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THIRD
INTERNATIONAL
GEOCHEMICAL EXPLORATION
SYMPOSIUM

Program and Abstracts



April 16-18, 1970
King Edward Hotel
Toronto, Ontario, Canada

THIRD INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM

Sponsors:

The Geology Division of The Canadian
Institute of Mining and Metallurgy;
The Society of Economic Geologists

Location:

King Edward Hotel, Toronto, Ontario, Canada

Date:

April 16-18, 1970

TECHNICAL SESSIONS

Thursday a.m.....	<i>Opening Session</i>	Ballroom
Thursday p.m.....	<i>General Session</i>	Ballroom
Thursday p.m.....	<i>Session on Remote Sensing</i>	
	Hunting Room
Friday a.m.....	<i>General Session</i>	Ballroom
Friday a.m.....	<i>Session on Petroleum and</i>	
	<i>Natural Gas</i> ..	Mayfair Room
Friday p.m.....	<i>General Session</i>	Ballroom
Friday p.m.....	<i>Session on Primary Halos</i>	
	Sheraton Room
Saturday a.m.....	<i>General Session</i>	Ballroom
Saturday a.m.....	<i>Session on Statistics</i>	
	Mayfair Room
Saturday p.m.....	<i>General Session</i>	Ballroom

SOCIAL FUNCTIONS

- Wine and Cheese Party..... Wednesday, April 15,
8:00-10:00 p.m. Sheraton Room, King Edward
Sheraton Hotel. Courtesy Bondar-Clegg and Com-
pany, Ltd., Ottawa, Ontario.
- Cocktail Party..... Thursday, April 16, 8:30 p.m.
Ballroom, King Edward Sheraton Hotel.

SYMPOSIUM COMMITTEE

- R. W. BOYLE (Chairman), Geological Survey of Canada, Ottawa
- W. SMITHERINGALE, Memorial University, St. John's, Newfoundland
- C. F. GLEESON, SOQUEM, Ste-Foy, Québec
- J. L. WALKER, Barringer Research Ltd., Rexdale, Toronto, Ontario
- J. A. HANSULD, Amax Exploration Inc., Toronto
- A. Y. SMITH, 10 Cherrywood Drive, Ottawa
- G. LAPOINTE, Université de Sherbrooke, Sherbrooke, Québec
- J. R. SMITH, Saskatchewan Research Council, Saskatoon
- J. BARAKSO, Anaconda American Brass Ltd., Britannia Beach, B.C.
- I. L. ELLIOTT, Falconbridge Nickel Mines Ltd., Vancouver
- R. G. MCCROSSAN, Geological Survey of Canada, Calgary
- J. A. COOPE, Newmont Mining Corp. Canada, Limited, Toronto, Ontario
- R. G. GARRETT, Geological Survey of Canada, Ottawa
- H. C. SAKRISON, Cominco Ltd., Exploration Eastern District, Toronto

GENERAL INFORMATION

- 1.— All technical sessions will be held in the King Edward Sheraton Hotel, Toronto. Rooms where sessions are to be held are indicated in the program.
- 2.— It is anticipated that the proceedings of this Symposium will be published as a Special Volume of The Canadian Institute of Mining and Metallurgy.
- 3.— The registration fee includes three tickets for the cocktail party on Thursday night. More tickets can be purchased at the cash bar.
- 4.— Coffee is available during coffee breaks near the rooms where the sessions are in progress.
- 5.— Grateful acknowledgment is made to Amax Exploration Inc., Toronto and the Geological Survey of Canada, Ottawa for the use of their typing, drafting and reproduction facilities.

PROGRAM SCHEDULE

Wednesday, April 15

Pre-Registration — King Edward Sheraton Hotel — 3:00-5:30 p.m.

Get-together and wine and cheese party — Sheraton Room, King Edward Sheraton Hotel — 8:00-10:00 p.m.

Thursday Morning, April 16

Registration — King Edward Sheraton Hotel — 8:00-10:00 a.m.

BALLROOM — OPENING SESSION: 10.00 a.m.

Chairman: Dr. Y. O. FORTIER, Director,
Geological Survey of Canada,
Ottawa.

Welcoming Remarks:

Dr. J. M. HARRISON,
President, The Canadian Institute of Mining and Metallurgy,
Assistant Deputy Minister (Mines and Geosciences),
Department of Energy, Mines and Resources,
Ottawa.

Dr. C. H. SMITH,
Regional Vice-President, North America,
Society of Economic Geologists,
Chief, Crustal Geology Division,
Geological Survey of Canada,
Ottawa.

Opening Address:

Dr. D. R. DERRY,
Derry, Michener and Booth, Consultants,
Toronto.
Geochemistry — the link between ore genesis and exploration.

COFFEE BREAK — Coffee courtesy Noranda Exploration Co., Ltd., Toronto

J. ALAN COOPE — The Association of Exploration Geochemists — 11.30 a.m.

Thursday Afternoon, April 16

BALLROOM — GENERAL SESSION

Co-Chairmen: R. KELLY, Ministère des Richesses Naturelles, Québec
R. L. ERICKSON, U.S. Geological Survey, Denver, Colorado

- C. **Lepeltier**: Geochemical Exploration in the United Nations Development Programs 1.00-1.20
- B. **Bölviken, C. A. Nilsson and H. Wennervirta**: Research and Development in Geochemical Exploration in Scandinavian Countries (Read by Mrs. Britt Nairis) 1.20-1.35
- L. **V. Tauson, et al**: The Use and Development of Geochemical Prospecting Methods for Ore Deposits in the U.S.S.R. 1.35-1.50
- J. **S. Webb**: Research in Applied Geochemistry at Imperial College, London 1.50-2.05
- M. **Dall'Aglio**: Trends in Geochemical Exploration in Italy 2.05-2.20
- G. **L. Coetzee**: Geochemical Exploration in Southern Africa and Madagascar 2.20-2.35
- H. **Bloom and H. E. Hawkes**: The Continuing Education of the Exploration Geochemist 2.35-2.50

COFFEE BREAK — Coffee courtesy Cominco Exploration Division, Toronto

- A. **R. Archer and C. A. Main**: Casino, Yukon — A Geochemical Discovery of an Unglaciated Arizona-type Porphyry 3.30-3.50
- A. **K. Chakrabarti and P. J. Solomon**: A Geochemical Case History of the Rajburi Antimony Prospect, Thailand 3.50-4.10
- G. **H. Friedrich and W. L. Pluger**: Geochemical Prospecting for Baryte and Fluorite Deposits 4.10-4.30
- H. **W. Lakin, G. C. Curtin and A. E. Hubert**: Geochemistry of Gold in the Weathering Cycle 4.30-4.50
- R. **J. Allan and E. H. W. Hornbrook**: Exploration Geochemistry Evaluation Study in a Region of Continuous Permafrost: The Coppermine Basalt Belt, N.W.T., Canada 4.50-5.10
- N. **Varlamoff**: Behaviour of Tungsten Minerals and Ores in the Weathering Zone under Equatorial and Tropical Conditions 5.10-5.30
- S. **S. Shannon**: Evaluation of Copper and Molybdenum Geochemical Anomalies at the Cumo Prospect, Boise County, Idaho 5.30-5.50

HUNTING ROOM — SESSION ON REMOTE SENSING METHODS

Co-Chairmen: A. R. BARRINGER, Barringer Research Limited,
Rexdale, Toronto
A. G. DARNLEY, Geological Survey of Canada,
Ottawa

- B. **Cook, J. Duval and J. A. S. Adams:** Progress in the Calibration of Airborne Gamma Spectrometers for Geochemical Exploration 1.15-1.40
- C. **H. Johnson:** Recent Advances in Sensitivity and Data Analysis of Airborne Gamma-ray Spectrometry for Mineral Exploration 1.40-2.05
- R. **Bennett:** Exploration for Hydrothermal Mineralization with Airborne Gamma-ray Spectrometry 2.05-2.30
- A. **G. Darnley, R. L. Grasty and B. W. Charbonneau:** Mapping from the Air by Gamma-ray Spectrometry 2.30-3.00

COFFEE BREAK — Coffee courtesy Cominco Exploration Division, Toronto

- F. **C. Canney:** Remote Detection of Geochemical Anomalies; a Preliminary Feasibility Study 3.30-4.00
- O. **Weiss:** Airborne Geochemical Prospecting 4.00-4.30
- A. **R. Barringer:** Optical Detection of Geochemical Anomalies in the Atmosphere 4.30-5.00

Friday Morning, April 17

BALLROOM — GENERAL SESSION

Co-Chairmen: C. F. GLEESON, Soquem, Ste-Foy, Quebec
M. DALL'AGLIO, Centro Di Studi Nucleari Della Casaccia, Laboratorio Geominerario, Rome

- G. **Liberto de Pablo:** The Present Status of Geochemistry in Mexico 9.00-9.15
- R. **L. Erickson:** U.S.G.S. Program in Geochemical Exploration Research — 1970 9.15-9.30
- J. **L. Walker and P. M. D. Bradshaw:** Summary of Research and Development in Geochemical Exploration in Canada 9.30-9.45
- N. **H. Fisher:** Recent Research in Geochemical Prospecting in Australia 9.45-10.00
- S. **E. Rodriguez:** Geochemical Investigations for Base Metals and Silver in the Coast Geosyncline, Northern Venezuela, South America 10.00-10.15

COFFEE BREAK — Coffee courtesy Texas Gulf Sulphur Company, Exploration Division, Toronto

- I. **Nichol**: An Assessment of Requirements and Future Trends of Exploration Geochemistry in Canada 10.40-11.00
- S. **H. U. Bowie, D. Ostle and T. K. Ball**: Geochemical Methods in the Detection of Hidden Uranium Deposits 11.00-11.20
- W. **Dyck, et al**: Comparison of Regional Geochemical Uranium Exploration Methods in the Beaverlodge Area, Saskatchewan 11.20-11.40
- F. **R. Siegel**: Marine Geochemical Prospecting — Present and Future 11.40-12.00

MAYFAIR ROOM — SESSION ON GEOCHEMICAL PROSPECTING FOR PETROLEUM AND NATURAL GAS

Co-Chairmen: W. M. ZARRELLA, Gulf Research and Development Corporation, Pittsburgh, Penn., U.S.A.
G. W. HODGSON, Exo-Biology Department, University of Calgary, Calgary, Alberta

- B. **Housse**: Geochemical Prospecting for Hydrocarbons 9.00-9.20
- V. **A. Sokolov**: The Theoretical Foundations and Development Tendencies of Geochemical Prospecting for Petroleum and Natural Gas 9.20-9.40
- C. **R. Evans**: Regional Facies of Organic Metamorphism 9.40-10.00

COFFEE BREAK — Coffee courtesy Texas Gulf Sulphur Company, Exploration Division, Toronto

- J. **L. Rumeau et G. L. Kulbicki**: Caractères géochimiques de la Keg River Formation 10.40-11.00
- R. **E. Gerard**: Application of Data Processing Methods to Geochemical Prospecting for Petroleum 11.00-11.20
- R. **G. McCrossan**: An Evaluation of Surface Geochemical Prospecting for Petroleum, Caroline Area, Alberta 11.20-11.40
- J. **B. McClusky**: Gas Geochemistry in the Sevens — Challenge and Concepts 11.40-12.00

Friday Afternoon, April 17

BALLROOM — GENERAL SESSION

Co-Chairmen: I. NICHOL, Department of Geological Sciences,
Queen's University, Kingston, Ontario
W. F. BONDAR, Bondar-Clegg and Company, Ltd.,
Ottawa, Ontario

- W. P. Sears:** Mercury in Base-Metal and Gold Ores of the Province of Quebec 1.15-1.35
- P. B. Trost and R. E. Bisque:** Differentiation of Vaporous and Ionic Origin of Trace Mercury in Soils 1.35-1.55
- M. Dall'Aglio:** Comparison between Hydrogeochemistry and Stream-Sediment Methods in Prospecting for Mercury 1.55-2.15
- J. J. Barakso and B. A. Bradshaw:** Molybdenum Surface Depletion and Leaching 2.15-2.35
- R. F. Horsnail and I. L. Elliott:** Some Environmental Influences on the Secondary Dispersion of Molybdenum and Copper in Western Canada 2.35-2.55

COFFEE BREAK — Coffee courtesy Technical Service Laboratories, Toronto

- R. G. Garrett:** The Dispersion of Copper and Zinc in Glacial Overburden at the Louvem Deposit, Val d'Or, Quebec 3.15-3.25
- C. F. Gleeson and R. Cormier:** Evaluation by Geochemistry of Geophysical Anomalies and Geological Targets Using Overburden Sampling at Depth 3.25-3.35
- B. Woznessensky:** Geochemistry — A Tool in Regional Metallogenic Exploration 3.35-3.55
- A. A. Levinson:** Hydrogeochemistry of Rivers in the Mackenzie Drainage Basin 3.55-4.15
- O. M. Clarke:** Geochemical Prospecting in Lateritic Soils of Alabama 4.15-4.35
- K. F. G. Hosking:** Problems Associated with the Application of Geochemical Methods of Exploration in Cornwall, England 4.35-4.55
- F. M. Smith:** Geochemical Exploration over Complex Mountain Glacial Terrain, Yukon 4.55-5.15

SHERATON ROOM — SESSION ON PRIMARY HALOS AND LITHO-GEOCHEMICAL METHODS

Co-Chairmen: J. E. RIDDELL, International Geochemical Associates, Montreal, Quebec
G. R. WEBBER, Department of Geological Sciences, McGill University

- V. V. Polikarpochkin and N. A. Kitaev: Endogenic Halos of Epithermal Gold-bearing Deposits 1.15-1.35
D. M. Hausen and P. F. Kerr: X-ray Diffraction Methods of Evaluating Potassium Silicate Alteration in Porphyry Mineralization 1.35-1.55
B. H. Flinter: Tin in Acid Granitoids; the Search for a Geochemical Scheme of Mineral Exploration 1.55-2.15
B. Nairis: Endogene Dispersion Aureoles Around the Ruttjebacken Sulphide Ore in the Adak Area, Northern Sweden 2.15-2.35
D. Brabec and W. H. White: Distribution of Copper and Zinc in Rocks of Guichon Batholith, B.C. 2.35-2.55

COFFEE BREAK — Coffee courtesy Technical Service Laboratories, Toronto

- E. Bolter, Z. Al-Shaieb and N. H. Tibbs: Trace Element Anomalies in Igneous Wallrocks of Hydrothermal Veins 3.15-3.35
W. R. Hesp: Correlations Between the Tin Content of Granitic Rocks and their Chemical and Mineralogical Composition 3.35-3.55
B. M. Hamil and M. P. Nackowski: Trace Element Distribution in Accessory Magnetite from Quartz Monzonite Intrusives, etc. 3.55-4.15
R. Darling: Minor Element Anomalies in Biotite from Quartz Monzonite Associated with Contact-Metasomatic Tungsten Ore, California 4.15-4.35
V. Velchev and M. Tokmakchieva: Preliminary Results on the Primary Deep Geochemical Aureoles of Elements in the Pyritic Copper Mine, "Radka" (Bulgaria) 4.35-4.55
R. B. Kayser and W. T. Parry: Geochemical Trends within the Texas Canyon Stock, Cochise County, Arizona 4.55-5.15

Saturday Morning, April 18

BALLROOM — GENERAL SESSION

Co-Chairmen: W. M. TUPPER, Department of Geology, Carleton University, Ottawa

J. A. HANSULD, Amax Exploration, Inc., Toronto

- M. L. Jensen:** Stable Isotopes in Geochemical Prospecting 9.00-9.20
- M. Shima and H. G. Thode:** A Geochemical Prospecting Method Using Stable Isotopes 9.20-9.40
- A. P. Pierce, J. C. Antweiler and R. S. Cannon:** Suggested Uses of Lead Isotopes in Exploration 9.40-10.00
- E. E. Angino, E. D. Goebel and T. C. Waugh:** Lead Isotopes and Metallic Sulphides as Exploration Guides in Mid-Continent Paleozoic Rocks 10.00-10.20

COFFEE BREAK — Coffee courtesy Barringer Research Limited, Rexdale, Toronto

- F. Cachau-Herreillat and J. P. Prouhet:** The Utilization of Metalloids (Arsenic, Phosphorus, Fluorine) as Pathfinders for Skarn Tungsten Deposits in Pyrénées (France) 10.40-11.00
- D. H. Rostad:** Offset Geochemical Anomalies at the Ima Mine, Lemhi County, Idaho 11.00-11.15
- C. Leduc and M. Boucetta:** A Study of the Distribution and Localization of Lead and Zinc in the Weathered Mantle of the Granite de Fougères, Northwest Brittany 11.15-11.30
- L. C. Huff:** A Comparison of Alluvial Exploration Techniques for Copper Deposits 11.30-11.45
- D. W. Muller and P. R. Donovan:** Stream-Sediment Reconnaissance for Zinc Silicate (Willemite) in the Flinders Ranges, South Australia 11.45-12.00

MAYFAIR ROOM — SESSION ON STATISTICS AND EVALUATION

Co-Chairmen: R. G. GARRETT, Geological Survey of Canada, Ottawa

R. A. BLAIS, Ecole Polytechnique, Département Génie Géologique, Montréal

- J. M. Botbol:** Geochemical Exploration Data-Processing Techniques Utilized by the Branch of Exploration Research 9.00-9.20

- A. **H. Beers, M. P. Nackowski and W. T. Parry:** 9.20-9.40
Trace Element Study of the Oquirrh Mountains, Utah.
- B. **Bölviken:** A Statistical Approach to the Problem of Interpretation in Geochemical Prospecting 9.40-10.00

COFFEE BREAK — Coffee courtesy Barringer Research Limited, Rexdale, Toronto

- L. **Martin:** Computerized Regional-Residual Mapping and Its Use in the Evaluation of Geochemical Anomalies 10.40-11.00
- A. **W. Rose and N. H. Suhr:** Major Element Content as a Means of Allowing for Background Variation in Geochemical Exploration 11.00-11.20
- J. **H. Schuenemeyer, C. E. Lienert and G. S. Koch:** 11.20-11.40
Recognition of Geochemical Anomalies from Anomalous Points by Measuring Perimeters of Convex Hulls
- E. **M. Cameron, G. Siddeley and W. R. A. Baragar:** 11.40-12.00
Distribution Functions of Ore Elements in Rocks for Evaluating Ore Potential
- B. **W. Brown:** Geochemistry and Ore Exploration 12.00-12.20

Saturday Afternoon, April 18

BALLROOM — GENERAL SESSION

Co-Chairmen: H. V. WARREN, Department of Geology, University of British Columbia
D. R. CLEWS, Barringer Research Limited, Rexdale, Toronto

- Monica **M. Cole:** The Importance of Environment in Biogeographical/Geobotanical and Biogeochemical Investigations 1.15-1.35
- E. **M. El Shazly, et al:** The Use of Acacia Trees in Biogeochemical Prospecting 1.35-1.55
- M. **A. Chaffee and T. D. Hessin:** An Evaluation of Some Geochemical Sampling in the Search for Concealed "Porphyry" Copper-Molybdenum Deposits on Pediments in Southern Arizona, U.S.A. 1.55-2.15

E. H. W. Hornbrook: Effectiveness of Geochemical and Biogeochemical Exploration Methods in the Cobalt Area, Ontario	2.15-2.35
H. V. Warren, et al: The Copper and Zinc Content of Trout Livers as an Aid in the Search for Favourable Areas to Prospect	2.35-2.55
COFFEE BREAK — Coffee courtesy Phelps Dodge Corp. of Canada Limited, Toronto; McIntyre Porcupine Mines Limited, Toronto; Newmont Mining Corp. of Canada Limited, Toronto.	
A. N. Chowdhury and B. B. Bose: Role of Humus Matter in the Formation of Geochemical Anomalies	3.15-3.35
J. O. Larsson and I. Nichol: Analyses of Glacial Material as an Aid in Geological Mapping	3.35-3.55
R. E. Delavault and R. J. Manson: Spectroscopic Determination of Arsenic in Geochemical Prospecting Samples	3.55-4.10
T. E. Green, W. J. Campbell and S. L. Law: Application of a Combined Ion Exchange Paper — X-ray Spectrographic Method to Geochemical Exploration	4.10-4.25
J. R. Foster: Analytical Requirements in Geochemical Exploration	4.25-4.40
D. R. Clews: Summary	4.40

Papers read by title

- K. Bloomfield, J. H. Reedman and J. G. G. Tether:** Geochemical Exploration of Carbonatite Complexes in Eastern Uganda
- R. W. Boyle:** Boron and Boron Minerals as Indicators of Mineral Deposits
- F. Cachau-Herreillat and P. LaSalle:** The Utilization of Eskers as Ancient Hydrographical Networks for Geochemical Prospecting in Glaciated Areas
- E. M. Cameron and D. Hobbs:** Computerized Methods for Interpreting Reconnaissance Geochemical Surveys
- R. I. Dubov:** The Quantitative Study of Geochemical Fields for Ore Deposits Search

- H. E. Hawkes:** Recent Articles on Geochemical Prospecting, 1965-1969 (Copy available on Registration)
- D. H. Johnson, A. J. Holmes and B. R. Cooper:** Geochemical Investigations of Base Metal Occurrences in Western Liberia
- R. W. Lewis:** Status of Geochemical Prospecting in Brazil
- R. H. Morse:** Comparison of Geochemical Prospecting Methods using Radium with those using Radon and Uranium
- A. Nigrini:** Investigations into the Transport and Deposition of Copper, Lead and Zinc in the Surficial Environment
- D. Norton, J. Suthard and R. Hendricks:** A Chemical and Mineralogical Study of the Weathering Processes in West-Central Puerto Rico
- H. Ling Ong:** Status of Geochemical Exploration in Indonesia
- V. V. Polikarpochkin:** The Quantitative Estimation of Ore-bearing Areas by Sample Data of the Drainage System
- A. S. P. Rao:** Meteoritics in Geochemical Exploration
- B. M. Shmakin, et al:** Use of the Petrographical-Geochemical Prospecting Method for the Discovery of Hidden Muscovite Deposits in Different Geological Environments
- V. A. Sokolov, et al:** The New Methods of Gas Surveys; Gas Investigations of Wells and Some Practical Results
- D. N. Stevens, G. E. Rouse and R. H. DeVoto:** Radon in Soil Gas: Three Uranium Exploration Case Histories in the Western United States
- L. V. Tauson and S. G. Petrovskaya:** Endogenic Halo Types of Hydrothermal Molybdenum Deposits

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ABSTRACTS OF PAPERS

(alphabetically, by author)

Exploration Geochemistry Evaluation Study in a Region of Continuous Permafrost; the Coppermine Basalt Belt, N.W.T., Canada.

ALLAN, R. J., and HORNBROOK, E. H. W., Geological Survey of Canada, Ottawa, Canada.

During the summer of 1969, the authors conducted a geochemical exploration feasibility study in the Coppermine River basalt belt, immediately north of Dismal Lakes, Coppermine River area, N.W.T. The general objective was to evaluate geochemical exploration methods in areas of continuous permafrost. The study was particularly concerned with the detection of copper mineralization in this basalt series.

Because this was a feasibility study, samples were collected from a variety of materials: O/A, B and C horizons of soils; mineral soil samples from silty frost boils; stream sediments; vegetation; and lake waters. Most samples came from the vicinity of a known copper orebody (the 47-zone of the Coppermine River Company, Ltd.) and a mineralized quartz vein (the 13-showing of the Coppermine River Company, Ltd.). Lake waters were sampled over a 200-sq.-mile area, as were some background soils and frost boils. Analysis of all samples was by hot nitric acid leach and atomic absorption spectroscopy.

Concentrations of copper in twenty-five lake waters separated four anomalous (above 15 ppb Cu) lakes, two of which were very close to the 47-zone, from seven threshold (about 8 ppb Cu) lakes, most of which were close to known mineralized showings, and from fourteen background (about 2 ppb Cu), lakes, randomly distributed within the sample area.

Anomalous concentrations for stream sediments from four streams occurred only for the two which crossed the 47-zone orebody. For these two, concentrations immediately downstream from the orebody were three- to four-fold (about 3,000 ppm Cu) those above the orebody (about 800 ppm Cu) in a background area.

O/A horizons were not entirely satisfactory for exploration purposes because of the prolonged time and effort required for collection. Anomalous and regional background B-horizon concentrations, 1,000 ppm Cu and 70 ppm Cu respectively, defined an anomalous zone immediately downslope from the 47-zone orebody. Silty frost boils were collected on only one line across this orebody. A comparison of the anomalous to background contrasts for the silty frost boils, B horizon and O/A horizon on this line shows the following: silty frost boils, 60 fold; B horizon, 25 fold; and O/A horizon, 50 fold. Material from the C horizon, immediately above the permafrost, in the thawed zone, at three soil profiles in the vicinity of the 47-zone, had substantially higher (17 fold in one case) copper concentrations than B-horizon material in the same soil profiles. The phenomenon of increasing copper concentrations with depth was also found in silty frost boils at the 13-showing, but the increase was considerably less pronounced (a maximum of 2 fold) and occurred only very close to the mineralized quartz vein.

Regional background for silty frost boils is in the order of 45 ppm Cu (eight boils on a 25-mile traverse ranged from 20 to 71 ppm Cu). At the 13-showing, analysis of silty frost-boil surface samples showed dispersion of copper to be limited to 100 to 200 feet downslope from the vein.

Results of biogeochemical exploration (76 samples were collected over the 47-zone) indicate that flowering shrubs in stream valleys and certain lichens have an exploration potential.

Sufficient chemical processes such as leaching, absorption, etc., and physical processes such as solifluction and frost heaving, etc., take place to develop geochemical dispersion halos in lakes, stream sediments and soils in the vicinity of copper deposits.

Based on the results of this feasibility study, the following approach for geochemical mineral exploration in the Coppermine basalt belt appears to be effective: (1) lake water analysis (one axis of the lake should be at least 1,000 feet), followed by (2) stream sediment analysis (sample every 1,000 feet), followed by (3) silty frost-boil surface soil analysis (sample every 100 feet on traverse lines or grids).

Lead Isotopes and Metallic Sulphides as Exploration Guides in Mid-Continent Paleozoic Rocks.

ANGINO, E. E., GOEBEL, E. D., and WAUGH, T. C.,
State Geological Survey, University of Kansas, Lawrence.

Acetic acid insoluble residues of Paleozoic cherty-carbonate rock cores commonly include several metallic sulphide minerals. The minerals identified are pyrite, chalcopyrite, marcasite, sphalerite, galena and bornite. Pyrite and marcasite are present most often, followed by chalcopyrite, sphalerite, bornite and galena — not necessarily in that order. Whole-rock analyses of six cores from Woodson and Greenwood County, Kansas, by semi-quantitative emission spectrography for Pb, Ni, Mn, Cr, V, Co, Cu, Zn, Mo and Sn, indicated the presence of unusual mineralization levels. Two highly mineralized cores had Ni concentrations of 300-1,600 ppm with 11 of 28 samples greater than 1,000 ppm. Cr levels (300-1,250) also greatly exceeded background levels. Measured concentrations of Zn, Pb, Cu, Co and Ag were comparable to or exceeded those of productive jasperoid from several mining districts of the western United States.

In searching for "big" ore deposits of the Mississippi Valley type, Cannon and Pierce suggested that one should search for J-type leads in which the Pb^{206}/Pb^{207} ratio is near 1.40. Pb-isotope analyses of galena samples from a wide area of the Mid-Continent are identified as J-type. Applying the concept of Cannon and Pierce, most samples examined yielded $Pb^{206}/207$ ratios in the range of 1.30-1.50. However, samples from the Big Jumbo, an abandoned mine in Pennsylvanian rocks in Linn County, Kansas, yielded a value of 1.41, which strongly suggests the need for further evaluation of this prospect.

Isotope ratios (206/204) of J-type Pb from surface and mine samples ranged from 21.6 to 22.5; in contrast, ratios from subsurface core samples exceeded 22.5 and ranged to 27.1. Also, 207/206 ratios from the mine and surface samples were greater than 0.7; those from the second category were less than 0.7. Samples from succeeding older stratigraphic units (relative age determined by conodont biostratigraphy) yielded generally increasing 207/206 ratios. The significance of the seeming correlation between these two types of data is not clear, but the possibility of a meaningful relationship merits further investigation.

Casino, Yukon — A Geochemical Discovery of an Unglaciated Arizona-type Porphyry.

ARCHER, A. R., and MAIN, C. A., Archer Cathro and Associates Ltd., Whitehorse, Yukon.

The first copper-molybdenum porphyry deposit in Yukon was found on the Casino Silver Mines property by Brameda Resources Ltd. in 1968, using geochemistry. The deposit is situated in the Dawson Range, 180 miles northwest of Whitehorse, in one of the few portions of Canada that escaped Pleistocene ice-sheet glaciation. The unglaciated surface of the deposit displays a well-developed zone of surface leaching. A zone of secondary chalcocite enrichment underlying the leached capping and hydrothermal alteration pattern are more similar to porphyry deposits in Arizona than those in British Columbia. Stream-sediment geochemistry located the area of interest, and soil geochemistry proved to be the most effective tool for locating the mineralized zone. The exploration history of the deposit and the geochemical response for copper, molybdenum, lead, tungsten, gold and silver are discussed.

Molybdenum Surface Depletion and Leaching.

BARAKSO, J. J., Anaconda American Brass Ltd., Britannia Beach, B.C., and BRADSHAW, B. A., Copper Range Exploration Company Inc., Toronto.

A litho-geochemical study was carried out on three major molybdenum properties in west-central British Columbia (Alice Arm, Endako and Berg). The purpose was to observe the extent of supergene oxidation and depletion of molybdenum under different climatic environments.

Oxidation and leaching is not fully appreciated in exploration, but it clearly reveals itself in open-pit operations.

In the case of the Alice Arm deposit, the amount of near-surface depletion was not realized until pre-production stripping was done, because of the solubility of molybdenum oxides in drill water under those conditions. Leaching at the Berg deposit extends to 200 feet or more for copper, but molybdenum oxides were noted down to only 50 feet. In the case of Endako, annual precipitation is only 15 inches per year. The oxidation of molybdenite extends only to a few feet.

A study was devoted to the search for the influencing factors of oxidation and leaching in the field and laboratory, including chemical, mineralogical and bacterial characteristics. It was concluded that there is depletion of molybdenum at these properties at a variable rate depending on major controlling factors, such as the amount of sulphide present, Eh and pH relationships, and the presence of iron and other complexing ions, as well as the amount of rainfall.

All these factors, individually and/or in conjunction can be responsible for the depletion of molybdenum in a given environment.

Optical Detection of Geochemical Anomalies in the Atmosphere.

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Certain elements such as mercury and iodine have a high vapour pressure and are present in the atmosphere in vapour form in significant concentrations. These elements may be detected by optical methods either by sampling the atmosphere in multipath optical cells or by true remote sensing techniques in which gaseous absorption or emission spectra are identified by optical correlation. Work by Williston, McCarthy and others has already indicated the potential exploration value of atmospheric measurements of mercury, and the present writer and his colleagues are currently investigating the possible uses of iodine remote sensing. Optical equipment has been constructed for measuring both atmospheric mercury and iodine on a continuous basis, and work is underway on airborne installations of this equipment. Some of the details of this instrumentation are described. High-altitude experiments from a stratospheric balloon have already been successfully carried out to establish the feasibility of making certain types of gas measurements by remote sensing from satellites.

Although the development of techniques appears promising, much remains to be done in establishing the operational value of atmospheric geochemical measurements in exploration. Considerable experience will have to be obtained in interpreting complex meteorological effects. The effects of vegetation are also being investigated.

Trace-Element Study of the Oquirrh Mountains, Utah.

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The Oquirrh Mountain Range, trending north-south, is about 30 miles long and 10 miles wide, is located approximately 20 miles west of Salt Lake City and is the hub of metal mining activity in Utah. Mining districts within the mountain range include: Bingham-Lark (West Mountain), Ophir, Rush Valley, and Mercur. Of these, the Bingham district is the largest. Copper, lead, zinc, silver, gold and molybdenum are the principal metals produced from these districts.

A rectangular area encompassing nearly 400 square miles has been sampled on a quadrilateral grid. Three hundred soil samples have been collected on section corners about one mile apart throughout the mountain range at a depth of 8-12 inches to prevent possible contamination from operating and former smelters located near the boundaries of the mountain range.

These soil samples have been analyzed for copper, lead, zinc, silver, molybdenum, manganese and iron by X-ray fluorescence using arsenic as an internal standard. The arithmetic mean metal content of the soil is as follows: copper averages 129 ppm; lead averages 226 ppm; zinc averages 244 ppm; the silver content is lower and averages 10 ppm; the molybdenum content is 169 ppm; and the manganese content averages 721 ppm. The frequency distributions of the elements are positively skewed and are represented by log-normal or exponential curves. These data have been transformed to approximate normal distributions and trend surfaces of trace metals and trace-metal ratios and their residuals have been prepared.

The mining districts are effectively delineated. Contamination from smelter fumes is evident and localized. Trace-element anomalies separate from those representing known mining districts are suggested.

Exploration for Hydrothermal Mineralization with Airborne Gamma-Ray Spectrometry.

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Airborne geochemical prospecting is possible by surveying with a high-sensitivity airborne gamma-ray spectrometer with large-volume NaI (Tl) crystal detectors. The high-sensitivity spectrometer measures

small variations in the concentration of potassium (as K^{40}), thorium (as Tl^{208}) and uranium (as Bi^{214}) along the flight lines in the area surveyed. Hydrothermal dispersion patterns are indicated by anomalous measured values of the concentrations of potassium, thorium, uranium, or their ratios. In two survey areas, copper mineralization was located along favorable structures within hydrothermal dispersion patterns delineated by airborne geochemical surveys. In metamorphic terrane where there had been potassium metasomatism, the hydrothermal dispersion patterns were indicated by high potassium/uranium ratios (K^{40}/Bi^{214}). In a sedimentary environment that had been intruded by a stock, the path of hydrothermal fluids was indicated by uranium (Bi^{214}), thorium (Tl^{208}) and uranium/thorium (Bi^{214}/Tl^{208}) ratios. Examples from Canada, Australia and the United States will be presented.

Geochemical Exploration of Carbonatite Complexes in Eastern Uganda.

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The eight known carbonatite complexes, which occur between $34^{\circ}00'E$ and $34^{\circ}30'E$, are divisible into an early Tertiary sub-volcanic group and a later Tertiary group associated with widespread alkaline volcanism. The former, restricted to southeast Uganda, follow a 65-km-long NNE-SSW line and comprise the Budeda, Butiriku, Bukusu, Tororo and Sukulu complexes. The latter, represented by the Lolekek, Napak and Toror complexes, occur farther north, in Karamoja, and are the roots of dissected volcanoes.

A comprehensive economic mineral appraisal of six of the centres is at present being undertaken as a special Carbonatite Exploration Project. This involves detailed geochemical soil and stream-sediment surveys, with systematic residual soil mineralogy in poorly-exposed areas, followed by geophysical work, pitting and drilling.

Pioneer geochemical surveys of the thickly mantled Bukusu Complex, similar geologically to Palabora in South Africa, revealed four high-contrast copper anomalies in residual soils overlying carbonatized ultramafic and alkaline rocks. Similar copper anomalies have been found at the almost completely obscured Butiriku Complex. At both localities, residual soil geochemistry and mineralogy are used as mapping aids and as pathfinders of possible mineralization.

Thick eluvial and colluvial soils overlying carbonatite at the Sukulu Complex carry abundant magnetite and apatite with some pyrochlore, but current interest lies in strong coincident lead and zinc anomalies ($>1,350$ ppm and $>15,600$ ppm respectively), probably indicative of late-stage mineralization.

Geochemical surveys of the Karamoja carbonatites, where the climatic environment is semi-arid and markedly seasonal in contrast to the humid conditions farther south, indicate, in addition to ubiquitous Nb, enrichment in rare earths, Mo, Ba, Sr and, of particular interest, Be. At Napak, where the background is approximately 2 ppm, soils contain up to 80 ppm Be, i.e. values similar to those obtained over beryl pegmatites. The presence of a fourth unexposed carbonatite is suggested by local soil enrichment in Nb, Be and rare earths.

A Miocene sedimentary series, derived from carbonatite(s) masked by volcanics, contains local concentrations of pyrochlore and apatite, the richest sections being indicated by stream-sediment sampling.

The Continuing Education of The Exploration Geochemist: A Report of an Experimental Workshop.

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A group of twenty-five North American exploration geochemists participated in a three-day experimental workshop held in April 1969 at the Colorado School of Mines. The objective of the workshop was to provide for a free exchange of ideas and the discussion of geochemical problems in an informal atmosphere. No publications were planned. Audience participation increased as it became apparent that company security need not be involved. Seven sessions, led by specialists, included these topics: Statistics, Remote Sensing, Mercury Instrumentation and Application, Uranium Exploration, Exploration in Nevada, Problems in Reconnaissance, and Sample Analysis.

The results of the meeting were encouraging and provided guidelines for holding future workshops.

Trace-Element Anomalies in Igneous Wall-Rocks of Hydrothermal Veins.

BOLTER, E., AL-SHAIEB, Z., and TIBBS, N. H., Department of Geology, University of Missouri at Rolla, Missouri.

Two hundred and fifty vein and andesitic wallrock samples from two low-grade gold-silver deposits of the Searchlight District, Nevada, were analyzed for gold, silver, copper, lead and zinc. The samples were collected along lines normal to the veins at intervals of 1 to 10 feet. Analysis was performed by neutron activation and atomic absorption spectrophotometry.

In most cases, the concentration of the elements decreases with increasing distance from the vein and reaches background values at a distance of 40 to 120 feet. The results suggest that gold and silver are more mobile than copper, lead and zinc. Anomalies are better developed in the hanging wall than in the footwall of a vein. Frequently, the wallrock has relatively low concentrations in the immediate vicinity of the vein.

Summary of Research and Development in Geochemical Exploration in Scandinavian Countries.

BOLVIKEN, B., Geological Survey of Norway, Trondheim; **NILSSON, C. A.,** Geological Survey of Sweden, Stockholm; and **WENNERVIRTA, H.,** Outokumpu Oy, Outokumpu, Finland.

The role of geochemistry as an aid in prospecting is growing rapidly in Scandinavia. In Finland the investigation of soil and till dominates, whereas in Norway emphasis is placed on regional stream-sediment surveys. In Sweden the two methods are used to about the same extent — stream sediments for regional reconnaissance and till sampling for detailed investigations. Biogeochemical methods are tested as to their applicability in detailed prospecting work. It is thought that bedrock geochemistry will develop into a valuable tool in prospecting for blind ores. Investigations on trace-element patterns in the wall rocks of several orebodies are being carried out, mainly in Finland and Sweden. In the course of prospecting for uranium, a geochemical program, including sampling and analyses of water from streams, is being developed in Sweden. Modern computer techniques have been successfully applied to the treatment and interpretation of the increasing number of analyses.

A Statistical Approach to the Problem of Interpretation in Geochemical Prospecting.

BOLVIKEN, B., Geological Survey of Norway, Trondheim, Norway.

The concepts **background** and **anomaly** in geochemistry can be considered as statistical distributions. Both should, therefore, depict straight lines when plotted on probability paper. A simple graphical method using probability paper for separating empirical geochemical distributions into background and anomalous will be described and some examples of its practical use demonstrated.

Geochemical Exploration Data-Processing Techniques Utilized by the U.S. Geological Survey¹.

BOTBOL, J. M., U.S. Geological Survey, Denver, Colorado.

Recent advances in analytical techniques have resulted in the acquisition and accumulation of vast amounts of geochemical data. The U.S. Geological Survey in Denver is utilizing a modern computer and a geochemical data information and statistical processing system not only to process the data, but also to aid in their evaluation. This information system is called the Rock Analysis Storage System (RASS) and has provision for all analytical results and brief geologic descriptions (including latitude and longitude) for every sample entered in the system. Conceptually, RASS is a large rectangular array with a fixed number of columns and an infinite number of rows. The columns represent geologic and chemical variables, and each sample

¹Publication approved by the Director, U.S.G.S.

occupies one row. Data are entered into RASS on standard punched cards and are stored on magnetic tape or disk. Retrievals are formulated on the basis of any value or values for any variable or combination of variables. Retrieved data sets are transferred to a magnetic tape or disk and are automatically transformed to a format that can be easily manipulated by a series of statistical and processing programs called STATPAC. Once a selected data set is in STATPAC format, the data can be evaluated statistically and plotted.

The geochemical study of the Coeur d'Alene district, Idaho, is the first major project in which all geochemical data have been completely processed within the framework of the U.S. Geological Survey's geochemical information system. Data sets were retrieved on the basis of formation and type of sample. There were nine major formational groups and four types of samples. The retrieval created 36 STATPAC data sets. For each data set, the 50th, 75th and 90th percentiles were computed for each element. Linear correlation coefficients among logarithms of values for all pairs of elements were computed. New variables were created by calculating the ratios of selected elements. All variables were then gridded on 1,000-foot intervals, and the average for each 1,000-foot block was computed. The gridded data were then automatically scribed onto a plastic film. Mylar positives were made from the scribed negatives, and ozalid work sheets were made from the positives. The positives were suitable for publication, and preliminary statistical results and maps were released in an open-file report.

In all, about 6,000 soil samples and 2,500 rock samples were collected during three successive field seasons. Each sample was analyzed for 41 elements. With the aid of the computer, RASS and STATPAC, the Survey geologists began the evaluation of three seasons' fieldwork at the close of the third season and released useful intermediate results within a few months. The final evaluation of the analytical data will be completed within a year.

New methods of communication with the computer are currently being developed. An experiment involving remote entry of analytical data on a time-share basis was successfully completed at a distant field site and at the U.S. Geological Survey laboratories in Denver. The free-field format of the input at the time-share terminal results in data preparation that is three times faster than conventionally punching the same data onto formatted cards.

Geochemical Methods in the Detection of Hidden Uranium Deposits.

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Conventional methods of prospecting for uranium using radioactivity detectors are ineffective in regions where there is a relatively thin inactive overburden. Research based on a geochemical approach to discover hidden orebodies is described — in particular the use of neutron activation methods of sample analysis. Indicator elements, including radon, have been investigated, and the use of these techniques applied to soils, stream sediment and water samples — both on a regional and local scale — is discussed. The pitfalls to be avoided are also mentioned.

Boron and Boron Minerals as Indicators of Mineral Deposits.

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Boron and boron minerals are widely diffused in many types of endogenic and exogenic mineral deposits. The minerals most commonly found in endogenic deposits include tourmaline, axinite, danburite, datolite, dumortierite, kotoite, ludwigite and nordenskiöldine. Those in exogenic deposits include numerous borates such as borax, boracite, colemanite, kernite, and tinalconite. Boric acid (sassolite) and other soluble borates occur in steam jets, hot springs, and other natural waters.

The following types of deposits are characterized by the development of boron minerals or boron metasomatism.

Deposit	Characteristic Boron Minerals
Pegmatites (simple and complex types)	Tourmaline
Skarn (including those containing Be, Fe, Cu, Zn, Pb, Sn, Bi, rare earths, Mo and W)	Tourmaline, axinite, danburite, dumortierite, kotoite, ludwigite, nordenskiöldine

Greisenized, sericitized and albized granites and similar rocks containing Be, Sn and W	Tourmaline
Tin-tungsten veins and lodes	Tourmaline, axinite
Gold quartz veins and lodes	Tourmaline
Polymetallic (Cu, Pb, Zn, Ag, etc.) veins and lodes	Tourmaline, axinite
Porphyry Cu and Mo deposits	Tourmaline (only certain deposits)
Native copper deposits in basalts, conglomerates and sandstones	Datolite, axinite
Native silver deposits	Datolite (rare), axinite
Mercury deposits	Tourmaline (rare)
Bedded borates	Borates
Hot springs and steam jets	Boric acid (sassolite), borates

Weathering, oxidation and leaching of endogenic deposits yields soluble borates and the boron resistate minerals, mainly tourmaline and axinite. Both the soluble borates and boron resistate minerals collect in the soils and in nearby stream sediments. Near bedded borate deposits, the natural waters may be greatly enriched in soluble borates. Vegetation in the vicinity of boriferous deposits may become enriched in boron and may also exhibit endemic characteristics (Buyalov and Shvyryayeva, 1961).

Geochemical surveys based on soils, stream sediments, waters, heavy minerals and vegetation using boron as an indicator are useful in searching for the types of deposits noted in the table above. Specific examples are given by Boyle (1965) for soils over a tin occurrence in Yukon and by Gleeson (1968) for stream sediments in Yukon. In the latter survey, both skarn-type deposits of scheelite and polymetallic deposits containing Pb, Zn, Cd and Ag are indicated by boron analyses of the stream sediments. Others examples, not yet published, suggest that boron analyses of soils and stream sediments may indicate gold-quartz deposits and pegmatites.

Analyses of tourmaline and other boron minerals obtained in heavy-mineral surveys suggest that these minerals may indicate certain types of deposits in a terrane. Thus, tourmaline from lithium pegmatites is enriched in Li, Cs and Rb; and tourmaline from tin deposits is enriched in Li and Sn.

Difficulties may be encountered in interpreting geochemical surveys based on boron as an indicator of mineral deposits where the country rocks contain abundant tourmaline, dumortierite, or other boron minerals, resulting mainly from metamorphism or igneous intrusion.

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Distribution of Copper and Zinc in Rocks of Guichon Batholith, B.C.

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Aqua-regia-extractable copper in 354 fresh-rock samples from the Guichon batholith, B.C. shows a multi-modal lognormal distribution, with values ranging widely from 1 to 1,600 ppm. Aqua-regia-extractable zinc, as determined in 253 samples, has a normal distribution and a much more limited range of values from 5 to 80 ppm. The proportion of total copper extractable by acid attack is considerably

higher than that of zinc, indicating that the two metals differ in their form of occurrence.

Trend surfaces computed for both copper and zinc show patterns that correlate with the zonal arrangement of major rock phases; i.e. a general decrease in metal values from the marginal hybrid phase inward. This trend is much better expressed for copper than for zinc. The mean copper content of the two central phases, Bethlehem and Bethsaida, is significantly lower than the means of the other phases at 0.05 t-probability level.

Both copper and zinc show little or no correlation with the modes of main rock-forming minerals nor with the iron and sulphur content.

On a regional scale, the central rock phases, containing the main porphyry copper deposits in the Guichon batholith, are lowest in copper. This fact must be kept in mind when estimating the background values for any kind of geochemical prospecting in the area. A relatively high copper content of a granitic phase is not indicative of superior ore potential.

Geochemistry and Ore Exploration.

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Geochemical science and the prospecting arts of geochemical search ought to be placed in a true perspective for the ore search mission. Geochemical prospecting and the search for actual orebodies with the aid of geochemistry are not strictly synonymous. The word geochemistry is in itself an anomaly because it embraces two unlike disciplines; only the second is factual, and the first is traditionally stochastic and hypothetical. What is needed for success in geochemical exploration is a marriage between the strictly geochemical science and a probabilistic art. The exploration game can be played either from the statistics of immediate experience or from the base of an a priori judgment. We have not yet generated sufficient experience in geochemical exploration under various terrains and climate to justify the former approach. On the other hand, some principles have emerged out of our efforts which can be used in a priori hypothetical ways as guides to a more economical search in future experience. In practice, emphasis must be placed on the dimensionality of the search problem and its suggested geochemical solution. Orebodies are three-dimensional realities, whereas geochemical data are, at their optimum, unidimensional facts of space.

The Utilization of Metalloids (arsenic, phosphorus, fluorine) as Pathfinders for Skarn Tungsten Deposits in Pyrénées (France).

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The discovery of scheelite deposits in skarns associated with granitic intrusions is mainly the result of field geology and conventional prospecting. However, the correlation of these deposits with the apical parts of batholiths leads to the utilization of airborne geophysics and of geochemistry to discover buried intrusions which can be of mining interest.

To achieve this goal, the deposits of Salau and Avrenere were sampled at the "tactical" and "strategic" levels of exploration, and the samples were analysed for tungsten, lead, zinc, copper, molybdenum, arsenic, phosphorus and fluorine.

Tungsten shows very strong anomalies that are closely restricted to the trace of the deposit and to the hydrographic network downstream from the deposit. The other metals show clear but smaller anomalies which do not enlarge the target.

The metalloids show increasingly larger anomalies in the order arsenic - fluorine - phosphorus. The enlargement of the target is up to 500 meters for fluorine, without any field indication of hydrothermal alteration.

The metalloid elements appear to be good indicators in regional prospecting for granitic intrusions and their associated mineral deposits.

Distribution Functions of Ore Elements in Rocks for Evaluating Ore Potential.

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Several investigators have shown that the frequency distribution by size of genetically related economic ore deposits within a given area or rock unit obeys probability laws, with many of these distributions approximating lognormal distribution functions. The lower bounds of these distributions appear to be always 'artificially' limited by economic considerations such as size and grade. The sampled deposits are, therefore, probably only the extreme right tail of a more general probability distribution for the ore minerals in the given unit, with the lower, much more frequent, components of the distribution being represented by segregations of ore material ranging in size from 'showings' to single grains.

Unfortunately, the function best describing an empirical distribution cannot be relied upon to remain constant across the entire range of size classes. It is, therefore, not possible to predict, by conventional probabilistic methods, the frequency and size of ore deposits from data on the more frequent size classes of the given unit. It does, however, behoove the geochemist to make the best use of the latter data, which may readily be obtained by chemical analysis of samples from surface exposures, to estimate the ore potential of a rock unit or area. Such data are unlikely to become one of the more useful inputs to mathematical methods of decision-making in mineral exploration.

The distribution of ore elements has been investigated for two types of ore deposit where it may reasonably be supposed that the ores have been derived by segregation of sulphides from the magma of the rocks that are the host of, or closely adjoin, the ore deposit. In the first case, the distribution of HNO_3 soluble copper in 715 samples of Coppermine (N.W.T.) basalt has been compared with similar data for 195 samples of mainly basaltic lava from the Yellowknife (N.W.T.) greenstone belt. The former series contains copper deposits and abundant showings of this metal; in contrast, there are no known copper deposits of the segregation type in the Yellowknife greenstone rocks that were sampled. The Coppermine data show the type of frequency distribution which is believed to be the likely accompaniment of related ore deposits — a right skewed distribution which is continuous into the range of thousands of ppm copper. The Yellowknife data are not right skewed, and no sample exceeds 273 ppm copper.

For the second phase, 1,080 samples from more than forty ultramafic bodies distributed across the Canadian Shield were analysed for ascorbic acid - hydrogen peroxide - soluble nickel, copper and cobalt. Bodies that are associated with nickel and/or copper mineralization tend to be enriched in these elements, particularly copper and nickel, compared to barren ultramafic bodies. Multivariate methods are used to classify the ultramafic bodies by ore potential on the basis of analyses of the above three elements.

Computerized Methods for Interpreting Reconnaissance Geochemical Surveys.

CAMERON, E. M., and HOBBS, D., Geological Survey of Canada, Ottawa.

The principal purpose of computerized methods for interpreting reconnaissance data is to extract and lucidly display the greatest amount of information relating specifically to potential ore deposits. An important by-product is the considerable reduction in the labour of manual collation, interpretation and plotting.

The procedures used for interpretation aim at the separation of the chemical "signal" caused by ore deposits from other signals and from random noise. At present, perhaps the most generally useful technique is to contour by computer the residuals from a low-order polynomial trend surface. The trend surface removes the gradual variation due to regional lithologic change, climate, vegetation and topography; the moving average approach utilized in computer contouring reduces the effect of random noise and reveals zones of consistent local variation. The choice of the most appropriate form of trend surface and of the parameters of the contouring method remain highly subjective, and thus the comparison of the effectiveness of other surface-fitting methods is urgently required. The many methods developed for communications theory and other

sciences offer considerable scope for the geochemist. Because, in most reconnaissance surveys, material is sampled at intervals along linear drainage features, such techniques as Markov schemes are of potential application. Apart from these sophisticated techniques, simpler methods may often be quite effective in separating the signals. For instance, if the rocks of an area can be subdivided into a few, relatively homogeneous lithologic types, the element concentrations in each sample may be normalized using the mean and variance of all samples overlying that particular rock type.

The above methods utilize the relationship between the concentration of one element in a sample to the concentrations of the same element in surrounding samples to differentiate the signal of interest from other sources of variation. A different approach to separating the signals is to use multivariate techniques which employ the relationship between the different elements contained in the samples. The methods that have sparked most interest are component and factor analysis, although other methods may prove to be more effective. Each factor that is extracted hopefully represents the variation that is due to but one geological or geochemical process, rather than the sum of processes that is usually represented by the concentration of an element. Scores may be computed measuring the influence of every factor on each sample, and these data may be trend-surfaced, contoured and plotted in the same fashion as the original element data. It may often be useful to apply component or factor analysis to the residuals from a trend surface, as the trend surface may be effective in removing some "factors" and thus simplifying the task of the multivariate procedures.

Notwithstanding the above, factor analysis may often be inappropriate for the interpretation of reconnaissance data. The methods are designed to extract a set of factors operating within a single population. If the area studied is heterogeneous in terms of its geology and assemblage of mineral deposits, there may be a very large number of different factors or processes acting upon the same variables, which is quite beyond the ability of factor analysis to resolve. The interpretation given by factoring these conditions may be quite misleading. Such effects may be tested by subdividing the data by subarea and determining whether the factor matrices are reasonably constant between the subareas. The second impediment to utilizing factor analysis for reconnaissance surveys is that six to eight elements may be too few to significantly resolve the factor structure, which remains constant, irrespective of the number of elements that may be determined.

It is perhaps not generally appreciated that the introduction of such powerful statistical methods may require changes in other aspects of the reconnaissance survey. For instance, to get the best results from trend-surface and contouring methods demands a reasonably even distribution of samples over the area and more attention to optimizing the sampling interval in terms of both economics and the size of the expected anomalies. In general, the utility of factor analysis increases with the number of variables factored. More attention should be given to determining major elements simultaneously with the trace metals (as may be done with a direct-reading optical spectrometer). Factoring of such data would considerably reduce the effect of variation of the trace indicator metals that is due to varying quantities of major minerals in the sediment.

The Utilization of Eskers as Ancient Hydrographical Networks for Geochemical Prospecting in Glaciated Areas. CACHAU-HERREILLAT, F., B.R.G.M.-D.S.G.N., B.P. 818, 45 Orléans, France; and LA SALLE, P., M.R.N., 1620 Boulevard de l'Entente, Québec 6, Québec, Canada.

In the area of the "Clay Belt" of Abitibi, mining exploration is a challenging problem to which airborne geophysical surveys failed to give a complete solution. Geochemical prospecting in soils or stream sediments also failed to discover such deposits as Joutel (R. Kelly, personal communication, 1968). The interference of up to 200 feet of glacial drift in places prevents the sampling of ground moraine, which is generally effective (Wennervirta, 1968). H. A. Lee (1965) suggested sampling eskers in the same way as actual streams are used for mineral exploration.

The Department of Natural Resources of Québec and the Bureau de Recherches géologiques et minières of France decided to sponsor a joint study of both the mineralogical and geochemical constitution of the eskers in the mining region of Abitibi.

The first step in 1968 consisted only in the sampling of the Mattagami esker* at $\frac{1}{2}$ -mile intervals, wherever access was possible. A mineralogical sample of 50 to 100 pounds of esker sand and gravel, and two geochemical samples, one in the "B" horizon of the podzol and one in the "C" horizon, were collected. The geochemical samples were analysed for copper, zinc, lead, silver, gold and molybdenum. The sampling of the B horizon was done simply for the sake of completion and should definitely be ruled out as a geochemical prospecting tool in the eskers of the Abitibi area. The C horizon shows some high values. However, in the absence of mineralogical data, we do not yet know in which minerals the anomalous elements are concentrated. Furthermore, the absence of any known source along the Mattagami esker, makes the evaluation of the distance of transport, based on published literature on the subject, no more than an educated guess for the moment.

*The eskers are deposits of ancient streams associated with the melting of continental ice sheets. In the Abitibi area, they appear to be evenly spaced (average spacing: 5 miles). They are stratigraphically earlier than the varved clay, but they appear as topographic "highs" through the clays.

Remote Detection of Geochemical Anomalies — A Preliminary Feasibility Study¹

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Spectral reflectance curves for red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L) Mill), based on in situ measurements, were obtained at Cathart Mountain, Maine, where a large low-grade copper-molybdenum deposit occurs on a forested mountainside. Large areas of soil contain highly anomalous amounts of copper and molybdenum which are also anomalously concentrated in the trees. Five specimens of each species growing in the area of metal-rich soils were measured and compared with similar specimens growing in a nearby unmineralized area. Other factors — such as soil type, soil moisture and exposure — that might affect reflectance were kept as constant as possible between the two groups.

Simultaneous spectroradiometric measurements were obtained of the solar radiation incident upon and reflected from the trees at 27 different wave lengths in the 350- to 1,100-nanometer region of the spectrum. These data were used to compute per-cent directional reflectance at each wave length. To make the reflectance measurements meaningful for possible future experiments using an aerial sensor, the spectroradiometer was placed above the tree and pointed downward.

The spectral curves for both background and anomalous groups of red spruce are essentially the same in the visible region, but in the near infrared the anomalous group shows a uniform pattern of decreased reflectance. The curves for balsam fir contrast markedly with those of spruce because, at every wave length, the anomalous fir group has a higher reflectance than the background group.

The inferences to be drawn from the data are limited by the small sample size, but, on the basis of this experiment, multispectral aerial photographic techniques could probably be used to separate balsam fir trees with anomalous metal contents from the other tree groups sampled. The present results are encouraging enough to warrant additional studies.

An Evaluation of Some Geochemical Sampling in the Search for Concealed "Porphyry" Copper-Molybdenum Deposits on Pediments in Southern Arizona, U.S.A.¹

CHAFFEE, M. A., and HESSIN, T. D., U.S. Geological Survey, Denver, Colorado.

A detailed geochemical survey has been made over a "porphyry" copper-molybdenum deposit located on a desert pediment on the eastern edge of the Vekol Mountains, Pinal County, southern Arizona. Only a few mineralized outcrops remain exposed today in the vicinity of the deposit; the greater part of the deposit is now buried by postmineralization alluvium as much as 300 feet thick.

¹Publication approved by the Director, U.S.G.S.

About 2,400 samples of soil (-60 mesh) and bedrock, plus leaves and stems from three species of deep-rooted plants common to the area (creosote, ironwood and foothill palo-verde), were collected and analysed for zinc, copper, molybdenum and manganese by wet chemical methods.

The patterns exhibited by copper, molybdenum and manganese in soils do not correlate spatially with the concealed portions of the deposit. The anomalous patterns present merely reflect the chemistry of subjacent metallized outcrops. The restricted nature of these patterns suggests that these elements have only a limited mobility in this environment. Zinc soil patterns, on the other hand, show that zinc has migrated from zinc-rich outcrops downslope toward active drainage channels. Although these zinc patterns do not define the known copper-molybdenum deposit, they do suggest a favorable fringe-zone environment.

The plots of zinc, copper and molybdenum (but not manganese) in the ash of parts of all three plant species show anomalous patterns which extend as much as 800 feet beyond mineralized outcrops into areas in which postmineralization alluvium overlies the concealed deposit, but in which there are no corresponding soil anomalies. Because the roots of these plants may penetrate as much as 100 feet of overburden, it appears that the anomalous metal contents of the plant reflect mainly the concealed mineral deposit. Biogeochemical sampling of deep-rooted plants should, therefore, be a useful tool in the search for concealed mineral deposits in the Basin and Range province.

A Geochemical Case History of the Rajburi Antimony Prospect, Thailand.

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The Rajburi antimony prospect occurs in the Kanchanaburi series of sediments (Carboniferous?), overlain by Rajburi limestone (Permian?). Surface outcrop of the in situ mineralized showings is practically nil, but occasionally mineralized boulders have been encountered. A detailed soil geochemical sampling program was undertaken on a 50-metre grid, and a hand auger was used to collect samples from a depth of 1 metre below the surface.

The survey delineated several highly anomalous antimony and lead areas; 100 ppm and less were considered as background values, and the significant anomalies reached as high as 4 per cent Sb_2S_3 and 1.2 per cent Pb. The significance of the anomalies is emphasized because of the low mobility of antimony and the flat nature of the country.

The trend of the anomalies, being at large angles to the regional N-S trend, largely nullifies the effect of high background rocks as the source of the anomalous values. Maximum concentrations occur primarily along an E-W trend, with minor NW-SE and NE-SW trends.

Following the geochemical study, test-pitting by bulldozer led to a better knowledge of the mineralization. High-grade mineralization was found mainly in quartzite locally interbedded with silicified shale. Thus, a low-cost soil geochemical study led to the buried ore.

Role of 'Humus Matter' in the Formation of Geochemical Anomalies.

CHOWDHURY, A. N., and BOSE, B. B., Geological Survey of India, Calcutta.

Residual soil is one of most widely employed sampling materials for tracing geochemical anomalies in geochemical exploration. Systematic studies on the phenomenon of the formation of geochemical anomalies in residual soils are being carried out by the Geological Survey of India. All the different factors contributing to the retention of metal and leading to the formation of geochemical anomalies are being studied in detail. The role of 'humus matter' in soil is recognized as an important factor. The paper reports some results obtained on the reaction and equilibrium of 'soil humus matter' with dilute solutions of heavy metals, such as Cu, Pb, Zn, Ni and Co.

'Humic acid' was separated from a typical sample of soil and purified by electrodialysis. Suspensions of the 'humic acid' were brought to equilibrium with dilute solutions of the heavy metals, and the amount of heavy metal retained by the humic acid was measured.

The equilibrium amount of metal retained was more or less the same for the five metals studied. The shape of the adsorption isotherm (metal retained versus equilibrium concentration in solution) was different for the different metals. The equilibrium concentration of the metals in solution required for maximum retention was in the order $Pb < Cu < Zn < Ni < Co$. Pb attains equilibrium with a minimum concentration in solution. The metal-holding capacity of the 'humic acid' was observed to be in the order of 400 micro-equivalents/gm of humic acid. The release of the metals from metal humates prepared separately was also studied. The release of the metal from the saturated metal humates at different pH's showed an interesting order of release. Co was released first and Pb released last; that is, the metals are released in the reverse order compared to the order of metal retention mentioned earlier. The nature of the 'humic acid-metal' system was also studied, and the relative chelating ability with different metals was reported. The stability of the chelates appears to be in the order $Pb > Cu > Zn > Ni > Co$. The significance of the results in relation to the formation of geochemical anomalies is discussed.

Geochemical Prospecting in Lateritic Soils of Alabama¹. CLARKE, O. M., Jr., Geological Survey of Alabama.

Different soil horizons were sampled over the Hatchet Creek disseminated copper prospect in Clay County, Alabama. The prospect is in greenstone and has been explored by drilling. Results of soil sampling indicate that the highest copper values are in the B3 horizon. On slopes subjected to erosion, soil samples from any horizon reflect accurately the underlying mineralization. Lower copper values were obtained on terraces and plateaus that are underlain by thick, well developed soils than on slopes. Copper values in the B horizon over mineralized areas average 550 parts per million on the plateau and 1,600 parts per million on slopes. The "background level" of unmineralized greenstone ranged from 50 to 100 parts per million copper.

Copper was also found concentrated in the B3 and upper part of the C1 horizon on plateaus in lateritic soils that are not associated with mineralization. A "false anomaly" of 300 to 500 parts per million copper was noted over mafic rocks in Tallapoosa County. Weathered rock below the gibbsite zone and soil from adjacent slopes contain a maximum of 100 parts per million copper, which is normal for mafic rocks in this area. The maximum concentration of copper overlying mineralized granite gneiss was 200 parts per million. This also occurred in the B horizon, and lower copper values were noted below.

Conflicting analytical results in lateritic soils on plateaus indicate that soils and topography should be considered as well as rock types in planning and interpreting geochemical surveys. This conclusion will apply to other regions where lateritic or sublateritic soils occur.

¹Publication authorized by the State Geologist, Geological Survey of Alabama.

Geochemical Exploration in Southern Africa and Madagascar.

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Geochemistry was first introduced in central Africa in the early fifties, notably in Zambia where it has been used extensively and successfully. Its application to prospecting in southern Africa has been significant only in the past decade.

Annual precipitation in the area reviewed ranges from 3 metres in the rain forests of eastern Madagascar and the eastern escarpment of southern Africa to 0.2 metre on the margins of the Kalahari Desert in the Republic of South Africa, South West Africa and Botswana. The conditions for geochemical prospecting are favourable because soils are residual over virtually the entire area, with the exception of those in the Kalahari basin, and the drainage systems are commonly well developed; consequently, extensive silt-sampling drainage reconnaissance surveys have been undertaken in Madagascar, Rhodesia and the Republic of South Africa. Large concession areas can be obtained, and thus areas exceeding 20,000 square kilometres have been prospected, usually at a sample density of one sample per square kilometre. Follow-up work in done by grid soil sampling of the C-zone in the high rainfall regions and of the B-zone in the thin soils of the more temperate regions.

The prospecting for copper, cobalt, nickel, zinc, lead, tin, niobium and molybdenum deposits has not, as yet, however, achieved any significant success.

Recent mineral discoveries in the arid regions on the margins of the Kalahari basin have given impetus to the use of biogeochemistry and geobotany. New techniques for prospecting for fluoride and phosphate have been developed, involving some major departures from the methods employed in metal prospecting, especially in sample preparation. In the past ten years, the use of multi-channel emission spectrographs has become more popular than colorimetric methods, and in the past three years, atomic absorption and X-ray spectrography have been more widely used.

The Importance of Environment in Biogeographical/Geobotanical and Biogeochemical Investigations.

COLE, MONICA M., Bedford College, London, U.K.

Biogeography/geobotany and biogeochemistry provide useful prospecting tools when the distributions of vegetation associations, plant communities and individual species are fully understood. These distributions represent plant response to the interplay of all the factors of the environment in space and time. The relative importance of individual factors varies spatially and according to the toxicity of an individual mineral.

The importance of environment in biogeographical/geobotanical and biogeochemical studies is reviewed in the light of hitherto unpublished results of investigations undertaken in Africa, Australia and Europe.

The environmental factors are assessed in the search for copper ores in the contrasting environments of South West Africa and Botswana and Bougainville Island in the Solomon chain. They are evaluated in the search for nickel ores in the contrasting environments of Rhodesia and Western Australia.

The success of geobotany in the low tree and shrub savanna country of South West Africa is attributed to a semi-arid climate with rainfall in the summer period of active growth, when plants are particularly susceptible to toxic conditions in the soil, combined with a direct relationship between vegetation and bedrock, which characterizes those parts of the area where level surfaces are planed across steeply dipping sedimentary rocks. Where the presence of transported Kalahari sand complicates plant/bedrock relationships, soil sampling at finer fractions than is normal and the analysis of samples of selected deeply rooted plant species offers promise. Where calcarete is particularly thick in Botswana, the recognition of anomalous plant communities in pans receiving drainage circulating from mineralized bedrock beneath the calcarete is promising. In both South West Africa and Botswana, copper mineralization has been found beneath geobotanical anomalies. Geobotany is assisting the elucidation of geological structure as well as the location of mineralization.

In the tropical rain forests, difficulties of access and of species recognition necessitate prior reconnaissance from a low-flying aircraft. On Bougainville Island, mountainous relief is responsible for altitudinal variations in the species composition of the forest, but the areas with the highest copper levels in the soils over the porphyry copper deposit carry a distinctive tree association which is independent of height above sea level.

The use of geobotany and biogeochemistry in the search for nickel ore is confronted by several problems, particularly that of distinguishing 'false anomalies' over ultrabasic rocks — notably serpentinite or hypersthene with high nickel contents — from true anomalies over sulphide orebodies.

The relatively simple vegetation/environment relationships in the vicinity of the Empress nickel deposit, located in Rhodesia in savanna woodland country experiencing summer rainfall, are compared with the complex ones over the Kambalda orebody and several other prospects in the sclerophyllous woodland and shrub country in Western Australia, which receives its rainfall in winter. Here, in some areas, relict laterite produces high nickel values in the soil which eliminate the normal background vegetation; in other areas, calcareous horizons in the soil profile counter the toxicity and permit background vegetation values to be obtained over areas underlain by sulphide-bearing rocks. The nickel contents of plant samples from both countries are compared, and the role of indicator and accumulator plants assessed.

Within the areas cited, attempts are made to assess the relative importance of climatic and geomorphological factors and soil profile characteristics, as well as geology, on the form and composition of the vegetation and on the mineral uptake of the plants. Attention is also given to the rooting habits and growth rhythms of individual species, their status as indicators of accumulators of particular metals, and the degree of toxicity of these metals in an over-all assessment of the importance of environment in biogeographical/geobotanical and biogeochemical studies.

Progress in the Calibration of Airborne Gamma Spectrometers for Geochemical Exploration.

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In principle, gamma-ray spectrometry can yield quantitative data on the contribution of Th, K and, in favorable cases, U. In the laboratory, the technique has been refined, particularly for Th and K, and less satisfactorily for U because of secular radioactive disequilibria in the U-238 series in many geologic samples. After thirty years' experience, most logging tools are still giving relative outputs in counts per unit time. Collimated gamma spectrometers for quantitative outcrop measurements have been in use for over eight years.

The calibration of airborne gamma spectrometers is difficult because of the large and usually heterogeneous area surveyed, terrain roughness and U-238 series disequilibria. Altitude and ground-speed variations also present problems. Using an outcrop gamma spectrometer to establish ground truth, a helicopter-borne gamma spectrometer, operated at an altitude of 50 feet and a ground speed of 60 knots, is being calibrated for Th, the simplest case, K is the next simplest case, and U will be the most difficult. Quantitative Th/K ratios are particularly convenient outputs. The low-flying-helicopter data are considered a necessary intermediate to calibrating fixed-wing systems that survey much larger areas during each measurement interval.

In terms of cost per analysis, volume of investigation per analysis, live-time data reduction and speed of survey, airborne gamma spectrometry is an attractive geochemical exploration technique for large areal operations.

The Association of Exploration Geochemists.

COOPE, J. A., Newmont Mining Corporation of Canada Ltd., Toronto.

The objects and purposes for which the Association of Exploration Geochemists is being constituted are: the advancement of the science of geochemistry, especially as it relates to exploration and associated research; to foster the common scientific interests of exploration geochemists; to encourage research and development of geochemical exploration methods in universities; to advance the status of the profession of exploration geochemistry; and to protect and maintain a high professional standing among its members.

Details of the contents of the constitution and some proposals on the organization and operation of the Association will be presented.

Trends in Geochemical Exploration in Italy.

DALL'AGLIO, M., Geochemical Group of Laboratorio Geominerario del CNEN, C.S.N. della Casaccia, Roma (Italy).

In Italy, geochemistry has been applied only recently to mineral exploration, and geochemical prospecting surveys have been undertaken to some extent only in the last twelve years. Geochemical prospecting was introduced by F. Tonani in the field of uranium research. Geochemical exploration has been employed only in a restricted sense, mainly by CNEN, for uranium and other elements.

From a methodologic point of view, the following results obtained in the last decade are of some interest.

- (a) Organizational and methodologic problems dealing with the determination of trace elements in water and alluvia samples have been solved. Some new analytical methods were devised to meet the needs of geochemical surveys, such as the determination of mercury, copper and zinc in natural waters and the determination of mercury in alluvial samples, etc. Complete mobile laboratories, mounted in car, van and house-trailer, and also compact portable laboratories for analyses in situ were built and tested.
- (b) Automatic processing of geochemical data has been applied by the CNEN Geochemical Group for some ten years. All geochemical data are transferred to punched cards and then submitted to automatic processing by means of computer. This procedure makes it possible to select anomalous samples in an objective and complete manner and to obtain, as a by-product, basic information on the distribution and circulation of the elements in the exogenic environment.

From a geochemical viewpoint, some interesting results have been achieved.

- (a) Geochemical prospecting on a regional scale has been applied in many Italian regions. This method is based on the study of water and alluvial samples collected over wide areas (10,000-50,000 square kilometers) with a low sampling density (1 sample every 10-20 square kilometers). The determination of all major constituents and some of the trace elements in water samples allows us to collect information on the prevailing conditions of weathering and to select the most promising areas for detailed prospecting in a short time and at a low cost.
- (b) The validity of hydrogeochemical methods in the exploration of many trace elements (Hg, F, heavy metals, etc.) was proven.

The methodologic results achieved and the practical results obtained in the discovery of new ores are discussed.

Comparison Between Hydrogeochemistry and Stream-Sediment Methods in Prospecting for Mercury.

DALL'AGLIO, M., Geochemical Group of Laboratorio Geominerario del CNEN, C.S.N. della Casaccia, Roma (Italy).

During the last few years, a concerted effort has been made by the researchers of CNEN Geomining Laboratory to achieve a better understanding of mercury, both in the basic and applied fields. As a first step in this program, new analytical methods have been devised for the determination of mercury in alluvial and soil samples and also in natural water samples.

Prospecting surveys were then carried out in order to evaluate the efficiency and applicability of various geochemical prospecting methods to the exploration for ore deposits. On the one hand, the hydrogeochemical behaviour of mercury was investigated in order to determine the characteristics of hydrogeochemical halos and the role of natural waters in the transportation of mercury. On the other hand, a regional geochemical survey of the whole of Tuscany was carried out. The analyses of about 1,000 samples of alluvia, collected over an area of 20,000 square kilometers, outlined some major anomalies. Such information subsequently led to the discovery of previously unreported new mercury deposits. The feasibility and the importance to prospecting of cinnabar halos in alluvia was also investigated by the mineralogists of the CNEN Geomining Laboratory.

In the paper, the above results are discussed in detail and some general conclusions are drawn with respect to the efficiency of the different prospecting methods for mercury.

Mapping From the Air by Gamma-Ray Spectrometry.

DARNLEY, A. G., GRASTY, R. L., and CHARBONNEAU, B. W., Geological Survey of Canada, Ottawa.

Since 1967, the Geological Survey of Canada, in conjunction with Atomic Energy of Canada Ltd., has been developing a high-sensitivity airborne gamma-ray spectrometer system for the purpose of measuring surface concentrations of K, eU and eTh. During the initial stages of the program, which have been described in earlier publications, problems of optimum spectrometer design, calibration and data correction were investigated. At the same time, ground investigations were undertaken to compare the K, eU, and eTh content of various rock types and overburden. One of the most important findings of this research was that in the Shield areas examined there is a close similarity between the radiometric composition of rock and its associated overburden.

In 1969, the first extended trials of the complete spectrometer system took place with a detailed survey of approximately 600 square miles in the Bancroft area of Ontario. Flight lines flown 400 feet above surface were spaced at $\frac{1}{4}$ -mile intervals, and radiometric data were accumulated and read-out onto magnetic tape at approximately 500-foot intervals along the flight line. In this way, approximately 75 per cent of the total surface of the area has been radiometrically sampled. The data on the magnetic tape have been corrected to allow for variable atmospheric-radioactivity, for variations in terrain clearance and for Compton scattering contributions in the spectrometer's lower energy channels. Corrected profiles have been computer-drawn along each flight line, and a variety of computer-drawn geochemical maps have been made over the area covered, based on a contouring program devised by Holroyd and Bhattacharyya. These show good correlation with the known surface geology, and the principal rock

types in the area can be distinguished. Information is also provided about the NE-SW zone of uranium and thorium enrichment which crosses the area, and a subdivision of granitic types can be made. The relative abundances of the various radioelements are shown to be a sensitive indicator of unusual concentrations, and these variables are particularly significant in using this type of data for mineral exploration purposes.

Minor Element Anomalies in Biotite from Quartz Monzonite Associated with Contact-Metasomatic Tungsten Ore, California.

DARLING, R., Department of Geological Engineering, Ecole Polytechnique, Montreal.

Samples of quartz monzonite were collected along nine surface and underground traverses perpendicular to intrusive contacts between quartz monzonite and other older rock types. The traversed marble-quartz monzonite contacts are mineralized with contact-metasomatic W-Mo-Cu ore. Contacts against quartzite and quartz diorite are barren.

Biotite was separated from forty-four of these samples, and the biotite separates were analysed by microprobe for fluorine and by emission spectroscopy for the elements B, Bi, Cr, Cu, Fe, Ga, La, Li, Mg, Mn, Mo, Na, Ni, Pb, Sc, Sn, Sr, Ti, V, Y, Yb and Zn.

The analysed samples were grouped into "ore" and "non-ore" groups for comparative purposes. The former were taken on traverses that cross ore-bearing contacts and the latter from traverses across barren contacts. Mean values for the two groups show that the biotite from "ore" samples contains more B, Bi, Cu, F, Li, Mn, Mo, Pb, Sc, Ti, Y and Zn and less Na, Ni and Sn than biotite from "non-ore" samples.

For samples of the "ore" group, the correlation between biotite chemistry and distance to the ore-bearing contact shows a change in biotite chemistry with proximity to ore. The portion of this change that is not genetically related to the presence of the ore is indicated by similar correlations obtained from "non-ore" samples. In this way, it is possible to isolate the changes in biotite chemistry that are related to the presence of nearby ore. These are an addition of Bi, Li, Pb, Mn, Y, Yb and Zn and a removal of Cu, F, Mg, Na, Ni, Ga, Sr and V.

Spectroscopic Determination of Arsenic in Geochemical Prospecting Samples.

DELAVALT, R. E., and MANSON, R. J., Department of Geology, University of British Columbia, Vancouver.

Results of arsenic determinations by a chemical method and by D.C. arc spectroscopy on duplicate samples are compared. Factors peculiar to spectroscopic analysis allow only a rather loose correlation; but nearly all the samples of plant or soil where more than 10 ppm had been detected by chemical methods gave a positive result by spectroscopy. Where arsenic is used as a pathfinder for silver, cobalt or other metals, spectroscopy has at least the same kind of reliability as that offered by cold extractable methods for zinc or copper.

The Quantitative Study of Geochemical Fields for Ore Deposit Search.

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A mathematical, statistical and model approach to the treatment of geochemical data is discussed with special reference to the application of moving averages in an attempt to minimize the effects of random errors.

Comparison of Regional Geochemical Uranium Exploration Methods in the Beaverlodge Area, Saskatchewan.

DYCK, W., DASS, A. S., DURHAM, C. C., PELCHAT, J. C., and GALBRAITH, J. H., Geological Survey of Canada, Ottawa.

To evaluate the relative merits of regional geochemical exploration methods for uranium, particularly those employing radon and uranium in surface waters, a 500-square-mile block in the Beaverlodge area, Saskatchewan was sampled during the 1969 field season. The area

sampled extends for about 22 miles north from the shore of Lake Athabaska and from the town of Eldorado some 23 miles east. Surface lake-water samples were collected at an average density of 1.3 samples per square mile. Stream-water samples and sediment samples were collected from the same site at a density of about 1 per square mile. Approximately 95 rock samples from the major rock formations were collected. All field notes and analytical results were recorded on cards for computer storage and processing. Radon, pH and the alkalinity of all samples were determined in a field laboratory, and the temperature was measured at the site. The stream sediments and acidified aliquots of water were shipped to Ottawa for uranium and other trace-element analyses.

Estimates indicate that the background value for uranium lies under the detection limit of the method employed for this work, i.e. 0.4 ppb, for both lake and stream waters. Radon background values in streams and lakes are approximately 30 and 2 picocuries per liter, respectively. The background for uranium in stream sediments is about 3 ppm. The raw data outline a number of known uraniumiferous zones. There are at least six areas, excluding a 3-mile area around the town of Eldorado, in which the radon and the uranium concentrations in lake and stream waters and in stream sediments were greater than twice the background or twice the detection limit. These areas are located: between Cornwall Bay and Fishhook Bay; near Gibbs Lake; between Cutler Lake and Mickey Lake; in the vicinity of Dyke Lake; between Donaldson Lake and Gebee Lake; and south of Dusyk Lake. Another area in the vicinity of Beckwall Lake gave anomalous uranium values in streams only.

Seasonal tests of samples from four lake sites and four stream sites over an eight-week period showed little variation in the concentration of ionic species, i.e. uranium, pH and bicarbonate. The radon content at the surface of lakes, on the other hand, varies considerably from day to day. In streams, the variation in radon concentration with time is less than in lakes. Meteorological data indicate that low radon values in the lakes roughly coincide with windy days.

In general, the uranium pattern compared to that of radon is somewhat more diffused, particularly in the lakes. This is probably due to the fact that uranium is more soluble in surface waters than radium.

In rugged terrain like the Beaverlodge area, lake sampling is more economical than stream sampling. However, analytical costs are somewhat higher for lake samples because of lower concentration levels.

Radon and uranium in surface waters of the Beaverlodge area outline uraniumiferous areas equally well, and both should be used where practical. Being simpler, the radon method is preferable where analytical facilities are unavailable or where it is desirable to have the results immediately.

USGS Program in Geochemical Exploration Research — 1970¹.

ERICKSON, R. L., U.S. Geological Survey, Denver, Colorado.

Some reorientation of the research program in geochemical exploration by the U.S. Geological Survey has been initiated since the last International Geochemical Exploration Symposium at Golden, Colorado, in 1968. The principal changes are: (1) a shift in emphasis to a climatic province or environmental approach to exploration geochemistry; (2) a strong thrust in research, development and appraisal of methods of measurement of volatile elements in the atmosphere in relation to mineral deposits; (3) upgrading of our analytical laboratories to meet the demands of increased use of trace-element data for other than exploration work — geologic mapping, geology and health, and remote sensing; and (4) research and development in computer approaches to mineral exploration problems.

¹Publication approved by the Director U.S.G.S.

The Use of Acacia Trees in Biogeochemical Prospecting. EL SHAZLY, E. M., BARAKAT, N., EISSA, E. A., EMARA, H. H., ALI, I. S., SHALTOU, S., and SHARAF, F. S., Geological Society of Egypt, Cairo, Egypt, U.A.R.

Acacia trees grow in the valleys of the Eastern Desert of Egypt under an extremely arid environment with very little rainfall, high evaporation and mild weather in winter, but hot otherwise.

In areas with sulphide mineralization, methods have been applied for the sulphophile elements nickel, copper, lead, zinc, and cobalt. During these procedures, roots, twigs and stems of *Acacia raddiana* and *Acacia ehrenbergiana* have been sampled and analyzed. Plants are found to be more useful in prospecting than alluvium and water. Rock exposures show localized geochemical anomalies, but a large number of analyses are required.

Furthermore, in an area with beryl and other minerals, geochemical methods have been applied for the oxyphile elements beryllium, lithium and boron. Twigs of *Acacia raddiana* have been analyzed for these elements. Beryllium anomalies are found in plants, but the element is present in appreciable concentrations only where there is groundwater stored under plant roots on an impermeable basement. The beryllium anomalies in plants do not coincide with the alluvial anomalies. Lithium is concentrated in plants growing in the bends of the valleys and where these valleys meet. On the other hand, boron is common in high concentrations in plants, showing only small differences in concentration from one plant to another. For all these elements, alluvium has been found more useful in prospecting than plants. Lithium is more suitable for biogeochemical prospecting than beryllium, which seems to be absorbed by plants in appreciable amounts only when groundwater is particularly available. Boron, however, is not suitable for biogeochemical prospecting, as it is absorbed by plants without notable discrimination regarding their spatial relation to alluvial or rock anomalies.

It is concluded that biogeochemical prospecting may be used with varying degrees of success for a variety of elements in *Acacia* trees which are of wide geographical distribution in many arid regions of the world.

Regional Facies of Organic Metamorphism.

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Organic constituents in both fine-grained rocks and reservoirs undergo a well defined series of chemical and physical changes with increasing temperature. These changes result in the destruction of crude oil at temperatures well below those required for the metamorphism of the rock matrix. By examining and analysing fine-grained rocks, it is possible to detect and map the metamorphic limit of oil occurrence. In addition, the changes which occur before oil is destroyed have a large effect on the type of product to be found in less altered regions.

At present, we can recognize three major facies of organic metamorphism. The immature facies yields dry gas and medium to heavy oil; the mature facies yields mainly medium to light oil, wet gas and condensate. Only methane, H_2S and CO_2 can be expected from the metamorphosed facies, which is recognized by dry cuttings, gas and black organic matter.

Recent Research in Geochemical Prospecting in Australia.

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Research in geochemical prospecting in Australia during the past two years falls under four main headings:

1. chemical procedures
2. significant geochemical associations
3. improvements in field techniques
4. comprehensive studies of exploration problems or of ore deposits.

Chemical procedures include: identification of analyses where X-ray fluorescence methods have advantages over atomic absorption, such as those for Nb, Ta, Sn, etc.; the use of the infra-red spectrophotometer in mineral analyses; studies on the relative efficacy of cold extraction methods for Cu, Pb and Zn from geological materials; and the development of a modified form of the Shapiro field test for phosphate exploration.

Element associations that have been shown to be relevant to exploration for orebodies include nickel-copper in the ultrabasic areas and tellurium-gold and arsenic-gold in the goldfields; studies have been made of trace elements in tourmalines as ore indicators.

Research into field procedures has shown that, for much of Australia, samples are best taken below the soil in the top of the weathered rock; sizing analysis of stream sediments has indicated the particular size fractions that contain the highest proportion of certain metals under various conditions of climate, topography and geology; mineralogical studies of associated rocks enable more meaningful interpretation to be made of the results of geochemical surveys; optimum line and sample spacings have been determined under various sets of

conditions; geochemical anomalies have been used to localize I.P. surveys, and to locate drilling targets over geophysical anomalies.

Systematic geochemical research projects have been carried out: on element distribution in the rocks surrounding the Mt. Isa orebodies; on the processes of change from rock to soil, laterite and other weathering products and the chemical and physical processes involved; and on the occurrence and nature of mineralized 'halos' around orebodies.

In addition, some work has been done on the applications of computers to geochemical exploration.

Tin in Acid Granitoids: The Search for a Geochemical Scheme of Mineral Exploration.

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A review of the literature on the occurrence of tin in granitoids indicates that although a number of correlative trends have been noted for individual igneous bodies, none is generally applicable. For the development of a geochemical scheme for the detection of mineralized granitoids, a more systematic approach than appears to have been used in the past is needed, and correlations should be sought within groups of rocks having similar features. In this paper, major aspects of the history of a wide range of granitoid rocks are examined in relation to tin content. These include rock type, origin, mode and time of emplacement, age, major and minor mineral content, major and trace element content, and the role of intruded rocks. It appears that the most important single aspect of a stanniferous granitoid is its origin, and there is much evidence to suggest that the main source of the tin is in the pre-existing rocks which have become incorporated during the evolution of the granitic material.

Analytical Requirements in Geochemical Exploration.

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The successful implementation of geochemical prospecting methods is complicated in Canada due to the complexities of metal distribution related to glacial history. Successful geochemical exploration is dependent on the adoption of appropriate sampling, analytical and interpretational procedures. The general requirements of analyses in geochemical exploration was the topic of a panel discussion at the previous Geochemical Exploration Symposium at Denver in 1968. It is considered that the careful selection of optimum analytical procedures for specific problems stands to make a significant contribution in future geochemical exploration. Examples are given from case histories to illustrate the significance of selecting appropriate analytical techniques to meet specific requirements of particular exploration problems.

Geochemical Prospecting for Baryte and Fluorite Deposits. FRIEDRICH, G. H., and PLUGER, W. L., Abteilung für Angewandte Lagerstättenlehre Technische Hochschule Aachen, West Germany.

The exploration for barite and fluorite veins and stratiform deposits which occur in different types of rocks, particularly siliceous schists, limestones, volcanics and granites, is discussed. According to the mineralogical composition of the ore, different geochemical indicator elements had to be found for each deposit.

Geochemical studies have been carried out at the Dreislar barite deposit (West Germany), which is confined to a large NW-striking tectonic feature. Mineralization is known only in the area of the Altenbüren-Kellerwald fracture. The ore mined consists mainly of barite with small amounts of quartz and siderite and traces of hematite, pyrite, chalcopyrite and galena. The barite contains from 1.17 to 4.23 per cent SrSO_4 , and mercury is present in amounts of up to 250 ppm. Geochemical studies of soil samples have shown that mercury may be used as a pathfinder element. The distribution of this element in rocks and ore and in the soil will be discussed.

Geochemical methods for the exploration of fluorite deposits in the Schwarzwald and Wölsendorf areas in West Germany and in Spain have been tested and found to be successful in locating known deposits. In these areas, mercury, zinc and lead (in soils), and fluorine (in stream waters and stream sediments), may be used as indicators in reconnaissance surveys and in the detailed stages of prospecting.

The Dispersion of Copper and Zinc in Glacial Overburden at the Louvem Deposit, Val d'Or, Quebec.

GARRETT, R. G., Geological Survey of Canada, Ottawa.

The dispersion of copper and zinc in the basal till and overlying glaciolacustrine sediments was investigated in the down-ice direction from the suboutcrop of the main copper pipe at the Louvem deposit, some 12 miles east of Val d'Or, Quebec. A total of 34 holes on 100-foot centres were sunk to an average depth of 38 feet in overburden and continued for an average of $3\frac{1}{2}$ feet into bedrock. Sampling was carried out with an AX-size split spoon, which was overdriven by 50 to 100 per cent to ensure complete recovery. Samples were taken in advance of NX-size casing which was ultimately sunk to bedrock, where AXT core drilling was commenced.

The samples were dried, and copper and zinc were determined in the -80-mesh fraction by a pyrosulphate fusion and colorimetric method in a field laboratory established at Val d'Or. The analytical information was thus immediately available for the direction of the drilling program.

Although the surface topography is gentle, with a slope to the northeast, the bedrock topography is rugged, and as a result the basal till thickness is variable (0-20 feet). The till is easily distinguishable from the overlying glaciolacustrine deposits by its coarse average grain size and its complete lack of sorting. The glaciolacustrine sands are well sorted and are thought to owe their origin to a large esker some 2 miles to the east.

Local background in the glaciolacustrine sediments is around 10 ppm for both Cu and Zn, and there is very little variation in the data on the sediments. Local background in the basal till is 20 ppm for both Cu and Zn, and there is a much greater spread in the data. Threshold values of 60 ppm Cu and 50 ppm Zn were chosen; using these, anomalous levels in the basal till were observed for some 400-500 feet in a down-ice direction from the deposit. In the case of Zn, it is possible to outline a zone of high background (>25 ppm) which extends away from the drilled area, some 800 feet southwest.

To improve contrast between background and anomalous levels, the 80-230-mesh fraction of all till samples was subjected to a heavy-mineral separation prior to analysis. This size fraction was chosen to increase the number of grains in a 200-mg aliquot relative to the +80-mesh fraction, the analytical reproducibility being a function of the number of grains analysed. Both Cu and Zn were determined as in the -80-mesh fraction. The local backgrounds for Cu and Zn were established at 60 and 30 ppm respectively, and threshold values of 200 ppm Cu and 100 ppm Zn were used to delimit an anomalous dispersion train more than 800 feet long for Cu and some 700 feet long in the case of Zn.

In certain samples, there is evidence of a limited hydromorphic dispersion of Zn, because anomalous levels of Zn in the -80-mesh material are not reproduced in the heavy-mineral analyses, a feature which indicates that the Zn is not present in the sulphide form. There is also evidence that the anomalous zone escalades within the till. Close to the suboutcrop and outcrop of the ore, the anomalous levels of Cu and Zn are found at the base of the till; however, as one proceeds in a down-ice direction, the anomaly appears to rise at a gradient of about 1 in 100 within the till. This feature is known as overriding and is well known in Quaternary geology.

At the Louvem deposit, elastic dispersion of copper and zinc as sulphide grains appears to be the dominant dispersion mechanism. There has, however, been some saline dispersion of zinc. The elastic dispersion train is controlled by the sum of the ice movements, but dominantly by the last readvance of the ice-sheet, and is thus relatively easy to trace to source. The saline dispersion patterns are controlled by the local hydrological regime, which is in turn related to the bedrock topography, and more often than not there is insufficient information on these two features to make a thorough interpretation. Due to the relative ease of interpretation of elastic dispersion patterns versus saline dispersion patterns it is preferable, in the authors opinion, to study the heavy-mineral fraction of the till.

It is concluded that overburden sampling and subsequent geochemical analysis has application in exploration programs at two levels. First, it offers a tool by which geophysical anomalies and geological extrapolations may be tested, assuming that part of the mineralized zone, or its envelope of disseminated mineralization, suboutcrops. In this case, it is sufficient to analyse the -80-mesh fraction, as the method is simply being used as a confirmatory tool before expensive diamond drilling is undertaken. Second, the method has application in more regional studies where larger belts of potentially mineralized rocks are under investigation. In this kind of work, the extra expense of heavy-mineral separations would be easily justified because a lower sample density could be used, and any anomalies found would be elastic and more readily traced to source.

Application of Data Processing Methods in Geochemical Prospecting for Petroleum.

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Mapping hydrocarbons concentration anomalies is a problem complicated by the fact that different soil or subsoil horizons have different gas retention properties and/or react differently to chemical treatment. Experiments tend to show that the assumption, for a given facies, of normalcy for the hydrocarbon gas content background distribution cannot be rejected. For a given facies, a sample value is anomalous if the corresponding Student's "t" statistic exceeds the four sigmas level. Anomalous values are plotted on the map and weighted by the probability of having an anomalous sample within a small neighbourhood.

Evaluation by Geochemistry of Geophysical Anomalies and Geological Targets Using Overburden Sampling at Depth.

GLEESON, C. F., and CORMIER, R., Soquem, Ste-Foy, Québec.

As a result of some experimental work done early in the winter of 1967, a method of taking overburden geochemical samples at depth was developed. The technique proved to be an efficient, practical and economical means of obtaining basal till samples for geochemical analyses in the search for base metal deposits in areas covered by glacial lake sediments.

The method involves the use of a light, portable, gasoline-operated drill which drives into the ground a stainless steel sampler attached to a series of steel rods. When the desired sample depth is reached, the sampler is opened and then filled by driving it into the material to be sampled.

This system has been used in the Abitibi region of Quebec to evaluate E/M geophysical anomalies that would not ordinarily warrant diamond drilling. Hole depths have varied from less than 10 feet to over 100 feet, but generally have averaged about 50 feet.

At one place, an E/M anomaly was found to be due to a barren pyrite zone. However, geochemical analyses of the basal till several hundred feet away indicated abnormally high zinc values. The area in the vicinity of the geochemical anomaly was subsequently diamond-drilled, and a zinc deposit was found.

Orientation work over two known but buried copper deposits in the Val d'Or - Barraute region showed that geochemical analyses (Cu, Pb, Zn) of the -80-mesh fraction of the basal till normally gave positive results. However, much greater contrast was found when the +80-mesh heavy-mineral fraction was analyzed.

Microscopic examination of the heavy and light +80-mesh fraction from the basal till has also been helpful in detecting bedrock types, base-metal-bearing sulphides, graphite and barren sulphides. The last two have been found to be the cause of many of the E/M anomalies.

Geochemical anomalies found in the basal till have shown little horizontal displacement by glacial action; generally, the abnormal values occur over or in the immediate vicinity of the suboutcrop of the base metal deposits.

Another useful application of this drilling method has been the determination of depths of overburden either for engineering purposes or to correct for bedrock configuration in gravity surveys. Over 80 per cent of the gravity anomalies tested to date have been found to be caused by increases in the elevation of the bedrock surfaces.

The overburden sampling technique has also been successfully applied in delineating a niobium-bearing carbonatite about 15 miles west of Oka, Quebec. Because of the weathering characteristics of the carbonatite, it was possible to systematically sample the weathered carbonatite, which was covered by 0 to 70 feet of glacial overburden. Samples were visually examined for carbonatite fragments and then assayed for Nb_2O_5 . Geochemical analyses for zinc and silver were also done.

After putting together the analytical information on the samples taken at depth, it was possible to show, in a very short time and at minimal cost, that instead of having two small separate carbonatite bodies, as was originally thought, actually there was one large body of niobium-bearing carbonatite.

Costs for these programs have varied from 50 cents to 2 dollars a foot.

Application of a Combined Ion Exchange Paper — X-Ray Spectrographic Method to Geochemical Exploration.

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Previously published work by the authors (*Anal. Chem.*, 38 987 (1966)) has shown that collecting metal ions on ion exchange resin-loaded papers and determining the collected metals by X-ray spectrography provide a useful analytical technique. This technique is especially applicable to the determination of small quantities of metals because the ion exchange collection provides high sensitivity by presenting the collected metals to the X-ray spectrograph in a nearly ideal form. Detection limits for most metals are in the range of one microgram or less. However, the technique has also been found useful for determining major components in samples such as nickel-cobalt-chromium alloys for which wet methods of analysis are complicated and time-consuming.

The chief advantages of the method are:

- reduction of matrix effects;
- applicability to large samples, thereby increasing sensitivity and reducing sampling errors associated with inhomogeneous materials;
- simplification of the problem of preparing X-ray standards.

The collection procedure is extremely simple and requires only a minimum of equipment. For solutions, only adjustment of acidity and filtration through the resin-loaded disks is necessary. The only additional step required for solid samples is treatment with a solvent capable of dissolving the desired components. Therefore, the technique should be especially suitable for field applications. The collected metals are firmly retained on a light-weight (0.12 gram) paper disk which can easily be transported to a central laboratory for X-ray determination. The disks may also be filed for future reference.

Commercially available resin-loaded papers contain nonselective resins which collect most of the common metals. Each of the collected metals can be determined on the same disk. For determining individual metals, or selected groups of metals, more selective resins can be used. An example is the selective collection of gold and platinum metals on disks containing Ionac SRXL resin.

A special modification of the technique is used for gold. Samples weighing several hundred grams are heated with aqua regia. The damp residue is then taken up with water and a resin-loaded disk is suspended in the resulting solution. Removal of the insoluble silicate residue is not necessary. A small quantity of ^{195}Au radioactive tracer added to the original sample serves as a collection monitor. The gold collected on the disk is determined by X-ray spectrography, and the ^{195}Au collected on the disk is determined by mounting this disk in front of the scintillation counter of the X-ray spectrograph. The ratio of these two instrument readings is a measure of the gold content of the original sample.

Results obtained by this method compare favorably with results obtained by other methods.

GOLD FOUND, OZ/TON

	Ion exchange X-ray method	Solvent ext. atomic abs.	Fire assay
Bureau of Mines Reference Ore	.215	.206	.206
Std. deviation	(.007)	(.005)	(.003)
College Park Low Reference Ore	.0531	.0527	.05
Std. deviation	(.0011)	(.0015)	single det.
College Park High Reference Ore	.370	.373	.35
Std. deviation	(.011)	(.011)	single det.
USGS Gold Quartz Standard	.0776 ^(a)	.0774 ^(b)	.0761 ^(c)

^(a)average of .0781 and .0770 oz/ton

^(b)average of .0787, .0758, .0773 and .0779 oz/ton

^(c)recommended value, USGS Circular 598

Future work is planned on the use of papers containing other selective ion exchange resins and on the use of complexing agents to develop other selective procedures for special application.

Trace-Element Distribution in Accessory Magnetite From Quartz Monzonite Intrusives and Its Relation to Sulphide Mineralization in the Basin and Range Province of Utah and Nevada — A Preliminary Report.

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Accessory magnetites were concentrated from 14 monzonitic intrusives in ten districts of the Basin and Range province, Utah and Nevada — a total of 88 samples. Districts sampled included the Tintic mining district, the Bingham mining district, the Park City - Little Cottonwood area, the Iron Springs district, the Mineral Range stock, the Gold Hill mining district and the Ibapah stock, all in Utah, and the Robinson district and the Kinsley stock in Nevada. These areas include stocks with known associated major sulphide mineralization, some stocks with known associated minor sulphide mineralization and some stocks with no known associated sulphide mineralization.

Concentrates were analysed for their trace metal content by X-ray spectrochemical method using synthetic standards. Sample mineralogy was determined by a quantitative X-ray diffraction method. Of the elements analysed, Ti, V, Mn, Cr and Zn were detected in most samples above the reliable quantitative detection limits of the analytical method. Of the other elements detected, Ni, Cu and Mo were above reliable quantitative limits in a few samples. One or more of the elements Co, Ga, Ge, As, Se, In, Sn and Sb were detected in a majority of samples in amounts below the quantitative reliability limit.

The equivalence of variances of trace-element abundances in magnetites from groups of the individual stocks or districts were determined by means of the F-test. Comparisons were made on the basis of the distribution of groups about the mean element abundances for all samples and empirically modified from the examination of a graphical comparison of geometric means and standard deviations of the trace-element abundances on magnetite until statistically significant groups were obtained.

The results of the comparisons show the following:

1. Each stock or district belongs to its own individual trace-element population.
2. In general, accessory magnetites from major lead-zinc districts have high trace-element abundances. Magnetites from major copper-producing districts have trace-element abundances near the mean abundances for all districts.
3. The abundance of chromium appears to be reduced in magnetites from stocks which have been hydrothermally altered. It is the only trace element thus affected.
4. High trace-element abundances of Ti and Zn in accessory magnetite correlate with major lead-zinc mineralization associated with the parent intrusive. Low trace abundances of Ti and Zn in accessory magnetite correlate with major copper mineralization associated with the parent intrusive.
5. The supposedly unmineralized Last Chance stock is the major anomaly of this study in that it contains accessory magnetite with trace-element abundances similar to those in magnetites accessory in intrusives associated with major lead-zinc mineralization.
6. Trace-element abundances in accessory magnetite correlate with sulphide and iron mineralization associated with Basin and Range intrusives.

Recent Articles on Geochemical Prospecting, 1965 to 1969. HAWKES, H. E., 4422 Macomb St., N.W., Washington, D.C.

The bibliography and index of the literature of geochemistry as applied to mineral exploration, starting with January, 1965, includes the more important and relevant citations listed in the standard English-language abstract journals that were available on December 1, 1969. Papers written in Slavic or Oriental languages and unsummarized abstracts are not included.

X-Ray Diffraction Methods of Evaluating Potassium Silicate Alteration in Porphyry Mineralization.

HAUSEN, D. M., and KERR, P. F., Newmont Exploration Ltd., Danbury, Connecticut.

It has long been recognized that concentric zones of altered rock surround many hydrothermal orebodies. Such zones are variable in shape and size, but generally surround the concentrations of mineralization as geometric halos. A determination of the types and intensities of alteration often yields mineralization trends. In more recent studies, alteration patterns have been established by methods of grid sampling combined with the analysis of selected alteration minerals by microscopic and X-ray diffraction techniques.

Silicification, feldspathization and sericitization have been evaluated semi-quantitatively by the X-ray analysis of quartz, potash feldspars and sericitic micas in altered rock. The resulting analyses have found special application in delineating several "porphyry-type" mineral deposits. Facies of potassium silicate alteration correlate closely with molybdenum and copper mineralization in a variety of examples in which a plot of alteration values on a geologic map may be sufficient to outline the limits of mineralization and the direction of the most probable ore occurrence. Types of alteration may be measured vectorially around centers of mineralization, but may usually range in thickness and intensity with differences in rock type and locality. As a result, an individual study of each occurrence is essential. The interpretation of alteration patterns frequently permits the projection of inferred reserves along trends that might otherwise go unrecognized.

Correlation of alteration anomalies with geophysical and geochemical anomalies from a number of molybdenum and copper "porphyry" prospects had demonstrated the validity of alteration parameters as an ore guide in the exploration and development of a number of mineral deposits of the mesothermal to hypothermal "porphyry" type.

Correlations between the Tin Content of Granitic Rocks and Their Chemical and Mineralogical Composition.

HESP, W. R., CSIRO, Division of Mineral Chemistry, Chatswood, N.S.W., Australia.

A wide range of Australian granitic rocks (67 samples) are statistically characterized, involving the frequency distribution of SiO_2 (range 64.5-77.5 per cent) and the tin content in rocks (2.5-45 ppm) and in biotites (7-315 ppm).

The biotites carry up to 45 per cent of the total tin content and the crystallochemical affinity between Sn^{4+} and Fe^{3+} appears to play a major role in the mechanism of tin-accumulation. Of the other cations occupying octahedral sites in the biotite, tin shows a direct relationship with Li^+ , and it is inversely related to Fe^{2+} , Mg^{2+} , Ti^{4+} and Mn^{2+} . On the basis of these relations, a composite factor, the "tin holding capacity" (THC) of biotites, is used to characterize the chemical composition of biotites in the following regression equations:

$$\text{Log } (\text{Sn}_{\text{Bi}}) = 0.0357. X + 1.354 \quad (r = 0.90; 95 \text{ per cent conf. limit } \pm 0.46)$$

$$\text{TA} = 2.946 (10 \times \text{THC} + \text{Bi}) - 1.4529 \quad (r = 0.95; 95 \text{ per cent conf. limit } \pm 9.1)$$

where Sn_{Bi} = conc. of Sn in biotite in ppm; $X = 10 \times \text{THC} + \text{Sn}_{\text{R}} - 2 \times \text{Bi}$; $\text{THC} = (\text{Fe}^{3+} + \text{Li}^+ / \text{Fe}^{2+} + \text{Mg}^{2+}) - (\text{Ti}^{4+} + \text{Mn}^{2+}) / 10$; Sn_{R} = Sn in rock in ppm; Bi = modal per cent of biotite in rock; TA = percentage tin accumulation in biotite = $(\text{Sn}^1_{\text{Bi}} / \text{Sn}_{\text{R}}) \times 100$; $\text{Sn}^1_{\text{Bi}} = (\text{Sn}_{\text{Bi}} \times \text{Bi}) : 100$.

The lack of correlation between the tin content of rocks and their chemical and mineralogical composition suggests that the concentration of tin was not uniform in the various source materials. The composition of these source materials rather than the degree of enrichment during rock-forming processes appears to determine the tin content of the rocks. The composition of a wide range of tin-bearing granitic rocks from the U.S.A., Canada, the U.K., the Soviet Union and Malaya supports the above conclusions.

Effectiveness of Geochemical and Biogeochemical Exploration Methods in the Cobalt Area, Ontario.

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The effectiveness of geochemical and biogeochemical exploration methods in detecting the silver vein deposits at Silverfields Mining Corp. Ltd., Hi Ho Silver Mines Ltd. and Agnico Silver Mines, Ltd., was studied during the summer of 1968.

At these mine sites, bark, leaf, spur and/or twig organs of trembling aspen and white birch, together with B-horizon soils and (Ao + A1) horizons combined, were collected and analyzed for Ag, Co, Ni, Mn, Cu, Pb and Zn.

A major part of the study was conducted at the Silverfields Mining Corp. Ltd. mine because certain geological features of the mine, described as follows, were particularly appropriate for this study:

The principal ore veins occur in the 100- to 200-foot-thick assemblage of Cobalt sediments which overlie Keewatin greenstones containing sedimentary interflow bands. The sediments and greenstones are capped by approximately 175 to 200 feet of Nipissing diabase sill.

In the Cobalt sediments, ore veins have the following dimensions: length, 50 to 900 feet; vertical extent, 50 to 200 feet; thickness, seldom more than 6 inches for an individual vein. In some places, ore veins pinch out or swell for several feet along strike, or they frequently horsetail and may or may not continue. They occur in the form of single veins or closely spaced multiple veins comprising a family or vein system. Vein systems may be separated by up to tens of feet of wall rock from other similar, roughly parallel vein systems. Some of the narrow fractures at the surface of the diabase contain traces of ore elements, suggesting that ore veins extend upward through the diabase as thin, probably discontinuous seams.

Because the principal ore veins being mined at depth have a surface expression, they are amenable to detection by soil or plant exploration methods. Further, the reflection at the surface of the configuration of the near-vertical ore veins at depth facilitates their correlation with anomalous distributions of ore elements in soils and vegetation.

A rectangular grid (500 feet by 2,000 feet) was established perpendicular to the strike of the roughly parallel, principal ore veins. Samples were collected at 25-foot intervals from five lines, 100 feet apart. The (Ao + A1) combined horizons sieved to minus 10 plus 80 mesh, were the most effective soil horizons to sample because they were enriched in most elements compared to the B horizon. Similarly, birch spurs were the most effective plant organ to sample of those studied, followed by aspen twigs. Thus, anomaly maps were constructed from (Ao + A1) horizons and birch spur analytical data.

The anomalies developed, particularly for Ag, Co and Ni, not only defined anomalous target areas where several vein systems occurred as opposed to relatively barren areas within the mine, but also established the anomalous expression of an individual ore-vein system within a target area. In addition to the determination of the proper type of sample material to be collected and the appropriate indicator elements, the factors responsible for the effectiveness of these methods significantly include the sampling density. A method incorporating sample collection at 100-foot or even 200-foot centers would detect the anomalous target areas.

Some Environmental Influences on the Secondary Dispersion of Molybdenum and Copper in Western Canada.

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Certain broad variations in the geochemical environment of British Columbia, and their influences on the secondary dispersion of molybdenum and copper, are described. Some complicating factors in the use of geochemistry as an exploration tool for molybdenum and copper mineralization are outlined.

Three environments, controlled by topography and climate, are considered:

- (a) strong relief, high rainfall, podzolic soils;
- (b) subdued relief, moderate rainfall, interrupted drainage, water-logged organic-rich overburden;
- (c) moderate relief, low rainfall, caliche accumulations in overburden.

Some areas of waterlogged overburden show accumulations of Cu in organic topsoils where groundwater, made acid by the oxidation of pyrite, enters the swamp. To a lesser degree, enhancement of Mo is also apparent. Accumulation of Mo, with some W but not accompanied by Cu, is observed in areas where swamps are underlain by weakly alkaline clay. In neither case is any accumulation of Fe, Mn, Co, Ni, Pb or Zn apparent.

Fe and/or Mn hydroxide precipitates, in both drainage channels and soil profiles, are described from areas of high rainfall. The accumulation of Mo with Fe-rich seepage precipitates is observed, and Mn-rich deposits have high Co contents.

The distribution of Cu and Mo in caliche-bearing overburden is described. Caliche appears to inhibit the mobility of both elements. This leads to concentration on steep, seepage-fed slopes covered by calcareous talus fans. However, on level sites, Cu mineralization in bedrock appears to be effectively masked by calcareous till, and no anomaly appears in near-surface subsoils.

These studies illustrate some effects of the ionic potentials and Eh-pH conditions of aqueous dispersion media on trace-element migration. Acid groundwater, particularly in the vicinity of oxidizing pyrite, promotes the mobility of Cu, whereas Mo is mobile under weakly alkaline conditions. The mobilities of Mo and Cu appear, to varying degrees, to be restricted by chelation with organic compounds, scavenging by Fe and Mn hydroxide precipitates, and precipitation in the vicinity of caliche.

Some techniques, involving multi-element analysis and partial extraction studies, are suggested to aid in the recognition of common effects of the geochemical environment.

Problems Associated with the Application of Geochemical Methods of Exploration in Cornwall, England.

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In recent years, during the resurgence of interest in the mineral potential of Cornwall, geochemical methods of exploration have been applied with varying degrees of success in the County. From over 600 mines, one or more of the elements Sn, Cu, W, Pb, Zn, U, As, Fe, Sb and Mn have been recovered in economically important amounts, and cassiterite and wolframite have been won from many placers. Contamination, due to mining, mineral beneficiation and smelting operations, is widespread, and further contamination results from the presence of domestic and factory waste in the rivers, and the employment of metal-bearing fungicides by farmers.

Intensive investigations into the nature and origin of any contamination likely to occur in an area selected for exploration is necessary before decisions are reached concerning the feasibility of applying geochemical methods, and, if feasible, the best program to adopt.

However, despite the magnitudes of the contamination problem in Cornwall, geochemical methods, particularly those involving soil analysis, have, when prudently applied, facilitated the search for parallel lodes, permitted the extensions of known lodes and vein systems to be rapidly delineated, and pointed to a possible mineral potential in areas that had been neglected in the past.

Finally, on occasion, contamination due to mining has aided exploration. The local inversion of placers during past mining operations sometimes permits the parent lodes to be located with comparative ease by geochemical methods. Similarly, geochemical and allied studies of old mine dumps have revealed information concerning the lodes from which the discarded material came, which is very broadly equivalent to that which might be obtained from diamond drill cores.

A Comparison of Alluvial Exploration Techniques for Copper Deposits¹.

HUFF, L. C., U.S. Geological Survey, Denver, Colorado.

Copper from porphyry copper deposits in the Gila Mountains near Stafford, Arizona, can be traced 5 to 7 miles downstream along several desert washes. Seven different types of subsamples were prepared from alluvial materials collected near the mouths of these washes and from neighbouring washes which do not drain copper deposits. These types are: (1) the minus-80-mesh size fraction from the normally coarse alluvium on the bed of the wash; (2) the minus-80-

¹Publication approved by the Director, U.S.G.S.

mesh size fraction of finer, slack water alluvium along the sides of the wash; (3) the 30- to 80-mesh size fraction of the coarse alluvium; (4) sets of hydrothermally altered pebbles; (5) ultrasonic concentrates of grain coatings; (6) magnetic heavy minerals; and (7) nonmagnetic heavy minerals. The copper content of the magnetic heavy minerals failed to identify the washes draining copper deposits and the 30- to 80-mesh fraction yielded only slightly better results. The copper content of the ultrasonic concentrates of grain coatings and the nonmagnetic fraction of the heavy minerals has a high range and clearly identifies anomalous washes. Such samples appear to be well suited for tracing anomalies for long distances. Both types of minus-80-mesh samples and the pebble samples have a lower range in copper content, but also clearly identify anomalous washes. They appear to be satisfactory here for routine geochemical exploration.

Stable Isotopes in Geochemical Prospecting.

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As the knowledge of chemical differences between rocks, minerals and hydrothermal altering solutions have been fundamental in mineral exploration, measurements of variations in stable isotopic compositions are providing an additional fundamental step in mineral exploration and a better understanding of the genesis of mineral deposits.

Measurements with high-precision, dual-collector mass spectrometers of the stable sulphur isotope ratio S^{34}/S^{32} have enabled the economic geologist to determine if sulphide minerals have formed at low temperatures (bacteriogenically — generally syngenetically) or at high temperatures (epigenetically). Primary sulphates can readily be distinguished from secondary sulphates and from primary studies in hydrothermal deposits by the differences in the S^{34}/S^{32} ratios of their respective sulphur. In some deposits, primary sulphates are associated with primary metal values and secondary sulphates are not. In addition, the distinctions between the magmatic hydrothermal and sedimentary origin of sulphide deposits can generally be resolved by sulphur isotopic measurements.

The increasing application of hydrogen, carbon and especially oxygen isotopic studies to petrogenesis and their application to mineral exploration appears most promising. The O^{18}/O^{16} isotopic fractionation between coexisting oxygen-bearing minerals or of hydrothermal solutions transiting oxygen-bearing rocks decreases with increasing temperature.

Hydrothermal dolomitization extending thousands of feet from the higher temperature, possible ore-forming site may form three-dimensional isopleths of equal O^{18}/O^{16} ratios, each indicative of the changing isotopic equilibration temperature of the carbonate mineral with the hydrothermal water. This may be applied at distances from a potential hydrothermal ore deposit that greatly exceed those of almost any other remote sensing technique — whether it be geochemical or geophysical.

Recent Advances in Sensitivity and Data Analysis of Airborne Gamma-Ray Spectrometry for Mineral Exploration.

JOHNSON, C. H., Geophoto Services, Inc., Dallas, Texas.

The airborne digital gamma-ray spectrometer developed by Texas Instruments is a high-sensitivity dual system. Six $11\frac{1}{2}$ - by 4-in. NaI(Tl) crystals and a 400-channel pulse-height analyzer measure radiation from all directions. Two additional crystals of the same size, shielded from radiation from the ground, and a second 400-channel analyzer are used to separate the data into its airborne and surface source components. This technique effectively prevents airborne radon from masking small concentrations of uranium at the surface and allows reproducible measurements to be made of surface concentrations of uranium, thorium and potassium in the parts per million range.

Data from these two spectrometers, a proton-precession magnetometer, a broad-beam radar altimeter, a 24-hour clock and several other bookkeeping devices are recorded in flight digitally on computer magnetic tape every two seconds. Subsequent processing is done on a Univac 1108 computer and includes energy calibration, spectrum unfolding, background corrections, separation of the airborne component and altitude correction. The final data are contoured or profiled and also plotted by the computer.

Geochemical Investigations of Base Metal Occurrences in Western Liberia.

JOHNSON, D. H., U.S. Geological Survey¹, HOLMES, A. J., Liberian Geological Survey¹, and COOPER, B. R., Liberian Geological Survey¹.

Geochemical soil sampling methods were used in examining two base metal occurrences in western Liberia to evaluate the applicability of the methods to prospecting for base metals in Liberia. Geologic studies to determine the likelihood of minable ore at either prospect were made concurrently.

In the Gboeya Creek - Galena Creek area southwest of Tawalata, former gold placer mining had disclosed fragments of galena in the stream gravels. A strong shear zone trends N 70°E parallel to the foliation of the granite-gneiss country rock and controls the course of Gboeya creek. At the junction of Galena and Gboeya creeks, a small outcrop of cataclastic sericite-quartz schist contains sparse tiny grains of galena, sphalerite and pyrite. No other mineralized outcrops were seen. Pits and trenches were dug to bedrock both up and down stream from the junction and across the shear zone. A few small grains of galena and pyrite were found in weathered sericite-quartz schist at the bottom of one trench about 100 feet downstream from the junction. Samples of the material excavated from each pit or trench were jigged and panned. A single grain of galena about a millimeter in diameter and several 1- to 2-mm grain of pyrite were found along Galena creek about 250 feet upstream from the junction. Many samples yielded a few colours of gold, but none contained enough gold to warrant mining.

Geochemical soil samples were collected from the upper soil horizon in a random net over the area, and at closely spaced intervals from the surface down to bedrock in the wall of each pit and trench. The samples were analyzed for total cold extractable heavy metals by the methods described in U.S. Geological Survey Bulletin 1152, and those samples showing more than 10 parts per million (ppm) cold extractable heavy metals were further analyzed for total lead and zinc by methods described in the same bulletin. Most samples showed zero to a few ppm cold extractable heavy metals. The only samples that showed more than the background value of 10 ppm were some from the bottoms of pits and trenches at the contact between soil and weathered bedrock. Total lead and zinc in those samples ranged from 16 to 7,000 ppm, with a median value of about 400 ppm. Most of the samples that showed more than background contents of lead and zinc were of grayish to blackish discolorations at the base of stream sediments and in the upper part of the underlying weathered bedrock. The mineralogical character of the discoloration has not been determined. Anomalous lead/zinc values were found over an area more than 1,500 feet long and 200 feet wide.

Although geochemical sampling of surface soil showed negligible metal values, the same methods applied to samples from the bottoms of pits and trenches revealed anomalous values which were not indicated on mineralogical or geological evidence. Lack of geochemical indications of lead and zinc in the upper part of the soil is probably due to the low topographic position of the mineralization (virtually in a stream bed) and to the covering of the mineralization by stream sediments rather than by residual soil.

At Sam Davis creek near Gondoja, tiny grains of galena, pyrite, sphalerite and chalcopyrite are sparsely scattered in small quartz veins in weathered amphibolites, pyroxenites and peridotites. Several old trenches, an adit and a vertical shaft reveal only a few small mineralized quartz veins, and limited outcrops of vein quartz on the hillside appear largely or entirely barren. Visual estimation of the ore minerals in some of the more strongly mineralized vein material indicates a grade of combined lead, zinc and copper of about 1 or 2 per cent.

Samples were taken of the upper soil horizon in a random pattern near the surface workings and outcrops, and of soil and weathered rock at several different depths from the surface to the bottom of each trench. Cold extractable heavy metals were determined in the field by methods described in U.S. Geological Survey Bulletin 1152, and individual determinations of copper, lead and zinc were later made in the laboratory by methods described in the same bulletin. Cold extractable heavy metals ranged from 6 to 116 ppm; lead, from 0 to 12,500 ppm; zinc, from 200 to 1,000 ppm; and copper, from 100 to 600 ppm. Generally, the higher values were found in samples taken beneath or down slope from mineralized vein material. The onset of

¹Publication authorized by the Director, U.S. Geological Survey, and the Director, Bureau of Natural Resources and Surveys, Liberia.

the rainy season prevented the determination of an areal background level and of the size of the area in which anomalous geochemical values could be detected.

At both prospects, geochemical soil sampling methods indicated target areas larger than could be recognized on the basis of geology alone, although at the Gboeya Creek - Galena Creek area deep sampling was required. Even though geochemical soil sampling was not used for prospecting as such, the results of these studies suggest that geochemical soil sampling would be useful in prospecting for concealed deposits of base metals in Liberia.

Geochemical Trends within the Texas Canyon Stock, Co-chise County, Arizona.

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A geochemical exploration program was designed to test the presence of useful geochemical trends within a large igneous stock. The Texas Canyon stock was chosen for the experiment because of its excellent sampling accessibility and close relationship with known contact mineralization. The Johnson Camp area on the northeast border of the stock has produced over 25 million dollars in copper-zinc ore from contact deposits. Minor copper mineralization occurs in metamorphosed sediments along the south and southeast contacts of the stock. If the contact mineralization is related to the stock, then geochemical sampling and analysis of outcrops within the stock should detect metallic element concentration gradients trending toward the mineralization.

To detect the presence or absence of such trends, a four-level, hierarchical sampling system was designed. The stock was divided into $\frac{1}{2}$ -mile-square cells, and sample sites within the cells were chosen randomly. The hierarchical sampling made it possible to evaluate geochemical variability on four levels — within a hand specimen, within an outcrop, within a $\frac{1}{2}$ -mile-square cell, and within the stock. The objective of the sampling system was to determine if geochemical variations between cells were greater than variations within cells.

One hundred and thirty-four samples were analyzed by atomic absorption spectrophotometry for Au, Ag, Cu, Pb, Zn, Mo and W. Analytical results were statistically analyzed to determine significant levels of variation. Trend surface techniques were used to detect metallic element concentration gradients. The results of this program indicate that a properly designed sampling program and a careful analysis of the analytical data can detect elemental concentration gradients within an igneous body that may be useful exploration guides to related metallic mineral occurrences.

Geochemistry of Gold in the Weathering Cycle¹.

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Gold is mobile in the supergene environment under certain weathering conditions. Its presence in plant tissues has been reported by many investigators. Because colloidal gold is not taken up by plants and because the simple ions, Au^+ and Au^{+++} , cannot exist in appreciable quantities in aqueous solutions, gold must enter the plant as a soluble complex ion. The enrichment of gold in forest humus mull and near-surface soil also suggests that its mobility as a complex ion is transitory.

We have considered that the following complex ions possibly play a role in the migration of gold: $AuCl_4^-$, $AuBr_4^-$, AuI_2^- , $Au(CN)_2^-$, $Au(CNS)_4^-$ and $Au(S_2O_3)_2^{3-}$.

The standard electrode potentials (Latimer, 1952) listed below illustrate the marked dependence of the oxidation potential on the nature of the gold complex that is formed:

$Au + 4Cl^- = AuCl_4^- + 3e^-$	$E^\circ = -1.00v$
$Au + 4Br^- = AuBr_4^- + 3e^-$	$E^\circ = -0.87v$
$Au + 4CNS^- = Au(CNS)_4^- + 3e^-$	$E^\circ = -0.66v$
$Au + 2I^- = AuI_2^- + e^-$	$E^\circ = -0.50v$
$Au + 2CN^- = Au(CN)_2^- + e^-$	$E^\circ = +0.60v$

¹Publication approved by the Director, U.S.G.S.

No electrode potential for the reaction $\text{Au} + 2\text{S}_2\text{O}_3^{2-} = \text{Au}(\text{S}_2\text{O}_3)_2^{3-} + \text{e}^-$ is available, but because gold reacts with $\text{Na}_2\text{S}_2\text{O}_3$ in aerated water the potential of the complex is probably near -0.6 or -0.7 volt.

Consequently, the oxidant and pH required to oxidize gold changes markedly. Thus, at a pH of 2 in a solution of $\text{Fe}_2(\text{SO}_4)_3$ and CuSO_4 containing 0.05 M Cl^- , gold leaf is dissolved very slowly, if at all — $<0.004 \text{ mg/l}$ in 1 month; when 0.05 M Br^- is used, 1.2 mg/l are dissolved in 1 month; but with 0.05 M I^- , 72 mg/l of gold are dissolved in 1 week. In contrast to the halide complexes, aqueous 0.05 M solutions of the sodium salts of CN^- , CNS^- and $\text{S}_2\text{O}_3^{2-}$ (pH 5 to 7) dissolve 14 mg/l , 0.16 mg/l and 3.4 mg/l , respectively, of leaf gold in 1 month, offering the possibility of solution of gold in normal soils.

In a carbonate-free environment, the oxidation of pyrite produces an acid solution suitable for the oxidation of gold by chloride if MnO_2 is also present. Although the ease of oxidation of gold increases in the order Cl^- , Br^- , I^- , the abundance of these halides in the earth's crust decreases in the same order — their molecular abundance ratio in the crust is approximately 100, 0.6, 0.06. In a carbonate environment, the oxidation of pyrite may produce sufficient $\text{S}_2\text{O}_3^{2-}$ to dissolve gold.

In an oxidizing environment at pH of 5 to 8, only $\text{S}_2\text{O}_3^{2-}$, CNS^- and CN^- may be expected to dissolve gold. Thiosulphates are transient products of biological activity in soils, but never reach substantial concentrations. Thiocyanates are even less abundant in soils. Cyanides are produced by the hydrolysis of cyanogenetic glycosides which are abundant. Over 1,000 species of plants yield HCN on hydrolysis; many arthropods produce HCN; and some fungi also produce appreciable amounts of HCN. Masearated aqueous suspensions of sixteen species of native plants collected in Colorado, Utah, Nevada and Arizona dissolved leaf gold.

The stability of the gold complex has a marked effect on the mobility of gold, as illustrated by the removal of gold from solution by various minerals.

With radioactive gold as a tracer, 114 mineral powders were mixed for 1 minute with solutions, at pH 6, of these six gold complexes, and immediately centrifuged to obtain a clear supernatant liquid and a mineral centrifugate. The radioactivity of these separates was then measured to determine the amount of gold remaining in solution. Of the 114 minerals tested, the numbers of minerals removing 90 per cent or more of the gold from solution were, respectively: 52 from gold chloride, 47 from gold bromide, 23 from gold iodide, 6 from gold cyanide, 4 from gold thiocyanate and 3 from gold thiosulphate.

The absorption of gold from solution by a given plant species is a function of the gold complex present. Gold chloride, thiocyanate and thiosulphate are very weakly absorbed through the roots of *Impatiens hostii*; gold bromide and iodide are moderately absorbed; and gold cyanide strongly absorbed (100 x the chloride) (Shacklette and others, 1970).

In summary, acidic oxidation of pyrite gold deposits may result in transient mobilization of gold as AuCl_4^- ; alkaline oxidation of pyritic gold deposits may result in transient mobilization of gold as $\text{Au}(\text{S}_2\text{O}_3)_2^{3-}$; in soils under native vegetation gold may be mobilized as $\text{Au}(\text{CN})_2^-$. Whatever the circumstances, the gold solutions would be transitory.

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Analysis of Glacial Material as an Aid in Geological Mapping.

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The problems of mineral exploration and geological mapping in areas of glacial overburden and extensive peat cover are well known. In the west of Ireland, bedrock is mostly covered by glacial deposits and peat, giving rise to a situation whereby geological mapping on the basis of surface exposure has a low confidence level. From a mineral

potential viewpoint, recognized favourable geological environments include Devonian sandstone - Carboniferous limestone contacts. It is, thus, important to be able to identify these geological features in poorly exposed terrain with some degree of confidence. Attention was given to establishing the feasibility of identifying the nature of the underlying bedrock on the basis of sampling and analysis of the overlying surficial materials. The mineralogical composition of the silt-sized fraction of the till, as determined by X-ray diffraction analysis, was found to be specific to the underlying bedrock. In this way, the mineralogical composition of the till can be used as an aid in geological mapping.

A Study of the Distribution and Localization of Lead and Zinc in the Weathered Mantle of the Granite de Fougères (Bois-Neuf-en-Vieux-Vy Mineralized Zone, Northwest Brittany). The use of a trace metal extraction method in geochemical prospecting.

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This study was made on the weathered mantle of a narrow lode (containing galena and a little sphalerite) and that of the enclosing granite. A geochemical survey provided data on the horizontal distribution of lead and zinc in the A₁ horizon. The vertical distribution of these elements was studied on a cross section of the mantle across the strike of the vein. The localization of lead and zinc was investigated in four soil profiles in the mineralized zone and in a profile of the weathered barren granite.

The results are as follows:

1.—The horizontal and vertical distribution of lead and zinc suggest that zinc is more mobile than lead under the local conditions of weathering. Nevertheless, leaching experiments have shown that an appreciable quantity of lead can migrate in ground waters above and near the lode.

2.—The study of the localization of each metal was undertaken on several fractions of the weathered mantle. Iron and aluminum oxides and hydroxides were found to be the most important carriers of lead and zinc. These compounds retain about 50 per cent of total metals and may be considered as good indicators of the presence of mineral deposits overlain by a residual overburden. Clay minerals of the "clay fraction" fix relatively little zinc and lead (respectively 16 per cent and 7 per cent). In the mineralized zone, 20 per cent of the lead is bound to organic compounds. The study of the rock-forming minerals has shown that, in close proximity to the vein, feldspars and chlorites have a high content of lead.

3.—Concerning geochemical prospecting in soils in temperate climates, three applications are given. The first two concern the depth of sampling and the suitable particle-size class to be analyzed for lead and zinc. The third is a proposed method to extract heavy metals bound to iron and aluminum oxides and hydroxides. These metals are extracted by an ammonium oxalate-acid solution.

Geochemical Exploration in the United Nations Development Programs.

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Since 1960, sixty-six mineral projects sponsored by UNDP have been entrusted to the United Nations as executing agency, and forty-eight of them have carried out (or are carrying out) geochemical exploration programs. As of December 1969, twenty-seven have been completed and twenty-one are in progress. Data about operations and costs have been collected from thirty-four projects. The information received reflects the over-all importance of geochemical prospecting in the U.N. projects in the last eight years of operation (about 400,000 samples collected and 1,600,000 determinations carried out in total) and its growing share among the various exploration techniques; it compares favourably with geophysics, and this year can expect a collection of about 100,000 samples and 400,000 determinations. It also shows the evolution in personnel and techniques toward

greater specialization and sophistication. The bottleneck of analytical determinations was overcome around 1966 by the introduction in the laboratory of the atomic absorption spectrometer. In addition, the geochemists are now usually assisted by chemists.

One of the main features of U.N. geochemical surveys is their extreme diversification: by the personnel (geochemists from fifteen nationalities), by the type of operation (reconnaissance, detailed, institute building, orientation), by importance and organization (small ancillary surveys to full-scale campaigns), and by distribution (world-wide under all climatic conditions). Notwithstanding this great variety, the costs of reconnaissance stream-sediment surveys, which make up the bulk of the program, are relatively steady; they vary from (US) \$8 to \$14 per square kilometre, with an average of (US) \$10 per square kilometre, or from (US) \$5 to \$40 per sample, with an average of (US) \$15 per sample. The costs of detailed follow-up (soil surveys) are more variable, from (US) \$20 to \$1,000 per square kilometre, depending on the sampling density and local conditions. In the laboratory, the cost per determination of the common base metals may be as low as 20 cents per determination in the case of large operations; the average is below 50 cents per determination. Considering the usually difficult conditions and the relatively long period of initial "tune up", the productivity is high in most of the projects, both in the field and laboratory. Some typical case histories are briefly reviewed.

The main drawback of such a variety of exploration programs is the lack of uniformity in the recording and presentation of the data and, to some extent, the failure to finalize interpretations. The recording and presentation of the data in a computer-recoverable form and a more sophisticated interpretation of the results is the immediate aim of the Division.

Status of Geochemical Prospecting in Brazil¹.

LEWIS, R. W., U.S. Geological Survey/USAID/Brazil, Vania Nabuco de Araujo Mello, and GONÇALVES, Gustavo Noronha Diniz, Departamento Nacional da Producao Mineral, Rio de Janeiro, Brazil.

Brazil, one of the world's largest countries, has considerable mineral potential, the development of which faces problems of inaccessibility and great distances from ports and consumption centers. In addition, much of the bedrock is masked because intensive tropical weathering has formed deep saprolites that seriously hinder mineral exploration. The discovery and evaluation of ore deposits have not kept pace with the Brazilian Government's desire for development of the minerals industry. In recent years, however, the Government has shown considerable interest in establishing geochemical prospecting laboratories and field projects to help overcome some of these problems. Several of these laboratories have now acquired considerable experience in basic techniques and have executed some extensive regional projects; for instance, regional soil surveys and stream-sediment sampling. The next step will be basic research related specifically to the problems of mineral prospecting in areas of tropical weathering and the application of computer-oriented techniques of data interpretation.

¹Publication approved by the Director, U.S.G.S.

Hydrogeochemistry of Rivers in the Mackenzie Drainage Basin.

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Little is known about the major- and trace-element composition of rivers in the Mackenzie drainage basin, and even less is known of the variations to be expected from various parts of the basin. As part of a continuing study in this area, 101 water samples were collected from all major tributaries of the Peace, Athabasca and Mackenzie rivers, as well as from various localities on the main rivers, and analyzed for major and trace elements. The samples were collected mostly within a two-week period during late July and early August 1969, when the river is close to "average" flow.

Results are presented which outline variations for many elements, including several of significance in geochemical exploration; for example, uranium, boron and selected base metals. Background values for these elements in various parts of the basin can now be stated

with a reasonable degree of accuracy (at least for the time of year sampled), thus assisting in the recognition of geochemical anomalies. Variations in the composition of many elements in the rivers is discussed in relation to bedrock geology and other parameters.

Computerized Regional-Residual Mapping and Its Use in the Evaluation of Geochemical Anomalies.

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Geochemistry as a prospecting tool can have a two-fold usefulness: locally, one or more closely spaced anomalies can diagnose a deposit; regionally, the distribution of certain elements can define areas and horizons favourable to the occurrence of deposits.

As the chemical analysis of a sample for a given element yields one value representing the combined effects of local and regional causes, the separation of these components becomes a necessary step in the meaningful interpretation of a survey. Two suitable mathematical methods are Surface Fitting and Moving Averages.

The least squares fitting of polynomial surfaces of given degree to represent broad features is generally known; a major drawback has been the necessity of *a-priori* selecting the degree and form of the surface. The use of orthogonal polynomial techniques has given us a more flexible tool whereby the coefficients of the approximating surface are determined not by arbitrary choice but by a preliminary analysis of the data.

Moving averages methods approximate the regional effect by the mean of all values falling within a square centered at a given point on the map. In most techniques, the square is moved in fixed steps, giving an estimate of the regional effect at a regular network of points generally not corresponding to the sampling sites. By computing the average at the collection points, we are able to produce not only a regional map but also a residual map, thus separating local and background effects into distinct patterns.

The evaluation of individual anomalies as local indicators is then carried out by applying classical statistical methods to the residual component of the sampled value.

New techniques based on recent geostatistical theories are currently being tested on geochemical data.

An Evaluation of Surface Geochemical Prospecting for Petroleum, Caroline Area, Alberta.

McCROSSAN, R. G., Geological Survey of Canada, Calgary.

A geochemical prospecting technique for hydrocarbon was tested in the Caroline area of southwestern Alberta (Twp. 33-36, Rng. 3-6 W5). Approximately 6,000 samples were collected below the soil profile from a depth of 5 feet. The method used is that of Geoservices, which is described in an accompanying paper.

Although the data have not been fully processed at the time of writing, some preliminary observations can be made. The area of some 1,000 square miles contains several oil fields in the Mississippian, Viking and Cardium as well as numerous oil and gas shows in these and other horizons. The maps of the various hydrocarbons all show numerous anomalies throughout the area, both associated with and away from the main pools. The "lively" nature of the area, with the numerous commercial and non-commercial accumulations, may have a bearing on the ubiquity of the anomalies. It is apparent from this type of surface study that this is a hydrocarbon-rich area. It also appears that all commercial pools have some sort of an anomaly associated with them. Other anomalies between pools make it evident that this tool must be used with caution in conjunction with other methods.

The propane anomalies outnumber the methane anomalies in number, size and strength, which may reflect the oiliness of the area. Moreover, the methane and ethane anomalies tend to be more associated with gas fields, and the propane anomalies more widely distributed. When the data processing is completed, statistical correlations will be attempted between the fields and anomalies. A set of control samples have also been taken which will permit additional statistical checks.

Gas Geochemistry in the Seventies — Challenge and Concepts.

McCLUSKY, J. B., J. B. McClusky, Limited, Toronto.

The discovery and exploitation of the world's natural resources presents a formidable challenge to man in the nineteen seventies.

To meet this challenge, earth scientists must evolve bold, new and definitive concepts. Although these concepts will embrace current technology, many of them in terms of today's thinking will be considered bizarre, unorthodox and unconventional. Nevertheless, such concepts will be necessary to challenge, stimulate and revolutionize thinking in the earth sciences, including the exploration for oil, gas and minerals.

The question arises, "What role can gas geochemistry play in the evolution of such new concepts".

Although past experience demonstrates that gas geochemistry surveys in soil and rocks can present formidable problems in arriving at useful interpretations, nevertheless, in the author's opinion, gas geochemistry can and will generate basic information for some of the most startling concepts of the seventies.

This opinion is based on comprehensive studies undertaken by the author in the past decade. These studies attempted to correlate gas surveys in soils and rocks with surface and subsurface geology and geophysics over several hundred thousand square miles, including data from over one hundred thousand wells and extensive computer studies.

These correlations resulted in numerous interpretations, both real and imaginary, but the over-all result was the evolution by the author of a basic concept. This concept embodies a "frame of reference" — expanding and diminishing in terms of time, space and matter.

When earth science data are related to this "frame of reference", an astonishing array of observations, conclusions and concepts evolve. Some of the concepts evolved are discussed, bearing in mind that some may have evolved or will evolve from other considerations.

The concepts enumerated pertain to the alignment of the axis of rotation of the earth, continental drift, the shape and mosaic of continents, world rift systems, global, continental and local fault systems, the orientation of intrusives and other structural phenomena. Other concepts pertain to the geographic disposition of mining camps and major oil structures and the possible application of fundamental laws to the interpretation of geophysics.

An example of information which can be obtained from the application of the "frame of reference" to an entire sedimentary basin is illustrated. A new structural concept evolved for exploration in the basin concerned.

Fundamental laws governing the "frame of reference" are being formulated and evaluated in various earth science fields, including mining and oil and gas exploration.

Comparison of Geochemical Prospecting Methods using Radium with those using Radon and Uranium.

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A rapid analytical method for detecting radium-226 in sediment and soil, suitable for geochemical prospecting, has been developed. The sample is immersed in water in a sealed bottle. After several days equilibrating time, radon-222 in the water is measured. The detection limit is 0.02 pc/gm (picocuries per gram), but no samples were below this limit. Replicate determinations give an average deviation from the mean of 18 per cent. Twenty determinations can be made per day using a single radon counting system. An alternate method, in which radon-222 builds up in air, was tested and found to give superior precision.

A drainage survey, carried out at Bancroft, Ontario, gave the following results:

		median	range
Radium-226, pc/mg	organic sediments	0.92	0.02 - 400
	clastic sediments	0.28	0.03 - 28
Uranium, ppm	organic sediments	3.4	<0.5 - 220
	clastic sediments	1.3	<0.5 - 480
Radon-222, pc/l	stream water	23	<1 - 12,000
	lake and swamp water	1.8	<1 - 9,000
Uranium, ppb	stream water	0.2	<0.1 - 40
	lake and swamp water	0.1	<0.1 - 12

Results for organic sediments can be shown on the same map as those for clastic sediments by applying a correction factor. All the methods tested show a positive response to ore deposits. Methods using sediment are superior to those using water.

Radon-222 in water is negatively correlated ($r = -0.4$) with the size of stream and with water temperature and positively correlated ($r = 0.7$) with radium-226 in sediments. Radon-222 has two sources: most comes from radium-226 in the associated sediments and the rest from the influx of groundwater.

In a soil survey, the usefulness of radium-226 and uranium in A and B horizons was tested. All four methods are useful in reconnaissance prospecting; all but uranium in the A horizon are useful in detailed prospecting.

Stream-Sediment Reconnaissance for Zinc Silicate (Willemite) in the Flinders Ranges, South Australia.

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The Lower Cambrian Archaeocyathinae limestones in the Flinders Ranges contain weak lead and zinc mineralization over a considerable area. Following an initial discovery of a high-grade willemite orebody by routine stream-sediment sampling, a new program was designed to explore specifically for further occurrences of this mineral.

Orientation studies showed that coarser fractions gave the most meaningful results in this semi-arid to arid area bounded on three sides by arid plains traversed by sand dunes. Wind-blown sediment apparently falls mainly in the finer fractions and dilutes the contrast.

Microscopic inspection of the coarse fractions of anomalous sediments has made it possible to distinguish between willemite sources and zinciferous limestone.

As a result of the program, a second outcropping willemite orebody was located 7 miles northwest of the initial discovery.

Endogene Dispersion Aureoles around the Rudtjebäcken Sulphide Ore in the Adak Area, Northern Sweden.

NAIRIS, B., Geological Survey of Sweden, Stockholm.

The distribution of seventeen elements (Cu, Pb, Zn, Sn, Bi, Ag, Mo, As, Fe, Mg, Ti, Ca, Mn, Ba, V, Co, Ni) around a complex, epigenetic sulphide ore has been studied, and 241 samples from seven drill-cores in a profile through the ore have been spectrographically analysed. The results of these analyses show that there exist complex aureoles of Cu, Zn, Pb, As, Ag, Mo and Bi around the orebody.

The distribution of the aureole-forming elements in the vein mineralization of the deepest drill-core in the Rudtjebäcken profile has been investigated and shows higher contents of these elements in the veins compared to the rock samples; wider aureoles are also present.

An Assessment of Requirements and Future Trends of Exploration Geochemistry in Canada.

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Current problems of geochemical exploration in Canada largely require the development of techniques applicable to the search for conventional mineralization in particular surface environments or for types of mineralization that are becoming of increasing economic significance. To date, geochemical exploration techniques have been widely used in the Yukon, British Columbia and the Maritimes, but elsewhere have found limited application, such as in the extensive glaciated Shield areas, because of the problems posed by the glacial history.

Successful geochemical exploration is dependent on the implementation of appropriate sampling, analytical and interpretational procedures. The development of critical sampling techniques according to the varying provenance of the glacial overburden together with the selection of analytical techniques to accommodate the varying modes of occurrence of metals in the natural environment appear to be par-

ticularly attractive aspects for investigation. Automated data processing techniques, carefully selected according to the nature of a specific exploration problem, may materially aid the interpretation of geochemical data. The shortage of appropriately qualified exploration geochemists has been discussed at length at the previous Geochemical Exploration Symposia.

A research program, at Queen's University, working on significant exploration problems is discussed; it is hoped that this program will go some way to fulfilling this need for geochemical exploration technology and personnel.

Investigations into the Transport and Deposition of Copper, Lead and Zinc in the Surficial Environment.

NIGRINI, A., Geological Survey of Canada, Ottawa.

A study of three streams associated with sources of Cu, Pb and Zn in the Bathurst area of New Brunswick, suggests that ground waters, after contact with these sources, are highly charged with CO_2 , H^+ and metal cations. As these waters are exposed to the atmosphere, there is a rapid increase in pH, rapid decreases in P_{CO_2} , Cu, Pb and Zn, and concomitant deposition of hydrous iron oxides rich in Cu, Pb and Zn. These changes occur within a few feet or tens of feet of the site of exposure of the ground waters to the atmosphere. Further transport of Cu, Pb, and Zn is by physical means rather than chemical. Accumulations of Cu, and Zn in sediments farther downstream from the site of emergence of the charged ground water are a function of changes in physical conditions in the streams.

At sites of ground-water inflow, P_{CO_2} in the stream water is as high as 100,000 ppm, whereas P_{CO_2} in the atmosphere is approximately 320 ppm, pH is as low as 2.7, and Cu, Pb and Zn values are 30, 6 and 300 ppb respectively. Downstream, P_{CO_2} stabilizes at approximately 2,000 ppm, pH stabilizes at approximately 7, and Cu, Pb and Zn values average <1 , <1 and 5 ppb respectively. This P_{CO_2} is out of equilibrium with the atmosphere and represents an equilibrium between the rates of biochemical production of CO_2 and its escape from the river to the atmosphere.

A Chemical and Mineralogical Study of the Weathering Processes in West-Central Puerto Rico.

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The chemical and mineralogical nature of soils and stream silts and the chemical nature of stream waters produced by the weathering of mineralized andesitic volcanic and dioritic intrusive rocks have been documented for a restricted area in west-central Puerto Rico. The area has a subtropical climate characterized by a mean annual temperature of 70°F and a rainfall of 80 inches (bimodal distribution). Samples of water, silt and soil were collected and analyzed for the major rock-forming elements, and mineralogical determinations were made on the clay size fraction of the silt and soil samples.

The results of this survey are discussed for a 0.6-km² drainage basin. The principal clay-mineral phases in the silts are gibbsite, kaolinite, muscovite and chlorite. The soil profile samples (1 meter long) have variable clay-mineralogy. The upper horizons (0-70 cm) are dominated by kaolinite and gibbsite, with minor amounts of montmorillonite, chlorite and muscovite. Rock samples collected from road cuts contain dominantly muscovite and chlorite. The muscovite and chlorite in the soils are considered to be residual phases from the moderately weathered bedrock. The stream-water samples contain: SiO_2 , 20 ppm; Na, 7 ppm; Ca, 3-10 ppm; K, 1 ppm; Mg, 5 ppm; and have a pH of 4.5-7.0 on the average. Samples from different streams show minor variation from this composition.

The stream-water compositions are compared with the published data on the system $\text{K}_2\text{O}-\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$. When referred to diagrams showing phase relationships in K^+/H^+ vs SiO_2 and Na^+/H^+ vs SiO_2 , the water compositions plot in the kaolinite stability field. A discrepancy exists between data on the 5-component system (Hess) and actual mineral-water relationships. This discrepancy could be explained if waters in the drainage basin equilibrate with the portion of the soil profile that contains predominately kaolinite, and their composition does not change appreciably on entering the stream environment.

Status of Geochemical Exploration in Indonesia.

ONG, H. LING, Department of Geology, Institut Teknologi Bandung, Bandung, Indonesia.

In the last two years, Indonesia has experienced the greatest amount of mineral exploration since its independence in 1945. The exploration activities include geochemical exploration carried out by foreign companies, by the Geological Survey of Indonesia, by the State Mining Company and by the Department of Geology of the Institut Teknologi Bandung.

Since 1967, eight foreign mining companies have been granted exploration rights in Indonesia, with a total investment of (U.S.) \$463,207,000. This amounts to 59 per cent of the foreign investment total budget, represented by 72 companies. Some of these companies are doing regional stream-sediment, soil and colluvium sampling to delineate areas of interest. Other foreign companies are now doing geochemical exploration at a number of places in the Archipelago and are placing considerable emphasis on the results of this work in obtaining new concessions.

In 1968, the Geological Survey of Indonesia started a systematic sampling of stream sediments in West Java, Central Sulawesi, Sumatra and West Kalimantan, as part of the five-year development program. Samples taken at $\frac{1}{2}$ - to 1-km intervals were analysed in the field colorimetrically for Cu, Pb, Zn and Mo. The Geochemical Exploration Section of the Geological Survey is currently operating with a budget of (U.S.) \$149,500. This amounts to 17 per cent of the Survey's total budget for 1969-1970.

The state mining company "Aneka Tambang" is carrying out soil and stream - sediment sampling in Central Sulawesi and in its Tjikotok/Tjirotan gold concession in West Java.

The Department of Geology of the Institut Teknologi Bandung is currently engaged in soil sampling for academic purposes in the Lok Ulo area in Central Java, where its field school is located. Although this area has no mineralization, the presence of serpentinite is reflected in the soil by the high Ni, Cr and Co content. Consequently, this area can also be used as a training ground for students taking courses in geochemical exploration. The above institution is the only one in Indonesia offering courses in geochemistry.

Problems encountered by government geologists involved in geochemical exploration in Indonesia are briefly discussed.

Application of Endogenic Geochemical Aureoles in Prospecting for Sulphide Deposits.

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Sulphide deposits of different composition and formed under different geological conditions are characterized by endogenic aureoles, comprising zones of scattered mineral and/or elemental impregnations that border the orebodies. The great extent of endogenic geochemical aureoles over deposits permits their use in the detection of orebodies and deposits occurring at great depth.

One of the most interesting peculiarities of endogenic aureoles is their vertical zoning, caused by the differential distribution of element-indicators in vertical section. As a result of endogenic aureole investigations on various sulphide deposits, a single series of vertical zoning of element-indicators was established, as shown in the appended table.

The vertical zoning of the endogenic aureoles is of great practical importance, because it helps to determine the depth of the erosional section of geochemical anomalies (to distinguish supra-ore and sub-ore aureoles).

As a result of the weathering of rocks in the endogenic aureoles, secondary dispersion halos are formed. These secondary dispersion halos are usually connected with endogenic ones and also may be used for evaluation of the depth of the erosional section of geochemical anomalies.

In the USSR endogenic and hypergenic aureoles are widely used in the search for blind ore mineralization. As a result of investigations carried out in the Soviet Union over the last few years, the high efficiency of this method has been established. Within the ore field of Kurusaikoe (Middle Asia), as a result of geochemical surveys of bedrock, twelve anomalies were recommended for prospecting by drilling. Blind orebodies of commercial interest have been detected within all of them.

VERTICAL ZONING OF ENDOGENIC AUREOLES OF VARIOUS DEPOSITS

Type of Deposit	Vertical Zoning*
Lead-zinc deposits in skarns	antimony, arsenic, barium, silver, lead, zinc, copper
Lead-zinc deposits in acid effusive rocks	arsenic, barium, silver, lead, zinc, copper, bismuth, cobalt
Skarn-scheelite deposits	barium, lead, zinc, copper, tungsten, molybdenum
Quartz-gold ore deposits	antimony, arsenic, silver, lead, zinc, copper, bismuth, molybdenum, gold, cobalt, beryllium
Copper-gold deposits	silver, copper, molybdenum, gold
Copper-bismuth deposits	barium, silver, lead, zinc, copper, bismuth, cobalt
Uranium-molybdenum deposits	silver, lead, zinc, copper, molybdenum, uranium
Mercury deposits	barium, mercury, antimony, arsenic, silver, lead, zinc, copper, nickel, cobalt
Sulphide-cassiterite deposits	silver, lead, zinc, copper, molybdenum, tin
Stratiform lead-zinc deposits	arsenic, barium, silver, copper, lead, zinc, cobalt

*From left to right: passing from indicators of supra-ore sections to indicators of sub-ore sections.

The Present Status of Geochemistry in Mexico.

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Geochemistry, as a method of geological exploration, has not been extensively used in Mexico and hence is still in a stage of development. However, geochemical reconnaissance is frequently employed in conjunction with other exploration techniques.

Prospecting for the non-ferrous metals — gold, silver, lead, zinc, copper and mercury — using stream sediments and soils in certain areas of Baja California, Jalisco, Michoacan, San Luis Potosi and Guanajuato, did not indicate interesting sites. Analysis of extractable copper and molybdenum in samples from Nacozari, Sonora, was successful in locating important copper deposits of the porphyry type averaging 1.2 per cent Cu and 0.02 per cent Mo. In Guerrero state, in southwest Mexico, similar methods have indicated interesting sites characterized by gold-copper-silver mineralization.

Lead and zinc distribution patterns have been useful in locating drill holes at a new development in Zacatecas. In Durango, some interesting work is being carried out on the distribution of tin in rhyolitic rocks. In lateritic soils, geochemistry and mineralogy are used in the study of the formation of gibbsite.

Isotope geochemistry has been of recent interest in the study of areas of intense hydrothermal activity, useful in the production of electricity. In geochronology, the lead/alpha and rubidium/strontium methods are commonly used.

Geochemical research in Mexico is of a more basic character and is concerned mainly with geochronology, isotope studies, mineral synthesis, phase equilibria, petrology, mineralogy and analysis.

Suggested Uses of Lead Isotopes in Exploration¹.

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The application of lead isotope techniques in mineral exploration and development offers great promise. In the past decade, we published two brief papers for the prospector suggesting the application of lead isotope techniques to prospecting for radioactive materials and for Mississippi Valley lead-zinc ores. Several of our scientific papers issued during this period allude to yet other possible applications of lead isotopes in exploration. Now, for the first time we present a comprehensive appraisal of all such possibilities.

Better understanding of genesis might guide the prospector, in some instances, directly to the discovery of new ore. Lead isotope studies are a powerful tool for providing new information on the genesis of ores.

¹Publication approved by the Director, U.S.G.S.

Delineations of target areas by the inductive interpretation of patterns of lead isotope variation observed within a district or region are perhaps of even greater immediate promise. For example, we have observed evidence of a lead isotope gradient in the Leadville district that appears to point toward the focus of mineralization. Also, in the Upper Mississippi Valley district, lead isotope data available at present indicate portions of the district within which one might expect better chances of making a major discovery, and a favorable direction in which to look for an extension of the district.

An empirical comparison of a new isotope analysis of lead with the known pattern of lead isotope data from productive mines and unproductive prospects can be most informative. A single lead isotope analysis of galena from a prospect, or of soil from a geochemical anomaly, may reveal valuable information about the potential of the occurrence. The existing record shows that specific isotopic varieties of lead (i.e., distinctive ranges of isotopic composition) tend to characterize uranium ores, certain gold ores, large metal deposits or ore deposits related to a particular episode of mineralization. Such "blood-typing" of the lead in a prospect, at a cost of only a hundred dollars or so, might provide a better evaluation of the potential of the prospect than exploratory work by traditional methods costing far more.

The Quantitative Estimation of Ore-bearing Areas by Sample Data of the Drainage System.

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A formula is given by which anomalies in drainage systems can be screened to indicate those possibly related to deposits and requiring further study from those that are related to other causes and can be disregarded.

Endogenic Halos of Epithermal Gold-Bearing Deposits.

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In Transbaikalia, in the Far East, and in the Northeast USSR, epithermal gold-bearing deposits occur which are related to effusive and subvolcanic formations. Others are found in areas where there is no volcano-plutonic activity of the corresponding age. The deposits are comparatively young (Upper-Mesozoic-Tertiary). Their discovery is difficult because there has been little erosion of the deposits and commercial mineralization occurs over a small vertical interval. To aid in their search, we studied endogenic halos of three deposits: Baleisky, Onokhovskiy (Eastern Transbaikalia) and Belay Gory (Lower Cisamur).

It is a characteristic of these three deposits that their elemental composition and that of their halos is practically the same. In addition to marked concentrations of Au and Ag, they also contain As, Sb, Hg, Cu, Pb, Zn, Ge, Ga, Tl and sometimes Mo. Argillization associated with the mineralization is accompanied by introductions of Li, Rb, Cs, F and Cl. Te was not found (using an analytical method with a sensitivity of 1.10^{-4} per cent).

In the Baleisky ore field, where the investigation was carried out in detail, the halos are wide and extend some 200 to 300 metres above the commercial mineralization zone. A clear zonality can be made out, with high contents of Ag and Au in the zone of optimal mineralization, an increase of Pb and Mo in the subore zone, and an increase of As, Sb, Cu and Hg in the supra-ore zone. This zonality is also present at the Belay Gory and the Onokhovskiy deposit. Graphs of the concentrations of the different elements show that at Belay Gory the upper part of the deposit, including the optimal mineralization zone, has been eroded. It is of interest that the elemental composition in the zones of the halos is constant over great distances (Belay Gory is 1.5 thousand km from Baleisky), a feature that is apparently common for the whole province of epithermal gold deposits.

Summarizing, one can say that the supra-ore halos of As, Sb, Hg and Cu can be used in the search for hidden deposits of epithermal gold deposits.

Meteoritics in Geochemical Exploration.

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The author (Rao, 1969), from the primary mineral and chemical similarities between achondrites and ultramafics and also from the

hydrodynamic interpretation of primary sedimentary structures (Irvine, 1965, 1967) of ultramafic rocks, has shown that ultramafic rocks are derived from the fall of meteoritic showers.

The present paper maintains that the ore deposits (chromite, magnetite, sulphides, etc.) associated with ultramafic and ultrabasic rocks (Adirondacks, Bushveld, Stillwater, Skaergaard, Great dyke, and other layered rocks) have resulted from falling meteoritic showers which have settled in an aqueous medium as "hydraulically equivalent particles".

The above conclusion is supported by:

1. Most spectacular, conformable and parallel layers over long distances.
2. Distinctive and repetitive patterns of rocks and ores.
3. Extremely thin layers (inch scale) over long distances.
4. Crossbedding, plutonic breccia, loose crystal cumulates.
5. Zone of large blocks and slump structures in the neighbourhood of large blocks.
6. Lognormal distribution of each mineral and also bimodal distribution of two or more minerals.
7. Coexistence of "hydraulically equivalent" particles at any depth.
8. Lateral variations in grain-size and thickness of beds and planar arrangements of platy minerals giving fissility.
9. Reversed gravity stratification.

The author, therefore, considers the following parameters as important guides in any mineral exploration program:

1. Rate of accretion of meteoritic showers.
2. Distribution patterns of showers and their sequence in compositions.
3. Source or sources of showers, their size, shape, velocity and composition, and the density, shape and size of particles.
4. Distribution of geosynclines or basins suitable for deposition of meteoritic matter.
5. Size, shape, depth and life span of basins/geosynclines.

Geochemical Investigations for Base Metals and Silver in the Coast Geosyncline, Northern Venezuela, South America.

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Two mineralized zones had been outlined by geochemical methods in the western part of the Coast Geosyncline, Venezuela. The whole area forms part of a complex sequence of metamorphic and igneous rocks with a complicated tectonic history. Several copper mines were worked in the area during the 1930's and 1940's and estimated reserves of over a million tons of copper ore are present.

This paper presents the results of geochemical studies carried out near these copper deposits. A complex silver, antimony and lead deposit containing boulangerite, polybasite, tetrahedrite and pyrrargyrite, filling parallel fractures in limestones and metamorphic rocks, was discovered using geochemical methods in a highly faulted area. In the northeastern part of the zone, typical pyrrhotite-chalcocopyrite-pyrite veins were located within limestone units. It is possible that syngenetic mineralization is also present in this zone. The Bloom method for base metals was used in all the geochemical investigations, and was shown to be an excellent tool in this kind of preliminary work. Problems such as landslides, tropical weathering and seasonal rainfall constituted serious obstacles in the geochemical sampling. At present, these mineralized areas are under study by the Economic Geology Division of the Geological Survey (Ministry of Mines and Hydrocarbons).

Major Element Content as a Means of Allowing for Background Variation in Geochemical Exploration.

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Background and threshold values are known to vary from place to place and sample to sample in a geochemical survey because of physical and chemical processes and changes in rock type. Detailed chemical, mineralogical and statistical studies of forty stream sediments indicate that important metal-bearing phases are vermiculite clay (Cu, Zn), iron oxides (Cu, Zn, Co, Cr, Ni) and organic matter (Zn, Co).

The quantitative effects of variation in these major phases can be evaluated by regression of the trace-metal contents against key major

elements found in the phases, using a large group of normal samples to determine regression coefficients. Regressions of Fe, Mn and nineteen lithologies against six trace metals for 460 Pennsylvania drainage basins demonstrates that iron is the most significant variable for Cu, Ni, Co, Cr and V, and is important for Zn. Anomalies relative to expected values computed from the regression are a significant improvement over the raw data. Regression of Fe, Mn, Mg, Ca and Al, plus lithologic variables for 84 samples from the Allentown-Bethlehem area, shows that one or more major elements are significant for each of the six trace elements.

Both major and trace-element data for use in regression equations can be efficiently obtained by the use of a direct-reading emission spectrometer. The combination of this data with the regression technique is suggested as an effective tool in the interpretation of large geochemical surveys.

Offset Geochemical Anomalies at the Ima Mine, Lemhi County, Idaho.

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Mineralization consisting of tungsten, silver, copper and molybdenum at the Ima mine in Lemhi County, Idaho has been related to a Tertiary granite stock which apexes within the mine from 300 to 1,400 feet below surface. Molybdenite mineralization is the earliest in the sequence and is found in disseminations and narrow quartz veinlets in the upper part of the stock and in the overlying Precambrian quartzites. Tungsten mineralization, predominantly in the form of huebnerite, was mined from strong north to northwesterly striking quartz veins which cut both the quartzites and the granite. Huebnerite-bearing veins in the eastern group dip westerly, whereas the veins on the west side of the mine dip east.

The molybdenum content of the soils is generally very low, but is strongest in the outcrop or projected outcrop areas of huebnerite-bearing quartz veins. Because of the distance, updip, on the vein projections from the granite to the surface, these projected outcrop areas are, for the most part, offset from the area directly over the granite stock. The associated molybdenum anomalies, therefore, do not indicate vertically underlying molybdenite mineralization.

Caractères Géochimiques de la Keg River Formation.

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Dans le secteur de Rainbow la formation carbonatée du Keg River, encadrée par deux épisodes évaporitiques (Chinchaga et Muskeg formations) est subdivisée en deux termes :

- 1 - Lower Keg River Member, plate-forme carbonatée de 180 pieds d'épaisseur à crinoïdes, brachiopodes, trilobites, algues.
- 2 - Upper Keg River Member, dans lequel se développent des édifices récifaux (pinacles, patch-reefs) à crinoïdes, coraux et stomatopores, de 700 pieds d'épaisseur (Rainbow Member Reef), tandis que les faciès off-reef est formé par 180 pieds de micrites litées pratiquement dépourvues de restes fossiles.

L'étude géochimique s'est fixée comme objectif l'estimation de la quantité, de la qualité et du degré d'évolution diagénétique de la matière organique dispersée en tenant compte des caractéristiques des trois lithofaciès de la formation. Dans ce but ont été utilisés la diffraction X sur roche totale, le dosage du carbone organique, l'extrait organique soluble, les teneurs en éléments-traces et le degré de carbonisation.

Les faciès construits en milieu oxydant (Rainbow Member Reef) sont caractérisés par des teneurs faibles en carbone organique, par l'absence de corrélations Mo - Carbone organique et Cu - Carbone organique et par des rapports Mo/Carbone organique et Cu/Carbone organique généralement faibles.

Le Lower Keg River et l'Upper Keg River off-reef présentent au contraire des teneurs beaucoup plus élevées en Carbone organique et des corrélations Mo - Carbone organique et Cu - Carbone organique. Les rapports Mo/Carbone organique et Mo/Cu apparaissent d'autant plus élevés que le milieu de dépôt a été plus réducteur. On est aussi conduit à admettre que l'Upper Keg River off-reef a pu être la roche-mère des gisements de Rainbow. Le degré d'évolution du kérogène ne contredit pas cette hypothèse. La matière organique est au contraire beaucoup moins évoluée dans des secteurs plus orientaux du bassin de l'Elk Point (Winnipegosis).

Recognition of Geochemical Anomalies from Anomalous Points by Measuring Perimeters of Convex Hulls.

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Consider a set of points, some of which are **anomalous** (determined to be anomalous by a geochemical or other survey), located on a plane. Whether some or all of these points are clustered to form one or more **anomalies** or, alternatively, whether these points are scattered at random may be investigated by measuring perimeters of **convex hulls**. A convex hull is the smallest convex polygon that will encompass a group of points. (Examples of convex polygons are triangles, rectangles and all other regular polygons; examples of polygons that are not convex are stars, arrowheads and T-squares.)

The perimeters of convex hulls of selected anomalous points are measured. If a perimeter is smaller than expected by chance (at specified risk levels), the points are considered to be clustered to form an anomaly; otherwise, they are considered to be randomly scattered. Tabled values of perimeters to define clustering at several risk levels have been computed by mathematical simulation.

If too large a percentage of sample points is anomalous, the method of convex hulls may not be useful, and an alternative minimum-configuration model is explained. The minimum-configuration model defines various configurations of contiguous points and compares the observed number of configurations per unit area with the expected number.

Applications are discussed in several fields of geology and geochemistry — including geochemical exploration surveys, rock textures, heavy-mineral spatial distributions and distributions of metals in tabular orebodies — as well as in mining (dust control), metallurgy, biology, ecology and medical geography.

Specific applications to a geochemical survey in the Coeur d'Alene district, Idaho, and to the distribution of gold in part of the City Deep mine, Central Witwatersrand, South Africa, are reviewed.

Mercury in Base Metal and Gold Ores of the Province of Quebec.

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The distribution of mercury in selected base metal and gold deposits in the Province of Quebec was studied. Approximately six hundred ore samples were taken from nineteen producing base metal mines, three producing gold mines and five previously operating base metal properties. These specimens were chosen to be representative of the orebodies of each mine.

Analysis of the samples has demonstrated that mercury is more abundant in zinc sulphide ores than in iron, copper or lead sulphides, and that, generally, there is an increase in mercury with increasing zinc content of the ore.

The work has shown that the base metal ores of two mines from the Grenville province of the Precambrian Shield have the highest tenors of mercury of all ores sampled, followed by the base metal ores of the Superior province of the Precambrian Shield, the Appalachian region and the St. Lawrence lowlands.

Samples of three gold deposits from the Superior province show that, contrary to expectations, the gold ores are extremely low in mercury.

Evaluation of Copper and Molybdenum Geochemical Anomalies at the Cumo Prospect, Boise County, Idaho.

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The Cumo prospect is in west-central Idaho, approximately 35 miles northeast of Boise. During airborne reconnaissance, limonitic discoloration was noted in soils in a forested area having outcrops and a maximum relief of 1,750 feet. Soil samples cut along ridges and spurs contained anomalous amounts of copper and molybdenum.

A 2.5-mile road was constructed and several trenches were excavated to make exposures. The 0.3-square-mile anomalous area includes a small part of a northeasterly trending dyke swarm in quartz monzonite of the Idaho batholith of Cretaceous age. Rhyolite porphyry, dacite porphyry, biotite lamprophyre and calcareous diabase dykes are aligned subparallel to the principal joint sets.

Molybdenite and chalcopyrite occur as disseminated grains and along

fractures in rhyolite porphyry, lamprophyre and dacite porphyry dykes. The sulphide content of the wall rock and the intensity of silicification decrease outward from the dyke margins. Thin quartz veinlets containing molybdenite and chalcopyrite cut some dykes and the quartz monzonite pluton. However, veinlets thicker than 1 mm commonly are barren. Rare coarse molybdenite occupies scattered alteration voids in quartz monzonite. Fresh diabase dykes contain up to 10 per cent calcite, but no primary copper or molybdenum minerals. Chrysocolla, limonite and minor amounts of tenorite, azurite, cuprite and malachite occur along faults and within and next to weathered diabase dykes.

The molybdenum ions travelled only short distances from molybdenite occurrences before they were precipitated. Hence, the linear molybdenum anomalies are closely related spatially to the molybdenite-bearing dykes. The copper ions were carried by groundwater until they were precipitated by the calcite in diabase or under reducing conditions along faults. Therefore, copper soil anomalies are displaced from primary sources and are related to the distribution of calcareous diabase dykes and faults.

A Geochemical Prospecting Method using Stable Isotopes. SHIMA, M., The Institute of Physical and Chemical Research, Yamato-machi, Saitama Pref., Japan, and THODE, H. G., McMaster University, Hamilton, Ontario.

The use of stable isotope abundance variations in geochemical prospecting is discussed in terms of observed correlations between variations in minor element contents and in $^{34}\text{S}/^{32}\text{S}$ values near four orebodies. Observations show that each of these orebodies is enriched, relative to wall rock, in the indicator elements — copper, zinc, sulphate — and in the ^{32}S content of the sulphides, and that in each case the concentration of these indicator elements, as well as ^{32}S , decrease with distance from the orebody. The precise mechanism which causes the sulphur isotope abundance variations is not known, but the results show that a redistribution of sulphur isotopes may be involved in processes of rock alteration and that such effects may form the basis of a useful prospecting method.

Use of the Petrographical-Geochemical Prospecting Method for the Discovery of Hidden Muscovite Deposits in Different Geological Environments.

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Muscovite deposits and other types of nonmetallic deposits have no direct geochemical indicators. However, with indirect indicators it is possible to use secondary aureoles to discover granites and pegmatites, but it is impossible to determine those that are mica-bearing from those that are barren.

Mica bearing veins are frequently accompanied by wide primary zoned aureoles of altered country rocks. These include zones of oligoclazation, muscovitization and silicification of gneisses and schists. Microclinization is common around pegmatite veins containing K-feldspar. Magnesian skarns frequently have wide calciphyral zones at the contacts of micaceous pegmatites and marbles. All these circumstances permit the use of primary aureoles in the search for 'blind' micaceous pegmatite bodies and for the evaluation of bodies without commercial mica.

Positive anomalies, three to four times background, of Ba, Rb and Pb in the zones of microclinization (10 to 60 metres from pegmatite contacts), positive anomalies, two to three times background, of Ba, Rb, Cs, Li, Pb, Tl, Be and Tr in the zones of muscovitization (5 to 20 metres from pegmatite contacts), and negative anomalies of the majority of elements in the zones of silicification are present near the contacts of pegmatite bodies rich in K-feldspar.

Positive anomalies of B, Be, Rb, Cs, Li and Ba occur around quartz-muscovite-plagioclase veins in gneisses and schists. However, mineral aureoles (up to 15 metres) of secondary muscovite are only satisfactory for the purposes of distinguishing commercial mica-bearing veins. This type of muscovite is about twice as frequent in abundance near commercial veins as near those that are barren.

Anomalies of Ba, Rb and Cs around K-feldspar-containing veins do not show enough contrast where the country rocks are rich in kyanite. Petrographical control and quantitative methods of analysis are necessary in most cases to distinguish these bodies.

The calciphyre zones can be easily located in the marbles even by semiquantitative methods. These zones have high-contrast positive anomalies of K, Ba, Rb and Li, mostly concentrated in phlogopite.

Marine Geochemical Prospecting — Present and Future.

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Applied geochemistry must not limit its horizons to terrestrial prospecting alone, but must project into the future and conceive of using and improving existing exploration techniques and developing new ones for marine geochemical prospecting. For fourteen significant commodities, 7.9 per cent of their total worth derives from offshore (continental shelf) mining operations (excluding beach sands) and has a value of more than \$4,170 million.

Of the 70.8 per cent of the earth's surface covered by the seas, 7.6 per cent has water depths of less than 200 meters and is both explorable and exploitable. The U.S. Navy Sealab I and II investigation and the government- and/or industry-supported development and operation of undersea deep research vessels have demonstrated the feasibility of in situ inspection of areas of the ocean floor and the collection of materials comprising the floor to 200 meters. Another 8.5 per cent of the oceanic area has water depths of between 200 and 2,000 meters and is explorable and in part exploitable. The R/V Prospector is involved in a manganese nodule suction mining pilot program on the Blake Plateau in 300 to 900 meters of water. The remaining 83.9 per cent of the oceanic area includes waters with depths greater than 2,000 meters and is explorable, although at this moment not exploitable.

As with terrestrial geochemical prospecting, several stages are involved in marine mineral exploration: review of known regional features and trends, television or other undersea photography, mapping, sampling, mineralogical and chemical analyses of samples, interpretation, and evaluation of the prospect. Equipment for 'in mare' semi-quantitative analysis of sediments, sedimentary rocks and other rock types must be developed and/or adapted in a manner similar to the alpha scattering experiment which was used to give the first chemical analyses of three sites on the lunar surface. Such equipment will undoubtedly be based on activation analysis methods and will be used in conjunction with geophysical data and perhaps natural radioactivity surveys. Whether for metals, non-metals or hydrocarbons, the practicality of exploitation will be dictated by the economics of the particular project.

Radon in Soil Gas: Three Uranium Exploration Case Histories in the Western United States.

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Radon²²², a gaseous daughter product of uranium²³⁸, disperses from the point of formation by travelling in solution in groundwater, by diffusion, and by barometric pumping, for distances measurable in inches to hundreds of feet. This paper describes very diverse results for three field examples of this prospecting approach in soil-gas above sandstone uranium targets of the Western U.S.

In the first case, the geology is typical of the Tertiary basins of Colorado. In a 2-square-mile area of pervasive alluvial cover, a uranium-bearing sandstone bed, 0 to 30 feet below surface, was readily delineated by Rn²²² values of up to 39 cps (counts per second) (background = 3 cps).

In the second case (on the Colorado Plateau), uranium mineralization occurs in a widespread 5-foot-thick blanket of calcite-cemented Mesozoic sandstone below 19 to 400 feet of interbedded shales and mudstones. Radon in soil-gas, and scintillometer readings, were moderately to strongly anomalous over outcrops of uraniumiferous sandstone and mine dumps within the ore trend. However, radon in soil-gas over buried mineralization showed no anomalies, even within 19 feet of mineralization, apparently because of the impermeability of both the calcite matrix and the relatively unfractured overlying shales and mudstones.

In the third case, the geology is typical of the Tertiary sandstone-type uranium deposits of Wyoming. Nearby camps where geology is very similar have radon in soil-gas anomalies of 8-30 cps (background = 4 cps) over known mineralization 50-200 feet below surface and readings of 100-150 cps in the ore itself. Radon in soil-gas readings in virgin ground yielded up to 32 cps, with background values of 4 cps. Subsequent drilling revealed mudstones and interbedded sandstones which gamma-ray activity indicates to be totally devoid of uranium except for background values. No geological or geochemical explanations for these radon anomalies are known at present.

These diverse findings illustrate that radon²²², despite its uniqueness as a short half-life gaseous pathfinder, can result in problems common to other geochemical exploration techniques.

Geochemical Exploration over Complex Mountain Glacial Terrain, Yukon.

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The alpine-glaciated Yukon River Valley, especially in its upper portion, displays many glacial-lacustrine-fluvial tills and outwash sediments. Topography along the sample area consists of flat plains and gently rolling hills along the glacial floor and flank. Vegetation is boreal to sub-boreal, with minor alpine features, and the soils are primitive, usually orthicbrown in character. Along the "Copper Belt", the bedrock is a granodiorite batholith - miogeosynclinal sediment contact area. The mineralization is of the pyrometamorphic type, with copper primarily, and occasionally molybdenum.

Overlying soils vary from a few inches to 40 feet in thickness, with an average of about 25 feet. The soils are acidic, with a mean pH of 6, except where calcified due to underlying sediments.

Typical Yukon soil sampling techniques were applied, with the samples analyzed for copper only. The values were rigorously attacked with statistics and contoured with a rolling-means smoothing technique.

Geochemical surveys employed to find skarn-type mineralization in mixed acidic and basic environments must be carefully interpreted on the basis of subtle features, due to the complex mobility patterns of the various elements present. These subtle features can only be noticed by employing thorough statistical examination of the data, with special consideration to the problems of repeatability of assay and of sampling value.

The New Methods of Gas Surveys; Gas Investigations of Wells and Some Practical Results.

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The paper describes the new methods of subsurface and deep gas surveys as used in geochemical prospecting for petroleum and natural gas. Methods of deep gas surveys are described, which are employed where the gas indications in the upper layers of a stratigraphic section are feeble, or where there is a high background. The method of investigation of gases in cores through stratigraphic sections of rocks is also described.

The shape of gas anomalies is more reliable in the upper stratigraphic layers, owing to the large number of sample points. Gas anomalies in deeper layers, although obtained on a smaller number of points, have more contrast, for example 4-8 for methane and 10-20 for heavier hydrocarbons. The method of interpretation of gas anomalies, combined with the investigations of gases through the section, is founded on the concept of "base horizons", shapes of anomalies and situation of wells. The concentrations of gases in cores are higher and more in accordance with the conditions obtaining in deep layers, when a special hermetically sealed core-lifter is used.

In the paper are described the results of geochemical prospecting and their efficiency under different geological conditions.

The gas-logging methods and their interpretation in determining the presence of petroleum and gas deposits through stratigraphic sections of rocks are also described.

The Theoretical Foundations and Development Tendencies of Geochemical Prospecting for Petroleum and Natural Gas.

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The geochemical methods of prospecting for petroleum and natural gas are founded on the determination of gas and petroleum indicators in the near surface or deeper layers of rocks. The direct indicators are hydrocarbons, migrating from petroleum and gas deposits. These hydrocarbons are determined by the methods of subsurface and deep gas surveys and by investigations of gases in cores obtained from

the rocks. The foundations of these methods are the specific chemical composition of hydrocarbons, their vertical migration and their differentiation.

Gaseous hydrocarbons may migrate considerable distances from the petroleum and gas deposits and form gas anomalies with straight or halo shapes at different levels of the stratigraphic section and hence indicate the presence of deposits at greater depths.

The influence of the presence of petroleum and gas on the geochemical conditions and the alteration of components migrating from the deposits are the basis of prospecting methods utilizing hydrochemicals, bitumens, etc. Geochemical genetic indications characterize the possibility and scales of petroleum and gas formation. Some gaseous components are the indicators of certain metallic ores.

In the paper are described the results of new theoretical investigations about the composition and formation of hydrocarbons and other gases under different geochemical conditions, the role and scale of their migration, differentiation and chromatographic distribution, and the nature and peculiarities of gaseous and other geochemical anomalies at different stratigraphic levels. In the paper are also described the foundations of methods of geochemical prospecting under different geological conditions, especially offshore prospecting, and prospecting for deeply buried deposits.

The perspectives and tendencies of developments in geochemical prospecting for oil and gas are discussed on the basis of the results obtained and the efficiency of the methods employed.

The Use and Development of Geochemical Prospecting Methods for Ore Deposits in the U.S.S.R.

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The most widely used geochemical prospecting methods in the USSR are metallometric surveys based on secondary halos in soils and overburden and stream sediments in drainage systems. These are followed by geological, geophysical and detailed geochemical methods. Modern developments in the geochemical methods include the following: (a) widening the sphere of elements analyzed and using automated methods of analysis to attain the best analytical results and to cut the costs (the main methods are analytical, semi-quantitative emission spectroscopy, and in some cases atomic-absorption); (b) the use of statistical methods and computers for processing the sample data and the mapping of geochemical anomalies; and (c) assessment of the ore potential of the areas by theoretical and empirical formulae based on the data of the halos in the overburden and stream sediments. The metallometric survey method is adapted to the prevailing landscape and geochemical conditions, particularly to the nature of the halos in the overburden and to the dispersion of the elements in the drainage systems.

For locating hidden halos, samples are chosen from boreholes, and hydro-, atmo- and biogeochemical surveys are carried out.

In the last decade, methods for locating hidden deposits and for prospecting for mineralization at depth, using supra-ore primary halos of ore elements and volatile and petrogenic elements, have been intensively investigated. By these methods, deposits at a depth of some hundred metres have been discovered.

Studies of the prospective ore potential of areas by an investigation of the geochemical features of magmatic intrusions and vulcano-plutonic complexes are actively being pursued.

For developing the theoretical basis of geochemical prospecting methods, an investigation of the geochemistry of ore-forming processes and the formation of halos associated with deposits is pursued along thermodynamical and physico-chemical lines, accompanied by experimental and mathematical modelling.

Endogenic Halo Types of Hydrothermal Molybdenum Deposits.

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The study of endogenic halos of ore elements within the ore fields of some hydrothermal deposits of molybdenum in Eastern Transbaikalia has revealed that these halos have a complex and heterogenic structure. Deposits confined to extensive weak yet penetrating structural zones are characterized by three endogenic halo types:

The first halo type has a considerable extent, being ten and more times the size of the ore zones. Within this halo there is an increase

in the content of Mo, Cu, Pb, Zn, and Hg of from two to ten times the general background. In places, the increase may be 25 times the normal background. These halos are not accompanied by any of the postmagmatic changes common in rocks. The increased molybdenum concentrations are simply related to small dispersed impregnations of molybdenite.

The second halo type is characteristic of areas close to the ore zones. It is characterized by a sharp increase or decrease in the concentration of molybdenum (up to 0.5-1 γ/g decrease and up to 20-70 γ/g increase) and exhibits signs of postmagmatic reworking of the enclosing rocks.

The third type of endogenic halo is that associated with the orebodies. They show a marked ore element concentration, a zonality of structure with respect to the orebodies and an intensive hydrothermal reworking of enclosing rocks. Outward from the orebodies the concentrations of the ore elements decrease in the following order: Mo - Pb - Zn - Cu - Hg.

The total effect of these endogenic processes leads to an unusual distribution of elements, reflecting the complicated and multistage formation of the endogenic halos.

The first and widest endogenic halo, representing the earliest process, is apparently related to the late-magmatic degassing of productive intrusions. The second and third are related to the processes of the redistribution of the ore elements during postmagmatic processes, including the hydrothermal stage.

Differentiation of Vaporous and Ionic Origin of Trace Mercury in Soils.

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Differentiation of a vaporous or ionic (aqueous) source of trace mercury in soils can be accomplished by analysis of both humate-rich and clay-rich horizons. This conclusion was suggested by a field study in one geologic environment, supported by laboratory investigations and substantiated in another geologic environment. The approach presents a useful refinement in soil-mercury geochemical prospecting and is particularly applicable to buried deposits.

Field sampling in southwest Oregon and central Colorado, in areas described by previous independent studies, corroborate the laboratory results. Two portions were taken at each sample site, one of organic trash and mull and another of the clay-rich horizon. Hg_{organic}/Hg_{clay} ratios less than unity correlate with an ionic source, whereas ratios greater than five correlate with a vaporous source for the mercury.

Laboratory studies involved organic material from various types of vegetation and three types of clay. In most instances, the Hg_{organic}/Hg_{clay} ratio resulting from exposure to a vaporous source of mercury was an order of magnitude greater than the same ratio resulting from exposure to an ionic source.

Behaviour of Tungsten Minerals and Ores in the Weathering Zone under Equatorial and Tropical Conditions — Possibilities of Geochemical Exploration and Prospecting.

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Tungsten ores are composed mainly of wolframite or scheelite or both these minerals; they are extracted from alluvial, eluvial or primary deposits.

Taking into consideration the fact that the tungsten ore minerals are mainly wolframite and scheelite, many geochemical investigations related to tungsten dispersion and migration are devoted to the study of their mechanical properties or to their reactions in different kinds of solutions or reagents. In fact, in the zone of weathering, particularly in hot, humid and forested equatorial and tropical conditions, the dispersion and migration of tungsten do not start with fresh minerals but with the products of their alteration, namely anthoinite, ferritungstite, hydrotungstite, meymacite and tungstite, which, in this zone, may represent as much as 50 to 75 per cent of all tungsten-bearing minerals.

The above-mentioned products of alteration strongly affect the mechanical resistance of wolframite and scheelite, such that they cannot survive for more than some hundred meters of alluvial transportation. At the same time, they facilitate their chemical solubility.

In the present paper, the author examines the main mechanical and chemical properties of primary and secondary tungsten minerals and gives some examples from the Eastern Democratic Republic of

Congo, Rwanda, Burundi and Uganda of the distribution of these minerals in the weathering zone and of the dispersion and migration of tungsten in eluvial and alluvial soils.

Under equatorial and tropical conditions, during eluvial processes, all the above-mentioned products of alteration are pulverized almost completely and are partly dissolved and partly mixed with the finest products of eluvium, which absorbs at least part of the solution.

During the alluvial processes, the products of alteration are dispersed and transported for distances that may be expressed in kilometers and tens of kilometers. They are mixed with the finest products of the river silts and soils. The coarse wolframite and scheelite are concentrated in river beds near the primary deposits over some hundred meters.

Geochemical halos of dispersion are produced by these products of dispersion in regions where granitic cupolas are not reached by erosion. In regions where granitic cupolas outcrop, the tungsten of granites is added to these products.

Geochemical tests have been made in different parts of Congo, Rwanda and Burundi on different types of geochemical dispersion halos of tungsten.

Preliminary Results on the Primary Deep Geochemical Aureoles of Elements in the Pyritic Copper Mine "Radka" (Bulgaria).

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The "Radka" mine is a pyritic-copper mine. The enclosing rocks comprise andesites, andesitic tuffs and eruptive-flow breccias, dacites, dacitic tuffs and breccias, and marly limestone (Senonian). The rocks exhibit a regional propylitic alteration.

Hydrothermal wall-rock alteration near the orebodies consists of: silicification, albitization, sericitization, epidotization (in fissures), hematitization, alunization, pyrophyllitization, carbonatization, barytization and anhydratization. Exogenous kaolinization is also present.

The ores are: (a) compact pyritic ores; (b) impregnation pyritic ores; (c) compact copper sulphide ores; and (d) impregnation copper sulphide ores.

The principal ore minerals are: pyrite, chalcopyrite, bornite, sphalerite, galena, enargite, tennantite and chalcosite (several varieties). The accessory minerals are: native gold, native silver, stannite, germanite, renierite, idaite, tetradymite, beegerite and chrysocolla. The vein minerals are: quartz, sericite, chlorite, albite, alunite, epidote, pyrophyllite, calcite, anhydrite, gypsum, barite and kaolinite.

The primary geochemical aureole of elements was examined in the deep levels, where there are no exogenic migrations of elements. Analyses were done by spectrograph on representative channel samples.

Preliminary results suggest that, near the orebodies, there is an endogenous geochemical aureole of Pb, Ag, Mo, Sn, Bi, As and Mn. The largest aureole is that represented by the dispersion of zinc. Arsenic is usually found in the greatest amounts above the orebodies. Cobalt, titanium, vanadium and gallium give negative anomalies. Tungsten shows an inverse relationship with respect to vanadium and chromium and also to cobalt.

The results of the analyses are graphically treated and can be used for geochemical exploration and the discovery of deeply buried copper ores in the "Radka" mine in Bulgaria.

Summary of Research and Development in Geochemical Exploration in Canada.

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Expenditure on research and development in exploration geochemistry in Canada has reached an all-time high as a direct result of the recent successes of geochemistry, which themselves have resulted from a better knowledge of the factors controlling the collection, analysis and interpretation of geochemical data.

A brief summary of current research in exploration geochemistry being undertaken by universities, government departments and industries in Canada is given.

Considerable data are being collected in case-history studies of a wide variety of mineralization types in almost every environment of Canada. Although these studies are important to an understanding of the use of exploration geochemistry in a particular area, emphasis in this paper is placed on a description of fundamental studies which affect the use and interpretation of geochemistry on a broad front.

Mercury continues to be of great interest, and a considerable amount of research is being undertaken by a number of institutions. Investigations into the mode of occurrence of mercury in bedrock and soil are receiving close attention, and this information, when available, will permit a much closer interpretation of mercury anomalies. This work is being supplemented by experiments investigating the rate at which plants transpire mercury into the atmosphere and the effect of different soil, atmospheric and plant conditions on this rate. In conjunction with these investigations, instrumentation has been developed which can measure the concentration of mercury in the atmosphere either from the ground or from low-flying aircraft.

References are made to the use being made of computers for data handling, the correlation of field and laboratory observations, data plotting, the formation of a national data bank of geochemical information and interpretational programs.

Increasing attention is being paid to the use of bedrock geochemistry at all phases of exploration, including locating geochemical provinces, the detection of mineralized intrusives and volcanic sequences, and the recognition of significant wall-rock anomalies.

Although the application of overburden geochemistry within the Canadian Shield has been considered unreliable in the past, this area is also receiving increasing attention with the development of techniques for deep overburden sampling, which has yielded positive results.

As well as research and development into an understanding and interpretation of methods currently used on a routine basis, considerable effort is being put into an investigation of the use of a range of other elements and compounds, particularly the volatile components, as applied to mineral exploration. This work is particularly directed to the identification and detection of any volatile components which may be present in the soil, air or atmosphere. Experimental work is being carried out on the modifying effect of organics, particularly those related to plant transpiration. The development of instrumentation capable of detecting these products is also being undertaken.

The Copper and Zinc Content of Trout Livers as an Aid in the Search for Favourable Areas to Prospect.

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Ninety-six Rainbow and Cut-throat trout livers were collected from forty-seven widely separated localities in British Columbia. The livers from thirty localities contained 60 or less ppm copper (wet weight), and those from forty-four localities had 50 or less ppm zinc.

All of the livers with more than 50 ppm zinc came from fish living in water known to be associated with economic zinc mineralization.

Of the seventeen localities where the fish livers showed more than 60 ppm copper, four are known to contain significant mineralization (Stellako River (2), Buttle Lake, Okanagan Lake), and at least seven, on the basis of their background geology, merit further "serious investigation". These seven are Tlowils, Camp and Elsie Lakes on Vancouver Island; Mud, Hyas and Rhoda Lakes north of Kamloops; and Sleeping Water Lake in the South Okanagan. The other six anomalous copper localities, equally divided between the Cariboo and the southeast Kootenay districts, suggest possibilities, but the authors lack the detailed geological data necessary for any assessment of their potentialities.

Disease and/or pollution may cause the copper content of human livers to be higher than normal. We do not know if fish livers may be similarly affected. However, neither disease nor pollution are known to occur in those lakes meriting "serious investigation".

Research in Applied Geochemistry at Imperial College, London.

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The Applied Geochemistry Research Group was founded in 1954 for work on problems of mineral exploration, with particular reference to prospecting in tropical terrain. Over sixty projects have been undertaken in nineteen countries, mostly in Africa, Australia, the Far East and the Southwest Pacific area. Since 1963, the scope has been enlarged to include the application of geochemistry in marine mineral exploration, agriculture, shell-fishery and pollution. Considerable effort has been given to the development of multi-purpose geo-

chemical reconnaissance and, latterly, to geostatistical aids to interpretation and automatic plotting systems. Recent research in these various fields is summarized below.

Problems of mineral exploration in peat- and drift-covered terrain are being examined in Ireland. Renewed attention is being given to mercury dispersion in organic environments following the discovery that the anomaly contrast for mercury in stream sediments in the vicinity of Gortdrum is ten-fold greater than that for copper. Mineralogical analysis by X-ray diffraction of the fine fraction of glacial till promises to aid geological mapping in areas overlain by ground moraine.

The discovery of high-grade ore at Kalumbila on the edge of the Kalahari sand cover in Zambia has increased the already considerable interest in methods of prospecting for mineralization beneath aeolian cover. It has recently proved to be possible to trace the extension of mineralization beneath the Kalahari by the analysis of partial extracts of selected fractions of surface sands. Spurious anomalies have been distinguished by expressing the results in terms of the copper: iron and other metal ratios.

Stream-sediment sampling of 80,000 sq. miles in Zambia, at a density of 1 sample per 100 sq. miles, indicates that variations in the background content of Cu, Sn and Sr correlate with the known copper, tin and carbonatite provinces. Stream-sediment reconnaissance of Northern Ireland at a density of 1 sample per sq. mile has been completed, and a similar survey of England and Wales is under way. Maps are being compiled for up to 25 elements, and the results are providing unique opportunities for identifying and examining the factors influencing the interpretation of regional-stream sediment data.

The regional data are also being studied in relation to the incidence of plant and animal diseases, and pollution. Also in the biogeochemical field, anomalous zinc in estuarine waters derived from old mine workings has been implicated in problems of oyster culture.

Research in applied marine geochemistry has been concerned with the development and improvement of prospecting techniques for a variety of economic and potentially economic marine mineral deposits. Near the coast, some success has been achieved in locating detrital heavy mineral deposits and primary tin mineralization concealed by bottom sediments. In greater water depths on the Moroccan continental shelf of the Atlantic, extensive occurrences of phosphorite have been proved, and submerged radioactivity counting has been demonstrated as an aid to prospecting for this type of deposit.

Research in the deep ocean off the continental shelves has been confined to metalliferous hot brines and associated deposits, and to manganese nodules and encrustations. Investigations in the Red Sea have shown the existence of an extensive zinc-copper anomaly in the sediments related to the known brine occurrences in the center of the Sea. These results have application in the search for similar metalliferous deposits occurring elsewhere and in earlier geological times.

Studies of manganese deposits in the oceans demonstrate that a marked variation in average composition can be recorded over a distance of a few miles. Evidence is now accumulating that these differences can be explained by environmental factors.

Finally, in geostatistics, an evaluation is being made of the scope for various smoothing and filtering techniques in the interpretation of the geochemical data obtained during the course of these various studies. Two-dimensional moving averages and principal component analysis have assisted in the delineation of some regional stream-sediment patterns, and cluster analysis has shown particular promise in the study of compositional variations in manganese nodules and mineralogical variations in glacial till. The examination of computerized automatic plotting systems includes various types of line-printer and CRT outputs, and will be extended to cover inter-active CRT displays. The application of pattern recognition techniques is also being studied.

The over-all program outlined above is planned on a continuing basis, and enquiries concerning opportunities for research by or within the Group are always welcomed and should be addressed to the Applied Geochemistry Research Group, Geology Department, Imperial College, London S.W.7, England.

Airborne Geochemical Prospecting.

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Airborne geophysical exploration methods have become important tools in mineral exploration. With the exception of the airborne gamma-ray technique, none of the airborne methods are able to identify directly the specific metal content of a mineralized site. Experiments with remote-sensing methods based on the analysis of

vapours emanating from ore deposits promise to indicate the existence of mineralization, but it is questionable whether the specific metal content of such deposits can be identified.

The new airborne geochemical prospecting technique (U.S.A. Patent No. 3309518 dated 14th March 1967; Canadian Patent No. 805117 dated 20th January 1969) is based on the discovery that minute particles of outcropping mineralized rocks or soils are carried by air currents into the atmosphere, forming particulate aerosols. By the use of micro-analytical techniques, it is possible to determine the identity of the elements in these particles, and thus to identify the nature of the ore deposits. Broadly speaking, the new technique comprises the collecting of airborne particles of minerals, and the analysis of such particles for the elements they contain.

In addition, the new technique can also locate the mineral deposit. For this purpose, the particles collected are analysed, not only for the content of elements but also for the number and size distribution of the particles of elements. In this manner, it is possible to locate the centers of mineralization, because the largest particles of the elements derived from mineralization on the ground occur in largest numbers in the air immediately above the area of mineralization, after applying corrections for wind velocity and direction.

The collection of the airborne particles is achieved (U.S. Patent No. 3462995 dated 26th August 1969) by winding thin nylon or similar threads, with a diameter of 0.1 mm, on light aluminum frames. Such frames, 1 foot square with 450 windings, i.e. 900 feet, of threads, are towed from an aeroplane or helicopter, on a strong nylon line, at 100 to 200 feet above the ground. A small high-speed electrical winch, with two drums on the same axis, lowers one frame while simultaneously lifting another frame which has been previously lowered. The air resistance of the two frames balance, to a very large degree, the power requirement.

The exposed collector frames are packed in plastic bags and taken to the laboratory, where half of the threads cut from the frames are subjected to spectrographic analysis. If such analysis finds traces of metals of interest, the second half of the threads are pulled through an abrasive pad. The particles rubbed off in this manner form two streaks on the folded pad. These thin streaks, of the order of a fraction of a millimetre, contain the concentrate of the particles, and these can be subjected to analysis for size distribution by means of electron beam micro-analysis. The correlation of the samples and the position of the aircraft is determined by the well known process of aerial photography and electronic methods of location. Contours and profiles of the concentration of different metallic elements and of their size distribution are used for locating the position of ore deposits.

This new method of airborne geochemical exploration, like all geological and geophysical techniques, has its own possibilities and limitations. It makes possible the direct detection and identification of the metals in mineralized outcrops. Its limitation is that it cannot be used over ground covered by water, snow or thick tropical forest. On the other hand, its great advantage is its speed of sampling at a rate of 100-200 mph, and it can reach areas which are difficult of access, such as cliffs, canyons, mountain peaks, etc. This airborne geochemical exploration method can also be used to screen magnetic and electromagnetic anomalies.

The speed of the technique, whereby in two months' suitable weather it is possible to cover 15,000 square miles with traverses half a mile apart, results in a large coverage and hence a greatly increased statistical probability for the discovery of mineralized areas.

Geochemistry — a Tool in Regional Metallogenic Exploration.

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An intensive regional geoeconomic prospecting survey is currently being carried out by a team of metallogenic research workers of the Geological Survey of Venezuela (Dirección de Geología) in the Venezuelan Andes.

Seventeen "prognostic areas" have been outlined on the preliminary metallogenic map (1:250,000) based on regional metallogenic analysis. Thus far, eight areas have been explored geochemically with positive results. The methods used were adapted to the characteristics of the particular ores likely to be found, the nature of the orebodies, and the geological and physiographic setting of the area under investigation.

The paper summarizes the geochemical methods used and the results obtained.

Symposium Notes

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