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REPORT ON OVERSEAS TRIP - JANUARY TO APRIL, 1956

by

A. H. Debnam

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The purpose of the trip was to investigate the latest overseas developments in the field of geochemical prospecting, both for metals and for oil. Of the 10 week period, from 21st January to 8th April, 3 weeks were spent at the Royal School of Mines, London, 3 days in Eastern Canada at Montreal (McGill University), Ottawa (Geological Survey) and Toronto (Kennco), one week in Texas at Houston and Dallas (private companies), 4 weeks in Denver at the U.S. Geological Survey, and finally 2 days at the University of British Columbia, Vancouver. All travelling was by air.

Whenever possible the writer had discussions with the people who have carried out field projects or developed methods so that first-hand information was always obtained. The most instructive period was that spent at the U.S. Geological Survey in Denver. The Geochemical Prospecting (GX) Section is now an important unit, and many new prospecting methods have been developed there during the last few years. However, it is generally conceded, even at the United States Geological Survey, that the Russians are probably much more advanced in this field.

Each section of the trip will be considered in detail in the following order:

1. UNITED KINGDOM AND THE COLONIES.

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      (i) Dr. J. S. Tooms

         Northern Rhodesia.

      (ii) C. H. James

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         (b) Sebakwe, Rhodesia.
         (c) Lalapanzi, Rhodesia.
         (d) Cumberland, England

      (iii) J. Jacobson.

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3. UNITED STATES OF AMERICA.

   A. GEOCHEMICAL PROSPECTING FOR PETROLEUM.

      (i) Horvitz Research Laboratories, Houston
      (ii) Geochemical Surveys, Dallas
      (iii) Tripp Research Laboratories, Dallas
      (iv) Large Oil Companies
      (v) U.S. Geological Survey.

   B. U.S. GEOLOGICAL SURVEY.

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1. UNITED KINGDOM AND THE COLONIES.

   A. ROYAL SCHOOL OF MINES.

Dr. J. S. Webb has established a large section at the Royal School of Mines, Imperial Institute, at South Kensington to investigate and apply geochemical prospecting methods. Much assistance, including financial, is supplied by Messrs. Rhodesian Selection Trust Ltd. Up to six research assistants, working for Ph.D. degrees, can be accommodated in the modern laboratories, and several permanent laboratory assistants attend to the routine analyses of samples forwarded from the field. The research assistants are expected to develop analytical methods to suit their own specific projects and to spend sufficient time in the field to prove that the methods work under practical conditions.

The analytical techniques so far used at the Royal School of Mines have been adapted from those developed either by the U.S. Geological Survey or the Chemical Research Laboratories at Teddington. Modifications are made to suit local conditions.

To enable a student to work out in the laboratory the most useful methods for use in his area, a suite of samples is collected by Selection Trust personnel and forwarded to the student in London. During the field season (March to October) he carries out as much field work as possible, using perhaps one assistant to help with sampling. Testing is carried out at a base camp, although in some reconnaissance work it is performed at the sampling point. After two seasons the student will have collected sufficient data to enable him to prepare a Ph.D. thesis.

A brief review of some of the recent work carried out by the staff and students will be given.

(i) Dr. J. S. Tooms.

The thesis is titled "Geochemical Dispersions Related to Copper Mineralization in Northern Rhodesia". The area studied is in the Northern Rhodesian Copper belt (Baluba, Chibuluma and Vitanda) where the surfade is a low-relief peneplain of Miocene age. The climate is tropical, similar to that of Northern Australia, with heavy rainfall in the hot summers and cool dry winters. At the headwaters of streams are swamps, called "dambos", which dry out during the dry season.

Two main soil types were studied; residual "ferralitic" soils and the partly transpoted "glei" soils in the dambos. Ferralitic soils are red owing to the accumulation of iron oxides, whereas glei soils are grey with strongly reducing conditions. Oxidation extends to a depth of 300 feet.

The mixed colour dithizone technique was used for the copper estimations. Cobalt was determined either with α-nitroso - β-napthol or by the chromatographic method if a nickel result was also required. Six thousand copper and 150 cobalt analyses were carried out.

The most important conclusions are listed below.

Ferralitic Soils

(a) Anomalies due to bedrock mineralization extend through all the soil horizons.

(b) Dispersion is dominantly via the agency of groundwater.

(c) Vertical distribution aboge the maximum level of the water-table is probably via the biogeochemical cycle.

(d) The ore metals (Cu-Co) are fixed in the soil by both the clay fraction and the sesquioxide accumulation (nodules).

(e) Sizes of anomalies in all horizons are related to both the tenor of the mineralization and the lithology of the bedrock.

(f) Copper and cobalt have similar dispersion patterns.

Glei Soils

(a) Anomalous copper is present in all dambos draining areas of mineralization.

(b) The range of copper values depends on the proximity of the dambo to mineralization, the direction of groundwater movement, and on the tenor of mineralization.

(c) Dispersed ore-metals are transported to the dambos via groundwater.

(d) Maximum values occur near centres of "wet" dambos and in shallow-hole depressions in "dry" dambos.

(e) Groundwater from mineralization may cross topographic divides.

(f) Variations in organic carbon content or pH do not account entirely for variations in copper content through the soil profile.

Dispersion down Drainage System.

(a) Dispersion of metals from mineralization down the drainage system is apparent in water, sediment, bank, and alluvium samples. Anomalous values in all materials decrease downstream.

(b) Anomalous metal is present in stream waters draining headwater dambos containing mineralization within their catchment areas.

(c) Metal content of stream waters will show variations due to seasonal dilution effects and flushing of water from the zone of oxidation.

(d) The copper content of sediment size fractions decreases with increasing grain size.

(e) Much of the copper in stream sediments is in an organic form, and is probably in equilibrium with the metal content of the stream waters.

In the work described it was necessary that anomalies resulting from various sources could be distinguished from each other. These sources were: sub-economic mineralization in shales; mineralization in quartzites; bedrock with high background copper content; and mineralization in granite. A study of copper:nickel and copper:cobalt ratios enabled a differentiation to be made between apparent and true anomalies.

(ii) C. H. James, Research Student.

(a) Motapa, Rhodesia.

Motapa is on the Bembesi River, 1,000 miles inland, and at an elevation of 5,000 feet. Rainfall is 25-30 inches falling between November and January. Gold associated with arsenopyrite occurs in wide quartz zones in greenstone rock. Soil samples were collegted at 1 ft. depth and tested for arsenic as an indicator element for gold. The geochemical prospecting discovered a probable extension of a gold-bearing vein. Arsenic contamination from the metal in the smoke from the smelter stack was found to extend for several miles down-wind from the mine.

(b) Sebakwe Mines (Near Que-Que), Rhodesia.

Gold associated with arsenopyrite and stibnite occurs in quartz reefs. General broad anomalies of low intensity were obtained for antimony and arsenic. Antimony predominates at one end of the area and arsenic at the other end.

(c) Cambrai Chrome Mine, Lalapanzi.

This mine is on the Great Dyke which is 400 miles long and 7 miles wide running north-south through Rhodesia. On either side of the dyke chrome seams, averaging 1 foot in width, occur in ultra-basic rocks (peridotites, pyroxenites, norites) which alter to serpentine. The serpentine weathers easily, and the chromite grains remain in the soil in the vicinity of the seam. Background values of about 2% chromium occur in the Great Dyke soils and anomalous values increase up to 12% over seams. The surface anomalies and those obtained when sampling at 1 foot depth are similar. Dispersion of the chromite is considered to be purely mechanical.

(d) Cumberland, England.

A lead survey was carried out by C. H. James in the Alston District of Cumberland where lead seams occur in lime-stone below grey waterlogged clays with a peat top-soil which is as deep as 9 feet. The only high lead values were obtained near a road which was found to be constructed with material from an old mine dump. No lead anomaly was present in the peat above a lead-bearing vein.

Water issuing from one particular spring contained abnormally high amounts of heavy metal. The spring is probably associated with a fault. The water passes into a peat bog only 30 feet from the spring, and within the next 10 feet the high lead values disappear and the metal is completely scavenged from the water. Although the peat is very acid it is also strongly reducing and apparently this reducing action caused the lead to become fixed and concentrated in the peat. A traverse above the spring indicated strong lead values in the soil.

(iii) J. Jacobsen, Research Student.

(a) Cardigan, Wales.

In a traverse between two mines a very sharp intense lead anomaly was obtained whereas zinc values were erratic and only just above background. The soil may be glacial till overlying slate country rock which contains veins of lead-zinc mineralization. It was found that in general lead values increase on passing up the soil profile when sampling away from a vein but the reverse holds in anomalous areas.

(b) Uganda

The area under investigation receives 65" of rain during the wet season, and is at an elevation of 7,000 feet. The geochemical expression of copper from 2% copper mineralization was investigated. Samples of the soil profile were collected from pits. Downslope dispersion of copper was found to be very limited, less than 400 feet at the surface, although there is a wider dispersion at depth. A wide primary dispersion in the bedrock was not detected at the surface. Sampling at depth of 2 ft. readily detected the anomaly.

(iv) R. Holman, Research Student.

Ruwenzori, Uganda.

Ruwenzori is on an upthrust portion of country in the middle of the Rift Valley. Topography is very rough; the ridges rise to 8,000 feet with slopes of 15 to 30°, completely covered with soil on which thick elephant grass is growing. The main rivers are fed by glaciers and have an average gradient of 6°. Tributaries may drop 2,000 feet in a distance of 1 mile. Stream sediments are used for copper prospecting and it is possible to indicate the presence of copper mineralization which has been crossed by a stream.

Water samples all gave results less than 0.01 ppm. However, the -80 mesh fraction of sediments gave up to 200 ppm. copper in a positive stream. The results spread down-stream and the sediments gave 80 ppm. before entering the main stream which gave 50 ppm., the general background. The distance from the anomaly source to the junction was 2,000 feet. The bank soil (slumped A horizon) gave up to 400 ppm. copper in a very local anomaly, although it was still 80 ppm. near the junction and 40 ppm. at the main stream. The above results were obtained using a fusion method for copper extraction. A cold citrate extraction of the stream sediments gave a peak value of 23 ppm., with erratic values down to 5 ppm. near the main stream which contained less than 1 ppm. Stream sediments supply the only material which can be economically sampled in such rough terrain.

(v) G. J. Govett.

Strontian, Scotland.

G. J. Govett obtained similar results at Strontian to those obtained by J. Jacobson at Cardigan. He found that lead values increased on passing down the soil profile when over an anomalous area but they decreased downwards when away from the anomaly. At intermediate points values are constant throughout the whole profile. Lead has a greater dispersion in the upper parts of the soil profile.

Zinc values were always found to increase on passing down the soil profile. However, zinc results are more erratic than those for lead, and a more extensive anomaly is obtained. A cold citrate extraction, an exceptionally rapid field test, was found to be particularly convenient for locating heavy-metal anomalies.

On testing different fractions it was found that larger fractions unexpectedly gave higher results than the fine fractions.

(vi) General.

The metals tested for, and the methods used, at the Royal School of Mines are given below:

(a) Copper: Solution by cold citrate extraction, hot acid extraction or fusion, and determination by colorimetric (biquinoline or dithizone) or chromatographic methods.

(b) Zinc: Solution by cold citrate extraction, hot acid extraction or fusion, and estimation by colorimetric method (dithizone).

(c) Lead: Hot acid extraction with colorimetric determination (dithizone).

(d) Nickel: Fusion followed by chromatographic determination.

(e) Cobalt: Fusion followed by chromatographic or colorimetric (α-nitrose-β-naphthol) determination.

(f) Tungsten: Fusion and colorimetric (dithiol) determination.

(g) Molybdenum: Fusion and colorimetic (dithiol) estimation.

(h) Arsenic: Fusion and chromatographic determination.

(i) Manganese: Fusion followed by colorimetric determination (permanganic acid).

(j) Heavy metals: Use citrate buffer and colorimetric (dithizone) estimation.

In the cold citrate extration for copper, lead and zinc a cheap solvent, white spirit, has been found to be very satisfactory for the solution of dithizone. This replaces xylol which cannot be obtained in a very pure form in England.

(vii) Statistical Series.

Statistical methods are applied to determine the accuracy obtained by students who are practising the analytical methods. A "statistical series" of samples is prepared for each element by mixing in various known proportions two soils, one which contains very little of the element in question and another which contains a large amount of the element. From the calculated amount of the element in each sample and the values obtained from hundreds of determinations by reliable operators using the analytical method it is possible to determine a factor called the "Standard Deviation". Using this factor the accuracy of the work of any new student analysing the same suite of samples can be determined. The writer achieved an accuracy of 12% on a nickel statistical series and 15% on a copper series using the cold extraction method. An accuracy better than 40% is considered to be good when using field methods.

B. THE GEOLOGICAL SURVEY.

The only geochemical prospecting attempted by the Geological Survey has been in connection with hydrogeochemical prospecting for uranium. This work has been carried out at the River Fal in Cornwall. Interest has recently been revived in this area after some unexpected high results were obtained. A resin extraction, followed by ignition, fusion, and fluorimetric determination is the method used for uranium analyses. However, the workers had omitted to determine the pH of the water samples, a fact which would make interpretation of the results rather difficult. The portable ultra-violet lights used for the fluorimetric determinations are not peaked at a wavelength of 3650A and this could cause erroneous results through interfering fluorescence of other elements.

C. CHEMICAL RESEARCH LABORATORIES.

A visit was made to the Chemical Research Laboratories at Teddington. All difficult problems of analysis encountered by members of the Geological Survey or the Royal School of Mines are studied at these laboratories. A. A. North has developed methods for tungsten and molybdenum, described in the Scientific Report C.R.L./A.E. 127 "Geochemical Field Methods for the Determination of Tungsten and Molybdenum in Soils". E. C. Hunt, A. A. North and R. A. Wells have described their chromatographic methods in Scientific Report C.R.L./A.E. 114 "The Application of Paper Chromatographic Methods of Analyses to Geochemical Prospecting". The resin method of uranium extraction was developed with the help of chemists of the Chemical Research Laboratories.

2. CANADA.

A large proportion of the money required for geochemical prospecting research in Canada is supplied by the National Advisory Committee on Research in the Geological Sciences. This committee was established in 1949 for the following purposes:

(a) To co-ordinate geological research throughout Canada.
(b) To suggest research projects that should receive attention.
(c) To aid in having these projects undertaken, and in securing finances where needed.

Eight sub-committees were set up to help the National Committee by making a continuous survey of the needs and developments in its particular field and by advising it of the problems most urgently in need of investigation in this field. Geochemical prospecting projects fall within the scope of the Metallic Mineral Deposits sub-committee.

In the first report of the Committee for 1950-51 more than eighty projects were listed for attention. Very few of these could be undertaken without increasing facilities for geological research, and the Committee recommended:

(a) An expansion of the research laboratories and increase in technical staff of the Geological Survey of Canada.

(b) Provision of money for the stimulation and support of geological research in the universities.

As a result of these recommendations the Geological Survey set up a spectrographic laboratory, a sedimentology laboratory was equipped, and a mass spectrometer purchased. A sum of ten thousand dollars was made available by Parliament for research grants at the universities. Twelve research projects were supported, including research on the improvements of biogeochemical and hydrogeochemical techniques at the University of British Columbia. The grants allow many workers with different viewpoints considerable freedom to work on widely diversified problems at a relatively small cost.

During the 1955-56 period the Federal Government provided twenty-five thousand dollars for geological research in the universities, and in 1956-57 the amount will be forty thousand dollars.

The following research projects dealing with geochemical prospecting were in progress during the period June 1954 to May 1955:

1. Cross, C., Research Assistant, University of British Columbia: The relationship between trace elements in soils and in trees growing thereon.

2. Delevault, R.E., Warren, H.V., et al, University of B.C.: Relationship between trace elements in water and trees growing nearby.

3. Riddell, J.E., Professor, and Telford, W., graduate student, McGill University: An investigation into small-scale application of geophysical and geochemical methods as reconnaissance techniques in mineral exploration.

4. Riddell, J.E., Professor, and Schmidt, R.C., and Sims, W., graduate students, McGill University: Investigations into the movement of base metals in secondary dispersion zones, based on studies of soils and vegetation.

5. Riddell, J.E., McGill University: Investigations of the use of geochemical dispersion fans and trains in the zone of weathering as an aid to identification of metallogenetic province.

6. Schmidt, R.C., McGill University: A study of the dispersion of certain base metals in soils under the influence of weathering.

7. Warren, H.V., Professor, Delevault, R.E., Research Associate, Lok, S.K., Research Assistant, University of B.C.: Biogeochemistry of molybdenum.

8. Warren, H.V., Professor, and Delevault, R.E., Research Associate, University of B.C.: Biogeochemistry in areas of permafrost; and biogeochemistry of nickel and cobalt.

A. McGILL UNIVERSITY, MONTREAL.

On the advise of Dr. Webb at the Royal School of Mines a day was spent on Montreal for a visit to the McGill University, where a large research programme in geochemical prospecting is being carried out. Unfortunately the most experienced worker, J. E. Riddell was in New York at the AIMM meetings. Dr. J. E. Gill of the Geology Department discussed the set-up of the geochemical section, and outlined the work being carried out in Canada by his staff and students. Two students, D. Schmidt and W. Sims, discussed their individual projects.

The geochemical section is self-contained, having its own chemists to carry out routine chemical analyses; university geophysicists are available so that they do not require personnel from outside the university.

The work so far carried out by McGill staff and students has dealt mainly with the distribution of metals in stream and lake waters and sediments. Some work has also been done on primary zinc haloes in the country rock around orebodies. The zinc values were determined on drill-core samples from drills located away from the known mineralization. The zinc haloes were found to extend horizontally for many hundreds of feet, particularly along fault zones. Soil analysis is not always applicable in Canada owing to either lack of soil or the glacial origin of the soil. No biogeochemical work has been carried out at McGill.

The students, D. Schmidt and W. Sims, are working on stream and lake sediments in New Brunswick. Their research work includes an investigation into the adsorptivity of the different size fractions of the minerals in the sediments, e.g. clays, quartz, feldspars. They are attempting to relate the adsorptivities of these minerals to each other and to surface area. pH is recognised as an important factor affecting the adsorption of metals by sediments.

They have established that clays adsorb a much greater amount of metal than do feldspars, which in turn adsorb more than quartz. Most of the experiments have dealt with samples of -150 to -230 mesh. With coarser fractions the amount of adsorption decreases directly with the surface area. Similar results have been obtained on bank sediments.

The sediments will adsorb metals from stream and lake waters up to a certain degree at which maximum adsorption appears to occur. Metal present above this amount remains in the sediment as interstitial metal which can readily be removed by washing with metal-free water. Additional repeated washings with metal-free water will not remove the adsorbed metal.

As New Brunswick, and Eastern Canada in general, has a large number of lakes, rivers and streams, a prospecting method utilizing their sediments has a particularly wide application. One lake has been particuarly noted for its anomalous results. Streams entering the lake from opposite sides contain sediments high in copper, zinc and iron, and in the lake itself the anomalous metals occur in the sediments as a band crossing the lake and joining the streams with high metal content. A mineralized zone appears to be indicated, but additional work will be carried out to investigate the possible presence of other conditions, not related to mineralization, which may be causing the anomalous results.

B. DEPARTMENT OF MINES AND TECHNICAL SURVEYS, OTTAWA.

One day was spent in Ottawa investigating geochemical work in progress at the Government Department of Mines and Technical Surveys.

(i) The Geological Survey.

Dr. R. W. Boyle, who is in charge of the geochemical prospecting surveys, was not available and Dr. S. C. Robinson supplied a general review of the work being carried out.

The Geological Survey employs about 100 geologists full-time, and during the field season the long university vacation makes it possible to engage undergraduates as field assistants. Up to 300 undergraduates are employed during the summer, and it is possible to have 80 parties in the field. Five of these parties are engaged in geochemical prospecting, each party consisting of a graduate and one or two undergraduates. The work of these parties is co-ordinated by Dr. Boyle. The geological parties consist of a party chief, a technical officer, and two undergraduates.

In 1950 S. C. Robinson made a preliminary investigation into the use of the biogeochemical method for uranium at Goldfields, Saskatchewan. The results were indecisive as only 24 trees were sampled, although it did appear that willows, alders and birch accumulated some uranium in leaves and stems.

More recently a large survey for heavy metals has been carried out by R. W. Boyle and C. B. Craig in the Keno Hill-Galena Hill Area, Yukon. Copper, lead and zinc were determined in soil samples, glacial material, and stream waters. The presence of permafrost considerably hindered the sampling. Methods of analysis were similar to those developed by the U.S. Geological Survey but modified to suit the Canadian conditions. The mineralization under investigation was associated with vein faults.

The results of the investigation show that heavy metal anomalies occur both in areas that have been extensively prospected and those that have been relatively untouched. Hydrogeochemistry can be applied successfully during the period when the active layer of the permafrost zone has thawed sufficiently to allow spring and stream waters access to veins and mineralized areas from which they can leach heavy metals.

In 1956 prospecting will be carried out in Nova Scotia.

(ii) Mines Branch.

The Mines Branch carries out the assaying of minerals and ores for all elements, but the methods used for uranium and thorium were of particular interest.

Uranium determinations are carried out by four different procedures as detailed below. The colorimetric and fluorimetric methods are the most popular.

1. Uranium in concentrates is determined by separating the contaminants by means of an ethyl acetate extraction using aluminium nitrate as a salting agent. After the uranium is stripped from the ethyl acetate layer by means of water, a colorimetric determination is carried out by the sodium hydroxide-hydrogen peroxide method. The procedure is accurate, rapid, and easily adaptable to routine work.

2. In another method an ether extraction of uranyl nitrate is performed in a cellulose column. The ether in the extract is distilled off and the uranium remaining can be determined colorimetrically (sodium hydroxide-hydrogen peroxide), volumetrically (Jones reductor and dichromate), gravimetrically (oxine) or fluorimetrically.

3. The use of stannous chloride to reduce uranyl salts eliminates some of the troublesome features encountered with the Jones reductor. The freedom of the stannous chloride reductor from interference by phosphate, bismuthate, and arsenate has resulted in a substantial saving of labour and time. The uranium is determined volumetrically by titrating with dichromate.

4. The fluorimetric method is most useful when dealing with low uranium concentrations. Samples for fluorimetric assay are in a 10 per cent nitric acid solution. Aliquots of the solutions are transferred to platinum dishes, evaporated under infra-red lamps, and fused in a sodium fluoride flux. Fluorescence is determined with an M.I.T. Model 3 fluorimeter.

Thorium can be determined colorimetrically or gravimetrically after using a methyl oxalate precipitation or a mesityl oxide separation. The colorimetric reagent is 1-(o-arsenophenylaso)2-naphthol 3-6 disulphonic acid. A recent development is the thorium-emanation method which offers the advantages of simplicity of operation plus high sensitivity, and is based on the principle of alpha particle detection. Little time is required when the method is used for checking purposes, as a portion of the solution used for chemical analysis can be utilized for a thorium determination with the added advantage that none of the sample is destroyed.

C. KENNCO EXPLORATION, TORONTO.

The day in Toronto was a Saturday and a private visit was made to C. J. Sullivan, formerly Assistant Chief Geologist of the Bureau, and now Vice President of Kennco Exploration (Canada) Ltd.

This company spends about 1.5 million dollars annually on exploration alone. This is 1% of the total amount spent each year on prospecting and exploration in Canada. As much money is spent annually in Canada on exploration as Australia receives from its total mineral production.

Kennco does not carry its own geochemical prospecting section. It relies on the work of consultants, usually H. V. Warren of the University of British Columbia, H.E. Hawkes of Massachusetts Institute of Technology and Harold Bloom of the

Colorado School of Mines. They work in the areas of most interest, and Kennco is prepared to investigate fully any anomalies discovered and recommended by the consultants.

Most of the work is carried out in New Brunswick and Quebec, using stream and lake waters and sediments, or vegetation and soil where available. Many promising areas have recently been discovered.

D. UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER.

Professor H. V. Warren of the Geology Department, University of B.C., is well known for his biogeochemical investigations in British Columbia. He has attempted to establish norms (the normal metal content) for many species of trees, and has applied the results to biogeochemical prospecting.

Some interesting results have been obtained with metals such as silver and gold. Trees in areas where no silver mineralization of significance is known have been found to contain up to 1.4 parts per million of silver. In auriferous areas horsetails may contain as much as 0.07 parts per million of gold.

Warren's chemist, Dr. R. E. Delevault, has developed an extremely sensitive test for heavy metals in water, using acetonic dithizone and an emulsion technique. His latest test is a rapid field method for copper using Rubeanic acid.

In their prospecting it is essential to keep the equipment required to a bare minimum, as the country being explored is usually inaccessable to vehicles, and everything has to be carried by the prospector. Horses are sometimes used. The very sensitive test for heavy metals in water was necessary owing to the excessive dilution of stream waters by surface run-off and melting snow. The method proved to be almost too sensitive, as one very high zinc anomaly was traced to a sheet of galvanised iron.

The research carried out by Warren at the University of British Columbia is partly financed by Kennco Exploration and partly by the National Advisory Committee on Research in the Geological Sciences.

3. UNITED STATES OF AMERICA.

A. GEOCHEMICAL PROSPECTING FOR PETROLEUM.

(i) Horvitz Research Laboratories, Houston, Texas.

Dr. Horvitz has been carrying out geochemical prospecting surveys for oil and gas for the past 20 years, first in conjunction with Dr. E. E. Rosaire in a Dallas company called Subterrex, and more recently with his own Laboratories, Horvitz Research Laboratories, in Houston.

In addition to the central laboratory at Houston he has several mobile trailers fitted out for geochemical well-logging at the well-site. The company engages in contract work for small drilling companies which cannot afford to, or do not wish to, run their own geochemical surveys.

In contrast to the geophysical prospecting methods, e.g. seismic, gravimetric, and magnetometric which are indirect in that they measure some physical property associated with structures which may contain oil or gas, the geochemical methods are direct, as they measure hydrocarbons or other significant constituents which have migrated from an oil or gas accumulation to the surface. The use of geochemical methods has resulted in a substantial lowering of the percentage of dry holes drilled. Recent figures compiled by Dr. Horvitz indicate that one hole in every two drilled within a geochemical anomaly is a producer.

Two types of geochemical prospecting are carried out---near-surface and subsurface. They both rely on the assumption that volatile hydrocarbons migrate continually and almost vertically from the oil or gas reservoir to the surface. A satisfactory theory has not yet been advanced to account for this migration, but experimental results clearly indicate that it does take place.

Early workers in Germany and Russia collected soil air from shallow bore-holes for analyses but Horvitz found that more reliable results were obtained if soil samples were collected from depth of 8 to 12 feet, and the adsorbed and occluded gases extracted by an acid treatment in the laboratory. A complicated apparatus which includes low-temperature fractionation and combustion sections, McLeod guages and mercury diffusion pumps, is required for the gas analysis. Hydrogen, methane, the group ethane-propane-butane, and heavier hydrocarbons (hexane), are determined, and one operator can analyse two gas samples per hour. The hydrocarbons in the soilare usually found to be concentrated in halo patterns vertically above the edge of the oil or gas pools. The consistent manner in which the geochemical halo coincides with the edge of production is one of the main features of the geochemical prospecting. By restricting drilling to the area of low values within the hydrocarbon halo it is possible to eliminate a large number of dry holes which would otherwise have been drilled.

When applied to bore-logging, i.e. determining the amount of hydrogen and hydrocarbons in drill cuttings, it is possible to predict whether a hole will be dry, or a producer and, if a producer, whether it will yield gas or oil. Near-misses drilled just outside the edge of a pool can be easily recognized.

Other soil constituents can sometimes be used to outline anomalies over an oil or gas accumulation. The top inch of soil has been found to contain a wax which is probably a polymerisation product of the light hydrocarbons. This wax can be extracted by organic solvents and determined by one of several methods. The numbers of methane- and ethane-consuming bacteria vary in relation to the amounts of these gases present in the soil, and bacteria counts on soil samples may reveal significant anomalies. Inorganic soil constituents often vary over oil or gas accumulations, and determinations of sulphates, halides, carbonates and bicarbonates have been used in prospecting. These soil constituents supply an indirect method of geochemical prospecting. However, Horvitz considers that the method which will give the most reliable and consistent results is the direct one involving hydrogen and hydrocarbon determinations.

Several case-histories have appeared in the literature, and the discoveries of a number of new oil-fields have been attributed entirely to geochemical prospecting. One such case is the Hardy oil field, Jones County, Texas. This discovery, in November 1943, followed from drilling on a geochemical anomaly, in the immediate vicinity of which there was no evidence of closed structure from a reflection seismograph survey or from a core drill investigation. Development of the field has shown that the sand pinches out across a nose, forming a typical stratigraphic reservoir.

Dr. Horvitz discussed a survey where a geochemical anomaly was discovered in an area which had previously been investigated and dropped by one of the large oil companies. All seven wells drilled to date within the anomaly are producers, from a sand at a depth greater than 7,000 feet.

In a paper published by Dr. Horvitz in Mining Engineering, December 1954, the geochemical exploration carried out during the 11-year period ending 1953 is reviewed. Sixty nine surveys revealed 109 anomalies, 39 of which were considered to be associated with oil or gas accumulations. Drilling proved 23 discovery wells in the 39 anomalies (59% confirmation).

The Russians claim that they have found many new oil-fields by using geochemical prospecting methods.

In an effort to assist the writer in convincing geologists and any other interested observers in Australia that geochemical methods can be of use in oil prospecting Dr. Horvitz offered to test, at no cost to the Bureau, 100 soil samples collected in the vicinity of a producing well (or potential producer). The samples must be collected from a depth of 12 feet on a grid pattern, with spacing selected so that the whole areal extent of the oil reservoir is covered by the 100 samples. The sampling must be around a known potential producing well, otherwise the chance of obtaining an anomaly would be rather slim. This amount of work will cost Dr. Horvitz 1500 dollars in time and materials, and for it he would normally charge a client 2,500 dollars.

To take advantage of the above offer it will be necessary to find an area with both a producing well and a suitable soil cover. Unfortunately there is little soil in the vicinity of our only known potential producer at Rough Range. Other possibilities are at Wilkatana, Lakes Entrance, and Papua, but an oil strike will have to be made first.

(ii) <u>Geochemical Surveys Inc., Dallas, Texas.</u>

This company is conducted by serveral ex-geophysicists who have found that geochemical prospecting is somewhat more rewarding than geophysical prospecting. Three of them Dr. E. E. Rosaire, W. R. Ransone and E. McDermott, figured prominently in the controversies during the early days of geochemical prospecting (1938-41). The company seems to be quite successful; in fact, they claim to have discovered 31 oil accumulations in the 98 geochemical anomalies they have investigated.

Unfortunately the visit to their office was not very enlightening. No information could be obtained on the methods of soil analyses which they use. They merely stated that it was some parameter of the soil which altered significantly over an oil or gas accumulation. From a quick look over their laboratory it appears that they are determining one or more of the inorganic constituents of the soil, i.e. carbonate, nitrate, sulphate, etc. Their equipment is almost fully automatic, and has taken many years to develop. To obtain full secrecy it has not been patented. The assumption that the direct hydrocarbon methods are not being used is strengthened by the fact that they do not always obtain anomalies over known reservoirs, and also that they get some anomalies which are not associated with oil or gas. Even with these apparent flaws a method with a success ratio of 1 in 3 is not to be scorned.

(iii) Tripp Research Laboratories, Dallas.

Dr. Maurice M. Tripp has been interested in geochemical prospecting since the late 1930's. He applied it to metalliferous prospecting before World War 2, and had carried out much work in the field before it was taken up by the U.S. Geological Survey in 1946.

Tripp has applied thermodynamic principles to the migration of gaseous hydrocarbons from a depth of 4,500 feet to the surface. His studies at the Fort Collins Anticline, Colorado, indicated that the vertically migrating gas contained decreasing amounts of water vapour as it ascended from 4,500 feet to 1,000 feet, but above 1,000 feet the amount of water vapour increased exponentially. However, 81% of all water evaporated from the formations is removed from the zone between the surface and a depth of 25 feet. He was thus able to account for the anomalous concentrations of the more insoluble inorganic salts and radioactive minerals which occur in the near surface above oil and gas accumulations. In the Rocky Mountain area, petroleum never occurs where the formation waters have lower than 2,000 parts per million dissolved salts. It is also characteristic to find much higher salt content associated with high production.

At Fort Collins a soil wax survey revealed anomalous wax concentrations above the oil reservoir. The soil samples were collected from the top half-inch of soil and the extracted waxes are probably heavy aliphatic hydrocarbons.

Tripp assembled the results from his oil prospecting surveys, and had them analysed by a completely unbiased adjudicator. This person found that results almost unbelievable, and stated that Tripp should be in the oil business if he could find oil so easily. However, Tripp has heavy commitments in metalliferous prospecting at present and is unable to persue geochemical prospecting for oil.

(iv) Large Oil Companies, Dallas.

Whilst in Dallas visits were made to the laboratories of the Magnolia Oil Company and the Atlantic Oil Company. No information on methods or results could be obtained, but they did indicate that geochemical prospecting is being used in the search for oil. It is apparent that the large oil companies wish to keep their work secret, as they fear too much competition if the methods and results are released.

(v) The U.S. Geological Survey, Denver.

The Survey is interested in geochemical prospecting for petroleum, although no actual prospecting has been carried out. A bibliography of the available literature on the subject has been compiled, but it is not as comprehensive as the one already assembled by the writer.

The large oil companies have been approached with the proposition that their investigations should be pooled at a central agency in the Geochemical Section of the Survey. All information would be treated as top secret. In this way

Survey officers could assemble and co-ordinate the most promising methods for use in the event of a national emergency. Not one for the oil companies would co-operate in this scheme. A similar reluctance to give information on methods and results of metalliferous geochemical prospecting has been encountered with private companies.

B. UNITED STATES GEOLOGICAL SURVEY, DENVER, COLORADO.

Four weeks were spent with the Geochemical Exploration (GX) Section of the U.S. Geological Survey. The section was set up in 1946 to develop new analytical techniques of trace-element analysis, and to publish the results promptly, to carry out field investigations of the fundamental principles of geochemical dispersion, and to field-test promising techniques under controlled conditions. Some routine geochemical exploration is carried out, but the GX Section is primarily concerned with fundamental principles underlying the distribution, migration and concentration of elements in the earth's crust.

The present staff numbers 26, comprising:

1 Chief (a geologist, T. S. Lovering), 1 Chief Chemist (Bert Lakin), 6 Chemists (3 for research, 3 for field analyses), 1 Soil Scientist, 2 Analysts, 1 Geobotanist, 5 Geologists, 1 Geochemist, 1 Spectrographer, 2 Field Samplers, 1 Secretary to the Chief, and 4 Clerks.

Some of the research projects at present in progress are:

1. Development or improvement of rapid and sensitive analytical methods suitable for the determination of traces of metals and other minor elements in various materials, such as rock, soils, plants, and water. Rapid field methods are available for copper, lead, zinc, heavy metals, uranium, vanadium, manganese, cobalt, nickel, arsenic, phosphorus, antimony, molybdenum, and tungsten. Rapid laboratory methods are available for titanium, germanium, bismuth, niobium, iron, selenium, and silver. These tests could be carried out in the field, but, owing to the large amount of equipment required, they are better carried out in the central laboratory. Precise laboratory methods, in which complete extractions are made, and the results are obtained with colorimeters, are used for copper, lead, zinc, molybdenum, nickel, cobalt, and niobium.

2. The relation of geochemical anomalies in plant materials to the geochemical distribution of elements in soils surrounding the plant.

3. A study of the dispersion haloes in transported sedimentary cover, such as glacial drift and alluvium over known orebodies.

4. A study of the behaviour of ore metals in the weathering cycle.

5. A study of the behaviour of the ore metals during magmatic differentiation. This requires a study of the distribution of minor metals in fresh igneous rocks and their component minerals, in a well established differentiation series, and in adjacent country rock.

6. A study of the dispersion of metals in primary haloes in the wall rock surrounding orebodies.

7. Regional and local studies of the metal content of surface waters and groundwaters in mineralized and barren areas.

In addition to the well-equipped laboratories and offices at the Federal Center, there is a mobile chemical laboratory (a 30-foot house trailer), a mobile spectrograph, a power waggon fitted with rock crushing equipment, a mobile auger-type mechanical soil sampling unit fitted on a Jeep, and a new mobile utility laboratory of special design. Each of these units will later be discussed in detail.

The laboratory facilities are available to visitors, both local and foreign, and they are able to receive tuition and practice in the field methods for any desired period. Personnel from mining companies are usually only interested in tests for one or two elements, and remain in the laboratories only a few days, whereas overseas visitors are normally interested in all methods of analysis, and spend periods between 1 week and 6 months in the GX Section laboratories.

In addition to carrying out some of the more complicated methods in the laboratory the writer spent much time discussing the chemical procedures with the chemists who developed the methods. These discussions were very profitable, but were not entirely one-sided, as the GX chemists displayed considerable interest in the methods used by the writer in Australia. One general lecture on geochemical prospecting in Australia was given to a large group of U.S.G.S. staff (more than 100 were present), and a talk on analytical methods was given to GX chemists. (A general lecture was also given to staff and students of the Colorado School of Mines at Golden).

The information obtained at the GX Section will be considered under the following headings:

(a) Sample Preparation

(b) Analytical Procedures, other than for uranium.

(c) Uranium Methods.

(d) Mobile Crushing Unit

(e) Mobile Spectrograph

(f) Mobile Utility Laboratory

(a) Sample Preparation.

Rock samples are first crushed in a jaw crusher, split into two parts, and pulverised. Soil samples are split with a Jones splitter after crushing, if they contain small rock particles, and then pulverised. A Braun pulveriser reduces the samples to -100 mesh between ceramic discs. The powdered sample is passed through a 105 mesh stainless steel sieve, is transferred to a cardboard box containing a perforated partition, and is then placed in a mechanical mixer which was designed in the GX Section.

Suction ducts above the crusher and pulveriser remove dust, and a jet of compressed air is used to clean out the apparatus between samples. Mineral-free sand can be passed through the disc-grinder for cleaning.

A special grinder for botanical samples reduces them to 20 mesh for ashing.

All crushing and grinding equipment is housed in a special sampling room near the laboratory.

(b) Analytical Procedures, other than for uranium.

The methods developed by the GX Section utilize a vigorous extraction of a small amount of sample (0.1 gm. to 1 gm.). Either fusion with potassium bisulphate or digestion with hot nitric acid is required. The writer's extraction procedures require only very dilute acid for cold extration of a large weight of sample (5 or 10 gms). The U.S.G.S. methods have the advantage that a larger percentage of metal is extracted from the sample, but the large amounts of chemicals, particularly acids, and the heating apparatus required are distinct disadvantages.

The analytical methods are either colorimetric or chromatographic. Full details of all methods have been obtained by the writer, who has either tried them on selected samples or discussed them with the GX Section chemists and analysts. All special equipment required has been noted, and will be obtained in the near future.

(c) Uranium Methods.

Two methods are available for the analysis of samples for uranium. The GX Section has developed a chromatographic method, whereas the Trace Elements Investigations (TEI) Section has concentrated on improving the more sensitive fluorimetric method.

The chromatographic procedure requires only a minimum expenditure on equipment, but lacks sensitivity (4 parts per million is the lower limit), and erroneous results can easily be obtained if a strict control is not kept on the humidity conditions during drying of the chromatographic paper. One hundred samples can be analysed per man day.

The fluorimetric method requires some expensive equipment such as platinum dishes, an ultra-violet light, and a fluorimeter. A special fusion apparatus has been designed by the GX Section to control temperature and mixing during fusion and cooling. The sensitivity is approximately 1 part per million for soil and rock samples if 5 mgm of sample are used. The TEI Section achieve much greater sensitivity by treating a larger sample with acid and extracting the uranium with ethyl acetate. This procedure reduces output to 20 samples per man day.

For samples containing more than 4 parts per million the two methods give similar results. The correlation coefficient obtained from the results on 16 samples was determined to be 0.98 (1.0 is max.).

Chemists of the GX Section are at present developing a method for determining uranium in waters (both natural and mine). They want a procedure which can be applied in the field by relatively unskilled prospectors. The method consists of taking 500 millilitres of water sample and treating it with nitric acid, ammonia, and sodium phosphate. The uranium phosphate is then collected on a filter pad or a resin which is dried and ashed. The ash is dissolved in a nitric acid-aluminium nitrate reagent, and the amount of uranium present is determined chromatographically. The lower limit of sensitivity is only 10 parts per thousand million, and the writer suggested that this could be lowered by ashing the section of the chromatographic paper containing the uranium and completing the determination fluorimetrically.

It should be possible to determine as little as 0.02 parts per thousand million uranium in water by this procedure. With this sensitivity, background results should be positive.

Mine waters present a much more difficult problem than natural waters owing to the large amounts of dissolved iron, calcium, and magnesium which interfere with the phosphate precipitation.

Fluorimetric methods for the determination of uranium have received considerable attention, and many fluorimeters have been developed. The instruments normally measure the fluorescence of solid discs, and are operated by the ordinary AC electrical supply or by batteries. Several are available commercially, and one in particular, the Galvanek-Morrison, which was designed for the AEC, and is produced by the Jarrel Ash Company, sells for less than 1,000 dollars. The Water Resources Section of the U.S.G.S. uses one of these instruments and they claim a sensitivity of 0.1 parts per thousand million, using a 10 millilitre water sample. The unit is line-operated.

The need for a sensitive battery-operated fluorimeter by the TEI Section at Denver led L. F. Rader and E. E. Parshall to design a unit to suit their own requirements. It is made from readily available Beckman Spectrophotometer components, and can be operated from either line-current or battery. The presence of 0.005 micrograms of uranium in a solid sodium fluoride disc can be determined. The writer has obtained complete details of this instrument, and will have one assembled in the instrument shop at the Australian National University.

Several members of the staffs of the GX and TEI Sections have carried out geobotanical surveys for uranium with varying results. Helen Cannon, the geobotonist, claims that a number of new areas containing uranium mineralization have been discovered using geobotanical methods. R. E. Gilbert states that sagebrush and juniper are useful plants for use in uranium prospecting at Marysvale, Utah. However, R. S. Jones, I. C. Frost and L. F. Rader have reached the same conclusion as the writer, namely, that tests on soil samples supply superior results to those on plant samples in uranium prospecting.

Philip F. Fix has carried out an intensive research programme on the occurrence of uranium in natural waters. He has found that pH is the most important factor to be considered, as it controls the amount of uranium which can be held in solution. Only a very small amount of uranium is dissolved from a rock or ore by water with a pH of 7. As the pH becomes lower more uranium is dissolved, and below pH 4.3 the amount of uranium taken into solution increases very rapidly. There is probably a similar increase in solution of uranium as the pH increases above 7.

Experiments have shown that there is little loss of uranium if samples have to stand in glass or polythene bottles for several days before analysis. Samples are returned to Denver for analysis by the Water Resources Section. A sensitivity of 1 part per thousand million is required, and the actual background values are not determined.

Fix considers that hydrogeochemical prospecting for uranium should be used in an area before the aerial scintillometer survey owing to the relative cheapness of the method. It can also be used to help localise deposits indicated by the regional survey.

(d) Mobile Crushing Unit.

This unit consists of a jaw crusher and a pulveriser (similar to those in the central laboratory) mounted on the tray of a Dodge Power Waggon. The power plant is a twin cylinder aircooled engine which works a 5KW generator, which in turn works the crushing equipment. A separate $\frac{1}{2}$ h.p. electric generator works an air-compressor, which gives 80 lb. pressure, for clearning the crushers.

The rear canopy of the power wagon can be raised to give head-room to the operator, The whole unit is used in the field in conjunction with the mobile spectrograph.

(e) Mobile Spectrograph.

The design of the mobile spectrograph unit was achieved by the joint efforts of F. C. Canney (geologist), A. T. Myers (spectrographer), and F. N. Ward (Chemist). The unit is built into a 12'x7' insulated and air conditioned van-type truck body, and carries complete equipment for making qualitative, semi-quantitative, and quantitative analyses of soils and rocks. The spectrograph is a Wadsworth type with a fixed-position 1.5 meter grating, recording the spectrum range 2063 to 4837A^{o} in the second order on a 20 inch strip of film. Accessories are a projection type comparator-densitometer, film processor, and other minor items. Trailer-mounted motor-generators supply 230 volt DC for the arc source unit, and 115 volt AC for lights and accessories. This unit is completely self-contained. Total cost was about 25,000 dollars.

When commencing a geochemical survey in a new area there is always some doubt as to which element or elements should be used for collecting the geochemical data. For instanee, if gold is the metal sought it is most unlikely that direct tests for this element will be made, and it will generally be necessary to test for some other indicator metal which is associated with the gold, and for which a rapid field method is available. It is in the early stage of such a survey that the spectrograph is most useful, owing to the large number of elements that can be determined from a single spectrogram, enabling a rapid determination of the most diagnostic element or suite of elements. The chemical methods developed for the prospecting are less useful in the orientation phases of a programme when the diagnostic elements are not known. Surveys have been known to fail because the operators took only a kit to determine copper, lead and zinc, or cobalt and nickel. The presence of another significant element was probably missed because tests for it were not made.

The mobile spectrograph gives results for 60 elements simultaneously. Ten elements can be determined on a single sample with only a little more effort than is required to determine one. In a survey in Texas one man made 2832 semi-quantitative determinations on 354 samples in 12 days, averaging 236 determinations per day. Results were available to the party chief in less than 48 hours after collection.

If the spectrograph indicates that only 1 or 2 diagnostic elements need to be tested for in a survey, then the less expensive colorimetric or chromatographic methods should be used. If 3 to 5 elements must be determined the relative costs of these methods and spectrographic methods are about equal, and the sensitivities required would be the deciding factors. If determinations for 6 or more elements are required the spectrographic method is the least expensive, and the spectorgraph would remain in the area to complete the survey. If not required it could move to another project.

Without the spectrograph the necessary data on the diagnostic elements could not be obtained. Even with the transport facilities available in the U.S.A. the U.S.G.S. officers find that it is impracticable to return samples to Denver for spectrographic analysis if the field parties are operating more than a few hundred miles from Denver. The delay in return of results would be too great, as they must be available within 48 hours of collection if maximum benefit is to be obtained.

(f) Mobile Utility Laboratory.

The GX Section required an extremely versatile mobile laboratory which could travel rapidly between areas which are great distances apart. The design incorporated a ¾-ton utility with a special enclosed rear section measuring 7'x7'. On the right hand side is a hinged section which in the up-position is the side of the van but when in the down-position (horizontal) is a work-bench. Shelves are built into the space enclosed by this hinged section, and a water demineralizer with an overhead tank occupies the forward end.

Panels on the left-hand side open to reveal testing kits. A separate kit for each element to be tested is contained in a special box. This box is easily removed and taken to the bench on the other side of the vehicle. A section is reserved for equipment which is common to all tests.

The centre section is accessible from the rear and provides useful storage for samples and spare equipment. A canopy can be erected from theworking side of the vehicle.

Soil sampling equipment is stored in compartments in front of and behind the rear wheels, below the bench level. This equipment is accessible from the side of the vehicle.

The first project in which this vehicle is to be used will be carried out in Maine in the near future.

RECOMMENDATIONS.

1. The Geochemical Branch of the Geological Section (or a separate Geochemical Section) should be expanded to include at least three graduate chemists, or two chemists and one geologist. Each of these officers should have one permanent field and laboratory assistant.

2. A second mobile laboratory should be built, and it should be of the utility type described above.

3. A special vehicle (long-wheel base Landrover) should be fitted out as a mobile crushing unit.

4. Mechanical soil sampling equipment should be fitted to a Landrover with power-take-off.

5. Equipment for hydrocarbon analysis could be set up in Canberra to handle analysis of soil samples and drill cuttings for geochemical prospecting for petroleum.

6. The 100 soil samples covered by the analysis offer of Dr. Leo Horvitz should be obtained and forwarded to him as soon as oil is discovered in an area suitable for soil sampling.

7. Some investigations should be carried out in petroliferous areas to determine if soil wax or bacteria can be used for geochemical prospecting surveys for oil. These materials require only a small amount of equipment for determination, and surveys could be carried out at very low cost.

8. Provision should be made to obtain a mobile spectrographic unit during the 1957/58 financial year. The cost will be approximately £15,000.