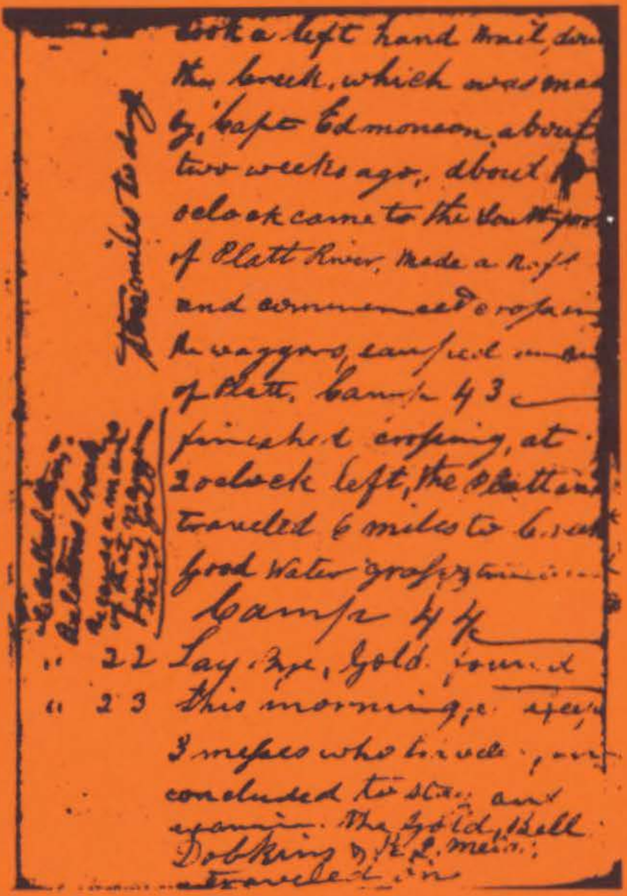
The Association of Exploration Geochemists

SEVENTH INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM

April 17-19, 1978

Golden, Colorado

Program



took a left hand trail, down
the creek, which was ma
by, Capt Edmonson, about
two weeks ago, about
oclock came to the South for
of Platt River, made a Raft
and commenced crossin
the waggons, camped on
of Platt, Camp 43
finished crossing, at
2 oclock left, the Platt an
traveled 6 miles to a creek
good Water grass
Camp 44
" 22 Lay bye, Gold found
" 23 this morning, we
3 messes who travels
concluded to stay and
examine. The Gold, Bell
Dobkins & R.L. mess
traveled in

Four miles to day

Called this; Ralston Creek [illegible]

Record of the first gold discovery in Colorado. A page from John Lowery Brown's diary for June 20, 22, and 23, 1850. The discovery was in Ralston Creek on the present site of Arvada.

--Courtesy of the Arvada Historical Society

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Acknowledgments

The generous efforts of the following people have made this symposium possible:

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J. Webb
E. Young

In addition, many companies have generously helped the Organizing Committee by providing information and making staff members available for discussion at the various properties visited on the field trips. The companies listed below are gratefully acknowledged: Bear Creek Mining Co., Climax Molybdenum Co., Continental Oil Co., Cotter Corp., Exxon Co., Hecla Mining Co., Kennecott Copper Corp., Kerr-McGee Corp., Copper Corp., Newmont Mining Corp., Noranda Exploration Inc., Phelps Dodge Corp., Rocky Mountain Energy Co., Skyline Labs, and Westland Travel Service.

The Organizing Committee also thanks the Papago Tribe and the Gila River Indian Community for permission to examine deposits on their reservation.

General Information

1. The A.E.G. Symposium office (279-7611) will be open beginning at 12 noon, Friday, April 14th, at the Holiday Inn West, Golden, Colorado. All registrants for pre-Symposium field trips should check with the A.E.G. Symposium office between 12 noon and 10 p.m. on Friday, April 14th. A spouse/guest accompanying a registrant on a field trip need only pay the $3.00 registration fee in addition to the field trip costs. Monday and Tuesday evening poster sessions will be held at the Holiday Inn West, and most of the tours will depart from here.

2. Free bus service is available between 7:30 a.m. and 5:30 p.m. to transport registrants between the official Symposium motels and the Green Center. A #64 Denver RTD bus runs from the airport to within about two blocks (200 m) of the Holiday Inn West between 5:49 a.m. and 10:17 p.m.

3. All daytime technical sessions will be held at the Green Center, at Cheyenne and 16th on the Colorado School of Mines campus in Golden, Colorado.

4. On-site registration will be as follows:

Sunday, April 16, 1978 Holiday Inn West	1-10 p.m.
Monday, April 17, 1978 Lobby, Green Center, Golden	8-4 p.m.
Tuesday, April 18, 1978 Lobby Green Center, Golden	8-4 p.m.
Wednesday, April 19, 1978 Lobby Green Center, Golden	8-12 p.m.

On-site fees are as follows:

Registration fees:	
Member	$45.00
Non-Member	$50.00
Bona-fide Student	$25.00
Symposium volume:	
Members & Students	$35.00
Non-Members	$40.00

Refund Policy.

Fees paid by any advance registrant who cannot attend the Symposium or participate in field trips and who has sent in a written request for refund postmarked on or before April 1 will be refunded in U.S. funds by mail after the meeting. A service fee of $5.00 will be deducted from refund requests postmarked after April 1.

5. Coffee will be served in the lobby of the Green Center during morning and afternoon breaks in the technical sessions.

6. A full lunch will be available to ticket holders in the Green Center banquet room. Cost is $4.50 per day. Each lunch will include a hot entree, rolls, choice of salads, beverages, and dessert. Only limited meal facilities are available in downtown Golden.

7. Message boards will be located in the lobbies of the Green Center and the Holiday Inn West.

SPOUSE/GUEST ACTIVITIES

Monday, April 17. 7:45 a.m. Bus loads for an all-day tour of historic Georgetown and nearby areas including Loveland Pass. Cost of $15 includes transportation, luncheon at the Silver Queen Restaurant, slide show, and museum fee. Bus returns to Holiday Inn West approximately 4:30 p.m. Limit 38 people.

Tuesday, April 18. 8:45 a.m. Bus loads for a morning tour at the uniquely designed Denver Art Museum, featuring aspects of the American Indian and Spanish cultures of the American frontier. An afternoon of shopping at Larimer Square, a restored part of Old Denver. Cost of $13 includes transportation, luncheon, and museum fee. Bus returns to Holiday Inn West approximately 4:30 p.m. Limit 40 people.

Wednesday, April 19. 8:45 a.m. Bus loads for a morning tour of the internationally renowned Denver Museum of Natural History including a behind-the-scenes tour. An afternoon of shopping at artisans' Heritage Square and a non-technical geologic tour of beautiful Red Rocks amphitheater. Cost of $7 includes transportation and museum fee only. Bus will stop at Holiday Inn West about 12:30 p.m. for those who do not wish to participate in luncheon and afternoon tour. Bus returns to Holiday Inn West approximately 4:30 p.m.

A $3.00 registration fee is required for spouse/guest activities; badges must be worn. Spouse/guest activities are not limited to adults, but regular fees must be paid for accompanying children.

A spouse/guest hospitality room will be located in the Holiday Inn West, providing coffee and information daily. The motel contains a swimming pool, two saunas, a Jacuzzi pool, and other recreational facilities for guests.

The elevation of Denver is 1600 m. (5280 ft.), Golden is 1720 m. (5675 ft.), Georgetown is 2600 m. (8519 ft.), and Loveland Pass is 3650 m. (11,992 ft.). The weather can be cold and windy, so head scarves and warm clothing are recommended; wear comfortable walking shoes.

Coors Brewery Tour

A special tour is planned exclusively for A.E.G. registrants on Wednesday night. The tour is limited to 120 people. Sign-up for this activity will be on a first-come, first-serve basis at the registration booth, with preference given to out-of-town registrants. Visitors are also welcome during working hours on weekdays.

PROGRAM

April 14, Friday

12:00
Noon — A.E.G. Symposium office opens at the Holiday Inn West. All registrants for pre-Symposium field trips should check in before 10 p.m. to confirm departure information.

April 15, Saturday
Morning

Field Trips. Please note, visits to field areas are contingent upon their accessibility at the scheduled time and on sufficient registration. Participants should be prepared for possible snow, rain, and cold weather.

7:00 Departure for Climax molybdenum deposit.

A visit will be made to the open pit mine (no underground visit) following a discussion of the orebody geology and the mining operation.

Total cost: $25.00 (Includes transportation and box lunch).

Trip leaders: Roger Steininger, Vaughn Surface, and Dick Brumbaugh (Climax Molybdenum Co.).

Limit: 79 people.

8:00 Departure for Cripple Creek gold telluride deposits to see surface exposures in the famous Cripple Creek Mining district, 20 miles southwest of Colorado Springs.

Total Cost: $30.00 (Includes transportation and box lunch).

Trip leaders: J. Howard McCarthy, Jr. (USGS) and Rudy Epis (Colorado School of Mines) with discussions by area geologists.

Limit: 38 people.

April 16, Saturday
Morning--Continued

8:00 Departure for one day field orientation trip to Precambrian mineral deposits near Golden. Experiments in several new geochemical prospecting techniques will be discussed by local experts, and geochemical tests on stream sediments will be demonstrated.

Total cost: $25.00 (Includes transportation and box lunch).

Trip leaders: Lyman Huff, Douglas Sheridan, and Sherman Marsh (USGS); Harold Bloom (Colorado School of Mines).

Limit: 38 people.

8:30 Departure for a vein-type Precambrian uranium deposit--surface exposures near the Cotter Corporation's Schwartzwalder Mine.

Total cost: $25.00 (Includes transportation and box lunch).

Trip leaders: Ed Young and Alan Wallace (USGS).

Limit: 40 people.

April 16, Sunday
Afternoon

1:00 Geochemical laboratory Tours.

Transportation at cost will be provided for those wishing to visit one or more Denver-area geochemical laboratories between 1 and 5 p.m. Check with the A.E.G Symposium office in the Holiday Inn West (279-7611).

4:00 A.E.G. Council meeting, Holiday Inn West.

April 17, Monday
Morning

6:45 Authors' breakfast. Holiday Inn West.

OPENING SESSION--WELCOMING TALKS

Chairman Paul K. Theobald

8:45 R. F. Horsnail, President, A.E.G.
Guy McBride, President, Colo. School of Mines
John Rold, State Geologist, Colorado
Introduction by C. E. Thompson

Keynote Address by H. W. Lakin

10:00 BREAK. Posters on display in the lobby. Free coffee.

URANIUM GEOCHEMISTRY

Chairmen Mike Reimer and Fred Ward

10:30 Dunn, C. E., and Ramaekers, P. Surface geochemical patterns associated with uranium in and beneath the Athabasca Sandstone, Saskatchewan, Canada.

10:50 Parslow, G. R., and Stolz, H. Underwater gamma ray scintillometry: Its uses and limitations as a uranium exploration tool.

11:10 Guilinger, J. R., and Awald, J. T. Geochemical remote sensing correlation of uranium distribution across eastern Colorado.

11:30 Rose, A. W., and Korner, L. A. Radon in natural waters as a guide to uranium deposits.

11:50 LUNCH

April 17, Monday
Afternoon

REGIONAL SOIL/SEDIMENT GEOCHEMISTRY

Chairmen Ralph Erickson and Richard Horsnail

1:30	Antweiler, J. C. Snowfield silt--a useful medium in geochemical exploration.
1:50	Barringer, A. R., and Bradshaw, P. M. D. SURTRACE--An airborne and ground exploration technique based on surface micro-layer geochemistry.
2:10	Bradshaw, P. M. D., and Thomson, I. The use of surface soil geochemistry in the search for buried and blind ore deposits.
2:30	Lett, R. E. W., and Fletcher, W. K. The secondary dispersion of transition metals through a copper rich hillslope bog in the Cascade Mountains, British Columbia, Canada.
2:50	BREAK. Posters on display in the lobby. Free coffee.

Chairmen F. C. Canney and M. A. Chaffee

3:30	Owen, R. M. Geochemistry of platinum-enriched sediments of the coastal Bering Sea.
3:50	Price, V. NURE geochemical investigations in the eastern United States.
4:10	Wu, I. J. and Mahaffey, E. J. Mercury-in-soils geochemistry over massive sulfide deposits in Arizona.

April 17, Monday
Evening

7:00-9:00 POSTER PRESENTATIONS. Holiday Inn West

Hassaan, M. M., and Al-Hawary, M. A. Geochemical orientation survey for manganese deposits in the arid conditions of the Eastern Desert of Egypt.

Huang, C., Rose, A. W., and Deines, P. Fluid inclusions and isotopic gradients as a guide to ore at Ely, Nevada, U.S.A.

Hunt, C. W. Uranium exploration using effused radium, radon halos, and migrated bismuth.

Maurice, Y. T., and Coker, W. B. Methods of interpretation and follow-up of reconnaissance lake sediment data in the northern Canadian Shield.

Mercready, R. B., Sayala, D., and Siegel, F. R. A computer-based cartometric system applied to geochemical exploration for mineral deposits.

Mosier, E. L., and Allcott, G. H. Geochemical evidence for thorium and associated elements in northern Sonora, Mexico.

Mukherjee, K. K. Fluorine as a direct indicator in local soil geochemical survey in humid tropics -- a case history.

Phelps, D. W., and Buseck, P. R. Mercury in soils as an indicator of geothermal activity: Yellowstone National Park, Wyoming

Zeegers, H. Regional geochemical prospecting in equatorial areas: an example in French Guyana.

April 18, Tuesday
Morning

6:45	Authors' breakfast. Holiday Inn West

LITHOGEOCHEMISTRY

Chairmen I. Nichol and J. A. Coope

8:30	Doe, B. R. The application of lead isotopes to mineral prospect evaluation of Cretaceous-Tertiary magmatothermal ore deposits in the Western United States.
8:50	Mason, D. R. Ferromagnesian mineral chemical variations: a new exploration tool to distinguish potentially mineralized and barren stocks in porphyry copper provinces.
9:10	Wahl, J. L., and Govett, G. J. S. Rock geochemical exploration techniques for massive sulphides of the Bathurst type (New Brunswick, Canada).
9:30	Divis, A. F., and Clark, J. R. Exploration for blind ore deposits and geothermal reservoirs by lithium isotype thermometry--atomic absorption "mass" spectrometry.
9:50	BREAK. Posters on display in the lobby. Free coffee.
10:30	Tihor, L. A., and Crocket, J. H. Lithogeochemical guides to ore at the Kerr Addison gold mine, Ontario.
10:50	Siewers, U., and Van den Boom, G. Data evaluation with multivariate statistical methods of multi-element analyses of hard rock samples from a concealed stratiform deposit.
11:10	Shmakin, B. M. Geochemical indicators for the evaluation of granite pegmatites.
11:30	DISCUSSION
11:50	LUNCH

April 18, Tuesday
Afternoon

PARTIAL DISSSOLUTION CHEMISTRY AND TECHNIQUES

Chairmen T. T. Chao and John Watterson

1:30 Carpenter, R. H., and Hayes, W. B. Fe-Mn oxide coatings in routine exploration geochemical surveys.

1:50 Hoffman, S. J., and Fletcher, W. K. Extraction of Cu, Zn, Mo, Fe, and Mn from soils and sediments using a sequential procedure.

2:10 Thomson, I., and Read, D. The character and application of various chemical analytical techniques in uranium exploration.

2:30 Dijkstra, S., van den Hul, H. J., and Bill, E. Experiments on the usefulness of some selected chemical quantities in geochemical exploration in a former mining district.

2:50 BREAK. Posters on display in the lobby. Free coffee.

HEAVY MINERAL SEPARATES

Chairman W. R. Griffitts

3:30 Zantop, H. Heavy-mineral panning techniques in the exploration for tin and tungsten in northwestern Spain.

3:50 Watters, R. A., and Sagala, F. P. Geochemical reconnaissance for uranium and base metals using heavy mineral separates in central and southern Sumatra--A preliminary report.

4:10 Annual Meeting of the Association of Exploration Geochemists followed immediately by presidential address of outgoing A.E.G. President Dr. R. F. Horsnail.

April 18, Tuesday
Evening

7:00-9:00 POSTER PRESENTATIONS. Holiday Inn West

Baum, L. F. Judging the volcanic exhalative mineralization potential of a terrane using geochemical analyses of a few outcrops in areas of transported or deep residual overburden.

Cachau-Herreillat, F., Capdecomme, H., Laville-Timsit, L., Leleu, M., and Wilhelm, E. Behaviour of base metals around ore deposits: application of geochemical prospecting in temperate climates.

Carlson, E. H., and Manus, R. W. Application of a campsite technique for the analysis of total fluoride to the exploration for fluorspar.

Pride, D. E., Timson, G. H., and Robinson, C. S. Use of selected elements to study hydrothermal alteration-mineralization of a porphyry molybdenum prospect, Breckenridge mining district, Colorado.

Reise, W. C., Brookins, D. G., Lee, M. J., and Della Valle, R. Application of trace element geochemistry to prospecting for sandstone-type uranium deposits.

Robinson, G. D., and Carpenter, R. H. Partitioning of copper, zinc, and lead in soil overlying a base-metal sulfide deposit in eastern Georgia.

Spirakis, C. S., Goldhaber, M. B., and Reynolds, R. L. Thermoluminescence as a potential uranium prospecting tool.

Talapatra, A. K. Gossan geochemistry as a guide to exploration of different types of sulfide mineralization in parts of Rajasthan, Western India.

April 19, Wednesday
Morning

6:45 Authors' breakfast. Holiday Inn West

BIOGEOCHEMISTRY AND GAS TECHNIQUES

Chairmen J. H. McCarthy, Jr. and H. L. Cannon

8:30 Sharp, W. E., and Bølviken, B. Brown algae: a sampling medium for prospecting fjords.

8:50 Walker, N. C. Biogeochemistry for uranium prospecting in areas of glacial overburden.

9:10 Stahl, W. J., Faber, E., and Carey, B. D. Carbon isotope methods in hydrocarbon exploration.

9:30 Brooks, J. M., Bernard, B. B., and Sackett, W. M. Characterization of gases in marine waters and sediments.

9:50 BREAK. Free Coffee.

GEOSTATISTICS

Chairmen A. J. Sinclair and R. G. Garrett

10:30 Garrett, R. G. and Goss, T. I. The evaluation of sampling and analytical variation in regional geochemical surveys.

10:50 McCammon, R. B., Bridges, N. J., and McCarthy, J. H., Jr. Estimate of mixed geochemical populations in rocks at Ely, Nevada.

11:10 Polikarpochkin, V. V. Computer estimation of deposit productivity based on geochemical sampling of the drainage basin.

11:30 To be announced.

11:50 LUNCH

April 19, Wednesday
Afternoon

HYDROGEOCHEMISTRY AND ELECTROGEOCHEMISTRY

Chairmen I. R. Jonasson and G. J. S. Govett

1:30 Cadigan, R. A., and Felmlee, J. K. Uranium resource estimation from radium and radon concentrations in waters in an area of radioactive springs.

1:50 Steenfelt, A. and Kunzendorf, H. Geochemical methods in uranium exploration in northern East Greenland.

2:10 Olade, M. A., and Goodfellow, W. D.* Development of hydrochemical methods of exploration for uranium, tungsten, and molybdenum mineralization, Tombstone batholith, Yukon, Canada.

2:30 Tilsley, J. E. Electrochemical interpretation of some geochemical phenomena.

2:50 BREAK. Free Coffee.

GEOCHEMICAL EXPLORATION IN GLACIAL TERRAIN

Chairmen E. M. Cameron and C. F. Gleeson

3:30 Sinclair, I. G. L. Geochemical investigation of the Clyde River zinc prospect, Lanark County, Ontario.

3:50 Closs, L. G, and Sado, E. V. Geochemical drift prospecting studies near gold mineralization, Beardmore-Geraldton area, Northwest Ontario, Canada

4:10 Peatfield, G. R., and Armstrong, A. T. The Red-Chris porphyry copper-gold deposit, northwestern British Columbia, a geochemical case history.

* Speaker

April 19, Wednesday
Afternoon

1:45 Departure for Silver City, New Mexico area base- and precious-metal deposits (two days). At 1:45 p.m. a bus will leave from the Green Center and make very brief stops at the official Symposium motels to pick up baggage enroute to Stapleton Airport.

Visits will be made to the operating porphyry copper deposits at Chino and Tyrone. Altered areas and base- and precious-metal deposits of skarn- and vein-types of past production or current exploration interest may also be visited. Discussions will include field sampling techniques in this semi-arid region, sampling media, preparation, analysis, and interpretation of data related to various areas that have been studied geochemically. Bring good walking shoes. Several easy hikes of up to 1 mi (1.6 km) are possible. Temperature range should be approximately 40°-70°F (4°-21°C).

The cost of this trip includes one-way plane fare from Denver to El Paso, Texas; bus transportation from El Paso to Silver City and around the Silver City region; and return bus transportation to El Paso. Also included are two box lunches and two nights lodging in Silver City. Participants will depart Denver Airport on WEDNESDAY at 3:45 p.m. Thus, they will miss most of the last afternoon of the technical sessions. Registrants must make their own continuing/return travel arrangements. Participants may book the afternoon flight (Frontier #588 4:49 p.m.) from Silver City to Albuquerque, New Mexico, (and from there to Denver, etc.); however, no refund for the unused bus return trip to El Paso will be made. The field trip will be completed in time to meet the 4:49 p.m. flight and for those so desiring, the bus can leave you at the Silver City airport. Anticipated arrival at the El Paso airport by bus will be about 8:00 p.m. Mountain Time on Friday. Accommodations can be arranged in El Paso for that night if desired.

Total cost: Single--$140; Double, per person--$130.00.

Trip leaders: K. C. Watts and J. R. Hassemer, (USGS) with additional discussions by Silver City area geologists.

Limit: 30 people.

April 19, Wednesday
Afternoon--Continued

4:30 Departure for <u>Southern Arizona porphyry copper deposits</u> (three days). At 4:30 p.m. a bus will leave from the Green Center and make very brief stops, at the offical Symposium motels to pick up baggage enroute to Stapleton Airport.

Visits will be made to a number of porphyry copper deposits for which there is geochemical information. These deposits will include Kalamazoo, Florence, Mineral Butte, Vekol, Lakeshore, Red Mountain, and Twin Buttes. Bring good walking shoes. Several level hikes of up to 1 mile (1.6 km) are necessary. Temperature range should be approximately 50°-80°F (10°-27°C). The cost of the trip includes one-way air transportation (Frontier #29) from Denver to Tucson, Arizona at about 6:42 p.m.; bus transportation around Arizona; three nights lodging and three box lunches. Participants will have to make their own continuing/return transportation arrangements from Tucson. The trip will end Saturday afternoon. Arrival at the Tucson airport will be at approximately 4:30 p.m. Mountain Time on Saturday, April 22. Return to Tucson motel will be about 5:30 p.m.

Total cost: Single--$200.00; Double, per person--$180.00.

Trip leaders: M. A. Chaffee and J. R. Watterson, (USGS) and K. A. Lovstrom (AMAX), with additional discussions by area geologists.

Limit: 30 people.

April 20, Thursday
Morning

8:00 Departure for Cripple Creek gold telluride deposits.

A visit will be made to surface exposures in the famous Cripple Creek Mining district, 20 miles (32 km) southwest of Colorado Springs. This district has produced over 21 million ounces (approximately 600 million grams) of gold since its discovery in 1891. A geochemical sampling program of surface rock samples revealed extensive anomalies of gold, silver, tellurium, and other elements. A one-day tour will examine and discuss the geology, ore deposits, and geochemistry of the district.

Total cost: $30.00 (Includes transportation and box lunch).

Trip leaders: J. Howard McCarthy, Jr. (USGS) and Rudy Epis (Colorado School of Mines) with discussions by area geologists.

Limit: 38 people.

8:00 Departure. One day field orientation trip to Precambrian mineral deposits near Golden.

Visits will be made to several Front Range Precambrian mineral deposits near Denver that have been studied experimentally using geochemical methods. The morning will be spent visiting an old copper mine near Idledale. This visit will require about a three-mile hike (5 km), round trip. Ore minerals in this vein-type deposit include pyrrhotite, chalcopyrite, and sphalerite. Local geology will be discussed by Douglas Sheridan and Sherman Marsh, geochemistry of stream sediments by Harold Bloom, and geochemistry of soils by Lyman Huff.

After lunch in a nearby park, participants will examine a rutile-rich belt in the Precambrian metamorphic rock near Bergen Park. During the day, experiments in several new geochemical prospecting techniques will be discussed by local experts, and geochemical tests on stream sediments will be demonstrated.

Total cost: $25.00 (Includes transportation and box lunch).

Trip leaders: Lyman Huff, Sherman Marsh, and Douglas Sheridan (USGS); Harold Bloom (Colorado School of Mines).

Limit: 38 people.

8:30 Departure for Schwartzwalder Mine, a vein-type Precambrian uranium deposit.

A visit will be made to surface exposures near the Cotter Corp. Schwartzwalder Mine. A discussion will be given of the local geology as well as the geochemistry around this uranium deposit.

Total cost: $25.00 (Includes transportation and box lunch).

Trip leader: Ed Young (USGS).

Limit: 40 people.

April 21, Friday
Morning

7:00 a.m. Departure time. First day of visits to two Colorado molybdenum deposits.

A visit will be made to the Climax molybdenum mine. This trip will include a discussion of mine geology and mining methods followed by a trip to the open pit mine (no underground tour). The group will return to Golden for the night. Note that the mine is at about 11,500' (3500 m.) elevation. Be prepared for cold weather (32°-50°F/0°-10°C).

On Saturday, (see below) a visit will be made to the Henderson mine that will include a discussion of orebody geology, surface geochemistry, and a trip underground. The mine is warm and damp. Participants will need to bring underground clothes, mine boots, and lamp belts.

Total cost: $40.00 (Includes transportation and two box lunches).

Trip leaders: Members of the Climax Molybdenum Co. geological staff and Vaughn Surface, Jim LeAnderson, Roger Steininger, Dick Brumbaugh, and Arne Ward.

Limit: 40 people.

7:00 Departure for a Central Wyoming sandstone-type uranium deposit (two days).

A two-day trip will be made to the Powder River Basin to visit the Bear Creek open pit mine where a roll-front deposit is being worked. The group will also tour the modern Bear Creek uranium recovery mill. Travel will be by bus. Be prepared for windy, cold weather (30°-50°F/0°-10°C).

Total cost: Single--$70.00; double, per person--$60.00. (Includes transportation, two box lunches, and one nights lodging in Douglas, Wyoming).

Limit: 40 people.

April 22, Saturday
Morning

7:00 Departure for Henderson mine underground tour. (Second day of tour of Colorado molybdenum deposits, see schedule for Friday morning above.)

ABSTRACTS

Listed alphabetically by first author, these abstracts represent contributions to the technical sessions of the 7th International A.E.G. Symposium, Golden, Colorado, April 17-19, 1978. Publication of the Symposium Proceedings is intended within the year; announcements will be made in the Journal of Geochemical Exploration and in the Newsletter of the Association. Prepaid volumes will be mailed directly to addresses given on the registration forms. Please advise the Association at its Toronto office (P.O. Box 523, Rexdale, Ontario M9W 5L4) of any change in address. Additional volumes may be ordered from the Association Secretary at the address given above ($35 members, $40 non-members).

SNOWFIELD SILT--A USEFUL MEDIUM IN GEOCHEMICAL EXPLORATION

John C. Antweiler, U.S. Geological Survey, Box 25046, Denver Federal Center, Denver, Colorado 80225

The Absaroka Mountain Range of Wyoming and Montana is one of many ranges in western North America for which climate and topography restrict the usefulness of stream sediments in geochemical exploration. As much as 75 percent of the precipitation occurs as snow, which accumulates into a thick snowpack during most of the year. Mountain summits are typically 800 to 1,700 meters higher than master drainages. Rapid melt of the snowpack in a few weeks of early summer results in ubiquitous flooding during which the products of rock decomposition are sluiced off the steep slopes and drainages.

The minus-80-mesh fraction and heavy-mineral concentrations of stream sediments, which have been so effective as geochemical sampling media around the world, may be either unavailable or greatly diluted by unsorted debris. An attractive alternative medium is silt produced by weathering of rock underneath snowfields that constitute headwater drainages. Such weathered rock is always saturated with moisture, and its decomposition is hastened by frost weathering in cracks, veins, and joints. Gravity and percolating water help the snowfield pick up the products of rock decomposition and carry them downward. The fine-grained or silt-sized fraction, herein called snowfield silt, often accumulates at the lower end of the snowfield and is easily sampled. The sample is processed and analyzed in the same manner as conventional stream silt samples.

Orientation experiments using snowfield silt as a sampling medium showed sharp anomalies of copper, lead, and zinc in known mineralized areas compared to background areas of non-mineralized terrain. When used as a geochemical sampling medium in a mineral resources survey, snowfield-silt samples led to the discovery of a previously unknown mineralized area. Subsequent exploration revealed characteristics commonly associated with porphyry copper deposits.

Snowfield silt might also be useful as a sampling medium in other rugged mountainous areas that have short cool summers and long cold winters. It should be particularly useful in surveying areas that are concealed by an extensive snow cover most of the time, or in steep-walled cirques that are difficult to traverse but retain perennial snowfields.

SURTRACE--AN AIRBORNE AND GROUND EXPLORATION TECHNIQUE BASED ON SURFACE MICRO-LAYER GEOCHEMISTRY

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The earth's surface is covered with a thin micro-layer of particulate material that exists on virtually all surfaces including those of soil, vegetation, and water. The proportion of organic to inorganic material varies widely in this surface micro-layer according to the type of environment. Particularly in arid regions, fine-sized fractions (generally less than 200 microns) can be highly contaminated with material that has undergone atmospheric dispersion from distant sources. Generally the material coarser than approximately 200 microns is entirely local in origin. The chemistry of coarse surface particulate material closely relates to the chemistry of underlying parent soil, and the collection of such material in the appropriate size ranges provides a rapid and convenient means for geochemical exploration. Special equipment is necessary to both collect and analyze surface particulates, and a variety of techniques have been developed for this purpose. The most novel of these techniques is a helicopter-borne system that can traverse a variety of terrain types at speeds in the range of 30 to 50 miles per hour, while collecting samples at five-second intervals. This equipment sieves and fractionates particles that are suctioned off vegetation and soil by a specially designed sampling probe and impacts these sequentially on an adhesive tape. The samples are analyzed for 25 elements by automated micro-analytical techniques, and the data are stored on magnetic tape for subsequent computer plotting and/or statistical treatment.

The properties of surface micro-layer particulates differ from the plant and soil materials used in conventional geochemical exploration, and the method shows a potential that extends well beyond the mere advantages of convenience and speed. Initial tests over known mineral occurrences have produced excellent high-contrast multi-element anomalies.

JUDGING THE VOLCANIC EXHALATIVE MINERALIZATION POTENTIAL OF A TERRANE USING GEOCHEMICAL ANALYSES OF A FEW OUTCROPS IN AREAS OF TRANSPORTED OR DEEP RESIDUAL OVERBURDEN

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Two geologically correlative volcanic eugeosynclinal terranes 60 km apart in northeastern Washington State, covered by glacial and fluvial debris and judged beforehand to be non-mineralized and mineralized respectively on the basis of published and field data, have been compared geochemically using bedrock copper, zinc, nickel and iron values, and relatively simple data processing. The objective is to determine if the two areas have any geochemical "fingerprints" which may be useful in attempting to discriminate between potentially mineralized and non-mineralized areas during routine exploration.

Twenty random samples each of Permo-Triassic graywacke sandstones, shales, diorites and volcanic greenstones were collected during structural and stratigraphic mapping of the two areas. Also, within each of the two areas, each of the four rock types was systematically sampled along two orthogonal lines in each of two subareas spaced from 300 to 500 m apart, where 20 samples were collected at 30 to 300 cm intervals parallel to bedding, foliation, or length of the rock body, and 20 samples were collected in a similar fashion normal to that direction.

Analysis of variance and Duncan's multiple range test for the orthogonal pairs of sample lines in the two areas combined show that 75 percent of the sandstone pairs, 81 percent of the shale pairs, 87 percent of the greenstone pairs, and 94 percent of the diorite pairs estimate the same metal content in either sampling direction, suggesting that the igneous-component rocks have a more homogeneous distribution of values on the outcrop scale than the sedimentary rocks. However, the coefficients of variation for 32 sample lines are lower in the sedimentary rocks than in the greenstones-diorites. Thus the sedimentary rocks actually have a more homogeneous (low relative variance) metal distribution within subareas (outcrop scale) than the igneous-component rocks.

Coefficients of variation for orthogonal sample lines in non-mineralized sandstones and shales are up to twice as high as for the same rocks in the mineralized area. Exactly the opposite is true for greenstones and diorites. These differences in relative dispersion show in the scatter diagrams and Pearson correlation coefficients. For example, element pairs in the non-mineralized sandstones are more highly correlated and show a better defined regression line than for the mineralized sandstones.

Other simple statistics and graphical techniques such as ternary diagrams are useful in further "fingerprinting" mineralized and non-mineralized areas.

THE USE OF SURFACE SOIL GEOCHEMISTRY IN THE SEARCH FOR BURIED AND BLIND ORE DEPOSITS

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As exploration continues in any area, the search is expanded sooner or later (generally sooner) for deposits which are either blind by transported overburden or are buried under rock capping. In such areas, geophysics has traditionally been the only indirect method of exploration. This paper describes a series of techniques which have yielded geochemical anomalies in surface soils relating to mineralization blind by up to 500 m.

All these techniques rely on the basic premise that the chemistry of surface soils comprises an original (background) content related to the parent material (rock, till, etc.), plus an anomalous content added from mineralization at depth by any one of a number of possible transporting processes. The background metal content is generally present in much greater concentrations than the anomalous metals making identification of the anomalies difficult at best. In order to uniquely identify an anomaly related to mineralization, two techniques have proven successful: (1) the isolation of specific fractions of the soil which contain a large portion of the anomalous metal, and (2) the application of selective or differential analytical procedures which are blind to the background metal content while efficiently removing the anomalous metal added from the mineralization at depth. Recent studies have shown that a combination of these techniques can yield well defined, high-contrast anomalies related to otherwise blind mineralization under a wide range of geologic and surficial environment conditions.

Examples of the successful application of these techniques are given from areas covered with glacially transported material of foreign origin and for deposits which are blind under a solid rock cover.

CHARACTERIZATION OF GASES IN MARINE WATERS AND SEDIMENTS

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Hydrocarbon gases in marine sediments can originate as a product of microbial decomposition of organic matter in recent sediments (biogenic gas) and from abiotic clay mineral catalysis at elevated temperatures and pressures of refractory organic material within the sedimentary column (thermocatalytic gas). Biogenic gas consists principally of CH_4 and CO_2, whereas thermocatalytic gas associated with reservoired oil and gas can contain a wide spectrum of gaseous hydrocarbons with significant quantities of helium. Characterization of sources of hydrocarbon gases is important since anomalous concentrations in marine waters and sediments can be used in geochemical prospecting.

We have developed techniques to measure the molecular and carbon isotopic compositions of hydrocarbons and the concentrations of helium in the interstitial water of sediments and in near-bottom waters. Sediment samples obtained by standard coring techniques are inserted and sealed without appreciable gas loss in specially fabricated jars containing hydrocarbon and helium-free water and nitrogen. The dissolved gas in the interstitial water of the sediment is partitioned into the nitrogen headspace of the container with a high-speed shaker. The headspace gases are analyzed for helium, light hydrocarbons, and stable carbon isotope ratios of methane. Total dissolved gases extracted from near-bottom seawater samples are analyzed for the same parameters.

Gases found in marine sediments and near-bottom waters can be differentiated on the bases of their molecular and isotopic compositions. Analysis of seep and sediment gases indicate that biogenic gas consists almost exclusively of methane, having $C_1/(C_2+C_3)$ hydrocarbon ratios greater than 1000, $\delta^{13}C_{PDB}$ values of methane more negative than -60°/∘∘, and negligible amounts of helium. Petroleum-related hydrocarbon gases generally have $C_1/(C_2+C_3)$ ratios smaller than 50, $\delta^{13}C$ values of methane greater than -50°/∘∘, and measurable amounts of helium. To positively characterize the source of a hydrocarbon gas, both the $C_1/(C_2+C_3)$ ratio and the $\delta^{13}C$ value of methane are required since alteration of (1) hydrocarbon compositions by chromatographic processes during migration, (2) isotopic compositions by substrate depletion during bacterial oxidation, and (3) mixing of biogenic and petrogenic gases can lead to misinterpretation of gas sources when only one parameter is utilized.

These techniques have been used to characterize (1) hydrocarbons originating from natural seeps in the Gulf of Mexico, (2) dissolved hydrocarbons in interstitial waters of Gulf of Mexico sediments, and (3) the history, as recorded in the sediments around the crater, of hydrocarbons emanating from a well blowout.

BEHAVIOUR OF BASE METALS AROUND ORE DEPOSITS: APPLICATION TO GEOCHEMICAL PROSPECTING IN TEMPERATE CLIMATES

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The secondary dispersion of base metals is traced from weathered bed rocks to stream sediments and stream waters around six different ore mineralizations, all situated in the temperate climate conditions of France. These different test areas are representative of various geomorphological, geological and metallogenetic environments.

Samples collected consisted of: 210 hard rocks, 240 soft and weathered rocks, 730 soils, 240 stream sediments, 130 pan-concentrates, and 140 surface waters. This sampling program allowed us to understand the complete process of the dispersion of the metals from the primary mineral deposit to the materials carried downstream.

Bulk samples and samples fractionated by various methods, as granulometric, densimetric, and magnetic separations, were analyzed for several elements. The mineralogical fractions obtained were controlled by optical microscopy, microprobe analyses, and X-ray diffraction.

The principal phases, carrying most of the metals usually analyzed in bulk samples during geochemical prospecting were:

- iron hydroxides, associated sometimes with manganese; in anomalous zones, generally more than 50 percent of the metal weight is located in this phase;
- primary and supergene weathering minerals;
- organic matter linked to iron.

In all cases, the "iron hydroxide" fraction, directly related to the weathering of sulphides (gossans), appears in the early stages of the superficial alteration of primary rocks. It is then mechanically dispersed and diluted by barren products but still predominates in the definition of geochemical anomalies.

These results lead to refinements in geochemical exploration methods. For example, the "iron hydroxide" phase can be separated by its paramagnetic properties, and its assays show a significant increase in the metal concentrations of anomalous values (x4), as well as in the contrast of the anomalies (x3). Unfortunately, only a slight increase appears in the size of the anomalies.

Compared to the usual geochemical analysis of the whole fine-grained fraction, the better definition and selection of the significant anomalies obtained by these partial analyses allow us to lower the density of the sampling grid.

This significant improvement should be weighed against the correlative increase in the cost of sample preparation and analysis, and the loss of information concerning the other fractions.

Work is continuing at the Bureau of Research on the possibility of applying such techniques to regional exploration and to following up isolated or weak anomalies.

URANIUM RESOURCE ESTIMATION POSSIBLE FROM RADIUM AND RADON CONCENTRATIONS IN WATERS IN AN AREA OF RADIOACTIVE SPRINGS

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Uranium geochemical exploration is usually accomplished by the detection of uranium itself. Other reliable indicators are alpha, beta, and gamma radiation resultng from the decay of uranium and its daughter products. Still others are the measurable daughter products ^{226}Ra, ^{222}Rn, and ^{4}He.

Present use of these indicators in rock, water, sediment, or soils follows conventional geochemical exploration practice: sample values are analyzed statistically; an anomaly threshold is established; detected anomalous values are then interpreted in a qualitiative manner to determine if their presence is indicative of a uranium resource. After an anomaly is recognized, quantitative data may be further exploited, in special environments, to estimate the amount of U in the source rocks.

Ra and Rn are more mobile in hydrothermal spring environments than are their parent nuclides. They are rapidly transported under pressure through fracture systems for distances as great as hundreds or thousands of meters. For a geochemical model of the systems studied, we used an area along the fault system at the base of the Wasatch Mountains north of Ogden, Utah, that contains seven noted radioactive hydrothermal springs. Spring discharge values range from 100 to 12,000 L/min. The springs contain Ra values up to 220 pCi/L and Rn values up to 1,800 pCi/L. Ra values exceed equilibrium values with U in the waters up to 25,000 times; Rn values exceed equilibrium values with Ra by more than 100 times. This suggests that most of the Ra and Rn measured at the surface are supplied by U and Ra within the fault and fracture system.

Calculations of the minimum U required to produce Ra and Rn at the present rate in this geographic area yield an estimate of 80,000 metric tons of U in the system. The U may be distributed through 60 km^3 of fractured rock with no significant ore concentrations, or if favorable host environments are present some of it could be concentrated in ore deposits probably related to the fault and fracture system through which the waters move to the surface.

Data for interpreting the complete hydrogeochemical system and related U source location are either incomplete or their potential unrecognized. The model, however, is presented to encourage the prediction of potential resources of U.

APPLICATION OF A CAMPSITE TECHNIQUE FOR THE ANALYSIS OF TOTAL FLUORIDE TO THE EXPLORATION FOR FLUORSPAR

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A campsite technique for the analysis of total fluoride was developed and found applicable to exploration for fluorspar deposits. Stream sediments were chosen as the sampling medium for reconnaissance work. As the method relies on the dissolution of fluorspar itself, the technique is applicable in arid and semi-arid regions as well as in areas of humid climates that have moderate to high relief.

The method devised relies on the ability of an aluminum chloride solution to dissolve fluorspar with the resultant formation of an aluminum fluoride complex ion. The soluble complex can then be dissociated by the addition of a sodium citrate solution, which puts the fluoride in the simple ionic form. Finally the pH of the sample solution is adjusted to between 5 and 6 by means of an acetate buffer in order to eliminate other interference effects. Fluoride values measured by this method compare favorably to those obtained from a sodium hydroxide fusion technique.

The technique was tested in an area of known fluorspar deposits that occur in the eastern portion of the Christmas Mountains, Brewster County, southwest Texas. Sixty-two stream-sediment samples were collected along the major washes and their tributaries from an area of about 12 square miles (31 km^2). The samples were dried and sized to -60 and -120 mesh fractions, and portions weighing 2 grams were analyzed. Fluoride measurements were performed on a portable Orion fluoride combination electrode using appropriate standard solutions. Even though aluminum chloride solutions react vigorously with calcium carbonate, stream-sediment samples with moderately high calcite contents were analyzed successfully. Water for the analyses was obtained in the field and was demineralized by a simple gravity flow apparatus. One man was able to analyze about 30 samples per day.

Fluoride values measured ranged from 8500 to less than 125 ppm. The median sample value, 126 ppm F^-, was utilized as the local background level for the area. Values at least three times greater than the background readings were considered anomalous. All values greater than 500 ppm came from the vicinity of the Paisano Fluorspar Mine. Secondary dispersion in the stream-sediment samples could be traced several miles downstream from this mine into East Corazones Draw. Additionally, two smaller anomalies were discovered where fluorspar deposits were not previously known.

FE-MN OXIDE COATINGS IN ROUTINE EXPLORATION GEOCHEMICAL SURVEYS

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Recent studies indicate that routine geochemical exploration for Cu, Zn, Pb, Co, and Ni (and possibly other metals), using Fe-Mn oxide coatings on boulders as a sample medium, can be performed at costs less than that required for the analysis of conventional stream sediments. Because coated surfaces downstream from mineralized zones are enriched in base metals, relative to Mn and Fe, the ratios metal/Fe, metal/Mn, or metal/Mn+Fe, serve to define anomalous areas.

The coatings are removed chemically, either in the field or laboratory, and an aliquot (50 ml or less) is analyzed directly by AAS. Drying, screening, weighing, and measurement of solution volume are not required. Hydroxylamine hydrochloride and oxalic acid are effective in removing coatings and do not react appreciably with the rock substrate. Digestions in the field utilizing concentrated digesting solutions (10-20 strength) which are diluted with stream water prior to analysis eliminate the need for transporting heavy boulders to the laboratory for analysis.

Preliminary studies also suggest that X-ray fluorescence analysis may be applicable to routine surveys using coatings. Counts of characteristic X-rays/unit of time (corrected for background) can be used to calculate ratios (e.g. counts Cu/counts Mn) for small chips of the coated surfaces. Well defined anomalies have been identified by this procedure downstream from several known base metal occurrences. This method has the advantage of requiring no sample preparation, and the analytical time is short (10 - 100 seconds/determination).

GEOCHEMICAL DRIFT PROSPECTING STUDIES NEAR GOLD MINERALIZATION, BEARDMORE - GERALDTON AREA, NORTHWEST ONTARIO, CANADA

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Prospecting within many of the areas of Ontario which are geologically favorable for gold mineralization is hampered by the masking effect of glacial overburden. Increasing attention has been placed upon combined exploration geochemistry-glacial geology methods to establish means of prospecting in these environments. In 1974 the Ontario Geological Survey carried out an orientation drift prospecting investigation near areas of known 'vein-type' gold mineralization in the Beardmore-Geraldton area, northwest Ontario. The purpose of this program was: (1) to study metal dispersion in soils and glacial sediments overlying and down-ice from these known occurrences and (2) to assess the effectiveness of sampling these media as a means of prospecting for 'vein-type' gold deposits in glaciated terrain.

Area selection was based upon bedrock, economic, and surficial geology criteria. Three areas were selected for detailed sampling, with till being the preferred sampling medium. Soils and glacial material were collected from areas measuring 910 m perpendicular to the direction of ice movement and 1,525 m in the direction of ice movement. Organic A horizon soil samples were collected at each site within one of the survey areas. B horizon soils and tills were analyzed (1) by atomic absorption for hot HNO_3 - HCl extractable Ag, As, Cu, Cr, Zn, and Pb; (2) by emission spectrography for Sn, B, and Zr; and (3) by a combined fire assay concentration - atomic absorption estimation for gold. Both the -250 mesh (silt and clay sized material) and the heavy mineral separate of the -60 to +250 mesh fractions of till were analyzed chemically. Organic A horizon soils were analyzed for hot HNO_3 - HCl extractable Mn, Cu, Zn, Ni, Co, and Pb; and organic carbon content was estimated by determination of loss-on-ignition.

Gold provides the most consistent indicator of its deposits. It is frequently difficult to obtain sufficient sample material for gold determinations in the heavy mineral separate of tills. Optimum sample fraction selection is aided by knowledge of the mineralogical nature of gold occurrences within a particular area. The trace element pathfinder suites which can aid in raising anomaly selection confidence vary with the content of vein and gangue minerals associated with specific deposits. A sound appreciation of both the regional and local Quaternary geology is essential to the successful planning, field sampling, and interpretation of a drift prospecting program.

EXPERIMENTS ON THE USEFULNESS OF SOME SELECTED CHEMICAL QUANTITIES IN GEOCHEMICAL EXPLORATION IN A FORMER MINING DISTRICT

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The Moresnet region in northeastern Belgium represents an example of a typical old lead-zinc mining district with several scattered dumps of mine and smelter materials. The presence of the latter materials restricts the applicability of common techniques of geochemical reconnaissance. Especially techniques using total metal extraction or hot HCl metal extraction provide results that are highly problematic. Geochemical stream sediment profiles are irregular in appearance, because anomalies associated with smelter heaps tend to camouflage anomalies derived from in situ mineralization.

As far as the Moresnet region is concerned, it appears that this adverse situation can be considerably improved by the use of selected quantities such as hydroxylamine hydrochloride extractable zinc minus sodium dithionate - sodium citrate extractable zinc, and sodium dithionate - sodium citrate extractable lead minus magnesium chloride extractable lead.

These quantities provide smooth geochemical profiles that can be readily interpreted; the effect of trace metal dispersion from smelter heaps is considerably reduced. The paper gives details of the authors' experiments, and attempts to define the selected quantities in terms of modes of occurrence of trace metals concerned.

EXPLORATION FOR BLIND ORE DEPOSITS AND GEOTHERMAL RESERVOIRS BY LITHIUM ISOTOPE THERMOMETRY - ATOMIC ABSORPTION "MASS" SPECTROMETRY

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The Li^6/Li^7 isotope system displays characteristics which make it highly desirable as an exploration technique. It shows strong fractionation in natural hydrothermal systems. Although lithium is a trace element in most geological systems, it occurs in sufficient abundance for analysis by atomic absorption techniques. In the case of lithium-6 (Li^6) and lithium-7 (Li^7), isotope analyses can be carried out rapidly and accurately by atomic absorption flame techniques. The procedure, a method for atomic absorption "mass" spectrometry, promises to be a unique technique applicable to the exploration for "cryptic" haloes associated with "blind porphyry" molybdenum, tin, and copper deposits as well as geothermal reservoirs.

The lithium 7608 Å line, a doublet with 0.15 Å spacing, undergoes an isotopic shift (Li^6 to Li^7) of approximately 0.15 Å, resulting in apparent triplet 6708 Å in natural isotopic mixtures. Normally, this fine resolution would not be possible in a conventional atomic absorption spectrometer. However, the availability of monoisotopic hollow cathode lithium lamps permits isotope ratio determination of high precision and accuracy by employing the isotope specificity of these sources.

Lithium isotope analyses were carried out using a Perkin-Elmer 360 atomic absorption spectrometer with digital readout in flame atomization mode (air acetylene flame). Monoisotopic (99 percent) Li^6 and Li^7 hollow cathode lamps are used in conjunction with standard Li^6/Li^7 ratio solutions prepared from monoisotopic lithium metal (better than 99 percent pure) obtained from the Oak Ridge National Laboratory. A calibration curve of Li^6/Li^7 absorbance ratio versus atomic percent Li^6 is essentially linear from 0 to 100 percent Li^6 for solutions in the concentration range 0.05 to 0.5 μ gm/l. By employing standard solutions of appropriate corresponding concentration range, solutions ranging in concentration to 30 μ gm/l can be analyzed.

The accepted "normal" abundance of the lithium system is Li^6: 7.52 percent, and Li^7: 92.48 percent (Bainbridge and Nier, 1950). Our analyses of igneous rock and mineral samples indicate that natural geologic fractionation of the lithium isotope system result in Li^6 abundance ranges from 5 percent to 20 percent. This fractionation is presumed to result from a combination of equilibrium exchange and kinetic effects. The equilibrium exchange effect, with lithium behaving as an ideal Henry's Law solute (?), is probably the dominant process in most geologic systems. This equilibrium partitioning is a function of absolute temperature and resembles the fractionation of the oxygen isotope system in many respects. The relatively large mass difference between the isotopes of lithium (14 percent--similar to that of oxygen: 12 percent) suggest that the system should show comparable fractionation as a function of temperature.

In an investigation of island arc volcanic and plutonic rocks, inluding porphyry copper plutons, it has become obvious that plutons associated with hydrothermal mineralization show very strong fractionation and enrichment of Li^6, even though the samples analyzed showed little or no petrographic evidence of hydrothermal mineralization. Unmineralized volcanic rocks typically show very little fractionation, with $Li^6 = 7.5 \pm 3$ percent.

- Lithium isotope ratios may be determined by conventional atomic absorption techniques with existing unmodified equipment.

- Lithium isotope analyses may be performed rapidly and cheaply on a reconnaissance basis (30-50 analyses per man day on unmodified equipment).

- Lithium isotope ratios are indicative of the temperature and circulation patterns of hydrothermal systems; they are therefore valued in the exploration for and the investigation of thermal alteration haloes and mineralization.

THE APPLICATION OF LEAD ISOTOPES TO MINERAL PROSPECT EVALUATION OF CRETACEOUS-TERTIARY MAGMATOTHERMAL ORE DEPOSITS IN THE WESTERN UNITED STATES

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Magmatothermal ores are deposits formed as a result of igneous activity either directly by magmatic differentiation, or as a result of associated circulating cells of heated waters. The metals in the ores may or may not be derived from the igneous rocks by the heated waters. Much of the western United States contains reactivated Precambrian basement (herein called rejuvenated cratons) that was depleted in uranium in Precambrian time relative to the upper crust either because the rocks forming the lower crust are of intermediate to mafic composition or because the lower crust has undergone a granulite-facies metamorphism. These rejuvenated cratons contain most of the largest base and precious metal magmatothermal ores of Cretaceous-Tertiary age. The rejuvenated cratons are located in Idaho, Wyoming, and Montana; and Arizona, Colorado, New Mexico, and Utah as well as parts of Nevada and California that have been designated as areas Ia (underlain by Archean rocks) and Ib (underlain by Proterozoic rocks) by R. E. Zartman in a 1974 study. Zartman pointed out that the lead isotopic compositions of these ores are generally characterized by non-radiogenic ratios--the isochron model lead age calculated from the $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ values is older than the oldest possible age of the deposit. A closer look at the $^{206}Pb/^{204}Pb$ values with regard to production (in dollars) of these ore deposits indicates that, the more radiogenic the lead, the smaller the largest ore deposit or district that might be expected:

Production ($) Group	Maximum $^{206}Pb/^{204}Pb$ Observed	Largest District or Deposit in Each Production Group
>$1.5B	18.0	Butte, MT; Bingham, UT; Climax and Urad/Henderson, CO; Globe-Miami, AZ; Santa Rita/Hanover and Tyrone, NM
$150M-$1.5B	19.1	Tintic and Park City, UT; pene- and post-caldera ores, San Juan Mountains and Leadville/Gilman, CO; Bisbee, AZ
$15M-$150M	22	Selected deposits: Wood River, ID; Ophir and Milford, UT; Alma and Central City/Silver Plume, CO
$1.5M-$15M	20	Selected deposits: Star and Big Cotton Wood, UT; Hilltop, CO
<$1.5M	25	Santaquin (Mt. Nebo), UT: Yarmony and pre-caldera ores (Embargo dist.), San Juan Mountains, CO

In the part of the western U.S. underlain by rejuvenated Precambrian cratons, the most valuable magmatothermal deposits have values of $^{206}Pb/^{204}Pb$ less than 18. The production potential for some districts in the less than $1.5B groups may not be fully realized, of course, and a few of these also have values of $^{206}Pb/^{204}Pb$ less than 18--such as Leadville/Gilman and Alma, Colorado. There is some indication, however, that the ultimate potential of districts with values of $^{206}Pb/^{204}Pb = 18.0\text{-}19.1$ is not as great as for the supergiants with values of $^{206}Pb/^{204}Pb < 18.0$. The largest district with $^{206}Pb/^{204}Pb$ greater than 20 is the Wood River district of Idaho where total aggregate production is less than $100M; and the potential for major districts with $^{206}Pb/^{204}Pb$ greater than 20 appears to be slim on the basis of available data.

An attractive feature in the use of lead isotopes is that their variation in any given ore deposit has been found to be small (<2 percent) compared to the isotopic intervals in each economic interval (approximately 10 percent or greater). Thus only one sample per prospect is required. It should be mentioned that the isotope relations do not necessarily apply to the area underlain by Precambrian lower crust not depleted in uranium or to those areas of thick sections of miogeosynclinal sediments (areas II and III in Zartman's 1974 study) that contain Washington, Oregon, and parts of California and Nevada.

SURFACE GEOCHEMICAL PATTERNS ASSOCIATED WITH URANIUM IN AND BENEATH THE ATHABASCA SANDSTONE, SASKATCHEWAN, CANADA

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Major uranium deposits marginal to the Precambrian unmetamorphosed Athabasca Sandstone exhibit differing suites of associated elements. Dispersion patterns of U, Cu, Ni, Pb, Zn, Co, Mo, V, Fe, Mn, and Cr in tills and lake sediments near mineralization show considerable variation in concentrations and size of halos: lakes down drainage from Rabbit Lake contain anomalous uranium for up to 5 km, with weakly associated Cu, V, and Mo; uranium from the Key Lake deposit extends for 30 km and is in strong association with Ni, Co, and to a lesser degree, Zn. Fluoride in lake waters correlates with dissolved uranium near Rabbit Lake but not near Key Lake. Factor analysis of various trace metal populations around the sandstone emphasizes the variability in trace metal associations within an area of apparently consistent and monotonous geology: the Athabasca Sandstone.

Geochemical patterns are controlled by: (1) different chemical compositions of the ore bodies; (2) composition of crystalline basement subjacent to the sandstone; (3) pre-Athabasca topography and basement weathering; (4) basic igneous intrusions: possible traps for uranium-bearing solutions; (5) carbonates: locally present are Aphebian calc-silicates and Helikian marine carbonates; (6) post-Athabasca faulting: perhaps much more significant than previously supposed; (7) paleo-current systems within the sandstone; (8) grain size (hence porosity): uranium is commonly more concentrated in regions where the basal Athabasca clastics are coarse; (9) unconformities within the sandstone, especially deposystem boundaries; (10) subsurface water movements, past and present; (11) glaciation: a major factor in confusing geochemical patterns by: (a) forming a multi-level geochemical barrier (e.g. superimposed tills); (b) modifying drainage; (c) producing mineralized boulder trains, with secondary geochemical halos.

THE EVALUATION OF SAMPLING AND ANALYTICAL VARIATION IN REGIONAL GEOCHEMICAL SURVEYS

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Prior to interpreting regional geochemical data it is desirable to determine the relative magnitudes of the data variability across the region, on some local scales and in analysis. Then if a significant part of the variability is at the regional level the data may be interpreted with confidence.

In the past various methods of analysis of variance have been used to study this problem. These have had certain disadvantages; since not all samples and analyses could be replicated, these methods split the data into groups. Whereas such complete replication, leading to balanced analysis of variance models may be practicable in orientation surveys, it is economically unfeasible in routine regional reconnaissance surveys.

As part of Canada's National Geochemical Reconnaissance, an analysis of variance model has been developed that allows all samples to be considered simultaneously and a minimum of replication carried out. The model has been applied to center-lake bottom surveys at regional sample densities of 1 sample per 13 km^2; specifically the variance may be apportioned across the region, within 13 km^2, within a lake, or may be due to analysis. The type of analysis of variance design is known as "staggered and inverted" and is both logistically and statistically efficient.

Results obtained from 1977 field surveys indicate that the major part of the data variability is across the regions surveyed, and lesser amounts occur at the 13 km^2 and analytical levels. In some instances there is less variability due to sampling in single lakes than there is due to analysis; this fact indicates the homogeneous nature of center-lake bottom sediments when compared to routine methods of chemical analysis. Two conclusions may be drawn: firstly, in terms of the variabilities determined, the lake sediments surveys are adequate for mapping regional geochemical trends and detecting exploration target areas of mining-camp size, i.e., greater than 30 km^2; and secondly, if economy in sampling and analysis is desired it is the duplicate lake samples that should be eliminated as it is at this level that the lowest variability is generally observed.

As a by-product of the analysis, a factor (termed the reliability factor) is computed that allows the determination of the range within which a single resampling or re-analysis should lie. It is proposed that this factor is a useful single number for appreciating the effects of the magnitude of data variability at different levels.

GEOCHEMICAL REMOTE SENSING CORRELATION OF URANIUM DISTRIBUTION ACROSS EASTERN COLORADO

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A study of the State of Colorado east of the Continental Divide was undertaken to locate sites of maximum uranium content on surface outcrops. The study area can be categorized into five general geologic provinces; Precambrian Complex; Dawson Formation; Fox Hills, Dakota, and Laramie Formations; White River and Ogallala Formations; and the Pierre Formation. An initial set of statistically controlled stream-sediment samples was collected and analyzed for their uranium content. Several broad anomalies were thus defined. Remote sensing was then used to correlate unique outcrop reflectivities with anomalous geochemical results. Additional ground follow-up sampling and geologic mapping were completed over these areas, defining targets of less than 1 km^2 in dimension.

As a result of this study, eight properties were either leased or staked; three in the Precambrian Complex; two in the Dawson

Formation; and three in the Fox Hills Formation. The stream-sediment sample results for the properties in the Precambrian Complex ranged in value from a low of 14.0 ppm to a high of 1,180 ppm. These, in turn, were related to outcrop samples with values of 80 ppm to 270 ppm recoverable U_3O_8. The properties in the sediments contained values ranging from a low of 4 ppm to a maximum 24 ppm recoverable U_3O_8. Ground radiation at all of these sites was found to be at least five times background.

There is a definite correlation between the geochemistry and remote sensing. Using remote sensing as an intermediate step in a geochemical exploration program greatly increases the probability of finding higher geochemical values and lessens the time of the follow-up sample collection.

GEOCHEMICAL ORIENTATION SURVEY FOR MANGANESE DEPOSITS IN THE ARID CONDITIONS OF THE EASTERN DESERT OF EGYPT

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A geochemical orientation survey was carried out for the manganese occurrences of Esh El Mallaha situated 26 km north of Ghurgada. Various propecting methods were applied to determine their feasibility, the type of geochemical dispersion, the optimum sampling interval, and the most effective grain sizes to be sampled. The geochemical parameters, area "S", areal productivity, and mean content "C" were also determined. Several types of samples were collected from a depth of 10-20 cm:

(a) 522 lithogeochemical samples weighing about 25 gm and representing the -0.5 mm fractions from the dry channels. The density of samples was 2.0-2.5 (1:100,000), and 10 (1:50,000) samples every 1 km^2.

(b) 4 bulk samples each weighing about 2 kg representing the anomalous autochthonous and allochthonous detrital overburden.

(c) 126 lithogeochemical samples representing the -0.25 mm fractions of debris of the Abu-Shaar Locality on a 100 X 20 m grid (1:5,000).

(d) One water sample from the nearby well.

The bulk samples were screened to nine fractions. Heavy mineral separation of the sandy fractions (-1 mm to 0.1 mm) was carried out. The separated heavy minerals were subdivided into five magnetic fractions. The grain-size and magnetic fractions were microscopically examined. The micro components in the water sample were precipitated according to the CdS method. The fractions, the lithogeochemical samples, and the CdS precipitate were powdered and spectrally analyzed. Variation diagrams of the manganese content in the granular and magnetic fractions were constructed. The geochemical background (C_b) and minimum anomalous content (C_{an}) were evaluated by cumulative frequency distribution curves and proved to obey the normal distribution law (C_b = 0.09 percent; C_{an} = 0.15 percent).

Mn distribution in the granular and magnetic fractions indicates that mechanical dispersion of manganese minerals plays the chief role in the formation of dispersion trains and aureoles. The chemical dispersion of manganese (adsorbed on clay minerals) takes place as a very low percent of its total dispersion.

The most effective size fractions of the autochthonous and allochthonous debris were -0.25 to +0.1 mm to -2 to +1 mm in diameter, respectively.

Six dispersion trains related to known occurrences show the feasibility of regional exploration for dispersion trains in the Eastern Desert and the efficiency of the sampling interval used. However, the trains are slightly contrasted due to the sampling of fractions less than 0.5 mm.

The water well contains a high Mn content (100 ppm) relative to other wells situated far from manganese occurrences (0 to 5 ppm).

Five dispersion aureoles are delineated. The largest two aureoles are related to mineralized zones and indicate the efficiency of this method in defining the position of ore occurrences.

EXTRACTION OF CU, ZN, MO, FE, AND MN FROM SOILS AND SEDIMENTS USING A SEQUENTIAL PROCEDURE

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A sequential partial extraction procedure was developed whereby a set of reagents is applied in series in order to estimate the quantity of trace elements associated with specific fractions comprising geochemical samples. Reagents were chosen which maximized selective dissolution of Cu, Zn, Mo, Fe, and Mn associated with individual sample fractions, and minimized heterogeneous release of metals bound in other fractions. Samples of soils, stream sediments, and lake sediments are from three areas on the Nechako plateau, central British Columbia.

Organic matter and sulphide minerals, if present, are dissolved first, using an alkaline solution of sodium hypochlorite (pH 9.5). More than half of the total Cu, Zn, Mo, Fe, and Mn is liberated from most organic-rich samples, but very little of these elements is dissolved from mineral horizon soils, with the exception of Mo which is soluble under alkaline conditions. Easily soluble carbonate minerals are dissolved next in weakly acidic hydrochloric acid (pH adjusted to 3.0), followed by the amorphous Mn oxides (hydroxylamine hydrochloride, pH 2.5). Both treatments commonly release only minor quantities of Cu, Zn, Mo, and Fe. By contrast, the amorphous Fe oxides, dissolved by acid ammonium oxalate (pH 3.5), appear to scavenge 20 to 50 percent of the Cu, Zn, and Mo. Leaching of Cu is shown to be medium dependent, and increases in the sequence: soils<stream sediments<lake sediments, whereas the fraction of Fe in this soil component remains approximately constant at 30 percent.

The crystalline Fe oxide fraction (estimated using sodium dithionite in a citrate-bicarbonate buffer, pH 7.0; followed by a hydrogen peroxide leach to redissolve precipitated trace element sulphides) is an accumulator of Mo, particularly in some lakes. Although often present in twice the concentration of the amorphous fraction, the crystalline Fe oxides apparently scavenge only minor amounts of Cu. Substantial amounts of Cu, Zn, Mn, and Fe are within silicate minerals leached last using a nitric and perchloric acid (4:1) digestion. Metal liberation appears to be a function of the degree of weathering of the medium, being highest in soils and lowest in lake sediments.

Sequential solution of Cu, Zn, Mo, Fe, and Mn appears to depend on composition of the sample, geological environment of the study area, and factors peculiar to individual samples. Practical application of the extraction procedure in mineral exploration is based on its ability to aid in interpretation of the genesis of geochemical anomalies.

FLUID INCLUSIONS AND ISOTOPIC GRADIENTS AS A GUIDE TO ORE AT ELY, NEVADA, U.S.A.

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At Ely, Nevada, U.S.A., the predominantly limestone country rocks intruded by mid-Cretaceous quartz monzonite show the effects of contact metamorphism and metasomatism collectively called the tactite stage. The minerals of the tactite stage, including garnet, pyroxene, wollastonite and recrystallized calcite were subsequently affected by hydrothermal activities, the clay-sulfide stage, during which chalcopyrite, pyrite, magnetite, actinolite, epidote, clay and calcite were deposited. Five concentric zones of alteration in the country rocks were recognized by James (1976). They are, from the contact outward, the garnet-rich tactite, the pyroxene-rich tactite, the silica-pyrite, the wollastonite, and the peripheral zones.

Heating of fluid inclusions allows estimates of the salinity and temperatures of ore-forming fluids. Most inclusions in garnet, pyroxene, and quartz of the tactite stage are of moderate to high density with one or no daughter mineral, and give homogenization temperatures of 450° to 600°C. Inclusions in quartz of the clay-sulfide stage contain up to 42 weight percent NaCl equivalent and have wide range of densities. Some homogenize as a vapor, suggesting boiling, although most of them homogenize as a liquid at temperatures between 250° and 500°C. The minimum fluid pressure during the clay-sulfide stage was estimated at 200 atm based on the fluid inclusion study. Jasperoids derived from oxidization and leaching of silicified mineralized rocks contain highly saline inclusions similar to those of the clay-sulfide stage. Inclusions in this quartz have been protected from supergene effects.

$^{18}O/^{16}O$ ratios of hydrothermal calcite and marble increase systematically from the contact to the peripheral zone, but are mostly higher than the coexisting quartz, suggesting isotopic disequilibrium. Excluding calcite, minerals of different stages have $\delta^{18}O$ values corresponding to the tendency to concentrate ^{18}O under equilibrium conditions. $\delta^{18}O$ values of quartz are 9.1 to 12.8 per mil (%o) (vs. SMOW); of pyroxene, 8.3 to 12.4 %o; of garnet, 5.3 to 8.5 %o; of two actinolites, 7.2 and 7.8 %o; of magnetite, 3.7 to -0.3 %o. Quartz-magnetite pairs give isotopic temperature estimates between 663° and 355°C for the clay-sulfide stage (using the calculated fractionations of Becker, 1971).

The calculated oxygen isotopic composition of waters associated wiht quartz of the clay-sulfide stage in the tactite zone within the Veteran pit shows a regular outward decrease from 10.5 to 7 %o. Mixing of the ore-forming fluid with groundwater may be responsible for this zonal pattern.

The preservation of hypogene fluid inclusions in leached outcrop can be used for recognizing deep-seated mineralization. The zonal pattern of calculated $\delta^{18}O$ values of water found in this porphyry copper deposit may aid in the exploration of similar ore deposits, especially during a detailed study.

URANIUM EXPLORATION USING EFFUSED RADIUM, RADON HALOS, AND MIGRATED BISMUTH

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Radon techniques in exploration are not in favor with industry despite the discovery in 1970 by Morse that radium migrates and that radon can be used for its measurement. The only radon system that has achieved any degree of acceptance is the "Track Etch" system, which measures indiscriminately the ambient radon (migrating rock gas) and evolved radon (a parameter of in situ radium), thus ignoring their respective importance.

By its concentration upon gamma radiation, which is emitted by bismuth 214, industry exposes itself to a high proportion of failures due to the frequent occurrence of two-stage migration preceding its emission, once at the radium stage, and once at the radon stage.

Comparison of relative amounts of the three decay products permits back-tracking along the migration path toward the undiscovered ore. In theory it should be possible to find areal excesses of radon over bismuth and of radium over radon. The system recognizes the value of the relative quantities of decay products and degrades the value of their absolute quantities for exploration purposes.

Examples of radium migration and quantitative methods for exploring both for new orebodies and for extensions of known orebodies are presented.

THE SECONDARY DISPERSION OF TRANSITION METALS THROUGH A COPPER RICH HILLSLOPE BOG IN THE CASCADE MOUNTAINS, BRITISH COLUMBIA

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Abundances of six transition metals and carbon have been studied in a small, hillside, (mineralotrophic) bog close to a known copper mineral occurrence located 29 km northwest of Princeton, British Columbia. An extensive, thin lodgement till almost completely covers the contact zone between porphyry dikes and metamorphosed Triassic volcanics. Previous exploration indicates that the copper mineralized volcanics may extend below the bog.

Mineral soil, organic soil, and till samples have been analyzed by a nitric-perchloric acid digestion and atomic adsorption spectrometry for total copper, cobalt, manganese, iron, nickel, and zinc as well as organic carbon (Walkley-Black technique) and pH. The copper, zinc, iron, manganese and carbon contents and pH in a number of bog water samples were also determined. Polished sections of

heavy mineral separates and dried organic material mounted in epoxy resin were examined under a reflecting microscope. Several of these sections were analyzed for copper, iron, and sulphur by electron microprobe.

Soils with more than 16 percent carbon are enriched in copper, cobalt, zinc, and nickel. Metal and carbon abundances increase with depth especially where organic soil accumulations exceed 3 m. Metal values fall sharply in the underlying till except for a small area in the northwest corner of the bog where the till contains more than 1,000 ppm copper. By contrast, iron and manganese contents are generally greater in the till than in organic soil.

Small spherical pyrite concretions and irregularly shaped grains of chalcopyrite and covellite are visible in heavy mineral separates from organic soil. Copper and iron sulphide textures suggest that minerals were mainly formed during diagenesis of bog sediments, although some grains may have been originally detrital. Microprobe analyses indicate that copper is associated with remnant plant cell structures and is also present as small copper-iron sulphide inclusions in amorphous organic matter.

Subsurface, weakly acid bog waters have high manganese, iron, carbon, and variable copper contents. Surface waters, however, are very acid and have high copper, but low iron, manganese, and carbon levels. Copper may be accumulated from surface water by living bog plants and can also be concentrated with cobalt, nickel, and zinc from mineralized ground water solutions by humic substances. Metal sulphides precipitate when copper and iron are remobilized during diagenesis of organic rich material.

FERROMAGNESIAN MINERAL CHEMICAL VARIATIONS: A NEW EXPLORATION TOOL TO DISTINGUISH POTENTIALLY MINERALIZED AND BARREN STOCKS IN PORPHYRY COPPER PROVINCES

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Major element microprobe analyses are presented for amphiboles and biotites of fresh, unaltered rocks from porphyry copper-mineralized and barren stocks in the southwest Pacific porphyry copper province.

Mineralized and barren stocks are characterized by different mineral chemical variations, a feature not readily apparent in thin section. In barren stocks, amphiboles display variations which are usually considered to be 'normal' for calc-alkaline rock suites (i.e., variable or increasing Fe/Mg from cores to rims of individaul crystals). In mineralized stocks, the reverse trend is observed (i.e. decreasing Fe/Mg toward amphibole crystal rims). Qualitatively similar changes are observed in coexisting biotites from mineralized and barren stocks.

Available evidence suggests that the chemical variations may be attributed to differences in oxygen fugacity (fO_2) in the melts during crystallization: high fO_2 (increasing during crystallization) in those magmatic systems that generated mineralizaton, and low fO_2 in systems that did not generate mineralization. Conditions of high fO_2, possibly related to critical water contents, are appropriate for magmatic systems that have evolved hydrothermal solutions as a final crystallization product.

An exploration strategy is suggested using the above observations. Rapid collection of representative samples from the prospective area is followed by laboratory assessment for mineral assemblages indicative of crystallization under high fO_2 conditions (amphibole + magnetite + sphene), and assessment for the ferromagnesian mineral chemical variations described above. Advantages over other exploration techniques include: (1) sampling of large target areas (plutons, batholiths), and (2) rapid assessment of prospective areas.

The data presented here were obtained from stocks only in the Papua New Guinea region. Preliminary data from the Philippines and the Caribbean support the present conclusions, indicating that the chemical variations are of more than regional significance. It is possible that the technique might be applicable to exploration for other types of hydrothermal ore deposits associated with intermediate to felsic calc-alkaline rocks.

METHODS OF INTERPRETATION AND FOLLOW-UP OF RECONNAISSANCE LAKE SEDIMENT DATA IN THE NORTHERN CANADIAN SHIELD

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The Canadian Federal-Provincial Uranium Reconnaissance Program begun in 1975 has surveyed some 160,000 square miles (414,000 km^2) of the Canadian Shield utilizing center-lake sediment and water sampling at a density of one sample per 13 km^2. In order to assess these data, in terms of their usefulness to the mineral industry as a regional exploration tool, and also to recommend methods of interpretation and follow-up, two detailed programs were carried out in 1976. One program was conducted in the Nonacho Lake area, south of the East Arm of Great Slave Lake, and the other, in northwestern Manitoba along the postulated extension of the Wollaston fold belt.

The paper first discusses methods of interpreting the reconnaissance lake sediment data. These are varied and range from the examination of simple features such as element concentrations and areal extent of the anomalies, to assessing the significance of element associations and performing multivariate statistical analyses. By means of these interpretive procedures areas were selected for field follow-up, and the second part of the paper examines the methodology adopted and some results obtained during this phase. The application of such techniques as detailed lake water, lake sediment, stream and spring geochemistry, overburden geochemistry, lithogeochemistry, and ground and airborne radiometric techniques in follow-up operations are critically assessed in terms of specific surficial and bedrock conditions.

ESTIMATE OF MIXED GEOCHEMICAL POPULATIONS IN ROCKS AT ELY, NEVADA

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The frequency distribution of metal concentrations in altered rock samples from the Ely District in Nevada can best be described as mixtures of lognormal populations. A new method for separating mixtures of lognormal populations has been developed. This method combines a graphical with an analytical approach and is performed in an interactive computer graphics environment. The distributions for copper, lead, zinc, silver, and tellurium in both gossans and jasperoids were found to consist of a mixture of two lognormal populations. In every case, the existence of a single population could be rejected based on a chi-square goodness-of-fit test. This test is made each time a dissection is performed. For each metal the population associated with the lower concentration values is considered as the District background, whereas the population of higher concentration values is considered as the District anomaly. Most metal concentrations are greater in the gossans than in the jasperoids. In view of the arrangement of sampling locations in the study of the District, the mixing fraction for the anomaly population gives a rough measure of the relative areal extent of anomalous ground in the District. Depending on the metal, the mixing fraction ranged from 20 to over 50 percent. The concentration value which best separates the two populations for each metal provides a means of locating the geographic boundary which divides anomalous from non-anomalous ground. The overlap of the two populations as defined by the probability of misclassification also gives an indication of how sharp the dividing boundary might be. For the metals considered, the amount of overlap was generally less than 10 percent probability of misclassification, suggesting that relatively sharp dividing boundaries exist.

In performing the dissections for the Ely data, it was found that a dissection was most readily obtained when the cumulative frequency curve on which the dissection is based was constructed using equal probability intervals with the interval boundaries chosen to fall in the gap between the two nearest reported concentration values. Difficulties in dissection were encountered only when too

few values of too few reporting intervals were used. This new method of dissection has proven to be of invaluable assistance for interpreting mixed populations in geochemical data.

A COMPUTER BASED CARTOMETRIC SYSTEM APPLIED TO GEOCHEMICAL EXPLORATION FOR MINERAL DEPOSITS

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A cartometric analysis system was developed and implemented to test the application of advanced computer mapping and statistical programs in a research project involving geochemical data. The research project (reported in "Regional Geochemical Exploration for Mineral Deposits in Virginia Appalachian Highlands," Sayala/Siegel/Mercready) was based on 425 collected soil and stream samples in an area of Virginia encompassing parts of the Piedmont, Blue Ridge and Valley-Ridge provinces. It was the purpose of the cartometric system to provide for the statistical analysis of the distribution of 11 elements (Ag, Au, Mo, Cu, Pb, Zn, Mn, Fe, Ni, Cr, and Co) in the samples and to create mapped statistical surfaces of this distribution.

The cartometric system was configured to accept as input the results of the chemical analyses. A data base was designed and two separate subsystems were employed consisting of the Statistical Packgage for the Social Sciences (SPSS) distributed by the National Opinion Research Center at the University of Chicago, and the SYMAP program from Harvard University's Laboratory for Computer Graphics and Spatial Analysis.

The data base was configured to provide dual access to both the statistical and mapping programs and eliminate the usual problem of incompatable input strategies. Each sample site represented a separate record within the data base file, and the measurements of the trace elements derived from the chemical analyses comprised the record content for each sample site.

The data base was initially entered in the SPSS subsystem to compute derivitive statistics which, in turn, formed part of the input to the SYMAP program. It was the purpose of the mapping subsystem to compute and output "regional deviation maps" representing sample anomalies, i.e., measurements of elements which exceeded by mean plus two standard deviations, and also to generate polynomial trend surface maps to define the regional distribution of elements related to the probable mineral deposits. For both of these purposes, each sample site was designated as a data point within the SYMAP program. The contouring option, available in SYMAP, was used to create the regional statistical surfaces. To achieve trend surface optimization, maps of first through sixth order were computed for each of the eleven elements under study. Additionally, residual maps were also generated for these same surfaces to compare with the regional deviation surfaces. For the purpose of comparative evaluation of anomalies, separate sets of maps were computed for the different provinces and for the total study area.

The results of this cartometric analysis have considerable significance in mineral exploration. SPSS adapts exceptionally well to regional geochemical data. Similarly, the SYMAP program, which is relatively easy to use and inexpensive with respect to computing costs, is ideally suited to regional deviation and trend surface mapping. Since this is the first intensive application of SYMAP in mineral exploration, certain inadequacies in the program were uncovered. It is possible to work around these problems and action will be initiated to have the program modified to enhance its application in this field.

GEOCHEMICAL EVIDENCE FOR THORIUM AND ASSOCIATED ELEMENTS IN NORTHERN SONORA, MEXICO

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The United States Geological Survey, in cooperation with the Consejo de Recursos Minerales de Mexico, conducted a regional geochemical exploration study in northern Sonora as part of an interdisciplinary mineral-exploration investigation undertaken to develop new mineral-exploration techniques and apply them to the Sonoran environment. The investigation was designed to sample washes draining exposed or thinly covered bedrock in a 15,000 km2 strip of land extending from the U.S.-Mexican border (centering on Nogales) southeastward through Cananea and Nacozari to the vicinity of Villa Hidalgo (Oputo). Included in this report are emission spectrographic analyses of two sampling media: a minus-0.18-mm stream-sediment sample and the nonmagnetic fraction of a panned-concentrate sample.

A multivariate 10-factor-analysis computer program was applied first to a matrix of 1,267 stream-sediment samples analyzed for 31 elements and second to a matrix of 951 nonmagnetic panned-concentrate samples analyzed for 31 elements. One of the factors derived from both sample media included thorium, yttrium, lanthanum, scandium, niobium, and tin.

This predominantly rare-earth-element assemblage generally occurs in a belt approximately 50-km wide, which extends from the northwest corner of the region that was sampled southeastward to the vicinity of Nacozari. The geographical distribution of results for thorium, yttrium, lanthanum, and tin, obtained from the analyses of stream-sediment samples, indicates at least four separate anomalously high areas in the region studied. However, the geographical distribution of results showing anomalous scandium and niobium from stream-sediment samples suggests a more extensive distribution of the rare-earth assemblage. Results for thorium, yttrium, lanthanum, and tin obtained from the analyses of the nonmagnetic fraction of the panned-concentrate samples show the same extensive geochemical distribution pattern delineated by stream-sediment scandium and niobium and also accentuate and better define the areas of high rare-earth concentration.

Thorium and uranium determinations obtained by neutron-activation analysis of some selected stream-sediment samples show an approximately seven to one ratio of thorium to uranium. The host thorium mineral has been isolated and identified as thorite.

The belt of rare-earth-element assemblage in northern Sonora may have thorium and uranium resource potential; thus, the region warrants further study. In addition to whatever potential the belt may have for uranium and thorium deposits in crystalline rocks, the occurrence of a high thorium and uranium content in sediment samples from some of the streams suggests the possibility of local concentrations of detrital thorium and uranium minerals that could have more immediate economic potential.

FLUORINE AS A DIRECT INDICATOR IN A LOCAL SOIL-GEOCHEMICAL SURVEY IN THE HUMID TROPICS--A CASE HISTORY

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Application of fluorine as an indicator element in mineral exploration is a recently developed geochemical tool which has been successfully employed in temperate regions and glaciated terrains for regional- and soil-geochemical surveys (Kesler et al., 1973; Schwartz and Friedrich, 1973; Lalonde, 1974). This paper illustrates its use as a direct indicator in a local soil-geochemical survey, a test case in the humid, tropical parts of India. The investigation has been carried out by the author in the Chandidongri mineralized area (21°05'N:80°38'E), which is a part of the Dongargarh Precambrian belt. The mineralization, up to 6 m thick, consists of quartz-fluorite with minor lead-zinc sulphide association and is confined to a steeply inclined shear zone (Kotnapani fault) within Dongargarh granite. The deposit has a total strike length of 300 m and has been quarried in two blocks, each about 100 m long with average grades of 16 percent, and 25 percent CaF_2. The outcrop of the mineralized zone is marked by gossan and low hummocky relief in otherwise flat country with a mean elevation of 350 m above m.s.l.

Dispersion of fluorine has been studied in residual B-soils and gossan horizons across the mineralized zone, taking samples at 8-15 m intervals along a traverse. The local background has been established from orientation survey samples as well as by graphical methods.

Fluoride content has been determined by the potentiometric method of Van Loon and others (1968), using a specific ion sensing electrode and TISAB reagent. Ion concentration has been measured by direct potentiometry in preference to a spiking method alternately known as Gran's Plot or the standard addition method, to save time. Potential differences were read from an ordinary pH meter (Beckman-Zeromatic II). The lowest detectable limit of fluoride obtained with this arrangement was 50 ppm. The low sensitivity of the instrument restricts its use to the determination of total fluoride in the samples. Analysis was carried out by the Central Chemical

Laboratory, Geological Survey of India. Analytical procedure is rapid and low cost.

The values obtained agree with the field observations and pinpoint the mineralization as a sharply defined anomaly over 40 times the local background (360 ppm). A higher anomaly is certain to have existed over the quarried sections of the lode zones. Another anomalous zone has been detected by this method in an extension of the area which is under further study. The data indicate the promising aspect of the technique as a direct indicator.

DEVELOPMENT OF HYDROCHEMICAL METHODS OF EXPLORATION FOR URANIUM, TUNGSTEN AND MOLYBDENUM MINERALIZATION, TOMBSTONE BATHOLITH, YUKON, CANADA

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The Tombstone batholith, a Cretaceous alkaline intrusive complex composed of a syenite-monzonite core and a tinguaite border phase is host to 'porphyry-type' uranium mineralization in association with disseminated tungsten and molybdenum in the Selwyn Fold Belt of the central Yukon Territory. Vein-type Pb-Zn-Ag mineralization is also localized within quartzites near the southern contact of the batholith.

As part of an extensive uranium reconnaissance program and orientation work, integrated geological and geochemical studies of the batholith were undertaken utilizing rocks, stream sediments, and waters, with the objective of investigating physical and chemical processes affecting primary and secondary (dominantly clastic) dispersion in an Alpine glaciated high latitude environment in the Canadian Cordillera.

Samples were analyzed for a suite of elements (and in the case of stream waters, anionic species) that were considered necessary to understand the nature of the interaction among stream waters, sediments and rocks, particularly for streams draining known mineralization. Results to date demonstrate that U, Mo, F, Pb and W anomalies are associated in certain cases with uranium mineralization, reflected as extensive dispersion trains in stream sediments and waters. The dominant dispersion process in stream sediments seems mechanical, whereas in stream waters there is a significant hydromorphic component, although it is not very apparent how important is the chemical exchange at the stream sediment-water interface.

GEOCHEMISTRY OF PLATINUM-ENRICHED SEDIMENTS OF THE COASTAL BERING SEA

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Alluvial deposits of Pt have been mined in the Salmon River Valley district of Alaska since 1934. The source of the Pt is Red Mountain, an ultramafic mass located along the Bering Sea coast between Goodnews Bay and Chagvan Bay. Recent studies have shown that Pt enrichments aove background levels also exist in the surficial sediments of Chagvan Bay. These known offshore deposits were used in this study as a test site for investigations aimed at improving marine exploration techniques. Surficial sediment samples recovered from Chagvan Bay were divided into two groups based on their Pt content: a background group (Pt <0.01 ppm) and an anomalous group (Pt >0.01 ppm). All samples also were analyzed for grain size distribution and for various heavy metals (Co, Cr, Cu, Fe, Mn, Ni, V, and Zn). An R-mode principal components analysis was then determined on the data from each sample group and, by comparing the results of these statistical analyses, it was possible to identify key geochemical relationships which could serve as exploration clues. The dominant factor controlling the distribution of heavy metals in both the background and anomalous sample groups is the mineralogy of the land-derived lithogenic material, which is composed of detrital fragments of dunites and diorites and individual grains of quartz and feldspar. Platinum enrichments occur in both coarse-grained (>0.06 mm) and fine-grained (<0.06 mm) sediments in the Chagvan Bay area. The coarse-grained, Pt-enriched detrital fragments are similar in composition to the dunites of Red Mountain, while the fine-grained particles are associated with bay muds and occur where the Kinegnak River and other smaller streams enter Chagvan Bay. Statistical correlations exist between certain transition elements (Mn, Ni, V, and Zn) and Pt-enrichments in the coarse-grained fraction of the sediments. These correlations are best suited for identifying depositional environments where conditions are favorable for the formation of high-energy placers, but are unsuitable for low-energy placers. An empirical relationship exists between Zn (>135 ppm) and Pt which can be used as an efficient indicator of Pt enrichment in both coarse-grained and fine-grained sediments. Moreover, the distribution of samples containing Zn >135 ppm suggests that unexplored areas to the east and south of Chagvan Bay may be mineralized and, further, that the Pt-enriched bay muds are probably derived from these areas rather than the Salmon River Valley, as was previously believed.

UNDERWATER GAMMA RAY SCINTILLOMETRY: ITS USES AND LIMITATIONS AS A URANIUM EXPLORATION TOOL

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In order to evaluate the uranium potential of lake-covered areas in northern Saskatchewan, a system was developed that could determine the bottom radioactivity. Basically this system, designated LBL-1 - lake bottom logger, consists of a probe dragged along the bottom plus associated electronics on a surface vessel. The probe contains a 922 cm^3 thallium-activated sodium iodide crystal (NaI(Tl)) as the radiation sensor plus a current and two potential electrodes to measure the electrical resistivity of the bottom. On the surface, a four-channel spectrometer (total count, K, U, Th) and resistivity multiplex direct the information from the probe to a six-channel analogue recorder. Navigation and water-depth information is recorded separately and is synchronized with the geophysical parameters. The LBL-1 was found to generate signals indicating two types of anomalies. The first, of a high amplitude, high frequency variety was caused by the presence of highly radioactive float in the vicinity of the probe. The finding and positioning of these anomalies is of great advantage to the exploration process in glaciated terrain. The second type of response is of a low-amplitude low-frequency nature and is far more difficult to interpret. The present study shows that these fluctuations are only remotely related to the abundance of uranium in the bottom material. The following factors are thought to be the main reasons for the observed disparity: (1) sediment samples represent discrete localities while LBL-1 data are derived from averaging up to 0.2 m^3 of materials; (2) sediment sample sites never coincide exactly with the track of the "eel" as it is pulled over the lake bed; (3) the geometry of the lake sediment with respect to the radiometric sensor is variable because of the different depths to which the sensor sinks into the sediment; (4) uranium values are quoted as ppm on a w/w basis whereas a w/v basis may be more applicable for comparison with data from the sensor which responds to a relatively constant volume; (5) much of the uranium in the sediments is hydromorphic and therefore not in radioactive equilibrium with its daughter products. It is concluded that the LBL-1 system has application in tracing submerged mineralized boulders. However, general radiometric mapping of lake sediments is not feasible because of the difficulty in quantifying the effects of the five interfering factors.

THE RED-CHRIS PORPHYRY COPPER-GOLD DEPOSIT, NORTHWESTERN BRITISH COLUMBIA--A GEOCHEMICAL CASE HISTORY

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The Red-Chris deposit comprises two or more discrete zones of moderate to intense quartz vein stockworking carrying pyrite, chalcopyrite and rare bornite, with low but consistent gold values. The mineralized zones occur within an elongate, highly altered sub-alkalic monzonitic sub-volcanic pluton of mid-Mesozoic age emplaced into volcanic and volcaniclastic rocks of the upper Triassic Takla Group. Much of the mineralized system, including all of the area where reserves have been delineated, is covered by a thin (2-10 m) veneer of dark clay-rich till, containing rounded pebbles and cobbles of terrigenous clastic rocks of the Jurassic Bowser Lake Group. Lying above this till unit is a thin layer (50 cm average) of black organic soil, almost exclusively water saturated.

Stream-sediment sampling yielded highly anomalous results where the mineralized pluton is dissected by deep stream gullies, but where little copper-gold mineralization has been exposed. Swampy drainages from the delineated reserve zones yielded silt samples with only low copper values. Conventional surface soil sampling showed a similar pattern, with high copper values where altered bedrock is exposed, and only very spotty anomalies over more strongly mineralized but till-covered areas. A limited program of hand auger sampling, to a depth of approximately 1 m, gave results which were no better than those gained from surface sampling.

Sampling of till profiles exposed in the walls of bulldozer trenches suggests that the till has effectively blocked upward migration of high geochemical values from the bedrock surface. The till-bedrock interface is very sharp, and there seems to be no more than 30 cm upward migration of copper values. A comprehensive survey was undertaken using a hand-held gasoline powered drill to collect samples from the bedrock surface. Several hundred samples were collected, and the -10 mesh fraction was analyzed.

The results of this work are most gratifying. Two basic anomaly types are present, with values ranging up to well in excess of two orders of magnitude above background. The anomaly patterns correspond very well with the outlines of the two reserve zones. The anomaly over the main or lower-grade dispersed zone is large and subcircular with relatively gently sloping sides, and the second anomaly, over the narrow, high-grade East zone is narrow, linear, and very sharply defined. Neither anomaly shows any significant evidence of lateral migration.

MERCURY IN SOILS AS AN INDICATOR OF GEOTHERMAL ACTIVITY: YELLOWSTONE NATIONAL PARK, WYOMING

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To further investigate the use of Hg as a tool for geothermal exploration, we have undertaken a detailed study of the occurrence of Hg in soils from the geothermal systems in Yellowstone National Park. Soil was collected from the A soil horizon at 5 to 10 cm depth, sieved and the -80 fraction retained for analysis. Mercury concentrations were measured in nearly 1,000 soil samples using a portable thin gold film detector. Initially, samples were collected at a 1.6 km (1 mile) interval along the road system and major foot trails in order to obtain an overall pattern of the Hg distribution in soils throughout the Park. In addition, samples were collected at 50 m intervals along traverses within the Norris Geyser Basin, Mammoth Hot Springs, and Mud Volcano area. Samples were also collected from the Upper, Lower, West Thumb, Shoshone, and Heart Lake Geyser Basins.

Initial results show background levels of 20-30 ppb in soils from non-geothermal areas with very high concentrations (>500 ppb) occurring in the immediate proximity of thermal features. Background levels are comparable inside and outside the Yellowstone caldera. The 1.6 km sampling interval was not sufficient to detect the presence of the ring fracture system marking the caldera edge.

Anomalous Hg concentrations were found in soils from all thermal areas investigated, although the concentration and distribution of Hg varies from basin to basin. Results from the Norris and Upper Geyser Basins show an irregular distribution of Hg, whereas the anomalous Hg values from the vapor-dominated system of the Mud Volcano area contour around areas of major vent activity. Mercury concentrations in soils from the travertine-depositing Mammoth Hot Springs are significantly lower and anomalies are more localized than those from any other of the major hot spring or geyser basins that we studied in the Park.

All investigated thermal areas in Yellowstone exhibit narrow anomalies extending outward only a few hundred meters from the surface expression of the geothermal system. In addition, anomalous Hg concentrations with no apparent associated hot spring activity were found at two localities. These anomalies are narrow with high peak to background ratios (50:1), consistent with the character of the anomalies found associated with hot spring activity in Yellowstone. The anomalous areas possibly indicate places of incipient thermal activity.

Although the data are prelminary, the lack of broad anomalies suggests that, at least in Yellowstone, a 1.6 km sampling interval used alone may be too large to successfully carry out a regional exploration program. However, the data do show that Hg geochemistry can be used as a pathfinder for geothermal activity, but that it is necessary to alter the sampling interval according to the local geologic framework.

COMPUTER ESIMATION OF DEPOSIT PRODUCTIVITY BASED ON GEOCHEMICAL SAMPLING OF THE DRAINAGE BASIN

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Geochemical anomalies related to ore deposits are often easily observed in stream sediments and water. But their assessment is often difficult because the productivity (size and grade) of a deposit is only one of the factors influencing the magnitude of an anomaly formed in stream sediments or water. Other important factors are: size of stream basin, stream-dynamics, fraction-phase transitions as a result of mineral fragmentation, aggregation, solution, and deposition from solution.

Available estimation methods (A. P. Solovov, H. E. Hawkes) consider the contrast of the anomalies and the size of the stream basins; Solovov also makes a correction for local slopes. Our earlier proposed formula also includes a stream dynamics factor. The new mathematical model is for automatic data processing of geochemical stream samples which includes making maps of the calculated productivity of deposits based on their geochemical anomalies. The basis for the productivity determination is an equation expressing the ideas of mass balance and stream kinetic processes:

$$\frac{1}{k'} \cdot \frac{\Delta P}{\Delta x} = \underline{a}(C \cdot C_b) + \frac{\Delta (BP')}{\Delta x}$$

where P = deposit productivity (metal quantity per unit depth)
C = element concentration at the sampling point
C_b = element background concentration
P' = dispersion train productivity (a product of the element concentration above background and the area of the upper stream basin; $P' = (C-C_b)F$, where F is the area of the upper stream basin)
Δx = sampling interval
$\underline{a}$ = an element accumulation coefficient
B = an element loss coefficient
k' = a computed productivity coefficient

The area of the stream basin is thus a component of P', the dispersion train productivity; stream dynamics and the hydraulic characteristics of the carried matter are components of $\underline{a}$ and B, the accumulation and loss coefficients. Fraction-phase transitions are also a characteristic component of $\underline{a}$, the accumulation coefficient. The equation is good for various granulometric and mineralogic fractions of a solid aggregate, and, to a major extent, for waters.

The equation has a two-step usage. First, in the dispersion trains where there is no deposit ($\Delta P = 0$), we define the values of the coefficients $\underline{a}$, B, and the gradient $\Delta B/\Delta x$. The dispersion trains are taken to be areas of a lower concentration C, or more precisely, as productivity P'. Then, by using the found coefficient values, we can define the values of $[1/k'] \cdot [\Delta P/\Delta x]$ for the entire surveyed area. An IBM computer automatically plots $[1/k'] \cdot [\Delta P/\Delta x]$ values; this shows the distribution of the ore-bearing areas and their specific productivity per unit of stream length. The total productivity of the ore-bearing areas P, is taken as the sum of ΔP and is also given on the maps.

As the value of the coefficient k' is unknown, ΔP and P are given numerically, without an assigned monetary value, in order to compare the productivity of different areas and select the most favorable areas for further work. If one of the surveyed deposits can be assigned a monetary value P, we can find the monetary value of all other deposits of this type.

By summing the productivity P of all the stream basins present, we can calculate the total productivity of the studied territory and also classify resources by type, size, and distribution of deposits.

Examples are given that show the method to be useful.

NURE GEOCHEMICAL INVESTIGATIONS IN THE EASTERN UNITED STATES

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The Savannah River Laboratory (SRL) is conducting a hydrogeochemical and stream-sediment reconnaissance of the eastern United States as part of the National Uranium Resource Evaluation (NURE) program of the United States Department of Energy (DOE). An extensive development program is underway to provide field techniques and interpretive models for the reconnaissance survey. Manuals for subcontracted sample collection, based on SRL development work, have been published. SRL reports, together with information developed by other DOE subcontractors, will be used to define areas for detailed resource appraisal. All NURE program information will be released to the public by the Grand Junction, Colorado, office (GJ) of DOE. In addition to their value in minerals exploration and resource appraisal, these reports will provide an environmental data base of unprecedented scope.

Stream samples are collected at a density of one per 13 km^2 in crystalline rock areas and 20 km^2 in sedimentary rock areas. Stream sediment (-40 mesh) is taken at each site and stream water is concentrated on ion exchange resin in some areas. Ground water samples are collected at an average density of about one site per 20 km^2.

Measurements made at each site include alkalinity, pH, and conductivity of water. Dissolved ions are recovered quantitatively in the field from one liter of water with ion exchange resin. Sample preservation problems are avoided by this method.

Measurements of the radon and helium contents of ground water samples were made on a semi-regional scale in pilot studies.

Samples are analyzed at SRL by neutron activation techniques. Concentrations of uranium and about 20 other elements are determined quantitatively in concentrated water samples. Automated pneumatic transfer of samples and automated data processing permit analysis of up to 4,000 samples per week.

Results from several orientation studies are discussed including: a Triassic Basin area near Sanford, North Carolina, the North and South Carolina Coastal Plain; and from reconnaissance studies in the Carolinas-Virginia Piedmont and Blue Ridge areas.

In the Sanford Triassic Basin Area, uranium content averaged 0.035 ppb in ground water from the organic-rich Cumnock Formation and 1.8 ppb in the arkosic Pekin Formation. Tuffaceous metavolcanics in the adjacent Carolina Slate Belt yielded water averaging about 0.1 ppb U.

Studies in the Carolina Piedmont and Coastal Plain and near Chattanooga, Tennessee, include helium, He/Ne, and radon determinations in ground water. Background helium contents average about 5 ppm of the total dissolved gas; anomalous samples range up to about twenty times background. Determination of ^{22}Ne simultaneously with ^{4}He compensates for instrument drift and sample collection variations.

During the next several years, an extensive data base will be established and published for elemental concentrations in stream sediment and surface and ground waters over much of the United States.

Development is in progress in field methods, analytical methods, data management, interpretation of geochemical data, and use of regional and semi-regional geochemical data in resource appraisal.

USE OF SELECTED ELEMENTS TO STUDY HYDROTHERMAL ALTERATION-MINERALIZATION OF A PORPHYRY MOLYBDENUM PROSPECT, BRECKENRIDGE MINING DISTRICT, COLORADO

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Mapping in the eastern Breckenridge mining district has identified a middle Tertiary intrusive complex of rhyodacite porphyry, intrusive breccia, and explosion breccia in an area mapped previously as quartz monzonite and monzonite porphyry. Pervasive hydrothermal alteration ranges from phyllic and argillic in the center of the complex to propylitic around the margins. The age, composition, and multiple nature of the intrusive activity, the pervasive alteration, the presence of base- and precious-metal mineralization in the surface rocks, and the proximity of the complex to known molybdenum occurrences, suggest that porphyry molybdenum mineralization may exist at depth.

To test this hypothesis, and to provide information on the intensity and timing of mineralization within the complex, 44 rock-chip samples of monzonite, quartz monzonite and rhyodacite porphyry were analyzed for Rb, Sr, K_2O, CaO, Na_2O, Mo, Cu, Pb, Zn, Ag, and Au. Ten samples of intrusive breccia and explosion breccia also were analyzed for Mo, Cu, Pb, and Zn.

Contoured dispersion patterns for Rb, Sr, K_2O, CaO, and Na_2O clearly reflect alteration zonation within and about the intrusive complex. Rb and K_2O increase consistently into the region of phyllic and argillic alteration, and Sr, CaO and Na_2O demonstrate the reverse trend, increasing in value toward and into the region of propylitic alteration. Maximum values for the ratios Rb/Sr (>25), K_2O/CaO (>50), and K_2O/Na_2O (>50) occur in the area of most intense phyllic alteration.

Contoured data for the heavy metals, except for molybdenum, also are centered directly on the intrusive complex. Maximum values for copper (>1,000 ppm), lead (>2,000), zinc (>2,000), silver (>10 ppm), and gold (>0.5 ppm) occur within the region of most intense phyllic alteration. Molybdenum is sporadically distributed; however, maximum values (>10 ppm) occur within the phyllic-argillic zone. The low concentrations suggest that, if present in significant quantities, molybdenum was precipitated at depth within the higher temperature environment.

Comparison of metal contents versus rock types indicates that mineralization with respect to Cu, Pb, Zn, Ag, Au, and perhaps Mo, probably began during or shortly following emplacement of the rhyodacite porphyry and the associated intrusive breccia. Metal enrichment also within the explosion breccia, which postdates the intrusive breccia, indicates further that mineralization within the complex occurred in more than one pulse. The multiple nature of the mineralizaion, coupled with element dispersion patterns that are centered upon the intrusive complex, suggest that porphyry molybdenum mineralization may be present at depth within the complex.

APPLICATION OF TRACE ELEMENT GEOCHEMISTRY TO PROSPECTING FOR SANDSTONE-TYPE URANIUM DEPOSITS

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We have looked for patterns of zoning in the distribution of a number of alkaline earths, transition metals, and several actinide and lanthanide series elements (Lee, 1976; Riese, 1977; Brookins et al., 1977) with the intention of delineating previously unrecognized elemental (or mineralogical) zonation patterns which would be of use to the explorationist. Our analytical methods were selected with regard to their accuracy, their precision, their speed and facility, and their cost, as well as for providing data for genetic models.

Our results show that there are exploration alternatives to the models of Harshman (1970) and Rubin (1968); there are a number of trace elements in addition to iron that are useful as exploration tools. Of particular interest are thorium and multivalent lanthanide series elements. Ratios of Ce/U and Th/U are useful pathfinders in uranium exploration. Absolute abundances of molybdenum, titanium, and barium are also useful in closer proximity to orebodies. The utility of nickel, chromium, and cobalt has not yet been fully evaluated.

In addition, clay mineral zoning provides a useful tool for explorationists, showing a variation in mineralogy from montmorillonite in front of the ore, to chlorite in ore zones, and finally to kaolinite behind. The relationship of this paragenetic sequence to trace element chemistry is still being worked out.

Carbon as present in organic materials shows a direct correlation with uranium in terms of its abundance. This variation shows up in analyses of whole-rock samples and is not enhanced in analyses of the -2μ size fraction. Total carbon as present in organics does not show any appreciable variation at any distance from ore, and is not useful for exploration.

PARTITIONING OF COPPER, ZINC, AND LEAD IN SOIL OVERLYING A BASE-METAL SULFIDE DEPOSIT IN EASTERN GEORGIA

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Sphalerite-galena-chalcopyrite mineralization at the Chambers prospect is detectable in the minus 80 mesh fraction of near-surface soils. Drilling in the area has shown that an intense copper, zinc, and lead soil anomaly is directly underlain by an intersection of 33 feet of 3.7 percent zinc with traces of copper and lead. Soil profiles from the anomaly and a nearby background area of trace metal concentration were separated into 42 subsamples, each representing a unique combination of grain size and depth. The concentrations of copper, zinc, lead, and individual mineral phases in the profiles are delineated on size-depth isopleth diagrams.

In the profile from the anomaly (CA), copper and zinc are concentrated in sand-size fractions at maximum profile depth (2.59 m); lead is concentrated in clay-size fractions of the B horizon. In the background profile (CB) lead is concentrated in sand-size fractions; copper and zinc concentrations display no trends with either grain size or profile depth.

A series of selective leaching extractions and analyses of monomineralllic fractions were utilized to establish trace metal partitioning between various soil constituents in profile CA. Iron oxide-hydroxide grain coatings are significant residence sites of copper, zinc, and lead. Organic material and surface adsorbed ions account for only small proportions of the total trace metal concentrations. Primary and secondary residual minerals are also important residence sites of trace metal in profile CA.

Comparing the size-depth distribution of copper and zinc in the two profiles shows that maximum anomaly constrast is exhibited by sand-size fractions at the bottom of profile CA. For lead, clay-size fractions at mid profile depths (B horizon) give the best anomaly discrimination.

RADON IN NATURAL WATERS AS A GUIDE TO URANIUM DEPOSITS

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Radon^{222}, a daughter in the radioactive decay of U^{238}, has potential as a pathfinder for uranium deposits because of its very high mobility and its ease of determination. A disadvantage is its short half-life (3.8 days). Although a great deal of work has been done on radon in soils as an ore guide, only a few studies of radon in stream and ground waters have been made. The purpose of this project, which was supported by the ERDA, was to test the use of radon in stream and ground waters near sandstone-type uranium prospects in northeastern Pennsylvania and to evaluate the causes for variations in the radon contents of natural waters.

The direct parent of Rn^{222} is Ra^{226} (half-life 1600 yr), which is relatively soluble in water but is strongly sorbed to Fe oxides, as confirmed by measurements on samples near the Pennsylvania prospects. Most natural waters contain far more radon than can be formed from their dissolved radium, so the source of the radon is inferred to be leakage or emanation of radon from radioactive decay of radium in solids encountered by the water.

Radon in 150 samples of well and spring water is anomalously high near deposits in Pennsylvania. Some of the samples anomalous in Rn are not anomalous in dissolved uranium. Using the newly designed radon detector (Allen, 1976), measurements can be made in the field in about 15 minutes and used immediately in follow-up. Temporal variations and sampling problems were investigated and found to be relatively minor. A model has been developed relating radon content of ground water to uranium in the rock, the emanation coefficient of radon from the rock, and porosity. Extensions of the model to evaluation of water from exploration drillholes have also been made.

Rn is added to surface waters mainly by inflow of Rn-rich groundwater into streams and lakes. The radon is degassed from the water over distances of a few tens to hundreds of feet, so that anomalies are very short and reflect locations of influx of ground water rather than uranium mineralization. Calculations and measurements of emanation of Rn from stream sediment demonstrate that Rn added to stream waters from sediment is negligible. Measured radon contents of stream waters near the prospects confirm the lack of usable anomalies in stream waters.

BROWN ALGAE: A SAMPLING MEDIUM FOR PROSPECTING FJORDS

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In certain parts of the world, heavy growths of marine brown algae (seaweed) cover the bare rock and boulder beaches of the coast line. In fjords supplied by rivers polluted with heavy metals, the brown algae can accumulate up to several hundred ppm of copper, zinc, and cadmium. It is possible, therefore, that the heavy metal content of brown algae from unpolluted fjords may reflect the natural heavy metal status of the upland drainage. If this is so, chemical analysis of brown algae could be used as a prospecting method of special interest in countries with long inaccessible coast lines such as Canada, Chile, Greenland, New Zealand, and Norway. An introductory study aimed at evaluating this potential has been performed in Norway.

Ascophyllum nodosum, a ubiquitous species which is easy to collect, was sampled and analyzed for heavy metals. The work shows that with increasing age the plant accumulates V, Mn, Fe, Co, Ni, Cu, Zn, Ag, Cd, and Pb but not Mo, Ra, or U. Preliminary data in the Trondheim area indicate that high values of Cu, Mo, and U may originate from ocean water; V, Fe, Co, Zn, and Cd from fresh water; and Ni from the local substrate while the origins of Mn, Ag, and Pb are in doubt.

As a part of the development effort, a reconnaissance survey was made of the unpolluted Tosen fjord which lies on the western coast of Norway about 150 km south of the Artic circle. Anomalies of Cd, V, Zn, and to some extent Ni, Cu, and Pb were found associated with several of the drainage basins along the fjord.

GEOCHEMICAL INDICATORS FOR THE EVALUATION OF GRANITE PEGMATITES

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Preliminary evaluation of pegmatites by taking small samples is common in exploration programs. It is most difficult to evaluate pegmatites containing minerals difficult to identify (pollucite, amblygonite, etc.) or microconcentrations of valuable minerals (tantalite, wodginite, microlite). An inexperienced prospector cannot even discriminate muscovite of high quality from widespread noncommercial pegmatite micas. The solution of such problems is facilitated by using geochemical indicators.

Geochemical studies of pegmatites in recent years have shown an essential difference in trace element contents between different types of pegmatites. Pegmatites of the same type but from different regions (Siberia, Karelia, India, U.S.A.) are very similar in geochemical characteristics.

The most characteristic indicator for muscovite pegmatites is Ba; its average content in pegmatite bodies of intrusive muscovite pegmatites from different regions is 0.2-0.4 percent. The host mineral of Ba is K-feldspar (Kfs). Early generations of Kfs contain as an average 0.3-0.8 percent Ba and a maximum of 3-4 percent Ba. The Ba contents of other potash minerals, biotite and muscovite, are increased too.

The rare-metal pegmatites have elevated contents of rare alkalies, Nb, Ta, etc., but concentrations of Ba are lower. Host minerals of Rb, Cs, and many other trace elements are again Kfs and micas. For instance, Nb contents in these minerals average 0.2-0.8 percent and sometimes up to several percent.

The concentrations of some trace elements in K minerals can be used for the identification of commercial pegmatites. Because of differences in element contents between the mineral generations, only comparable generations must be used. The earliest and the most convenient generations are the Kfs of graphic intergrowths, muscovite from quartz-muscovite aggregates and large, tabular biotite crystals.

The Ba:Rb ratio in potash minerals is a useful geochemical indicator for characterizing pegmatites. Its value may vary by two to three orders of magnitude. Also, pegmatite micas are well distinguished by the value of the Ti:Nb ratio. The largest values of these ratios are found in muscovite pegmatites, but minimal ones in rare-metal types. Intermediate values of Ba:Rb and Ti:Nb ratios are characteristic of noncommercial rare-metal muscovite pegmatites as well as other less well defined varieties.

The accessibility of small-size monomineralic samples (including fragments of minerals in loose sediments) together with the speed and good quality of modern analytical methods allow us to use these geochemical indicators of pegmatite type as a standard evaluation method. After the similarities of element levels in minerals of any region are defined, we can use the geochemical indicators in all areas of pegmatite occurrence.

DATA EVALUATION WITH MULTIVARIATE STATISTICAL METHODS OF MULTI-ELEMENT ANALYSES OF HARD ROCK SAMPLES FROM A CONCEALED STRATIFORM DEPOSIT

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In a geological target area of stratiform, synsedimentary Pb, Zn, Cu-deposits covering about 10,000 km^2 several attempts have been made to find another deposit. The area is within the Devonian/Carboniferous Variscan Zone in the Federal Republic of Germany.

Water, stream-sediment, and soil sampling have been unproductive methods in this special situation of geochemical exploration work. Of those 27 elements which are named below only the correlation of Ba and Sr in soil samples could be used to decide between ore and non-ore horizons. The concentrations of all other elements have been so homogenized within the secondary dispersion, that no differences were detectable, not even with cluster, factor or discriminant analysis.

Geochemical investigations within the Meggen ore body have shown that samples from the hanging wall and the footwall cannot be distinguished from each other. Nevertheless, a lateral change in the chemical composition of the ore can be shown. As and Sb sharply decrease toward the rim of the ore body, whereas Ba increases. With discriminant analysis, samples from the center of the ore body may be distinguished from those of the outer zone.

An attempt has been made to trace this lateral change in chemical composition beyond the ore body so as to recognize a larger geochemical halo suitable in exploring for concealed or deeply buried synsedimentary stratiform deposits.

More than 200 hard rock samples were analyzed for the following 27 elements with X-ray fluorescence analysis (XFA): SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, Na_2O, P_2O_5, Ba, Ce, Co, Cr, Cu, La, Mn, Nb, Ni, Pb, Rb, Sc, Sr, Th, V, Y, Zn, and Zr.

With discriminant analysis and after several alterations which take into consideration mathematical refinements, finally a central group of 28 samples emerged which lies exactly over the deposit, spreading 7 km along the direction of strike and 2 km perpendicularly across it. The other samples divided into two groups which bound the deposit on all sides.

So a halo of up to 2 km could be detected, whereas the ore containing layer itself is not more than 8 m thick. Therefore, with discriminant analysis for every new sample out of the target area, the probability of the sample's relationship to the central ore group can be calculated. We now have a tool for geochemical exploration work on a larger scale, for this type of deposit, using only one to two hard rock samples per 1 km^2.

GEOCHEMICAL INVESTIGATION OF THE CLYDE RIVER ZINC PROSPECT, LANARK COUNTY, ONTARIO

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The Clyde River Zinc Prospect is located near the village of Hopetown some 80 km east of Ottawa in Southern Ontario. The zinc mineralization occurs as sphalerite bands in dolomitic marble within the Grenville Province of the Canadian Shield.

The prospect area is mantled by glacial till which generally does not exceed 7 m in thickness; however, there is a swamp within the area which in underlain by an unknown thickness of glaciolacustrine clay.

The presence of zinc mineralization was not known until 1975 when several sphalerite-bearing boulders were observed within piles of rocks cleared from the land during settlement of the area in the nineteenth century.

A soil survey was carried out in an attempt to locate the source of the mineralized float. B-horizon samples were analyzed for zinc, and a strong anomaly extending for some 400 m up-ice from the boulders was detected; some other smaller anomalies were also outlined. Several short holes were drilled to test these anomalies but no significant mineralization was intersected.

A series of trenches was then dug close to the up-ice terminations of the anomalies and samples of basal till and bedrock collected. Zinc distribution in the basal till was used as a guide to further trenching; this led to the discovery of three zones of mineralized bedrock of a tenor similar to that of the float.

In the swamp the overburden was found to consist of 0.5 m of organic-rich soil underlain by an unknown thickness of glaciolacustrine clay. The zinc content of the clay is uniformly low but several anomalous zones occur in the organic-rich layer. These anomalies are believed to be of hydromorphic origin and to be related to the presence of mineralized marble on the higher ground nearby.

Analysis of bedrock samples showed that sphalerite-bearing marble bands contain anomalous concentrations of mercury. The distribution of mercury in till profiles overlying such bands was compared with that in till over barren rock to investigate the possible usefulness of mercury analysis as a prospecting tool; the results suggest that it is not a reliable guide to the presence of concealed mineralization in this environment.

THERMOLUMINESCENCE AS A POTENTIAL URANIUM PROSPECTING TOOL

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Studies of sandstone from a south Texas roll-type uranium deposit indicate that thermoluminescence (light emission from heated crystals) is a potential indicator of uranium mineralization processes. TL (thermoluminescence) arises from the escape of electrons trapped in crystal defects as a crystal is heated. Free electrons generated by ionizing radiation from nearby radioactive elements may be captured in the defect traps. For example, when the local concentration of radioactive elements has been increased for a time, such as by the passage of a uranium-mineralized solution front, the TL of the host sandstone will be affected.

In this study, samples of sandstone from drill cores were disaggregated and sieved to less than 115 mesh (125 micrometers). Calcite and clay were removed from the samples prior to TL measurements. The samples were split, and their TL was measured in the temperature ranges of 100° to 322°C and 315° to 400°C. Both low-temperature and high-temperature TL are dependent on the number of crystal defects and both are increased by mineralizing processes. Low-temperature TL, however, fades much more rapidly than high-temperature TL. Only high-temperature TL maintains the effect of mineralization for geologically significant spans of time. Consequently, the ratio of low-temperature TL to high-temperature TL can be used to normalize the effect of between-sample variations due to differences in the number of crystal defects.

The ratioed data fall into two statistically well defined groups, one for oxidized samples subjected to the passage of a mineralized solution front and one for barren reduced samples. Thus, ratioing of TL data from two temperature ranges is an effective method of detecting radiation-induced thermoluminescence and of distinguishing oxidized from reduced ground around a deposit. TL may also be useful in detecting the passage of a mineralized solution front in areas where alteration related to oxidation has been obliterated by post-mineralization reduction.

CARBON ISOTOPE METHODS IN HYDROCARBON EXPLORATION

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Carbon isotope ratios have been shown to be useful in hydrocarbon exploration.

$^{13}C/^{12}C$ ratios are routinely determined on hydrocarbons taken from gas deposits or gas shows during drilling, on small quantities of methane desorbed from disaggregated rock samples, and on various fractions extracted from oils and source rocks.

The carbon isotope ratios of the gas samples identify the temperature regime under which the gases were formed, and thus the maturity and origin of their source. Conversly, studies of methane desorbed from cuttings or soil samples make it possble to predict areas of potential oil and gas formation.

In addition, carbon isotope ratio comparisons of oil fractions and of kerogens to oil fractions by the "isotopic type-curve technique," a sensitive, new technique developed in our laboratory, show possibilities for predicting the source beds of the studied oils.

Examples from different areas around the world demonstrate the usefulness of these techniques in exploration.

GEOCHEMICAL METHODS IN URANIUM EXPLORATION IN NORTHERN EAST GREENLAND

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A reconnaissance and regional uranium exploration program performed in northern East Greenland from 1973 to 1977 included geochemical exploration in selected areas between 73° and 74 1/2° N. covering approximately 10,000 km^2. As systematic geochemical exploration for uranium had not previously been employed in Greenland, an important part of the exploration program was concerned with testing sample methods and media.

Stream sediments and stream water were used as sampling media. The sampling was carried out on different scales: (1) reconnaissance; one sample site per 25 km^2, (2) regional; one sample site per 2-5 km^2, and (3) detailed sampling at 200 m intervals along streams. A helicopter was used for reconnaissance and regional sampling. Additional sampling programs were directed toward the study of seasonal and compositional variations in the chemistry of the sampling media within a sampling site area.

Samples were treated and analyzed for U in home laboratories. Stream sediments were additionally analyzed for selected major and base metals. Major elements were analyzed in a number of the stream water samples, and conductivity was measured in all of them. Rock samples were collected and analyzed to establish the background bedrock geochemistry.

On a regional scale, stream sediments and stream waters were found to represent the bedrock geochemistry well. The location of mineralization by stream sediments requires sampling on a detailed scale, as the dispersion halo is generally small. The conductivity of the stream water varies considerably, hence "normalized" uranium contents of the stream water samples were used.

The geochemical survey indicated uranium enrichment in a major fault zone. Small mineralizations and joint impregnations by uraniferous hematite were clearly registered. The results of the geochemical survey gave information on the character of anomalies recorded by a radiometric survey, and they provide a valuable contribution to the evaluation of the uranium potential of the investigated area.

GOSSAN GEOCHEMISTRY AS A GUIDE TO EXPLORATION OF DIFFERENT TYPES OF SULFIDE MINERALIZATION IN PARTS OF RAJASTHAN, WESTERN INDIA

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Most of the important base-metal sulfide deposits, especially in the arid to semi-arid parts of the world, are often characterized by well marked gossan zones occurring as weathered mantle above unaltered sulfides. In India we find a number of such sulfide deposits, often polymetallic in nature, associated with typical gossan zones. A considerable number of such gossan occurrences have been located by the Geological Survey of India in the western parts of the country, mostly in the state of Rajasthan. However, it has been observed that not all of these gossan zones or zones of ferrugination are underlain by important sulfide mineral deposits with significant base-metal content. In this context, the evaluation of precise geochemical relationships between the sulfides and the corresponding gossan zones of the potential deposits appeared to be very useful in classifying the different types of gossans with special reference to their base-metal values.

In order to establish the characteristic trace element association of the different gossans and their geochemical relations with underlying sulfides, the following study was done. A suite of 208 gossans, leached rocks, and false-gossan samples from ten different occurrences of the three mineralized belts, namely, (1) Rajpura-Dariba Zn-Pb-Cu belt (Dariba, Rajpura, Bethunmi and Jasma), (2) Khetri Cu belt (Khetri, Saladipura, Satkui and Dhanaota), and (3) Alwar-Jaipur Cu belt (Kalighati and Naldeswar), together with 101 sub-surface samples of sulfides from the mines and drill cores from four of the above occurrences were analyzed for twenty elements, namely Pb, Zn, Cu, Ni, Co, Cr, V, Sr, Ga, Ba, Mn, Sn, Mg, Sb, Cd, As, Ag, Mo, Bi, and Zr. Computer-based statistical analyses of the geochemical data have revealed significant element association within individual gossan occurrences with some element pairs showing highly significant correlation coefficient values. Moreover, simple statistical parameters like arithmetic mean, geometric mean, standard deviation, etc. of some of these elements also appeared to be significantly different for different gossan occurrences. Thus, the statistical studies of the geochemical data have been successfully used in these areas in conjunction with mineralogical characteristics for differentiating 'true-gossans' from 'false-gossans' and for delineating gossans that have formed essentially after specific base-metal sulfides along the extension areas of the known mineralized belts. Because of these results, the detailed geochemical evaluation of the different gossan occurrences of Rajasthan has proven to be highly successful in exploring for various types of sulfides.

THE CHARACTER AND APPLICATION OF VARIOUS CHEMICAL ANALYTICAL TECHNIQUES IN URANIUM EXPLORATION

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For some time, exploration technologists searching for base metals have realized that different analytical methods provide geochemical data of varying character. This is because the various procedures for partial and total extractions remove trace elements from different mineral combinations in the sample material. These techniques can provide considerable geological information relating to the occurrence of the trace element in the rock, soil, or stream sediment and its dispersion history.

In uranium exploration in North America, two analytical techniques are widely used as routine. In the United States, the USGS $HF\text{-}HNO_3\text{-}HClO_4$ extraction is the most usual method employed, whereas in Canada, the GSC $4N.HNO_3$ extraction is in general use. The USGS method extracts the total contained uranium from all the minerals present in the samples, including the resistates. In contrast, the GSC method is a partial analysis and the uranium extracted is primarily associated with the relatively soluble oxidized products, principally secondary minerals. These secondary minerals in soils and stream sediments tend to contain uranium which has moved hydromorphically, thus giving a degree of specificity towards potentially economic mineralization.

The characteristics of these two analytical methods are examined in detail together with other partial extraction techniques. Critical attention is given to the geological implication of the results and their application to problems of uranium exploration in a variety of geologic and climatic situations.

LITHOGEOCHEMICAL GUIDES TO ORE AT THE KERR ADDISON GOLD MINE, ONTARIO

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The early Precambrian gold deposits of the Kerr Addison Mine are located in the southern part of the Abitibi Greenstone Belt, Ontario.

"Flow-ore", economically the most important of the three types of gold ore, is a black volcanic rock, rich in finely disseminated pyrite cubes. Abundances of the relatively immobile elements, Y, Zr, Nb, P, and Ti are similar to those in Fe-rich, Mg-poor tholeiites associated with komatiitic rocks in Munro Township, Ontario, and elsewhere. The rare-earth element pattern resembles that of mid-ocean-ridge tholeiites, particularly those of the Indian Ocean. Although flow-ore is found invariably in contact with komatiitic ultramafic volcanic rocks or their quartz-carbonate alteration products, the gold-bearing rock itself is a low-MgO tholeiitic basalt.

"Carbonate-ore" is a close second in economic significance. It is a chromian-muscovite-bearing quartz-carbonate rock. Immobile element and rare-earth abundances are similar to those of ultramafic volcanics nearby.

"Albitite-ore" occurs as discrete, elongate, albite-rich bodies showing sharp, intrusive contacts with their quartz-carbonate wallrocks.

We interpret the flow-ore as syngenetic, exhalative, having formed during the final stages of pyroclastic tholeiitic volcanism, concurrent with komatiitic ultramafic volcanic activity. Carbonate-ore was formed by much later hydrothermal remobilization of gold from flow-ore deposits and redeposition in a set of sub-parallel fractures in CO_2 metasomatized ultramafic volcanics. Albitite-ore is the result of assimilation of gold by sodium-rich melt passing through zones of flow-ore and carbonate-ore.

Flow-ore is rich is Na_2O (6.12 percent) and S (21,646 ppm). These values end abruptly at the boundaries of the ore.

Carbonate-ore is within pronounced, gradational, local zones of enrichment in Na, K, As, and Cl and weaker zones of S and CO_2. This is accompanied by a mineralogical zonation outward from emerald-green, quartz-rich carbonate-ore grading into pale green quartz- (or sericite-) carbonate rock to grey carbonate rock and finally to calcite-rich talc-chlorite schist.

Albitite-ore is rich in S (6,615 ppm) and Na_2O (9.79 percent) but poor in K_2O (0.10 percent) and As (32 ppm). It exhibits strong local enrichment haloes of K and Na and weaker haloes of As, S, and possibly Au.

In conclusion, lithogeochemical haloes of some mobile elements should be useful in prospecting for blind deposits of carbonate-ore and albitite-ore at Kerr Addison. Flow-ore seems to exhibit no useful geochemical haloes. However, the chemical characteristics of flow-ore and its stratigraphic position provide some prospecting tools.

ELECTROCHEMICAL INTERPRETATION OF SOME GEOCHEMICAL PHENOMENA

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Distribution of metals, minerals, and complexes are influenced by electrical currents which are observed to flow in response to potential gradients that develop between zones of differing Eh in soils, sediments and rocks.

Applied current models have been evolved that seem relevant in interpretation of results of mineral exploration geochemical surveys.

In addition, the concept appears to provide an acceptable explanation for the origin of native metals observed in ice crystals and for the migration of metal values into snow overlying mineralized bodies.

ROCK GEOCHEMICAL EXPLORATION TECHNIQUES FOR MASSIVE SULPHIDES OF THE BATHURST TYPE (NEW BRUNSWICK, CANADA)

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Anomalous geochemical aureoles have been detected in bedrock around five major sulphide zones investigated in New Brunswick, Canada (Heath Steele A-C-D and B zones, Brunswick No. 12, Key Anacon, and Caribou). Whereas there are broad similarities in patterns around all the deposits, there are considerable variations in the intensity and extent of the anomalies and also some differences in individual element distribution patterns among the deposits that are attributed to the distance of the deposits from the primary source. In analogy with massive sulphide deposits on the Canadian Shield, proximal and distal deposits have been recognized.

Detailed illustrations are provided by the Heath Steele deposits where the A-C-D zone is interpreted as a proximal deposit and the B zone is interpreted as a distal deposit. Both the hanging wall and the footwall sedimentary and felsic volcanic rocks at the A-C-D proximal deposit are intensely altered mineralogically, whereas alteration is confined to a thickness of about 50 m immediately below the sulphide zone at the B zone distal deposit, and there is no visible alteration in the hanging wall rocks. Around both of the Heath Steele deposits Cu, Pb, Zn, Co, Cr, and P increase in concentration towards the ore zone; Ni, V, and Sr decrease towards the ore zone. At the A-C-D zone the combined trace element aureole is similar in intensity and extent (not less than about 100 x 1,000 m) in both footwall and hanging wall sedimentary and felsic volcanic rocks. At the B zone the footwall aureole is poorly defined; in the hanging wall only Pb and Zn give a recognizable halo--although this is extensive (360 x 1,700 m) when defined by discriminant analysis. Major element (Mg, Ca, Na, K) aureoles are similar in extent to trace element halos in hanging wall and footwall rocks of the A-C-D zone; at the B zone the major element anomalies are neither as intensive nor as extensive as at the A-C-D zone and are best defined by variations in Mg/Ca ratios.

An important conclusion of practical significance is that the geochemical aureoles described are detectable--and in some cases enhanced--by the rapid hot HNO_3 digestion procedure. Provided due allowance is made for variations in element distribution patterns due to distance from the source of mineralizng fluids, multi-element analysis of bedrock is a reliable technique to detect deeply-buried and blind volcanic-sedimentary massive sulphide deposits in the Bathurst district.

BIOGEOCHEMISTRY FOR URANIUM PROSPECTING IN AREAS OF GLACIAL OVERBURDEN

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A total of 854 ashed plant and soil samples from above the Key Lake uranium-nickel orebody, northern Saskatchewan, were analyzed for U by neutron activation/delayed neutron counting and 382 of these were also analyzed for Ni, Co, Cu, Pb, Zn, Cd, V, Mo, Fe, Mn, and Ca by atomic absorption spectrophotometry. The plant species comprise Pinus banksiana (jack pine), Picea mariana (black spruce), Vaccinium angustifolium (blueberry), and Ledum groenlandicum (Labrador tea); the soils are A_0, A_1, and B horizons, conifer samples were split into twigs, needles, cones, bark and wood; and small plants were split into stems, leaves and roots.

This paper deals essentially with uranium. The values of uranium in plant and organic soil ash are generally greater than the values in the B soil horizon. Co in roots and Pb in blueberry leaves and Pb and Cd in the B horizon all show sympathetic correlation with the trace of the ore zone. U correlates with Pb and Co in the ash of conifer twigs growing over an area of glacially transported, buried radioactive boulders lying 6.5 km from the ore zone.

Uranium profiles (from three lines spaced 50 m apart) for needles, twigs, and wood of Pinus banksiana, stems, leaves, and roots of Vaccinium angustifolium and also for A_0 (forest litter) and A_1 (humus) showed, in two or more of these media, anomalies over the trace of the Deilmann ore zone, even where the ore is as much as 75 m below ground surface. The range of U values in ppm for each medium sampled on these three lines is: twigs, 0.1-9.8; needles, 0.2-14.5; cones, 0.3-8.8; bark, 0.5-11.5; wood, 0.8-41.2; stems, 0.9-14.5; leaves, 0.5-21.8; roots, 0.9-5.2; A_0 horizon, 2.8-14.4; A_1 horizon, 2.8-14.2; and B horizon, 1.3-11.5.

Numerous plant organs have anomalous uranium concentrations over the orebody. Preliminary investigations indicate that the trunk wood may be the most useful sampling medium. Uranium is concentrated most efficiently by ashing trunk wood, because wood has a higher loss on ignition than other organic material.

Wood is the component most likely to survive the frequent burns which in many localities limit the availability of plant and organic soil material. Samples can be collected easily in all seasons, and a rapid preliminary evaluation of an area is possible using stakers or line cutters.

GEOCHEMICAL RECONNAISSANCE FOR URANIUM AND BASE METALS USING HEAVY MINERAL SEPARATES IN CENTRAL AND SOUTHERN SUMATRA--A PRELIMINARY REPORT

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A reconnaissance drainage basin survey has been carried out in Central and Southern Sumatra, primarily for uranium, but also for several base metals. An area of 40,000 km^2 has been covered in less than eleven months field work at a cost of less than $1 per square kilometer, using a combination of traditional geochemical methods and the rather less common heavy mineral panned concentrate as sampling medium, followed by tetrabromoethane separation in the laboratory.

The results indicate an enhancement of contrast in the heavy mineral separates, as compared to the corresponding ordinary stream sediments. This phenomenon is evident for most of the elements, including the primary target, uranium.

It is suggested that the coprecipitation of elements with Fe and Mn hydroxides is more important than their adsorption on clays, and that the dominant means of dispersion is mechanical rather than chemical, once the solution transporting the element is exposed to the atmosphere.

Several areas have been delineated as worthy of follow-up, and this work is proceeding.

The importance of such rapid, cheap reconnaissance for the developing countries is underlined.

The work can be carried out using semi-skilled field personnel with junior geologists in supervision. One senior qualified project manager is required to coordinate movements, data processing, and sample treatment.

MERCURY-IN-SOILS GEOCHEMISTRY OVER MASSIVE SULFIDE DEPOSITS IN ARIZONA

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The exploration potential of a new portable highly sensitive gold-film mercury detector was evaluated by conducting soil geochemical surveys over five massive sulfide deposits in west-central Arizona. Results indicate that the new mercury detector may have widespread applicability in massive sulfide exploration in semi-arid regions such as the southwestern United States.

All deposits studied occur in Precambrian metavolcanic and metasedimentary rocks. At the Old Dick deposit south of the Bagdad district, a strong soil-mercury anomaly of more than 500 ppb sharply defines the ore zone. A traverse over the orebody, located 450 feet (140 m) below the surface, shows a response equal to that obtained over the gossan. At the Copper Queen deposit, about 3000 feet (900 m) south of the Old Dick deposit, a rather weak soil-mercury response was obtained, but the mineralization is defined by a regional threshold of about 100 ppb Hg which also outlines all known mineralization in the Old Dick area.

Soil-mercury traverses across two parallel massive sulfide deposits in the Binghampton area east of Prescott show distinct strong anomalies of 200 to more than 1000 ppb Hg over a background with a geometric mean of about 50 ppb. At the Antler mine southeast of Kingman, narrow anomalous spikes were recorded, but the massive sulfide ore at a depth of 300 to 500 feet (90 to 150 m) below surface gives no measureable response.

The soil-mercury halos in the Old Dick and Binghampton areas strongly indicate the presence of a hypogene mercury halo in the host rocks of massive sulfide bodies. Such hypogene mercury halos are significantly larger than the corresponding massive sulfide bodies. Mercury released from the hypogene mercury halo is probably as important as that derived from massive sulfides. The depth from which a massive sulfide orebody can be detected by soil-mercury survey may largely be determined by the size of the hypogene mercury halo, and the permeability of the host rocks and overburden.

The soil-mercury survey can sharply define a near-surface massive sulfide target. The anomalous area surrounding Binghampton has a width of about 2000 feet (600 m). In such cases, there is probably no problem in locating the targets in a wider-spaced sampling survey following preliminary geologic mapping. On the other hand, in the case of the Antler mine and the Copper Queen mine in the Old Dick area, where the anomalies are either narrow or weak, a sound strategic sampling scheme is essential.

HEAVY-MINERAL PANNING TECHNIQUES IN THE EXPLORATION FOR TIN AND TUNGSTEN IN NORTHWESTERN SPAIN

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A regional exploration program for tin (cassiterite) and tungsten (wolframite, scheelite) was carried out in northwestern Spain from 1971 to 1974. The explored area is in the Hercynian belt of Europe, and is characterized by granites, migmatites, and schists of Paleozoic age. Cassiterite mineralization typically occurs in high-temperature quartz veins, as dissemination in kaolinized granite-schist contacts, and in Quarternary alluvium; wolframite and scheelite mineralization is in high temperature vein assemblages.

Geochemical stream-sediment sampling at a density of 2-4 samples per square kilometer was done in an attempt to delimit areas for detailed follow-up. Results from stream-sediment geochemistry soon proved to be of little value, as samples downstream from known areas of mineralization frequently failed to show a corresponding anomaly, and as a large number of one-sample spot anomalies appeared which were useless as guides to mineralization.

A test program was run in which geochemical sampling was supplemented by panning of heavy-mineral concentrates at a density of 1 pan concentrate every 2 km^2. The mineral concentrates were sent for analysis, and the analytical values were treated like traditional geochemical results. This was a decisive improvement over geochemical procedures, as a series of coherent anomalies now marked the areas of interest, instead of randomly appearing spot anomalies. Analysis of the pan concentrates did not indicate, however, whether the tin and tungsten content was due to cassiterite, wolframite, and scheelite, or whether it represented a high content of these metals in non-economic silicates or oxides. To further improve the method, the heavy-mineral composition of pan concentrates was determined using a binocular microscope. After a few months training, our "heavy minerals specialist" was able to reliably estimate the percentages of cassiterite, wolframite, scheelite, gold, rutile, ilmenite, monazite, zircon, and other heavy minerals of potential economic interest in a matter of 10 to 15 minutes per sample. The advantages of this exploration method for cassiterite, wolframite, and other heavy minerals over traditional geochemical methods are: (1) that a much lower sampling density is sufficient to obtain meaningful results; (2) that the problem of hard-to-evaluate spot anomalies is largely eliminated; (3) that the results are available immediately, and can be used to guide the on-going exploration program; and (4) that the presence of economically exploitable minerals rather than the presence of metal percentages in stream sediment is determined. The heavy-mineral panning method outlined here for stream-sediment surveys can be applied equally well for soil sampling and for a preliminary economic evaluation of the heavy-mineral content of kaolinized rock, alluvium, and beach sands.

REGIONAL GEOCHEMICAL PROSPECTING IN EQUATORIAL AREAS: AN EXAMPLE IN FRENCH GUYANA

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Mineral exploration in French Guyana has been recently reactivated, and geochemical prospecting has been selected as the main method for the evaluation of the mineral potential of the country.

The present study deals with geochemical reconnaissance over an area of about 6,000 km^2 of Precambrian volcano-sedimentary belts located in the north of the country.

The main object of the exploration was to discover sulfide deposits related to volcanism; however, the wide spectrum of elements analyzed could theoretically lead to geochemical identification of any other type of deposit.

The geochemical techniques used and the results obtained are described and discussed.

Along sampling lines cut every 2 km through the forest, soil samples were collected every 500 m; and stream-sediment samples were collected at intervals that depended on the density of the drainage pattern. The average sampling density was between one and two samples per square kilometer. Roughly 9,000 samples were collected.

Dried samples were sieved and analyzed for 33 elements, including 7 major elements, using a direct reading spectrometer. High iron concentration in most of the samples made it necessary to work out a computer program that would eliminate spectral interferences.

The analytical results, after processing, revealed three types of information. First, the behavior of trace and major elements in ferrallitic soil has been studied, in order to outline which elements can be used for geochemical prospecting in such environments. This has been achieved by studying (in more than 6,000 samples) the correlation between each element and the Fe_2O_3 and Al_2O_3 concentrations, both linked to the degree of weathering. The main feature noticed in most of the collected samples is that elements like Pb, Cu, Zn, Ni, and several others are not strongly leached or enriched during weathering. This is probably due to incompete weathering in the sample horizons. Nevertheless, in case of very active supergene processes, some leaching can be observed for Cu, Zn and Ni.

More classical behavior has been observed, in the case of Cr, V, Ti, and P, which are strongly enriched together with Fe and/or Al; others like K_2O, Na_2O, MgO, are partly or totally leached following the loss of silica.

Next, a successful attempt has been made to use the soil content of selected trace and major elements to deduce the mineral assemblages comprising underlying bedrock and characterizing the main lithologic units in the surveyed area.

Finally, the interpretation of the soil and stream-sediment data using various statistical methods has led to the selection of about 60 anomalies, mostly of base metals.

This study has shown that geochemical prospecting appears to be well adapted to mineral exploration under the conditions of French Guyana, as long as sampling density, analytical facilities and interpretation techniques are adequate.

A number of new anomalous areas have been identified by the geochemical reconnaissance, where the conventional prospecting results were notoriously disappointing.

AUTHOR INDEX

IS PROSPECTING A DISEASE?

Perhaps not, but many prospectors have suffered from the life-long habit. Take Ed Schiefflin. Ed made a fortune by discovering the rich silver deposits at Tombstone, Arizona. But he continued prospecting for the rest of his life. In his will he wrote:

> "It is my wish, if convenient, to be buried in the dress of a prospector, my old pick and canteen with me, on top of the granite hills about three miles westerly of the city of Tombstone, Arizona, and that a monument such as prospectors build when locating a claim be built over my grave, and no other slab or monument be erected."

His wish was fulfilled when the Tombstone miners erected what may be the grandest claim monument ever made.