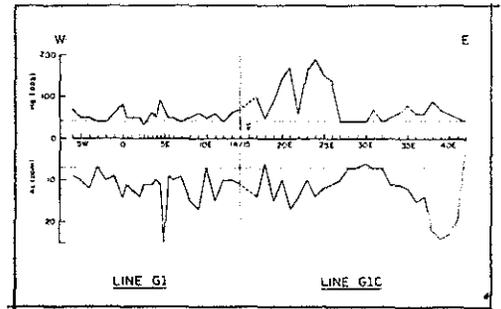Mean values and standard deviations are listed in Table 1 for three sets

Figure 1

Figure 2

TABLE 1

Means and Standard Deviations
for Soil Line Samples

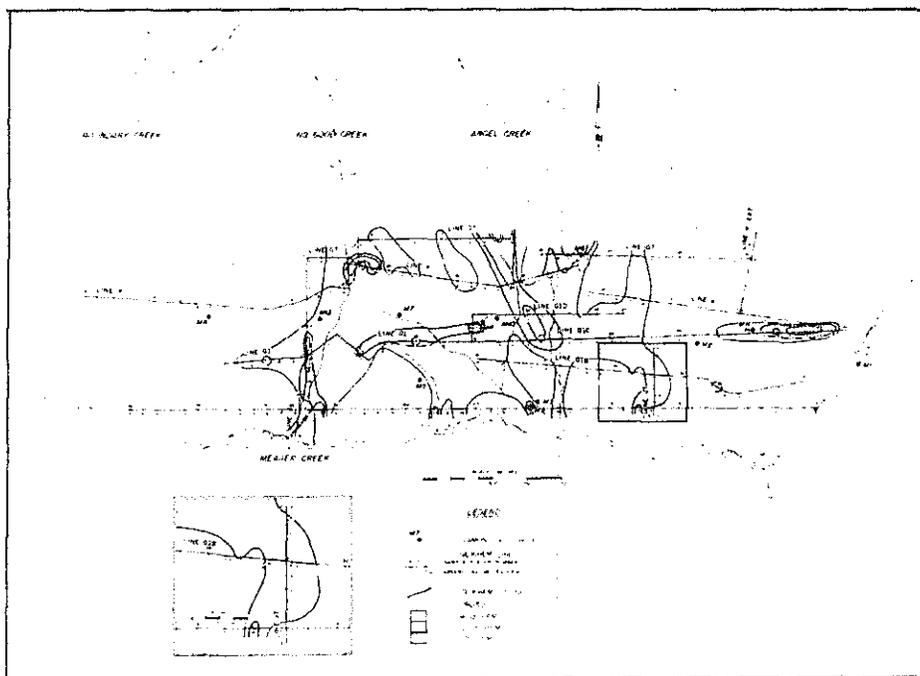| Samples	Hg (ppb)	As (ppm)
outside South Reservoir	44 ± 19	5.6 ± 4.7
over South Reservoir	77 ± 67	9.1 ± 6.0
Line S	31 ± 11	5.0 ± 1.9

Figure 3

Figure 1: Location Map of Geothermal Area, Geochemistry Lines, and Resistivity Anomalies.

Figure 2: Representative Hg and As Results over the South Reservoir Area (Lines G1 and G1C).

Figure 3: Contoured Results for As over the South Reservoir.

of samples. Line S is outside the geothermally active area and is underlain by the same rock types as the South Reservoir. It can thus be used to establish background values for the South Reservoir area. General background values for the entire project area can be represented by the mean for all samples outside the South Reservoir.

Figure 2 shows results typical of the South Reservoir. The background As and Hg values are shown as profile lines and it can be seen that most values for the South Reservoir are anomalously high, as suggested by the mean in Table 1. There is good correspondence between Hg and As on a sample by sample basis.

The contoured As results are presented in Figure 3. There is one trend corresponding to No Good Creek, a second trend running east-west and a third southeast-northwest trend in the Angel Creek area.

The Hg results are similar but less discrete. One large anomalously high response is centred roughly around Angel Creek and a second zone around No Good Creek.

The most significant result from the soil profiles is that on the geothermally active parts of the area Hg is enriched at depth and depleted at the surface, including the A-horizon. Profiles outside the South Reservoir area showed strong Hg enrichment in the organic A horizon and a flat, low response over the rest of the profile.

In Figure 1 areas having anomalous As and Hg soil values are marked by heavy lines. The two areas noted by an asterix in Figure 1 are characterized mainly by strong As responses.

Discussion

The principle resut of the study is that the South Reservoir has been clearly delineated by the As-Hg soil geochemistry. The As and Hg responses are remarkably coincident with the dipole-dipole resistivity anomaly in Figure 1.

Three structural features in the South Reservoir area have been proposed as controls on fluid movement, at least in the near surface environment; the No Good Creek zone, east-west faulting parallel to the Meager Creek Fault, and the Ryan River Lineaments. The latter feature has been identified in air photos and is correlated with a predominant fracture set in the South Reservoir area. Geothermal activity along these three features is recorded by three trends of anomalously high As values.

To the southeast and on strike with the Ryan River Lineaments swamps and streams have been found with highly electrically conductive waters indicative of above normal salinities and water chemistry similar to waters of probable geothermal origin. The waters in the swamps and streams are cool and are considered to represent outflow waters from the South Reservoir that have been channelled along the Ryan River Lineaments.

The South Reservoir is characterized by complimentary Hg and As responses. If such geochemical behaviour is a general rule for geothermal areas then the two reconnaissance targets defined principally by high As values may be due to non-geothermal causes.

Surface depletion of Hg in soil profiles has also been observed by Buseck (1977) and Capuano and Bamford (1978) and thus seems to be characteristic of geothermal systems. It may represent a diffusion gradient of elemental Hg degassing into the atmosphere.

On a reconnaissance scale electrical conductivity results also compliment the anomalous geochemical results in the Job Creek-Affliction Creek area. Job Creek itself has high electrical conductivities as do many small streams coming into Job Creek and Affliction Creek. This area is thus a high priority

target for further exploration.

Conclusions

Hg-As soil geochemistry clearly delineates the South Reservoir and combined with other work indicates that the Ryan River Lineaments, a regional feature, are prime targets for permeable structures in the deep reservoir. Production drilling should be oriented to intersect these structures at high angles.

In the northern part of the project area prime interest areas within the broader targets have been outlined by the present work.

Soil profiles are an important integral part of any Hg-As soil geochemistry survey. They are essential to determining optimum sampling depths and are potentially useful as a discriminating tool.

SURFACE GEOCHEMISTRY AT ROOSEVELT SPRINGS KGRA, UTAH
by
J.S. Lovell, W.T. Meyer, and D. Atkinson

As part of a research program conducted on behalf of the Department of Energy, available data on the Roosevelt Springs KGRA were synthesized to determine the spatial arrangement of the rocks, and the patterns of mass and energy flow within them. The resulting model led to a new interpretation of the geothermal system, and provided "ground truth" for evaluating the application of soil geochemistry to exploration for concealed geothermal fields. Preliminary geochemical studies comparing the surface microlayer to conventional soil sampling methods indicated both practical and chemical advantages for the surface microlayer technique.

The elements arsenic, antimony and cesium in the surface microlayer samples in particular, gave a strong expression of one of the principal faults in the geothermal field. In contrast the analysis of soil samples from only 20 cm below the surface gave little or no expression of the geothermal field.

As a consequence, the surface microlayer was the chosen sampling medium for the second field program, which entailed the collection of a total of some 300 samples on both a regional and detailed pattern covering about 250 km^2. These samples were subsequently analyzed by a variety of methods yielding data on 41 elements and ions.

Computer contouring revealed that, on a single element basis cesium, antimony and arsenic provided the best expression of the KGRA, and indicated other interesting areas of geothermal leakage. Elements such as beryllium and lithium, which are present in highly anomalous concentrations in the opaline sinter deposited by geothermal leakage, do not have an expression in the overlying soils or the surface microlayer. Computer manipulation of the multi-element data using R-mode factor analysis provided the optimum method of interpretation of the surface microlayer data. A single factor in which the principal contributors were arsenic, antimony and cesium provided the best indication of the leakage of geothermal solutions within the KGRA. Anomalies in the Escalante Desert to the west of the geothermal field are associated with the trace of a fault zone, and may, therefore, be an indication of further, as yet untested, zones of hydrothermal activity. Trend surface analysis of the soil mercury data has indicated a regional high in this element in the Mineral Mountains to the east of the KGRA, which may indicate the position of a dry heat source at depth.

These data demonstrate that surface microlayer sampling on a regional scale can serve as a prospecting tool for geothermal resource areas. However, it is possible that the optimum pathfinder elements may vary with the nature of heat source, the geochemistry of the local rocks and the local surficial environment. It is therefore recommended that a multi-element approach should be adopted, with subsequent computer processing of the data.

GEOCHEMICAL INDICATORS OF A HIGH-TEMPERATURE GEOTHERMAL SYSTEM
by
J.N. Moore, R.M. Capuano and O.D. Christensen

The intensity and distribution of hydrothermal alteration are frequently used during the exploration and assessment of a geothermal prospect to estimate the size, shape and temperature of a thermal system. Geochemical and petrographic observations used to characterize hydrothermal alteration include the mapping of both trace and major element dispersion patterns and of the distribution of secondary mineral assemblages.

This paper describes the trace element and mineralogical distributions common to many of the high-temperature systems ($> 150^{\circ}$C) that we have studied. However, examples of important geochemical relationships are primarily drawn from our detailed investigations of the Roosevelt Hot Springs thermal system in southern Utah. The hydrothermal fluids at Roosevelt Hot Springs are enriched in sodium chloride and contain approximately 9 000 ppm total dissolved solids. The reservoir, with a base temperature near 270°C, is located in fractured gneisses and granites.

At Roosevelt Hot Springs, the surface discharges consist of opaline and chalcedonic sinter, and alluvium cemented by silica, calcite, Mn oxide and Fe oxide. The geochemistry of these surface deposits is extremely variable, but locally they contain significant concentrations of up to 5.5 ppm Hg, 858 ppm As, 18.8% Mn, 230 ppm Cu, 290 ppm Sb, 294 ppm W, 17 ppm Li, 68 ppm Pb, 26 ppm Zn, 4.9% Ba and 100 ppm Be High concentrations of Au and Ag, although not present in the sinters at Roosevelt Hot Springs, occur in hot spring deposits from other chemically similar systems such as Steamboat Springs, Nevada.

Hg and As are the most widely distributed trace elements in surface samples. Their distribution in soils overlying the thermal system expands the area of interest and helps define the high-temperature portion of the system. The highest concentrations of Hg and As, of up to 5.5 and 26 ppm, respectively, occur in soils within 300 m of thermal discharge. A broader area extending up to 1 000 m from surficial thermal activity also contains anomalous Hg in soil but with lower concentrations ranging from 50 to 800 ppb. Mercury in soil tends to mark the location of faults within the uppermost portions of the reservoir and areas where the thermal fluids move laterally away from the thermal system toward the adjacent valley.

Depletions of Mn, Cu and Zn are found in the acid-altered soils and in alluvium associated with the hot spring deposits and fumaroles. The acid alteration occurs locally in areas of surficial thermal activity and persists of depths of less than 60 m. Alteration minerals within these zones include alunite, jarosite, native sulphur, opal, chalcedony, kaolinite, sericite, montmorillonite, and mixed-layer clays. The formation of acid waters occurs near the surface and results from the oxidation of H_2S contained within gases evolving from the fumaroles or within waters discharged by the hot

springs. The locally intense acid-sulphate alteration and scavenging of metals within the soils occurs as the fluids percolate downward.

Alteration mineralogy at depth is determined through examination of down-hole samples which penetrate the geothermal system to depths in excess of 2 km. Reservoir rocks with temperatures below about 210°C contain an alteration assemblage with mixed-layer clays, montmorillonite, sericite, pyrite, hematite, magnetite, calcite, chlorite, quartz, and potassium feldspar. At higher temperatures, mixed-layer clays and montmorillonite disappear and anhydrite appears locally.

Altered rocks within the high temperature portions of the thermal field are characterized by anomalous concentrations of As and Li. Selective chemical leaching of the altered rocks and electron microprobe analyses indicate that As is contained primarily in pyrite or iron oxides after pyrite whereas Li occurs in clays and micas.

Mercury exhibits an inverse relationship with temperature and is concentrated in the cooler portions of the thermal system to depths marked approximately by the 200°C isotherm. This distribution is similar to the distribution of clay minerals in the reservoir rock. Heating experiments indicate that Hg occurs primarily as Hg^0 and that it is readily mobilized by the thermal system at temperatures in excess of 200-250°C.

EXPLORATION FOR GEOTHERMAL ENERGY IN INDIA
by
K.S. Murty

India's oil import bill during the 1980-81 financial year was around Rs.5 500 crores while its export earnings hardly crossed Rs.7 000 crores. In fact, the trade gap has been around Rs.2 500 crores. This position, despite some encouraging news of new discoveries of oil fields, might become worse if the OPEC price hike continues at the present rate. According to one estimation, by 1985-86 India would be importing about 23 million tonnes of crude and crude products, paying about Rs.17 100 crores whereas its export earnings might not cross Rs.11 000 crores. India has rich coal deposits and can hope to exploit the hydroelectric power sources to a greater extent. If the development of the fast breeder reactor progresses well, nuclear sources might contribute about 10 000 MW by the end of the century.

Realizing this prospect, the Government of India constituted a Commission on Alternative Sources of Energy (CASE) to devise alternative energy sources of energy, mainly the non-commercial ones. The Sixth Five-Year Plan (1980-85) has made an allocation of about 25 per cent of the total outlay of more than 1 630 500 crores of rupees for the energy sector. The program using renewable sources of energy get about Rs. 1 000 crores. While greater emphasis would be on the utilization of solar and biomass energies, in view of the fact that 80% of India's population lives in rural areas, considerable importance has been given to the development of tidal power, draught animal power, wind energy and geothermal energy.

Important investigations into geothermal sources of energy was carried out by P.K. Ghosh during the thirties. Temperature, flow and seasonal variations of the thermal springs and their geology were studied. But these springs were known for the curative values. In 1965, the Government of India constituted a Hot Springs Committee which examined the compiled data of about 250 known hot

springs in India and evaluated their potential as possible sources of geothermal power. High priority was given to the detailed investigation of the most prospective regions of the northwestern Himalayas, viz., Puga Valley in Ladakh District of Kashmir, and Manikaran in the Parvati Valley in Himachal Pradesh. Other areas which have been marked for further investigation include Rajashtan, Gujarat and the West Coast.

GSI and ONGC by their recent studies established above-normal heat flows in hot-spring zones of N.W. Himalayas, Narmada-Son and Eastern Ghat lineaments in M.P., Bihar, West Bengal and Orissa and along the west coast central dislocation extending from Ratnagiri in the South to the Cambay Basin in the north. Out of the over 250 hot springs in the country, about 40% belong to the high temperature category, ranging between 160° and 226°C. The natural heat discharge from the Puga valley is estimated to be of the order of 10 000 kcal/sec. by NGRI scientists.

The Cl/B ratios in the waters from Parvati Valley (2.5 to 22), Sutlej valley (4.0 to 16.0) and West Coast (6 to 1 460) have been determined by GSI while these ratios are 1 for Puga Valley waters whose Na/K ratio has been found to vary between 8 to 20. Thge Regional Research Laboratory, Jammu, has carried out successful studies on the utilization of geothermal energy for refining crude borax and sulphur in the Puga Valley. The GSI has launched a five year program to completely survey the geothermal capacity in the country.

ASPECTS ON THE PROBABILITY DISTRIBUTION OF ANOMALOUS VALUES IN
GEOCHEMICAL DATA
by
A. Björklund

Geochemical data commonly consist of two or more populations which normally have overlapping frequency distributions. One or more of the populations are usually supposed to represent mineralization and are referred to as anomalous populations. The cumulative frequency graphs of metal contents of geochemical samples are commonly curved and frequently exhibit a sigmoidal form on probability paper. This has been interpreted as being the result of a population of anomalous values, which has a normal or lognormal frequency distribution superimposed on a normally or lognormally distributed background population. On probability paper straight lines have commonly been extracted from curves to represent the frequency distributions of the constituent populations. In the present paper the author presents an argument that the cumulative frequency curves of metal contents originating in mineralizations do not, in most cases, plot as straight lines on probability paper. It is suggested that anomalies are classified as independent or as additive depending on their spatial relation to the background population. The additive anomalies, which are more commonly encountered in geochemical exploration, have been transported from the source. The source may be very small as compared to the anomaly. The bulk of the samples collected from an additive anomaly is composed of material which does not originate in the source but in the surrounding rocks. Accordingly, part of the metals in the geochemical samples originate in the source of the anomaly and part in the background rocks. The anomalous contents and background contents are in one and the same samples and we can not separate samples into background and anomalous ones. A large number of researchers have shown that the decay

pattern of transported anomalies is exponential. From this one can conclude that the anomalous component in the anomalies may have a more or less exponential decay pattern with the distance from the source. In the case of equal sampling intervals the frequency distribution of the exponentially decaying contents of an anomalous component in the samples will have a hyperbolic form. This non-modal frequency distribution will plot as a curved line on probability paper (see Figure). A constituent anomalous population of this kind can not be extracted from a composite population by means of straight lines of probability graphs. The addition of an anomalous component to a background population having a normal or lognormal distribution but does not produce a new mode. It is concluded that in most cases there are no graphical or other simple ways of separating anomalous populations from a background population because we usually do not know the law of the distribution of the component populations and they are not situated in separate samples.
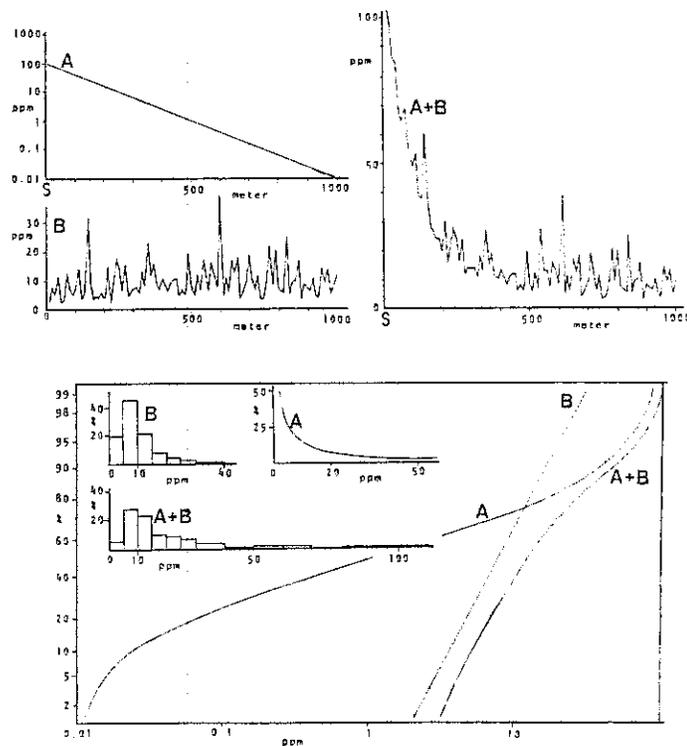

FIG. 1. A. The content profile of a perfect exponentially decaying fictive anomalous component and the frequency distribution and cumulative frequency graph of this component.

B. The content profile of a fictive background population having a lognormal frequency distribution and the histogram and cumulative frequency graph of this component.

A + B. The content profile of the fictive anomalous component (A) superimposed on the fictive background component (B) and the histogram and cumulative frequency graph of this composite population.

SCORESUM—A TECHNIQUE FOR DISPLAYING AND EVALUATING MULTI-ELEMENT GEOCHEMICAL INFORMATION, WITH EXAMPLES OF ITS USE IN REGIONAL MINERAL ASSESSMENT PROGRAMS
by
M.A. Chaffee

A technique called SCORESUM has been developed to clearly display

multi-element geochemical information for evaluation. The technique is simple enough so that the necessary information for plotting maps can be generated manually, and yet it is readily adaptable for computer applications, a valuable advantage for large data sets. The technique involves assigning a number, or "anomaly score", to each analytical value in a data set. This procedure has the effect of normalizing the large and variable ranges of chemical analyses for different elements to simple whole numbers so that all elements can be treated as equals; consequently, the elements can be manipulated and then studied to produce whatever biases the evaluator desires. The most common procedure has been to sum the anomaly scores for different combinations of elements considered likely to occur together in a given mineral-deposit environment; however, one could easily look at differences between elements, ratios of elements, or other mathematical combinations.

SCORESUM has been used to evaluate both large and small multi-element geochemical data sets. The greatest advantage lies in the user being able to look at plots representing different combinations of selected groups of elements to compare the geochemical signatures in areas of known mineral deposits to the signatures present in other parts of the area being evaluated. Such comparisons can be used to determine whether other parts of a study area might contain similar, and therefore favourable, mineral-deposit environments. Because the technique will indicate weakly anomalous areas that may be pesent around a small but highly anomalous area, SCORESUM can also be used to enlarge potential target areas.

Total mineralization maps can be plotted, using as many elements as are of interest, to delineate and rank all mineralized areas within a study area, regardless of deposit type or geochemical signature.

SCORESUM is a biased evaluation technique, meaning that the user can completely control how the technique treats a geochemical data set. This flexibility provides the user with a mechanism to compensate to some degree for analytical variation between samples that is at least in part a result of different rock types or of differing percentages of rock types. By adjusting the threshold values for each element on the basis of the predominant rock type or types, one can remove at least some of the effects of bulk-rock chemistry. As a result, the ore-related component in many weakly anomalous samples can be more effectively identified.

SCORESUM can use highly censored data, an important advantage not available in many other multi-element evaluation techniques. The ability to include highly censored ore-related elements in a large analytical data set can be especially useful in regional assessment programs where many chemically different types of mineral deposits may occur. Thus, the SCORESUM technique can identify significant anomalies that might not be revealed by other multi-element evaluation techniques because these anomalies account for such a small amount of the total analytical variability in a large data set.

The procedure outlined below illustrates the use of the SCORESUM technique in the mineral assessment study of the Walker Lake 1° x 2° quadrangle, California and Nevada. This study involved evaluating samples of minus 0.25-mm stream sediment and nonmagnetic heavy-mineral concentrate derived from active stream alluvium. More than 1 000 samples of each type were analyzed for as many as 37 elements.

1. The analytical data sets for each sample medium were divided into subsets based on the volume percentages of one or more of three major rock types (Paleozoic and Mesozoic metasedimentary and metavolcanic units, Mesozoic intrusive units, and Tertiary volcanic units) present in the stream

channels at each sample site.

2. Geometric means were calculated for each subset and several elements that showed the most obvious correlations to each of the three rock types were selected as indicator elements.

3. The concentrations of the indicator elements in the samples in each subset were compared to the means for those elements in each subset. Samples whose concentrations of the indicator elements indicated a mis-classification based on field observation were moved to the subset most closely approximating the indicator element concentrations, assuming that the gross geologic conditions permitted such a re-classification.

4. Threshold values for each of the final subsets based on rock type were then determined using percent-frequency histograms, cumulative-frequency plots, and visual comparisons of plots of the various selected elements. The concentrations for each selected element were then divided into four groups based on percentiles. The four groups were commonly 0-90%, 90-95%, 95-98%, and 98-100%. These groups were assigned numbers, or anomaly scores, of 0 (background), 1 (weakly anomalous), 2 (moderately anomalous), or 3 (strongly anomalous), respectively.

5. All analyses in each rock-type subset were next scored and the subsets were then merged.

6. Element suites were then selected, based on observed element associations in highly mineralized areas, and the scores for the elements in each suite were summed for each sample site.

7. Plots of the SCORESUM values were then made for evaluating a given selected suite of elements. Different combinations of elements were plotted to determine the most meaningful combinations.

Within the Walker Lake quadrangle, individual SCORESUM maps have been made that locate the most favourable geochemical environments for hydrothermal alteration (pyritization, argillization, silicification), base- and precious-metal deposits, porphyry molybdenum deposits, and contact-metasomatic tungsten deposits. These plots show that some districts previously considered to contain a certain type of deposit environment may well represent an entirely different environment. The areal distributions of some chemical environments indicate regional trends that suggest where additional prospecting should be done. Thus, the SCORESUM technique has proved to be an effective means of displaying geochemical information in order to evaluate large areas.

STATISTICAL EVALUATION OF THE SIGNIFICANCE OF CATEGORICAL FIELD PARAMETERS IN INTERPRETATION OF REGIONAL GEOCHEMICAL SEDIMENT DATA
by
P. Matysek, A.J. Sinclair and W.K. Fletcher

During collection of drainage sediments for regional geochemical surveys it has become customary to record for each site class-interval and categorical observations on the characteristics of the drainage catchment, the sample site and the sediment sample. Typical records include catchment geology, stream dimensions and velocity, texture and colour of sediment, presence of precipitates, contamination et cetera. However, apart from classifying geochemical data with respect to geology, subsequent utilization of this information is often so limited that the effort and cost involved in its aquisition and storage becomes difficult to justify.

In an attempt to study the value and utilization of categorical data collected during regional stream sediment surveys, we have taken data from the Canadian Uranium Reconnaissance Program in S.E. British Columbia (File OFR 514) as a data base. After an initial classification of the data into seven subsets on the basis of catchment geology, probability plots were constructed for each of 11 elements (Zn, Cu, Pb, Ni, Co, Fe, Mn, Mo, W, Hg and U) and used to identify and reject anomalous samples. The remaining background populations were then successively subdivided into groups according to their classification with respect to four sediment characteristics (abundance of fines, sand and organic matter, and sediment colour) and six environmental parameters (physiography, water flow rate, stream class, drainage pattern, bank type and contamination). After calculation of means and standard deviations for each group, differences between group means were tested for significance using Duncan's Multiple Range Test.

Results of Duncan's Multiple Range Test, which are conveniently presented as Venn diagrams, show that, despite their subjective character, many field observations can be systematically related to metal content of drainage sediments and hence used to refine estimates of background and threshold values for more reliable identification of anomalous samples. However, as would be anticipated, some elements are more susceptible than others to environmental factors and some factors influence few or no elements whereas other factors may influence the behaviour of many elements. For example, in sediments derived from granites there are significant relationships between sediment colour and concentrations of 8 elements (Zn, Cu, Ni, Pb, U, Fe, Mn and Hg). In contrast, the texture of these sediments, using estimates of fines content as an index, only significantly influences W concentrations.

With the methodology described, Duncan's Multiple Range Test provides a systematic method of utilizing non-parametric data to classify geochemical samples and improve estimates of background and threshold values. Results also provide objective criteria for assessing susceptibility of trace element dispersion to environmental factors and for deciding which factors warrant recording in future surveys.

SAMPLING AND ANALYTICAL ERRORS IN GEOCHEMISTRY: THEIR VARIATION WITH THE METAL CONTENTS IN STREAM SEDIMENTS

by

B. Bølviken, J. Ekremsaeter, R.T. Ottesen and T. Volden

From 1968 on the Geological Survey of Norway has been carrying out a regional geochemical mapping program in southern Norway based on a reconnaissance sampling of stream sediments. Up to now the contents of V, Mn, Fe, Co, Ni, Cu, Zn and Pb have been obtained from more than 6 000 sample sites.

The samples are collected at road stream intersections, and at each site two samples are taken. These samples are treated independently during the chemical analysis. This procedure enables an estimation of the precision of the element concentration at each sample site. For the 8 elements studied an average variation coefficient of around 20 percent is obtained. For most elements the relative error appears to have a minimum value in the middle of the concentration range and increases significantly toward both high and low concentrations. Copper shows a decreasing variation coefficient with increasing concentration and provides an exception from this rule.

GEOCHEMISTRY OF TIN, TUNGSTEN AND MOLYBDENUM IN SWEDISH PROTEROZOIC GRANITOIDS:
THEIR POTENTIAL USE IN REGIONAL MINERAL EXPLORATION
by
K-M. Drake

The primary aim of this broad regional study is to statistically determine
the Li-Sn-W-Mo-bearing potential of various granitoids using geochemical
criteria. Computer-based, univariate and multivariate statistical methods are
applied to major and trace element data from about 660 granitic rock samples
and over 800 major element analyses, selected from the Swedish geological
literature. The granitoids are subdivided following earlier
geotectonic-chronologic and newer geochemical-statistical principles.
Most granite types occurring in known Sn-W mineralized areas, except the
granites around the W deposit of Baggetorp, were identified as potentially
W-Sn-bearing. That is, they show significantly high mean and variance values
for W and/or Sn as well as promising values of the probability parameters for
these elements, compared to corresponding statistics for a calculated Swedish
average granitoid (SAG).
Evidence of very high total variability of Li, Sn and W within the
individual granite types suggests the need for further tests, to control the
variability errors due to sampling and preparation and errors of chemical
analysis. These sources of error may obscure natural elemental heterogeneity
of the granite type that is of interest in geochemical prospecting.
Interpretations of Sn, W and Li frequency distribution patterns,
petro-chemical trends and multivariate similarity tests suggest that the
primary chemistry of the granitoids is overprinted by a) postmagmatic
processes of broad regional nature, which have similarly affected the
individual granite types, and b) a wide varity of secondary alterations of
local character. These conclusions imply that potential Sn and W deposits may
be sought within all Swedish Proterozoic granitoids and their immediate
surroundings, where such processes have redistributed and concentrated these
elements. However, the granites which are highly differentiated,
Sn-W-Li-U-Th-F-enriched, and strongly magnetic are particularly promising
target areas for further, extensive rock-geochemical prospecting and other
exploration surveys.

COMPUTER ANALYSIS OF MINERALIZATION WITHIN EVOLVING CALDERA AND SUBVOLCANIC
SYSTEMS, BONANZA AND BRECKENRIDGE MINING DISTRICTS, COLORADO MINERAL BELT, USA
by
D.E. Pride and E.J. Hasenohr

Computer study of the data from large numbers (>500) of soil samples has
proven useful in summarizing the regional distributions of elements, and in
helping to understand the genesis of mineralization with respect to the
geologic development of the Bonanza and Breckenridge mining districts. It is
felt that vein-type mineralization in both districts may be related to the
presence at depth of one or more mineralized intrusions—intrusions that may
carry "Climax-type" porphyry molybdenum mineralization. The aim of the sample
surveys in both districts was to identify regional trends in mineralization

within the surface rocks, and to use the trends, together with the distributions of persistent positive residual anomalies, and the geology, to look for centres of mineralization in the subsurface rocks.

Computer studies included isochemical mapping of raw and log-transformed data, and trend surface and residuals mapping at the 1st, 2nd, 3rd, 4th, 5th and 6th orders. It has been possible to refine and simplify the raw data using trend surface and residuals maps. With few exceptions, we can identify persistent trends in mineralization with low-order surfaces, thus pinpointing regional patterns without having to carry the analysis to the point where the trend surface maps begin to resemble isochemical plots for the raw data. The first surface for which one or more persistent trends become evident is termed herein the principal surface, and the positive residual values for the principal surface that persist at the 6th order are termed the persistent positive anomalies. By combining the persistent positive anomalies and the principal surface, it is possible to summarize the computer analysis for each element on one map. The geology also may be included on the map. We feel that an understanding of the surrounding geology is essential to the interpretation of the trend surface and residuals data; conversely, the computer-generated maps help in interpreting the geochemical data with respect to the geology of both the Bonanza and Breckenridge districts.

A total of 1 566 soil samples were collected over an area of about 230 km^2 encompassing the Bonanza district; and 673 samples were collected within the 115 km^2 of the Breckenridge district. A grid spacing of 400 m was used in both sampling programs. Because of the relief in both areas, and the elevations (Bonanza, ranging from 2 600 m to >3 650 m; Breckenridge, from 2 775 m to >3 950 m), the "soil" samples largely were of colluvial debris plus a thin soil cover. The organic material was removed from the samples, prior to analysis for 28 elements by emission spectrograph. Copper, molybdenum, lead, zinc, and silver were chosen for detailed study.

The Bonanza district covers an area of about 75 km^2 and lies within a poorly understood caldera complex that developed in the late Oligocene within the San Juan volcanic field of southwest Colorado. Rocks of the district include andesitic and latitic lavas and tuffs that were intruded by rocks ranging in composition from monzonite to rhyolite. Two stages of hydrothermal alteration have been described for the district: an early pervasive silicification, and a later propylitic to phyllic phase accompanying vein mineralization. Economic mineralization consists of sulphide and telluride veins carrying lead, zinc, copper, silver, and gold. Fluorite gangue is present in some of the veins.

The Breckenridge deistrict is located about 95 km west-southwest of Denver, Colorado, and covers an area of about 115 km^2. The mineralization is within a composite Eocene (?) stock composed largely of monzonite, quartz monzonite, granite, and rhyolite porphyries. The complex probably formed in a subvolcanic environment and the accompanying volcanics were removed by erosion. The presence of several small bodies of intrusion breccia suggest that the intrusive activity was near-surface in nature. Wall rock and pervasive hydrothermal alteration in the district ranges from propylitic to phyllic-argillic in character, and the economic mineralization occurs as vein and breccia fillings carrying zinc, lead, gold, silver, and copper.

The principal trend surfaces for the Bonanza data are: molybdenum (2nd), lead and silver (3rd), zinc (4th), and copper (6th). Mineralization is present within the eastern part and across the eastern margin of the caldera. The principal surfaces and persistent positive anomalies indicate that mineralization is related to ring-type intrusions around the margin of the

caldera. Considered together, the distributions for all elements studied suggest that the northeastern margin of the caldera may be underlain by a large mineralized system. No ring intrusion crops out in this area, although the greatest surface elevations are present there. A second large-scale mineralized system may be present along the southeast margin of the caldera. A ring-type intrusion is present at the surface in roughly this locality, and the rocks there exhibit strong silicification. Published accounts of early drilling in the vicinity encountered high temperature alteration and mineralization a short distance below the surface. Anomalous molybdenum and zinc, external to the caldera margin on the east and southeast, suggest that the mineralization history in the southeast part of the Bonanza caldera may have been complex.

The principal surfaces and persistent positive anomalies for the Breckenridge district are: silver, molybdenum, and lead (3rd); and copper (5th). The trend surfaces and accompanying positive residuals indicate that in most cases the mineralization in the Breckenridge district is related to silicic intrusions and, in particular, to the intrusion breccias. This relationship is clearly demonstrated by the principal surface and a persistent positive anomaly for molybdenum, both apparently related to a body of intensely altered rhyolite porphyry and accompanying intrusion breccia in the south-eastern part of the district. In addition, the principal surfaces and certain large and persistent positive anomalies for lead, silver, and, to a lesser extent, copper and molybdenum are associated with a set of closely-spaced northeast-trending faults and fissure veins within the western part of the district. This information, plus the presence of silicic intrusions and intrusion breccias in the western and northern parts of the district, suggest that more than one centre of mineralization may be present in the Breckenridge district.

RECENT ADVANCES IN GEOCHEMICAL EXPLORATION IN CHINA

by
Xie Xuejing and Kang-Le Zheng

This paper summarizes the rapid advance of geochemical exploration in China since the 1980 Hannover Symposium.

A great deal of the research work is now being focussed on the "Regional Geochemistry-National Reconnaissance" Program. Development of multi-element analysis schemes suitable for the RGNR Program was jointly undertaken by many laboratories, using refined emission spectrographic methods, supplemented by atomic absorption, atomic fluorescence and polarographic methods for the rapid determination of 33 elements with satisfactory sensitivity, precision and accuracy.

Standard reference drainage sediment samples (GSD 1-8) have been prepared. Cooperative analysis of more than 40 trace element contents were undertaken by 39 laboratories. More than 7 000 sets of data were processed by computer and "usable values" of 30 elements published for use. A data monitoring system has been developed, and tested in large scale operation.

Effectiveness of mercury vapour surveys has been greatly improved by the development of a new gas sampler, and by the use of a new type of mercury vapour analyzer. Good results were obtained over various kinds of thick transported overburdens.

The evolution of analytical, sampling and data processing techniques by intensive research work is vindicated by the increasing number of successes in the discovery of new ore deposits.

A brief account of geochemical exploration for hydrocarbons and hydrothermal energy is given: both are in the early stages of development.

DISTRIBUTION OF MERCURY COMPOUNDS IN ORE AND COUNTRY ROCK AT SIGMA GOLD MINE, VAL D'OR, QUEBEC
by
A. Aftabi and L.M. Azzaria

There is continued interest in mercury distribution as an aid in the search for base and precious metals. A number of studies have also been carried out on the distribution of mercury compounds in wall rocks as guides to exploration for base metals. This investigation aims at evaluating the distribution of mercury compounds as a guide to gold mineralization. Ore zones and country rocks at the Sigma gold mine (Val d'Or, Quebec) are the subject of the study.

The Sigma gold mine occurs in ultrabasic to intermediate Archean volcanic rocks cut by intrusive rocks of dioritic and granodioritic composition. The volcanic rocks are metamorphosed, altered and deformed. Gold mineralization occurs in veins along shear zones and fractures. The veins contain quartz, tourmaline, pyrite and carbonates. Gold is frequently associated with pyrite. The main alteration types are chloritization, silicification and sericitization. All the rocks and structures of the known deposit are cut by late diabase dykes.

Ore and rock samples are heated in air and the liberated mercury collected on gold. The gold is heated to liberate the mercury which is measured by flameless atomic absorption. Mercury compounds are determined in the same way, but heating is done in steps depending on the mercury release temperatures of mercury compounds. Stepwise heating was chosen instead of continuous heating, as in the latter method curves from some mercury compounds are superposed. In addition, we suspect interference from sulphur oxides in the case of continuous heating.

It was found that maximum total mercury is released by heating samples, < 0.061 mm in size, for 40 minutes at 900°C. The results to date for total mercury are as follows: ultrabasic rocks, 1-2 ppb; basic rocks, 2-5 ppb; andesites, 4-6 ppb; tuffs, 4-6 ppb; porphyry dykes, 5-30 ppb; veins, 50-100 ppb.

Results show that the proportions of mercury compounds are as follows: 1) The mercury in porphyry dykes consists of 60 to 85% mercury chlorides, and 15 to 40% mercuric sulphide; 2) The mercury in veins is made up of 10-15% mercury chlorides, 35-45% mercuric sulphide, and 45-55% is released from pyrite.

To date anomalies of total mercury, of mercuric sulphide, and of mercury released from pyrite, are wider than the ore zone. On the other hand the concentration of mercury chlorides is lower in the ore zone than in the wall rocks.

THE USE OF K/Tl AND Tl/Sr RATIOS AS GUIDES TO MINERALIZATION
by
M. Ikramuddin, P.M. Nordstrom, K.P. Kinart, W.M. Martin, S.J.M. Digby, D.D. Elder, W.F. Nijak, and A.A. Afemari

A simple, rapid, and accurate method has been developed for the determination of thallium in geologic materials at the one part per billion level. The method is based on solvent extraction of Tl into an organic phase and determination by electrothermal atomic absorption spectrophotometry. Utilizing this method, about 300 rocks associated with uranium, gold, silver, molybdenum, and copper deposits have been analyzed. In addition contents of about 25 major and trace elements have been determined, and analyses of 200 additional samples are in progress. The rocks were collected from known mineralized areas in Washington and Montana which include uranium deposits of the Midnite Mine area, gold-silver deposits of the Republic district, the Mount Tolman copper-molybdenum deposit, and the gold deposits of the Kendall district.

Several recent studies have demonstrated that Rb and Sr can serve as potential pathfinders to locate ore deposits of hydrothermal origin and, in many cases, the hydrothermally altered rocks are known to have relatively low K/Rb and high Rb/Sr ratios.

We have found, however, an overlap of these ratios in altered and unaltered rocks in some cases. The work in progress in our laboratory indicates that Tl can be a better pathfinder element than Rb and that K/Tl and Tl/Sr ratios may be better guides to mineralization of hydrothermal origin than K/Rb and Rb/Sr ratios.

Abundances of K, Rb, and Tl in hydrothermally altered and unaltered rocks from known mineralized areas under study indicate a relatively high concentration of Tl in altered rocks. This high concentration may be due to the enrichment of Tl in hydrothermal fluids relative to K and Rb, since the Tl-O bond is more covalent than either the K-O or Rb-O bond and Tl is known to form highly volatile complexes.

The results obtained in the present investigation indicate that the concentrations of Tl in rocks from mineralized zones are significantly higher than those from non-mineralized areas. We believe, therefore, that the primary dispersion of Tl in conjunction with the dispersion of K, Rb, and Sr might prove to be a more useful guide in delineating ore deposits of hydrothermal origin.

CHEMISTRY OF THE 350°C HOT SPRINGS ON THE CREST OF THE EAST PACIFIC RISE AT 21°N
by
J.M. Edmond

Hydrothermal fields on submarine spreading centres were first studied systematically during dives of the deep submersible ALVIN on the crest of the Galapagos Ridge in 86°W in the spring of 1977. While the exiting waters had temperatures only about 20°C above that of the ambient water column detailed analysis of their chemistry showed them to be formed by mixing of cold seawater (as 'groundwater') with a hydrothermal end-member of approximate

temperature 350°C. Subsequently fields of hot springs with this temperature were found on the crest of the East Pacific Rise at 21°N by ALVIN in 2 600 metres water depth. Reconnaissance water sampling of these systems was made in November 1979 and a detailed study has just been completed (November 1981).

The 350°C solutions are completely depleted of their original seawater concentrations of Mg and SO_4. They are acid with a pH (25°C, 1 atmos) of 3.6 and an acidity of 400 μeq/kg. They contain about 7 mmol/kg of H_2S. The isotopic composition of this sulphur and the arsenic to sulphur ratio in the solutions indicate that about 85% of it is of igneous origin. The 'soluble elements' Li, K and Rb are strongly enriched over the seawater values, as are Ca and Ba. Sr is present at close to the seawater concentrations however the isotopic composition is identical to that of the basalts. The exiting solutions are clear and homogeneous super-critical fluids of in situ density approximately 0.65 gm/cc. Velocities in the throat of the orifices are around 1.5 m/sec. The iron concentrations are 1.8 mmol/kg and the Fe/Mn ratio is about 3. The reconnaissance samples gave Zn of 120 μmol/kg and Cu and Ni of about 15 μmol/kg. A complete account of the metal chemistry, based on the recent expedition, will be available for presentation at the meeting.

Upon mixing with seawater the hot springs precipitate a voluminous black 'smoke' predominantly composed of fine-grained FeS. Anhydrite is precipitated around the throat of the orifice producing chimney-like constructional features up to 10 metres high. As these grow vertically the anhydrite is replaced by sulphide minerals. The outer surface of the chimneys is colonized by several species of worms that secrete mats of tubes, up to several centimetres in diameter, composed of a tough organic material. Lateral growth of the chimneys via leaks in their walls leads to precipitation of sulphide minerals in a morphology controlled by the organic mats. All the numerous extinct sulphide deposits in the area have this characteristic surface texture.

The active deposits on the EPR are unlike ophiolite type massive sulphides chemically, mineralogically and texturally. However they do represent the primary precipitate. It appears that during lateral growth and coalescence of the chimneys in a given field the original deposit is re-worked chemically as the 350°C solutions stream through the disequilibrated, rapidly precipitated material. A 'zone refined' substrate results consisting of coarsely crystalline, permeable relatively pure pyrite. This secondary deposit is of course capped with juvenile chimneys. It is these that probably constitute the ochres, the oxidized surficial zones of massive sulphides historically worked for silver and other elements present at only trace levels in the bulk deposit.

As part of this presentation colour video and film footage of the hydrothermal fields will be shown. There will be a display of representative samples of the deposits themselves.

HYDROTHERMAL DEPOSITION ON THE EAST PACIFIC RISE AT 21°N
by
R.M. Haymon

In the spring of 1979, 350°C springs precipitating hydrothermal sulphides and sulphates directly on to the seafloor were discovered on the crest of the East Pacific Rise (EPR) at 21°N by the astonished scientific

party of the RISE submersible expedition. These hot springs are within a linear field of active and inactive hydrothermal vents extending 6 km along the rise axis. Typically the mineral deposits at EPR, 21°N consist of basal sulphide mounds surmounted by mineralized sulphide-sulphate edifices, or "chimneys", reaching heights up to 13 m above the seafloor. The mounds rest directly on fresh basalt and cover areas up to 450 m². Chimneys atop mounds may be active or dead. The hottest active chimneys (350°C) spew forth fluids blackened by fine-grained sulphide precipitates, dominantly hexagonal pyrrhotite and iron-rich sphalerite. These "black smokers" are distinguished from cooler "white smoker" chimneys which are encrusted by worm tubes and emit milky fluids bearing amorphous silica, barite, and pyrite.

Approximately 135 kg of hydrothermal precipitates were collected during the RISE program from eight active and inactive vent sites. The mineralogy, petrography, chemistry, and isotopic composition of these samples has been studied extensively by X-ray diffraction, scanning electron microscopy, X-ray energy dispersive analysis, ore microscopy, electron microprobe analysis, atomic absorption spectroscopy, neutron activation analysis, and mass spectrometry. This work has shown that the deposits as a whole are dominated by sphalerite and wurtzite along with abundant iron-sulphides (pyrite, marcasite, melnikovite, and rare pyrrhotite), and lesser copper-rich sulphides (chiefly chalcopyrite and cubanite with minor bornite-chalcocite solid solution, covellite, and digenite). In active chimneys anhydrite also is a major constituent. Minor but ubiquitous phases in the EPR 21°N deposits include amorphous silica, barite, talc, native sulphur, iron oxyhydroxides, jarosite and gypsum. Galena was found intergrown with sphalerite in a single sample. A magnesium-hydroxysulphate-hydrate phase intergrown with anhydrite was identified in one active black smoker sample. This new mineral, which will be named "caminite" after the Latin word for chimney, caminus, was expected in submarine hydrothermal systems on the basis of results from laboratory seawater heating experiments. In addition to the major and minor elements in the vent deposits (zinc, iron, copper, sulphur, calcium, magnesium, silicon, and barium), abundant trace elements include As, Cd, Mn, Sb, V, Ag, and Pb.

The walls of black smoker chimneys are mineralogically, chemically, and texturally zoned from interior to exterior. The exterior skin of a black smoker consists of fine-grained pyrrhotite, sphalerite, and pyrite in a matrix of anhydrite. The mineralogy and textures of the sulphide phases in this outermost zone closely match the mineral composition and quenched textures observed in the suspended black smoke particulates filtered from water samples collected above 350°C chimneys. Interior to this outer skin of quenched sulphides is a zone of coarser, more euhedral zinc-sulphide (sphalerite and/or wurtzite) and iron-sulphide (pyrite and/or marcasite) intergrown with anhydrite. No pyrrhotite is found in this zone. In the centre of the chimney, a zone of Cu-Fe sulphides precipitates. In some cases chalcopyrite and/or cubanite with rare pyrrhotite are the sulphide constituents of this inner zone. In other cases the inner chalcopyrite zone is separated from the zinc- and iron-sulphide outer zone by an envelope of bornite-chalcocite solid solution. The composition of the bornite envelope grades outward from iron-rich bornite into iron-poor bornite or chalcocite intergrown with covellite, digenite, and the zinc- and iron-sulphides of the outer chimney wall. Chimneys do not always develop a Cu-Fe-sulphide zone. Some dead chimneys are plugged by fillings of zinc- and iron-sulphides and native sulphur. These chimneys are covered with fossilized worm tubes and may well be the inactive equivalents of white smokers. Another dead chimney sample

possesses a chalcopyrite zone, but wurtzite precipitated into the chimney centre during the final stages of chimney activity. Sulphur isotopic values substantiate that sulphide in the deposits has an igneous source and that anhydrite in active chimneys precipitates from normal seawater.

The evidence suggests the following simplified story for the evolution of a vent deposit. Chimneys are initiated on the seafloor by the simultaneous precipitation of a pyrrhotite-sphalerite assemblage from quenched hydrothermal solutions and an anhydrite-caminite assemblage from heated seawater. These phases form the early walls of chimneys and contribute to the outward thickening and upward growth of chimney walls. The formation of the early walls protects the discharging solutions from mixing and quenching and maintains high temperatures and low pH within the central conduit. This allows Cu-Fe-sulphides to grow inward towards the chimney centre and to replace previously formed sulphides in the outer chimney wall. During the initial stages of chimney growth, mixing across chimney walls may produce an interior-to-exterior zonation of chalcopyrite → iron-rich bornite → iron-poor bornite → chalcocite + covellite. Sealing of the chimney walls by mineral precipitation eradicates mixing gradients and allows the chimney walls to heat up. The chalcopyrite zone then advances outward, replacing bornite and the copper-sulphides in the outer chimney wall. Eventually either the subsurface feeders or the central conduit of a chimney become choked with minerals, and the flow of water and heat are reduced to a trickle. The chimney then cools, and coarse blades of wurtzite grow into the central conduit. A chimney which was previously a black smoker may at this stage become encrusted by vent worms and transform into a white smoker. As individual chimneys fill with sulphides and die, the hydrothermal fluids seek new outlets and construct new chimneys. The dead chimneys are unstable features, physically friable, often top-heavy, and chemically suspectible to breakdown on the seafloor by dissolution, oxidation, and autocatalytic corrosion. Anhydrite and caminite are completely dissolved from dead chimneys and a new assemblage of oxyhydroxides and hydrous sulphates and chlorides are produced by low-temperature seafloor alteration of the sulphide minerals. In time, dead chimneys are reduced to rubble which accumulates to form basal mound structures. If the deposits are not covered and preserved by fresh lava flows at the rise crest the vent materials will disaggregate, oxidize, and virtually disappear in a few thousand years. Surficial vent deposits are thus confined to within a few kilometres of the ridge axis, although disaggregated remnants may persist as components of metalliferous basal sediments.

The influence of the axial vent activity on the geochemistry of sediments from the west flank of the EPR at 21°N was investigated by studying the mineralogy and chemical composition of gravity cores and submersible push cores on a transect perpendicular to the rise crest. The cores are siliceous clays composed of smectite, biogenic silica, detrital minerals, and variable calcite. Their chemistry does not in general depart from that of normal pelagic sediments, indicating that the hydrothermal plume emanating from the axial hot springs does not advect westward over the rise flank. Heat flow data and manganese concentrations in core tops away from the ridge crest suggest, however, that a low temperature, off-axis hydrothermal system may be operating 30-40 km west of the rise crest.

SULPHIDE MINERALIZATION AND WALLROCK ALTERATION IN OPHIOLITES AND MODERN OCEANIC SPREADING CENTRES

by
R.A. Koski

Massive and stockwork Fe-Cu-Zn (Cyprus type) sulphide deposits in the upper parts of ophiolite complexes represent hydrothermal mineralization at ancient accretionary plate boundaries. These deposits are probable metallogenic analogues of the polymetallic sulphide deposits recently discovered along modern oceanic spreading centres. Genetic models for these deposits suggest that mineralization results from large-scale circulation of seawater through basaltic basement along the tectonically active axis of spreading, a zone of high heat flow. The high geothermal gradient above 1 to 2 km-deep magma chambers emplaced below the ridge axis drives the convective circulation cell. Cold oxidizing seawater penetrating the crust on the ridge flanks becomes heated and evolves into a highly reduced somewhat acidic hydrothermal solvent during interaction with basaltic wallrock. Depending on the temperature and water/rock ratio, this fluid is capable of leaching and transporting iron, manganese, and base metals; dissolved seawater sulphate is reduced to sulphide. At the ridge axis, the buoyant hydrothermal fluid rises through permeable wallrocks, and fluid flow may be focussed along deep-seated fractures related to normal or transform faults. Metal sulphides are precipitated along channelways as the ascending fluid undergoes adiabatic expansion and then further cooling during mixing with ambient sub-seafloor water. Vigorous fluid flow results in venting of reduced fluid at the seafloor/seawater interface and deposition of massive sulphide. A comparison of sulphide mineralization and wallrock alteration in ancient and modern spreading centre environments supports this genetic concept.

Massive sulphide deposits in ophiolites generally occur in clusters of closely spaced (< 1-5 km) deposits. Individual deposits are a composite of syngenetic massive sulphide and underlying epigenetic stockwork-vein mineralization. The massive sulphide occurs as concordant tabular, lenticular, or saucer-shaped bodies in pillow lavas and pillow-lava breccia; massive lavas flows, hyaloclasite, tuff, and bedded chert are less commonly associated rock types. These massive sulphide zones are as much as 700 m long, 200 m wide, and 50 m thick. The pipe-, funnel-, or keel-shaped stockwork zone may extend to depths of 1 km in the sheeted-dike complex. Several deposits in Cyprus are confined to grabens or the hanging wall of pre-mineralization normal faults.

Polymetallic massive sulphide deposits and active hydrothermal vents at medium- to fast-rate spreading centres (the East Pacific Rise at lat. 21°N, the Galapagos Ridge at long. 86°W, the Juan de Fuca Ridge at lat. 45°N., and the southern trough of the Guaymas basin, Gulf of California) have interdeposit spacings on a scale of tens or hundreds of metres, and are spatially associated with structural ridges or grabens within the narrow (< 5 km) axial valleys of the rift zones. Although the most common substrate for massive sulphide accumulations is stacked sequences of pillow basalt and sheet flows, the seafloor underlying numerous deposits in the Guaymas basin consists of diatomaceous ooze and of terrigenous clastic sediment that was intruded by diabase sills. Mound-like massive sulphide deposits, as much as 30 m wide and 5 m high, occur over actively discharging vents on the East Pacific Rise, and many of these deposits serve as the base for narrow chimneys and spires of equal or greater height. Sulphides on the Juan de Fuca Ridge

appear to form more widespread blanket deposits in the shallow axial-valley depression. The largest deposit found to date along the axial ridge of the Galapagos spreading centre has a tabular form and a length of 1 000 m, a width of 200 m, and a height of 30 m.

The sulphide assemblage in both massive and vein mineralization in Cyprus type deposits is characteristically simple: abundant pyrite or, less commonly, pyrrhotite accompanied by minor marcasite, chalcopyrite, and sphalerite. With few exceptions, the composition of massive sulphide ranges from 0.3 to 5 wt% Cu, from 0.1 to 3 wt% Zn, from 0.5 to 30 ppm Au, and from 1 to 50 ppm Ag. The only common gangue minerals--quartz, chlorite, calcite, and gypsum--generally make up less than 10 percent of the massive zone.

Sulphide assemblages in massive sulphide samples recovered from the Juan de Fuca Ridge (abundant sphalerite, wurtzite, and pyrite; minor marcasite, chalcopyrite, and galena), lat. 21°N., East Pacific Rise (abundant sphalerite, pyrite, and chalcopyrite; minor wurtzite, marcasite, and pyrrhotite), and the Guaymas basin (abundant sphalerite and pyrrhotite; minor chalcopyrite) contrast with ophiolitic deposits. Bulk analyses of two zinc-rich sulphide samples from the Juan de Fuca Ridge yield the following average values: Zn, 56.6 wt%; Cu, 0.2 wt%; Pb, 0.15 wt%; Fe, 4.9 wt%; Ag, 260 ppm; and Cd, 775 ppm. Other minerals precipitated with sulphides at hydrothermal-vent sites include anhydrite, barite, gypsum, Mg-hydroxysulphate-hydrate, tac, sulphur, and amorphous silica.

Massive sulphide lenses in some Cyprus-type deposits are underlain by a silica-rich zone consisting of massive quartz, opaline silica, red jasper, or chert mixed with disseminated and veinlet Fe-Cu-Zn sulphides. Some deposits are overlain by ochre, a gossanous Mn-poor Fe-rich bedded deposit composed of goethite, maghemite, quartz, and finely disseminated and layered sulphide. In the British Solomon Islands, ochre is overlain by siliceous sinter containing anhydrite, barite, and sulphide; the sinter contains anomalous Ag, Au, Cu, Zn, and Hg, and grades upward into iron-rich chert and manganiferous wad. Amorphous Fe-Mn deposits (umber) and Mn-bearing chert enriched in Ba, Co, Cu, Ni, Cr, Pb, and Zn are common features near the top of ophiolite sequences. Although their genetic relation to sulphide mineralization is uncertain, they probably formed during off-axis hydrothermal discharge.

At modern, medium-rate spreading centres, thin blankets of unconsolidated hydrothermal sediment, composed largely of nontronite and, possibly, amorphous silica and sulphate, have been observed near hydrothermal sulphide deposits. Basalt fragments recovered with massive sulphide from the Juan de Fuca Ridge have surfaces coated with smectite, magnetite, hematite, opaline silica, and Fe-Mn-oxyhydroxides. Sediment mounds composed largely of Fe silicate and hydrated Fe and Mn oxides, and more distal basal metalliferous (Fe, Mn, Cu, Ni, Pb, Zn) sediment on the flanks of ocean ridges, are also products of off-axis hydrothermal processes.

Pillow lavas, diabase dikes, and gabbro in ophiolite sequences, and deeper, layer 2 basalt and diabase sampled from oceanic ridges, are pervasively recrystallized to greenschist-facies assemblages (albite+chlorite+ actinolite+sphene+quartz+pyrite) during high temperature sub-seafloor hydrothermal metamorphism near the axis of spreading. Chemical changes in the wallrock during this large-scale seawater/rock interactive episode depend on the water/rock ratio and temperature but generally include gains in Na, Mg, Fe^{3+}/Fe^{2+} ratios and H, and losses of Ca and Cu. Subsequent low temperature seawater/rock interaction away from the axis of spreading results in fracture-controlled zeolite-facies alteration, characterized by smectite,

celadonite, zeolites, calcite, prehnite, hematite, marcasite, and pyrite. This retrograde alteration involves local remobilization of Al and Si and increases in total Fe, Mg, and K in the wallrock.

Wallrock alteration in Cyprus type stockwork zones is more striking, in that the basalt and diabase between veins of Fe-Cu-Zn sulphides, quartz, and chlorite have undergone partial to complete conversion to fine-grained aggregates of quartz+chlorite+illite+pyrite; kaolinite and palygorskite may be present in minor amounts. Ca and Na are strongly depleted; K, Al, Ti, Mn, and Ni are leached to a lesser extent; and Fe, S, Cu, Zn, and Co are strongly enriched in the wallrock underlying massive sulphide. Mafic rocks at depth in the volcanic pile may be enriched in K, Rb, and Li, and depleted in Cu, Co, and Zn. Lavas lateral to and overlying massive sulphide mineralization may have low concentrations of Cu and high concentrations of Zn and Co relative to background levels.

Mutual consideration of hydrothermal sulphide deposits and associated wallrock alteration in ophiolites and at modern oceanic spreading centres can provide useful criteria for the development of regional exploration models for ophiolitic terrains.

ARCHEAN SEA-FLOOR HYDROTHERMAL SYSTEMS: THE THIRD DIMENSION
by
R.H. Ridler

Mafic to felsic predominantly marine volcanic members on the west flank of the major volcanic vent of the relatively unmetamorphosed and undeformed Archean upper Blake River Group of the Noranda area were sampled at approximately 100 m centres in a 100 km^2 area for whole rock analysis as part of an integrated exploration program during 1977-1980. Automatic processing of the resulting approximately 2 000 analyses yielded not only the expected improved definition of primary rock types but also synvolcanic alteration patterns of varying intensity. Essentially two dimensional sea floor "weathering" on paleo-bedding surfaces and the more fully three dimensional, hydrothermal, volcanogenic, footwall alteration systems were discovered. The data, when integrated with existing drill and mining information provide a unique insight into the hidden shape of the sub seafloor plumbing of the recently discovered active hydrothermal, biologic systems observed in two dimensions at crustal spreading centres on today's ocean floor.

Polarized compositional gradients observed within the footwall alteration patterns are interpreted to be potent exploration guides to proximal, polymetallic, sulphide facies exhalite deposits and their associated "stringer" zones.

TUFFACEOUS EXHALITES AS EXPLORATION GUIDES FOR VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS
by
S.D. Scott, S.I. Kalogeropoulos, R.J. Shegelski and J.M. Siriunas

Ancient hydrothermal activity on the sea floor not only resulted in

economic accumulations of copper, lead and zinc sulphides but, in some volcanogenic massive sulphide (v.m.s.) districts, it also produced an associated, distinctive, thin iron- and silica-rich sediment with geochemical and mineralogical anomalies which can provide stratigraphically-controlled lithogeochemical exploration guides. The distinctive rock type is referred to in Japan, as tetsusekiei (literally iron-quartz) and, in North America, as ferruginous chert, graphitic chert, cherty tuff, tuffite, sulphide iron formation, etc. The term we prefer is "tuffaceous exhalite" which denotes a rock consisting of a mixture of two very different components: (1) tuff which is commonly chemically and texturally indistinguishable from that of the indigenous environment, and (2) chemical contributions from the exhalative plume in the form primarily of silica, iron (oxide and/or sulphide), sulphur and various trace elements, and graphite or kerogen of uncertain origin. Of the two components, the latter is expected to reflect best any chemical or isotopic anomalies in seawater adjacent to metalliferous hydrothermal discharge, and therefore to provide the more useful lithogeochemical information in the search for v.m.s. deposits. On this basis, we have carefully separated the two components, either physically or statistically, in our analyses in order to avoid the problem caused by their variable ratios from sample to sample, which might mask real trends in the distribution of trace elements. In some cases, however, we have found that chemical interaction between the two components during penecontemporaneous alteration or subsequent metamorphism precluded the clean separation we were seeking. We have studied the following areas of tuffaceous exhalites of contrasting age and metamorphism as part of an ongoing research program on lithogeochemical exploration for v.m.s. deposits:

(1) Sturgeon and Savant Lakes, NW Ontario, Archean age, low grade metamorphism; (2) the iron formation hosting Willroy no. 4 orebody, Manitouwadge district, Ontario, Archean age, high grade metamorphism; (3) the Main Contact Tuff, Millenbach mine, Noranda, Quebec, Archean age, low grade metamorphism; (4) Austin Brook iron formation, Bathurst district, New Brunswick, Ordovician age, moderate metamorphism; and, (5) tetsusekiei of Fukazawa mine, Hokuroku district, Japan, Miocene age (13Ma), not metamorphosed.

The Sturgeon-Savant Lakes area contains both small isolated sulphide-rich tuffaceous exhalites and thick laterally-continuous oxide-rich tuffaceous exhalites. The latter are normal magnetite-bearing iron formations. Our study was not sufficiently well controlled stratigraphically with respect to known ore horizons to test the tuffaceous exhalites systematically for lithogeochemical prospecting. However, spatial associations here are significant. The sulphide-rich rocks were formed at higher submarine elevations within pyroclastic piles and closer to ore-forming and barren hydrothermal fumaroles than were the oxide-rich rocks. In this respect, the iron formations at Sturgeon-Savant differ from the Ordovician magnetite-rich Austin Brook iron formation which immediately overlies large v.m.s. deposits at Bathurst, although even the Austin Brook has a regionally persistent sulphide-rich basal portion. The geochemistry (pyrite/carbon ratios, S/Se and Co/Ni in pyrite, S and C isotopes) of the Sturgeon-Savant sulphide-rich tuffaceous exhalite is consistent with mixing a small amount of hydrothermal fluid with excess seawater in an otherwise normal, low temperature marine, sedimentary environment. Biogenic activity is permissible but not proven by the isotopic data. Abundance and distribution of base metals relative to the orebodies is erratic and nondiagnostic.

The Willroy no. 4 orebody is enclosed within a quartz-(formerly chert ?) and sulphide-rich (predominantly pyrite and pyrrhotite) tuffaceous exhalite

which grades laterally into normal magnetite-rich banded iron formation extending several hundred metres from ore. Three fractions (silicate, magnetic, sulphide) of drill core samples analyzed by INAA for Cu, Zn, Sn, Co, Ag, Au, V, Se, As, Sb, Mn, S, Ni and In give similar distribution patterns but, not unexpectedly, the pattern in the sulphide fraction is most sharply defined. Most elements are obviously anomalous only very close (a few metres) to ore. Ag and As give good haloes up to 200 m. Results are enhanced by factor analysis and mapping of factor scores. Haloes extend for several hundred metres from ore for factors Cu-Au-Ag-As and Zn-Sb-As-Sn. An anomalous zone of unknown origin was located within the tuffaceous exhalite about 400 m from the orebody.

The tuffaceous exhalites in the immediate hanging wall of the Japanese Kuroko v.m.s. deposits (e.g., tetsusekiei of Fukazawa mine) and of the Noranda v.m.s. deposits (e.g., Main Contact Tuff, MCT, Millenbach mine) are remarkably similar rocks despite the very large difference in their ages (Miocene vs. Archean). The main mineralogical difference is the presence of pyrrhotite in MCT and of hematite, imparting a deep red colour, in tetsusekiei, both in an assemblage consisting predominantly of chlorite, sericite, quartz and sulphides. Their chemical differences are restricted to elements that characterize the immediate ore environment. For example, Pb and Ba in Kuroko ores and tetsusekiei are absent in Noranda ores and MCT. Texturally, the MCT is coarse grained due to recrystallization during low grade regional and contact metamorphism whereas the unmetamorphosed tetsusekiei is very fine grained. Typically, tetsusekiei is discontinuous and covers an area about four times that of the ore deposit whereas MCT is laterally continuous over hundreds of metres. In addition to locating a horizon of fossil hydrothermal discharge and therefore possible ore, both tuffaceous exhalites display cryptic variations which provide exploration guides at different scales: (1) Fe/(Fe + Mg) ratio of chlorites in the Noranda MCT decreases by 0.32 (from 0.63 to 0.31) over a distance of 0.3 km approaching ore from the N, and by 0.4 (from 0.72 to 0.32) over 1.5 km from the S. This trend is somewhat parallel to that of the whole-rock FeO/(FeO + MgO) ratio (from 0.8 to 0.37) but the chlorite variation is more sensitive for sulphur-rich samples. (2) Ilmenite is altered within 0.3 km of ore to assemblages containing (a) rutile + hematite + pyrite (Kuroko), (b) rutile + pyrrhotite + pyrite (Noranda) and (c) rutile + sphene + pyrrhotite (Noranda). (3) The most manganiferous ilmenites (up to 18 wt % MnO) are found closest to Millenbach ore. (4) Whole-rock oxygen isotopic values decrease from +9 ^{o}/oo (Kuroko ore horizon tuff) to 5.1 + 0.8 ^{o}/oo (tetsusekiei) over a distance of 0.5 km from ore. (5) $(K_2O + MgO) * 100/K_2O + MgO + Na_2O + CaO$ for the tuffaceous component of tetsusekiei and correlative ore horizon tuff increases from about 50 to 90% over 2-3 km approaching ore. (6) Trace metals of exhalative origin are enriched in tetsusekiei and in MCT relative to normal pelagic rocks but their distributions are erratic and seem to be controlled by multiple sources, most of which did not produce ore.

In summary, not only are tuffaceous exhalites good indicators of ancient hydrothermal activity on the sea floor, but they contain a variety of geochemical and mineralogical changes relative to ore which hold promise for lithogeochemical prospecting. Unfortunately, trace element distributions, which are relatively inexpensive to obtain by whole-rock analyses, are commonly very erratic and are inconsistent from district to district so are not a panacea for exploration.

LATERAL AND STRATIGRAPHICAL ZONATION OF CHALCOPHILE ELEMENTS ABOUT THE
HOWARD'S PASS (XY) STRATBOUND ZN-PB DEPOSIT, SELWYN BASIN, YUKON
by
W.D. Goodfellow, I.R. Jonasson and J.M. Morganti

The Selwyn Basin from the Ordovician to Middle Silurian represented a
fault-controlled epicratonic sea developed on a continental margin, and
bounded by the Mackenzie Platform on the east and north and the Cassiar
Platform to the west. Facies relationships within the Selwyn Basin during
most of the Ordovician and Silurian were symmetrical about the axis with
lenticular shale troughs oriented parallel to the margins, and cherts
developed further out in the basin. These facies relationships which
developed during the Lower Ordovician are interpreted as reflecting subsidence
along large extensional faults running parallel to the continental margins.
Evidence for fault movement at that time include abrupt facies changes,
lenticular belts of alkaline mafic volcanic flows and tuffs and local
thickening in shale troughs. Within the shale trough oriented parallel to the
Mackenzie Platform, stratabound Zn-Pb deposits (e.g. XY, Anniv, OP) formed
within local third-order basins.
Shallowing of the sea, most likely due to tectonic uplift during Middle to
Upper Silurian, resulted in a change in bottom water conditions from anoxic
waters during which organic-rich shales were deposited, to oxygenated waters
during which bioturbated mudstone were deposited. Continued uplift during the
Lower to Middle Devonian resulted in the erosion of much of the Upper Silurian
to Middle Devonian regionally, although Lower Devonian conodonts in the
Howard's Pass area indicate that this unconformity may not be recorded locally
in deep third-order basins.
From Middle to Upper Devonian, shale and mudstone were deposited over a
large area of the Selwyn Basin and adjacent platforms during a marine
transgression. During the Devonian stratabound Zn-Pb-Ba (e.g. Tom, Jason) and
barite (e.g. Oro, Tea) deposits formed within local grabens characterized by
abrupt facies changes and the rapid thickening of debris flows shed off
uplifted blocks. The Mississippian marked a period during which coarse and
fine black clastics derived from uplifted areas to the northwest were
deposited over most of the Selwyn Basin.
The XY is a disc-shaped stratabound Zn-Pb deposit composed of
finely-laminated sphalerite and galena within a light grey argillaceous
limestone at the base, and a more carbonaceous dark grey cherty mudstone
towards the top. Sphalerite and, to a lesser extent, galena have been
remobilized locally into a soft sediment cleavage, although the degree of
movement is generally small and restricted to beds within the active zone.
Other sulphides are conspicuously low although the pyrite content can range up
to 10 percent locally. The Ag content of galena is very low and sphalerite
contains moderately high contents of Hg and Cd. Rocks in the Howard's Pass
area have a well developed axial plane cleavage reflecting the Laramide
Orogeny which folded the XY deposit into an open syncline, the axis of which
trends northwest-southeast. This slaty cleavage is not noticeably mineralized
but more commonly contains organic material, quartz, carbonate and a little
pyrite.
Surface sections and core from drill holes intersecting rocks ranging in
age from Ordovician to Mississippian were measured and sampled for geological
and geochemical study. At the XY Zn-Pb deposit, stratigraphical and lateral
zonation both in the active mineralized zone and enclosing rocks have been

observed. Within the mineralized zone, there is a gross zonation of base metals with Pb/Pb+Zn ratios decreasing upwards and laterally towards the margins of the deposit. This zonation parallels a change in matrix compositions from finely laminated argillaceous limestone at the base to finely laminated cherty mudstone towards the top of the active zone. On a more detailed scale, several cycles within the active zone can be recognized with each cycle exhibiting this zonation and younger cycles becoming progressively depleted in Pb relative to Zn. The Cd/Zn ratios of sphalerites are also zoned within the active zone as shown by increasing ratios stratigraphically upwards and towards the margins of the deposit. The Hg/Zn ratio in sphalerite, however, appears to behave much more uniformly.

The carbonaceous shales which can range up to 50 metres in thickness and are situated stratigraphically below the active zone are enriched in Ni, Cu, Co, Mo, As, Zn, Cd, Hg and Pb relative to rocks of similar age and composition located remote from mineralization. Ni, Cu, Mo, Co and As correlate positively with organic carbon which averages up to eight percent in this unit. The remaining chalcophile elements are distributed sporadically and show generally a low correlation with organic matter. Although several elements show a high positive correlation with organic carbon, a relationship which suggests they were accumulated by organisms or decaying organic matter, the Ni, Cu, Co and As now reside in framboidal pyrite. This pyrite, which is interpreted to be of diagenetic origin, most likely incorporated into its structure compatible chalcophile elements that were released from organic molecules during biogenic or thermal degradation of organic matter to high molecular weight tarry organic compounds now found in rocks at Howard's Pass. Pyrites separated from the footwall carbonaceous shales and overlying phosphatic carbonaceous chert contain between 2 000 and 4 000 ppm Cu and Ni, whereas pyrites both stratigraphically and laterally remote from mineralization generally contain less than 1 000 ppm Cu and Ni. The pyrites from the active member are generaly low in Cu and Ni, which supports the hypothesis that Cu and Ni were accumulated by organic processes. The high Cu and Ni content of pyrites from the enclosing rocks, relative to rocks remote from mineralization, is interpreted as reflecting the influx of ore-forming fluids that were enriched in these elements, at least relative to seawater. The local environment generated by these fluids during ore deposition may also have influenced the uptake of Cu, Ni, As and Co by organisms and decaying organic matter.

A period of hydrothermal activity during the Devonian, as evidenced by feeder-pipe mineralization below both the Tom and Jason Zn-Pb-Ba deposits, can be recognized in rocks of similar age at Howard's Pass by an enrichment of Zn, Hg, Sb, Pb, Ag, As, Ni and Mo in assocation with high contents of both organic and carbonate carbon. Although a Devonian hydrothermal event in the Howard's Pass area did not produce a Zn-Pb deposit similar to those occurring at MacMillan Pass to the northwest, the spatial association of Upper Devonian shales enriched in chalcophile elements with the underlying XY deposit suggests strongly that structures which most likely controlled the geometry of third-order basins as well as serving as conduits for the escape of metalliferous fluids during the Lower Silurian, were reactivated during the Devonian. Metal enrichment in sedimentary rocks reflecting the periodic reactivation of major long-lived structures may prove to be a valuable tool in the exploration for sediment-hosted base metal deposits that are now deeply buried below younger sedimentary rocks.

DIFFERENTIATION OF DIAGNOSTIC ALTERATION TYPES IN THE WALLROCKS OF ARCHEAN VOLCANIC-EXHALATIVE MASSIVE SULPHIDE DEPOSITS

by

S.D. Amor and I. Nichol

The present investigation is concerned with the identification of diagnostic lithogeochemical alteration signatures around volcanic-exhalative massive sulphide deposits in the Superior Province.

Previous work on data from the same deposits has indicated that, in general, the wallrock alteration related to the passage of metal-bearing fluids is marked by iron and magnesium enrichment, and calcium and sodium depletion. These features are, however, only detectable if the effects of igneous differentiation are taken into account. It would seem likely that the probability of detecting an alteration halo can be increased by consideration of element associations rather than single element distributions. The distribution of a function which combines unweighted Fe_2O_3, MgO, CaO, Na_2O values generally gives improved definition of the alteration around mineralization; however, the combination of the diagnostic elements in their unweighted form has the effect that strong, typical enrichment or depletion of one element may result in the masking of possibly atypical behaviour of the other elements. This grouping effect may be advantageous in that such atypical behaviour does not impede the identification of alteration haloes; on the other hand, its genetic implications may be overlooked.

Discriminant analysis has been applied to lithogeochemical data from each of the deposits in the study area. The discriminant analysis process offers a mechanism for establishing the optimum weighted combination of variables to distinguish mineralized from barren environments. The application of the process to the data from the eight deposits has drawn attention to the existence of two distinct types of alteration. The Joutel and Poirier deposits are characterized by "typical" Fe_2O_3 and MgO enrichment, and CaO and Na_2O depletion; at the South Bay, Sturgeon Lake and Mobrun deposits, Na_2O is also strongly depleted, but Fe_2O_3 and MgO are usually depleted and CaO is sometimes enriched. Both of these alteration styles are displayed at the Mattabi and East Waite deposits. Work is in progress examining the mineralogical manifestations of these two alteration types.

The geochemical alteration patterns delineated in this way constitute significantly larger exploration targets than the readily observable mineralogical alteration haloes and, in addition, are much more homogeneous than haloes indicated by the single element distributions.

Results of the current investigations indicate that the mineralizing processes associated with Archean volcanic-exhalative massive sulphide deposits have given rise to a number of geochemical responses in the wallrocks and thus it is an oversimplification to aim exploration at the detection of a single type of geochemical response.

LITHOGEOCHEMISTRY OF WAINALEKA CU-ZN VOLCANOGENIC DEPOSIT, VITI LEVU, FIJI, AND POSSIBLE APPLICATIONS FOR EXPLORATION IN TROPICAL TERRAINS

by
C.S. Rugless

A small volcanogenic massive sulphide deposit occurring in early Tertiary (Eocene to Middle Miocene) Wainimala Group rocks within Wainaleka Creek watershed, near the southern coast of Viti Levu, Fiji, was discovered in 1976 during follow-up of stream sediment anomalies by Australian Anglo American (Fiji) Ltd. Poor outcrop, due to the relatively deep soil profile developed beneath the jungle canopy, lessens the possibility of finding further mineralized lenses in the area by traditional techniques, such as stream sediment sampling, and ridge and spur sampling. The need for alternative geochemical sampling methods prompted research into the lithogeochemistry of the deposit to be used as an exploration guide for further mineralized lenses.

Wainaleka deposit has possible reserves of 10^5 tonnes of ore, grading 1.5% Cu, 5% Zn and 10 g/t Ag. The deposit exhibits mineralogical and alteration zoning comparable with many Archean and Phanerozoic proximal volcanogenic deposits. The mineralized lens has a sphalerite-rich top overlying massive pyrite grading into disseminated sphalerite and chalcopyrite. A stringer zone of chalcopyrite and pyrite extends 20 m below the mineralized lens. Gypsum veining occurs laterally to disseminated mineralization. Sulphide textures at the stratigraphic top of the deposit are suggestive of replacement of a fragmental host as the mode of deposition, rather than syngenetic deposition onto a paleo-ocean floor. The mineralization occurs at the top of a felsic fragmental pile mantling a sodic rhyolite domal complex. The domal complex occurs within predominantly basic to intermediate lavas and volcaniclastic rocks which have low K island arc tholeiitic affinities. Rock analyses of the volcanic suite plot within the island arc tholeiite fields on SiO_2 vs K_2O and SiO_2 vs $FeO_{(t)}/MgO$ variation diagrams.

Alteration associated with mineralization can be divided into four zones. Zone I is a quartz-sericite (phyllic) assemblage closely associated with mineralization and characterized by obliteration of most volcanic textures. It extends about 2 000 m along the mapped upper contact of the host fragmental unit, and up to 250 m below mineralization. Zone II is clay-sericite (argillic) alteration and typically contains preserved relict textures and envelops Zone I alteration as a broad 4 000 m long, 800 m wide zone within the fragmental unit. Zone III occurs within the acid volcanic domal complex, peripherally to Zone II. It has been termed the clay-carbonate zone and is typified by incipient clay alteration of plagioclase laths in a devitrified glassy matrix which contains patchy carbonate. Zone IV represents low grade propylitic alteration (chlorite, calcite $\pm$ epidote $\pm$ albite $\pm$ zeolite) of hanging wall andesite and basic fragmentals, extending 100 m stratigraphically above mineralization.

On the regional scale, geochemical trends obtained from surface rock chip sampling across the volcanic pile reflect alteration zoning. Samples were analyzed for SiO_2, Al_2O_3, K_2O, Na_2O, CaO and MgO by XRF and for Cu, Pb, Zn, Ag, Co, Mn, Rb and Sr by AAS after total $HF-HClO_4-HNO_3$ digestion. Distinctive geochemical trends are apparent over the altered domal complex. K_2O, Rb and to a lesser extent Mn are depleted up to 1 200 m below mineralization. MgO is enriched within this zone. Na_2O, CaO and Sr exhibit rapid depletion 200 m below mineralization corresponding with the zone of most

intense alteration (Zone I). Zn and Co have been depleted, and Cu enriched 500-600 m below mineralization. A similar traverse across the domal complex 600 m to the west, below a barren contact zone, exhibits broadly similar less intense depletions and additions of these elements.

Mine scale geochemical trends below the weathered zone were measured by analyzing average 2 m chip samples taken at approximately 10 m intervals in the hanging wall unit. Samples were analyzed by AAS for Na, K, Rb, Sr, Al, Mn, Mg, Ca, Fe, Cu, Zn, Ag, Pb, Ni, Co and Cr after total $HF-HClO_4-HNO_3$ digestion. The contact between hanging wall intermediate and acid volcanics, and footwall mineralized altered fragmentals provides a strong geochemical contrast. Mn, Ca, Sr and Na which are enhanced in the hanging wall are strongly depleted in the footwall. Slight Cu, Pb, Zn and Ag enhancement and K, Rb depletion occur in the non-mineralized hanging wall lithologies up to 50 m above the mineralized lens. Mg and Al exhibit strong depletion and K, Rb, Fe, as well as the ore metals, exhibit enhancement within the mineralized lens.

Orientation bedrock sampling along traverses above borehole sections indicate that geochemical trends apparent in the unweathered zone have persisted into the weathered zone. Weathered bedrock samples were collected at an average 1 m depth by hand auger. Hanging wall lithologies were sampled at 20 m intervals closing down to 10 m adjacent to mineralization, and 5 m over the mineralized lens and associated fragmentals. Samples were analyzed by AAS for K, Mg, Al, Rb, Sr, Mn, Li, Cu, Zn, Pb, Ag, Co, Ni, V and Cr after total $HF-HClO_4-HNO_3$ digestion. Additional elements including As, Bi and Hg were analyzed by AAS hydride generation and gold film mercury detection (Jerome model 301), respectively. Mn, V, Sr and to a lesser extent, Al, Na and Ni are depleted within footwall lithologies. Li, Rb and K enhancement are associated with the zone of strongest (phyllic) alteration. Mg is broadly enhanced in the footwall. Pb, Ag, Bi and As occur as discrete anomalies associated with the mineralized lens. Hg, Cu and Zn form broader anomalous zones over the mineralized lens, and associated footwall and unmineralized hanging wall lithologies.

Comparison of borehole data with surface samples taken along the borehole section show that Cu, Pb, Zn, Co, Mn, Mg, Na and Sr have been leached in the weathered zone although lithogeochemical trends are demonstrably retained. Persistence of Al and K, and depletion of Na can be attributed to the presence of clays (kaolinite and illite) in the weathered profile. The gossan developed above the sulphide lens has retained anomalous Cu (535 ppm - 21.5%), Zn (3300 ppm - 6.15%) and Pb (420 - 8 200 ppm) values due to the presence of secondary copper minerals and retention of sulphides in the gossan. The presence of sulphides at surface provide further evidence that the shallow weathering profile (< 20 m) would probably not mask primary element haloes in the secondary environment.

Results from surface borehole traverse sampling facilitated selection of a suite of elements that would effectively delineate alteration and mineralization in a regional rock chip program in the area. Samples were collected from creek outcrops and ridge auger holes at approximately 100 m spacings (70 samples/km^2), and analyzed for Na, K, Mg, Rb, Sr, Ca, Mn, Cu, Zn and Pb by AAS after total digestion. Populations for each element were established from histograms. Element values were computer plotted on to plans providing a basis for contouring by hand. The data were subjected to discriminant analysis; multiplicative elemental relationships were investigated.

Wainaleka deposit occurs within anomalous trends defined by Cu, Pb and Zn

contours, although the strongest anomalies occur to the west of the mineralized lens, along the hanging wall/footwall contact. A Mn depletion 'window' coincides with anomalous Cu and Zn contours. Ca, Na and Sr provide broad depletion zones enveloping Zone I and Zone II alteration phases. Mg exhibits a general increase in values in the altered footwall fragmentals, with isolated anomalies. K and Rb provide an irregular picture with high background values corresponding to the hanging wall/footwall contact zone.

Multiplicative elemental relationships comparing elements depleted with elements enhanced provide a useful index to alteration associated with mineralization.

Discriminant analysis of the sample set successfully defined alteration zones as well as hanging wall lithologies. Anomalous discriminant scores approximate the mineralized lens, as well as the Cu and Zn anomalous zone to the west.

The regional rock chip geochemical program has provided a cheap, rapid method of sampling poorly exposed tropical terrain, and successfully outlining a broad alteration zone associated with base metal mineralization. A similar method could be employed for exploration for porphyry styles of mineralization associated with altered intrusives in tropical areas.

ROCK GEOCHEMICAL EXPLORATION AT MOUNT MORGAN, QUEENSLAND, AUSTRALIA
by
M. Fedikow

The Mount Morgan Au-Cu pyritic sulphide deposit occurs in a north-northwest trending belt of Middle Paleozoic volcanic rocks located in south-central Queensland. This volcanic belt forms part of the Yarrol Basin in the Northern New England Fold Belt of the East Australian Tasman Geosyncline. The host rocks for the deposit are a normal sequence of rhyolitic and dacitic tuffs that have a north-northwest regional strike and easterly dips of 20° to 30°. The tuffs contain thin units of chert, jasperoid and carbonate rocks.

The Mount Morgan deposit is represented by a zone of sulphide mineralization 600 m long, 100-200 m wide and 300 m deep that transects stratigraphy and can be divided into: 1) an oxidized zone, characterized by a hematitic, Au-enriched gossan with minor stratiform sphalerite-argillite; and 2) a primary zone which can be subdivided into an upper zone of greater than 50 percent sulphide minerals, and a lower siliceous stockwork zone with approximtely 20 percent sulphide minerals. Pyrite is the most abundant sulphide mineral in both the upper and lower primary zones with lesser pyrrhotite and accessory chalcopyrite, sphalerite and gold.

A zone of silicification is associated with the deposit and forms an envelope around the orebody that extends stratigraphically downwards in a pipe-like zone for greater than 750 m. A second, non-economic 100 m thick pyrite body occurs approximately 300 m below the orebody within this alteration pipe. The orebody contained 67 million tonnes of 4.87 grams per tonne Au and 0.70 percent Cu.

The distribution and variation of Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo, Sn, Ba, Au, Pb, Ce, Th, U, H_2O^+, CO_2 and specific conductance were examined in 2 000 samples of the host rocks taken from diamond drill core and surface outcrops. This study was

designed to delineate major, minor and trace element geochemical haloes in the host rocks around the deposit.

Partial digestion of the rock samples was found to be the most useful technique due to the reduction in analytical time and a decrease in molecular interference during atomic absorption analysis. The reduced molecular interference permitted the utilization of a greater number of indicator or pathfinder elements.

The host rocks in the immediate vicinity of the mine are marked by the development of distinct chemical and mineralogical zones representing an outward progression from the most intensive to a less intensive alteration. A 50 m thick siliceous inner zone of intensely altered rocks, depleted in all investigated elements except Si, surrounds the orebody. This zone of silicic rock passes outward into a 100 m thick middle zone of dominantly sericite-pyrite characterized by high concentrations of K, Fe, Cu and Co. The sericite-pyrite zone, in turn, passes into an outer 100 m thick chloritic zone with high Fe, Mg, Mn and Zn concentrations. High concentrations of H_2O^+ are associated with the sericite-pyrite zone and the chloritic zone. The alteration pipe associated with the Mount Morgan orebody is characterized by a depletion in Na, Ca, and K and an enrichment in Fe and Mg. The non-economic pyrite body contained within this alteration pipe has a narrow zone exhibiting enrichment haloes in Fe, Mg, Zn, Cu and Co.

Due to the restricted nature of diamond drilling in the volcanic belt hosting the Mount Morgan deposit chemical manifestations of the alteration can only be traced southwards along strike of the host rocks. Depletions in Na, Ca and K and enrichments in Zn, Au, Ba, H_2O^+ and Mg are present for 1 200 m in diamond drill core samples whereas depletions in Na and K and enrichments in Mg, Fe and Mn were detected in surface outcrop samples for 1 400 m. Fe-rich jasperoid units within the host rocks are characterized by enrichments in Cu, Fe and Mg and depletions in Na and Ca for 1 100 m; Zn and Mn in these units are enriched for over 800 m south of the deposit.

X-ray diffraction and electron microprobe investigations indicate that the progressive destruction of primary feldspars and the alteration of primary ferromagnesian minerals to a progressively more Mg-rich chlorite towards the deposit, correlates with the depletion haloes in Na, Ca and K and the enrichment haloes in Mg and H_2O^+, respectively.

The geochemical haloes around the Mount Morgan deposit have dimensions of at least 1 400 m x 800 m x 750 m that can easily be detected by a 250 m^2 surface outcrop sampling grid. The haloes are probably more extensive than indicated; the paucity of diamond drilling, however, prevented the determination of their exact dimensions in this study.

The Mount Morgan deposit is considered to be of the exhalative massive sulphide type. The upper and lower primary zones of mineralization and the associated alteration pipe are comparable to the root zone of other "typical" exhalative-style proximal massive sulphide deposits. The overlying gossan present at the Mount Morgan deposit appears to have developed as a result of the weathering of outcropping sulphides that may have represented the stratiform syngenetic portion of the deposit.

LITHOGEOCHEMISTRY AS AN INDICATOR OF URANIUM AND TIN MINERALIZATION, SOUTH
MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA
by
G.K. Muecke and A.K. Chatterjee

The South Mountain Batholith (SMB) is a post-tectonic, peraluminous granodiorite-granite complex which outcrops over an area $> 10^4$ km^2 of south-western Nova Scotia (Fig. 1). During the past decade the SMB has been the site of increasingly intense mineral exploration which has culminated recently in the discovery of a major tin (East Kemptville, Shell Minerals Ltd.) and a major uranium (Millet Brook, Aquitaine Mining Corp.) prospect, as well as numerous other showings of these metals (Fig. 1).

The SMB mainly intrudes deformed metawackes and metapelites of the Cambro-Ordovician Meguma Group, but along its northwestern margin it cuts metasediments and volcanics ranging in age from Ordovician to Lower Devonian (Emsian). Country rock deformation and metamorphism is attributed to the Acadian Orogeny, which in this region has been dated at 415-400 Ma. Stratigraphic controls necessitate that the time of intrusion, crystallization, uplift and erosion of the batholith be bracketed between Emsian and Tournaisian times. Recent K-Ar, ^{39}Ar/^{40}Ar and Rb-Sr isochron studies assign ages of 372-361 Ma to the various episodes of intrusion in the batholith. Complete solidification and surface exposure of parts of the SMB cannot have been separated by more than a few million years and the rapid unroofing of the batholith during(?) and following its emplacement appears to have strongly influenced the localization of the associated mineralization.

The main mass of the SMB consists of biotite granodiorites into which are intruded a number of smaller, discrete bodies of biotite-muscovite monzogranites (including porphyry), leucocratic monzogranites, dykes and irregular bodies of aplite and pegmatite (Fig. 1). The major and many trace elements of this suite show continuous variation trends from the early to late-stage rocks. From this, McKenzie and Clarke (1975) concluded that the SMB consists of a cogenetic suite whose chemical trends were controlled by fractional crystallization involving mainly plagioclase and biotite. Muecke and Clarke (1981) concluded from the REE and Sr isotope data that fractional crystallization alone cannot account for the trace element geochemistry of the late-stage rocks. They suggest that three processes, namely fractional crystallization, country-rock assimilation, and fluid-phase transfer, have all operated during the crystallization history of the SMB. The generation of a fluid phase, possibly enriched in fluorine and/or carbonate ions, is thought to have played a major role in determining geochemical trends during the terminal phases of crystallization. The pesence of such a fluid would also have had a profound influence on the behaviour of such economically important elements as Sn and U, since they can form stable fluoride/carbonate complexes in aqueous solutions.

A para-intrusive suite, which consists of biotite leucogranites, argillized and sericitized granites, albitized granites and albitites, as well as various types of greisen, appears to be the product of the interaction of such a fluid phase with residual magma and/or the cogenetic crystalline rocks. Chemical trends in this suite are distinct and clearly diverge from those observed in the cogenetic suite. The Sn-W, Sn-Be, Sn-W-U, W-Mo-U, and U-P-F mineralization in the SMB is usually spatially and genetically associated with the monzogranite and leucocratic monzogranite bodies, and in

particular with para-intrusive rocks found within these complexes (Fig. 1).

The principal types of U and Sn mineralization so far recognized in the SMB are typified by the following:

1) In the New Ross area uraniferous shear zones occur in granodiorites at Millet Brook, in leuco-monzogranite at Lewis Lake, and at many other localities within the gneisen zones. The uraniferous shear zones are characterized by strong wall-rock alteration and autunite-torbenite-pitchblende associations.

2) The uranium mineralization at Gaspereau Lake and East Dalhousie is restricted to shear zones in leuco-monzogranite. The mineralization is characterized by autunite-meta-autunite-torbernite-pitchblende associated with hydroxyl-and fluor-apatites.

3) The Sn-W-Cu-Mo mineralization at Davis Lake, Plymouth, and Long Lake is restricted to greisen zones and greisenized granites within discrete bodies (?) of leuco-monzogranite. The dominant polymetallic mineralization at these localities is found mostly as disseminations and as quartz-topaz-cassiterite-sulphide veins. The greisen zones and the veins range in width from hairline fractures to tens of metres.

For most of the plutons in the SMB the U content increases with increasing degree of differentiation, whereas Th steadily decreases in abundance (Fig. 2a). The mean Th/U ratios change from $\sim$3 in the granodiorites to $\sim$0.5 in the leuco-monzogranites. Such a decrease in Th and Th/U (also of REE) is most unusual for a differentiated intrusive suite. The decrease in Th/U with differentiation is accompanied by strong progressive enrichments in F, Be, Li, Rb, Cs, Ta, Sn, U and depletions in Sr, Ba, REE, Sc, Zr and Hf. Trace element concentrations in many of the more differentiated rocks fall well within the limits set by Tischendorf (1978) for metallogenetically specialized granites, but Th and REE clearly do not follow his predicted behaviour. In the associated para-intrusive suite the above described elemental correlations often break down and particular elements may show more extreme enrichments (e.g. U, Sn, Li) or depletions (e.g. REE, Th).

The negative correlation between Th and U and the Th depletion with increasing differentiation (Fig. 2a) which we have observed for most of the plutons is, however, not shared by all plutons in the SMB or associated with it. Notable exceptions are the Davis Lake and Plymouth plutons which exhibit a positive correlation between U and Th and elevated Th abundances in the most differentiated rocks and the para-intrusive suite; both bodies are associated with substantial Sn-W mineralization (Fig. 2b).

From the above discussions it appears that two distinct geochemical trends can be discerned in the plutons which constitute the SMB: i) a Th-depletion (also REE depletion) trend in which increased igneous differentiation leads to low Th and low Th/U, both in the cogenetic and para-intrusive suites; and ii) a Th-enrichment trend in which highly differentiated rocks and para-intrusives are characterized by a concomitant increase in Th and U.

We have analyzed airborne gamma-ray spectrometric maps in an attempt to delimit the location of areas which display the above geochemical trends. In general, the areas of high total count (taken as > 10 μr) conform to the major bodies of monzogranite and more highly differentiated rocks (e.g. New Ross complex, Davis Lake pluton). In some cases these more highly radioactive bodies show low Th counts (e.g. New Ross) in accord with the Th-depletion trend observed in ground sampling. In other cases, the high total count value is accompanied by a high Th count (> 6 ppm eTh) and confirms the Th-enrichment trend observed in ground samples (e.g. Davis Lake). Superposition of the high total count (> 10 μr) and high Th (> 6 ppm eTh) areas yields a well-developed

Figure I

Figure 2a

SOUTH MTN. BATHOLITH

Figure 2b

DAVIS LAKE PLUTON
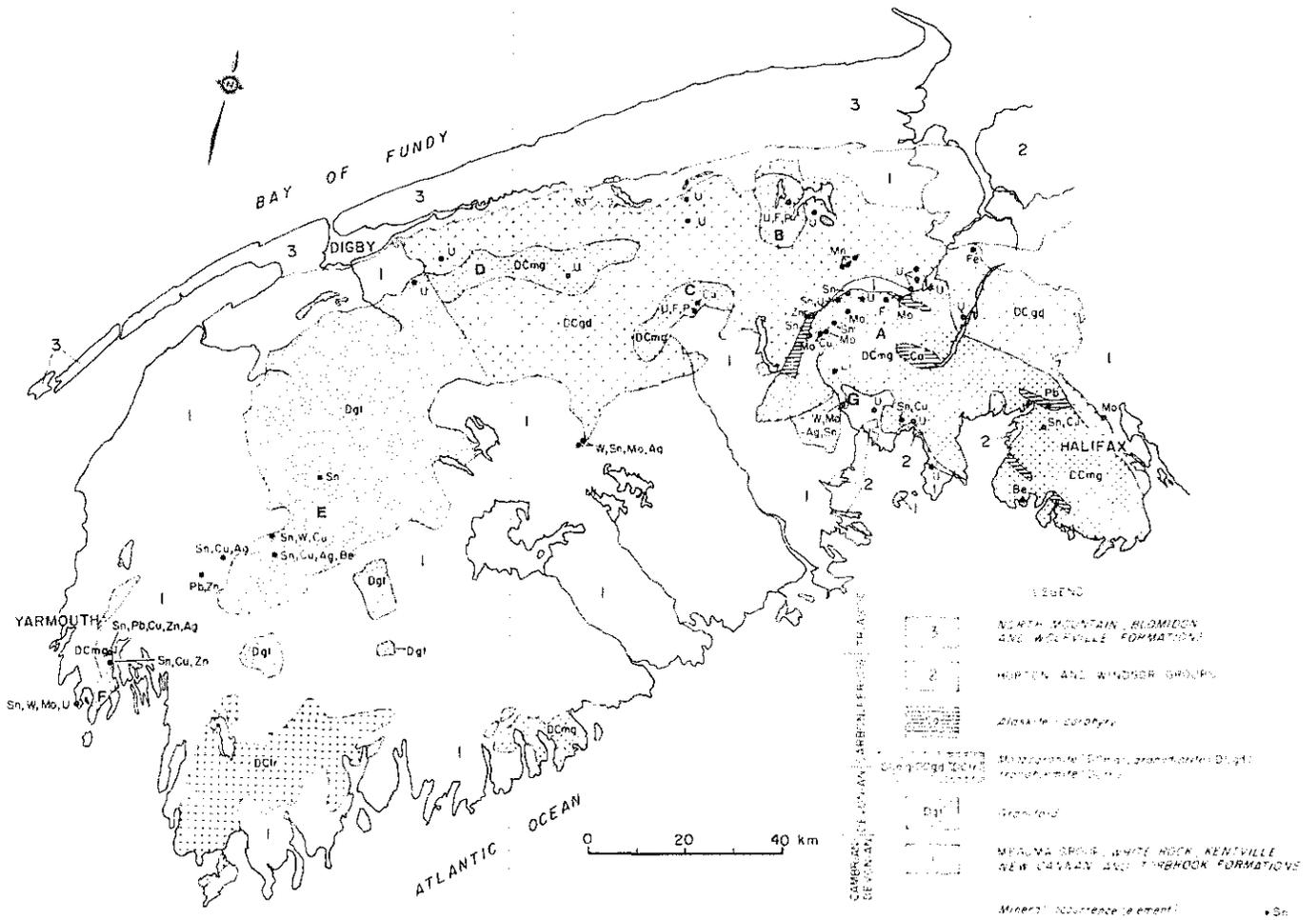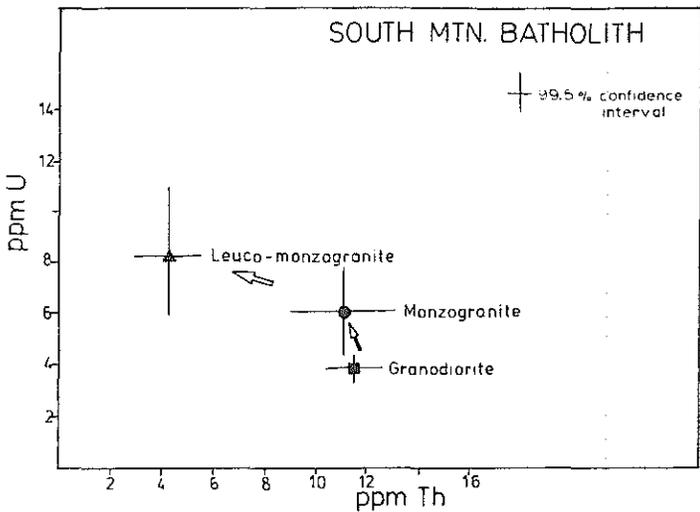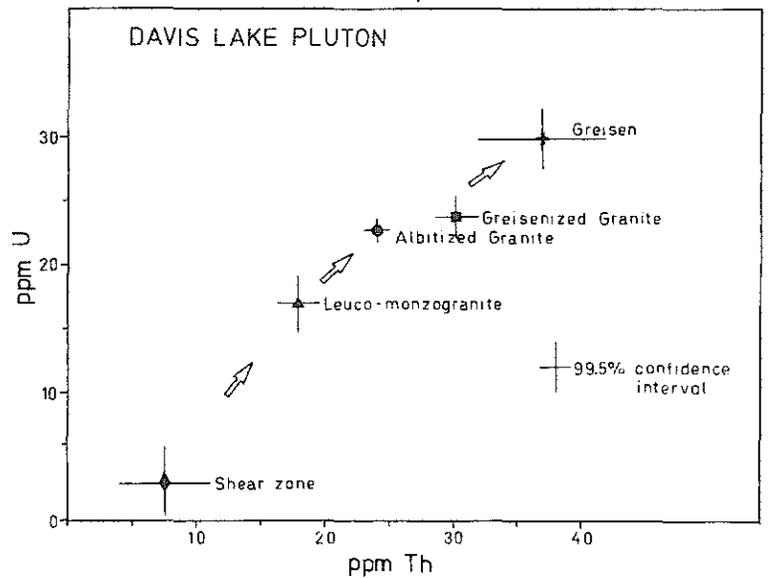
zonal distribution of areas with these characteristics near the margins of the batholith. Furthermore, a close correlation exists between such areas and major mineral occurrences (i.e. Plymouth and Davis Lake plutons with Sn prospects; Millet Brook U prospect) which may be of exploration interest. This approach suggests that bodies in the SMB which show the Th-enrichment trend may be more favorable areas for Sn-U mineralization than those showing the Th-depletion trend. Using these criteria a number of other areas in sparsely mapped portions of the SMB stand out as possible exploration targets.

On the ground the best lithogeochemical indicators of Sn-U mineralization in the SMB are the strong enrichments of F, Be, Li, Rb, Cs, Cu, Ta, Sn and U encountered in the associated para-intrusive suite. Furthermore, a preliminary study of REE in fluorites from Sn-U mineralized and apparently barren areas has shown that fluorites in the former have elevated REE concentrations and may prove to be guides to mineralization. Relative REE distributions in all the fluorites closely resemble those observed in the leuco-monzogranites and reflect the close genetic link between the highly differentiated, late crystallized fractions of the batholith and the evolution of the fluid phase which gave rise to the observed mineralization in the SMB.

Vertical profiles of U distributions in the New Ross area show that near-surface samples (<100 m) can be markedly deficient in uranium, other areas (e.g. Davis Lake) do not exhibit such a trend. We suggest that such distribution patterns are the result of the interaction of differentiated granitoid rocks with heated meteoric and/or internally generated fluids. These released and concentrated U through oxidation and complex formation.

The localization of U mineralization along shear zones in the SMB suggests that the rapid unroofing of the batholith following its emplacement produced dilatancy and shear fractures which acted as channelways for mineralizing fluids which were produced as internally generated fluids or by the interaction of the differentiated granitoid rocks with hot meteoric water. Uranium and tin concentrations of economic interest in the SMB are, therefore, the cumulative result of igneous differentiation processes and a hydrothermal system which acted on the cooling batholith during an episode of rapid uplift.

LITHOGEOCHEMISTRY OF HYPOGENE, SUPERGENE AND OUTCROP SAMPLES, BERG PORPHYRY COPPER DEPOSIT, BRITISH COLUMBIA
by
D. Heberlein, K. Fletcher and C.I. Godwin

Several studies have documented the primary lithogeochemical patterns that result from redistribution of elements during development of porphyry copper systems. Considerably less attention has been given to subsequent modification of these primary patterns during weathering. In this paper we examine the influence of the development of supergene oxide and sulphide zones on the original hypogene geochemical patterns at the Berg deposit, British Columbia.

The deposit, in the alpine zone of the Tahtsa Range, was logged (GEO-LOG) and sampled in fourteen diamond drill holes along a N-S section. Where possible, outcrop samples were collected in the vicinity of each hole. Major elements were determined by XRF, F by specific ion electrode and trace metals by AAS after nitric-percholoric acid decomposition. A sequential extraction (10% hydrochloric acid - ammonium oxalate - potassium chlorate/hydrochloric

acid - nitric/perchloric acids) was used to study distribution of elements between carbonate - oxide - sulphide and silicate phases.

Core logs and assays show that primary ore minerals (chalcopyrite - molybdenite) extend from the outer part of a porphyry intrusion into the surrounding hornfels where the best grades of copper are found close to the contact. Maximum copper grades, however, result from development of a supergene enrichment blanket. Within the hypogene zone principal lithogeochemical patterns reflect the differences in composition of the hornfels, originally basaltic to rhyolitic volcanics, and the intrusion, as well as the introduction of F and metals (Cu, Mo, Pb, Zn, Ag). Distribution of Ag is broadly comparable to that of Cu and Mo whereas anomalous Pb and Zn populations form peripheral haloes around the potential ore zones.

Emergence of strongly acidic groundwaters accompanied by precipitation of iron oxides indicate that leaching processes are active. Furthermore, although primary sulphides associated with both of their oxidation products and secondary sulphides can still be found in surface samples, sequential extractions of drill cores clearly indicate vertical redistribution of copper between oxide, carbonate and sulphide phases.

Comparing metal distribution patterns at the surface and in the supergene zones to those in the hypogene, it is apparent that anomalous concentrations of F, Cu, Mo, Pb and Ag - but not Zn - persist at the surface. However, at a strongly leached site (on a topographic high) absolute concentrations of Cu in surface samples are low compared to those in the underlying zones whereas Ag, Mo and Pb are enhanced. Consequently, it seems likely that under conditions of more intensive leaching of Cu, these elements, accompanied by F, would have provided the best geochemical guide to the existence of the porphyry copper deposit.

COBALT AS AN EXPLORATION TOOL IN THE OUTOKUMPU ZONE, FINLAND
by
P. Hakanen

The Outokumpu region in eastern Finland is an integral part of the Precambrian formations of the Karelidic orogeny. The copper-cobalt ore deposits discovered in the region are associated with a lithologic complex that consists of serpentinites, skarns, carbonate rocks and quartzites. The outer zone of this rock association adjacent to the surrounding mica schists is commonly occupied by black schists. The association constitutes the coherent stratigraphic sequence known as the Outokumpu zone, which is the environment in which the ore deposits of the Outokumpu type occur. The total length of the ribbon-like zone is about 240 km. Three Cu-Co ore deposits: Outokumpu, Vuonos and Luikonlahti are currently being exploited and four subeconomic ore showings have been found in the zone. All the deposits and ore showings are of the polymetallic sulphide type with copper, zinc, cobalt and nickel. There are also small amounts of silver, gold, tin and selenium in the ore bodies. These stratabound ore deposits are submarine volcanic exhalative in origin. The immediate host rock of the ore is commonly quartzite, interpreted as a chemical silica precipitate.

The Outokumpu copper-cobalt ore deposit was discovered in 1910. Owing to its economic potential, the Outokumpu zone is one of the most thoroughly studied parts of the Finnish Precambrian. More than 1 000 holes have been

drilled from the surface into the zone and provide a large source of material for lithogeochemical studies.

The association does not lend itself easily to geophysical investigations because of its complex geology, characterized by black schists and other rocks giving a strong geophysical response. For this reason, and because of the extensive drilling, lithogeochemistry has become an important exploration toolin the region.

The discovery of the blind Vuonos ore deposit in 1965 was the result of a comprehensive lithogeochemical study carried out in the early 1960's. Several old prospects were sampled in the Outokumpu zone and the sulphide phase was analyzed for Cu, Co, Ni and Zn.

Clustering of the analytical data gives five groups of rock types: (1) serpentinite, talc and chlorite schists; (2) quartzite-skarn-dolomite; (3) black schists; (4) mica schists; (5) copper-cobalt ore. The locations of these groups in Ni-Co and Cu-Co diagrams and in a Co-Cu-Ni triangular diagram are shown in Figures 1, 2 and 3.

The nickel content of serpentinites varies between 1 500 and 2 200 ppm and that of cobalt between 70 and 110 ppm. Thus the Ni/Co ratio averages 20:1. In the quartzite-skarn-dolomite-group the nickel content ranges from 900 to 3 000 ppm and the cobalt content from 50 to 120 ppm. The Ni/Co ratio averages 20:1. The nickel content of black schists varies from 150 to 500 ppm and the cobalt content from 20 to 60 ppm. The Ni/Co ratio is about 10:1. Mica gneisses are poor in sulphides. Their nickel content averages from 40 to 90 ppm and the cobalt content from 15 to 30 ppm.

The copper-cobalt ore occupies a discrete area in the Ni-Co diagram. Its nickel content varies between 1 000 and 2 000 ppm and the cobalt content between 1 000 to 3 000 ppm. The copper-cobalt diagram shows that the cobalt content of the serpentinites and the quartzite-skarn-dolomite group is fairly constant varying between 60 and 140 ppm. The copper content ranges from zero to 100 ppm in the former and from 10 to 100 ppm in the latter. In black schists the copper content varies from 100 to 300 ppm, the cobalt content being some tens of ppm. The mica gneisses are somewhat poorer in their Cu and Co contents. In this case, too, the copper-cobalt ore has a Cu-Co content distinctly apart from those of the other groups.

In the Cu-Co-Ni triangular diagram the serpentinite and the quartzite groups plot near the Ni apex of the triangle, the relative Ni content being 94-96% and that of Cu less than 1%. The black schists and mica gneisses have their own area near the centre of the Cu-Ni join with the Co content not exceeding 10%. There are several exceptions where points in the diagrams described above plot outside the normal field. Most of these anomalous points are located between the normal area of the rock type and that of the Cu-Co ore. The Ni-Co diagram in particular demonstrates that the deviations are due to the increase in the Co content.

In summary, the anomalies of the Outokumpu type have: (1) a Ni/Co ratio lower than 15:1 and (2) a Cu percentage of the sum Cu+Co+Ni = 100 higher than 5. These anomaly units are applied to rank the analytical data of the Outokumpu zone. It is evident from the diagrams that the increase in cobalt content outside its normal field is the prime indication of the proximity of the ore. Being rather constant, the nickel content is used as a reference. Thus a decrease in the Ni/Co ratio indicates the presence of the ore. In some cases the decrease in the Ni/Co ratio may be due to a local decrease in the Ni content. The anomaly can be checked by the Cu/Cu+Ni+Co ratio. Except when testing the anomalies with Co, Cu and Ni as described above, the Co content alone can be used as an indicator of the proximity of a Cu-Co ore body. This
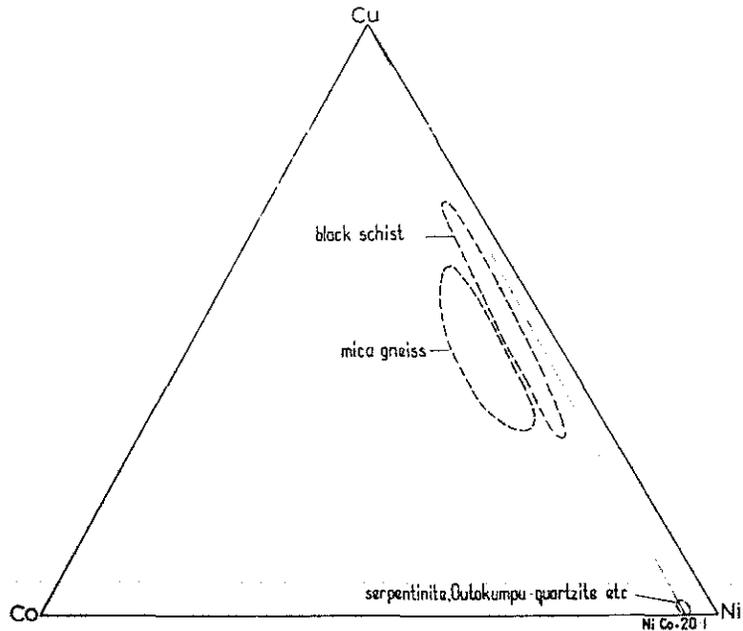
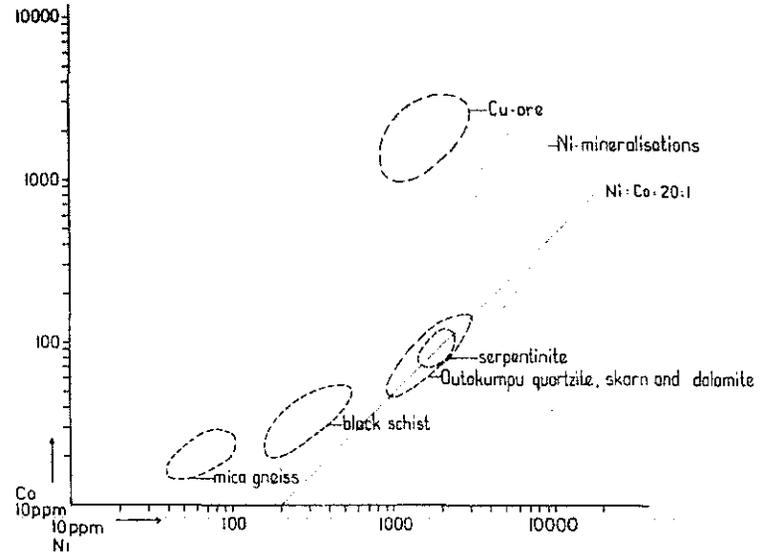Fig. 3 Cu-Co-Ni triangular diagram. The normal concentration fields for the rocks of the Outo-kumpu type.

Fig. 1 Ni-Co diagram. The normal concentration fields for the rocks of the Outokumpu type.

VUONOS Mine
CROSS SECTION Y=194.000
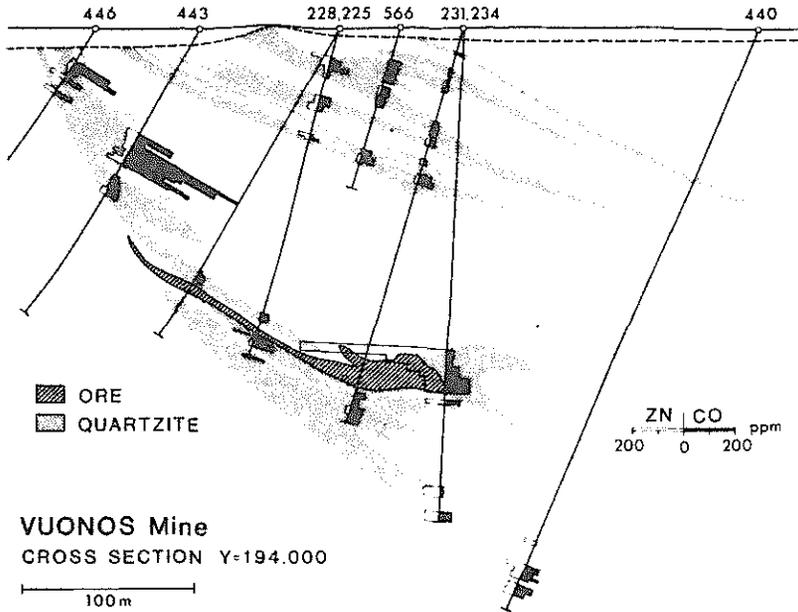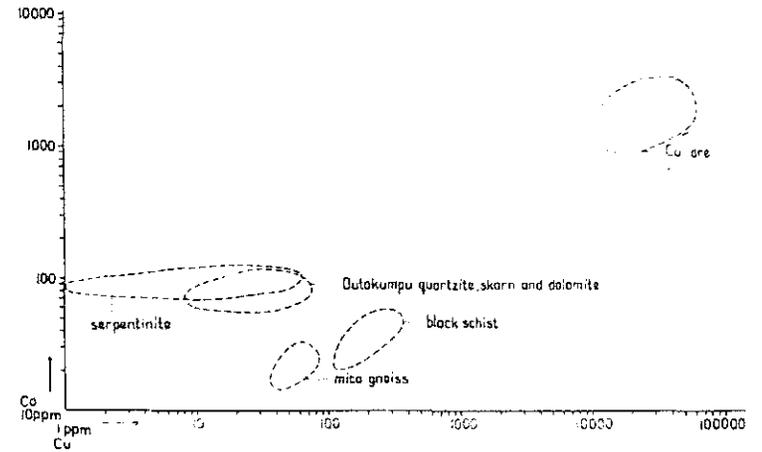
ORE
QUARTZITE

Fig. 4

Fig. 2 Cu-Co diagram. The normal concentration fields for the rocks of the Outokumpu type.

was tested in one section of the Vuonos ore body (Fig. 4). The pyrite phase of the quartzites was selectively leached and its Co content analyzed. It was noted that the Co content of pyrite increased somewhat when the ore body was approached along strike.

Before this method can be used more widely, the stratigraphical position and the structure of the potential ore horizon must be known fairly accurately. The proximity of an orebody can also be evaluated by means of theCo content of the black schists. As shown above, the Co content of the black schists is usually considerably under 100 ppm; it is usually over 100 ppm only adjacent to an orebody. Consequently, the extensive data on black schists in the Outokumpu zone can be sorted into potential and less potential ones.

THE USE OF THE "IMMOBILE" ELEMENTS Zr AND Ti IN LITHOGEOCHEMICAL EXPLORATION FOR MASSIVE SULPHIDE DEPOSITS IN THE PRECAMBRIAN PECOS GREENSTONE BELT OF NORTHERN NEW MEXICO
by
M.D. Petersen

Mineralogical and geochemical data of surface rocks of the Mid-Proterozoic Pecos greenstone belt in Northern New Mexico and results of drill core data of the Jones Hill deposit are presented and discussed within the geological framework derived from detailed geological mapping. Over 800 rock samples were analyzed for 25 elements (all major and several trace elements) and the lithologies were mineralogically and petrographically determined. The results show that the stratigraphic sequence of the Jones Hill deposit is composed of felsic pyroclastics, exhalites and pyroclastics of mafic and mixed felsic-mafic origin, upon which are superimposed certain alteration effects.

In volcanic rocks of felsic origin Mg, Fe, Mn, Cu, Pb, Zn, As are enriched and Na, Ca, Sr are clearly depleted when compared with their unaltered source rocks (Table 1). Zr and Ti are found to be relatively immobile during alteration and subsequent intrusive, deformational and metamorphic events. Alteration trends, best defined by the Na_2O/MgO ratios and systematic metal zoning, confirm that the stratigraphic sequence is overturned. Lithogeochemical anomalies outline a target which is bigger (over 300 m) and more precisely defined than do other methods, mapping of alteration assemblages or soil geochemistry.

New important aspects have evolved from this study, which are applicable to rock geochemical exploration and the recognition of alteration/mineralization anomalies in general. Zr/TiO_2 ratios can be shown to reflect the primary prealteration-premetamorphic composition of metavolcanic rocks (including shallow intrusives, flows, tuffs, and volcaniclastics). This ratio also enables the determination of the original composition of variably altered rocks of identical parentage (source rock). This determination is a fundamental prerequisite for the recognition and quantification of alteration trends. Direct applications are, for example, that apparently similar chlorite schists derived through hydrothermal alteration, metamorphism, and deformation from felsic volcanics are distinguished by their characteristic Zr/TiO_2 ratio of 0.04 (and greater); however chlorite schists derived from mafic volcanic sources and metamorphosed without much hydrothermal alteration have a much lower Zr/TiO_2 ratio of
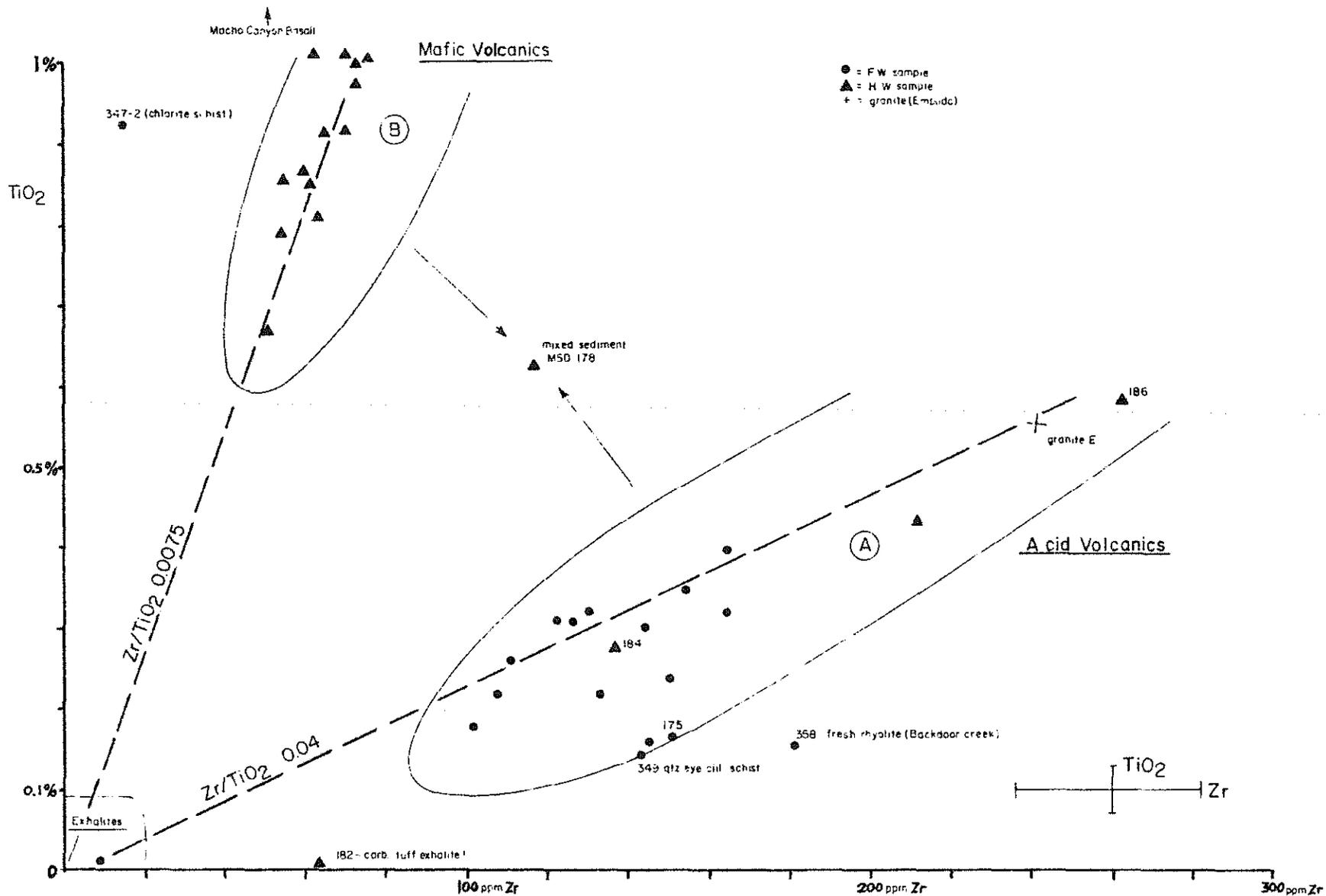
Figure 1. TiO₂ and Zr Plot Showing Data From the Drill Core Jones No. 1 and Surface Samples of the Jones Hill Area. The Analytical Accuracy (See Error Bars) is Based on International Standard Comparisons

TABLE 1

Sample Number	1		2		3		4		5	
Sample Location	MSD358, Backdoor creek 2.5 km SW of Jones Hill		MSD349, Jones Hill southern flank		MSD175, Jones No 1 Core 319' depth		MSD188. Jones No. 1 Core, 551 depth		MSD347-2, Southern Jones Hill	
Field Description	Pink rhyolite, flow banded with phenocrysts		Quartz-eye chlorite-sericite schist		Chlorite schist		Chlorite schist, with brown biotite layers "Jones Mine Sediments"		Chlorite schist	
Mineralogy (XRD)	Plagioclase, quartz K-feldspar		Quartz, Chlorite muscovite		Quartz, chlorite trace calcite		Plagioclase hornblende, chlorite quartz		Quartz, chlorite	
Zr TiO$_2$ Type	A		A		A		B		B	
Origin	Unaltered felsic volcanic		Altered felsic volcanic		Extremely altered footwall rock in contact with ore		Mafic schist		Mafic schist	
Analytical Method (%)	TEFA	AAS	TEFA	AAS	TEFA	AAS	TEFA	AAS	TEFA	AAS
SiO$_2$	78.06		74.83		53.29		51.49		46.90	
Al$_2$O$_3$	12.56		12.51		9.82		13.80		12.99	
Fe$_2$O$_3$	2.15	2.46	4.63	4.83	10.66	9.16	13.38	12.55	18.42	16.3
MgO	<0.50	0.11	4.63	4.79	13.02	11.12	9.26	7.76	13.66	13.21
CaO	1.04	0.83	0.23	0.07	<0.02	0.03	6.48	–	0.15	0.13
S	<0.02		<0.02		0.93		<0.02		0.04	
Na$_2$O	4.43	4.25	<2.00	0.19	<2.00	0.17	<2.00	3.02	<2.00	0.012
K$_2$O	2.13	2.04	2.04	1.88	0.12	0.19	0.37	0.43	<0.02	0.02
TiO$_2$	0.15		0.14		0.16		1.05		0.94	
P$_2$O$_5$	<0.05		0.05		0.08		0.24		<0.05	
MnO	0.07	0.025	0.09	0.036	0.19	0.09	0.23	0.19	0.42	0.28
Rb ppm	36		44		8		20		<5	
Sr	106		8		<5		146		<5	
Ni	<30		<30		33		72		63	
Zn	29		57		824	820	115		393	
Zr	181		144		145		74		<20	
Se	<10		<10		44		<10		<10	
U	<15		<15		<15		<15		<15	
Th	24		<20		<20		<20		20	
Mo	<5		<5		8		<5		<5	
Cu	<20		<20		4835	6200	64		63	
Pb	30		<30		70	89	39		<30	
As	<30		<30		3179		<30		<30	
Na$_2$O MgO		38.6		0.04		0.02		0.39		0.0009

0.0075 (and less). The altered rock related to massive sulphide alteration can thus be recognized and distinguished from similar rocks of different origin. In addition, the relative concentrations of the immobile elements Zr and Ti are useful in making stratigraphic correlations in structurally complex terrain such as the Pecos greenstone belt.

The assumption of a relative immobility of these elements in samples from Jones Hill is supported by the following observation:

1. The TiO$_2$ and Zr values of Jones Hill rocks fall in narrow clusters (Figure 1) as opposed to a random scatter plot.
2. The element abundances (ratios) are very similar to:
    a. Granite (Type A), fresh felsic volcanics (Type A) of the same area and same age (Table 1) and basalt (Type B) of the same area;
    b. Fresh basalts and rhyolites reported from young volcanic island arcs.
3. Highly altered chlorite schists directly underlying the main ore horizon and within the ore horizon, display Zr/TiO$_2$ ratios identical to less altered felsic rocks in the footwall.

These rock geochemical methods can be demonstrated to be applicable at all scales ranging from regional reconnaissance through local prospect evaluation down to detailed drill core interpretations during deposit delineation stages.

A PROMISING USE OF MULTIVARIATE STATISTICAL ANALYSIS IN LITHOGEOCHEMICAL PROSPECTING
by
O. Selinus

Mineral alteration zones in host rocks around mineral deposits have long been used as indicators of ores. Recently an increasing interest has developed in the chemical distribution patterns or haloes. These may appear more intense and therefore detectable over great distances, since both the mineralogical variation and the lattice substitution in the minerals may be detected chemically.

There are however several problems in this type of prospecting. One of the biggest problems is the possible presence of several populations in the samples which are analyzed after complete digestion. Only some of these populations are due to the haloes which one wants to detect, while others are disguising them. One way of solving this problem is to use multivariate statistical analysis.

In the Stollberg orefield, Central Sweden, these methods are being used. Several small and big stratiform zinc-lead- and iron ores are located within 6 km of one another in the same stratigraphical horizon in Precambrian volcanic rocks. Drifts are extended in the whole area down to a depth of 575 m. Approximately 3 000 rock samples have been collected from outcrops, drill-cores and drifts. These have been analyzed for 35 elements by XRF and IDES (Image Dissector Echelle Spectrometer). These samples represent an area of 3 x 9 km to a depth of 600 m.

The raw-values give insignificant correlations with mineralization owing to the presence of several populations. After reducing the skewness, factor analysis has been used and general distinct multielement zonations have been detected. After interpretation of these, factor scores have been used as input in discriminant analysis. Haloes have in this manner been obtained which have an extension of at least 1.5 km in all directions around all ore-types in the area. The ores can be detected in detail at great distance; furthermore some new very promising prospects have been discovered where drilling is to be done.

In conclusion it seems possible to use the trace element data to detect the orefields at a distance of several kilometres. Subsequently the major elements could be used at a distance of some kilometres to locate the ores in detail.

Also discussed is the genetic application of this method.

NEW DATA ON PRIMARY AUREOLES OF RARE-METAL PEGMATITES
by
B.M. Shmakin

There are three main types of rare-metal deposits in granitic pegmatites: (1) tantalum-cesium (tantalite-pollucite) deposits which contain lithium and niobium (columbium), sometimes with Sn and Be; (2) tantalum (tantalite, wodginite, stibiotantalite) deposits containing as a rule commercial lithium, sometimes with Nb, Sn, Be; and (3) proper lithium (spodumene) deposits, more or less simple in mineral and element composition. The average Li content in

pegmatite bodies is between 0.2 and 1.2%.

All commercial rare-metal pegmatite veins are of so-called replaced pegmatites. Because of large enrichments not only in Li, Ta and Cs, but also in H_2O, B, P, F, Cl, primary pegmatite zones are changed under the influence of solutions. Mostly there are autometasomatic processes of albitization, muscovitization, and silicification. Some minerals of Ta, Nb, and Sn in pegmatites are connected with secondary zones of metasomatism.

Primary aureoles in pegmatite areas are: a) the aureole of a pegmatite field; b) the aureole of a series of pegmatite veins; and c) the aureole of one pegmatite body. The first is very wide: it forms simultaneously with the pegmatites as a result of volatile components coming from the granite massif. Usually there is recrystallization of country rocks with some mineral replacement, but mainly there is enrichment of some elements (especially Li, Rb and Cs) causing new minerals to crystallize. The aureoles of a series of veins and a single pegmatite formed at the time that replacement took place inside the pegmatites. The aureole surrounds a pegmatite body or group of bodies as a "halo". The entry of rare elements into the country rock is a result of differences in element concentrations in solution. If there are enhanced concentrations of Li, Cs, Nb, Ta, Be, etc. in the pegmatite bodies, diffusion of these elements takes place into the wall rocks, giving rise to aureoles of these elements which may be used as pathfinders for discovering those elements in the pegmatites.

There are some specific minerals in primary aureoles of rare-metal pegmatites: holmquistite in altered amphibole-containing country rocks; Li-containing biotite in altered gneisses and schists; Cs-biotite in different wallrocks near the contacts of pegmatites enriched in pollucite or Cs-lepidolite. In one of the Siberian pegmatite fields, wide spreading of Li-chlorite was recently discovered. The chloritization in this field is analogous in the processes of Li-biotite and holmquistite formation in the other fields, but it takes place because of relatively low temperatures of pegmatite crystallization and replacement.

The main method of geochemical exploration for rare-metal pegmatites is called lithiometry. Because of high concentrations of Li in all three types of commercial rare-metal pegmatites it is possible to search their bodies (or series of bodies) using both primary and secondary aureoles. For the true lithium pegmatites, and for the Li, Ta, Cs pegmatites, lithiometry is a direct method of searching, but for Ta-Cs and for Ta pegmatites it is an indirect method.

The concentrations of lithium oxide in primary aureoles of Li-Ta-Cs pegmatite veins at one of the Siberian deposits are between 0.06% (weakly altered amphibolites) or 0.04% (quartz-biotite schists), and as much as 1.4-2.2% (intensively altered amphibolites with holmquistite). In aureoles of Ta pegmatite bodies of another Siberian deposit there is 0.3-0.4% Li_2O in chloritized amphibolites and 0.6-1.0% Li_2O in holmquistitized amphibolites. Near the pegmatite contacts there are almost monomineralic mica rocks ("sludites"). Where the mica is Cs-biotite, the rocks contain K_2O 4.6%, Li_2O 0.97%, Rb_2O 2.8%, Cs_2O 2.8%, MgO 5.8%, FeO 11.5%, etc.; where the mica is zinnwaldite, the analysis averages K_2O 7.9%, Li_2O 4.1%, Rb_2O 2.5%, Cs_2O 1.7%.

Near the contacts of pollucite-containing pegmatite veins such mica rocks can contain up to 5% Cs_2O. In such a case, when the thickness of "sludites" is up to 30-60 cm, it is possible to use Cs-biotite rock as the source of cesium along with pollucite from the pegmatite body.

In all cases encountered, Cs concentrations in the contact rocks are

evidence of cesium mineralization (pollucite or Cs-lepidolite) inside the pegmatite body.

Use of Cs (and Rb) as indicators is more questionable for wide aureoles of a pegmatite field or a series of pegmatite bodies, due to the fact that micas and amphiboles are very different in their capability for taking Rb and Cs admixtures into their structures. In the case of mica rocks included in amphibolite media, there are "Positive anomalies" of Rb and Cs even without the influence of pegmatites.

LITHOGEOCHEMICAL DISPERSION ASSOCIATED WITH THE RIRIWAI ZINC-TIN LODE NORTHERN NIGERIA
by
E.G. Imeokparia

The Ririwai complex forms a classic younger granite ring complex, 180 km^2 in size within the anorogenic younger Granite Province of Nigeria. An outer ring dyke of granite porphyry defines the caldera ring fracture in which fragmental rhyolite units (largely ignimbritic) and intercalated thin basalt flows are preserved. Into this volcanic cover a biotite granite with widely varying texture and degree of mineralization has been centrally emplaced.

Related to this biotite granite are two phases of mineralization: (1) an early dispersed phase in which the granite is texturally modified, recrystallized and columbite, xenotime and thorite are introduced, and (2) a later phase of fracture-controlled lode mineralization associated with acidic hydrothermal solutions in which sulphides are common.

The Ririwai tin-zinc deposit is one of the major lode mineralizations of considerable economic importance so far located in the younger granite Province of Nigeria. It is localized within a major fracture zone approximately 5 m wide and extending east-west for 5 km in the Ririwai biotite granite.

Principal ore minerals are sphalerite, cassiterite and minor galena, chalcopyrite and wolframite concentrated within quartz veins and greisens.

Studies of wall-rock alteration show that the central quartz veins are bordered by zones of greisen and greisenized granite that are characterized by zinnwaldite, quartz, fluorite and minor topaz. Inward from the greisen zones are envelopes of K-feldspar rich and reddened granite (orthoclase + chlorite + sericite + phlogopite) which locally pass outwards into kaolinized or unaltered granite.

The mineralogy and chemistry of alteration products indicate that they were produced by hydrogen and potassium metasomatism.

Geochemical analysis of unaltered bedrock samples indicates that the Ririwai biotite granite is characterized by trace elements high in Sn, Li, U, Th, Rb, F, Nb, W, Zn and Y and depleted in Ba, and Sr relative to barren rocks of similar composition. It is also characterized by high values for the following whole rock element ratios, Rb/Zr, Rb/Sr, Y/Sr, and low Ba/Rb and K/Rb.

These anomalous element concentrations are interpreted as reflecting geochemical specialization and an indication of the ore-bearing potential of the granite.

The above mineralogical and chemical changes are probably the result of

extreme fractionation with superimposed autometasomatic alterations.

THE USE OF SILVER AND COBALT AS PATHFINDER ELEMENTS FOR LOCATING COPPER-GOLD
BEARING QUARTZ VEINS IN TWO-MICA GNEISSES OF THE SERBOMACEDONIAN MASSIF,
KILKIS PROVINCE, NORTHERN GREECE
by
A. Kelepertsis, E. Karamanou, and V. Polyzonis

This is the first geochemical study in the area of Laodikino – Akropotamia
of Kilkis province. The purpose of the study was (a) to determine the
potential of the area of mixed sulphide minerals, (b) to find the kind of
mineralization paragenesis and (c) to determine pathfinder elements in
locating gold bearing quartz veins in the region of the western
Serbomacedonian massif.

The studied area lies in central Macedonia, 40 km NNW of Thessaloniki, and
is characterized by low relief with sparse vegetation. Soil horizons are not
well developed, and most of the geological formations are covered by "lithic
mountain soil" (C horizon and bedrock fragments). Downslope in areas of
gentler topographic relief, lithosols grade into deeper soils. These latter
are characterized by a greater profile development (A, B and C horizons).

In the area of geochemical research within the Serbomacedonian metamorphic
massif the following petrological formations can be distinguished: two mica
gneisses, quartz schists and ultrabasic rocks. These rocks are intruded by
acid aplites and pegmatites (aplitic and pegmatitic intercalations).

Mineralized constituents examined under the microscope in polished
sections from fresh drill core are typically pyrite, magnetite, arsenopyrite,
chalcopyrite. Quartz, barite, and calcite occur as gangue minerals.

A geochemical stream sediment survey has covered an area of about 15 km^2
with a sample density of 9 per km^2. The –80 mesh samples were analyzed by
AAS for Cu, Pb, Zn, Co, Ni, Cr, Ag, Au. The geochemical maps show that the
most significant anomalies are those of Cu. Factor analysis of the
geochemical data, established three factors: (a) a Cu-Co-V factor which is
the first mineralization factor (b) a Pb-Zn, the second mineralization factor
and (c) a Ni-Cr-V-Co factor due to the presence of ultrabasic rocks in the
area.

A soil sampling program was applied in order to investigate the
Cu-geochemical anomaly in detail. It covered an area of 3.75 km^2. The
collected samples were dried (in the open air), seived (-80 mesh fraction),
and analyzed for Cu, Pb, Zn, Ag and Au. The statistical treatment of the data
showed a very good correlation between Cu and Ag and a lower correlation
between Cu and Au. On the other hand there is a good correlation between Pb
and Zn.

The existence of Cu-Au quartz veins was confirmed by drilling. The
results of two boreholes placed in order to detect Cu-Ag geochemical haloes in
the area were positive. Drilling still continues.

Statistical treatment of chemical data of 48 analyzed samples taken from
the mineralized cores in the first borehole showed the same constituents as
the soil samples. There is a positive correlation between Cu, Ag and Au, and
an even stronger positive correlation between Pb and Zn.

The above distinction of two groups of elements, the first one including
Cu, Ag, Au and the second of Pb-Zn reflects the two different mineralizations

in the area studied. Cu-Ag-Au mineralization is the most significant in the area of Laodikino-Akropotamia and is confirmed by the drilling results. Primary Pb-Zn mineralization has not yet been found in the area.

ROLE OF LITHOGEOCHEMISTRY IN DELINEATING THE WESTERN EXTENSION OF THE SINGHBHUM SHEAR ZONE, EASTERN INDIA
by
A.K. Talapatra, C. Bhattacharya and S.S. Bose

The Singhbhum Shear Zone, with associated base-metal mineralization, is known to extend up to the Kharswan-Chakradharpur area in the west, where it splits into a northern shear and a southern shear with the Chakradharpur granite gneiss lying in between. In an attempt to explore the possible western and southwestern extension of these two branches of the shear zone, systematic geochemical sampling of bed rocks (1 363 samples) was carried out along ten different traverses straddling the 120 km linear belt from Kharswan to Rourkela, which resulted in identification of some promising narrow zones in all these traverses except the Rourkela. The results of geochemical analysis reveal that Cu, Zn, Ni, Co, Cr, Zr, Mn, V, Ti, Sr, Ga, Ba, Li and Rb, out of 25 elements analyzed show some significant values within the rocks of these narrow zones. Out of these, Cu, Co, Cr, Ni and V generally record moderately high values. The rocks of these zones also show some of the characteristic geochemical parameters which are typical of the rocks of the Singhbhum Shear Zone proper: namely, the range of trace-element values, elemental ratios of certain pairs of elements like Cu/Ni, Cu/Co, Cu/Cr etc., and statistically significant geochemical assemblages.
These narrow zones also show slight evidence of ductile shearing characterized by development of local mylonitic bands and sheath folds within the Precambrian metasedimentary and metavolcanic rocks of this tract. Locally these are migmatized. Development of strain slip cleavages (S$_3$) showing direction of movement/slip could be frequently observed up to Chakradharpur traverse and also in parts of Sonua, Tebo-Hesadi traverses, beyond that only axial plane schistosity (S$_2$) showing different angular relations with bedding (S$_1$) could be deciphered. Thus it appears that the effects of shearing gradually die out with the widening of the Singhbhum Shear Zone toward the west beyond Chakradharpur. Interestingly, the zones of the respective isolated traverses mentioned above, if joined together, fit with the probable south-western extension of the southern shear and western extension of the northern shear, respectively. Base-metal sulphide potential of these two narrow extension areas of the Singhbhum Shear Zone, excepting those of Kharswan and Chakradharpur traverses are yet to be worked out in detail.

EXTENDED ABSTRACTS – POSTERS

PRACTICAL FIELD–PORTABLE ATOMIC ABSORPTION ANALYSES
by
C. Castledine and J. Robbins

A new compact atomic absorption scpectrophotometer has been developed. Designated the Scintrex AAZ–2, the system uses flameless atomization and Zeeman modulation for maximum sensitivity and selectivity respectively.

The most important factor of AA instrumentation is the method used for vapourizing the sample. The atomizer furnace in the AAZ–2 is a tungsten ribbon rather than the conventional carbon furnace to avoid the need for high electrical power input and consequent water cooling. The ribbon is U-shaped to fit between the pole pieces of a powerful electromagnet, which provides the magnetic field required for Zeeman modulation of the absorption signal.

Zeeman modulation refers to the spectral displacement of atomic absorption lines in the presence of a magnetic field. By pulsing the field, the emission from the source lamp alternately does, or does not, coincide with the analyte absorption. A synchronous detection system then allows the extraction of the modulated signal from any unmodulated absorption due to nonspecific absorbers such as particulate scattering or some molecular species.

Zeeman modulation provides a method of baseline correction that is both more efficient and simpler than the commonly used deuterium arc correction and requires no moving components.

The AAZ instrument has already been characterized for a number of metals, in particular, those of exploration interest such as Au, Ag, Cu, Pb, Ni, Co. Zinc has been determined but difficulties in avoiding high blank concentrations have been found. Detection limits are typically 1 ng/ml or better (eg. Au – 0.4 ng/ml, Ag – 0.03 ng/ml). The metals usually requiring conversion to a gaseous hydride form before analyses have also been studied. Tin in the sub–ppm range has been determined after a simple extraction procedure. Work on arsenic, selenium antimony and bismuth is planned.

The entire machine weighs less than 25 kg and consumes 0.5 kilowatts making it suitable for use in remote areas using portable power generating equipment. Argon at low pressure and flow rate is the only gas needed for operation.

When used for analysis of samples in a base camp, close to the scene of a geochemical drilling program, the AAZ–2 can provide quick turnaround of the results and therefore on-the-spot guidance of these programs, without loss of sensitivity or data quality. In addition, the possibility of contamination by high-level samples is somewhat less in a field camp than in a long established laboratory.

HYDROGEOCHEMICAL INVESTIGATIONS OF THE MIDWEST AND McCLEAN U DEPOSIT
ENVIRONMENTS, NORTHERN SASKATCHEWAN
by
W. Dyck

In order to determine the extent and magnitude of hydrogeochemical

anomalies around the U-Ni deposits at South McMahon (SM) Lake and McClean Lake in northern Saskatchewan, and if these can be detected with exploration techniques, a number of semi-detailed and detailed surveys were carried out during 1979 and 1980. The main ore zones of both deposits lie nearly 200 m below the surface. The deposit under SM Lake is characterized by a well defined radioactive boulder train containing U-Ni ore grade boulders. The weathering of these boulders was postulated to be a source for the uranium in the regional geochemical anomaly in this lake. No such geological or geochemical features exist at McClean Lake.

In general, organic rich lake sediments examined in this study exhibited less erratic, and greater, contrasts between anomalous and background concentrations than did lake waters. The less erratic nature of the organic rich lake sediment patterns is due to the signal averaging effect of the sample media. The greater contrast for lake sediments is a direct result of the lower detection limit for trace elements, relative to average background levels, in solid samples than in water samples. Additionally trace element concentrations in water exhibited seasonal and depth related variability, concentrations being higher in winter and at lake bottoms.

The concentration of dissolved gases, O_2, Rn, and He, were markedly influenced by season and depth, with higher O_2 concentrations at the surface of lakes and in summer. Rn and He concentrations, and conductivity, were notably higher and pH lower in winter and near the bottom of lakes.

In the semidetailed survey, "Ase" Lake, one km south-west of SM Lake, contained the most anomalous samples and SM Lake and 2nd most anomalous samples for U, Ni and As in lake sediments, and He and Rn in lake waters. "Ase" Lake is fed by groundwaters carrying trace elements from either the deposit under SM Lake or some other, not as yet discovered, source. SM Lake is probably receiving some, if not all, its anomalous element concentrations from the radioactive boulder train. Winter levels of He and Rn in the waters under the ice of "Ase" and SM Lakes rose to 128 nL/L and 386 pCi/L, and 101 nL/L and 52 pCi/L, respectively, compared to background values of approximately 45 nL/L and 2 pCi/L in North NM Lake and elsewhere. In summer He levels dropped to equilibrium concentrations and Rn levels to about 20 pCi/L in "Ase" and SM Lakes. Sporadic anomalous concentrations of U and As in lake water were noted only in SM Lake. In the 3 lakes of the McClean Lake area, all lake water samples exhibited background or undetectable levels except for one winter site in "Candy" Lake, where 118 pCi/L Rn was found in the lake waters. The arithmetic means of the 5 pathfinder elements in the lake sediments of the semidetailed survey are presented below and compared to the regional mean:

	"Ase"	SM	NM	"Candy"	McClean	"Vulture"	Regional (mean)
U, ppm	4	9	2	2	2	2	2
Ni, ppm	12	11	8	10	6	7	8
As, ppm	45	14	2	3	7	3	1
Rn, counts/h/g	20	25	11	34	25	14	-
He, nL/L	55	52	48	51	55	91	-
No. of samples	10	20	18	9	7	8	437

The anomalous nature of "Ase" and SM Lakes is evident from the sediment data. The "Candy" Lake high mean Rn in sediment supports the Rn in water anomaly found in winter. In the immediate area of "Candy Lake", McClean Lake showed

enhanced As and Rn levels, and "Vulture" Lake had 3 highly anomalous He samples along the long axis of the lake, reflecting the presence of a fault.

Detailed water and sediment surveys of the anomalous areas of SM Lake confirmed the semidetailed results. Modal values of U, Ni, As and Rn in the waters dropped slightly in going from the southern end of the lake, close to the boulder train, towards the northern end in the direction of surficial drainage. Concentration changes of U, Ni, and As in the lake sediments of the detailed survey followed closely the changes of LOI, which was highest in the narrows towards the outflow end of the lake.

Analyses of approximately 500 groundwater samples from 26 drill holes at SM Lake revealed complex fracture controlled groundwater regimes. The majority of the holes are located in unmineralized ground. Water samples from a fence of holes across the ore zone gave highly anomalous concentrations of He, Rn, and ore elements right in the ore zone and revealed at least two distinct groundwater regimes. Typical average concentrations of some characteristic elements are summarized below:

	West of ore zone		Ore zone*	East of ore zone
	Valley	Drumlin		
pH	6.7	6.6	6.5	5.5
conductivity	80	30	150	30
He, nL/L	300	60	187 000	60
Rn, pCi/L	2 000	8 000	113 000 000	4 000
O_2, ppm	2	8	1.5	7
U, ppb	0**	0	6	0
Ni, ppb	0	0	10	0
As, ppb	0	0	100	0

* One sample from 188 m level after considerable pumping of sealed hole.
** 0 denotes less than detection limit of 0.2 for U, 0.5 for As, and 2.0 for Ni

The division between the groundwater regimes occurs at the edge the drumlin, immediately to the west of the deposit, and the valley further west. This valley also passes through the anomalous part of "Ase" Lake described in the semi-detailed survey. In combination, the field and laboratory observations suggest a fracture controlled southwesterly downward flow of groundwaters across the ore zone meeting an upwelling easterly flowing aquifer in the valley west of the drumlin.

Investigation of drill hole waters with depth and time showed measurable changes. Rn and He concentrations rose, and O_2 concentrations dropped markedly in samples collected in the spring of 1980 compared to the summer 1979 samples. However, relative trends along the fence of drill holes across the deposit at SM Lake remained the same. The U, Ni, and As levels in the water samples, for the most part, straddled the detection limit of the analytical methods. Sporadic anomalous values were observed in, or near, the ore zone drill hole samples, particularly acidified ones. These were due to the existence of fine ore grade grains and/or adsorbed trace elements on sandstone grains and hydrous iron oxides present in many samples.

At McClean Lake, 70 samples from 8 drill holes, mainly into mineralized ground, contained highly anomalous He and Rn concentrations with hole averages of up to 77 000 nL/L and 104 000 pCi/L, and individual maxima of 188 000 nL/L and 645 000 pCi/L, respectively. In general, concentrations were found to increase with depth. Rn concentrations decreased with distance from the richest part of the ore zone, whereas the He increased slightly with distance

from the richest known ore zone, suggesting the presence of a second source, or traps where He could accumulate. U, Ni, and As exhibited trends similar to that of Rn. Their presence in highly anomalous amounts in the drill hole waters is believed to be due to finely divided particulate ore, as a result of drilling. The elements were subsequently liberated when the samples were acidified to prevent the formation of hydrous oxides.

The U-Ni ore deposits at SM Lake and McClean Lake generate extremely high concentrations of Rn and He in groundwaters that permeate the deposits. The spatial dispersion of these dissolved gases seems to be dominantly controlled by groundwater movement through fractures in the host sandstones. The simultaneous presence of both gases in anomalous amounts in groundwaters (Rn greater than 4 000 pCi/L; He greater than 200 nL/L) increases the probability of finding U mineralization. Anomalous He alone is more likely to be an indication of major deep seated fractures.

Arsenic was found to be more abundant and mobile than U in ground water regimes. Therefore As could serve as an effective pathfinder for mineralization containing As minerals. Ni also appeared to be more mobile than U in ground waters, however, the poor detection limit of the analytical technique makes such an observation tentative.

These studies suggest the presence of Rn and He haloes extending at least 1 km along fractures and less than 300 m in sandstone. Detailed, well controlled field tests are required for more refined estimates of the size of the Rn and He haloes around U ore deposits.

GEOCHEMISTRY OF METAPELITES ASSOCIATED WITH URANIUM MINERALIZATION AT THE MIDNITE MINE, NORTHEASTERN WASHINGTON
by
M. Ikramuddin and G. Chou

Thirty-five Precambrian Togo metapelites, 26 schists collected from the Midnite uranium mine and 9 phyllites sampled from the surrounding areas, have been analyzed for SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, K_2O, TiO_2, MnO, H_2O, Ba, Co, Cu, F, Li, Mo, Ni, Pb, Rb, Sn, Sr, U, and Zn. Three pitchblende-coffinite ores collected from the mine have also been analyzed for Ba, Co, Cu, F, Li, Mo, Ni, Pb, Rb, Sn, Sr, U, and Zn.

The average chemical compositions of the phyllites and schists indicate that they were derived from pelites as a result of metamorphism. The schists are composed of mica schist and andalusite-mica schist. The mica schist adjacent to the contact is enriched in Fe_2O_3, FeO, MgO, CaO, Na_2O, MnO, Co, Cu, Li, Mo, Ni, Pb, Sr, U, and Zn and is depleted in K_2O, H_2O, F, Rb, and Sn relative to the phyllite from the surrounding areas. Variations in SiO_2, Al_2O_3, TiO_2, and Ba are minor. The andalusite-mica schist differs from the mica schist in having significantly higher contents of Al_2O_3 and K_2O.

A comparison of elemental abundance in the schist with the phyllite and enrichment of certain elements in the ore indicate that a large number of major and trace elements in the schist at the contact of the pluton were mobilized and redistributed at three different stages. Fe, Mg, Ca, Na, Mn, Co, Cu, Ni, Sr, and Zn in the metapelites seem to have migrated toward the contact aureole, whereas Sn mobilized away from the contact zone as a result of the contact metamorphism caused by the Cretaceous Loon Lake granite

intrusion. Enrichment of Li, Mo, Pb, and U in the schist at the contact took place when the hydrothermal fluids were introduced into the country rocks. High concentrations of Mo and Zn in the pitchblende-coffinite ore suggest that both elements along with U were mobilized by heated oxidized groundwater during Eocene time and later redeposited under reducing conditions.

The ferromagnesian trace elements, Co, Cu, and Ni, which normally substitute for Fe, show a positive correlation with FeO in the phyllites. This positive correlation is not seen in the mica schist; instead Co, Cu, and Ni correlate positively with Fe_2O_3. These data suggest that ferrous iron was a likely reductant, at least on a minor scale, in precipitating uranium.

It is suggested that a high concentration of Li, Mo, U, and Zn and significant positive correlation between ferromagnesian trace elements and Fe_2O_3 in the metapelitic rocks at the contact of granitic intrusions can be used to locate possible uranium deposits of hydrothermal origin.

GEOCHEMISTRY OF BIOTITE FROM GRANITIC ROCKS AND ITS RELATIONSHIP TO URANIUM MINERALIZATION AT THE MIDNITE MINE, NORTHEASTERN WASHINGTON
by
Y. Asmerom, and M. Ikramuddin

Biotite from 40 samples of granites, granodiorites and aplite dikes of the Loon Lake batholith from the Midnite mine area have been analyzed for 13 major and minor elements using an electron microprobe. These geochemical data are supported by whole-rock major and trace element analyses and petrographic studies.

Based on biotite and whole-rock major and trace element data two distinct granitic units are recognized, one in the western part of the mine and the other in the eastern part. The whole-rock SiO_2 values for the western granite range from 73 to 76 percent, and 70 to 74 percent for the eastern granite. Rb/Sr ratios range from 4.7 to 16 and 1.0 to 3.6 for the western and eastern phases respectively. The whole-rock K/Rb ratios in the two units overlap, but the average K/Rb ratio in the western granite is lower (115) compared with the eastern granite (140).

Biotite K/Rb ratios in the two units are significantly different; K/Rb ratios of biotites in the western granite range from 44 to 78 while the eastern granite biotites have ratios ranging from 125 to 370. Western granite biotite is enriched in Al, Fe, Mn, Cl, F, and Rb and depleted in Si, Mg, Ca, Ti, and Ba compared with the eastern granite biotite.

Fluorine is enriched in biotite in both the units, with enrichment increasing towards the mine. The granitic rocks at the mine, on the other hand, are depleted in F compared to similar rocks from other areas. Fe was probably mobilized after the reequilibration of biotite with the hydrothermal fluids. The X-phlogopite vs. F/F+OH data of the two units indicate post-crystallization reequilibration in the mine area.

Biotite alteration to chlorite is accompanied by rutile exsolution and zircon enrichment in chloritized parts of certain samples. Zircon in the study area has ten times the average U content of zircons from normal granitic rocks. Magnetite is found in association with biotite and its alteration products. High density of fission-tracks in the magnetite is noted by Nash (1979). These observations support the view that the hydrothermal fluids were enriched in uranium.

Fugacity ratios, Log (H_2O/HF), for 350°C are compared with those from the Henderson molybdenite deposit and the Santa Rita porphyry copper deposit. Biotites from granitic rocks of the Midnite mine area have higher ratios than Henderson and lower ratios than Santa Rita. Mine area samples have lower ratios than those away from the mine for the same unit.

Based on geochemical and petrographic data, the hydrothermal association of uranium mineralization at the Midnite mine is confirmed and two granitic units are defined. The more differentiated western granite is the most likely source for the uranium mineralization. Biotites and associated granitic rocks showing similar geochemical characteristics should be of interest for exploration.

GEOCHEMICAL PROSPECTING DEVELOPED BY METAMIG IN MINAS GERAIS - BRAZIL
by
J.D. Alecrim

Geochemical techniques have been intensively used by Metais de Minas Gerais S.A. - METAMIG, a government company, as an auxillary geological tool for selecting new areas for mineral exploration and for defining targets in its claims. Twenty-two geochemical surveys on several different scales have been conducted in 14 areas, using mainly soil, stream sediment and rock as sampling media. From 1976 to 1980 about 30 000 samples were collected with more than 180 000 chemical determinations, mainly for Cu, Pb, Zn, Ni, Cr, Co, Mn and Au. The application of the geochemical prospecting was to seek and/or define targets revealed by geological reconnaissance in: (a) carbonate rocks of the Bambui Group; and (b) ultramafic, mafic and intermediate rocks of metamorphic terrains of the southern and northern parts of Minas Gerais State.

EVALUATION OF THE URANIUM POTENTIAL OF PLIO-PLEISTOCENE TO RECENT SEDIMENTS OF WESTERN KANSAS
by
P. Berendsen and L.R. Hathaway

Plio-Pleiostocene sediments cover most of the western half of the state and are of potential interest as source rocks for uranium because they contain large volumes of volcanic ash derived from at least three volcanic centres in the western United States. As part of a study dealing with the chemical quality of irrigation waters, a total of 1 048 water samples were collected from 1974 through 1978 from the Plio-Pleistocene deposits which include the Ogallala Formation and the Pleistocene to Recent alluvial sediments associated with the more prominent streams - particularly the Arkansas River. Secondarily silicified sediments of the Ogallala Formation are known to contain anomalous amounts of uranium. These and other Ogallala sediments throughout the western part of Kansas were examined, sampled, and analyzed for their uranium content. Based upon these studies, it was concluded that the Plio-Pleistocene and younger sediments probably do not represent favourable environments for the accumulation of ore-grade uranium concentrations. However, it is possible that uranium-containing groundwaters may have had

access to older formations which may be better host rocks for uranium deposits.

The Ogallala Formation consists of stream-laid sand, gravel, silt, and some clay which were derived from a westerly source in the Rocky Mountain region of Wyoming, Colorado, and New Mexico. The sediments were deposited by aggrading streams that shifted position continually over the area. The thickness of the Ogallala Formation varies from a featheredge to over 90 m in the direction of its source area. Volcanic ash of widely varying ages (0.61 to 1.97 million years) and sources form deposits of limited areal extent as a result of redistribution, and reach thicknesses of up to 10 m. They are interbedded with the sediments and have been secondarily silicified and the resulting rock type has been referred to as chert or quartzite, depending on the texture, colour, degree of cementation, and the predominant lithology of the original rock type. The material referred to as chert shows anomalous uranium concentrations ranging up to 120 ppm U_3O_8. The silica and the uranium are believed to be derived from the volcanic ash as a result of dissolution processes. However, the cleaner and thicker ash deposits generally show little or no evidence of extensive devitrification. It may be that the ash which is intermixed with the sediments shows a larger degree of devitrification. The volcanic ash typically contains from 6 to 10 ppm U_3O_8. The best exposed silicified sediments of the Ogallala Formation occur in eastern Meade and western Clark counties in southwestern Kansas. They form a continuous 18 km northwest-southeast trending outcrop band having a composite width of about 3 km and a maximum thickness of 3 m near the centre and tapering towards either side. The degree or intensity of silicification also increases towards the centre. The unaltered, unsilicified sediments consist of quartz grains and pebbles cemented to varying degrees by calcium carbonate and contain only a few ppm U_3O_8.

The silicified sediments consist of a mixture of calcite, quartz, and alpha-cristobalite giving rise to a well-indurated rock unit. Ghosts of former pebbles can often be recognized in the rock. The uranium content is a function of the amount of alpha-cristobalite present in the rock. Samples of completely silicified material analyzed by J.R. Dooley of the U.S. Geological Survey using the radioluxographic method show that the uranium is evenly distributed throughout the specimen and appears as many tiny spots on the photograph. No uranium-bearing minerals have been identified and it is believed that uranium atoms are distributed throughout the structure of the alpha-cristobalite, perhaps even preventing this material from converting into a more ordered structure.

The volcanic ash contains four to five times more thorium than uranium, but the silicified samples contain five to ten times less thorium than uranium. What happened to the thorium in the dissolution and leaching process postulated for the ash is poorly understood, although several hypotheses may be forwarded.

No reducing environments have been identified within the Plio-Pleistocene sediments at present. However, additional studies need to be carried out before more definitive statements can be made.

The Plio-Pleistocene deposits and the Pleistocene to Recent alluvium are the main water-bearing units under development in western Kansas. The groundwater flow patterns are governed by the general dip of the beds and the lithology of the rock material. Regional and local structures such as faults, folds, solution collapses, and others exercise a modifying effect.

Generally, the basic groundwater flow patterns are in an easterly direction, but are locally modified by north-south flow patterns associated with the rivers traversing the area. One such feature that modifies the

movement of groundwater is the Scott-Finney depression which is an asymmetrical trough extending in a north-south direction from Scott City to Garden City. Calcium-magnesium-bicarbonate-type groundwaters predominate, but mixed cation sulphate waters become increasingly important along many of the drainages and in the Scott-Finney depression. Sodium-chloride-type waters are found west of the Crooked Creek-Fowler fault system in Meade County and in portions of the eastern half of the Great Bend Prairie south of the Arkansas River. Waters derived from the Ogallala Formation contain uranium concentrations from 2 to 172 ppb with a mean of 9.5 ppb. A significant correlation exists between the total dissolved solids content of the waters and their uranium content. Comparison of histograms in which uranium concentrations are plotted against various other properties for the observed distributions. Low $^{234}U/^{238}U$ activity ratios (values near 1.0), coupled with relatively high uranium levels in groundwater suggest an absence of significant reducing depositional environments. The uranium content of groundwaters associated with the two major drainages, the Arkansas River and the Smoky Hill River, is distinctly different. Water from the Arkansas River Valley contains in excess of 20 ppb westward from about the Finney-Gray country line, and about 5 to 15 ppb eastward. The lower values are likely due to recharge with fresher water from south of the river, effectively reducing the salinity of the water. Groundwater from the alluvium of the Smoky Hill River has a uranium content of only about 10 ppb in the western half and less than 4 ppb in the eastern half of the area. The nature of the source rocks and the behaviour of groundwater mass movement are responsible for these differences. In the Great Bend Prairie area south of the Arkansas River where the Ogallala sediments are no longer present, the uranium content of the groundwater is on the order of 2 ppb or less. The highest uranium values (up to 172 ppb) are measured in the Scott-Finney depression which is essentially an internal drainage basin in which accumulations of soluble salt from the surrounding area into the soils and groundwater has contributed to these high values.

The background values measured in the region are among the highest measured in the United States. Enough uranium is carried in groundwater that if given the proper environment for precipitation, a major uranium deposit could form. However, no such environment has yet been identified. Additional studies need to be carried out to fully evaluate the region.

DISPERSION AND MODE OF OCCURRENCE OF URANIUM IN STREAM SEDIMENTS
by
L. Bloom

In order to aid in the interpretation of exploration geochemical surveys techniques are constantly being refined to increase the contrast between samples with background and anomalous values, and lengthen the apparent dispersion train. One method of accomplishing this is to optimize the analytical technique used to determine metal contents in geochemical samples. The optimum analytical method will be selective for indicator elements in a mineralogical form which best reflects mineralization.

This approach was applied to stream sediment surveys from two areas of known uranium occurrence. These areas differ on the basis of the primary form of the uranium, geology and secondary environments.

The first survey was conducted over an area of 150 km^2, centred about Green Mountain, Fremont Country, Wyoming. The uranium occurrences are restricted to the Paleocene and early Eocene arkosic sandstones of the Wasatch and Battle Spring Formations, and are typical of Wyoming "roll-front type" deposits. A total of 81 stream sediment samples were collected at 500 m spacings from areas of outcropping Wasatch and Battle Spring Formations, as well as within the area of influence of outcropping conglomerate and Precambrian granite.

The second area included in the study is situated in southeastern Ontario, close to the village of South March. The area is underlain by the quartz-arenite succession of the Ordovician-age March Formation, which overlies the Nepean Formation sandstone and in turn is overlain by the Oxford Formation limestone and dolomite. Non-economic concentrations of thucolite and chalcopyrite are associated with two intraformational conglomerates within the March Formation. Forty-four stream sediment samples were collected at 50 to 150 m intervals.

The secondary environments of the two study areas differ substantially. The Green Mountain, Wyoming area is in mountainous terrain; stream waters are generally cold and fast flowing, with some localized swampy conditions due to beaver activity. In contrast, the South March, Ontario study area has been extensively reworked during continental glaciation; the area is flat and drainage is poor. Of particular importance is the existence of glaciolacustrine and/or marine clay sheets in South March for which there is no analogue in the Green Mountain area.

The samples collected were subjected to decomposition by a variety of selective digestive procedures. The procedures tested included acid digestions (0.1N HNO$_3$, 4N HNO$_3$, 10% HCl and HNO$_3$ plus HCl), hydrogen peroxide attack and hydroxylamine hydrochloride digestion of the samples. The resultant solutions were analyzed for uranium by fluorometry, and for copper, lead, zinc, nickel, iron, and manganese by atomic absorption spectrophotometry.

The total uranium content of the samples was determined by neutron activation/delayed neutron counting analysis (D.N.A.). A selection of samples underwent sieve fraction analysis plus organic and heavy mineral phase separations. The data acquired were interpreted through the use of map plots, graphical representations and statistical analysis.

It was concluded that the data derived from the selective digestion procedure could be used to evaluate the mode of occurrence of the trace metals. In the South March area the majority of the uranium in the sediments is in a readily extractable form, probably adsorbed on to organic matter or clays. In the Green Mountain area a large proportion of the uranium is held in a similar manner, but a significant fraction is dispersed mechanically, as uranium – bearing resistate minerals. The sources of the resistate minerals are the Precambrian granite and Crooks Gap conglomerate. These rock types do not host known economic concentrations of uranium but up to 300 ppm uranium is often concentrated in resistate mineral separates of zircon, monazite and xenotime. This mode of occurrence of uranium is not of exploration interest.

It is apparent that the mode of occurrence of uranium in the two study areas is different. Therefore, in order to optimize results of the geochemical survey, samples from the two areas should be analyzed for uranium using different techniques.

Uranium analysis by D.N.A. of South March samples gave the optimum discrimination of mineralized areas. The presence of high concentrations of iron/manganese oxides and low uranium values in these samples precludes the effective application of fluorometric analysis; the inherent drawbacks of the

fluorometric method are quenching of uranium fluorescence by Fe and Mn, and poor precision and accuracy at low levels.

The application of D.N.A. analysis for uranium for Green Mountain samples is not considered appropriate due to the presence of uranium-bearing resistate minerals. The optimum analytical technique in this case is nitric acid digestion of the samples followed by fluorometric analysis for uranium. This technique is selective for modes of occurrence of uranium which reflect mineralization, not bedrock sources.

It is recommended that the analytical method which is employed to determine trace metal contents of geochemical samples should be carefully selected. Application of the optimum analytical method will enhance the recognition of geochemical anomalies related to mineralization.

FLUID INCLUSION DECREPITATION MEASUREMENTS IN EXPLORATION FOR GOLD IN WESTERN AUSTRALIA
by
K. Burlinson

Introduction
Linden is an old gold mining area some 150 km NE of Kalgoorlie, WA. In December 1980 two mineral exploration claims in this area were explored for gold mineralization. This work included geological mapping, geochemical auger drilling and chip sampling of many of the quartz veins. The chip samples were analyzed for gold by Analabs, Kalgoorlie using an aqua regia extraction. Duplicates of 15 of these chip samples were also analyzed on the decrepitometer. For control purposes, double polished thick sections were prepared of 5 of these samples for visual examination of the types of fluid inclusions present.

Operational Details
Decrepitation analyses were carried out on the BGS decrepitometer Model 3, Version C. After initial tests to determine the optimum grain size for use in this survey the 15 samples were analyzed in 3 batches between 5/3/81 and 7/3/81. Within each batch at least one standard and one duplicate sample were run for quality control. The calibration and duplicate results are all within the normal reproducibility range.

Geology
Numerous quartz veins occur in this area within mafic - ultramafic host rocks. Porphyry dykes are also common and both these and the quartz veins show strong fault control. A major milky quartz vein strikes North - South and extends for in excess of 2 km. Many smaller veins occur and are commonly oriented East - West. These are often ferruginous and, based on the frequency and sizes of old workings, they seem to have been much more strongly mineralized than the main N-S vein.

Results
Many of the samples in this survey show abnormally low total decrepitometric activity (Da) in comparison with samples from other Australian mines. The results show 4 distinctly different types of quartz. Although there are significant between sample variations within each of these groups, it has not been possible to determine the significance of these variations because of the limited number of samples.

Group A includes samples 1, 2, 3 and 4. This group shows low to very low

Da with an ill-defined peak near 450°C. Sample 1 shows a particularly low Da, while 4 has a distinct lower temperature peak near 350°C. Three of these samples contain 2 to 4 ppm Au (sample 3 was not analyzed, but is immediately adjacent to sample 2) and all are from the more favourable E-W striking ferruginous quartz veins. Note that 4 is from a different vein set some 0.5 km distant from the other samples of this group. These samples are considered to represent a rich mineralization group.

Group B comprises samples 5, 6, 7, 12, 13 and 14. These show low to medium Da and distinct bi-modal histograms with peaks at 420°C and 530°C. Except for sample 6 all the Au analyses on these samples are at or below the detection limit (0.05 ppm). Sample 6 contained 15.8 ppm Au which was the highest value recorded at Linden. As this sample was collected within a strong shear zone it is possible that sample contamination has occurred. These samples are considered to be a marginally mineralized group, based on the frequent occurrence of small diggings nearby.

Group C comprises samples 9, 10, 11 and 15. These show low Da over a broad temperature range from 300°C up to the maximum temperature of 550°C, with no well-defined peaks of any sort. Au analyses of these samples were all at or below the detection limit. The samples all occur in the Southern portion of the claims and they are considered to be an unmineralized group.

Group D comprises only sample 8, which is unique in this survey. This sample shows a bi-modal histogram with a peak at 530°C as seen in group B, but the second peak is at 270°C. This is a considerably lower temperature than seen in any other sample in this area. The onset of massive decrepitation (which is generally indicative of the homogenization temperature) for this peak is at 190°C and a formation temperature of about 200°C, depending on pressure, is therefore implied. This sample was collected from the mullock heap of a major old mine and it analyzed 1 ppm Au. This quartz vein had been brecciated by post formational movement along the fault in which it formed and this low temperature peak is probably related to this late stage activity. It is likely that the gold mineralization at this location was also related to this activity.

Summary

Decrepitation analysis has outlined 4 distinct types of quartz at Linden. One of these groups shows a close relationship with anomalous Au analyses while samples from the other 3 groups contain only background Au levels. The one exception to this rule may be due to sampling problems.

A complex history of quartz formation has occurred at Linden: - Initially the major N-S vein was emplaced, this type B quartz being a higher temperature barren phase. As the temperature decreased the cooler type C quartz was emplaced in the southern part of this vein. Telescoping during the emplacement of this type C quartz caused local reheating and natural decrepitation as seen in sample 11. During the third stage the sulphide and gold mineralized type A quartz was emplaced in E-W striking shear zones. These crosscut the type B quartz near sample 6. During the fourth stage fault re-activation caused brecciation and low temperature alteration of the type B quartz in sample 8. This is the lowest temperature and presumably the last activity in the area.

Conclusions

Despite the limited number of samples in this survey some useful relationships between decrepitometric character and Au mineralization of the quartz veins are evident. The marked differences between the 4 quartz groups identified has also made it possible to distinguish between various types of quartz veins and to suggest a sequence for the formation of the quartz veins.

Although the results are not completely unambiguous there is certainly good justification for further such orientation surveys to consolidate this work.

EXPLORATION GEOCHEMISTRY IN NORTHEASTERN BRAZIL
by
G.N.D. Goncalves and D.C. Bruni

The region under exploration lies in the northeast part of Brazil. It is bounded by latitudes 3° to 16^oS. The general geological features can be described as follows:
(1) Archean and Proterozoic metamorphic rocks, represented by granite, gneisses, schists, and stratigraphically undifferentiated migmatites; (2) a rock sequence of "greenstone" type rocks; (3) Early Proterozoic (2 600 - 1 800 Ma) gneisses, granites, granulites, charnockites, basic and ultrabasic rocks, and migmatites; (4) Middle Proterozoic, schists, metavolcanics, conglomerates, quartzites, siltites, and granites; and (5) an Upper Proterozoic (570 - 1 100 Ma) sedimentary sequence of low metamorphic grade, comprising carbonate and pelitic rocks, and a volcano-sedimentary sequence. The Precambrian rocks are overlain by some Phanerozoic sedimentary basins. The geological structures exhibit three conspicuous trends: E-W, NE-SW, and NW-SE.

The area has been mined for the minerals chromium, manganese, gold, lead, tungsten, copper, magnesite, potash, gems, and petroleum.

Since 1973 CPRM (Federal Research Company of Mineral Resources) has been carrying out a regional geochemical exploration reconnaissance program based on low density stream sampling. In addition, the region is simultaneously being covered by geological mapping. The integrated geology/geochemistry surveying has permitted the selection of specific target areas with high concentration of trace elements, some of them related to mineral occurrences. As a result geochemical exploration has helped in the location of some mining districts. To supplement the program related information from other sources has been used for the regional geological mapping.

The usual sampling medium was stream sediment and "pan" concentrates (heavy minerals from alluvium). Less frequently rock and soil samples were collected for confirmation of geochemical interpretations. During the early stages and until 1975 the geochemical analyses were done by emission spectrographic (30 elements) and colorimetric methods. After 1975, the spectrophotometric atomic absorption technique became the acceptable method. The statistical data analysis and the preparation of geochemical maps and profiles are being done by the CPRM computer system.

This regional reconnaissance program has shown some particularly strong variations in metal concentration with emphasis on such metals as Cu, Pb, Zn, Au, Cr and Ni. Concession areas are being studied by CPRM and other federal and private Brazilian companies in the interest of establishing economic viability.

GEOCHEMICAL SAMPLE DIGESTION BY HIGH PRESSURE ACID LEACH
by
M. Hale and J.S. Lovell

A new technique has been developed and tested for the rapid and efficient digestion of geochemical samples prior to analysis. Crushed or sieved sample material is weighed into a unique design of borosilicate test-tube which incorporates a glass flange around the rim. After addition of the leaching reagent (normally an acid or acid mixture), the test-tube is sealed by a crimp-on cap with an inert liner, and seated in a custom-designed digestion block. When adequate sample dissolution has been achieved, the cap is removed, and the leachate diluted for determination of trace and major elements by atomic absorption spectrophotometry, inductively-coupled plasma emission spectrometry and/or other methods.

Experiments on the digestion of a variety of soil and stream sediment samples show that a mixture of nitric acid and hydrochloric acid under pressure at $175^{\circ}C$ for 1 hour generally produces a heavy metal leach comparable with that attained with fuming perchloric acid at atmospheric pressure. In addition, volatile sample constituents are not lost from the sealed tube as they are from conventional test-tubes, and are largely retained in the leachate for subsequent determination provided the tubes are allowed to cool prior to removing the cap.

Pressure digestions have capital investment and environmental advantages since no fumes escape from the sealed tube. This eliminates the need for fume extraction systems and obviates the exhaustion of noxious gases to the atmosphere. For safety reasons, pressure digestions should be carried out in an isolated space, such as a cupboard, but no tube failures have been experienced to date. The procedure is amenable to the digestion of large batches of samples usually encountered in geochemical exploration programs.

INTERPRETATION OF SECONDARY DISPERSION PATTERNS AT KEY LAKE,
NORTHERN SASKATCHEWAN
by
Y.T. Maurice, G.J. Strnad, and W. Dyck

The Key Lake U-Ni deposits are located just north of the southeastern edge of the Athabasca Group in northern Saskatchewan at latitude $57^{\circ}2'N$ and longitude $105^{\circ}40'W$. One of the two deposits, the Deilmann orebody, lies partly under Key Lake and is separated from the lake bottom by some 50 m of Athabasca sandstone and Quaternary deposits. The other, the Gaertner orebody, occurs under Seahorse and Karl Ernst Lakes and is in contact with the Quarternary deposits.

The orebodies occur at the intersection between an east-northeast striking fault within the Wollaston domain of the Churchill structural province and the sub-Athabasca unconformity. To date, reserves are approximately 83 000 m tons U_3O_8 at an average grade of 2.4% U_3O_8.

The host rocks include the nonmetamorphosed sandstones of the Helikian Athabasca Group and the metamorphosed and altered sediments of the Aphebian Wollaston Group. The latter comprises a variety of schists and gneisses and structurally disturbed lithologies such as mylonites. Much of the ore is

concentrated within the regolithic upper portion of the Wollaston rocks.

The principal uranium ore minerals are pitchblende, sooty pitchblende, and coffinite. The main nickel and arsenic-nickel minerals found are gersdorffite, millerite, niccolite, and bravoite. Bravoite also accounts for most of the cobalt in the deposits. In addition, there are lesser amounts of rammelsbergite, pentlandite (in pyrrhotite), galena, sphalerite, molybdenite, chalcopyrite, marcasite, and pyrite. Chlorite, kaolinite, illite, quartz, siderite, calcite, sphene, and epidote are the main gangue minerals but these are generally present only in minor quantities and are not observed everywhere.

Partial glacial erosion of one of the ore deposits, the Gaertner orebody, led to the formation of an extensive blanket of mineralized till that reached minable concentrations of uranium (about half a million tons averaging 0.5% U_3O_8). The ore minerals were further dispersed as clastic grains by an esker that cuts the mineralized till and the Gaertner orebody, extending to Zimmer Lake, some 10 km to the southwest. A hydromorphic anomaly of various elements derived from the mineralized detritus has formed within the surficial water system.

To investigate the nature and the extent of this secondary dispersion, an area of approximately 800 km^2 centred on the deposits was subjected to a lake sediment and water geochemical survey. Sediments from the profundal basins of lakes and near-surface waters were collected at an average density of one sample per 2 km^2. The waters were analyzed for U, conductivity and pH, and the sediments for U, Zn, Cu, Pb, Ni, Co, Ag, Mn, As, Mo, Fe, Hg, and loss of ignition (LOI). Metal associations were examined by factor analysis.

The ore-forming metals, U, Ni, As, and Co form a strong association. They all generate well defined anomalies in the vicinity of the orebodies and their extension in the direction of glaciation. Molybdenum also shows some enrichment along this trend but the other metals that occur in minor amounts in the ore, viz. Cu, Pb, and Zn show only minor contrast between anomalies and background resulting in rather diffuse patterns.

The highest uranium values in the sediments (1 500 ppm U) occur in Zimmer Lake. The strongest uranium anomaly in the waters (5-14 ppb) occurs in Karl Ernst and Seahorse Lakes over the Gaertner orebody. Both these lakes also show strong uranium anomalies in their sediments (500 to 1 000 ppm). Key Lake, on the other hand, which is underlain by the Deilmann orebody, shows only slightly higher than background concentrations of uranium both in its waters (up to 0.4 ppb) and in its sediments (up to 8 ppm). All three lakes, Key, Karl Ernst and Seahorse show Ni anomalies of comparable magnitude (100 to 200 ppm).

The anomaly in Key Lake is believed to originate from groundwater that comes in contact with the Deilmann orebody or the mineralized detritus derived from the Gaertner deposit. Reducing conditions associated with the ore prevent uranium from dispersing hydromorphically. Nickel, which is more mobile than uranium under these conditions, is dispersed by the groundwater and introduced into Key Lake.

Ore metal and molybdenum anomalies of somewhat similar characteristics to those associated with the ore-derived dispersion fan, but much less intense, were found throughout the survey area mostly over the Athabasca sandstone. They are always associated with eskers and it is suggested that they may indicate the presence of buried mineralization. The large anomaly associated with the ore deposits at Key Lake is unusual in that it required that a portion of the ore deposit be glacially eroded. The weaker anomalies associated with the eskers may represent the only surface expression of blind ore deposits. The presence of Mo in these anomalies is particularly

interesting because this element is known to form primary haloes around some of the ore deposits in the Athabasca region.

Where the influence of the mineralization is not felt, the metals are controlled by their affinity to organic matter (Zn, Cu, Ni, Co, U, Hg) and to the hydroxides (Mo, As). Lake size and depth also have a significant influence on the metal content of lakes in that area. Larger and deeper lakes tend to accumulate more metals and less organic matter than shallow lakes.

HOST-ROCK ALTERATION GEOCHEMISTRY IN THE VICINITY OF THE MAURICE BAY URANIUM DEPOSIT, SASKATCHEWAN
by
M. Mellinger

The Maurice Bay deposit is an unconformity-type uranium deposit, located on the northwest shore of Lake Athabasca in Northern Saskatchewan. The geologic setting of the deposit was investigated and a petrographical and mineralogical study was undertaken. Approximately 400 samples from the Athabasca Group and the basement complex were analzed for 12 major elements and 16 trace elements. Selected samples were also analyzed for rare earth elements. Data analysis was carried out using successively: univariate population analysis, correlation and bivariate analysis, and correspondence factor analysis.

Chemical variations related to pre-mineralization events, such as paleoweathering of basement rocks and diagenesis of sandstone were studied in those samples least affected by later alteration. A study of the chemistry of host-rock alteration in the vicinity of the Maurice Bay uranium deposit was then undertaken. Implications of lithogeochemistry for uranium metallogenesis and exploration are discussed.

## ELECTRONIC GEOCHEMICAL DATA TRANSMISSION
by
H. Blok and R.D. Morse

Geochemical surveys by their very nature require speedy turnaround of analytical data. As a result, much effort and expense is devoted to minimizing transit time of samples to the analytical laboratory and to expediting them through the preparation and analysis procedures. Yet, in many cases, once the analytical data are ready, the most common approach is a reliance on the postal system for dissemination of the data. Some other approaches that have been used to a minor degree are telephone (voice) and telex reporting of selected 'anomalous' values. These two are not satisfactory for routine reporting of data since they are time consuming, expensive and are prone to transcribing errors.

In this paper we describe our experience with the distribution of analytical data from an on-line data base to a variety of remote data receiving stations using ordinary dial telephone lines.

A schematic diagram of our distribution system is shown in the figure.

Analytical data from a central laboratory computer system is sent via dial

TYPICAL GEOLOGICAL DATA DISTRIBUTION SYSTEM
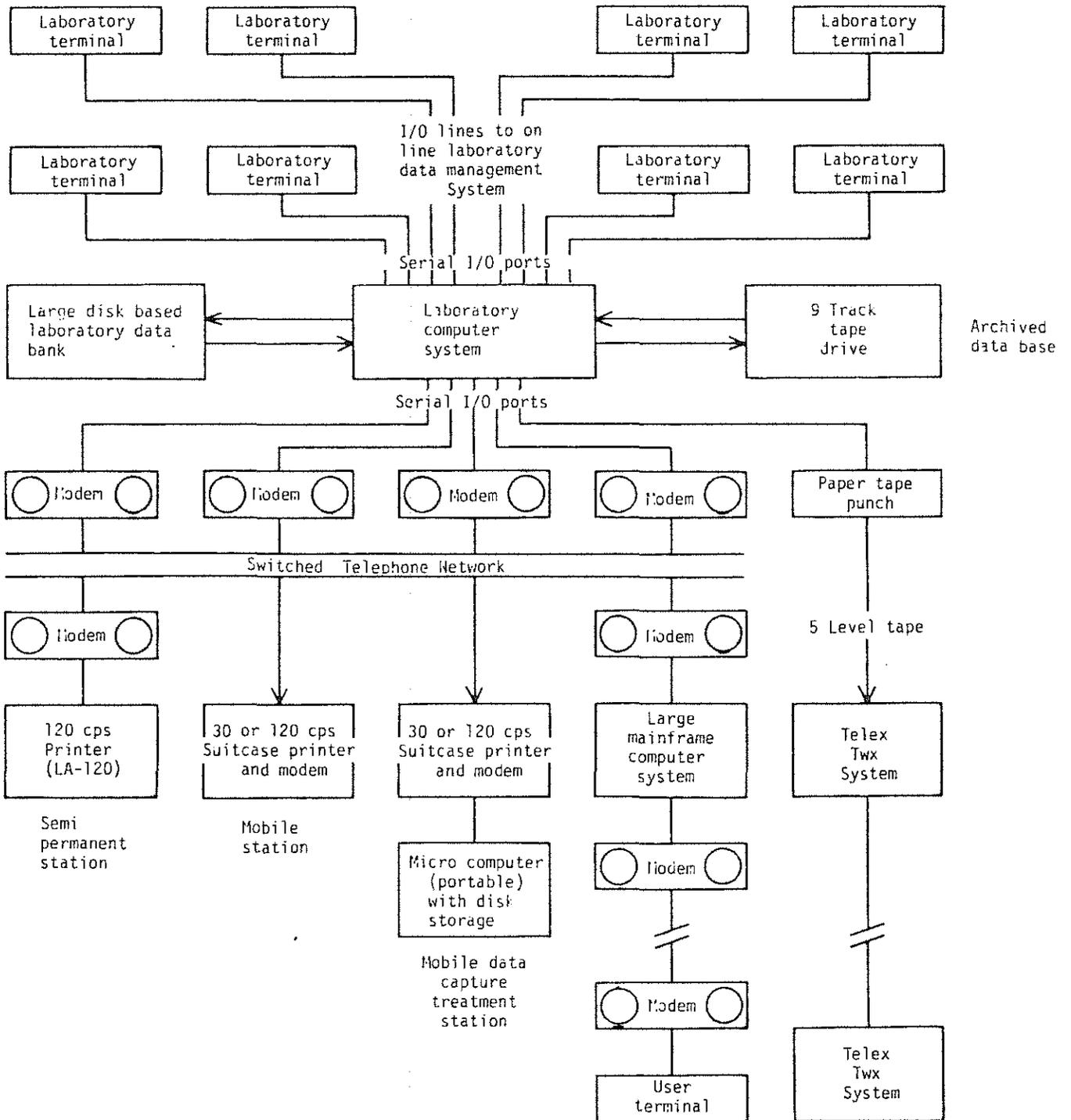
telephone line to a receiving device virtually anywhere within North America. The receiving device can be as simple as a briefcase size remote printer terminal, or as complex as a mainframe time sharing computer system. The portable systems are designed to travel with the project geologist, and printed data can be received in temporary field offices or motel/hotel rooms, even airport phone booths. In the case of sending data to a large scale computer centre using a special protocol, the end user can sign on to this system and can manipulate his data, merge it with other sensitive field data, and do statistical analysis of such merged data sets.

The rate of data transfer over switched networks is usually 30 characters per second and that remains the most commonly encountered data transmission speed. We have had good success in some applications using 120 characters per second. This is by far the preferred rate. Higher transfer rates require more expensive user supplied equipment but save on certain computer resources and minimize long distance telephone charges. The cost of these transmission services is of the order of 1% of the analytical costs. The time saving over regular mail service can be up to two weeks.

Some limited use has been made of the Telex system to transfer data. The transmission rate is 10 characters per second, however, and the preparation of teletype coded tape is cumbersome. We have used a paper tape punch interfaced to our main computer which converts computer code to teletype code and produces a tape. The tape can subsequently be run on a Telex. This is a useful approach for world wide data transmission. The Telex network is so well used for global commerce that the additional expense of transmission charges is usually less of a concern than the logistical problems of setting up an alternate mode of communication.

The transfer of large blocks of data can also be achieved by transferring to a mass medium, typically 9 track magnetic tape, and physically sending the medium to a computer centre where the data can be read back into the computer. This process usually takes place at the end of season when data are required for archiving etc. or for large reconnaissance operations where fixed schedules up to several years in advance predominate.

The next obvious step in transmission of analytical data to end users is to provide some means of data capture and manipulation within the field or project office, without the need of large time sharing computer systems. This will be accomplished by providing a portable microcomputer as the receiving device for analytical data and by providing software to enable field personnel with a minimum of computer experience to manipulate the data, merge field data with the corresponding analytical data and perform basic statistical and plotting operations on the expanded data set. These capabilities presently exist and are certainly cost effective. It remains to be seen if anyone is interested.

GEOCHEMICAL STUDY OF SOIL AND STREAM SEDIMENTS FROM GEBEL EL-RUSAS AND UM GHEIG AREAS, EASTERN DESERT, EGYPT
by
M.A. Morsy and F.H. Hassan

A geochemical survey of soil and stream sediments was carried out in Gebel El Rusas and Um Gheig areas to locate possible mineralized zones. From the Gebel El Rusas area, 100 soil samples were collected according to a pre-laid

grid measured by tape and compass at 25 m intervals through five profiles 100 m apart. In the Um Gheig area, 92 soil samples were collected from five profiles on a grid 50 by 25 m. Duplicates were taken at about 5% of the sampling points. Also, 70 stream sediments were collected from Gebel El Rusas and 32 samples from Um Gheig area.

The samples were digested in 2 ml 1:1 HCl at 90°C for one hour and AAS determinations were performed for Zn, Pb, Co, Ni, Cu, Mn and Fe.

Thresholds were found to range from 100 to 400 ppm for Zn and 50 to 200 ppm for Pb in the Gebel El Rusas and from 125 to 200 ppm for Zn and 50 to 100 ppm for Pb in Um Gheig. The highest Zn values are encountered in the northern and southern part of Gebel El Rusas and in the southern part of Um Gheig. Lead shows a similar behaviour to that of zinc.

Next to visual examination of the various distributions, certain ratios as the contrast index may help in quantifying differences in geochemical characteristics between the two mineralized areas. In comparing the contrast indices of soil values in both areas, it is evident that there are slight differences between the studied elements except for Pb. In Gebel El Rusas lead reveals a much higher contrast than that at Um Gheig. For stream sediments, the contrast indices are similar for Cu, Ni, Co and Mn, whereas for Zn and Pb they are highest in Gebel El Rusas area.

In conclusion, it appears that Zn values in soil and stream sediments give high anomaly constrasts in both areas. For Pb, the values are also high but more erratic. For Cu, Ni and Co, the values are medium to low.

REGIONAL GEOCHEMICAL AND PAN-CONCENTRATE EXPLORATION PROGRAMS IN PARAIBA STATE, BRAZIL

by

L.C.B. Pereira and J.J. Correia de Oliveira

This work includes a description and details of the results obtained through the regional geochemical and pan-concentrate exploration programs carried out in the Paraiba State, Northeastern Brazil.

The maps are to a scale of 1:500 000 where the limits of the areas studied, the number of samples collected, the different elements and minerals that are identified, and the principal anomalies obtained (of W, Sn, Au, Sb, Mo) are demarcated.

A geological base map is also prepared with the inclusion of the principal mineral occurrences, obtained from a systematic study of the State through cataloguing.

The data presented in this work is mainly based on the following projects carried out by Cia. de Pesquisa de Recursos Minerais (CPRM), supported by the Departamento Nacional da Producao Mineral (DNPM): (1) Rio Jaguaribe Project, (2) East of Paraiba and Rio Grande do Norte States Project, (3) Scheelite of Serido (Region) Project, (4) Lavras de Mangabeira Region Project and (5) Gold of Pernambuco and Paraiba States Project.

Considerations on the geochemical problems encountered in these areas, and on the behaviour of the elements in the secondary environment in semi-arid regions, are also given and discussed.

LASER-INDUCED FLUORESCENCE; A HIGH SENSITIVITY METHOD FOR URANIUM ANALYSIS
IN THE FIELD OR LABORATORY
by
C. Castledine and J. Robbins

A new, high-sensitivity method of analysis for uranium in an aqueous
solution has been developed and extensively proven in use over the past five
years. It is based on the special temporal characteristics of laser-induced
fluorescence of the uranyl ion in solution. An instrument designated the UA-3
has been constructed on these principles. It utilizes a sealed nitrogen
laser, especially designed for this purpose, which provides an intense pulse
of ultra-violet light, of very short duration, thereby creating the required
fluorescence in the sample. Appropriate optical and electronic devices
measure the characteristics of the fluorescence at preselected times, in order
to emphasize the uranyl fluorescence and minimize fluorescence from other
sources, for example dissolved organic matter. As a result, essentially
interference-free measurements of uranium, to the sub-ppb (.05 ppb) level, can
be made on most solutions.

The sensitivity of the UA-3 technique is better than that of the fused
disk fluorometric method and approaches that of fission track analysis.
Because of the low detection limit, complex samples may be readily diluted,
thereby diminishing matrix effects and still retaining the accuracy of the
uranium analysis.

The UA-3 itself has been designed for use in remote base camps as well as
established laboratories. It is rugged, light weight and consumes only sixty
watts of power. An individual measurement requires less than one minute, on
the average.

The UA-3 has found applications to date in uranium geochemistry drilling
programs, mining and process control, and in health and environmental
monitoring. In geochemistry, it is being used on samples of surface and
groundwaters (hydrogeochemistry), usually with no pre-treatment of the
samples. It is also being used routinely on soils, sediments and rock
samples, the uranium being extracted from the samples using a suitable wet
chemical procedure which, in each case, is field applicable. For low-level
hydrogeochemical sampling it is a major advantage to analyze the samples in
the field quickly after their retrieval, in order to avoid the problem of loss
(or gain) of uranium to (or from) the sample container. For all geochemical
and drilling applications the quick turnaround time afforded by in-field
measurements allows a more intelligent use of field personnel and greatly
improves the efficiency of such programs.

The UA-3 is being used extensively in uranium mills to monitor the uranium
content of the various mill streams. It is also used to analyze for uranium
in rather complex matrices, e.g. seawater, urine and acid leach solutions.

Extensive comparisons have been carried out, on all of these types of
samples, between the UA-3 analyses and those based on the more conventional
techniques, before concluding that laser-induced fluorescence is indeed a very
specific, sensitive, accurate and economical means for determining the uranium
content of solid or liquid samples.

SOME RELATIONSHIPS BETWEEN GRANITOIDS AND TIN-TUNGSTEN MINERALIZATION IN NORTHERN PORTUGAL
by
J.M. Santos Oliveira and E. Pereira

The tin and tungsten mineralization of Portugal has generally been assigned to late post-tectonic Hercynian granitoids (the biotite porphyroid granite and its differentiates). The present geochemical study, which was carried out within some stocks in the north of the country, in the Penafiel-Oliveira de Azemeis region, illustrates the possible association of mineralization with syntectonic (older) granitoids.

The low values of the Mg/Li and K/Rb ratios and the high values of the Rb/Sr ratio, together with the high values of the respective coefficients of variation, all indicate a particular degree of geochemical and metallogenic specialization of the syntectonic Freita granite. A hypothesis is therefore suggested for the existence of "mineralization and mineralization" i.e. mineralization related to granitoids emplaced at various stages during the Hercynian Orogeny.

The authors emphasize the importance in accepting this principle for the definition of the methodology to be used during tin and tungsten prospecting.

APPLICATIONS OF A LITHOGEOCHEMICAL TECHNIQUE, WITH EMPHASIS ON GOLD EXPLORATION
by
M.V. White and H.M. Verma

This paper is based on major and trace element chemical analyses of over 20 000 rocks collected mostly from Archean volcanic regions, hosting base metal and/or gold deposits within the Canadian Shield; a lesser proportion was collected in younger regions hosting uranium and porphyry copper deposits. The techniques discussed, were developed by the writer through his work with mineral exploration companies and from individual research over the past 10 years.

Presently there is considerable published and unpublished lithogeochemical data available and many exploration companies are applying lithogeochemistry in one manner or another in their search for mineral deposits. Many chemical elements can be used to define mineralized zones; those elements of most use have been discussed in the available literature and need not be listed as such.

Two important applications of lithogeochemistry have emerged: 1) the accurate identification of rock type for stratigraphic correlation in tracing ore-bearing horizons or rock units that are known to host ore bodies; and 2) defining potential mineralized areas and tracing alteration haloes that commonly accompany mineral deposits.

Most, if not all, mineral deposits have some kind of alteration zone that can be defined as chemically distinct from the regional rock types that host the deposit, though while deposit types have some chemical similarities, there is also considerable chemical element variation. Only by comparative orientation studies for any region of exploration interest can the most favourable lithogeochemical technique be decided upon.

The writer has found that a most useful and universally applicable parameter to lithogeochemical exploration techniques is a function of the alkali content of the potential host rock type. This can be expressed as a

function $Y=K_2O/Na_2O + K_2O \times 100$ where values of $f(Y) < 10$ and/or > 80 can be loosely regarded as indicative of potential mineralized zones when supported by other major or metal element variables and/or geological and geophysical criteria.

The function expressed above is particularly applicable to mineral deposits hosted in felsic volcanic and intrusive rocks, be they base metal, gold or uranium deposits. Some examples include the classic Noranda region, the Timmins area and the Makkovic uranium area. Felsic volcanic rocks in Noranda are commonly SiO_2 and Na_2O rich: local, individual mineralized centres display high $f(Y)$ values.

In the Timmins-Kidd Creek area, the felsic volcanic rocks shows regionally high SiO_2 and K_2O content. Individual gold and base metal deposits again have high $f(Y)$ values; though with respect to base metal deposits in the area, the local associated alkali variation is obscured by the regional K_2O enrichment. In the Makkovik, Labrador uranium area regional K_2O enrichment is also common; however, uranium deposits are commonly accompanied locally by strong Na_2O enrichment giving a low $f(Y)$ value.

While the alkali function is especially diagnostic for felsic extrusive and intrusive differentiates it can also be used in mafic rock types, especially those hosting Au mineralization. In general the diagnostic applications are restricted to high values of $f(Y)$ as low values that may have acted as mineral indicators are obscured by the overall low K_2O content characteristic of mafic igneous rocks. Numerous examples of high values of the $K_2O/K_2O + Na_2O$ ratio associated with gold deposits hosted within mafic lavas, exist in the Timmins area alone.

Another extremely useful and universally applicable lithogeochemical tracer is Au itself; an obvious choice in the exploration for Au deposits it is also enriched, though commonly at low levels, in base metal deposits (both massive sulphide and porphyry copper deposits). A lithogeochemical survey using Au content combined with the alkalis in possible ore hosting rocks, is a powerful exploration tool. Data can quickly be evaluated without involved statistical analysis, though areas designated for follow up should receive more detailed attention including lithogeochemical studies for additional elements that may better define the limits of the mineralized area and indicate drill targets.

Of equal importance in a lithogeochemical exploration program is the consideration of the possible size and distribution of alteration zones associated with the potential mineral target. Experience shows that there is no set distribution pattern or set size to alteration zones. On the assumption that alteration zones are the products of the "hydrothermal solutions that emplaced the mineralization with which they are associated, the best guidelines lie in comparison with recent hydrothermal systems - namely recent volcanic complexes, particularly the distribution of their fumaroles and hot springs. Commonly in recent volcanic complexes, there exist hundreds of fumaroles and volcanic vents. If this distribution, as seems probable, existed in the past, numerous additional ancient vents with potential for new ore bodies remain to be found in presently active mining camps in Canada. Many of these ore bodies, specifically, their associated alteration zones will someday be discovered by the application of lithogeochemical exploration techniques.

A critical problem in the application of lithogeochemistry, particularly in extensively glaciated regions such as Canada, is the lack of readily available outcrop. In many cases the only means of collecting rock samples for lithogeochemical studies is by diamond drilling or deep overburden

sampling, an option generally considered as too expensive by mining exploration companies. In areas where overburden is not in excess of 10 m, an effective, inexpensive sample collection technique involves a combination of overburden samplig for gold using flow-through samplers. Both a soil sample and rock chips are collected at the bedrock - overburden interface. In addition, where better rock samples are required, they can be obtained by one of two ways: The first involves pulverizing the surface rock with a hand-held percussion-hammer drill and retrieving the rock powder from the bottom of the hole with a vacuum cleaner, or the collection of a small rock-core sample by means of a small (GSC type) diamond drill. Both the above techniques have been used successfully by the writer in gold exploration programs, though considerable improvement can still be made on the sample collection method.

GEOCHEMICAL EXPLORATION AT THE CARACOLES Ag DISTRICT ANTOFAGASTA, CHILE
by
J. Cabello

The Caracoles Ag District is characterized by a vein system emplaced mainly in Jurassic marine sediments containing acid-intermediate intrusives of probable Tertiary age. Volcaniclastic continental rocks of Triassic to Tertiary age, deformed and faulted and with several unconformable contacts, are also present.

Geochemical methods were used to define anomalous areas within the district, and were examined in more detail. Rock, soil and vein geochemistry was utilized, the samples being assayed for Ag, Cu, Pb and Zn and the results subjected to statistical analysis by computer methods. Anomalies were classified according to size, geological characteristic and element association as major, minor and secondary.

Three major anomalies were defined, and one of these selected for more detailed study. This showed that the anomaly was related to partially exploited veins in brecciated andesites. The relationship of anomalies to previously identified geological and mineralogical features was also determined. Factor analysis was used to determine element associations.

EXTENDED ABSTRACTS - "BY TITLE ONLY"

SUSPENDED MINERAL MATTER AS A STREAM SEDIMENT SAMPLE FOR GEOCHEMICAL PROSPECTING
by
F.R. Siegel

Suspended sediment (or its mineral or organic components) has not been used as a sample for regional or follow-up land geochemical surveys because of problems in the field collection of the sample. Large volumes of water had to be transported to the laboratory for centrifuging or filtering to obtain the suspended solids. Also, because satisfactory results in geochemical exploration programs were achieved with a sieved fraction of bottom stream

sediments or alluvium, there was little need to develop a viable method for taking a suspended solid in the field. Nonetheless, the potential of the suspensate for targeting mineralization was demonstrated by Perhac and Whelan (1972) using three samples of suspended sediment and their corresponding bottom sediments from a northeast Tennessee Zn district.

The field sampling problem can be eliminated by using a polypropylene Buchner funnel with suction nozzle coupled with a hand-operated vacuum pump and Millipore 0.45 µm nominal pore size HA filters 142 mm in diameter. Millipore filters are preferred over other available filters because of their relatively rapid flow rate versus the other filters. The volume of water that must be put through the system to obtain a satisfactory sample varies with the amount of suspensate being carried by a stream. However, the sampling should not take more than half an hour. In the laboratory, the filter and organic suspended matter are volatilized at 500°C leaving the mineral suspensate for analysis.

In an orientation study using the technique six suspended sediment samples and their corresponding bottom sediment -100 mesh size fractions were taken from the area of the Eagle Ford gold mine (last worked in the 1940s), Montgomery County, Maryland (USA). The samples were fused with $LiBO_2$ and dissolved in 3% HNO_3. Standards were prepared in the same matrix. Analyses were made for Cu and Zn using AAS. The results are given in the table below:

Table 1 - Copper and zinc in mineral suspensates and the corresponding bottom sediments -100 mesh size fraction, Cool Spring Branch, draining mineralization of the Eagle Ford gold mine, Montgomery County, Maryland, USA. Sample #4 is topographically the highest, at the mineralization, and samples #3, #2 and #1 are sequentially lower at about 80 m intervals. Samples #5 and #6 are background samples taken 325 and 725 m from the stream draining the mineralization.

Sample #	Cu ppm -100 mesh fraction	Cu ppm mineral suspensate	Zn ppm -100 mesh fraction	Zn ppm mineral suspensate
#4	79	708	63	594
#3	60	636	72	443
#2	81	457	78	388
#1	54	240	64	257
#5	108	242	73	165
#6	71	286	75	240

The mineral suspensates have greater concentrations and better contrasts for copper and zinc than the bottom sediment -100 mesh size fraction. Whereas the bottom sediment fraction studied gave no indication that mineralization was being approached, the mineral suspensates show a notable increase in copper and zinc concentration upstream towards and at the mineralization.

If the future studies on larger sample populations prove that the mineral suspensate is a reliable sample for regional and/or follow-up mineral prospecting, the benefits of their use over bottom stream sediments can be important for the following reasons. First, for areas of difficult access, the field geochemist can carry many more suspensate samples than bottom sediment (or soil and/or rock samples), and hence collect a greater density of samples over a larger area during a given stint in the field if the weight of

samples one is able to carry is a limiting factor in a field program. Second, sample handling is minimized since only volatilization and weighing precede dissolution and analysis. Third, the suspensate may represent a "purer" sample than the bottom stream sediment which may have undergone diagenetic alterations while part of the bottom environment. Finally, the equipment for the operation can be purchased for less than US $100 - although the cost of the filters is high, approximately US $2 - each; if waters carry a high content of organic matter, it may be necessary to use two or three filters at each sample site. I invite you to test the suspended sediment sample as a geochemical prospecting medium during your next stream sediment survey and help determine if we do have a good, viable sample type for future land prospecting programs.

THE USE OF SEM-EDS IN GEOCHEMICAL EXPLORATION
by
R. Piispanen

One of the most difficult and fundamental problems associated with geochemical exploration and prospecting is that of knowing the mineralogical sources of the anomalous heavy metals in the analyzed geochemical samples. The results of the chemical analyses are often highly variable, not only because of variations in the amount of the economically interesting minerals, but also because of variations in the amount of silicates and other gangue minerals which, in certain cases can cause an anomaly in the heavy metal content. Also, depending on the method of chemical attack that has been used in the dissolution phase, the metals can be misproportionately represented in the results of the analyses. As a consequence different treatments during the dissolution phase may bring forth the amounts of the economically interesting metals in a strongly biased way even in cases where the petrographical composition and the amount the heavy minerals in the samples are the same. On the other hand, the results of the chemical analyses may show similar values of heavy metals in two samples that are not similar in any other respect. This is a consequence of the fact that the two samples may be carrying the same metals in minerals that differ fundamentally from each other, perhaps only one of them being interesting as soon as the exploitation·of the target ore is considered. In stream sediment and till samples in particular, it is important that the economically interesting metals are derived from minerals that are going to be utilized in the ultimate exploitation phase when the target ore has been found. Otherwise the anomalously high metal contents in the samples are of importance only as indicators, the meaning of which is often subject to considerable dispute.

On the basis of what has been outlined above it is apparent that successful geochemical exploration necessitates well-balanced co-operation between the chemist and the geochemist-mineralogist. The identification of the mineral phases is of vital importance and should form a routine part of the geochemist's work. Luckily, in a modern geochemical laboratory furnished with a scanning electron microscope (SEM) and an energy dispersive spectrometer (EDS) the work can be done with great ease.

For a study involving the SEM-EDS the same kind of polished thin sections that are made for optical microscopy can be used. A portion of the heavy mineral fraction is impregnated in an epoxy-resin from which a piece is cut

with a diamond saw and thinned and polished in the normal way.

Under the SEM-EDS the minerals can be identified on the basis of the characteristic X-ray radiation that is being liberated from them as a response to the agitation effect of the scanning electron beam. In addition to the unit generating the electron beam the apparatus has a unit to detect, measure and analyze the radiation from the target minerals. In contrast to the traditional way of analyzing the radiation on the basis of the wave-lengths, the analysis in the SEM-EDS is based on the measurement of the differences in energies of the X-ray photons. The measurement is performed channelwise, the channels being classes that are formed as based on the differences in the energies of the emitting photons. The energies can be compared with the energy spectra of various elements the spectra of which have been stored in the memory of an accompanying computer. With the aid of the analyzer it is possible to identify the spectra of the elements present in the mineral. When the elements that form the minerals are qualitatively matched the mineral can normally be identified without the more tedious quantitative chemical analysis of the elements. A quantitative analysis can, however also be performed with the apparatus.

STATISTICAL ANALYSIS OF REGIONAL GEOCHEMICAL EXPLORATION DATA
by
J.P. Brooke

Introduction

An area of about 200 square miles near Glen Innes, N.S.W. has been geochemically surveyed. Five hundred samples of stream sediment were collected and analyzed for eight elements by semiquantitative spectrochemical analyses. The specimens were obtained at predetermined locations along major streams and tributaries. The sample density was 3 per square mile. This technique was a fast and convenient method to prospect the entire area. A statistical analysis of the data has disclosed the presence of numerous small anomalies. These are considered real, but their significance has not been tested.

Sample locations were designed to avoid bias in analysis. An attempt was made to sample major streams and tributaries at one mile intervals. Experimental difficulties made it impossible to complete all of the sampling; water depth and velocity, and absence of sediments prevented sampling at about 10% of the locations. The locations of the samples followed a random pattern with regard to the geology.

Experimental Method

The samples were dried, and the minus 80 mesh fraction was analyzed by semiquantitative AAS for copper, lead, zinc, silver, molybdenum, tin, antimony, and bismuth.

The standards used by the laboratory were prepared using the "addition method". Primary standards were made from pure metals and added to a matrix similar to the materials analyzed. Cross checking was carried out by adding primary standards to selected samples. Tin samples were prepared for analysis by fusion prior to digestion. Colorimetric methods were used for verifying the accuracy of the molybdenum analyses.

The detection limits and precision of the analyses were:

Element	Detection limit	Precision		
		<50ppm	>50	<500ppm
Copper	1 ppm	+10%	+5%	
Lead	2 ppm	+10%	+5%	
Zinc	1 ppm	+10%	+5%	
Silver	1 ppm	+10%	+5%	
Tin	10 ppm	+10%	+10%	
Molybdenum	10 ppm	+10%	+10%	
Antimony	10 ppm	+10%	+5%	
Bismuth	10 ppm	+10%	+5%	

Presentation and Analysis of Data

The data were analyzed by standard statistical techniques to determine anomalous values indicative of metalliferous deposits. A preliminary scanning of the data indicated that no gross anomalies are present. The values were then searched for small anomalies.

The area was divided into 10 areas of influence in order to isolate anomalies. The size and shape of each area of influence was determined by the topography and geology. Means and standard deviations were computed for the entire area and for each individual area of influence. Computed values (in ppm) include:
1) Means: 1.9 Sb, 3.6 Bi, 17.4 Cu, 44.1 Pb, 0.05 Mo, 0.3 Ag, 0 Sn, and 30.4 Zn.
2) Standard deviations: 3.6 Sb, 6.8 Bi, 19.2 Cu, 51.6 Pb, 0.5 Mo, 0.9 Ag, 0 Sn, and 33.6 Zn.

Values which are 3 standard deviations greater than the mean have a 99% chance of being real and are considered anomalous.

Small Anomalies

The study revealed two antimony, five bismuth, five copper, six lead, four silver, four molybdenum and six zinc probable anomalies. Based upon statistical parameters these values are probably real and not due to chance errors. Some anomalies have been eliminated as a result of replicate analyses completed on one sample.

The significance of each of these anomalies might be determined with additional investigations. It is difficult to decide at this stage whether these anomalies are due to higher background, random fluctuations in trace element content or some concentration of economic mineralization. Detailed geochemical sampling would delineate and identify possible economic situations.

GEOLOGICAL MAPPING

Geological maps of selected portions of the region were prepared by the author as an aid in the interpretation of the geochemical data; these include the following:

Bald Nob

An area of approximately 3.5 square miles around Bald Nob has been geologically mapped. Small occurrences of dolerite intrusive (including Bald Nob) are present in the region. This rock type contains 5% magnetite causing magnetic anomalies. Other rock units in the vicinity include an adamellite, leucocratic granite, biotite granite, aplite, and quartz veins. No structural conditions or hydrothermal alteration were encountered that would be

indicative of mineral deposits. Molybdenite is a rare accessory mineral in the leucocratic granite. At some localities it occurs in concentrations up to 1 200 ppm, but commercial grade deposits are not present.

Quartz veins were encountered near the Gwydir Highway north of Bald Nob. Two quartz pipes were investigated in the vicinity of Quartz Creek. Normally, quartz is considered a favourable host rock for mineralization. However, no deposits of economic mineralization were encountered.

Greisen Veins in Parish of Bloxsome

About 40 cassiterite-bearing greisen veins in the Parish of Bloxsome, County Gough have been mapped and sampled. The veins are quite uniform, strike is 60°, and width varies from 1 cm to 1.5 m. The surrounding rock is a medium grained granite.

An extensive costeaning and sampling program was completed over the veins in July, 1970. Grab samples obtained at that time assayed potentially economic grades of tin. However, subsequent inspection of the veins in costeans revealed their increasingly barren nature with increasing depth. Thus, they are non-economic and should be abandoned.

Numerous small wolfram prospects and alluvial tin workings are located in the vicinity of the greisen veins. These were all inspected and evaluated as being non-economic. The wolfram is typically a minor accessory in quartz veins. The many alluvial deposits at the locality all have indications of tin but are too small to support a mining operation.

Gold assays were completed for each quartz vein in the area, but the values are non-commercial. The assays vary up to 1/2 ounce gold per ton of rock. The many quartz veins are devoid of economic mineralization.

Structural conditions of hydrothermal alteration zones indicative of mineralization are not present. Structures are all minor and include jointing and a vein system. Alteration is confined to surficial weathering.

Zone "F"

An area north of the Severn River trending east-west across the Dundee Road in the Parish of Bloxsome has been geologically mapped. The area was designated anomalous as a result of an airborne magnetometer survey. The rock types include fine grained leucocratic granite, greisen, rhyolite, dacite and metasediments. The greisen is a favourable host rock for tin mineralization, however, no commercial deposits are present in the zone. Small zones of cassiterite are present in the greisen, but they are non-economic. Many shallow shafts and workings in the area attest to the barren nature of the greisen at depth.

Some of the leucocratic granite outcrop contains small flakes of molybdenite as a rare accessory mineral. Typically it concentrates along small fissures. None of the occurrences are economic in grade.

Conditions favourable for mineral deposit occurrence are not present in this section. There are no structural features present to localize ore deposition. The rhyolite and dacite outcrops were also quite barren.

Airborne Radiometric Survey

An airborne radiometric survey was completed in July, 1970. The radiometric values are quite uniform with the total variation lying between 300 and 1 000 counts intensity. The total variations are small and indicate concentrations of radioactive minerals are not present in the exploration licence. The variations of the radiometric content might represent a normal background fluctuation in one rock unit or could represent contrasting lithologies or stratigraphic variations. A radiometric depression is coincident with Bald Nob. This indicates the low radiometric value of the dolerite intrusive.

Numerous radiometric highs and lows are present, their size, shape, and orientation appear quite random. Orientations vary from N-S to E-W with very little pattern or design apparent. Many of the differences are small enough to be insignificant or within instrumental errors. Large scale faults or discontinuities are not indicated by the radiometric data. Linear concentrations of radioactive minerals of linear contrasts in background are not present, thus indicating the absence of large structural features.

THE STREAM SEDIMENT GEOCHEMISTRY OF COPPER, MOLYBDENUM AND URANIUM IN THE LATERITIC ENVIRONMENT AROUND DALAKURA, SIERRA LEONE

by
D. Fode and H. Martin

The area studied is characterized by a multi-sulphide mineralization dominated by pyrite, chalcopyrite and molybdenite, at the brecciated contact zone between a high level granite and a complex of basic amphibolitic rocks. This work has led to the discovery, in association with the sulphides, of a silicate of uranium associated with rare earths, mainly thorium and yttrium. Laterite is of wide occurrence and may be exposed to give a continuous sheet of indurated surface.

A combination of geochemical analysis, including selective chemical extraction and statistical studies, shows that Cu and Mo are invariably associated with goethite. The orientation of high values of these elements along the stream channels can be directly related to the lateritized zone. Conversely, the distribution of uranium appears to be controlled by two factors: the lateritized zone along the upper reaches of the Sende on the one hand, and the granites drained by the Bei and the Digbe. These granites have higher mean values of uranium than the intruded amphibolites.

Results of mineralogical, textural and chemical extraction studies indicate that stream channels that flow through the lateritized zone acquire much of their Cu, Mo and U contents by the mechanical degradation and transport of the laterites proper. Fragments of iron concretions within the stream sediments are better representatives of the parent laterite and are therefore considered to constitute a more efficient sampling medium than the often used fine fraction in stream sediment geochemical surveys, under the particular weathering conditions.

GEOCHEMICAL DISPERSION PATTERNS IN GLACIAL TILL OVER SULPHIDE ORES AT AVOCA, EIRE

by
C.J. Moon and M. Hale

At Avoca, Eire, sulphide mineralization comprising massive stratiform cupriferous pyrite accompanied by massive lead-zinc ores and stringer pyrite are hosted by Ordovician sediments, calc-alkaline lavas and pyroclastics. The sequence has been subjected to low grade regional metamorphism and deformed by isoclinal folding and thrusting. The area is covered by glacial drift, about

2 m thick, which is probably of non-exotic origin.

Basal till and surface soil samples from a 2 km traverse across the strike of the mineralization were analyzed for 25 major and trace elements by inductively-coupled plasma emission spectrometry (ICP) following a HNO_3-HClO_4 attack, and for As, Sb, Bi, Se and Te by the introduction of the volatile hydrides of these elements into the ICP. The multielement basal till data allow the rapid discrimination of the sub-crop of the mineralization on the basis of Cu, Pb, Mo, Ag, Rb, Ba, As, Sb, Bi and Se anomalies, whereas the expressions provided by the principal ore elements alone are more ambiguous. Basal till geochemistry can also be correlated with bedrock lithology and alteration. The mineralized sequence comprises a foot wall of chloritic tuff with disseminated sulphides, followed by fine grained sediments and tuffs with massive sulphide at their base, and a hanging wall of magnesian tuffs. Arsenic and Bi are associated with the foot wall disseminated sulphides and the hanging wall magnesian tuffs are defined by high concentrations of Zn, Ba, V, Mn, Ti and Sb. The geochemical expression of lead mineralization is limited to Pb and As anomalies, while Rb is a good indicator of sericitisation.

A mineralogical and geochemical study illustrates the relationship between the distribution of minor elements in the ores and basal till. Native bismuth and bismuth sulphosalts are present in both massive pyritic and disseminated ore, while tetrahedrite is associated with both disseminated pyrite and lead-zinc ores. High TiO_2 values are related to lead and zinc-rich sericitic schists.

Most but not all of the multielement discrimination of lithology and mineralization is lost at surface, although some broad, diffuse anomalies remain. Antimony, Ba and V anomalies still occur over the zinc-rich magnesian tuffs while As and Bi are useful pathfinders for disseminated mineralization.

Thus the multielement geochemistry of the basal till of Avoca provides a ready means of mapping bedrock lithology and alteration zones, and clearly identifies the suboutcrop of the mineralization. The surface till contains significant anomalies of some transition metals and chalcophile pathfinder elements. Surface and basal till multielement geochemistry could therefore prove useful in the exploration of areas where outcrop is concealed beneath thin, non-exotic till.

THE WOLLASTON URANIUM BIOGEOCHEMICAL ANOMALY - NORTHERN SASKATCHEWAN
by
C.E. Dunn

Wollaston Lake lies adjacent to the eastern edge of the Helikian clastic sediments which comprise the Athabasca Group. In this vicinity numerous rich uranium deposits (including the Rabbit, McClean and Midwest Zones) have been discovered at the Athabasca/basement unconformity. Biogeochemical investigations were conducted to determine the response of vegetation of uranium mineralization, with the result that a uranium biogeochemical "province" of exceptional magnitude and areal extent has been identified.

About 2 000 samples representing all common indigenous plant species were collected, dried, separated into their structural components, ashed, and analyzed for U by neutron activation/delayed neutron counting. Results show that each part of each plant accumulates a different amount of U, and that in

this region nearly all species have much higher U concentrations than normal (i.e. a few ppm). Tree-trunk wood has the lowest concentration of U, with progressively higher amounts in the bark, roots, needles/leaves, and twigs.

The species which has proved to be the most sensitive to the presence of U is black spruce (Picea mariana). Spruce twigs are the strongest U accumulators of any part of any plant tested, with concentrations up to 2 270 ppm U occurring in the ash of the latest 10 years of twig growth. Studies have shown that most of the U occurs in the 2 to 4 year-old growth, but a practical amount to collect is the latest 10 years. Thus, the ensuing discussion of U in twigs refers to the concentrations in the ash of 1 to 10 year-old twig growth (less needles), inclusive.

The McClean North Zone contains very high grade U ore at the basal Athabasca unconformity, 150 m beneath the ground surface. Trees growing above, but laterally displaced from the mineralization contain up to 500 ppm U and outline elongate anomalous zones parallel to the ore bodies, thereby producing a "Rabbit's Ear" type of anomaly. This area lies toward the western side of a 500 km^2 region within which almost every spruce contains in excess of 100 ppm U in the ash of its twigs. The 50 ppm contour covers about 2 000 km^2, and the 10 ppm contour (which elsewhere would be considered anomalous) encompasses at least 3 600 km^2 – its northern extremity has not been defined. These trees all grow in immature podzols containing normal ($\sim$ 2 ppm) background concentrations of U; no positive relationship between the U content of the plants and any soil horizon can be discerned. Airborne contamination of this large area of forest is discounted since, not only would massive amounts of uraniferous dust be required to produce such contamination, but fission track images of twig sections show the U to be within the structure of the wood, not on the bark surface. Hence, although the near surface groundwaters generally contain < 1 ppb U, these low levels of U must be entering the roots in solution, and migrating to, and concentrating in, the aerial extremities of the trees.

Of particular interest is the presence of intense local anomalies in twigs (in places over 1 000 ppm U) where the forest is undisturbed by exploration activities. One such anomaly occurs close to a small lake 5 km to the northeast of the McClean Zones. Neither regional geophysical evidence, nor the local chemistry of lake waters, sediments, and their associated gases are indicative of mineralization, except for a high alphameter reading (849 cph) close to the highest biogeochemical values. In addition, a weak U, Ni, Co and Zn association is present in the sediments of a lake down-drainage, 2 km to the north. Further exploration is being conducted to ascertain the reason for the anomaly.

In summary, positive U biogeochemical anomalies occur near: a) the Rabbit, McClean and Midwest ore bodies; b) proven mineralization elsewhere in northern Saskatchewan (Uranium City and Cluff Lake); and c) in areas as yet unexplored. This biogeochemical technique may prove useful as a regional tool in assessing the uranium potential of an area or body of rock, and on a detailed scale it may help to define drill targets, particularly in the environment prevailing within and upon sandstone of the Athabasca Group.

ADDITIONAL PAPER FOR ORAL PRESENTATION

FAVOURABLE ENVIRONMENTS FOR POSSIBLE URANIUM MINERALIZATION, PENINSULAR
MALAYSIA
by
C.L. Heng, F. Chand and J. Ahmad

Certain granite bodies in Peninsular Malaysia appear to constitute
favourable uranium exploration targets, as indicated by a regional
reconnaissance geochemical survey initiated in 1977. Among these are the
Boundary Range Granite, the Senting Granite, and the Benom Igneous Complex
which were previously highlighted by an airborne magnetometric and
scintillation counter survey flown in 1956 over restricted parts of the
peninsula. The geochemical project was part of the Central Belt Project in
north-central Peninsular Malayasia which received technical aid from the
Canadian International Development Agency.

Recent follow-up work over a multi-element geochemical stream sediment
anomaly, delineated within the Boundary Range Granite, has resulted in the
discovery of some radioactive boulders and a significant radioactive outcrop.
Favourable lithologies and zones within this granite range appear to be roof
pendants, areas within the granite itself that contain a plexus of
magnetite-hematite veins, and late phase dykes. Yet another potential target
appears to be the Main Range Granite which, although not effectively covered
by the regional geochemical survey and thus not highlighted geochemically, has
the distinction of hosting the first recorded uranium occurrence in Peninsular
Malaysia. The uranium occurrence is in the form of quartz-torbernite veins
and torbernite-filled fractures. The torbernite recorded in these areas is
associated with cassiterite-fluorite mineralization.

The continental Mesozoic Tembeling-Gagau Group and Tertiary sedimentary
formations theoretically appear to be good hosts for possible sandstone-type
uranium mineralization. Besides an ideal source of uranium readily available
from the underlying and surrounding granites and acid volcanics, certain
sections within these fluvial-deltaic-estuarine formations contain the
necessary reductants and are suitably prepared in that they possess the
appropriate lithological and facies variations. Moreover the similarity of
sedimentary features with others noted in uraniferous sandstones elsewhere,
the nearest being the Khorat Group in Thailand, is indeed encouraging.
Although available reconnaissance geochemical results have not demarcated
interesting uranium-enriched zones within the continental Mesozoic formations
in Peninsular Malaysia, their uranium potential, and indeed the potential of
the entire Central Belt Project area can hopefully be better appraised once
the results of the airborne magnetometric and spectrometric survey, flown
within the Project area in mid-1980, are at hand. The Tertiary basins
unfortunately do not fall within the Project area, but perhaps a more direct
approach using reconnaissance drilling and downhole logging should be used to
assess their potential.

ADDENDUM

ABSTRACTS OF ADDITIONAL POSTER PRESENTATIONS

[Wed. 12 May]

PETROGRAPHIC AND GEOCHEMICAL CHARACTERISTICS OR IRON-RICH ROCKS AND THEIR
SIGNIFICANCE IN EXPLORATION FOR MASSIVE SULPHIDE DEPOSITS, BATHURST,
NEW BRUNSWICK, CANADA.
by
S-I Saif

About 25 economically significant, Kuroko-type massive sulphide bodies lie in a metamorphosed volcano-sedimentary complex (Middle Ordovician) known as the Tetagouche Group, in the Bathurst area, New Brunswick. Despite unresolved structural complexities, it does appear that they were deposited during a particular phase of volcanic activity and are, therefore, contemporaneous. Most of the sulphide bodies are closely associated with iron-rich rocks representing various facies of iron formation and, together with sulphides, these constitute the 'ore-horizon' which, therefore, is highly magnetic. Aeromagnetic and ground-magnetic techniques are useful for locating the ore-horizon, but problems are created because of the occurrence of iron-rich rocks with no sulphides associated with other strata in the Tetagouche Group.

Petrographic and geochemical characteristics of various types of iron-rich rocks have been studied to see if the iron-rich rocks of the ore-horizon can be distinguished from the magnetic rocks of the other strata. The iron-rich rocks found in the Tetagouche Group can be classified into five types: 1) cherty magnetite iron formation, 2) chloritic iron formation, 3) carbonate iron formation, 4) basic iron formation, and 5) maroon shale. The basic iron formation, which is quite magnetic, gives false indication of the ore-horizon; the presence of any of the first three types of iron formations is a positive indication. Unfortunately, the basic iron formation is generally similar in appearance and mineralogy to some rocks of the cherty magnetite and chloritic iron formations. The occurrence of ooliths in many of basic iron formation rocks may help distinguish it from the other rocks under microscope.

Regarding major element composition, TiO_2, Na_2O, Al_2O_3 and CaO are higher whereas Fe_2O_3, FeO and MnO are lower in the basic iron formation than in the other iron-rich rocks. These geochemical characteristics can help distinguish the barren rocks of the basic iron formation from those of the ore-horizon during exploration programs.

[Wed. 12 May]

R-MODE FACTOR ANALYSIS FOR THE MONTROSE QUADRANGLE, COLORADO
by
S.L. Bolivar, K. Campbell, and G.W. Wecksung

R-mode factor analysis is used to describe the relationships among 18 data sets for the Montrose $1^\circ x 2^\circ$ quadrangle, Colorado, a region that covers 19 000 km^2. The data sets contain reconnaissance-scale information and include landsat imagery, airborne geophysical information (eU, eTh, K40, aeromagnetics), elevation, and hydrogeochemical and stream sediment analyses. The elements U, K, Dy, Hf, V, Th, Ca, and Ba in sediments and U in waters were selected.

The results of the factor analysis for the entire quadrangle are compared to the results for a 500-m x 500-m test area containing several known uranium

occurrences. A four-factor model, with varimax rotation, accounts for 70.0% of the total variance in the data. The factors in the model are described as a felsic factor, a landsat factor, an economic or mineralization factor (in terms of uranium mineralization and potential mineralized areas), and a volcanic factor.

Gray-level pictures of the raw data, factor approximations, and residuals for each data set, and the four-factor model (both rotated and unrotated) make analytic results much easier to interpret.

[Thurs. 13 May]

THE REGIONAL GEOCHEMICAL MAPPING OF SOUTH AFRICA
by
C. Frick, S.W. Strauss, A. Nocton-Smith, and T. Deneyschen

The decision to map South Africa geochemically, using stream sediment samples on a one kilometre grid, was prompted by the need for more multi-parameter base maps for exploration. The prime requirements were that the maps had to be multi-elemental with a high resolution (1 kilometre). Exploration in South Africa obligates private enterprise to obtain exploration rights prior to exploration in any given area. The financial constraints to conduct such a long-term exploration program make it prohibitively expensive for a private concern, thus such a program could only be run by a disinterested, non-profit state department despite the obvious demerits of this approach.

The processes which enabled the first 40 sets of multi-element maps to be compiled and published are outlined, along with a brief description of the helicopter supported sampling system, sample handling and sample preparation, including the extraction of the most suitable fraction of the sample to be analyzed. The samples are all analyzed by x-ray spectrometric techniques for some 20 elements and the results are transferred on-line to a sophisticated data-bank. The latter is so organized to permit the rapid compilation of the final geochemical maps.

The final maps compiled by this venture must, by necessity, complement the range of geochemical and geophysical maps currently available, hence 1:50 000 and 1:250 000 series of the maps are produced. Examples of the final geochemical maps are discussed together with the fundamental approach underlying their compilation.

At present one set of 1:50 000 maps consists of an element distribution map depicting the raw data, a grey-scale map and a contour map for each of the 20 elements.

Based on experience thus far, two classes of anomalies can be discerned. Examples of both regional anomalies and spot anomalies are given with possible follow-up techniques. Two examples of new deposits which could not have been found without having used a multi-element approach are assessed.

In conclusion the long-term viability of a project of this nature is discussed. The most difficult technical problems result from analytical inconsistency over a decade or more, the incompatibility of new equipment with the old systems and contamination. Logistically, storage is a major problem as is the scarcity of scientists to ensure the smooth running of the project along with pilot orientation programs.

THE APPLICATION OF HYDROGEOCHEMISTRY TO URANIUM EXPLORATION IN THE PINE CREEK GEOSYNCLINE, NORTHERN TERRITORY, AUSTRALIA

by

A.M. Giblin and A.A. Snelling

The Jabiluka, Ranger, Koongarra and Nabarlek uranium deposits are all found in chloritized Lower Proterozoic metasediments of the Cahill Formation in the Alligator Rivers Province, Pine Creek Geosyncline. All deposits except Jabiluka 2 are in contact with present day groundwaters. High wet-season rainfall caused rapid groundwater-flow rates and short aquifer-retention times, with consequent low-salinity (<300 mg/l) groundwaters in the vicinity of each deposit. Pine Creek Geosyncline groundwaters are thus undersaturated with respect to aquifer minerals, so major element composition (Ca^{2+}, Mg^{2+}, $Na^+ + K^+$, Cl^-, SO_4^{2-} and total carbonate) of each water preferentially reflects the more easily soluble aquifer constituents, e.g. carbonates, and connate waters trapped during sediment lithifaction.

Concentration plots of major elements in ground waters from each deposit shown in Figure 1 illustrate similarities which suggest a host rock constituent which is common to all four deposits. This constituent is probably a chlorite which is appreciably soluble at low temperatures and which accompanies uranium in each deposit. The concentration plots constitute a mineralized aquifer "signature" with which the composition of groundwaters in exploration programs in the Pine Creek Geosyncline may be compared. Ground water leaching of this chlorite supplies high levels of Mg^{2+} (expressed as NMg = conc. Mg^{2+}/total conc. Ca^{2+}, Mg^{2+}, $Na^+ + K^+$ in milliequivalents per litre) to contained groundwaters. Progressive mixing of waters from mineralized aquifers with waters from non-mineralized aquifers causes graded reductions in NMg, so that contouring drill holes on a ground plan in terms of groundwater NMg delineates a hydrogeochemical aureole for Pine Creek Geosyncline uranium deposits of the type so far identified, for example, Fig. 2 illustrates NMg contours over Ranger No. 3 orebody.

A degree of coincidence is evident between high NMg (>0.7) and high uranium concentration (>20 μg/l) in groundwaters from the vicinity of Nabarlek, Ranger and Koongarra; for example, Fig. 3 shows NMg and U across Ranger No. 3 and Fig. 4 the same parameters across the Koongarra deposit. Because pH-Eh conditions in aquifers at Jabiluka favour uranium in solid rather than solution phase, <10 μg U/l is present in groundwaters, although NMg values are generally >0.8. However, at this stage of the Pine Creek Geosyncline study, observations indicate that even under least favourable pH-Eh — adsorption conditions, uranium will be above a detection limit of approximately 1 μg/l in water from mineralized aquifers. Also, to date NMg has always been <0.8 in non-mineralized aquifer waters, whereas uranium may be >50 μg/l in groundwaters from acid felsic aquifers, which can be identified as uneconomic by low (<0.4) NMg.

The value of groundwater levels of uranium and NMg as hydrogeochemical indicators, and of major-element composition plots, can be demonstrated by detailed interpretations of these parameters in groundwaters near the Koongarra deposit, using predictions of groundwater-aquifer rock interactions at each sample site. Uranium mineralization in the Koongarra deposit is contained in Mg-rich chloritized schists near a reverse-faulted contact with a younger sandstone unit. A total of 48 vertical percussion holes within the Koongarra Project area (Fig. 5) were sampled and their waters analyzed. On the basis of their major-element composition plots, the waters were grouped:

Group A Ground waters in this group have ion concentration plots which fit the mineralized aquifer signature shown in Fig. 1 and have NMg 0.8. Uranium levels range from 1-4 100 µg/1, with waters in holes which intersect mineralization having >80 µg U/1. The sampled area covered by this group is shaded in Fig. 6 and includes drill holes in and near both ore bodies, and drill holes both up and down strike of known mineralization. Additional potentially mineralized zones are therefore suggested by these ground water studies including the possibility of shallow mineralized-sources upflow under the sandstone escarpment (shown as the dotted NE-SW boundary in Fig. 5) related to No. 1 orebody in a similar manner to the relationship between Jabiluka 2 and Jabiluka 1 orebodies.

Groups B, C and D Concentration plots of ground waters in these groups reflect increasing degrees of mixing of waters from Group A with waters from non-mineralized aquifers which locally comprise dolomites, sandstones, amphibolites and various types of schist. As the degree of mixing increases from Group B, through C, to D, the mean NMg for waters in each group reduces from ≈ 0.7 to ≈ 0.4, while uranium levels range between 0 to 20 ug/1, with no apparent trend.

Four samples were also collected from drill holes 2 km S.E. of No. 1 orebody. These holes, however, intersect a different groundwater-flow regime where there is limited recharge through a lateritic and weathered schist aquitard overlying the apparently unmineralized, fractured, relatively unweathered mica schist and amphibolite aquifer; In this regime aquifer retention times are longer. The net result is waters with higher salinities than the waters to the north around the Koongarra orebodies. Even though the U contents range from 2 µg/1 to 91 µg/1, NMg is always < 0.5, in itself suggestive of non-mineralized aquifers. However, since these 4 holes are more than 1 km apart the high uranium values merit some closer-spaced exploratory drilling during which NMg levels in ground waters would be a useful parameter to follow.

In conclusion, the chemistry of ground waters in and around the Koongarra orebodies successfully indicates known mineralization and, by analogy, suggests other potentially mineralized zones which are compatible with feasible geological interpretation.

[Wed. 12 May]

PRESENTATION OF GEOCHEMICAL DATA IN AUTOMATICALLY PLOTTED COLORED MAPS
by
J.G. Knudsen and U. Siewers

During geochemical exploration programs, vast amounts of geochemical data are produced, especially when multi-element analyses are performed.

Plotting of the data will normally be the first step to get an impression of the general distribution of the analytical values. On black-and-white maps there are several problems:

- Each element is plotted on a separate map. With twenty elements there is confusion in trying to find similarities or differences, because on nearly every spot there is an anomaly of at least one element.

- When plotting real analytical values as figures, the figures may be so close to each other that they overlap and are no longer identifiable. Also, plotting time increases enormously with the number of figures to be plotted.

- When using different symbols for value ranges within classes, larger symbols may hide smaller symbols, which also results in loss of information.

For those cases mentioned above, and for producing regional geochemical maps, automatically plotted colored maps are of great advantage.

The colored maps presented, which are prototypes for a geochemical map of the Federal Republic of Germany, provide examples of the color-dimension. Other maps displayed include grid maps, contour maps and 3-D maps. Even at a scale of 1:2 million, with a sample density of one sample per two km^2, each single anomaly can be recognized from a viewing distance of more than ten meters when plotted as colored class values.

The maps presented have been plotted with an Applicon Color inkjet plotter using the UNIRAS software package of ESC, Copenhagen. Over 15 000 color shades are available, which means there are nearly no restrictions for special requirements. The smallest pixel size is about 0.2 x 0.2 mm.

For geochemical reconnaissance purposes, colored grid maps seem to be the optimal method for data presentation. The minimum grid size may be less than one mm but a range between one and five mm gives a good optical impression. The maps presented which show the distribution of lead, copper, zinc, nickel, cobalt, uranium and flouride in smaller streams, wells and springs from the Federal Republic of Germany are based on analyses of more than 60 000 samples over an area of 2 000 000 km^2. Recognition of a colored square with a special analytical range of values is much easier than any symbol type in black-and-white. Also, when there are different geological units, an association between the colored geological map units and the colored value ranges for the geochemical map can be easily obtained.

Differences between colored and black-and-white maps are even greater when plotting two or three elements; color shades can be plotted on top of each other, giving a two-or three-element map.

Where work is largely within one geological unit, or is in an area of unknown geology, contour mapping is possible. Otherwise, interpolation will be done across geological boundaries which may not be very meaningful. On the other hand, contour maps are very attractive because of their simplicity.

Another way of presenting data is on a 3-D map. A program is available giving a choice for the horizontal and vertical angle of observation, so that the maximum values can be rotated to the rear end of the plot.

With this technique any type of data can be plotted. The program produces a raster file which will be transferred to a magnetic plot tape. The cpu-time for producing a 600 x 500 mm grid map with 60 000 samples is about 10 to 20 minutes, depending on the host computer. The plot time for the tape will be less than 10 minutes.

[Wed. 12 May]

REGISTER GEOCHEMICAL MAPPING OF THE SOUTHERN COAST RANGES, CALIFORNIA
USING STREAM SEDIMENTS AND HEAVY MINERAL CONCENTRATES
by
J.M. McNeal, and W.R. Miller.

Regional geochemical mapping in the Southern Coast Ranges of California shows broad-scale trends that may be useful in targeting areas for detailed geochemical exploration. The distribution of 20 elements (B, Ba, Be, Ca, Co, Cr, Cu, Fe, La, Mg, Mn, Mo, Ni, Pb, Sc, Sr, Ti, V, Y, Zr) in the $<$ 0.18mm fraction of stream sediments and 17 elements (B, Ca, Co, Cr, Cu, Fe, La, Mg, Mn, Mo, Nb, Ni, Pb, Sn, Sr, V, Y) in the nonmagnetic fraction of heavy-mineral concentrates is displayed. These samples were collected from randomly selected, small, unbranched streams in each of 533 contiguous 10-km^2 cells in the Southern Coast Ranges and westernmost portion of the Transverse Ranges of California.

The heavy-mineral samples (sp. gr. $>$ 2.86), with the magnetite removed, were separated electromagnetically into a magnetic fraction (MF), and a nonmagnetic fraction (NMF). The stream sediment, MF, and NMF were analyzed for 30 elements using semiquantitative D.C.-arc optical-emission spectrographic techniques. Results were reported in six increments (1, 1.5, 2, 3, 5, 7) per order of magnitude. The elements that were not mapped had a large number of values either below or above the detection limits. Only the data for stream sediments and NFM are displayed. This is because elements in stream sediments and NMF are not correlated and the data from each sampling medium gives different information. In contrast, the elements in stream sediments and MF are highly correlated and thus the data for each sampling medium gives very similar information.

Approximately 5 percent of the cells were randomly selected for additional sampling according to an unbalanced, nested, analysis-of-variance design. This procedure apportioned the total variance of the whole data set into four components representing the variance due to differences between 1) cells (regional variation), 2) streams within cells (within cell variation), 3) samples within streams (within stream drainage variation), and 4) duplicate analysis of samples (analytical error). Approximately one-third to one-half of the total variance is due to regional variation, which is the portion of the total variance that shows the trends that occur on the geochemical maps. The sampling procedure within a stream is adequate because of the small variance measured for the within stream drainage basin variation. Approximately one-half of the total variance is equally divided between within cell variation and analytical error.

These studies can be used in geochemical exploration in several ways. Trends shown by some of the mapped elements can be related to mapped geologic units (California State Geologic Map, 1:250 000 scale) and therefore can be used to provide threshold and anomalous values of element concentrations for each kind of mapped unit. Thus areas within a mapped unit with samples that have unusually high or low element concentrations may warrant further study. Some trends cannot be related to the mapped units, but to the more general classification of tectonostratigraphic terranes. The identification of tectonostratigraphic terranes by geochemical mapping is useful in exploration because of the correlation between terranes and the kinds and abundance of mineral deposits that occur in them, as reported in a 1981 study by Albers.

The three terranes that dominate the study area, according to the 1981 study by Albers, are: 1) an oceanic crustal terrane, called the Franciscan assemblage, 2) the Salinian block, and 3) the Great Valley terrane, which includes the Coast Range ophiolite. The identification of terranes by geochemical mapping would be particularly useful in areas where the geology has not been mapped in detail. Finally, the trends shown by some of the maps are related to anthropogenic effects, and are not related to geologic setting.

Some elements have very broad concentration ranges in both the stream sediments and the NMF, and are particularly useful in identifying areas of differing mapped units and terrane. The wide range in the concentration of Cr in stream sediments ($<$10 ppm to $>$5 000 ppm) and NMF ($<$20 ppm to$>$5 000 ppm) serves as an example. The median Cr concentration of samples grouped by the predominant mapped unit of the drainage basin also has wide ranges. In the stream sediments, the median Cr concentrations range from 1 250 ppm for Franciscan volcanic and metavolcanic rocks to 70 ppm for Eocene marine sedimentary rocks. The median concentrations of Cr in the NMF range from 3 000 ppm for Miocene volcanic rocks to 70 ppm for Pliocene nonmarine sedimentary rocks. In general, high Cr concentrations were found in the Franciscan assemblage, and low Cr concentrations in both the Salinian block and the Great Valley terrane, except for the Coast Range ophiolites where high Cr values were found.

An example of an element that has different trends in stream sediments and NMF is Pb. The concentration of Pb in stream sediments shows essentially no relationship to the mapped units, but has higher concentrations in metropolitan areas, probably due to anthropogenic effects. In contrast, the Pb concentrations in the NMF show well-defined patterns that relate to geology, and suggest that the concentration of Pb in the Franciscan assemblage is somewhat lower than in the Salinian block.

The pattern for Mo, however, is similar for both the stream sediments and the NMF. Both types of samples have generally high values in Eocene to Pliocene marine sediments, Pleistocene marine and marine terrace deposits, Quaternary nonmarine terrace deposits, and Recent alluvial fan deposits in the Great Valley. Presumably the origin of the Mo is phosphorite-rich rocks, which occur in many of the marine sediments. Erosion of these sediments could result in high Mo in the more recent terrace and alluvial fan deposits.

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