# THE INTERNATIONAL GEOCHEMICAL MAPPING PROJECT— A CONTRIBUTION TO ENVIRONMENTAL STUDIES

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There are many types of world synoptic data maps, but only within the last few years has serious attention been given to the need for a world geochemical atlas to provide an overview of relative geochemical abundance levels, regional trends and anomalous patterns. Surficial geochemical data are relevant to a wide variety of mineral resource, agricultural, forestry, environmental and health questions as well as many geological problems. Systematic maps can provide an index and a starting point for detailed studies relating to the many applications of geochemistry.

In 1988 a proposal for an International Geochemical Mapping Project was accepted by UNESCO/IUGS, to be administered through the mechanism of the International Geological Correlation Program (IGCP). The purpose of IGCP Project 259 is to create a network of scientists and organizations willing to work towards the goal of preparing systematic geochemical maps of the world's surface. The scientific, technical and financial problems are considerable. There are many data sets but not all are readily accessible. Surveys were initiated primarily but not solely for mineral exploration purposes using a variety of media and sample densities. Stream sediment sampling has been one of the most widely used techniques. Samples have been analysed for different groups of elements by a variety of analytical methods, often with uncertain quality control. Nevertheless, from a practical viewpoint these represent a large reservoir of data which, despite the imperfections, should be utilised as fully as possible. To achieve this, and to provide preliminary coverage across unsurveyed regions of the world, plans are being discussed for a new, very low-density, more uniform, sample network using the minimum number of sample types to provide control and serve as an international reference grid.

A committee structure based on scientific/technical and geographic divisions has been established. Committees have been established for North America, Western Europe, Eastern Europe, USSR, India, China, Australia and Southern Africa. Each has responsibility for making progress in its own region. Arrangements for South America are currently under discussion.

Examples of large regional geochemical surveys from a number of countries, e.g. Fenno Scandia, British Isles, Germany, Canada, USA, China, covering in total several million square kilometers, serve to illustrate both the benefits of such surveys and the problems of attempting to unite them into a systematic format.

## HISTORY OF GEOCHEMICAL MAPPING

The concept of geochemical exploration dates back at least as far as Agricola in the 16th Century. The first geochemical soil studies were made for agricultural purposes by Liebig in 1840. In the 1930's Vernadski, Vinogradov and Fersman in the USSR, Goldschmidt and Vogt in Norway, Brundin in Sweden, Rankama in Finland pioneered geochemical mapping for mineral prospecting. In the 1940's, as a refugee from the Second World War, Goldschmidt, was a visiting scientist at the Macaulay Soil Research Institute in Scotland at a time when trace element studies on soils were receiving attention in order to improve agricultural productivity. After the war through the efforts of Webb, Hawkes and others in Great Britain and North America, geochemical surveys began to be introduced as a method of mineral exploration. A few progressive mining companies provided funding for research and experimental surveys. The method was being used extensively and successfully for mineral prospecting in Northern Rhodesia (Zambia) and New Brunswick, Canada, by the mid-1950's.

Government geological surveys and international development organizations began to undertake occasional geochemical surveys as a part of their operations in the late 1950's. The value of systematic geochemical surveys over large regions or whole countries had been recognised by Webb in the 1960's, and culminated in the Wolfson Geochemical Atlas of England and Wales (1978). However, the funds required for governments to place this type of work on the same routine basis as geological surveys were not made widely available until the oil-supply crisis of 1973 created a demand for uranium. Commencing in 1974 there were government programs in Canada, the USA, and elsewhere designed to assist in the discovery of uranium mineralisation. These programs provided for multi-element geochemical surveys, often in conjunction with airborne radiometric surveys, to be initiated with the intention of obtaining systematic reconnaissance coverage of large areas. It was possible to obtain acceptance of the need for multi-element surveys because geochemical anomalies can be classified on the basis of element associations. The bulk of the present North American data dates from this time.

## THE VALUE OF A GLOBAL OVERVIEW

The availability of satellite imagery of the earth and planets has dispelled any doubts that may once have existed concerning the impact and importance of obtaining a global overview of key parameters. Such displays provide perspective and scale to many features and problems that cut across continents and national boundaries.

World Geological Maps have been in preparation for several decades but the first edition was only completed in 1984. It consists of 22 sheets at scales of 1:10 or 1:20 million. This work has been done under the auspices of UNESCO by the Commission for the Geological Map of the World, located in Paris. The same Commission is now coordinating the preparation of two other World map series, Tectonic and Metallogenic. These are at scales of 1/2.5 and 1/5 million. They are incomplete.

A Soil Map of the World has been completed by FAO/UNESCO. Publication commenced in 1971 and was completed in 1981. It is in 10 regional volumes, with maps at 1:500,000 scale. Geophysical and geochemical methods provide unique information about the earth that is not apparent using other techniques. They complement and refine the naked-eye observations which form the basis of geology.

Within the last two decades satellites have provided direct measurements of the global magnetic and gravity fields, allowing coarse resolution maps to be produced of these geophysical data. The same types of geophysical data are available in detail for some continents, for example North America.

Geochemical data are lacking by comparison. Systematic national geochemical surveys were not attempted until the 1960's, almost 150 years after the first national geological surveys commenced and 20 years after systematic geophysical surveys began. Another less obvious but, in the writer's opinion, equally important factor has been the omission of surficial geochemistry studies in university teaching. Consequently the geological profession as a whole has been largely unaware of their significance. The field methods, largely empirically are developed in response to the needs of the mineral industry to find new and more effective exploration methods. The weathering, solution, transportation and deposition processes which control the distribution and concentration of chemical elements and compounds in different types of natural environment are complex and still incompletely understood.

## APPLICATIONS OF SURFICIAL GEOCHEMICAL MAPPING

As indicated above, surficial geochemistry was pioneered as a means of discovering otherwise non-obvious mineral deposits. In order to find such deposits, it was first necessary to ascertain geochemical background values; these have significance to broader aspects of geology, to soil science, groundwater studies, pollution studies, and every living thing that is affected by the composition of soil or water.

### Mineral exploration

A mineral deposit is, by its existence, an anomalous concentration of a particular element or group of elements. The element (or elements) that are of economic value may be accompanied by others which are present only in small or trace amounts but which are nevertheless more concentrated than in a normal unmineralized environment. These may form a faint but large halo (100's of meters in diameter) in the vicinity of a deposit and are sometimes called pathfinder elements. These and/or the elements that form the deposit may (commonly) give rise to abnormal concentrations in the soil overlying and adjacent to the mineralization and in the natural drainage system downstream from it. Thus it is possible to find mineralization which is close to the surface but not exposed. Many ore bodies have been discovered in this way in the past 35 years (Govett, 1986; Mazzucchelli, 1986). The extent to which surficial geochemistry is now recognized as a sub-discipline within the earth-science community has stemmed primarily from its success in finding mineral deposits. For a more detailed description of this topic see Rose, Hawkes and Webb (1979).

### Geological correlation

There is empirical evidence, recognised for many years, that certain groups of metals are congregated in certain geographic regions of the world. Rastall (1923) summarised that: "We can recognize metallogenic regions in space and metallogenic epochs in time". This predated by almost 50 years the modern concept of plate tectonics. The evidence for mobile continents, which over tens or hundreds of millions of years are subject to fragmentation and reassembly, carries with it the inference that it is possible to reconstruct, conceptually, the broken fragments of earlier continents by identifying the geochemical signatures associated with particular epochs. Thus, time and affinity-related groups of rocks may be characterized by trace element assemblages that differ from otherwise similar rock types of other ages or affinities. Certain granites are noted for their consistently high trace element levels of Sn and W. Some argillaceous rocks are noted for their distinctive metal content, for example Cu or U. Surficial geochemical studies can assist in understanding continental fragmentation. This is of considerable scientific interest as well as having the potential to assist in the mineral resource assessment of little known regions.

### Biological implications

Figure 1 is a reminder of the biological activity of elements in the periodic table. Some of the elements are essential to life, some are harmful, and some are passive. Most elements are derived initially from rocks; through the process of weathering they move into soils and surface waters; from there they enter organisms. Their distribution in rocks is not uniform, with concentrations commonly varying by an order of magnitude, depending upon the rock type. In unusual situations, for example in mineralised areas, larger variations occur. Therefore, it is important to know the factors that control their part in life processes. The quantity and availability of biologically sensitive elements affects in conjunction with other factors forest growth, crop type, and crop fertility and through the food chain, animal and human health and ultimately the size and quality of life of human populations.

Known forms of life require, in addition to C, O, H and N, obtained from the atmosphere, relatively large amounts of Ca, Mg, Na, K, Fe, P, and S.

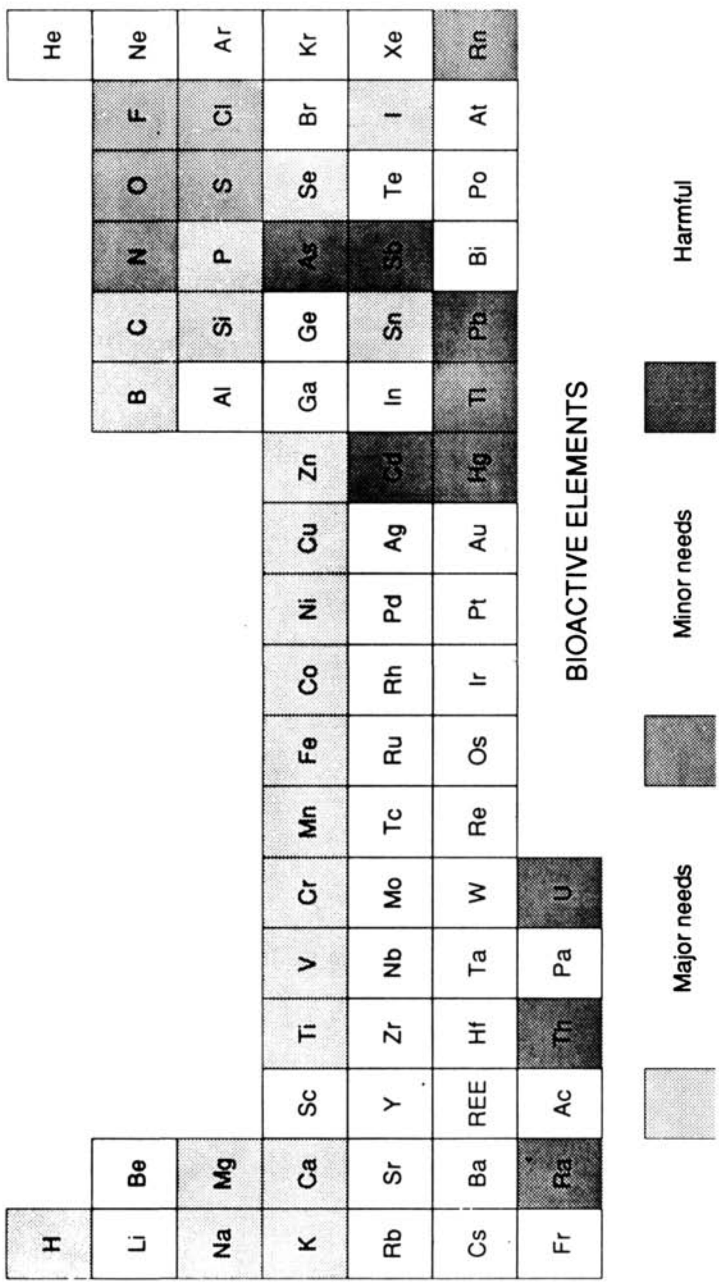


Fig. 1. Elements of periodic table which are known to be biologically active.

Trace amounts of B, Cu, Co, Se, Zn, Mn, Si, I, Cl, F, Cr, Ni, Mo, Sn and V play an equally vital, although less well understood, role. Too little or too much of any element can be harmful to organisms, with consequences manifesting themselves in many different ways. Selenium is a well documented example of a trace element which is necessary for human health, with adverse effects when the concentration in diet deviates significantly from the optimum amount (Crounse, 1986). Whilst different forms of life can have widely different tolerances, the optimal range for a given organism is often narrow.

Some elements, for example Al, although widely distributed in organisms, play an uncertain role in biological processes. Elements such as As, Sb, Be, Cd, Hg, Pb, Ra, Tl, Th and U, are generally consistently harmful to life. The consequences of their presence can be stunted growth, disease, and increased mortality amongst plants and animals.

Radioactivity is a potential hazard most commonly associated with U and Th and the decay products of these two elements, particularly Ra and Rn. However, K is in the anomalous position of being an essential constituent within most forms of life whilst possessing the harmful property of radioactivity. Potassium, U and Th are very widespread constituents in geological materials and their distribution is controlled by the same geochemical processes, and subject to the same variability, as applies to other elements.

Many factors in addition to abundance affect the availability of elements to biological processes and they may be controlling factors. These include the form in which an element occurs, the overall chemistry of a particular environment, organic as well as inorganic Hg is an example of an element where toxicity is very dependent upon form, rainfall, topography, drainage, pH, Eh, temperature, etc; many interactions, are poorly understood. The presence of unusual combinations of related elements can modify the availability of biologically active constituents, with beneficial or detrimental results. The mobility of anionic species of elements such as As, B, Se and U, is greater in alkaline and saline soils of arid regions than in acidic environments where cations such as Cd, Fe, Pb and Zn are more mobile. Anything which changes soil pH, e.g. acid rain, disturbs preexisting geochemical equilibria and so may disturb the biota. As an example, maple trees which are the commercial source of maple syrup in north-eastern North America are sensitive to the availability of K, Ca and Mg in the soil. Soils with an initially low concentration of these elements may become unsuitable for the growth of maple trees as a result of accelerated leaching of these elements by acid rain.

## OBJECTIVES OF IGCP PROJECT 259

This project was conceived as a precursor to the ultimate goal of preparing a geochemical atlas of the world. In brief, the objective of the project is to facilitate, for geological and environmental applications, the production of surficial geochemical maps of the world, to complement other forms of data which describe the surface characteristics of the earth. For demonstration purposes the project will assemble available geochemical data and publish it in a standardized map form. Appendix A contains a fuller statement of the objectives.

## METHODS OF GEOCHEMICAL SAMPLING

Geochemical surveys are undertaken primarily to ascertain the geographic distribution of the relative concentrations of given elements, to delineate patterns of high and low values, to obtain concentration values that will be reproducible under defined conditions and to provide explanations for the results.

Geochemical maps can be compiled from the analysis of rocks, soils and tills in glaciated regions, sediments in drainage systems, botanical samples and surface waters. All of these materials are being used, but their suitability varies considerably according to the purpose of the survey, the analytical information being sought, the region where the survey is being undertaken, the amount of detail (spatial resolution) required and the costs that can be sustained. To extend a survey into a new area, the desired sample medium or media and the sample spacing required need to be selected in advance, based on a combination of scientific, logistical and economic considerations.

Geochemical surveys of surface K, U and Th concentrations can also be carried out radiometrically from low-flying aircraft by virtue of the natural radioactivity of these elements. In this type of survey the method samples a continuous strip of whatever material happens to form the surface of the ground. Therefore the strip sampled is, most often, dominantly soil with some rock outcrop, the amount depending upon the geographic region. Although there are clearly differences in detail compared to the results obtained by conventional surface sampling the patterns obtained do not normally differ empirically by more than the differences between, for example, a stream sediment survey and a soil survey for the same area. The utility of K,U and Th surveys extends well beyond the search for radioactive mineral deposits, arising from the almost ubiquitous distribution of these elements and their distinctive behaviour in important geochemical processes. Nevertheless multi-element data are necessary for most general purposes and these can only be obtained by conventional surface sampling followed by laboratory analysis.

The advantages/limitations of the various alternative surface sample media are summarised in the following paragraphs; although these are written from the perspective of mineral exploration, the salient points apply whatever the purpose of the data. These are as follows:

(i) *Rocks* for geologically orientated investigations are the ultimate sample material, but exposures are non-existent in many places of interest and there can be no assurance that those that can be found are representative of the rocks which underlie the area; in regions where there are abundant rock exposures, because of diversity of rock types, it may be very difficult to obtain statistically representative samples except by taking a prohibitive number. For a review of the geochemical variations found in rocks in the vicinity of different types of mineralization see Govett and Nichol (1979);

(ii) *Soils* are materials derived from the weathering of rocks, admixed with living and dead organic matter; they may have developed from the *in situ* weathering of the underlying or adjacent rocks or from transported rock materials; climate and topography, age of the land surface and vegetation history control the type of soil that develops from a given rock type; soils in general thus exhibit wider chemical variability than the rocks from which they are derived, but within a given area, for similar sample sites, the relationship between parent rock type and soil composition is usually consistent within definable limits; soil sampling has been extensively used from the beginning of geochemical surveying, mainly where a closely spaced sampling pattern is required to achieve good spatial resolution of anomalous features. Useful reviews are given by Bolviken and Gleeson (1979) and Bradshaw and Thomson (1979);

(iii) *Tills*, the product of mechanical comminution of rocks by glacial action, are distributed over the extensive regions in the Northern Hemisphere which were subjected to the Quaternary glaciation; a till thus provides a composite sample of the rocks from which it has been derived; in general, in the absence of evidence to the contrary, it is assumed that the main mass of till at a given site has been derived from rocks within 2 or 3 kilometers in the direction of ice movement; till has usually been subjected to less chemical alteration than soil, which is advantageous for exploration and geological interpretation; because of the physical displacement of anomalies relative to bed-rock sources the latter can often only be located through extensive drilling. For a recent comprehensive review see Coker and Dilabio (1989);

(iv) Sediments from drainage systems are the preferred type of sample for most large area surveys; a single fine-grained sediment sample from a stream provides material which is approximately representative of the weathering products from the catchment area upstream from the point of collection; it is usual to sample streams immediately above a confluence; by selecting the size of drainage channel and if necessary sample intervals along the channel spatial resolution can be modified. In regions with large numbers of lakes and poorly defined surface drainage (such as recently glaciated areas in Canada and Finland) lake sediment sampling is an effective alternative to stream sediment sampling, with the lake catchment basin defining the limits of the source material, usually, mainly till in a glaciated region. Lake sediments have the advantage for environmental purposes of allowing, if a core is taken, a time sequence of sedimentation to be observed. For reviews on stream sediments see Plant, Hale and Ridgway, 1989 and for lake sediments see Coker, Hornbrook and Cameron (1979) and Hornbrook (1989);

(v) *Biological materials* via the analysis of particular parts of selected species of stream or swamp vegetation, or twigs, leaves or bark from certain tree species, etc., has been advocated as a method of prospecting for many years; recent work has encouraged a renewal of interest in these methods, but they have not yet been adopted for routine regional surveys; the variables which determine trace element content in vegetation are much more complex than those which apply to soils, tills or sediments and as such methods based on biological materials need to be very carefully described and controlled. For a recent concise overview see Dunn (1989);

(vi) *Surface waters* are commonly taken when sampling stream or lake sediments in order to determine pH, conductivity, U in solution and, in some surveys, F concentration. The concentrations for most elements of geochemical interest are too low in most natural waters to be determined from a small sample; there are logistical and potential contamination problems in handling large numbers of large water samples, especially where there is no convenient road access to the sampling sites. For a review see Miller (1979); and

(vii) *Radiometric* (gamma-ray spectrometric) sampling has the major advantage that sample material need not be removed and the analysis can be done in real-time from a moving vehicle, either a car or a low-flying aircraft. Adequate sensitivity is available for mapping purposes with suitable calibrated equipment. The limitation of the method is that it is restricted to radioactive elements, naturally occurring such as K,U,Th, or contaminants such as Cs-137. For a review see Darnley and Ford (1989).

Sample collection costs or flying costs in the case of an airborne survey are the largest part of the cost of undertaking a large area geochemical survey wherever there is no close-spaced road network. For conventional ground surveys orientation studies are required, prior to the main field operations, to ensure cost-effective control over site selection, sampling, labelling and handling procedures.

For regional surveys sample densities have normally ranged between 1 sample per square kilometer (in Europe) to 1 per 15 square kilometer (in N.America).

## ANALYTICAL SUITES AND METHODS OF ANALYSIS

Geochemical surveys were first made for the purpose of mineral prospecting, and therefore analytical work was limited to elements which might be of immediate economic interest. Low cost and simplicity of laboratory procedures were prime considerations, especially since in the early days of this work, during the 1950's, analyses were often undertaken in field camps. Copper, Pb and Zn were the essential elements, conveniently determined by colorimetry. As mineral discoveries were made, the demand grew for information about more elements, but the theoretically desirable list was often abbreviated by the complexity and therefore cost of the analytical procedures involved. In examining the output of different institutions, the analytical suites determined by their laboratories often seem to have been influenced at least as much by the availability of equipment, methods and personnel as by the significance of certain parameters.

The steady growth in the application of geochemical surveys over the past 40 years has stemmed in large part from the progressive introduction of new and more sensitive methods of chemical analysis, amenable to tight quality control, and suitable for the mass production of data. The succession of principal methods has been emission spectroscopy, colorimetric, atomic absorption, X-ray spectroscopy, neutron activation, inductively-coupled plasma optical emission spectroscopy.

For the period since 1965, when large regional surveys commenced, analytical data have been obtained for between 10 and 40 elements, sometimes with additional parameters (pH, bicarbonate, conductivity and loss on ignition), depending upon the area and country. Recent interest in the discovery of gold has resulted in the widespread adoption of neutron activation techniques, with a much more expanded analytical suite than was hitherto available. Analytical results show that, for any given element, natural levels of geochemical abundance commonly vary by one order of magnitude and that large areas several hundreds of square kilometer or larger may have a median abundance for particular groups of elements differing from adjoining regions by two or more orders of magnitude.

## Reference materials

An essential component of a systematic mapping program is the availability and use of analytical standards or reference materials. This is necessary to maintain as much consistency as possible in analytical data produced over a long period of time by different laboratories and to establish the analytical uncertainties in a quantitative manner. A survey by Abbey (1983) indicates that there were only 37 reference samples representing secondary materials out of a total of 167 reference materials of geological origin. Virtually all of these were certified for total, not partial, extraction determinations. The features which are desirable in reference materials for geochemical survey purposes include (Lynch, pers. com.): (i) the same type of sample media as will be used for routine surveys; (ii) the same type of sample preparation procedures; (iii) an appropriate range of concentration values; and (iv) determinations for both "total" extractions and specific "partial" extractions. Much time and effort is required to produce Certified Reference Materials for international distribution; and arrangements should be made by laboratories responsible for national programs to produce secondary or tertiary reference materials for routine analytical control of large sampling campaigns.

In order that airborne gamma-ray spectrometry can produce reproducible quantitative measurements of mean surface radioelement concentration, it also requires equipment calibration facilities and appropriate standards. These were first developed in the period 1968/70 and have been described in a number of subsequent publications (IAEA, 1976).

## CURRENTLY AVAILABLE GEOCHEMICAL MAPS

It is one of the objectives of the IGCP project to prepare an inventory of all areas of more than 5,000 square kilometer for which geochemical maps are available and to document sample type, sample spacing, elements determined, analytical methods, etc. Lund (1987) has undertaken this task for Canada.

Plant *et al.* (1989) have listed 38 multi-element stream sediment surveys from 30 countries where areas greater than 5,000 square kilometer have been covered. The total area covered by this listing is 3.6 million square kilometer. In addition, approximately 1.2 million square kilometer of Canada have been covered by lake sediment surveys. Almost all of the conterminous USA (approximately 8 million square kilometer) has been covered by airborne gamma-ray spectrometer surveys which have enabled maps of surface K, U and Th distribution to be compiled across the full width of the North American continent (Duval, pers. com.).

Figure 2, based on Plant *et al.* (1989), shows the frequency with which there are abundance data for different elements in twelve national surveys, which each cover areas larger than 100,000 square kilometer. Sample densities vary from 1/2.5 square kilometer to 1/30 square kilometer. The number of elements for which maps have been produced varies according to country, from 15 to 39. In total 53 elements have been measured, but only 4 are common to all map-sets. These are Co, Ni, Zn and Pb. V, Cr, Mn, Cu, As, Sr, Sn and Ba are usually determined but least commonly determined are, F, Si, Cl, Ga, Br, Rb, Hf, Ta and Hg. Selenium is shown as not determined in any of the surveys examined, but it should be noted that it has been mapped in some other investigations, for example of Southern California. (McNeal, 1989, pers. com.).

Reproduction scales of published Regional Geochemical Maps vary from 1:4 million to 1:250,000 (Geochemical Atlas of Northern Fenno Scandia, 1986; Geochemischer Atlas Bundesrepublic Deutschland, 1985; Lund, 1987; National Geochemical Reconnaissance, 1981; Wolfson Geochemical Atlas of England and Wales, 1978. A wide variety of formats have been employed for displaying the results. The primary analytical data for the elements are expressed as parts per million by weight in the material analysed. These numbers may be directly reproduced on detailed maps, but at larger scales a variety of point or linear symbols, pixels or contours are employed. This is a matter where some standardization would be beneficial to non-specialist casual users. A printed map is the most direct way of showing that data are available. Obviously the prime data file is digital and there are an almost infinite number of ways of displaying and combining the data for specialist purposes.

## ORGANIZATION OF THE IGCP PROJECT

A principal item of business in the first year of the project was setting up the organizational structure for the projects the aim is to encourage broad geographic participation in parallel with the establishment of specialised working groups. The latter will have to deal with technical problems on an international basis. Two groups of committees have been formed under the umbrella of a Steering Committee:

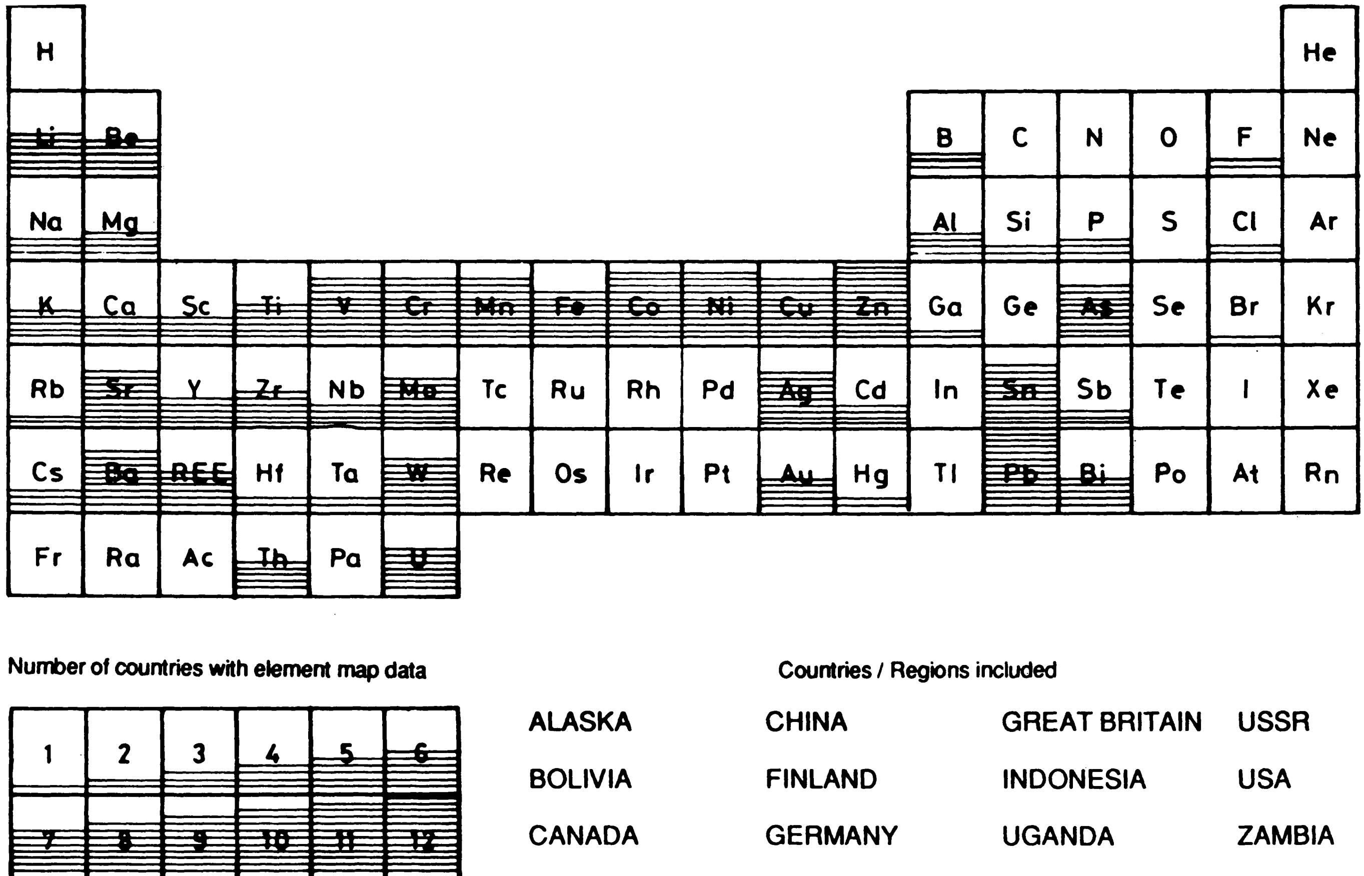


Fig. 2. Elements of the periodic table included in major (> 100,000 km²) national geochemical map compilations.

(i) Scientific and Technical; and

(ii) Geographic/Regional.

The Steering Committee, under the chairmanship of the IGCP Project Leader, is composed of the leaders of the Regional and the Technical Committees.

The Scientific and Technical Committees consist of:

(i) Field methods;

(ii) Analytical methods;

(iii) Data management; and

(iv) Radiometric methods.

The Regional Committees currently consist of:

(i) N. America;

(ii) W. Europe;

(iii) E. Europe;

(iv) USSR;

(v) India;

(vi) China;

(vii) Australasia; and

(viii) Southern Africa.

Discussions are in progress with respect to the formation of a Regional Committee for South America. In addition to the above some countries have established national committees. As of May 31, 1989, correspondents from 54 countries have expressed a desire to participate in the project (see Appendix D).

## RELATION TO OTHER INTERNATIONAL PROGRAMS

More than fifty international scientific unions, associations, committees and groups are concerned with different aspects of Global Change. At the first meeting of the Scientific Advisory Council for the International Geosphere-Biosphere Program (IGBP) on Global Change in Stockholm, 24-28 October, 1988, the IGMP was accepted by the relevant Working Group (Data and Information) as a base-line component in Global Change studies. Amongst other professional groups with a special interest in geochemical mapping is the International Society for Soil Science.

An important aspect of the IGMP is its relevance to developing countries. A Working Group report on Third World Cooperation, submitted to the Scientific Advisory Council for the IGBP on Global Change in 1988, listed the features needed to make projects connected with Global Change activities of real interest to developing countries. These include the need:

(i) To create a focus for activities in as many developing countries as possible;

(ii) To place emphasis wherever possible on issues relevant to the country or region concerned;

(iii) To identify and take advantage of relevant data already collected and activities currently underway (sometimes haphazardly) in individual countries;

(iv) To strengthen the gathering and use of base-line information.

(v) To provide an integrated program (data collection, analysis and interpretation) at the national as well as the regional and global levels; and

(vi) To arrange Regional Forums to exchange information, and initiate local seminars.

It is apparent that the IGMP fits the above requirements very effectively; The products are multi-purpose, many with a potential for creating short-term economic and social benefits. The project uses skills and facilities that should be within reach of and available to every developing country.

## DISCUSSION — QUESTIONS AND PROBLEMS

A variety of scientific questions will be investigated through the work of the various committees. Some are mentioned below. It is anticipated that as the project progresses the crucial issues will be discussed in workshops; it will probably be necessary to conduct some pilot studies; following these it is intended to formulate and publish recommendations in a series of technical reports.

Geochemists have long been aware of the significance of geochemical surveys to environmental studies. The practical problem is how best to convey this awareness to those that control policy. Informed members of the public, politicians and scientific policy makers in a number of countries have become aware over the past two decades of hazards posed by elements such as Rn, Cd, and As in the environment, and some recognize that "pollution" can arise from natural causes as well as from human carelessness. A few are aware of some paradoxical situations, for example potassium. The element is essential to many forms of life, but it is also weakly radioactive !

Over the past two or three years, increasing unease amongst the general public about the possibility of "Global Change" is beginning to create pressure for governments to take action to arrest these unwanted changes.

IGCP Project 259 is endeavouring to react to public concern about Global Change and the environment. As previously indicated, most existing geochemical surveys were conducted for geological/mineral exploration purposes. The Technical Committees will be considering what additional steps could be taken in order to maximize the environmental usefulness of existing or new data. For example, they are to determine to what extent environmentally significant data could be obtained from the analysis of retained sample material stored in government warehouses; also, to consider how the design of future surveys and analytical procedures could be modified.

It is particularly important to obtain a global geochemical overview as rapidly as possible in order to normalize existing survey data and fill-in gaps. To do this it is necessary to establish the most satisfactory method(s) of wide-spaced sampling, including the issue of single or composite samples. As indicated previously, stream (or river) sediments are generally considered to be the most generally available sample media but there are obviously geographic regions where alternatives must be found.

The major river systems of the world offer the possibility, by means of a few thousand samples, to achieve world-wide coverage of large areas very quickly. How would sample sites be selected? How long a sediment column should be taken? What would be the analytical requirements in order to detect significant regional differences? Could the material collected also serve for control reference purposes ?

There is a need to subdivide the world into physiographic-climatic zones within each of which geochemical methods can be optimized. It will be necessary to have overlap between the zones so that data can be normalized. Where are the most suitable areas for these overlap studies? Which institutions will take responsibility for this work ?

There are a number of important questions relating to analytical work. Should samples be totally or partially digested? For geological purposes the former is preferable; for mineral exploration applications some partial extractions are advantageous and for environmental studies more complex treatments may be required. It is easier to obtain standardized data where total extractions are used. In exploration only single element data has been reported; for environmental purposes it would be desirable to determine some complex species. Whatever procedures are adopted it will be essential to follow standardized analytical methods with routine use of intercalibrated reference materials.

There are also politically sensitive questions. A number of countries involved in the provision of technical assistance hold large files of geochemical data pertaining to developing countries. These data are potentially suitable for incorporation in world maps and it is highly desirable that they should be used, otherwise there may be delays of many years before there is information about some parts of the world. It will be necessary to obtain formal permission from the countries concerned before these data can be used for this purpose, but the initiative for seeking this permission should perhaps come from the countries that provided the technical assistance.

Lastly, but in many respects the most crucial question, concerns the need for a source of adequate funding for the work that has to be done. It is no longer possible if it ever was, to be able to find the human and material resources necessary to advance a project of these dimensions from the annual operating budgets of the national geological organizations of even the wealthiest of developed countries. The situation in developing countries is clearly much more difficult. The minimum financial provision is for funding to enable the scientists concerned with the project to meet together at regular intervals at least annually to ensure that a common project philosophy is being developed and followed, regionally and internationally, for funding to allow pilot projects to go ahead where required, and for some appropriate geochemical work to be done in each participating country. It seems probable that the necessary funding will only be found:

(i) If the project is accepted by developed countries as an integral part of national and international plans to address potential Global Change problems; and

(ii) If the project is accepted by developing countries as relevant to the solution of their economic needs.

## FUTURE PROGRAM OF IGCP PROJECT 259

The preparatory work that is required in order to prepare geochemical maps of the world consists of a number of parts:

(i) Establish what data and map sets already exist;

(ii) Ascertain the level of commonality;

(iii) Establish a method for normalizing as many as possible of the existing data sets;

(iv) Prepare compilations of geochemical data, as demonstration products, for two or more adjoining countries;

(v) Ascertain what changes could be made to existing "conventional" geochemical mapping in order to enlarge its environmental usefulness;

(vi) Investigate the feasibility of devising an ultra low density sampling approach (or more than one, if necessary) for use in unmapped regions, and for normalizing data from previously mapped regions, in order to obtain reconnaissance coverage of the world as soon as possible; and

(vii) Prepare recommendations for international standards relating to sample collection and preparation, analytical standards and methods, data treatment and compilation, for future geochemical survey work.

Note that the above desiderata also apply, in principle, to geochemical data for K, U and Th, collected by gamma-ray spectrometry.

## CONCLUSIONS

For environmental applications the currently available regional geochemical mapping is of somewhat limited value because the work was not undertaken with environmental significance as a prime consideration. Nevertheless, the data obtained provide the most geographically extensive and best-controlled geochemical coverage in existence and provide insight concerning the range of variables existing in the natural environment. The knowledge and experience gained in obtaining the existing data-base is an excellent foundation for expanding systematic geochemical surveys into all parts of the world. Since it is presently estimated that there are potentially useful data for not more than 10% of the world's land surface, there is some urgency to remedy this deficiency in the context of concern over "Global Change".

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# APPENDICES

## Appendix A—Objective of IGCP 259

The purpose of the project is to encourage and facilitate the compilation of an international series of systematic surficial geochemical maps by national and/or international organizations, based on the most appropriate types of sample material. The maps will show abundance levels, delineate regional trends and geochemical provinces, and permit the recognition of large scale anomalous features. They will complement existing international geological and geophysical map series, and will be published at scales suitable for direct comparison. To the greatest extent possible primary data will be stored in digital form to facilitate its reproduction at different scales in a variety of formats, for mineral resource, general geological and environmental studies. The data will be related to bed rock geochemistry wherever possible.

## Appendix B—History of Project

This project was conceived at a workshop attended by a group of uranium explorationists in Sweden in the fall of 1984. There was concern that large quantities of exploration-related geoscientific data, with many potential applications, collected at considerable expense from most of the continents, were in danger of being lost to posterity through widespread cost-cutting economy measures instigated by industry and government. It was suggested that there should be an international effort to preserve such data. Attention quickly became focussed on radioelement surveys and geochemical data sets. Although the workshop where this was discussed was convened under the umbrella of the International Atomic Energy Agency, whose mandate is restricted to matters relating to nuclear energy, the advocates of the project recognised the need to make the data sets as comprehensive as possible.

The project was launched in April 1987 when a proposal to initiate an International Geochemical Mapping project was approved by a resolution of a joint meeting of the International Association of Geochemistry and Cosmochemistry and the Association of Exploration Geochemists in Orleans, France. Subsequently the project was formally accepted by the Scientific Advisory Committee of the IUGS International Geological Correlation Program at their annual meeting in Paris in February 1988. This recognition has brought the project to the official attention of government earth science organizations, which is an essential step in order to obtain government funds to carry out the work required and provide budgetary support for participating geochemists.

The first scientific meeting held in connection with the project took place in May 1988 at the first V.M. Goldschmidt Conference in Baltimore, USA, with a session entitled "International Geochemical Mapping".

## Appendix C—Listing of Elements Analysed in Selected Surveys

| Element | | Region | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ALAS | CAN | E & W | NDKT | GER | NI | SCOT | BOL | CR | PRC |
| 1 | H[a] | | J | | | G | | S | | | |
| 2 | He | | | | | | | | | | |
| 3 | Li | A | | X | | G | | | B | | |
| 4 | Be | A | | | | | | S | B | | P |
| 5 | B | | | | | | | S | B | | P |
| 6 | C[b] | | J | | | | | | | C | |
| 7 | N | | | | | | | | | | |
| 8 | O | | | | | | | | | | |
| 9 | F | | J | | | G | | | | | |
| 10 | Ne | | | | | | | | | | |
| 11 | Na | A | | | O | | | | | C | |
| 12 | Mg | A | | | O | | N | | | C | |
| 13 | Al | A | | X | O | | N | | | C | |
| 14 | Si | | | | O | | N | | | C | |
| 15 | P | | | | O | | | | | | P |
| 16 | S | | | | | | | | | | |
| 17 | Cl | | | | O | | | | | C | |
| 18 | Ar | | | | | | | | | | |
| 19 | K | A | J | X | O | | N | | | C | |
| 20 | Ca | A | | X | O | | N | | | C | |
| 21 | Sc | A | | X | O | | N | | | C | |
| 22 | Ti | A | | | O | | | | | C | P |
| 23 | V | A | J | X | O | G | N | S | | C | P |
| 24 | Cr | A | | X | O | G | N | S | B | C | P |
| 25 | Mn | A | J | X | O | | N | S | B | C | P |
| 26 | Fe | A | J | X | O | | N | S | B | C | |
| 27 | Co | A | J | X | O | G | N | S | B | C | P |
| 28 | Ni | A | J | X | O | G | N | S | B | C | P |
| 29 | Cu | A | J | X | O | G | N | S | B | C | P |
| 30 | Zn | A | J | X | O | G | N | S | B | C | P |
| 31 | Ga | | | X | | | N | | | C | |
| 32 | Ge | | | | | | | | | | |
| 33 | As | A | J | X | O | | N | | B | C | P |
| 34 | Se | A | | | | | | | | C | |
| 35 | Br | | | | O | | | | | C | |
| 36 | Kr | | | | | | | | | | |
| 37 | Rb | | | | O | | | | | C | |
| 38 | Sr | A | | X | O | G | N | | | C | |
| 39 | Y | | | | O | | | | B | | |
| 40 | Zr | A | | | O | | | S | B | C | |
| 41 | Nb | | | | O | | | | B | | |
| 42 | Mo | | J | X | O | | N | S | B | C | P |
| 43 | Tc | | | | | | | | | | |
| 44 | Ru | | | | | | | | | | |
| 45 | Rh | | | | | | | | | | |
| 47 | Ag | A | J | | O | | | | B | C | P |
| 48 | Cd | | | X | | G | | | | | |

| Element | | Region | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ALAS | CAN | E & W | NDKT | GER | NI | SCOT | BOL | CR | PRC |
| 49 | In | | | | | | | | | | |
| 50 | Sn | A | J | X | O | G | | | B | | P |
| 51 | Sb | A | J | | | | | | | | |
| 52 | Te | A | | | | | | | | | |
| 53 | I | | | | | | | | | C | |
| 54 | Xe | | | | | | | | | | |
| 55 | Cs | A | | | O | | | | | | |
| 56 | Ba | A | | X | O | G | N | | B | C | P |
| 57 | La | A | | | O | | | | B | C | |
| 58 | Ce | A | | | O | | | | | C | |
| 59-71 | (A⁺) | A⁺ | | | | | | | | C | |
| 72 | Hf | A | | | | | | | | C | |
| 73 | Ta | A | | | | | | | | C | |
| 74 | W | A | J | | O | G | | | | C | P |
| 75 | Re | | | | | | | | | | |
| 76 | Os | | | | | | | | | | |
| 77 | Ir | | | | | | | | | | |
| 78 | Pt | | | | | | | | | | |
| 79 | Au | A | J | | O | | | | | C | |
| 80 | Hg | | J | | | | | | | C | |
| 81 | Tl | | | | | | | | | | |
| 82 | Pb | A | J | X | O | G | N | S | B | C | P |
| 83 | Bi | A | | | | | | | | | |
| 84 | Po | | | | | | | | | | |
| 85 | At | | | | | | | | | | |
| 86 | Rn | | | | | | | | | | |
| 87 | Fr | | | | | | | | | | |
| 88 | Ra | | | | | | | | | | |
| 89 | Ac | | | | | | | | | | |
| 90 | Th | A | J | | O | | | | | C | |
| 91 | Pa | | | | | | | | | | |
| 92 | U | A | J | | O | G | | S | B | C | |
| TOTAL | | 38 | 22 | 21 | 37 | 16 | 20 | 15 | 21 | 39 | 18 |

KEY: ALAS (A) Alaska (Los Alamos National Laboratory); CAN (J) Canada (Geological Survey of Canada); E&W (X) England & Wales (Imperial College, London); NDKT (O) Northern Fenno Scandia (Nordkalott Project); GER (G) Federal Republic of Germany (BGR, Hannover); NI (N) Northern Ireland (Imperial College, London); SCOT (S) Northern Scotland (British Geological Survey); BOL (B) Bolivia (British Geological Survey); CR (C) Costa Rica (Los Alamos National Laboratory); and PRC (P) P.R. of China (Institute of Geophysics & Geochemistry).

*Note: a = pH; b = Loss on ignition.

## Appendix D — Countries with Organizations Wishing to Participate in International Geochemical Mapping (IGCP 259)

[Type of institution indicated by code]

| | | | |
|---|---|---|---|
| Argentina | CNEA | Kenya | GS, MU |
| Australia | CSIRO, UNSW, SABM | Malaysia | GS |
| | | Mexico | IMP |
| Austria | GS, SU | Mocambique | GS |
| Botswana | GS | Morocco | BM |
| Brazil | CNEN, CPRM, URJ, UB | Netherlands | LU |
| | | New Zealand | UA |
| Burkina Faso | BM | Nigeria | GS, UPH, OSU |
| Canada | various | Norway | GS |
| Chile | GS | Pakistan | GS |
| China | MGMR | Poland | GS |
| Colombia | GS | Portugal | ENU, UA |
| Cyprus | GS | South Africa | NDC, UW |
| Czechoslovakia | GS, CU | Spain | UB |
| Denmark | RNL | Sri Lanka | UP |
| Ecuador | GS | Switzerland | UZ |
| Egypt | NMC | Syria | |
| Finland | GS, AA | Tanzania | BM |
| France | BRGM, CEA | Thailand | DMR |
| Gabon | BM | UK | BGS, UL |
| Germany (FRG) | BGR, TUB | USA | USGS, LANL |
| Germany (DDR) | ZGI | USSR | AS, MG |
| Ghana | GS | Venezuela | UCV |
| Greece | IGME | Vietnam | GS |
| Greenland | GS | Yugoslavia | GS |
| Guyana | GS | Zambia | GS |
| India | GS, AED, UU | Zimbabwe | UZ |
| Indonesia | GMR | ADB | |
| Iraq | GS | ESCAP | |
| Ireland | GS, UG | IAEA | |
| Israel | GS | UNESCO | IGBP-GC, IUGS/CGMW |
| Ivory Coast | BM | | |

Miscellaneous abbreviations:

GS = Geological survey
BM = Bureau of mines
U = University

## Appendix E — Supplementary Organizational Information

The Technical Committees will each have a minimum of 5 members. Responsibilities will be as follows:

(i) *Field Methods Committee* — To include all matters concerning selection of sample media; methods of sample collection; sample spacing, including ultra-wide spacing; sample mass; particle size(s) for analysis; collection of replicate samples; use of composite samples; selection and collection of material for reference standards; in-field sample processing, etc.

It was agreed at a meeting in Helsinki in November 1988 that a sub-committee will be established to investigate various approaches to wide-spaced sampling.

(ii) *Analytical Methods Committee* — To include all matters concerning sample preparation and digestion; selection of analytical techniques; use and adoption of reference materials; provision of international inter-laboratory reference materials; expansion of analytical suites, etc.

(iii) *Data Processing and Management Committee* — To include recommendations on the organization and contents of a world index of geochemical surveys; methodology for levelling/normalizing diverse data sets; development of standard formats for trans-border data-sets and map publication; evaluation of data interpretation methods for the principal user-groups, etc.

(iv) *Radiometric Methods Committee* — To include all aspects of the collection, standardization, compilation and interpretation of geochemical data obtained by airborne gamma-ray spectrometry. A working group has already commenced work on methods for combining existing airborne radiometric data, under the auspices of the International Atomic Energy Agency, Vienna. The Convenor is Mr. A.Y. Smith of the IAEA. Note that the Radiometric Methods Committee has comprehensive responsibility for this particular technique.

The function of each of these committees is to produce technical reports, summarising recommended methods and procedures, based on a review of international information and experience. Membership of the Technical Committees is listed in Appendix C. Additional members would be welcome; names should be sent to the Project Leader. An important consideration is that in addition to having the relevant experience, in order to be active participants, committee members should be able to obtain funds to travel to meetings. Committees cannot function without periodically meeting face-to-face.

*Regional Committees* — these have been or are being established in the following geographic regions, where there are institutions which have indicated their support for the project; the leaders are as follows:

| | |
|---|---|
| North America (including Greenland) | J. McNeal, USA |
| China | Xie Xuejing |
| Eastern Europe | F. Mrna, CSSR |
| Western Europe | B. Bolviken, Norway |
| USSR | P.V. Koval |
| Australasia | R.E. Smith |
| Southern Africa | N.J. Money |
| India | Contact not known. |

Additional Regional Committees are needed to initiate and coordinate activities in other parts of the world, such as Japan, SE Asia, Middle East, Mediterranean/N. Africa, S. America. It is open to earth scientists and institutions in these areas to discuss with their neighbours how they wish to group themselves together.

The UN and related international organizations (for example the Asian Development Bank) have been, or are being informed, and their assistance requested to spread information about the existence of the project and its relevance to practical problems.