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جامعة جنوب الوادى

Geologic course for fourth year students (Geology) of

Mineral exploration

G 414

I. Geophysical Exploration

Airborne geophysical surveys collect data from air either using a helicopter or a fixed wing aircraft. Generally magnetic, radiometry and electromagnetic data are collected from the air at the same time.

Airborne geophysical survey is a very useful method to investigate large areas quickly. Mapping a large survey area with extreme topography is a very difficult and expensive task to be done by ground based geophysical and geological methods.

Aircraft provide the capability of traversing regions that are otherwise difficult or impossible to cover. Examples include remote areas of the Rocky Mountains, and the thickly-vegetated Amazon basin.

Airborne geophysical techniques have been applied to mineral exploration since the Mid-1940, s ,but their application in the developing countries did not become widespread until the late 1960,s . Now approximatley 30-40 percent of the current annual worldwide expenditure of $30 million per year is applied to the developing countries

The primary role of airborne geophysics has been to aid in geological mapping, particularly on a reconnaissance bases in areas of poor outcrop exposures. Nationwide aeromagnetic surveys have assisted greatly in developing a geological data base in many parts of the world. Most of this work is funded by governments and international aid agencies.

A second application is the direct or semi-direct exploration for certain mineral deposits, including those of the base metals, iron, and uranium.

Other economic minerals can be detected through their frequent association with particular rock types in certain environments. Included

are niobium, nepheline, barite, the rare earths,

vermiculite, corundum, tin, tungsten and diamond.

The discovery of these minerals may involve from a program of geophysics conducted as an aid to the geological mapping

Used in the exploration role, airborne geophysics has been . highly successful in the industrialized countries.

In canada, it is credited with nearly all of the increase in the countries,s production of Lead, Zinc, Silver, Nickle and copper in the peroid of 1948- 1978.

On a worldwide basis some 39 discoveries were credited to airborne geophysics in the peroids up to 1966.

Some general considerations

The subject dealt with here is the applic-ation of airborne geophysics to mineral exploration. Since the techniques used in the developing countries are the same as those applied elsewhere

Airborne geophysics in Canada comprises only 5 percent of the total exploration expenditure, yet it has been credited (Derry, 1970) with more than 50% of mineral disco-veries in Canada since 1945.

On the bases of the above figures it would appear that each dollar spent on airborne geophysics is responsible for discovering $125 worth of minerals. However, this ignores the other activities that are essential parts of the exploration package.

In Canada roughly S 20 must be spent in geological, geochemical, and ground geophysical work, plus exploratory drilling, for every dollar spent in airborne geophysics.

The average cost of finding and proving an economic mineral deposit in early 1970,s was about $ 25 million.

THE ROLE OF AIRBORNE GEOPHYSICS

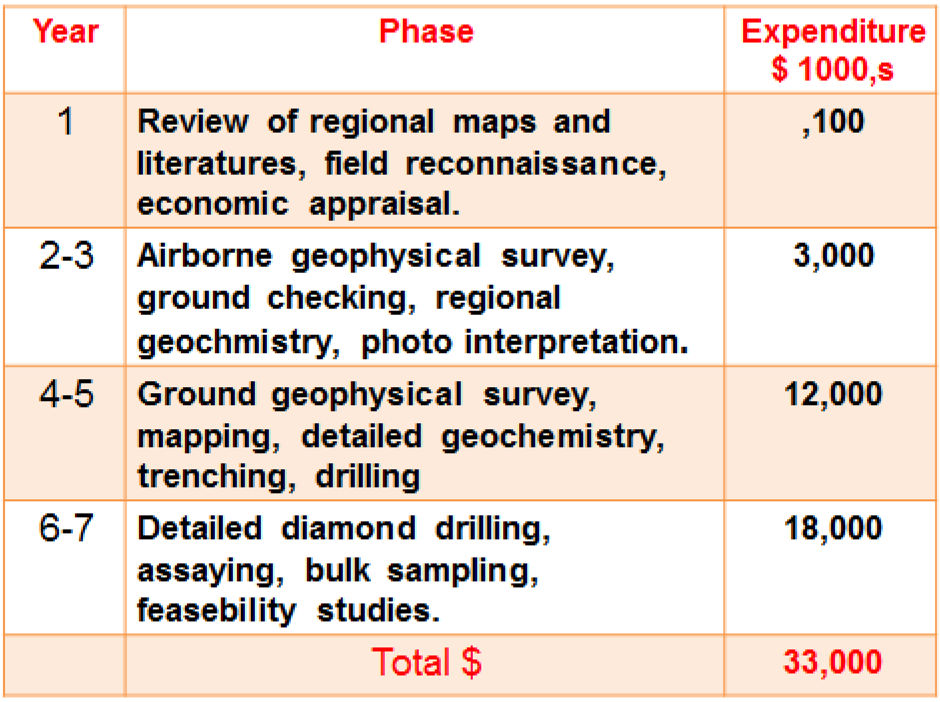
The role of airborne geophysics is two folds :

(i) To aid in geologic mapping , particularly on a regional basis ; and

(ii) To explore directly for the mineral deposits.

Most systematic regional exploration programs combine both of these roles, and to be effective an airborne geophysical survey is usually only a small component of an integrated and much more costly exploration package.

For example a major exploration program in an underexplored area, possibly in a developing country, might be conducted along the following lines :



Year	Phase	Expenditure $ 1000,s
1	Review of regional maps and literatures, field reconnaissance, economic appraisal.	,100
2-3	Airborne geophysical survey, ground checking, regional geochmistry, photo interpretation.	3,000
4-5	Ground geophysical survey, mapping, detailed geochemistry, trenching, drilling	12,000
6-7	Detailed diamond drilling, assaying, bulk sampling, feasebility studies.	18,000
	Total $	33,000

The anticipated outcome of such a program, if successful would be the establishment of new ore reserve totaling some 500- 1000 million dollars.

Of course, not all exploration programs are carried out on this scale. A complete program along the above lines, over a limited area of a few hundred square kilometers might be conducted in a peroid of three or four years for a total of S4 – S5 million.

However, such a program would have, on the average , a less than 10 percent chance of directly discovering an economic ore deposit.

Airborne geophysics does not always form part of a systematic exploration package partic-ularly in areas where mineral development has already taken place and where something is known of the geology and mineral distribution.

In such cases surveys may be conducted for such reasons as the following :

1. to extend existing geological mapping under a cover cover of alluvium, sediments or water.

2. to help solve a particular geological problem, such as mapping an unconformity, tracing a fault zone, or searching under a layer of young volcanics.

3. To look directly for extensions of the mineralized zone, or satellite bodies near a producing deposit.

These programs may vary in scale from small, helicopter surveys of a few square kilometers, costing S10,000- S20,000, to country – wide mapping projects costing of S 2 millions.

Airborne geophysical techniques

Geophysical instruments respond to variations in the physical properties of the ground:

* Magnetic methods respond to changes in magnetic susceptibility of rocks and minerals, chief of which is magnetite, a common iron ore mineral and a consti- tuent of most country rocks.

The objective of some magnetometer surveys is the direct location of iron ore deposits, but more often , is to aid in regional geologic mapping.

*** EM methods detect variations in electrical coductivity which in the case of most geologic materials depond upon clay and water content. Salinity is also important in coastal areas and regions of internal drainage.**

*** It is the metallic conduction that provides the primary incentive for airborne EM.**

*** Most base metal deposits and all volcanogenic sulphide deposits are good electrical conductors.**

Combined airborne EM and magnetometer surveys have had enormous success in directly locating massive sulphide deposits of copper, zinc, nickel, lead often with precious metals, since the advent of this technique in the mid-1950,s

Gamma-ray spectrometry responds to natural radioactivity, of potassium ,uranium and thorium, together with their daughter products.

This tool has as might be expected , led to the discovery of a number of uranium ore deposits, but its contribution to regional geological mapping (particularly the recog-nition and delineation of granitic bodies) has been equally important.

Gravity, in the air as on the ground , detects changes in the density or specific gravity of the earth materials. Since the

gravitational force is equivalent to vertical acceleration measurements from an airborne platform are not simple. Success to date has been limited to some petrolium exploration problems.

In addition to physical properties, the effects of size and distribution of earth materials are important.

*** A large body of low concentration may be more detectable than a small body of high concentration.**

*** A mass close to surface is generally easier to detect than one at depth.**

*** All airborne geophysical techniques are affected by surface topography, aircraft elevation and atmos-pheric conditions.**

*** These factors , and others , will be considered briefly in the following discussions of the various airborne geophysical application.**

Regional mapping

The largest proportion of airborne geophysics (Probably 90 % in terms of survey lines , 80% in terms of dollars) consists of airborne magnetometer or combined magnetometer /spectrometer

Surveys conducted as aid to geologic mapping. Most countries have carried out at least some national magnetic

programs and have published the results as contour maps of (the total magnetic field).

Combined magnetometer / spectrometer surveys have been conducted with international funds.in most of the African and Latin Amirican countries.

1- Magnetics

As stated earlier , the magnetometer responds to the variations in the magnetite content in the underlying country rocks. It is a fortunate fact of nature that different rock types often show differences in their levels and distributions of magnetite.

Table 1 of magnetic susceptibilities (.0025 e.m.u. roughly equals 1 percent $Fe3\ o4$) illustrates the variations in magnetic levels. For example , the magnetic field over a mafic igneous rock such as gabbro will be stronger than it is over a region of sediments.

The distribution of magnetite also varies from one rock type to another, frequently as a result remobili-zation and recrystilliation during metamorphism.

A relatively fresh granite intrusive may exhibit a fairly uniform or rounded magnetic texture, where as a granite gneiss a typically banded parallel to the gneissosity .

Table 1: Magnetic susceptibility of rocks

Rock type	Magnetic susceptibility (x 10^{-3} e.m.u.)
Mafic intrusives and extrusives	1 - 20
Intermediate intrusives and extrusives	.5 - 10
Felsic intrusives and extrusives	.01 - 2
Sediments (except iron formation)	0 - .00002

- Magnetic textures are characterized by a number of parameters that serve to aid in the identification of rock types in any given area.

- Finally, the parameter does not respond only to the rocks at surface, but also to materials at considerable depth. <u>This third dimension, while useful for exploration purposes often leads to apparent contradictions between the magnetics and the mapped geology</u>.

The main importance of magnetics in the mapping role rests in the ability to see through soil cover , vegetation, and water.

*** It is also a relatively inexpensive regional tool (15-20 Dollar per sq. Km. for 1:100,000 scale mapping with a line spacing of 1 Km.).**

*** Its main limitations are ambiguity of interpretation and the difficulty of application in mountaneous terrain, it is a problem calling for carful navigatio and hight control ,**

followed by sophisticated processing and interpretation tecchniques.

2- Combined Magnetometer / Spectrometer

Gamma-rays spectrometer surveys can be carried out concurrently with airborne magnetometer survey In most substances. Exceptions include reconnaissance surveys at wide line spacings and areas of extreamly steep topographic relief.

The justification for combine surveys rests in the ability of the spectrometer to recognize in the abundances of the radioactive elements in the underlying rocks, which can be used as a further guide in the identification of rock types.

The conventional spectrometer measures the gamma radiation in three energy bandwidths which lead to the calculation of the apparent abundances of radioactive potassium (k40), thorium and uranium in the ground.

A record is also made of the total gamma ray count. Since all rocks contain these three elements to a greater or lesser extent.

The method is complimentary to the airborne magne-tometer method in that many rocks of low magnetite concentration (eg. most sediments and felsic igneous rocks) show measurable gamma ray anomalies.

The spectrometer is well suited to the mapping of granitoids, which may not produce discernable magnetic anomalies.

The chief limitation of gamma ray spectrometry, namely the shielding effect of water and trans-ported overburden, is compensated to some extent by the magnetometer. Used in conjunction the the two methods provide a very powerful mapping survice.

While the magnetometer and spectrometer are the traditional geophysical aids to geological mapping, EM methods are now becoming quite popular.

The EM technique can be used to provide a rough measure of the conductivity of the ground.

Conductivity is a useful mapping in areas of residual overburden, as the variation in the concentration of secondary clay minerals, which is often characteristic of the primary lithology , leads to measurable variations in conductivity.

In areas of transported soil , conductivity can often provide a measure of water content, which may be an indirect aid in geologic mapping.

The more sophisticated EM instruments may be used to provide a rough indication of depth of weathering or depth of overburden. Such inform-ation can be very helpful in

interpreting magnetic and radiometric data as well as planning further exploration work.

EM methods also respond to structural features such as shear zones and faults particularly where these are water-filled or affected by clay- type alteration. Structural information of this type is often difficult to interpret by magnetic or radiometric means.

Prospecting by airborne EM for faults and Shears has become an accepted part of the search for several types of uranium deposit.

The association of uranium with faults in the Athabasca Basin of western Canada,the Arlet region of northern Niger and the Alligator river area of northern Australia, has led to the widespread use of EM methods for fault detection in such areas.

Orebody exploration

In recent years probably 50 percent of the expenditure has been directed towards direct or semi-dirct exploration for base metals, uranium ,iron and other specialized ore deposits.

The scale of such surveys varies in general from 1:20,000 to 1:50,000 deponding upon the particular target of interest.

1. Base Metals

The best- documented and probably the most sucsessful of the direct ore body detection methods

Is airborne electromagnetic, as applied to the search for massive sulphide deposits.

The writer (Pterson,1970) describes the applic-ation of this method, in Canada and provides the following breakdown of the sequence leading to the discovery of 16 massive sulphide ore bodies in the five year peroid 1955- 1959 (Table 2) .

Pemberton (1966) lists 95 worldwide geophysical discoveries, of which 39 were airborne and 20 by Airborne EM.

Table 2: breakdown statistics, Canada,1955-1959

Square miles surveyed*	**125,000 square miles EM**
Line miles	**500Line miles of EM**
EM anomalies Located	**100,000**
EM anomalies selected**	**10,000**
EM anomalies followed up on the ground	**3,000**
EM anomalies drilled	**1,000**
Sulphide bodies found	**0,800**
Potential ore bodies found	**16**

*** Include some areas flown more than once.**

**** Anomalies selected as probably significent by a process of**

interpretaion ..

A more recent analysis of the statistics of ore discovery by airborne EM from 1950- 1970 body was provided by the writer (Paterson 1972) which demonstrated that airborne EM had been primarily

responsible for the discovery of at least 19 base metal ore bodies in Canada at an average cost of less than S 1 million per mine.

Airborne EM has played an important role in the development of base metal mines with a grouth in mineral production in Canada including Cu, Zn, Pb and Ag Seigle (1980)

The airborne EM method depends upon the creation of an electromagnetic field by a transmitting coil located or suspended from an aircraft. This field energizes conducting bodies in the earth which, in turn, creats secondary fields which are detected by a receiving coil on or below the aircraft.

Since many geological materials besides massive sulphides bodies are good conductors, the succesful application of the method depends upon an ability to recognize significant anomalies within the background.

2. Iron – Titanium

Iron ore deposits containing magnetite may be traced directly with the airborne magnetometer, and in some cases

quantitative estimates can be made of tonnage, grade and dimensions.

iron ore exploration can be combined with geologic mapping, particularly if the target orebody is of adequate dimensions.

The airborne magnetometer has been used widely for the tracing of iron formation bands even when magnetite is only a minor constituent. In other cases, where magnetite is the primary ore mineral, structural mapping and grade and tonnage calculations have been possible.

Titaniferous magnetite in mineable concentration, is

detectable in the same way as magnetic iron. Ilmenite frequently found in association with titaniferous magnetite.

3. Radioactive minerals

The direct detection of uranium and thorium by airborne spectrometer surveys is a natural one, following from the ability of the spectrometer to recognize the different sources of gamma radiation.

The main restriction to the method is the blanketing effect of soil and water. In the higher latitudes snow creates a similar problem as illustrated in the following:

Several factors work in favour of direct detection of radioactive minerals even in soil covered areas:

*** Residual soil often contains radioelements derived by alteration from the primary radioactive minerals, soluble daughter products can migrate considerable distances giving rise to secondary gamma ray emitters. Radon gas is the most mobile of the daughter products.**

*** Radioactive boulders may be carried a surprising distance from their source by mechanical processes. In the Athabasca Basin , radioactive boulder trains have led to the discovery of uranium deposits buried more than 150 m below ground.**

Most uranium deposits occur in regions of above normal uranium enrichment.

*** Widely spaced (5 Km.) reconnaissance spectrometer surveys have been shown to indicate radioactive halos around the principle uranium areas in Canada.**

*** A well – executed uranium exploration program normally includes water or soil samplig for radon, and a careful screening of the anomalies against what is known of the geology and geomorphology.**

*** Ground follow-up is done by hand or vehicle- carried scintillometer or spectrometer, initially in the total count mode. The identification of the radioactive source, followed by rough field assay, is done by hand –held spectrometer.**

4. Mineralized intrusive rocks

Some types of intrusive rocks have a high proba- bability of containing certain economic minerals. Included are the following :

(Intrusive) : Alkalines (eg. Syenite, Carbonatite

Minerals: Niobium, nepheline, barite,uranium,

rare earths, vermiculite, corundum

(Intrusive): Granite (Certain ages and areas only)

Minerals: Tin, tungsten

(Intrusive): Kimberlite

Minerals Diamonds:

Some igneous rocks as serpentinite and dunite are hosts to asbestose, chrome, or mineable concen- trations of precious metals. The search of these intrusives follows the procedures outlined for geolo-gical mapping.

Important carbonatites and syenites have been detected geophysically in africa, north and south of America, soviet and elsewhere.

The average size of these bodies is of the order of 5 -15 Km2, so 1:100,1000 scale mapping with a line interval of 1 Km is adequate for their detection.

Tin – bearing granites, such as those in west America , the Sahara, Thailand, Bolivia, Indonesia and Europe, typically produce low magnetic and high radiometric responces, and can therefore be recognized both in areas of moderate or high magnetic relief, and in areas of low radiation background. The differentiation of such bodies from other non mineralized felsic plutons in a given area is aided by orientation surveys with high sensitivity spectrometer and magnetometer over known and barren bodies.

Tin and tundsten – bearing granites are generaly smaller in area than carbonatites, but a

1 Km line spacing is usually adequate for their primary recog-nition. Detailing at a 500 m spacing or less, may then be required.

Kimberlites provide a particularly attractive target for airborne geophysics, owing to certain characteri-stic properties that are nearly always present singly.

(Gerryts,1970; Paterson et al 1977)

<u>Firstly,</u> magnetite, as with other ultramafic bodies

is nearly always present in significant amounts. Typical magnetic anomalies vary from 50 to 200 gamma at a survey height of 150 m. In areas of sediments or weakly magnetic igneous rocks such anomalies are often easy to recognize because of their characteristic shapes and frequent associations with linear fracture systems.

In more magnetically disturbed areas (eg. Basalt, some biotite gneiss) and in areas cut by

recent dolerite intrusives recognition may be much more difficult.

Secondary characteristic of kimberlites noted by (Paterson 1977, and Heinrich,1977), is the high potassium (K40) radioactivity over some diatremes.

This probably results from the mineral phlogopite which is one of the constituents of Kimberlite. Moderate uranium and Thorium counts have also been recorded, with the result that the gamma ray signature can often be distinguished from that of felsic plutons (typically high k, low U and Th) and most mafic plutons (typically low K, U and Th). Large detector volumed are necessary to make this effective.

A third airborne approach to Kimperlite exploration is based on locally high conductivity of the alluvium formed by the surface weathering of the pipe.

II. Exploration Geochemistry

Geochemistry is now used in virtually every exploration program, if only to determine the grade of material to be mined. However exploration geochemistry has evolved from its early origins in assaying, to using the chemistry of the environment surrounding a deposit in order to locate it.

This particularly applies to the use of surficial material, such as soil, till, or vegetation, that can be used in areas where there is little outcrop. The object is to define a geochemical anomaly which distinguishes the deposit from enhancements in background and non significant deposits. The chapter explains how geochemistry may be employed in the search for mineral deposits. Exploration geologists are likely to be more directly involved in geochemistry than with geophysics which is usually conducted by contractors and supervised by specialist geophysicists.

A geochemical program can be divided into the following phases:

1 Planning;

2 Sampling;

3 Chemical analysis;

4 Interpretation;

5 Follow-up.

The field geologist will probably carry out phases 1, 2, 4, and 5, while analysis is normally performed by a commercial laboratory.

1. PLANNING

The choice of the field survey technique and the analytical methods depends on the
commodity sought and its location. In the same way as geological and grade–tonnage models are generated (see section 4.1.3) modeling cabe extended to include geochemical factors, summarized in Barton (1986).

Thus the geologist will start with :

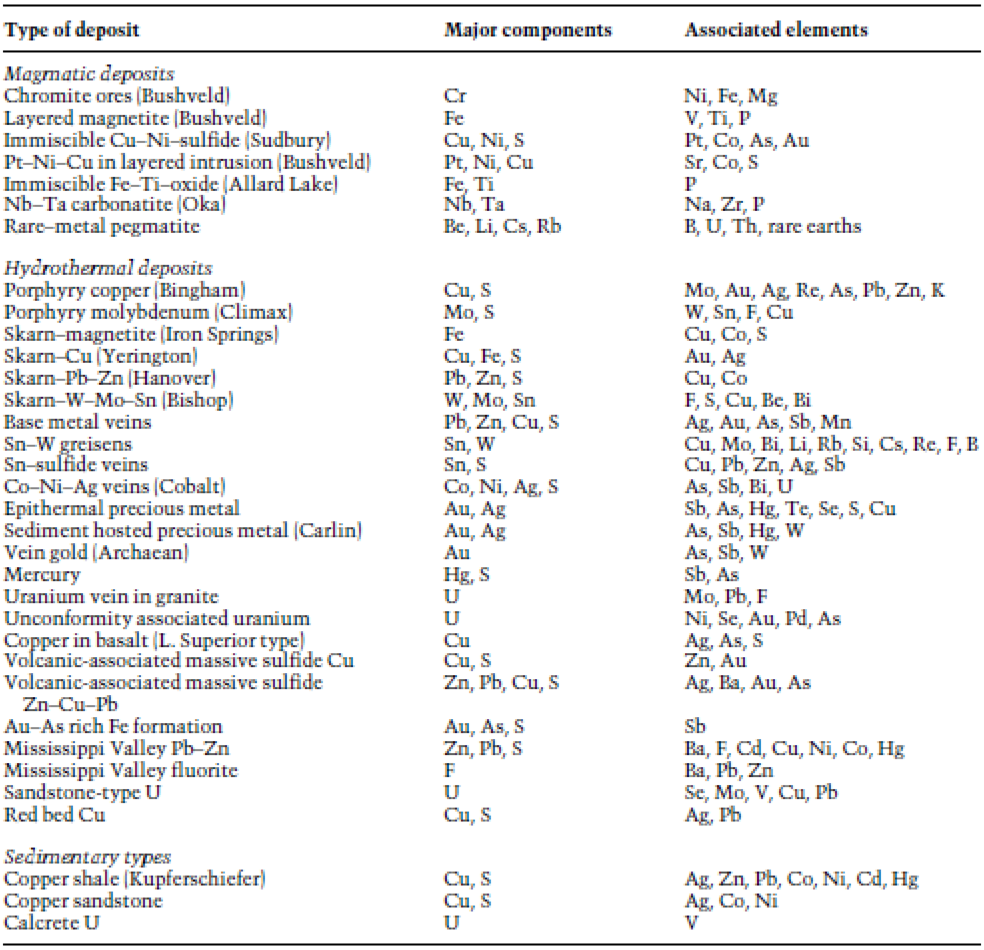
- A knowledge of the elements associated with a particular deposit type,
- An idea of the economic size of the deposit to be sought,
- The mineralogical form of the elements, and
- The probable size of the elemental anomalies around it.

The outline of a deposit is defined by economic criteria and the mineable material is surrounded by lower concentrations of the mined elements which are however substantially enriched compared with unmineralized rock. This area of enrichment is known as the ***primary halo***, by analogy with the light surrounding the outline of the moon, and the process of enrichment as ***primary dispersion*****.**

In addition ore-forming processes concentrate or deplete elements other than those mined. For example, massive sulfide deposits often contain substantial arsenic and gold in addition to the copper, lead, and zinc for which they are mined. A summary of typical elemental associations is shown in Table.1.

The geologist's problem is then to adapt this knowledge of primary concentration to the exploration area. The geochemical response at the surface depends on the type of terrain and especially on the type of material covering the deposit as shown in Fig. 1. The response in an area of 2 m of residual overburden is very different from that of an area with 100 m deep cover, or if the overburden has been transported. Also elements behave differently in the near-surface environment from that in which the deposit formed. For example, in cases where copper, lead, and zinc are associated in volcanic associated massive sulfide deposits, zinc is normally more mobile in the surface environment than copper and much more so than lead. Lead is more likely to be concentrated immediately over the deposit, as it is relatively insoluble, whereas zinc will move or disperse from the deposit.

TABLE 8.1 Elemental associations and associated elements (pathfinders) useful in exploration. (Largely from Rose et al. 1979 with some data from Beus & Grigorian 1977, p. 232, and Boyle 1974.)



Type of deposit	Major components	Associated elements
Magmatic deposits		
Chromite ores (Bushveld)	Cr	Ni, Fe, Mg
Layered magnetite (Bushveld)	Fe	V, Ti, P
Immiscible Cu–Ni–sulfide (Sudbury)	Cu, Ni, S	Pt, Co, As, Au
Pt–Ni–Cu in layered intrusion (Bushveld)	Pt, Ni, Cu	Sr, Co, S
Immiscible Fe–Ti–oxide (Allard Lake)	Fe, Ti	P
Nb–Ta carbonatite (Oka)	Nb, Ta	Na, Zr, P
Rare-metal pegmatite	Be, Li, Cs, Rb	B, U, Th, rare earths
Hydrothermal deposits		
Porphyry copper (Bingham)	Cu, S	Mo, Au, Ag, Re, As, Pb, Zn, K
Porphyry molybdenum (Climax)	Mo, S	W, Sn, F, Cu
Skarn–magnetite (Iron Springs)	Fe	Cu, Co, S
Skarn–Cu (Yerington)	Cu, Fe, S	Au, Ag
Skarn–Pb–Zn (Hanover)	Pb, Zn, S	Cu, Co
Skarn–W–Mo–Sn (Bishop)	W, Mo, Sn	F, S, Cu, Be, Bi
Base metal veins	Pb, Zn, Cu, S	Ag, Au, As, Sb, Mn
Sn–W greisens	Sn, W	Cu, Mo, Bi, Li, Rb, Si, Cs, Re, F, B
Sn–sulfide veins	Sn, S	Cu, Pb, Zn, Ag, Sb
Co–Ni–Ag veins (Cobalt)	Co, Ni, Ag, S	As, Sb, Bi, U
Epithermal precious metal	Au, Ag	Sb, As, Hg, Te, Se, S, Cu
Sediment hosted precious metal (Carlin)	Au, Ag	As, Sb, Hg, W
Vein gold (Archaean)	Au	As, Sb, W
Mercury	Hg, S	Sb, As
Uranium vein in granite	U	Mo, Pb, F
Unconformity associated uranium	U	Ni, Se, Au, Pd, As
Copper in basalt (L. Superior type)	Cu	Ag, As, S
Volcanic-associated massive sulfide Cu	Cu, S	Zn, Au
Volcanic-associated massive sulfide Zn–Cu–Pb	Zn, Pb, Cu, S	Ag, Ba, Au, As
Au–As rich Fe formation	Au, As, S	Sb
Mississippi Valley Pb–Zn	Zn, Pb, S	Ba, F, Cd, Cu, Ni, Co, Hg
Mississippi Valley fluorite	F	Ba, Pb, Zn
Sandstone-type U	U	Se, Mo, V, Cu, Pb
Red bed Cu	Cu, S	Ag, Pb
Sedimentary types		
Copper shale (Kupferschiefer)	Cu, S	Ag, Zn, Pb, Co, Ni, Cd, Hg
Copper sandstone	Cu, S	Ag, Co, Ni
Calcrete U	U	V

This process of movement away from the primary source is termed ***secondary dispersion*** and it can also be effected by mechanical movement of fragments under gravity, movement as a gas, or diffusion of the elements in the form of ions as well as movement in solution.

The background levels of an element in rocks and soils also have to be considered when trying to find secondary dispersion from deposits. All elements are present in every rock and soil sample; the concentration will depend on the mode of formation of the rock and the process forming the soil. Indications of background levels of elements in soils are given in Table 8.2.

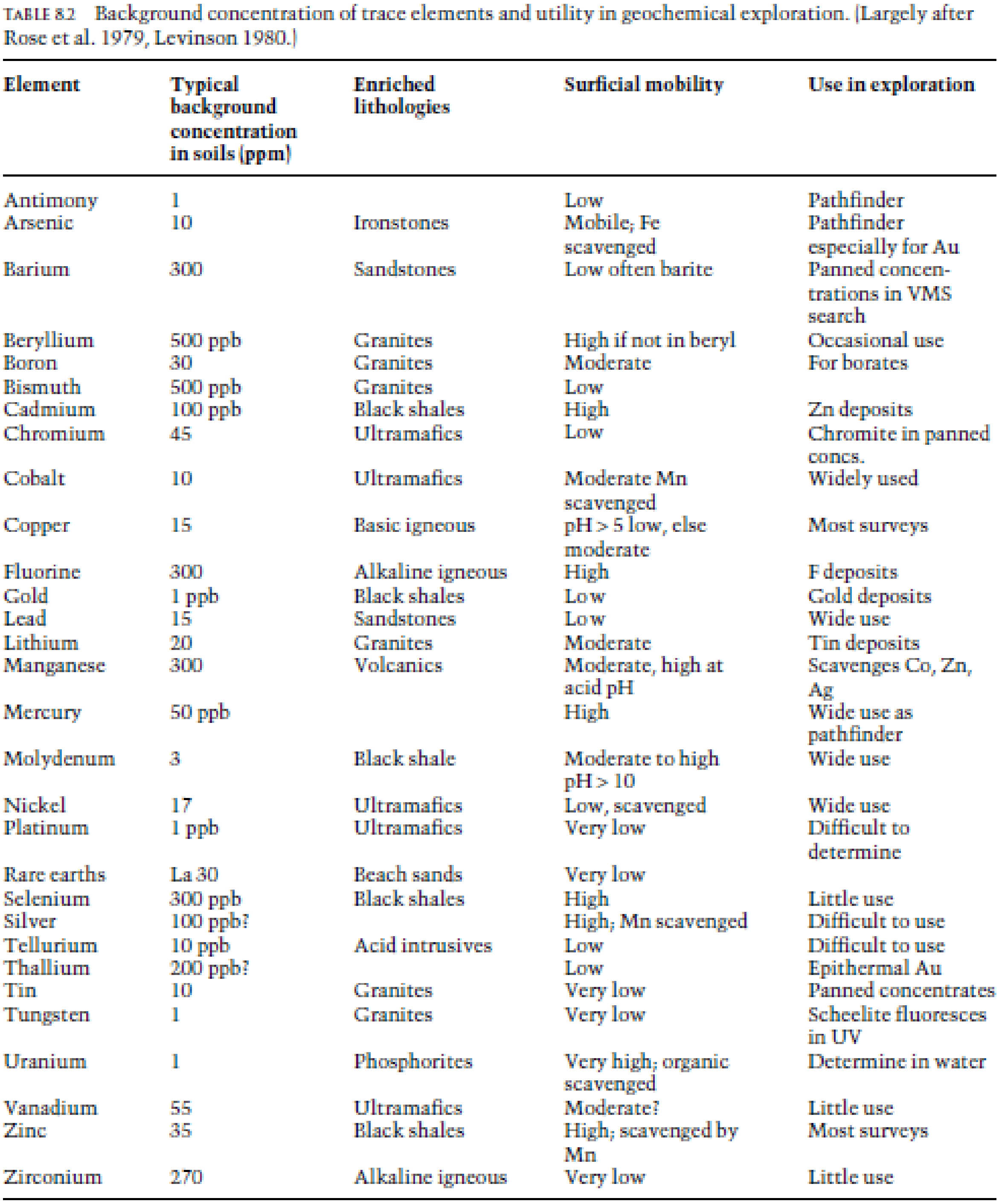


TABLE 8.2 Background concentration of trace elements and utility in geochemical exploration. (Largely after Rose et al. 1979, Levinson 1980.)

Element	Typical background concentration in soils (ppm)	Enriched lithologies	Surficial mobility	Use in exploration
Antimony	1		Low	Pathfinder
Arsenic	10	Ironstones	Mobile; Fe scavenged	Pathfinder especially for Au
Barium	300	Sandstones	Low often barite	Panned concentrations in VMS search
Beryllium	500 ppb	Granites	High if not in beryl	Occasional use
Boron	30	Granites	Moderate	For borates
Bismuth	500 ppb	Granites	Low	
Cadmium	100 ppb	Black shales	High	Zn deposits
Chromium	45	Ultramafics	Low	Chromite in panned concs.
Cobalt	10	Ultramafics	Moderate Mn scavenged	Widely used
Copper	15	Basic igneous	pH > 5 low, else moderate	Most surveys
Fluorine	300	Alkaline igneous	High	F deposits
Gold	1 ppb	Black shales	Low	Gold deposits
Lead	15	Sandstones	Low	Wide use
Lithium	20	Granites	Moderate	Tin deposits
Manganese	300	Volcanics	Moderate, high at acid pH	Scavenges Co, Zn, Ag
Mercury	50 ppb		High	Wide use as pathfinder
Molydenum	3	Black shale	Moderate to high pH > 10	Wide use
Nickel	17	Ultramafics	Low, scavenged	Wide use
Platinum	1 ppb	Ultramafics	Very low	Difficult to determine
Rare earths	La 30	Beach sands	Very low	
Selenium	300 ppb	Black shales	High	Little use
Silver	100 ppb?		High; Mn scavenged	Difficult to use
Tellurium	10 ppb	Acid intrusives	Low	Difficult to use
Thallium	200 ppb?		Low	Epithermal Au
Tin	10	Granites	Very low	Panned concentrates
Tungsten	1	Granites	Very low	Scheelite fluoresces in UV
Uranium	1	Phosphorites	Very high; organic scavenged	Determine in water
Vanadium	55	Ultramafics	Moderate?	Little use
Zinc	35	Black shales	High; scavenged by Mn	Most surveys
Zirconium	270	Alkaline igneous	Very low	Little use

These background levels can be of use in preparing geochemical maps which can be used to infer lithology in areas of poor outcrop. The reader is advised to get some idea of the background variation over ordinary rock formations from a geochemical atlas, such as those for England and Wales (Webb et al. 1978),Alaska (Weaver et al. 1983), the former West Germany (Fauth et al. 1985), and Europe (Salmimen et al. 2004).

The basis of a geochemical program is a systematic sampling program (Thomson 1987) and thus decisions must be made in a cost-effective manner as to the material to be sampled, the density of sampling, and the analytical method to be employed. **Cost/benefit** ratios should be considered carefully as it may be that a slightly more expensive method will be the only effective technique. The material to be sampled will largely be determined by the overburden conditions but the density and exact nature of the sample will be based either on previous experience in the area or, if possible, on an orientation survey.

Orientation surveys

One of the key aspects of planning is to evaluate which techniques are effective for the commodity sought and in the area of search. This is known as an orientation survey. The best orientation survey is that in which a variety of methods is tested over a prospect or deposit of similar geology to the target and in similar topogra-phical conditions to determine the method which yields the best results.

A checklist for an orientation study is given below (Closs& Nichol 1989):

1 - Clear understanding of target deposit type;

2 - Understanding of surficial environment of the search area;

3 Nature of primary and secondary dispersion from the mineralisation;

4 Sample types available;

5 Sample collection procedures;

6 Sample size requirements;

7 Sample interval, orientation, and areal density;

8 Field observations required;

9 Sample preparation procedures;

10 Sample fraction for analysis;

11 Analytical method required;

12 Elemental suite to be analyzed;

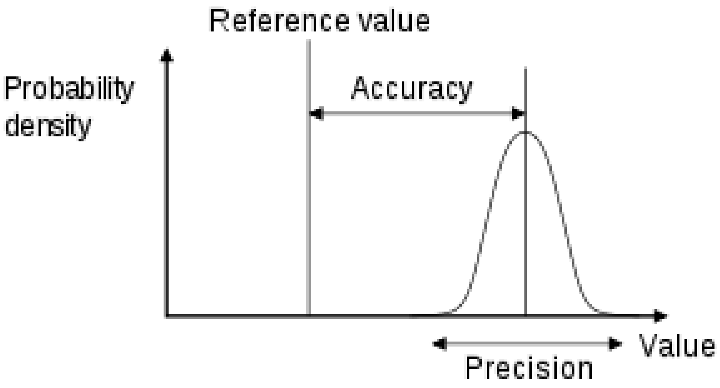
13 Data format for interpretation.

The relatively small cost involved in undertaking an orientation survey compared with that of a major geochemical survey is always justified and whenever possible this approach should be used. However, if a physical orientation survey is not possible, then a thorough review of the available literature and discussion with geochemical experts is a reasonable alternative option.

1.2 . ANALYSIS

As the geologist generally sees little of the process of analysis, which is usually done at some distance from the exploration project, analytical data tend to be used uncritically. While most laboratories provide good quality data they are usually in business to make a profit and it is up to the geologist to monitor the quality of data produced and investigate the appropriateness of the analytical methods used.

Accuracy and precision



Accuracy is the proximity of measurement results to the true value; precision, the repeatability, or reproducibility of the measurement.

In the fields of science, engineering and statistics, the accuracy of a measure-ment system is the degree of closeness of measurements of a quantity to that quantity's true value.The precision of a measurement system, related to reproduc-ibility and repeatability, is the degree to which repeated measurements under unchanged conditions show the same results.

A measurement system is considered *valid* if it is both ***accurate*** and ***precise***.A measurement system can be accurate but not precise, precise but not accurate, neither, or both. For example, if an experiment contains a systematic error, then increasing the sample size generally increases precision but does not improve accuracy.

The critical question for the geologist is how reproducible the analysis is and how representative of the “correct” concentration the concentration is, as shown in Fig. 8.2. The reproducibility of an analysis is termed the precision and its relation to the expected or consensus value the accuracy. For most purposes in exploration geochemistry it is vitally important that an analysis is precise but the accuracy is generally not so crucial, although some indication of the accuracy is needed.

At the evaluation stage the analyses must be precise and accurate. The measurement of accuracy and precision requires careful planning and an understanding of the theory involved.

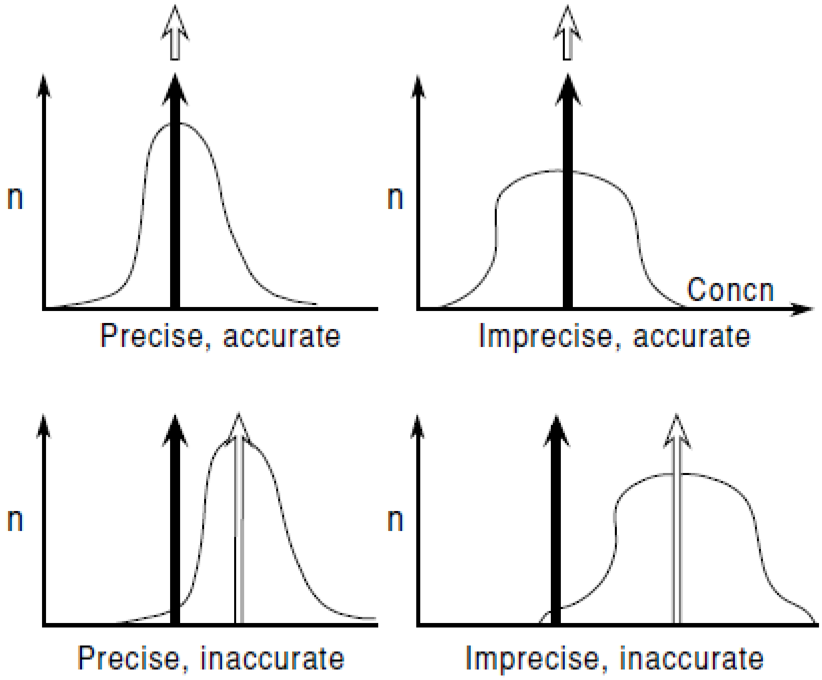


FIG. 8.2 Schematic representation of precision and accuracy assuming normal distribution of analytical error.

A number of schemes have been devised but the most comprehensive is that of Thompson(1982). Precision is measured by analyzing samples in duplicate whereas accuracy requires the analysis of a sample of known composition, a reference material. The use of duplicate samples means that precision is monitored across the whole range of sample compositions. Reference materials can be acquired commercially but they are exceedingly expensive(>US$100 per 250 g).

Sample collection and preparation:

Samples should be collected in non metallic containers to avoid contamination. Kraft paper bags are best suited for sampling soils and stream sediments because the bags retain their strength if the samples are wet and the samples can be oven dried without removing them from their bags. Thick gauge plastic or cloth are preferred for rock samples. All samples should be clearly labeled by pens contain-ning nonmetallic ink.

Most sample preparation is carried out in the field, particularly when it involves the collection of soils and stream sediments. The aim of the sample preparation is to reduce the bulk of the samples and prepare them for shipment. Soils and stream sediments are generally dried either in the sun, in low temperature ovens, or freeze dried; the temperature should be below65°C so that volatile elements such as mercury are not lost. Drying is generally followed bygentle disaggregation and sieving to obtain the desired size fraction.

Care should be taken to avoid the use of metallic materials and to avoid carryover from highly mineralized to background samples. Preparation of rocks and vegetation is usually carried out in the laboratory and care should be taken in the selection of crushing materials. For example, in a rock geochemical program a company searching for volcanic-associated massive sulfides found manganese anomalies associated with a hard amphibolite. They were encouraged by this and took it as a sign of exhalative activity. Unfortunately further work showed that the manganese highs were related to pieces of manganese steel breaking off the jaw crusher and contaminating the amphibolite samples.

Other less systematic variation can be caused by carryover from high grade samples, for example not cleaning small grains of mineralized vein material (e.g. 100,000 ppb Au) will cause significant anomalies when mixed with background

(1 ppb Au) rock. Contamination can be eliminated by cleaning crushing equipment thoroughly between samples and by checking this by analyzing materials such as silica sand.

2.3 Analytical methods

Most analysis is aimed at the determination of the elemental concentrations in a sample and usually of trace metals. At present it is impossible to analyze all elements simultaneously at the required levels, so some compromises have to be made (Fig.3). In exploration for base metals it is usual to analyze for the elements sought, e.g. copper in the case of a copper deposit. With modern techniques it is often possible to get 20–30 extra elements, including some that provide little extra information but a lot of extra data for interpretation . The major methods are as shown in Table 3.

The differences between the methods shown are cost, the detection limits of analysis, speed of analysis, and the need to take material into solution.

* Most general analysis in developed countries is carried out by inductively coupled plasma emission spectrometry (ICP–ES), often in combination with inductively coupled plasma mass spectrometry (ICP–MS), or X-ray fluorescence (XRF). All three methods require highly sophisticated laboratories, pure chemicals, continuous, non fluctuating power supplies, and readily available service personnel, eatures not always present in developing countries.

* In less sophisticated environments, high quality analysis can be provided by atomic absorption spectrophotometry (AAS), which was the most commonly used

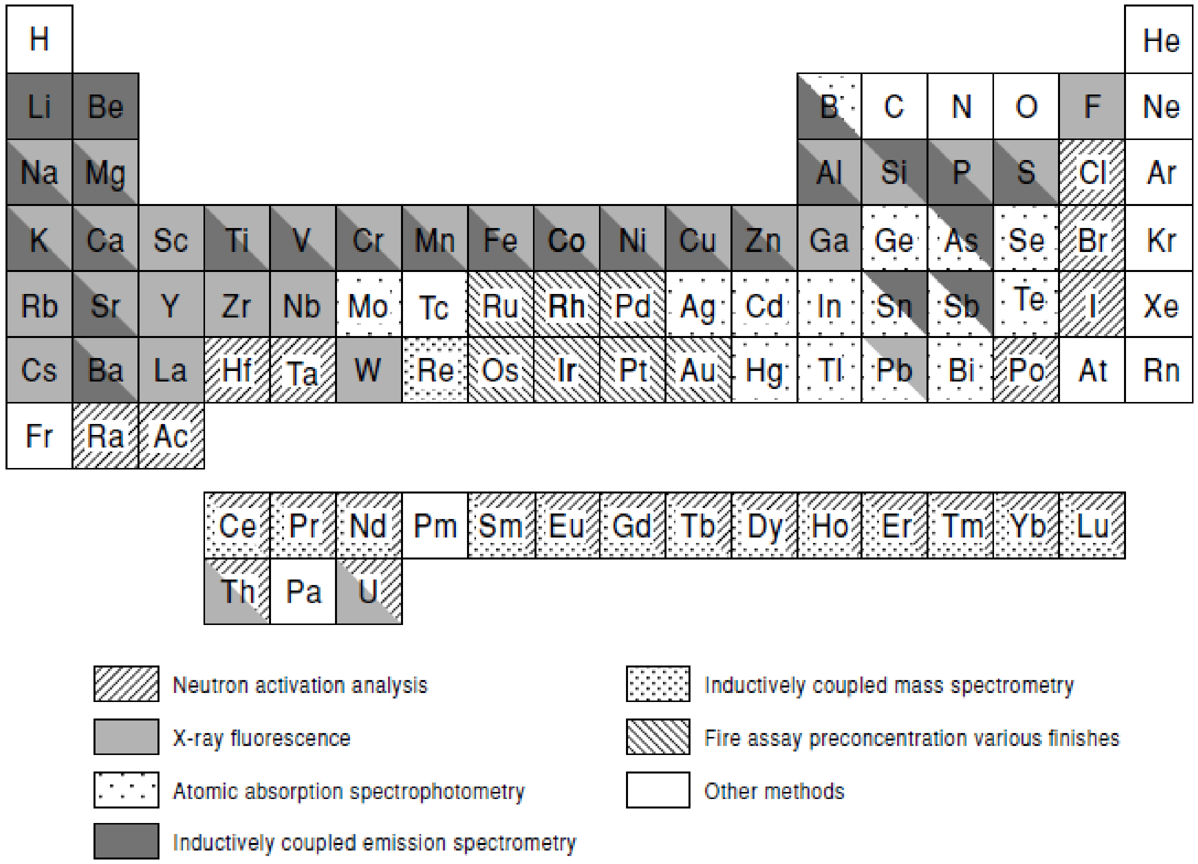


FIG. 8.3 Summary periodic table showing cost-effective methods of elemental analysis at levels encountered in background exploration samples.

TABLE 8.3 Summary of the main methods used in exploration geochemistry.

Method	Capital cost $ (approx.)	Multielement	Precision	Sample type ($US)	Cost per	comments sample
Colorimetry	8000	No	Poor	Solution	2–10	Good for field use and W, Mo
Atomic absorption spectrophotometry	60,000	No	Good	Solution	1–5	Cheap and precise
X-ray fluorescence	200,000	Yes	Good	Solid	20	Good for refractory elements
ICP–ES	150,000	Yes	Good	Solution	10	Good for transition metals
ICP–MS	150,000–1000,000	Yes	Good	Solution	10	Good for heavy metals. High resolution instruments very low detection limits

method indeveloped countries until about 1980. Anothermethod which is widely used in industry isneutron activation analysis (NAA) but its useis restricted to countries with cheap nuclearreactor time, mainly Canada.

* Precious metals (gold and platinum group elements) have been extremely difficult to determine accurately at background levels. The boom in precious metal explora-tion has, however, changed this and commercial laboratories are able to offer inexpensive gold analysis at geochemical levels (5 ppb to 1 ppm) using solvent extraction and AAS, ICP–ES or alternatively NAA on solid samples.

The analysis of precious metals is differentfrom most major elements and base metals inthat large subsamples are preferred to overcomethe occurrence of gold as discrete grains. Typically30 or 50 g are taken in contrast to 0.25–1 gfor base metals; in Australia, 8 kg are oftenleached with cyanide to provide better sampling
Statistics.

* Isotopic analysis is not yet widely used inexploration although some pilot studies, suchas that of Gulson (1986), have been carriedout. The main reason for this is the difficultyand cost of analysis.

* Most rock analysis uses total analysis by XRFor by ICP–ES/ICP–MS following a fusion ornitric–perchloric–hydrofluoric acid attack.

3- INTERPRETATION

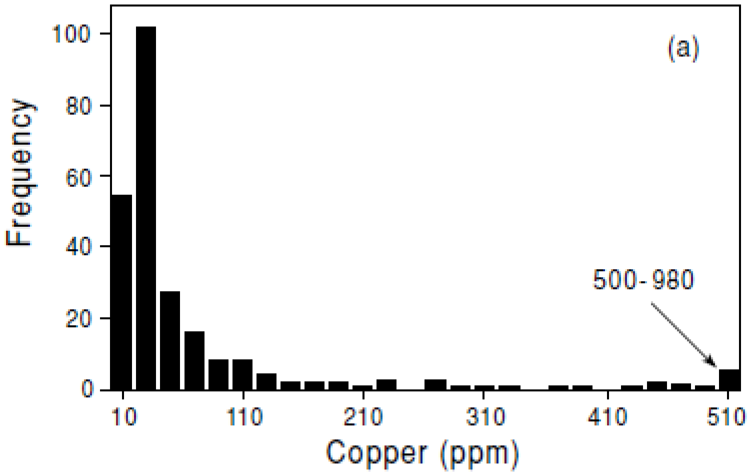
Once the analytical data have been received from the laboratory and checked for precisionand accuracy, the question of how the data istreated and interpreted needs to be addressed.As the data are likely to be multi-element and there are likely to be a large number of samplesthis will involve the use of statistical analysison a computer. It is recommended that the dataare received from the analyst either in the formof a floppy disk, CD-ROM, or over the Internet.

Re-entering data into a computer from a papercopy is expensive and almost certain to introducemajor errors. Normally the data will betransferred into an electronic database (seesection 9.1) to allow easy access or, in the caseof small data sets stored in a spreadsheet.

3.1 Statistics

The object of geochemical exploration is todefine significant anomalies. In the simplestcase these are the highest values of the elementsought but they could be an elementalassociation reflecting hydrothermal alterationor even element depletion. Anomalies are defined by statistical grouping data andcomparing these with geology and samplinginformation. Normally this grouping will beundertaken by computer and a wide variety ofstatistical packages are available; for micro-computers,one of MINITAB, SYSTAT, andSTATISTICA is recommended at a cost of$US200–500 each.

The best means of statistically grouping datais graphical examination using histograms and thisis coupled with description using measures ofcentral tendency (mean or median) and of statistical dispersion (e.g standard deviation).



The relationship of the groups toother elemental data should then be examined

by plotting and calculating the correlationmatrix for the data set. (Fig. 8.6) shows a strong correlation (0.765)between copper and silver (Fig. 8.6) which reflectsthe close primary association betweenthe two elements, whereas the correlationbetween copper and lead is low (0.12) reflectingthe spatial displacement of galena veins from chalcopyrite. If geological or samplingdata are coded it will be possible to comparethese groups with that information.

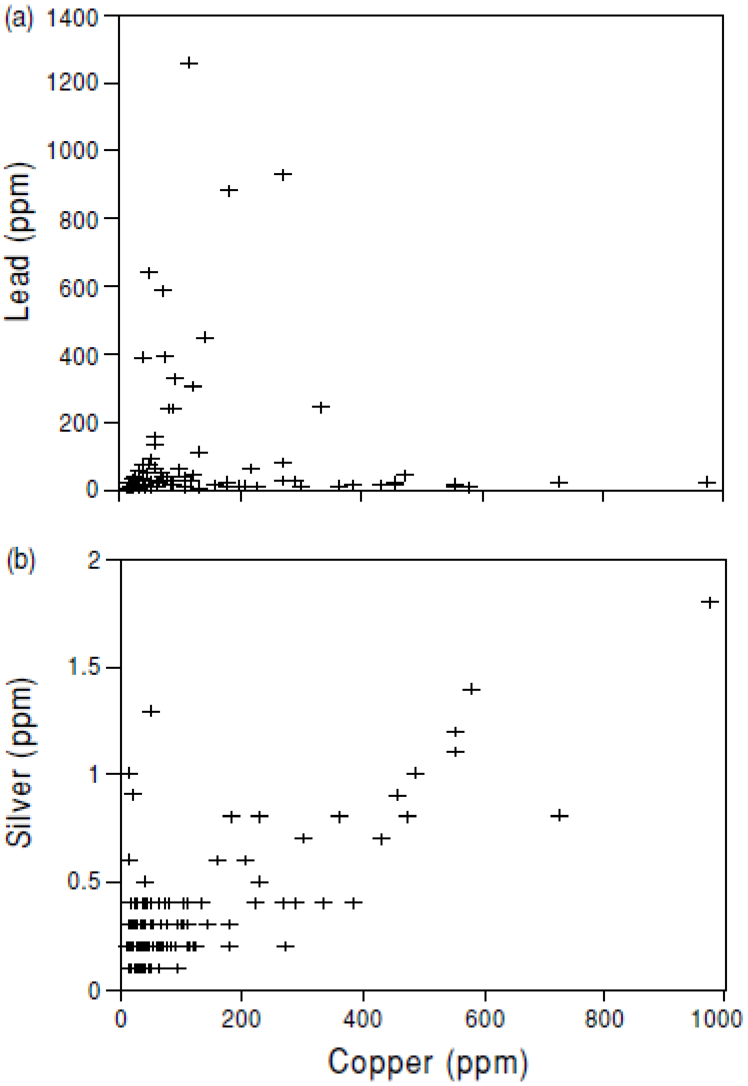


FIG. 8.6 Scatter plots of Daisy Creek data showing (a) the strong correlation of copper and silver and (b) the lack of correlation of lead and copper.

The spatial distribution of the data mustthen be examined by plotting elemental datausing the intervals that delineate the groups orby plotting the data by percent-tiles (percentageof data sorted into ascending order); 50, 75, 90, 95 are recommen-dedforelements that are enriched (see Fig. 9.8).

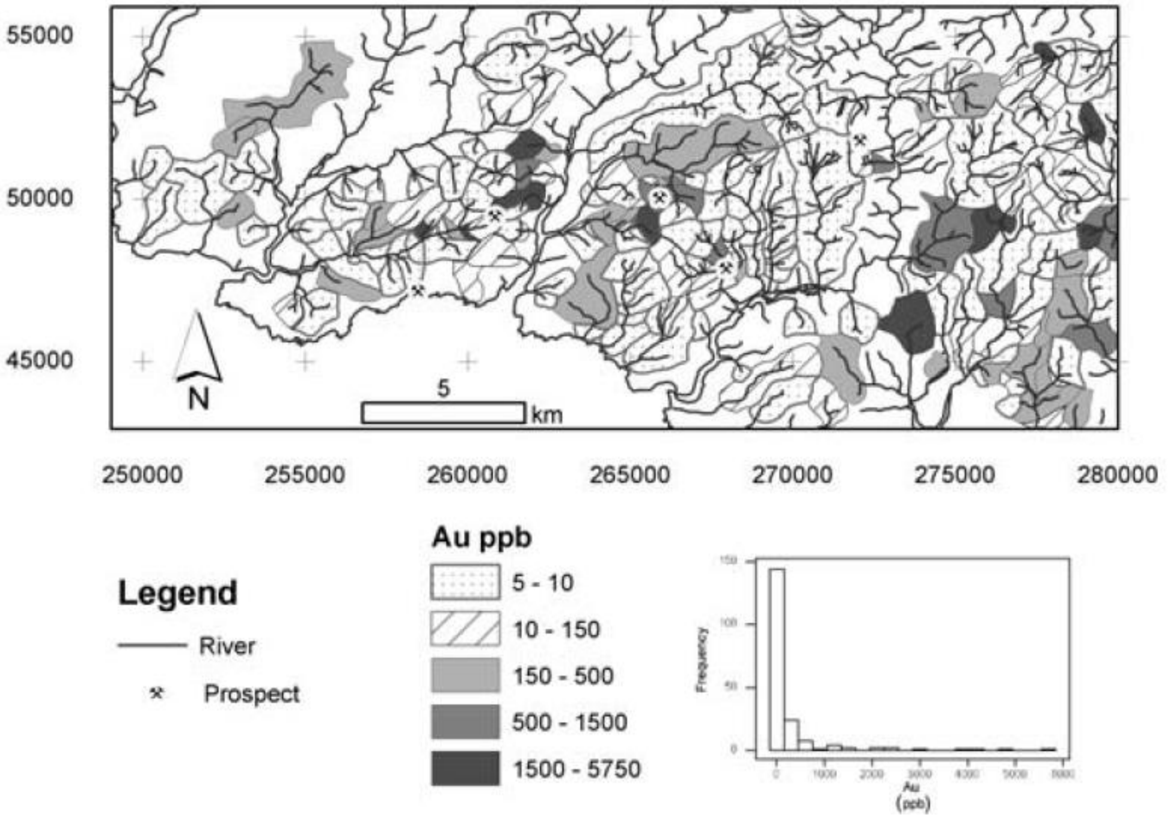


FIG. 9.8 Panned concentrate gold data in ppb. Intervals are approximately 50, 75, 90, and 95 percentiles, as discussed in the text. (Data courtesy British Geological Survey but converted into
their catchments (drainage basins) by C.L. Wang.)

Geologists are used to thinking in termsof maps and the most useful end product tocompare geochemical data with geology andgeophysics is to summarize the data in mapform using a gridding or GIS package suchasGeosoft Oasis Montaj, ArcView, or MapInfo(see section 9.2).
However, some care shouldbe taken with the preparation of these maps asit is extremely easy to prejudice interpretationand many maps in the literature do not reflectthe true meaning of the data but merely theeasiest

way of representing it. If the data reflectthe chemistry of an area, such as a catchment,it is best if the whole area is shaded with anappropriate color or tone, rather than contouring(e.g. Figs 8.8, 9.8). Data which essentiallyrepresent a point can be plotted by posting thevalue at that point or if there are a lot of databy representing them by symbols, which areeasier to interpret. Typical symbols are givenbyHowarth (1982). A more usual method ofpresentation if the samples were collected ona grid is to present the data as a contour plotusing the intervals from a histogram (Figs 8.7,8.4). Plots are best colored from blue to greento yellow to red – cold to hot, as an indicationof low to high concentrations.

The combined statistical analysis and elementmapping is used to define areas of interestwhich need to be investigated in detail,using detailed geology, topography samplinginformation, and, probably, a return to the site.These areas can be classified as to their suggestedorigin, seepage, and precipitation fromlocalgroundwaters, from transported material,or probable residual anomalies. The aim mustbe to provide a rational explanation for thechemistry of all the areas of interest and notmerely to say that they are of unknown origin.

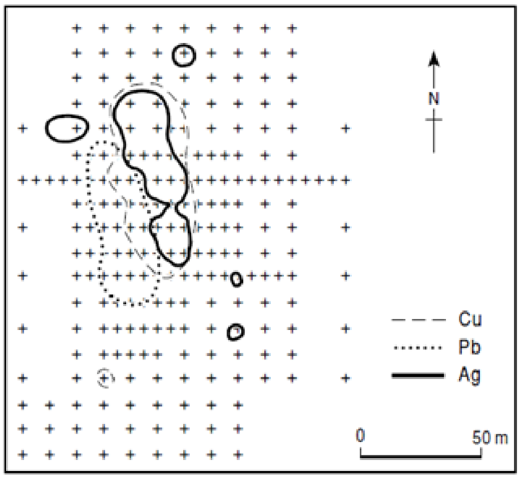


FIG. 8.7 Contour plot of Daisy Creek data showing the highest anomalous populations for copper (>128 ppm), lead (>69 ppm), and silver (>0.55 ppm). The relative size and relative positions of the anomalous areas reflect the primary zoning in the underlying prospect. (From Sinclair 1991.)

4. **RECONNAISSANCE TECHNIQUES**

The application of these techniques has beendiscussed in section 4.2.2 but the actualmethod to be used depends on the origin of theoverburden. If it is residual, i.e. derived fromthe rock underneath, the problem is relativelystraightforward but if the overburden is exotic,i.e. transported, then different methods must beused.

A summary of the application of variousgeochemical techniques is given in Table 8.4.

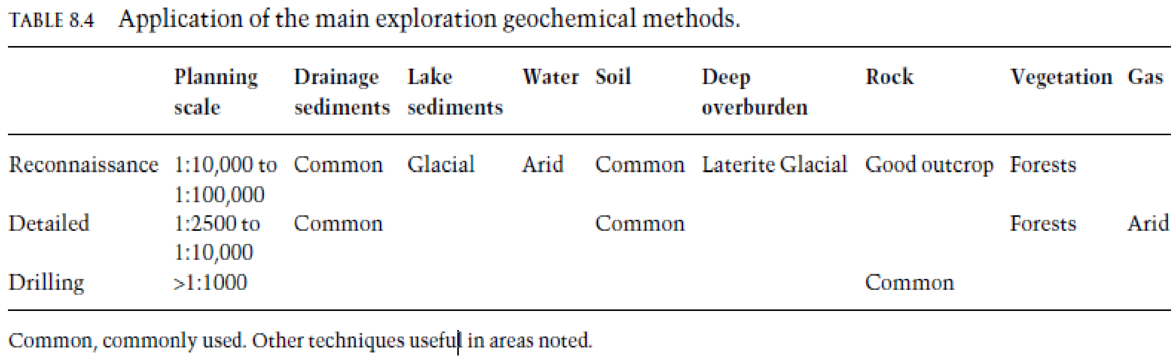


TABLE 8.4 Application of the main exploration geochemical methods.

	Planning scale	Drainage sediments	Lake sediments	Water	Soil	Deep overburden	Rock	Vegetation	Gas
Reconnaissance	1:10,000 to 1:100,000	Common	Glacial	Arid	Common	Laterite Glacial	Good outcrop	Forests	
Detailed	1:2500 to 1:10,000	Common			Common			Forests	Arid
Drilling	>1:1000						Common		

Common, commonly used. Other techniques useful in areas noted.

The most widely used reconnaissancetechnique in residual areas undergoing activeweathering is stream sediment sampling, theobject of which is to obtain a sample that isrepresentative of the catchment area of thestream sampled. The active sediment in thebed of a river forms as a result of the passage ofelements in solution and in particulate formpast the sampling point. Thus a sample can be

regarded as an integral of the element fluxes.The simplicity of the method allows the rapidevaluation of areas at relatively low cost. Interpretationof stream sediment data is carried outby comparing the elemental concentrations ofcatchments, as there is only a poorly defined relationshipbetween the chemistry of the streamsediment and the chemistry of the catchmentfrom which it is derived. The simple mass balancemethod put forward by Hawkes (1976),that relates the chemistry of anomalous soilsto that of stream sediments, works in tropicalareas of intense weathering but requires modificationby topographical and elementalfactorsin other areas (Solovov 1987, Moon 1999).

In stream sediment sampling the wholestream sediment or a particular grain size ormineralogical fraction of the sediment, such asa heavy mineral concentrate, can be collected.

In temperate terrains maximum anomaly/background contrast for trace metals isobtained in the fine fraction of the sediments asthis contains the majority of the organic material,clays, and iron and manganese oxides. Thecoarser fractions including pebbles are generallyof more local origin and depleted in traceelements.

Usually the size cut-off is taken at80 mesh (<177 μm). However, the grain size givingbest contrast should be determined by anorientation survey. For base metal analysis andgeochemical mapping a 0.5 kg sample is sufficientbut a much larger sample is requiredfor gold analysis due to the very erratic distributionof gold particles. A number of authors(Gunn 1989, Hawkins 1991, Akçay et al. 1996)have collected 8–10 kg of −2 mm material andcarefully subsampled this using methods suchas automated splitting (section 10.1.4).

The most common sample collectionmethod is to take a grab sample of active stream sediment at the chosen location. Thisis best achieved by taking a number of subsamplesover 20–30 m along the stream and atdepths of 10–15 cm to avoid excessive iron andmanganese oxides. Care must be taken, if a finefraction is required, that sufficient sample iscollected. In addition contamination shouldbe avoided by sampling upstream from roads,farms, factories, and galvanized fences. Anyold mine workings or adits should be carefullynoted as the signature from these will masknatural anomalies. Most surveys use quite adense sample spacing such as 1 km−2 but thisshould be determined by an orientation survey.

The main mistake to avoid is sampling largerivers in which the signature from a depositis diluted.

An alternative approach used by geologicalsurveys, for example the British GeologicalSurvey, is to sieve the samples in the fieldusing a minimum of water.

The advantages of this are that it is certain that enough finefraction is collected and samples are easier tocarry in remote areas. It also seems that thesamples are more representative but the costefficiency of this in small surveys remains tobe demon-strated. A full review of the use ofregional geochemical surveys is given in Haleand Plant (1994) and useful discussion inFletcher (1997).

An example of a stream sediment survey ishown in Fig. 8.8. The object was to define further mineralisation in an area of Besshi style massive sulfide minera-lisation and the copperdata is shown in the figure.

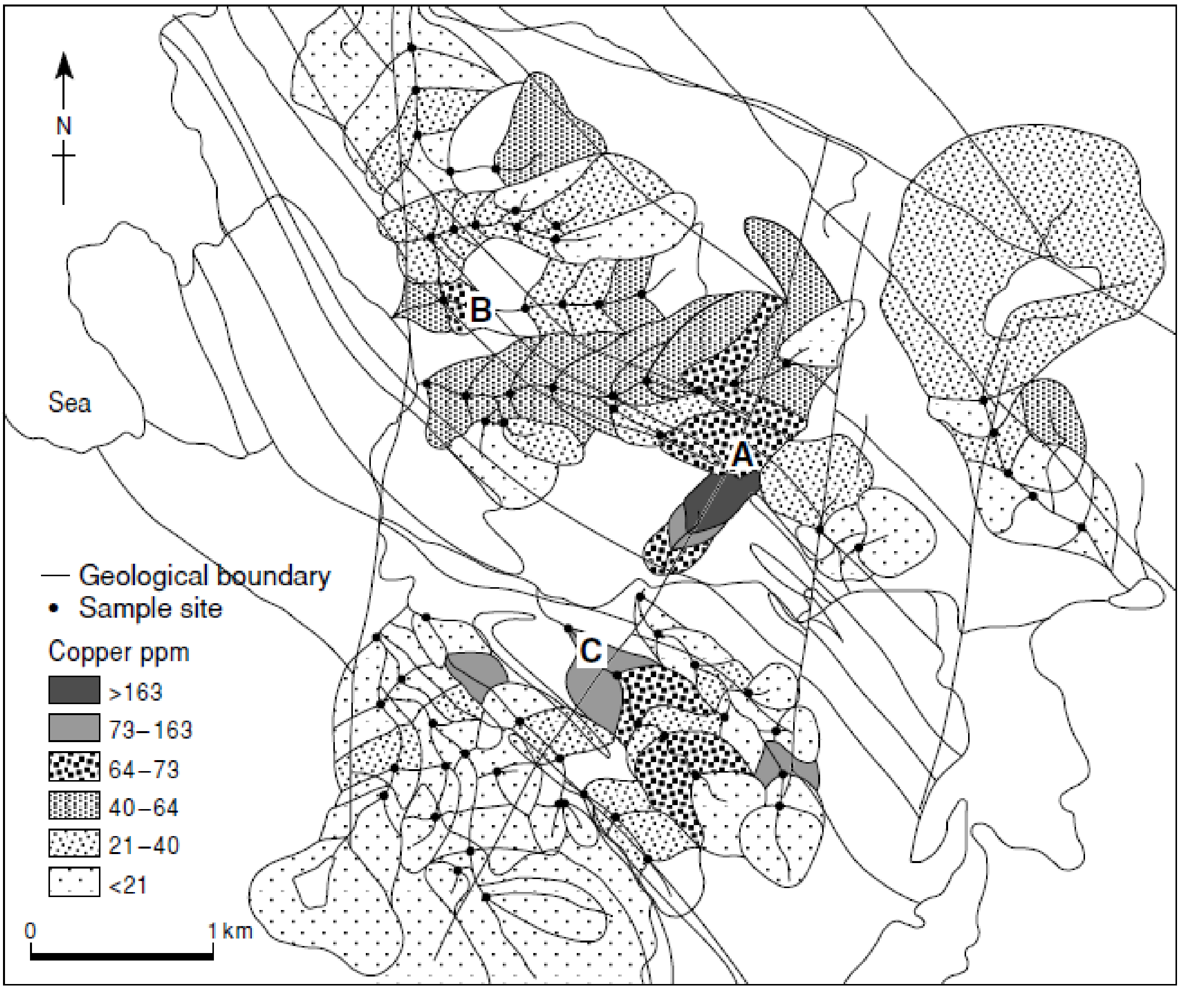


FIG. 8.8 Stream sediment survey of part of the Gairloch area, Wester Ross, NW Scotland.

The survey, which was designed to follow up known mineralisation (A), detected further anomalies along strike (B) and disseminated mineralisation at C. The analytical method was ICP–ES following a HNO3–HClO4 digestion.

The area sampled consists of interbedded units of amphibolites and mica schist, within which a deposit had been drilled at point A. The area suffers very high rainfall and much precipitation of iron and manganese; as a result dispersion trains are very short, of the order of 200 m, as shown by an orientation survey. Thus the regional survey was conducted at very close-spaced intervals.However, the deposit is clearly detected and other prospects were defined along strike from the deposit (point B) and disseminated chalcopyrite was found at C.

Heavy mineral concentrates have been widely used as a means of combating excessive dilution and of enhancing weak signals. The method is essentially a quantification of thegold panning method, which separates grainson the basis of density differences. Panningin water usually separates discrete minerals with a density of greater than 3. Besides precious metals, panning will detect gossanous fragments enriched in metals, secondary oreminerals such as anglesite, and insoluble minerals such as cassiterite, zircon, cinnabar,baryte, and most gemstones, including diamond. The mobility of each heavy mineral willdepend on its stability in water, for examplesulfides can only be panned close to theirsource in temperate environments where as diamonds will survive transport for thousands of kilometers.

The samples collected are usually analyzed or the number of heavy mineral grains are counted. The examination of the concentrate can prove very useful in remote areas where laboratory turn around is slow and the cost of revisiting the area high, as it will be possible to locate areas for immediate follow-up. The major problem is that panning is still some thing of an art and must be practised for a few days before the sampler is proficient. The diagram and photograph in Figs 8.9 and 8.10 show panning procedures. Useful checks on panning technique can be made by trial runs in areasof known gold or by adding a known numberof lead shot to the pan and checking their recovery.It is usual to start from a known samplesize and finish with a concentrate of knownmass. However, the differences in panning technique mean that comparisons betweendifferent surveys are usually impossible.

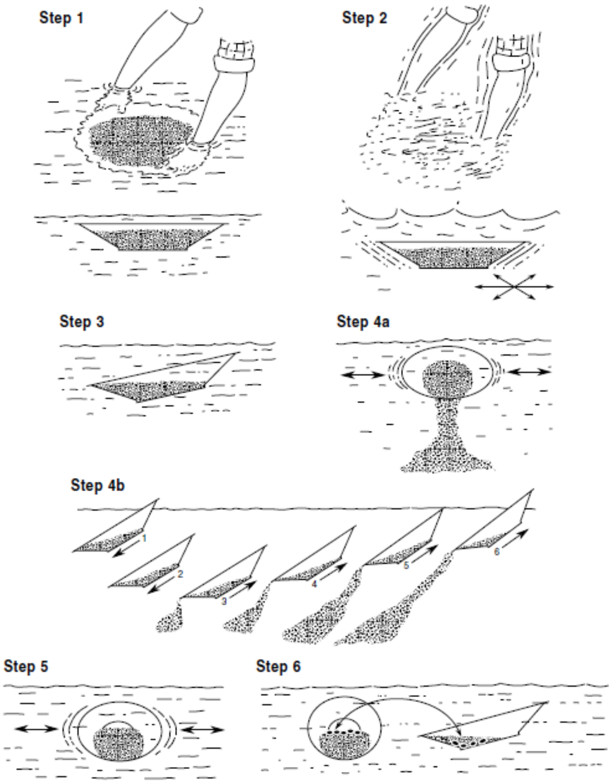


FIG. 8.9 The stages of panning a concentrate from sediment. Often the sediment is sieved to ≤ 2 mm although this may eliminate any large nugget. Note the importance of mixing the sediment well so that the heavy minerals stay at the bottom of the pan. For an experienced panner the operation will take about 20 minutes. (Modified from Goldspear 1987.)

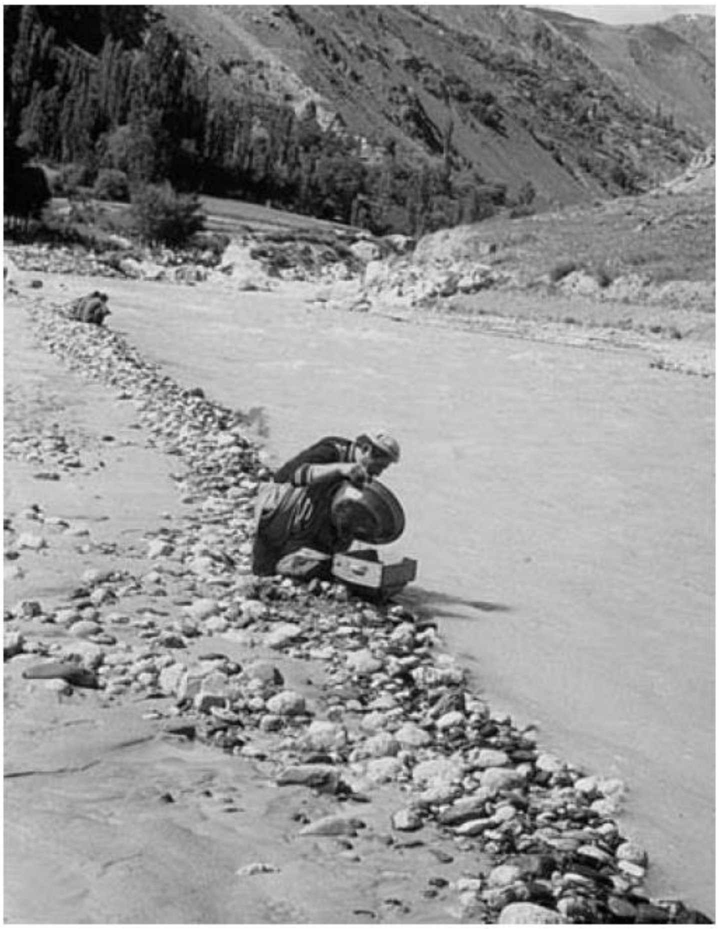


FIG. 8.10 Panned concentrate sampling in northern Pakistan. the water is glacial so edge of river sampling is essential.

4.2 Lake sediments

In the glaciated areas of northern Canada andScandinavia access to rivers is difficult on footbut the numerous small lakes provide an idealreconnaissance sampling medium as they areaccessible from the air. A sample is taken bydropping a heavy sampler into the lake sedimentand retrieving it. The sampling density ishighly varied and similar to stream sediments.Productivity is of the order of ten samples perflying hour. Essentially data are interpreted in asimilar way to that from stream sediments andcorrections should be made for organic matter.Lake sediment is only useful if glacial materialis locally derived and is ineffective in areasof glaciolacustrine material such as parts ofManitoba.

Further details are contained in thereviews by Coker et al. (1979) and Davenportet al. (1997).

4.3 Overburden geochemistry

In areas of residual overburden, overburdensampling is generally employed as a follow-upto stream sediment surveys but may be usedas a primary survey for small licence blocksor more particularly in areas of exotic overburden.Perhaps the key feature is that it isonly employed when land has been acquired.The results are generally plotted at scales from1:10,000 to 1:1000.

The method of sampling depends on thenature of the overburden; if the chemistry ofthe near-surface soils reflects that at depth thenit is safe to use the cheap option of samplingsoil. If not, then samples of deep overburdenmust be taken. The main areas where surfacesoils do not reflect the chemistry at depth are

glaciated areas, where the overburden has beentransported from another area, in areas of windblownsand, and in areas of lateritic weatheringwhere most trace metals have been removedfrom the near-surface layers.

Surface soil sampling

The simplest sampling scheme is to take nearsurfacesoil samples. The major problem is todecide which layer of the soil to sample, asthe differences between the layers are oftengreater than that between sites. The type ofsoil reflects the surface processes but in generalthe most effective samples are from a zone at around 30 cm depth formed by the downwardmovement of clays, organic material, and ironoxides, the B horizon indicated in Fig. 8.11, or the near-surface organic material (A horizon).

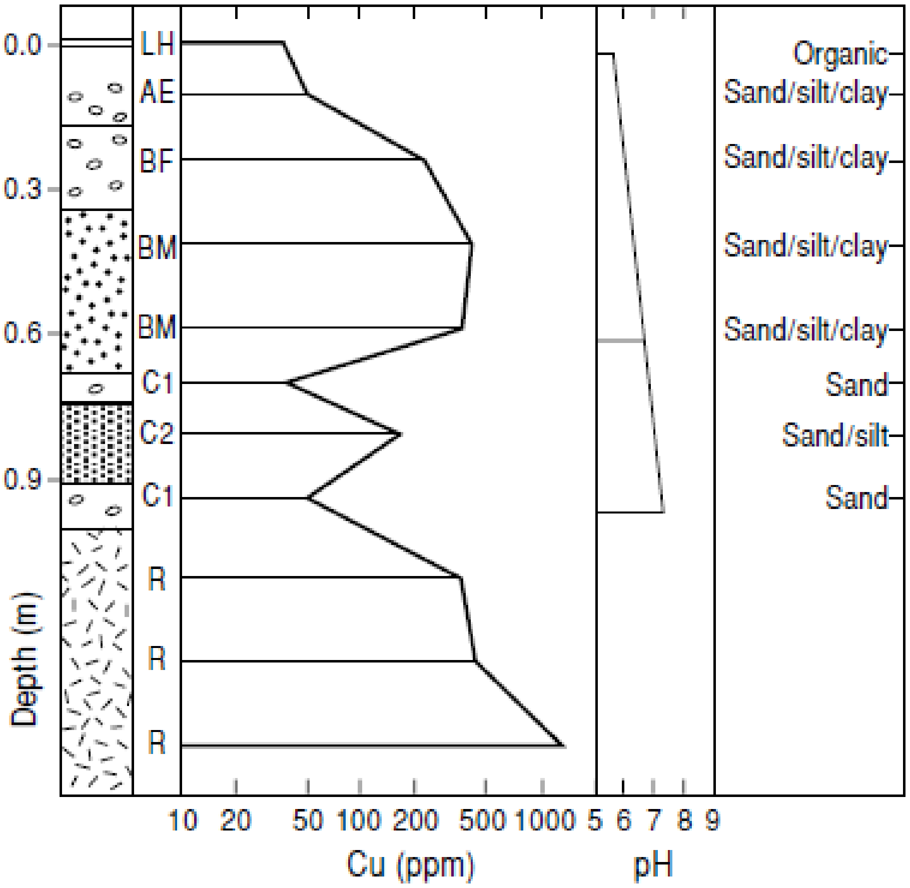


FIG. 8.11 Soil profile showing the effect of sample texture and soil horizons on copper

content. Note the bedrock copper content of 0.15% Cu. Letters refer to soil horizons

and subdivisions, from the top L, A, B, C, and R (rock). (From Hoffman 1987.)

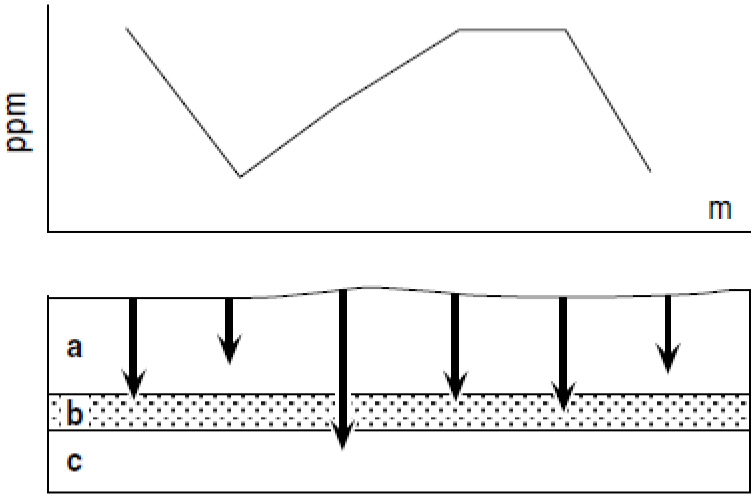


FIG. 8.12

Effect of sampling differing soil horizons with very different metals contents during a soil traverse.

FIG. 8.13 Typical surface soil sampling in temperate terrains using hand augers over the Coed-y-Brenin copper prospect Wales.

This downward movement of material is responsible for the depletion and concentration of trace elements causing variations that maybe greater than that over mineralisation. It isessential that the characteristics of the soilsampled are recorded and that an attempt ismade to sample a consistent horizon. If different horizons are sampled anomalies will reflectthis as shown in Fig. 8.12.

The usual method of soil collection in temperate terrains is to use a soil hand auger, as shown in Fig. 8.13. This allows sampling to a depth of the order of 1 m, although normally samples are taken from around 30 cm andmasses of around 100–200 g collected for basemetal exploration. In other climatic terrains,Partic-ularly where the surface is hard or wherelarge samples (500 g to 2 kg) are required forgold analysis, then small pits can be dug. The area of influence of a soil sample is relativelysmall and should be determined during an orientation survey.

The spacing is dependent on the size of the primary halo expected to occur across the target and the type of overburden,but a rule of thumb is to have at least

two anomalous samples per line if a targetis cut. Spacing in the search for veins may beas little as 5 m between samples but 300 mbetween lines, but for more regularly distributed disseminated deposits may be as muchas 100 m by 100 m. Sample spacing may also bedictated by topography: in flat areas or wherethe topography is subdued then rectilinear grids are the ideal choice, but in mountainous areas ridge and spur sampling may be the only reasonable choice.

A typical example of overburden sampling is shown in Figs 8.14 a–c. The area is on the eastern side of the Leinster Granite in Irelandand the target was tin–tungsten mineralization associated with microgranite dykes, which are also significantly enriched in arsenic and lesser copper and bismuth. Regional base of overburden sampling (usually 2–5 m depth), which was undertaken as the area has been glaciated, clearly delineates the mineralized dykes (Fig. 8.14a).

Surface soil sampling was also effective in delineating the dykes using arsenic and to some extent copper and Fig. 8.14b demonstrates the movement of elements through the overburden. Tungsten is very immobile and merely moves down slope under the influence of gravity whereas copper and arsenic are more mobile and move further down slope. The density of soil samples on the surface traverse is clearly greater than needed. The reader may care to consider the maximum sample spacing necessary to detect two anomalous samples in the traverse.

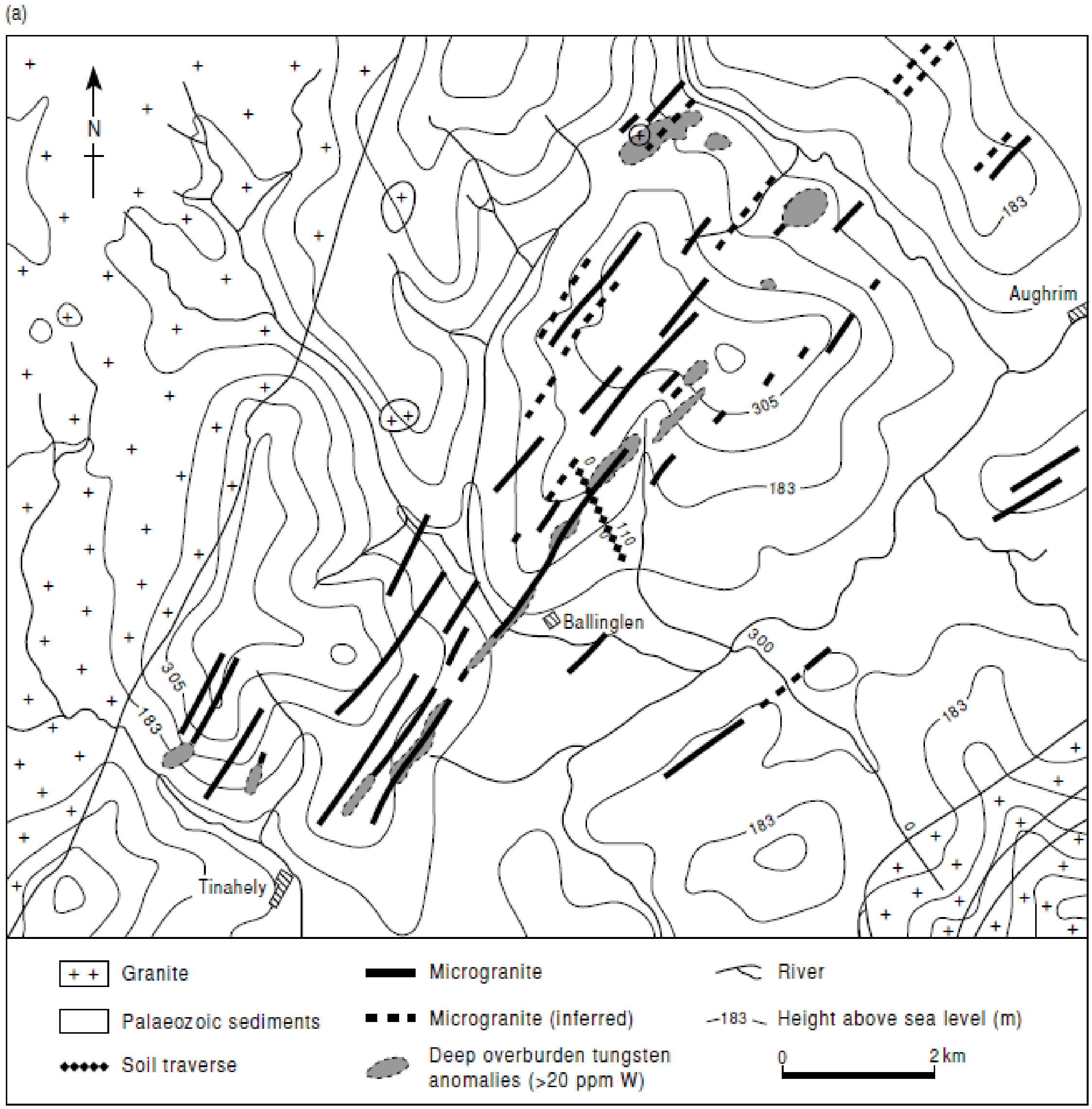


FIG. 8.14 (a) Regional geochemistry of the Ballinglen tungsten prospects, Co. Wicklow, Ireland. Detailed dispersion through overburden and soil response are shown in b and c. (From Steiger & Bowden 1982.)

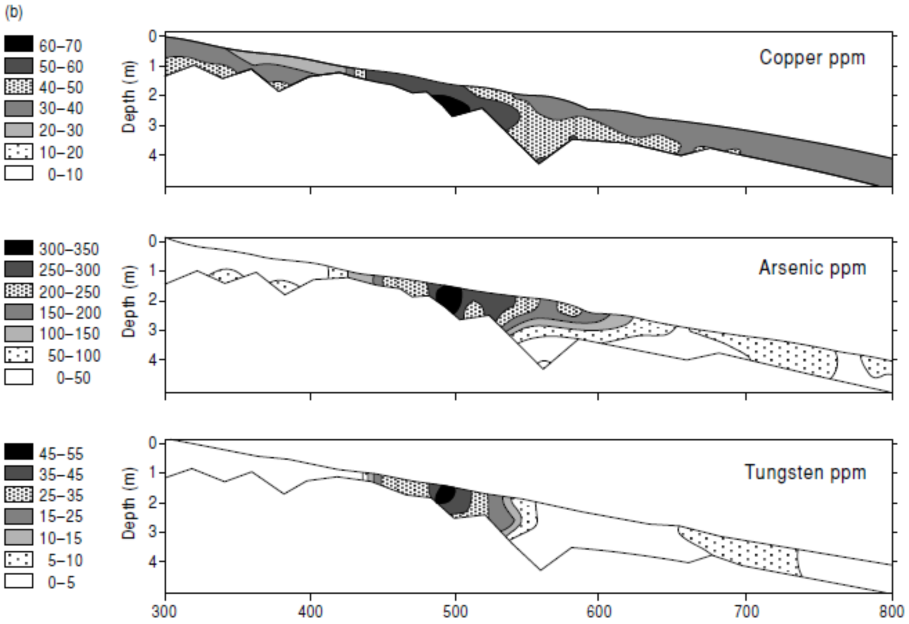


FIG. 8.14 (b) Dispersion through overburden along the soil traverse shown in Fig. 8.14(a). Note the different mobilities of tungsten, copper, and arsenic

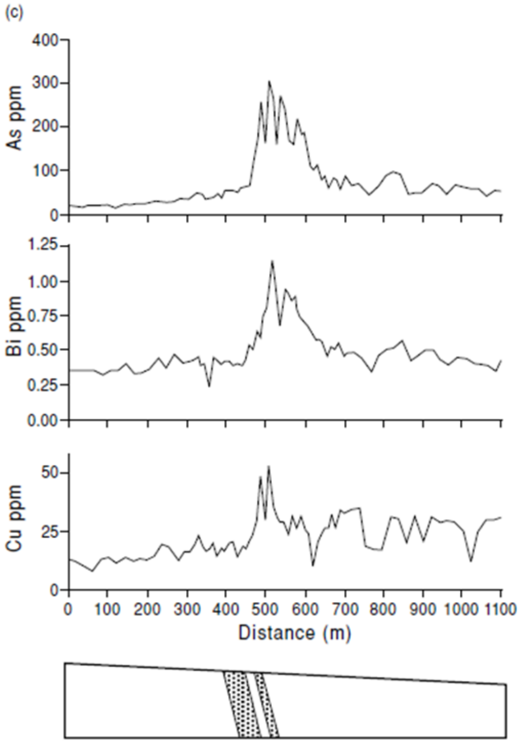


FIG. 8.14 (c) Soil traverse across the mineralized dyke. Note the sharp cut-off upslope and dispersion downslope.

A special form of residual overburden is found in lateritic areas such as in Amazonian Brazil or Western Australia where deep weathering has removed trace elements from the near-surface environment and geochemical signatures are often very weak. One technique that has been widely used is the examination of gossans. As discussed in section 5.1.6, gossans have relic textures which allow the geologist to predict the primary sulfide textures present at depth. In addition the trace element signature of the primary mineralisation is preserved by immobile elements. For example, it is difficult to discriminate gossans overlying nickel deposits from other iron-rich rocks on the basis of their nickel contents, as nickel is mobile, but possible if their multi element signatures are used (e.g. Ni, Cr, Cu, Zn, Mo, Mn) or the Pt, Pd, Ir content (Travis et al. 1976, Moeskops 1977, Smith 1977).

Drilling to fresh rock, often 50–60 m, has been widely used to obtain a reasonable signature despite the costs involved.

Transported overburden

In areas of transported overburden, such as glaciated terrains of the Canadian Shield, sandy deserts, or gravel-covered areas in the Andes, sampling problems are severe and solutions to them expensive.

In glaciated terrains overburden rarely reflects the underlying bedrock and seepages of elements are only present where the overburden is less than about 5 m thick. In addition the overburden can be stratified with material of differing origins at different depths. If the mineralisation is distinctive, it is often possible to use boulder tracing to follow the boulders back to the apex of the boulder fan, as in the case of boulders with visible gold, sulfides, or radioactive material. Generally however the chemistry of the tills must be examined and basal tills which are usually of local origin sampled. Figure 8.15 shows a typical glacial fan in Nova Scotia. Usually basal till sampling can only be accomplished by drilling; the most common methods are light percussion drills with flow-through samplers or heavier reverse circulation or sonic drills.

Lightweight drills are cheaper and easier to operate but results are often ambiguous, as it is not easy to differentiate the base of overburden from striking a boulder. The use of heavy equipment in most glaciated areas is restricted to the winter when the ground is frozen.

In sandy deserts water is scarce, most movementis mechanical, and most fine materialis windblown. Thus the −80 mesh fraction ofoverburden is enriched in windblown materialand is of little use. In such areas either a coarse fraction (e.g. 2–6 mm), reflecting locally derivedmaterial, or the clay fraction reflecting elements moved in solution is used (Carver et al.1987). One of the most successful uses of this approach has been in the exploration forkimberlites in central Botswana.Figure 8.16 shows the result of a regional sampling program which discovered kimberlite pipes in Jwaneng area. Samples were taken on a 0.5 km grid, heavy minerals separated from the +0.42 mm fraction and the number of kimberlite indicator minerals, such as picroilmenite, counted. The anomalies shown are displaced from the suboutcrop probably due to transport by the prevailing northeasterly winds.

Recent studies in Chile and Canada have examined the use of various weak extractions to maximize the signature of deposits covered by gravel and till. Figure 8.17 shows the result of a survey over the Gaby Sur porphyry copper deposit. The weak extractions, including deionized water, show high contrast anomalies at the edge of the deposit, probably generated by the pumping of groundwater leaching the deposit (Cameron et al. 2004).

Geochemical Exploration using Water, Vegetation, And Gases

Water, Plant and Gases can be used as sampling media in Geochemical Exploration.The sampling of natural water, Plant material, and gasses and the determination of elemental contents are considered important effective methods of geochemical exploration.

Hydrogeochemical Exploration

This include the analysis of water from:

- **Ground waters (Wells and Springs).**
- **Rivers and Lakes.**

Ground waters:

- **Dissolve the enclosing rocks**
- **Vary considerably from place to place in their content of dissolved solids**
- **Are generally from shallow sources.**
- **Most metal concentrations are in ppb range.**

Rivers and Lake waters:

- **Largely derived from surface run-off .**
- **Show much greater variation in content of dissolved solids**
- **Subject to large and sudden variation in run-off and pH.**

Sample collection:

- Samples are collected in clean polythene bottles (250-500 ml), using strong metal-free acid, and water being collected.

- Acidify the collected sample with three drops of metal-free conc nitric acid to prevent precipitation of any metal present.

- It is necessary to collect duplicate samples.

- It is necessary to filter the sample if they contain suspended solids (prior to analysis).

H.G. survey have been used allover the world in exploring for a wide range of elements using surface waters from streams and Lakes and G.waters from wells and springs.

In a study of an area of the Canadian shield Cameron (1977) concluded that Lake waters were a better sampling medium than Lake sediments, since the waters:

- Tend to be homogeneous across the surface.

- more easily collected and analyzed than the Lake - bottom sediments.

- Increase in concentration of indicator elements towards a source, unlike the same elements in Lake sediments which show a big variation depending on precipitation controls.

H.G. methods using groundwaters offer the possibility

of obtaining sample information from sources at depth. De Geoffroy (1967 and 1968) used successfully the groundwater survey for locating Zinc mineralization.

H.G. survey will probably remain of minor importance in geochemical prospecting owing to:

- **the metal content of waters may not only show big seasonal variation, but may also display wide variations over shorter intervals of time.**
- **Interpretation can be difficult as it is not always easy to determine sources.**
- **Productivity in sample collection is generally low in coparison with other methods.**

In spit of these drawbacks, H.G.survey may offer a useful alternative in many areas, eg.in uranium exploration where the high mobility of uranium and and its daughter element radon and the relative ease with which low levels of both elements can be detected make water surveys an impotant method.

Vegetation survey :

Vegetation is used in two ways in exploration geochemistry. Firstly the presence, absence of a particular plant or species can indicate the presence of mineralization, or a particular rock type,and is known as geobotany. Secondly the elemental

content of a particular plant has been measured, this known as biogeochemistry.

Biogeochemistry has been used more widely than geobotany and has found particular application in the forest regions of northern Canada and Siberia where surface sampling is difficult.

The type of soil and underlying rocks have a close relation on the type of vegetation that will grow most readily :

- **Some plants grow well only in acid soil and will not grow well in limestone (Calcifuges), eg. Shrub rhododendron.**
- **Some plants can tolerate high levels of Ni and Cr over ultrabasic rocks and hence grow in preference to others that cannot tolerate this environment.**

Such associations between plants and underlying geology are used in geologic mapping.

Elements in plant tissues can be divided into three groups, if one compares the element contents of the plant tissue to that in the soil in which the plant is growing :-

First group **: The biogenic elements and includes: H, C, O, N, P, S, which make up the bulk of the plant tissue with concentrations above those in the soil.**

Second group **: The essential trace elements which are necessary for healthy grouth, they include :B, Mg, K, Ca, Mn,**

Fe, Cu, and Zn with roughly the same concentrations as those in the soil.

Third group **: Are the non- essential and toxic elements, these include :Pb, Sr, Hg, Be, U, Cr, Ni, Ag, Sn and Se, with concentrations well below those in the soil.**

Geobotanical exploration: **involves the identification of plants , in particular flowers, associated with mineralization, they are called** *indicator plants*, **these plants seem to require minimum levels of certain elements, toxic to other plants, before they will grow, and there are a number of examples :**

*** The best famous of these is the small mauve- white copper flower (Beccium homblei) of the Zambian copper belt. This plant requires a soil copper content of 50 -1600 ppm Cu to thrive, conditions that are poisonous to most plants.**

*** In the western united states the selenium flora is a usuful indicator of uranium mineralization owing to the fact that Se usually accompanies uranium in the sedimentary deposits of the Colorado Plateau. Examples of indicator plants that have been used in some parts of the world are given in the table.**

On the other hand, morphological changes of plants may also indicate the presence of high concentration of toxic elements, eg. Pb, Hg, Ni, Cu etc. Where the vegetation shows Stunted growth, besides the yellowing of the leaves(chlorosis) .

EXMPLES OF INDICATOR PLANTS (from Brooks 1972)

Element	**Indicator plant**	**Region**
Copper	**Copper flower (Beccium homblei)**	**Zambia**
Nickel	**Alyssum(Alyssum murale)**	**Georgia**
Lead	**Beardgrass(Erianthus giganteus)**	**Tennessee& USA**
Selenium &U	**Woody aster(Aster venusta)** **Poison vetch(Astragalus)**	**W. USA**
Zinc	**Calamine violet (Viola calaminaria)**	**Belg, &Ger**
Boron	**Sea lavender (Limonium suffruticosum)**	**Caspian lowlands, USSR**
Gold	**Horsetail(Equisetum arvense)**	**Czechoslovakia**

Biogeochemical exploration

Geochemical exploration based on the chemical analysis of systematically sampled plants in a region, in order to detect elemental concentrations that might reflect hidden orebodies.

In this method

Plant material is ashed prior to analysis , this removes most of the biogenic elements and the elements of interest are concentrated in the residue. The ash is normally 1-3% of dry weight, so that the elements of interest are concentrated up to 100 times their levels in the original plant tissue.

It must be noted that:

*** Some elements my reach very high concentrations in ash of plants growing over mineralization,eg :**

-1.7 % Mo in the ash of fireweed (Epilobium angustifolium) growing on Edako molybdenum deposit, B. Colombia.

- 10000 ppm arsenic has been found in the twig ash of Douglas fir Pseudotsuga menzieii) growing over Arseniferous metal deposit.

*** Metal accumulation in shrubs and trees are greatest in the first- and second- year growth of twigs and shoots.**

*** Grassy plants accumulates Ni, Cu, Co, Mo, Zn, Cr, Pb, B and U in stems and leaves.**

*** Accumulation of elements increases with plant age as a result of expanding root system in depth, <u>which</u> show variation with species and great variation with climate.**

Procedure of biogeochemical survey :

- Collect a minimum of 300g of material from each plant in numbered bags. As a general role, young twigs gives the best results, but this can vary with different species.
- The material is left to dry to a flammable state.
- Prior to analysis the samples are finally ashed in porcelain crucibles at 450 - 500 C.

advantages:

* Very effective method in delineating the anomalous concentrations of elements related to mineralization.

* Provide a means of sampling at some depth below the surface by virtue of the plant's root systems.

* The method is best applied in areas with extensively developed thick , alluvial, Aeolian, deser sand, i,e where ordinary metallometric survey are ineffective.

Gaseous methods

Gases can diffuse through thick overburden. A number of gases have been used in this method, eg., mercury , radon, carbon dioxide ...etc.

- Mercury is the only metallic element which forms a vapor at room temperature, and it is widely present in sulphide deposits particularly volcanic associated base metal deposit.

- The gas radon is generated during the decay of uranium, and has been widely used with some success in uranium exploration.
- Enrichment of carbon dioxide and depletion of oxygen caused by weathering of sulphide deposits has been tested.
- Hydrocarbon gases are used in exploration of oil and gas.

In gas exploration a sampling grid or sampling profiles are plotted depending on local geological condition, a sample of soil air is taken at each point,then analysed.