

Geochemical prospecting

The use of chemical properties of naturally occurring substances (including rocks, glacial debris, soils, stream sediments, waters, vegetation, and air) as aids in a search for economic deposits of metallic minerals or hydrocarbons. In exploration programs, geochemical techniques are generally integrated with geological and geophysical surveys. See also: [Geophysical exploration](#)

History

Many fundamental principles of geology and chemistry were known in antiquity, and references to the use of chemistry in the search for mineral deposits are not infrequent in both classical and Renaissance literature. The techniques of modern geochemical prospecting originated in the Soviet Union and Scandinavia, where extensive research into methodology was conducted during the 1930s. After World War II these techniques spread to the western world and were further developed; by 1960 they had become widely used by both government agencies and mining companies. By 1970 geochemistry had become firmly established as one of the most effective tools of mineral exploration.

Several factors contributed to the rapid development of geochemical prospecting during the twentieth century. It was found that most metallic mineral deposits are surrounded by halos of abnormal trace-element concentrations in the adjacent and enclosing rocks. Also, abnormal trace-element concentrations in materials such as glacial sediment, soil, spring or stream water, and stream sediment were recognized as being derived from the weathering of mineral deposits. Precise and rapid methods of chemical analysis suitable for the detection of low concentrations (a few parts per million, or even parts per billion) of elements and compounds in natural media were developed. These methods include use of the emission spectrograph, specific and sensitive colorimetric reagents, atomic absorption spectrometry, and development of polyethylene laboratory equipment. The effectiveness of geochemical exploration has been greatly enhanced by the use of computer-aided statistical techniques for processing and evaluation of data. Sampling techniques have become steadily more effective with the use of helicopters and devices such as overburden drills.

Understanding of the significance of landscape in geochemical exploration has progressed considerably, permitting the most effective set of field techniques and interpretive procedures to be selected for any given set of field conditions.

Geochemical prospecting is employed extensively in all regions of the world from the Arctic to the tropics, and has contributed significantly to the success of many important mineral exploration programs. New technologies promising further advances include the use of plasma spectrography and of airborne particulate matter as a sample medium. See also: [Analytical chemistry](#); [Chromatography](#)

General Principles

Mineral deposits represent anomalous concentrations of specific elements, usually within a relatively confined volume of the Earth's crust. Most mineral deposits include a central zone, or core, in which the valuable elements or minerals are concentrated, often in percentage quantities, to a degree sufficient to permit economic exploitation. The valuable elements surrounding this core generally decrease in concentration until they reach levels, measured in parts per million (ppm) or parts per billion (ppb), which appreciably exceed the normal background level of the enclosing rocks. This zone surrounding the core deposit is known as a primary halo or anomaly, and it

represents the distribution patterns of elements which formed as a result of primary dispersion. In general, it is formed at, or near, the same time as the central ore body. Mineral deposits at, or near, the surface are subject to chemical and physical agencies of weathering. Many of the ore minerals undergo decomposition or disintegration, and their chemical constituents become dispersed into weathering debris, soils, ground water, and plant tissue. Further dispersion, often over considerable distances, may ensue due to the agencies of glaciers or stream and river systems. Abnormal chemical concentrations in weathering products are known as secondary dispersion halos or anomalies and are more widespread. All of these halos afford means whereby mineral deposits can be detected and traced; they form the geochemical anomalies which are the objects of search of all geochemical prospectors. See also: [Ore and mineral deposits](#)

Primary environment

Most igneous rocks have formed by a differentiation process. This starts with a parent magma, often of basaltic composition, and as cooling proceeds, early-crystallizing minerals are separated to form cumulate rocks. The remaining melt, having lost elements that are concentrated in the early minerals, becomes changed in composition. Through such a process the magma may pass through a differentiation series, such as gabbro-diorite-granodiorite-granite-pegmatite, in which each point has a distinctive composition of both major and minor chemical elements. In general, as differentiation proceeds, there is an overall decrease in iron, magnesium, calcium, and titanium in the rocks combined with an increase in silicon, aluminum, sodium, and potassium. Trace-element concentrations also change considerably with this sequence of rock type and major element alteration. The occurrence of trace elements in rock-forming minerals is generally controlled by a combination of ionic size, valency, and type of chemical bond. Some elements, however, including lithium (Li), boron (B), beryllium (Be), niobium (Nb), tantalum (Ta), tin (Sn), uranium (U), thorium (Th), tungsten (W), zircon (Zr), and the rare earths, do not enter rock-forming silicate minerals to any significant degree during magmatic crystallization. These elements tend to be concentrated in residual aqueous fluids together with compounds such as hydrogen fluoride (HF), hydrogen chloride (HCl), and carbon dioxide (CO₂), and remain in solution until the final stages of magma crystallization, exemplifying primary mobility. They eventually may become concentrated in pegmatites, and may play an important role in hydrothermal alteration and ore formation.

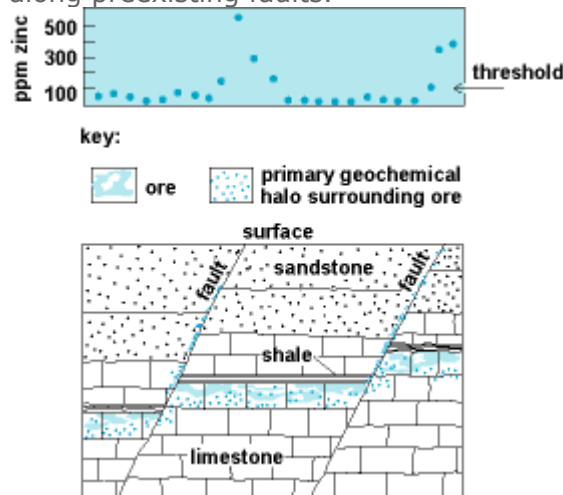
Primary dispersion halos vary greatly in size and shape as a result of the numerous physical and chemical variables that affect fluid movements in rocks. Some halos can be detected at distances of hundreds of meters from their related ore bodies; others are no more than a few centimeters in width. Some of the factors controlling the development of primary halos are presence or absence of fractures in the host rock, porosity and permeability of the host rock, tendency of mineralizing fluids to react chemically with the host rock, and volatility of the ore elements.

The main types of primary halos are syngenetic and epigenetic. Syngenetic primary halos are formed essentially contemporaneously with the enclosing rocks. Epigenetic primary halos are formed after the host rock has solidified, and result from the introduction of mineralizing solutions to open spaces such as fractures.

Epigenetic primary halos may cover large areal extents, as when a rock mass is pervasively altered by hydrothermal solutions, or they may be restricted to well-defined channelways through which mineralizing fluids have followed open spaces such as fractures or solution channels. They are frequently developed in rocks overlying an ore body and can be of great value in prospecting ([Fig. 1](#)). Volatile elements, such as mercury and radon, offer the greatest possibilities for successful

ore discovery utilizing leakage dispersion, because they move farther than other elements.

Fig. 1 Cross section showing use of surface rock chip sampling to detect leakage anomalies that reflect concealed zinc mineralization. Horizontal distance is 1 km (0.6 mi), vertical distance, 200 m (650 ft). Ore bodies have formed in a porous limestone bed capped by an impermeable shale; some mineralizing fluid has escaped upward along preexisting faults.



Many elements occur in hydrothermal mineralizing solutions, and some may be more mobile than others. In some cases, however, the element yielding the most extensive primary dispersion halo is not that of greatest economic significance in the ore body, even though it is closely associated geochemically. Such an element is referred to as a pathfinder, and is of value in prospecting because its halo is broader than that of the element of primary interest or because it may be detected more readily by conventional analytical procedures. Arsenic is frequently used as a pathfinder element in geochemical exploration for gold; radon is frequently utilized in similar manner in uranium exploration.

Secondary environment

Most samples analyzed are materials from the secondary environment, making it particularly important in geochemical exploration. Rocks and minerals that are stable in the primary environment are frequently unstable in the secondary; they undergo disintegration and modification through a variety of chemical and physical processes that are known collectively as weathering. Trace elements of ore bodies and their associated primary halos are frequently released by weathering processes to soils, overburden, and vegetation, with consequent generation of secondary halos. Some chemical constituents of ore bodies may be widely dispersed through the agency of ground waters or surface stream systems; analysis of spring and stream waters, or stream sediments, may indicate the presence of a mineral body from a considerable distance. Some volatile constituents of ore bodies may migrate through soil gas into the atmosphere where, again, they can be detected and serve as clues to the source. An adequate interpretation of geochemical data in the secondary environment requires that the various processes of weathering be distinguished. There are two primary types of weathering, chemical and physical. Chemical weathering requires abundant water, oxygen, and carbon dioxide; it involves the breakdown, by chemical means, of rocks and minerals with consequent release of their contained trace elements to the environment. Chemical weathering predominates in tropical environments, but is also important in temperate regions. Physical weathering comprises all processes of rock disintegration which do not involve chemical changes; it is most common in extremely cold or arid regions where frost shattering

and sand blasting occur. The relative influences of chemical and physical weathering depend on the nature of the landscape in question. See also: [Weathering processes](#) Secondary dispersion halos, or anomalies, are sometimes referred to as dispersion trains. The shape and extent of secondary dispersion trains depend on a host of factors, of which topography and ground-water movement are perhaps most important. Ground waters frequently dissolve some of the constituents of mineralized bodies and may transport these for considerable distances before eventually emerging in springs or streams. Further dispersion may ensue in stream sediments when soil or weathering debris that has anomalous metal content becomes incorporated through erosion in stream sediment. Analysis of the fine sand and silt of stream sediment can be a particularly effective method for detection of mineralized bodies within the area drained by the stream.

Geochemical mobility in the secondary environment depends on certain inherent properties of the elements in question and the main features of the landscape. In this context, important properties of elements are electronic configuration, ionic potential, stability relations with variation in acidity and oxidation potential (pH and Eh), tendency to form complexes with organic matter, and tendency to be coprecipitated or absorbed with iron or manganese hydroxides. Features of the landscape that can either significantly enhance or restrict geochemical mobility include topography, soil type, pH and Eh of ground water, presence or absence of decaying vegetation in soils, calcium carbonate precipitates in soils, and iron and manganese hydroxide precipitates in stream channels.

Survey Design

The degree of success of a geochemical survey in a mineral exploration program is often a reflection of the amount of care taken with initial planning and survey design. This phase of activity is often referred to as an orientation survey; its practical importance cannot be overstressed.

Orientation survey

When a geochemical prospecting survey is contemplated, four basic considerations must be addressed: the nature of the mineral deposits being sought; the geochemical properties of the elements likely to be present in the target mineral deposit; geological factors likely to cause variations in geochemical background; and environmental, or landscape, factors likely to influence the geochemical expression of the target mineral deposit. Elucidation of these factors in an orientation survey will permit design of a geochemical prospecting survey that is most likely to prove effective under the prevailing conditions. See also: [Prospecting](#)

Wherever possible, an orientation survey should include a study of the geochemical expression of a known mineral deposit similar to that which is the target of the proposed prospecting program, and which occurs in a geological and environmental setting similar to that of the proposed search. The geochemical expression of such a deposit should be determined in detail. Normally this will include comprehensive sampling of soils, stream sediments, vegetation, and water over and around the deposit. This will be followed by multielement analyses of the samples, and the result will be a thorough picture of the nature, intensity, and extent of the secondary geochemical dispersion train which indicates the presence of the deposit. From this information, deductions can be made as to the type of sampling medium, sample spacing, and analytical processing most likely to yield a positive indication of another such mineral deposit in a previously unprospected area. Estimates of time and cost likely to be involved in the proposed survey can also be made.

A further important element of an orientation survey is establishment of background against which geochemical anomalies can be compared. This is generally done by collection of a substantial number of samples (perhaps 100) of the materials to be

used in the geochemical survey (such as soil or stream sediment but excluding mineralized material) over a considerable area.

Further important aspects of orientation work are an assessment of variations in landscape conditions, or geochemical environment, within the survey area, their likely effect on mechanisms of geochemical dispersion, and the probable geochemical expression of a mineral deposit. In some cases landscape may vary greatly, perhaps from rugged mountain terrain with little soil or overburden cover and preponderant mechanical dispersion, to low-lying swampy terrain with thick overburden obscuring the bedrock where geochemical dispersion is chiefly chemical. In such a case geochemical prospecting methods suitable for one environment may be quite inappropriate for another, since the geochemical portrayals of a mineral deposit may be markedly different. Only experience and careful orientation work will permit these differences to be identified and assessed.

Sampling techniques

Representivity is of paramount importance in geochemical sampling. It is essential that adequate samples be taken that are representative of the material sampled at any given locality. These materials may be rocks, waters, gases, soils, stream sediments, or vegetation. Wherever possible, sampling should be confined to one type of material for any particular survey, such as one rock type in lithochemical surveys, one horizon in soil surveys, or one plant organ and plant species in biogeochemical surveys. If, through necessity such as landscape variations, diverse materials have to be sampled, correlative factors must be applied to the results before the geochemical patterns can be effectively interpreted.

Selection of analytical procedures for a geochemical prospecting survey is one object of the initial orientation survey. Samples collected during the orientation survey are often subjected to multielement analysis which will show the techniques most likely to yield maximum contrast between anomaly and background, and most likely to detect the target mineral deposit at the greatest distance. In many cases the sample decomposition procedure that tends to yield the most prominent and extensive anomalies is one which releases only a portion of the metal present in the sample. Similarly, anomaly recognition is often facilitated by several elements being determined, rather than by just one or two of the most immediate economic significance. However, as in sample spacing, cost must be an important consideration in choice of routine analytical procedures. Most geochemical analytical procedures are designed to detect elements at low concentrations such as parts per million or parts per billion. Techniques used for the analysis of geochemical sampling media are varied; some are intended for use in mobile field laboratories, and some are intended primarily for well-equipped permanent laboratories such as those operated by commercial firms or government agencies.

Field analysis

Analytical techniques for on-site sampling of water, soil, stream sediment, and lake sediment are usually based on colorimetry; they utilize a specific selective organic reagent, such as dithizone, which produces a characteristic color in the presence of a given metal in solution. The reaction of dithizone with zinc, which produces a range of blue, violet, and red shades, is commonly utilized in field geochemical prospecting. Field analytical techniques generally determine loosely bonded, or exchangeable, metal ions, which are extracted by a citrate, acetate, or dilute acid. See also:

[Colorimetry](#)

Laboratory analysis

When it is desirable to determine the total content of a given metal in a sample, analysis is generally performed in a laboratory. A wide range of techniques may be used, but the most common are emission spectrography and atomic absorption spectrophotometry. The latter technique is particularly suitable for routine

geochemical analysis since it permits a large number of samples to be analyzed relatively quickly and inexpensively to an adequate standard of precision. Sample digestion prior to atomic absorption analysis frequently involves a hot mineral acid or mixture of acids; one of the most common digestion agents is a mixture of nitric and perchloric acids. See also: [Atomic spectrometry](#)

Other geochemical analytical procedures include x-ray fluorescence spectrography, chromatography, and polarography. Gas chromatography is frequently used for analytical determination of hydrocarbons.

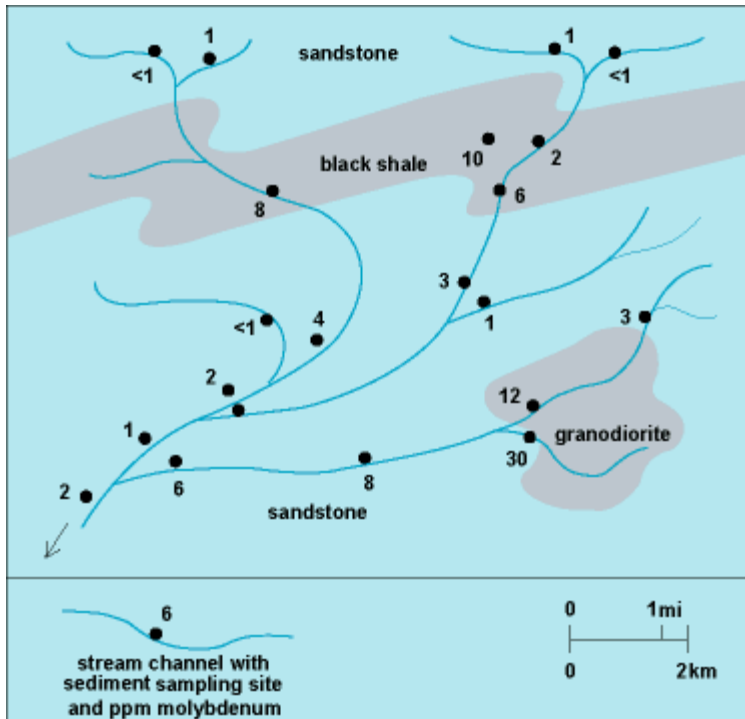
Geochemical data processing

Statistical analysis, particularly when large volumes of data are generated by major multielement surveys, commonly employs three categories of procedures: two-dimensional representations of geochemical data involving automatic plotting and contouring procedures; univariate statistics where populations, background ranges, and anomaly thresholds are determined for single elements; and multivariate statistics where correlations between, and associations of, several elements are sought and distinguished.

Geochemical prospecting surveys

Geochemical prospecting surveys fall into two broad categories, strategic or tactical, which may be further subdivided according to the material samples. Strategic surveys imply coverage of a large area (generally several thousands of square kilometers) where the primary objective is to identify districts of enhanced mineral potential; tactical surveys comprise the more detailed follow-up to strategic reconnaissance. Typically the area covered by a tactical survey is divided into discrete areas of high mineral potential within the general anomalous district. The sample medium most commonly used for strategic geochemical prospecting is stream sediment ([Fig. 2](#)). Experience in many regions has shown that carefully collected stream sediment samples yield good indications of the rocks and weathering products of the catchment areas. In a typical stream sediment sampling distribution, the sandstone may have molybdenum background of approximately 1 ppm and a threshold of 2 ppm, and the black shale a background of 6-10 ppm, but these values do not reflect mineralization. The granodiorite stock may contain molybdenum mineralization; this is marked by an anomalous dispersion train of 5 km (3 mi) length. The two categories of molybdenum anomaly could be distinguished if the samples were also analyzed for copper, zinc, nickel, and vanadium; all four elements would be high over the shale, but only copper would be enhanced with the molybdenum over the granodiorite. Stream sediment sampling offers a relatively rapid and reliable method of appraising the mineral potential of a large area. Where landscape conditions preclude effective stream sediment sampling, as in a desert or karst environment, other media, such as rock, soil, or atmospheric particulates, must be used. A variety of sample media may be used for the more detailed sampling required at the tactical level of prospecting; soil is the most common medium, but rock and vegetation are also frequently used.

Fig. 2 Typical stream sediment sampling distribution employed for strategic exploration.



Geochemical prospecting surveys include surveys where the sample medium is stream or lake sediment, stream, spring or lake waters, and detrital heavy minerals from stream sediment.

Natural waters

The background metal content of most natural waters is only a few parts per billion, rising to a few parts per million for certain elements in the vicinity of mineral deposits. Seasonal fluctuations often occur in these values and have to be considered in water surveys. Accurate and sensitive analytical methods are a requirement in water surveys. Most water analyses are done by sensitive colorimetric methods or by atomic absorption spectrometry.

Either surface waters or ground waters may be tested in water surveys, depending on local conditions. Surface waters are sampled at regular intervals along the drainage net, and a map of the value is prepared. An increase in the metal content of the water upstream may indicate approach to a mineralized zone. Surveys based on ground waters can be done only where there is a good distribution of wells, springs, or diamond drill holes. The metal content of the water in these is plotted on a map and contoured. Higher than normal contents in the water system may indicate sites or zones of mineralization.

Sediments

Surveys of sediments and heavy minerals are carried out to determine the migration path of dispersed elements and minerals along the surface-drainage channels of an area. Samples are collected from the fresh sediment in the bottoms of streams and also from old sediment on the terraces and floodplains. For chemically dispersed elements, the fine fraction (minus 80 mesh) is generally used for analysis; for mechanically dispersed heavy minerals, a coarser fraction is panned from the sediment. Sampling points are located at intervals along the length of the drainage system (Fig. 3), and the results of the chemical analyses of the stream sediment are plotted on a map of drainage. An increase in the metal content of the stream sediment upstream may indicate approach to a mineralized zone (Fig. 4). The heavy mineral fraction may be examined microscopically for ore minerals or accompanying gangue minerals, or the fraction may be analyzed for ore elements or indicator

elements. Both results are plotted on the drainage map and interpreted like the stream sediment data.

Fig. 3 Weathering of a Pb-Zn ore body producing an anomalous dispersion train in overburden and soils; this enters the stream system mechanically at point A and via ground-water seepages at point B. See also Figs. 4 and 5.

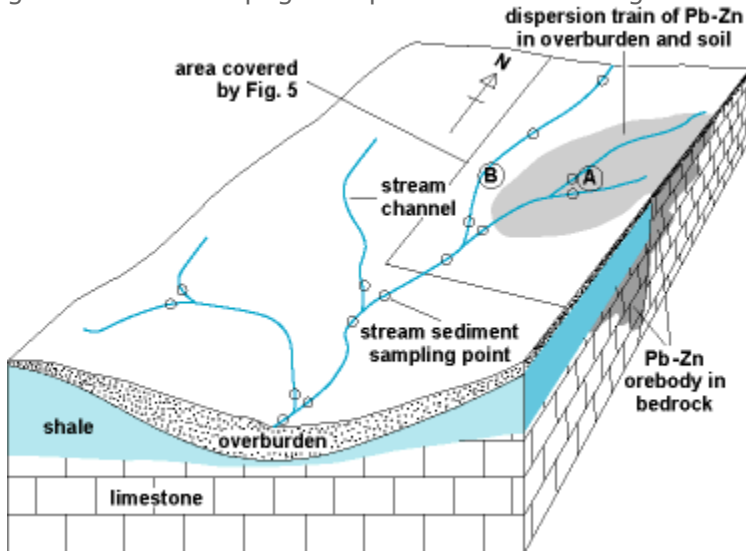
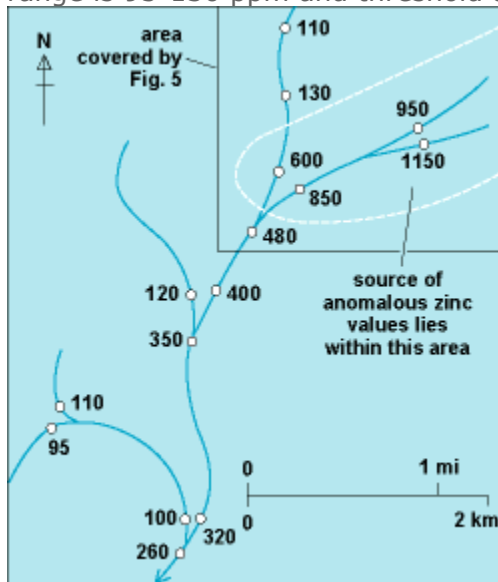


Fig. 4 Zinc (ppm) in stream sediments of area covered by Fig. 3. Background range is 95-130 ppm and threshold approximately 200 ppm.

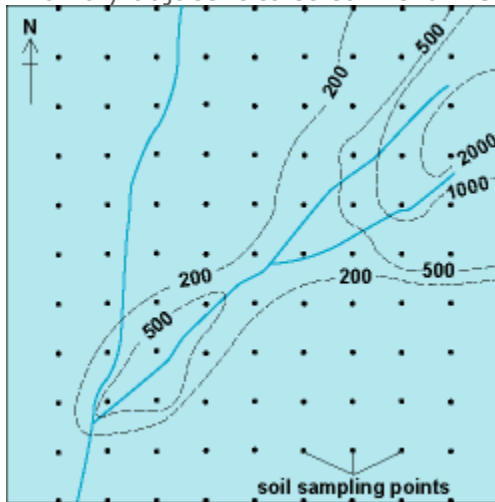


In areas where stream channels are frequently interrupted by lakes, as in many regions of eastern Canada, lake bottom sediment has proved an effective alternative sampling medium to stream sediment.

Soil geochemical surveys

Soil and glacial till surveys have been used extensively in geochemical prospecting and have resulted in the discovery of a number of ore bodies. Generally, such surveys are of a detailed nature and are run over a closely spaced grid (Fig. 5). One of the soil horizons is chosen for sampling, and a plan of the metal contents is plotted and contoured. Under favorable conditions, the highest values are centered over a deposit, but more generally the dispersion pattern is a train or a fan that requires careful interpretation to locate its source.

Fig. 5 Results of soil sampling in area of stream sediment sampling shown in Fig. 4; contours are ppm zinc in subsoil. Main anomaly reflects suboutcropping ore body. Anomaly adjacent to stream channel results from zinc migration in ground water.



Certain geological conditions may require that all horizons of the soil be sampled. Frequently, sampling of the organic horizon is effective in some areas, whereas in some regions other horizons are more rewarding. In some places, deep sampling of a horizon by drilling is the only satisfactory method for soil and glacial till surveys. Heavy and resistate mineral surveys of soil, till, and weathered debris have become increasingly useful. In these surveys the geological materials are panned, and the heavy and resistate minerals obtained. They are then examined microscopically for ore minerals or analyzed for ore and indicator elements; the results are plotted on maps. Heavy and resistate mineral maps, prepared on the same grid as those for soil surveys, provide valuable ancillary data and often aid in the interpretation of the elemental dispersion patterns.

In soil analyses the fine fraction (minus 80 mesh) is generally analyzed for the chemically dispersed elements, whereas for heavy and resistate minerals a coarser fraction is used.

In glaciated terrains, as well as in certain other terrains, heavy and light clast (mineral fragments, stones, and boulders) tracing has proved effective in the discovery of certain types of mineral deposits. Examples are quartz boulders or fragments as indicators of gold-quartz veins, and galena boulders or fragments as indicators of lead-zinc deposits. Surveys of this type are generally carried out on grids, the abundance of light or heavy clasts being visually noted and plotted at each sampling point or wherever they occur along the grid lines. In other surveys, large samples of the till or overburden are obtained at each sampling point, and the light and heavy clast indicators are counted in the light and heavy concentrates obtained from the samples. When all data from clast surveys are plotted, fans or trains are commonly outlined whose apexes or starting points often mark the sites of underlying mineralization.

Biogeochemical surveys

These surveys are of two types. One type utilizes the trace-element content of plants to outline dispersion halos, trains, and fans related to mineralization; the other uses specific plants or the deleterious effects of an excess of elements in soils on plants as indicators of mineralization. The latter type of survey is often referred to as a geobotanical survey.

Trace elements in plants

In the first type of survey, the trace-element content of selected plant material is determined on a grid over an area. Generally, samples are collected from parts of individuals of the same species of vegetation, such as twigs, needles, leaves, and seeds. These are dry- or wet-ashed, the trace-element content is determined, and the results are plotted for interpretation with respect to mineralized zones or deposits. Interpretation of vegetation surveys is frequently difficult, since a number of factors enter into the uptake of elements by plants, some of which are unrelated to mineralization. These include the content and nature of exchangeable elements in the soil, drainage conditions, soil pH, and growth factors in the vegetation. See also: [Physiological ecology \(plant\)](#)

Geobotanical surveys

Geobotanical surveys are carried out by mapping the distribution of indicator plant species, or plant disease symptoms diagnostic of high-metal-bearing soils, such as chlorosis and dwarfing. Where suitable indicator plants are present, this method is rapid and inexpensive, but unfortunately such plants are seldom consistent in distribution from one area to another. Geobotanical techniques require careful preliminary orientation surveys.

Animal media

Some biogeochemical surveys of a research nature have been conducted by utilizing various animals as the sampling media. The animals used have been fish (livers), mollusks (soft parts), and insects (whole organisms). The results of these surveys show that these animals commonly reflect the presence of mineralization in regions in which they occur by containing higher than normal amounts of various elements. Dogs can locate mineral deposits by sniffing out boulders of ore occurring in the dispersion trains and fans of sulfide deposits. They can be trained to become quite sensitive to sulfur dioxide (SO₂) and other gases associated with oxidizing sulfides.

Rock geochemical surveys

Most reconnaissance surveys are carried out on a grid or on traverses of an area, with samples taken of all available rock outcrops or at some specific interval. One or several rock types may be selected for sampling and analyzed for various elements. The distribution of the volatiles such as chlorine (Cl), fluorine (F), water (H₂O), sulfur (S), and CO₂ in intrusives with associated mineralization has received some attention as an indicator.

Geochemical maps are compiled from the analyses, and contours of equal elemental values are drawn. These are then interpreted, often by using statistical methods, in the light of the geological and geochemical parameters. Under favorable conditions, mineralized zones or belts may be outlined in which more detailed work can be concentrated. If the survey is executed over a large expanse of territory, geochemical provinces may be outlined.

Detailed rock geochemical surveys are generally carried out on a local basis and are aimed at the discovery or definition of primary or leakage halos associated with mineral deposits or petroleum accumulations. Chip samples of rocks on a definite grid are used in some cases, and samples from drill cores in others. All the analytical data are plotted on plans and sections, and compared with the geological situation. Frequently, primary halos can be discovered by this method, and these and leakage halos can be traced to the focus of mineralization if sufficient work is done.

In detailed drilling and development work, the use of ratios obtained from analyses of rocks along traverses or diamond-drill holes can frequently be employed to estimate proximity to mineralized loci. Particularly useful ratios include potassium oxide/sodium oxide (K₂O/Na₂O), silicon dioxide/carbon dioxide (SiO₂/CO₂), and SiO₂/total volatiles; the volatiles commonly include H₂O, CO₂, S, arsenic (As), and B. Many types of mineral deposits are characterized by a consistent increase in the ratio K₂O/Na₂O, which is essentially a manifestation of increasing potassic alteration.

Similarly, a number of mineral deposits, particularly those enriched in gold and silver, are marked by a consistent decrease in the ratio SiO_2/CO_2 as ore is approached. The ratio $\text{SiO}_2/\text{total volatiles}$ exhibits considerable variation among the various types of mineral deposits; in most cases, skarns excepted, there is a consistent decrease in the ratio as mineralization is approached.

Particulates

Gases, such as hydrocarbons, hydrogen sulfide (H_2S), and CO_2 ; volatile elements, such as mercury; and airborne particulate matter, or surface microlayer particulates, can also be utilized as sampling media. Generally the collection and analysis of such materials involves the use of sophisticated airborne equipment.

Mercury has been used extensively in both rock and soil geochemical surveys as an indicator of concealed sulfide mineral deposits. Sulfur dioxide (SO_2) has been suggested as an indicator of oxidizing sulfides.

Gaseous decay products of uranium minerals, namely radon and helium, have received considerable attention as geochemical indicators of uranium mineralization. Concentrations of radon and helium in soil gas have successfully indicated concealed deposits of uranium minerals. The practical use of helium in this manner is, however, restricted by the difficulty of preventing atmospheric contamination of soil gas samples. Radon had proved a more useful indicator of uranium since the alpha particles produced by its decay can be accurately measured by a variety of techniques. Interpretation of soil gas radon anomalies is, however, frequently complex. Radon determination in stream water has been used successfully in regional exploration for uranium.

Airborne gamma-ray spectrometers have been extensively used in prospecting for radioactive minerals. Such equipment is capable of discriminating between the radiation produced by uranium, thorium, and potassium-40 (^{40}K). The use of surface and airborne particulates as sampling media shows promise, particularly for strategic exploration in regions such as deserts, where conventional stream sediment prospecting may not prove effective. See also: [Gamma-ray detectors](#)

Isotopic surveys

These surveys are applicable to elements which exist in two or more isotopic forms. They employ the ratios between lead isotopes such as ^{204}Pb , ^{206}Pb , ^{207}Pb , and ^{208}Pb , or sulfur isotopes ^{32}S and ^{34}S to "fingerprint" or indicate certain types of mineral deposits which may share a common origin. Isotopic ratios may also be used to determine the ages of minerals or given rock types and may, thus, assist in elucidating questions of ore formation.

Hydrocarbon prospecting

Geochemistry applied to hydrocarbon exploration differs from that utilized in the search for metallic mineral deposits; the former chiefly involves detection and study of organic substances found during drilling, the latter chiefly involves detection and study of inorganic substances at the surface. Geochemistry may be applied at several stages during exploration of sedimentary basins for hydrocarbons. During the initial stages of exploration, when only a few wells have been drilled, geochemistry can provide valuable information on the petroleum-generating potential of a basin and permit recognition of major source rocks. This is chiefly accomplished by extraction, analysis, and microscopic study of kerogen from rocks sampled by drilling. Kerogen is a complex polymer, formed from organic matter originally incorporated in sedimentary rocks, and is an intermediate stage in the formation of oil and gas. See also: [Kerogen](#)

Once accumulations of hydrocarbons have been discovered, their classification into geochemical families becomes important. This may permit recognition of similar sources, hydrologic histories, timing of generation, pathways of migration, and loci of accumulation. Predictions of hydrocarbon potential in previously unexplored areas

can often then be made. Such geochemical classification is difficult, involving subtle indicators and complex analytical techniques.

The final stages of detailed exploration may involve complex multivariate computer-aided modeling of all available geological, geochemical, geophysical, and hydrological data; the objective would be to determine the ultimate hydrocarbon potential of a given basin. See also: [Petroleum geology](#)

Typical Geochemical Exploration Program

A full-scale geochemical prospecting program for metals would include the following stages:

1. Preliminary evaluation of areas, selected on the basis of available geological data, by sampling and testing intrusive, metamorphic, and sedimentary rocks and by noting the presence of mineralized zones. In this way, a metallogenic province can be identified.
2. Primary reconnaissance and orientation surveys, based on sampling major drainage basins, using water, stream sediment, lake sediment, and heavy-mineral surveys.
3. Secondary reconnaissance surveys based on detailed testing of drainage basins containing anomalous values. Poorly drained areas can be tested by widely spaced sampling of soil and ground waters.
4. Follow-up surveys along dispersion trains or fans to determine the cutoff points and the extent of dispersion patterns. These surveys are normally a combination of stream sediment, heavy mineral, water, and soil testing, but biogeochemical surveys may also be useful. Priority for follow-up surveys should be based on the presence of favorable rocks and geological structures, favorable geophysical indications, and intensity of the geochemical anomaly.
5. Detailed surveys carried out in the vicinity of the suspected metalliferous source by soil or vegetation sampling at closely spaced intervals. Interpretation of the results at this stage generally suggests sites for trenching, sinking of shallow shaft, or drilling to locate the precise source of the body giving rise to the geochemical anomaly. See also: [Geochemistry](#)

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