THE APPLICATION OF SOIL SAMPLING TO GEOCHEMICAL EXPLORATION IN NONGLACIATED REGIONS OF THE WORLD

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Abstract

Early work in the application of geochemistry to mineral exploration revealed evidence of a simple and direct relationship between geochemical patterns in residual soils and those in the underlying bedrock. Many geochemical features are common to soils developed under a wide range of physical and climatic conditions and thus permit the widespread use of geochemistry in exploration. A simple model, based on the ideal pattern, can be applied extensively in the unglaciated regions of the world, provided attention is given to the well understood and documented distortions caused by mechanical movement and hydromorphic dispersion. Significant differences are, however, noted in various places and the prime objective of the exploration geochemist is to correctly recognize these situations and to select techniques of sampling, analysis and interpretation to accommodate them. Under extreme circumstances geochemistry is not effective and its use should be avoided.

In this paper a review is presented of the application of geochemistry in nonglaciated soil environments. The basic geochemical characteristics of these soils are illustrated by the use of idealized models and case histories from around the world. Particular attention is given to effects which create conditions that differ markedly from the idealized situation, including leaching, seepage anomalies, calcrete development, duricrusts and the effects of transported overburden such as alluvium, blown sand, landslides and volcanic ash. In establishing methods, careful consideration must be given to variables such as optimum grain size, soil horizon to be sampled, analytical extraction employed, choice of elements to be analyzed and the interpretation of the various parameters measured and observed.

Résumé

Les premiers travaux sur l'application de la géochimie à la recherche de minéraux démontrent qu'il existe une relation directe entre les compositions géochimiques dans les sols résiduels et celles de la roche en place sous-jacente. Beaucoup de particularités géochimiques sont communes aux sols qui se sont formés par suite d'une grande variation des conditions climatiques et physiques, ce qui a permis l'utilisation considérable de la géochimie dans les travaux d'exploration. Un modèle simple, basé sur la composition idéale, peut étre appliqué, à grande échelle, dans les régions de la terre qui ont échappé aux glaciations, à condition de tenir compte des déformations causées par le mouvement mécanique et par la dispersion hydromorphique, qui ont déjà été constatées et appuyées par de nombreux documents. Toutefois, les auteurs remarquent des différences importantes dans divers emplacements et l'objectif premier du géochimiste est de savoir reconnaître parfaitement ces phénomènes et de choisir des techniques d'échantillonnage, d'analyse et d'interprétation qui conviennent. Dans des circonstances exceptionnelles, la géochimie n'est pas efficace et il faut éviter de l'utiliser.

Les auteurs présentent, dans ce rapport, un aper u de l'application de la géochimie à des milieux qui n'ont pas subi l'action des glaciations. Les particularités géochimiques de base de ces sols sont définies par l'utilisation de modèles optima et de dossiers provenant de toutes les parties du monde. On accorde une attention toute spéciale à des effets générateurs de conditions qui diffèrent passablement de la situation optimale, et qui comprennent le lessivage, les anomalies d'infiltration, la croissance de croûtes calcaires, les croûtes concrétionnées et les effets de la surcharge transportée comme l'alluvion, le sable éolien, les glissements et la cendre volcanique. Lors de l'élaboration des méthodes, il faut tenir compte tout particulièrement de données comme le grain de dimension optimale, l'horizon à échantillonner, le type d'extraction analytique utilisée, le choix des éléments à analyser et l'interprétation des différents paramètres mesurés et observés.

INTRODUCTION

At an early stage in the development of exploration geochemistry it was established that systematic sampling and analysis of soil, where the soil is residual and mineralization is not covered by younger rocks or transported overburden, represent a straightforward and generally reliable method of locating sub-outcropping mineralization. Furthermore, although geochemical anomalies developed in soils under these conditions may be distorted by downslope creep, seepage, and leaching, geochemical techniques for the reliable interpretation of these problems exist. This relatively simple condition probably prevails over as much as 70 per cent of the unglaciated areas of the earth's surface and undoubtedly there are still many places where straightforward collection and analysis of soils will lead to the discovery of new mineralization. However, as exploration

continues in any area, sooner or later the geologist is faced with the problem of exploring where the soils are of transported origin (e.g., alluvium, windblown sand, volcanic ash, and landslides) and/or the mineralization is blind under a younger rock cover. (In this paper the term buried deposits refers to those under transported overburden of remote origin while blind deposits are those covered by younger rock.) The correct identification of the presence of such conditions is the first and by no means always simple task of the exploration geochemist. Geochemical methods must then be adapted to meet the challenge of these areas.

This paper reviews the use of geochemistry in areas of residual soil and also examines the role of geochemistry in the more complex environments of transported overburden and blind mineralization. Extensive use of geochemistry over the last ten years has provided sufficient evidence for the confident application of techniques under a wide range of well defined environments. The basic concepts formulated in the early 1960's (Hawkes and Webb, 1962) have been largely proven correct. Advances in the science have refined the application of geochemistry in residual soil environments to the point at which specific procedures may be recommended for particular exploration problems.

RESIDUAL SOILS

Geochemical Anomalies in Residual Soils

During the normal process of weathering and soil formation, trace elements present in the bedrock become incorporated into overlying residual soils. Similar processes prevail over mineralization where the high trace element content of an orebody gives rise to the presence of anomalously high values in overlying residual soils.

As stated in the introduction, the location and identification of these anomalies in residual soil environments represents the most straightforward and direct geochemical method of locating mineralization. The success of this approach is evidenced by an extensive literature of case histories from around the world including Africa — Tooms and Webb (1961); Cornwall (1970); Ellis and McGregor (1967); Philpot (1975); Reedman (1974); Australia — Mazzuchelli (1972); Cox (1975); Mazzuchelli and Robbins (1973); the Southwest Pacific — Coope (1973); Govett and Hale (1967); Asia — Dasgupta (1963); Yellur (1963); Chakrabarti and Solomon (1970); South America — Lewis (1965); Lewis et al. (1971); Montgomery (1971); Thomson and Brim (1976) and North America — Worthington et al. (1976). Indeed, local workers have found indications that, in strictly residual soil and over-limited geographic areas, the strength of a soil geochemical anomaly may be directly related to the grade of mineralization in underlying fresh rock (Ong and Sevillano, 1975; Saigusa, 1975; Tooms and Webb, 1961; Nicholls et al., 1965).

The typical distribution of trace elements in soils overlying base metal sulphide mineralization is shown in Figure 14.1. The normal incorporation of metals in the soils results in the "fan-shaped" distribution depicted. The near-surface part of this fan is generally considerably wider than the soil anomaly near the rock contact. In flat areas the fan is typically symmetrical, while on slopes the fan spreads downslope (by mechanical means) as depicted in Figure 14.1.

The usefulness and importance of soil profile sampling to detect the exact location of the source of the anomaly is frequently overlooked in the application of exploration geochemistry. In a simple fan-shaped anomaly a soil profile taken directly over mineralization shows a geochemical response which remains about the same, or increases with depth, whereas to one side of the anomaly the values decrease with depth. This not only provides much more

precise definition of the exact source of the anomaly, but can also give an indication of the orientation of the source. For example, Figure 14.2 from Granier (1973) shows the distribution of copper and gold in a deep tropical soil profile over vein-type mineralization in the Ivory Coast. This example illustrates the manner in which a very broad anomaly at surface, distorted by downslope creep and local chemical redistribution, can be reduced to a narrow anomaly at depth closely related to the location of the mineralization. In addition, a measure of the dip of the vein can be obtained from the soil profile data. The extent to which information obtained from soil profiles can clarify the geochemical nature of an anomaly, its origin and geological relationship is further illustrated by Koksoy and Bradshaw (1969); Montgomery (1971); Granier (1973); Bradshaw et al. (1974) and is well explained by Hawkes and Webb (1962).

As indicated by the above example from the Ivory Coast, provided the soil is residual, a considerable depth of weathering does not necessarily destroy the surface soil response.

In all the examples quoted above, significant and readily identifiable anomalies were located directly over sub-outcropping mineralization. It is important to note in the interpretation of geochemical data that, except where a soil anomaly is modified by some of the processes indicated in later sections of this paper, the anomaly is related to the sub-outcrop of any mineralization and not necessarily the greatest thickness, highest grade, maximum sulphide concentration, etc. of mineralization. This is well illustrated by the work of Scott (1975) at Otjahase, Southwest Africa, where a strong soil anomaly was located over the sub-outcrop of copper-zinc mineralization. The best grades and highest content of sulphide mineralization are, however, between 100 and 150 m downdip resulting in an apparent separation of up to 200 m between the soil geochemical anomaly and the surface projection of the main body of mineralization.
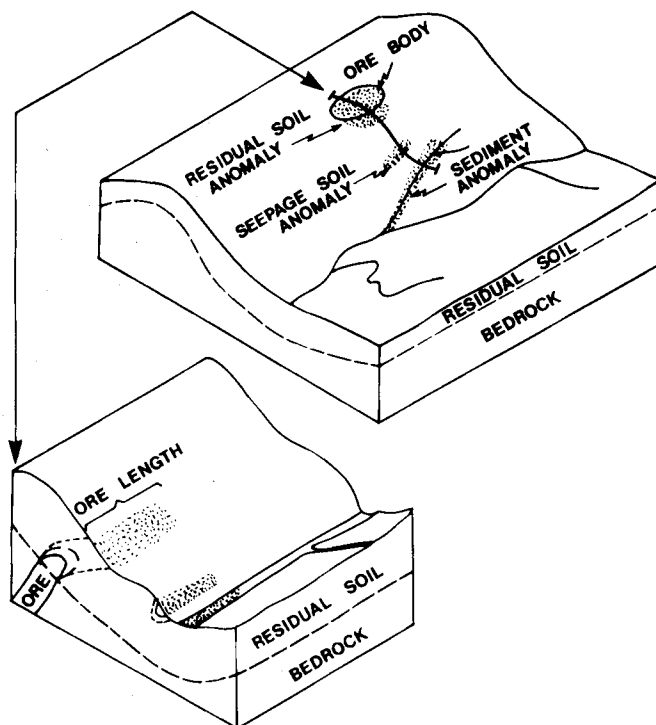

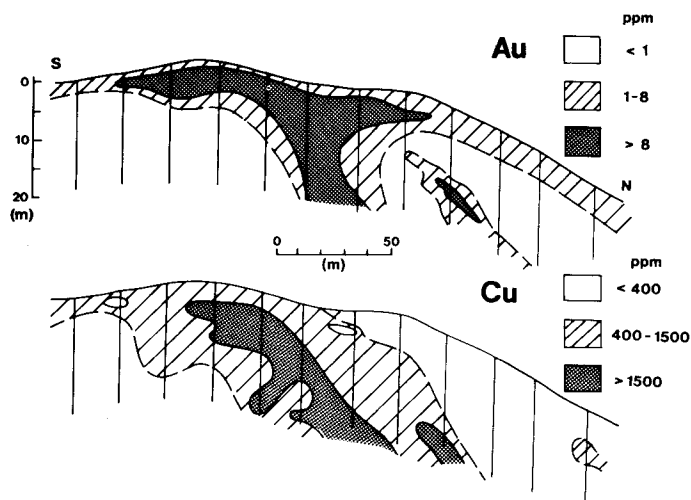*Figure 14.1.*   *Idealized diagram – geochemical anomalies in residual soil over mineralization.*

Figure 14.2. *Section showing the lateral distribution of gold and copper in residual lateritic soil over a gold-copper vein, Ivory Coast (after Granier, 1973).*

Similar relationships often lead to a spatial displacement of geophysical and geochemical anomalies, a fact that can be confusing at first sight. Electromagnetic anomalies, for example, have the strongest response over the greatest conductivity-thickness of a sulphide body (although the strength of the EM anomaly is also modified by the depth of the source). It is evident that, where mineralization has a shallow dip and oxidation has taken place to some depth, there can be a considerable relative separation of the geochemical and geophysical anomalies.

When mineralization sub-outcrops on a slope, the resulting soil anomaly is invariably distorted or displaced downslope by mechanical movement. The degree of displacement may not always be appreciable, but can in some cases have a significant effect on interpretation. However, as shown in Figure 14.2, the distance of downslope displacement and hence the location of the source of the anomaly can usually be accurately determined by soil profile sampling.

Seepage Anomalies

In addition to the incorporation of metals into soil by in situ weathering, a portion of the metals goes into solution in the groundwater and is dispersed in the direction of groundwater flow. (This is normally termed hydromorphic movement.) Around oxidizing sulphide mineralization the groundwaters are typically acidic (as a result of decomposition of the sulphides) and relatively reducing, two conditions which promote solubility of most metals. These metals stay in solution until a change in geochemical environment is encountered. Such a change occurs where the groundwaters come out in streams or lakes. In this case much of the metal is precipitated from solution into the lake or stream sediment resulting in anomalies in these media.

Groundwater can also reach the surface in a variety of other locations where, in response to the change in geochemical environment, metals come out of solution and are precipitated. On occasions, very large concentrations of metals may accumulate in the soil (Fig. 14.1). The principal location of such seepages are at breaks of slope and in low-lying areas, marshes, bogs, etc., although recognition of seepage zones in the field can sometimes be extremely difficult. This process results in the formation of

hydromorphically transported anomalies which, although related to mineralization, occur spatially separated from it and often create interpretation problems. These anomalies are frequently very much more intense than the residual anomaly directly over the source. For example, Webb and Tooms (1959, also quoted in Hawkes and Webb, 1962, p. 251) show seepage anomalies 1000 m downslope from known mineralization approximately 10 times stronger than the residual anomaly directly over the mineralization. Seepage anomalies are frequently encountered in humid environments and display a wide range of form and occurrence (Woolf et al., 1966; Cole et al., 1968) with their topographic position often an indication that they are hydromorphic features.

Soil profile sampling is of great assistance in the recognition and discrimination of seepage anomalies. Invariably seepage anomalies are of restricted extent and limited to the near-surface part of soil profiles having no "root" in mineralization. Furthermore, systematic profile sampling of a seepage area may reveal an asymmetry of metal distribution patterns indicating from which direction the metal entered the seepage zone.

An alternative approach to distinguishing residual and seepage anomalies is by the use of different analytical extractions (Hawkes and Webb, 1962). The hydromorphically transported metals tend to be present in secondary minerals with weak bonding and adsorbed or absorbed on the soil material. This metal is easily removed by a weak analytical extraction (such as EDTA) and contrasts with residual anomalies in which metals are typically firmly bonded (Bradshaw et al., 1974). Seepage anomalies are thus often characterized by high absolute values and/or a high percentage of weakly extractable metal.

Soil Differentiation

Weathering processes, both mechanical and chemical, may lead to modification of geochemical patterns between horizons within the soil. Soils typically display both a physical and chemical layering which may be very weakly developed and indistinct in some areas, with no significant effects on the geochemical patterns, or is visibly well developed in other areas, with a strong control on the distribution of metals. To minimize potential problems systematic sampling should be restricted to a single horizon. The so-called B horizon has become the preferred sample medium in routine soil surveys throughout the world. Generally speaking this is a sample collected at a depth of 10-30 cm below any zone of organic accumulation, in a constant horizon (rather than depth) recognized within any one area by distinctive colour or texture. Although the scheme may be modified to suit local requirements, normally only certain extreme conditions require a radical change in soil-sampling procedures. For example, in immature regolithic soils there may be no differentiation at all and thus no preferred sample depth. In other areas surface leaching may be such that a reliable geochemical signature can only be obtained by taking a sample at considerable depth. Also, in the presence of a thin layer of transported material overlying residual soil (alluvium, colluvium, blown sand, etc.) samples may be taken from deeper levels below the exotic overburden. Within the nonglaciated parts of the world a wide range of soil types are encountered. Fortunately, it is not necessary to give a detailed account of the geochemical characteristics of all these soils since the general principles of anomaly formation presented in this paper hold true in the majority of soil types. To illustrate the application of exploration geochemistry under changing residual soil conditions further consideration is given to leached soils and the effects of calcrete development.

Leached Soils

Under certain climatic and topographic conditions, trace elements become leached from surface soils. This condition has been the subject of intensive study over the last ten years and, with understanding, methods have been developed for exploration in these areas. Extensive work, particularly in Western Australia, has shown that despite strong leaching some contrast frequently persists between the metal content of residual soils developed over mineralization and unmineralized rock. As a result, although absolute trace element values may be very different from unleached soils, discrete anomalies related to mineralization may still be discerned, typically with reduced contrast (Scott, 1975; Lord, 1973; Butt, 1976). On occasion leaching can be so intense that the trace element content of residual soils is depleted to the point that no recognizable anomaly exists. This is certainly true for the more mobile elements such as copper and zinc. The metals may be redeposited lower down, forming a zone of secondary enrichment, or be completely removed from the area.

An example of the effects of severe surface leaching is shown by the work of Learned and Boisen (1973) who studied the geochemical response in soils over several porphyry copper prospects in Puerto Rico. In one instance, copper was so leached from residual soils developed on porphyry-copper mineralization that no recognizable copper anomaly could be found. However, it was found that gold, associated with the copper mineralization, formed a significant soil anomaly, undoubtedly because its low chemical mobility prevented its removal from the soils.

Further examples are provided by Nickel et al. (1977) and Butt and Sheppy (1975) from studies of nickel deposits in the Agnew area in Western Australia. In these cases, leaching has removed nickel from the near-surface soil and deposited at least a portion in a zone of secondary enrichment at depths of from 20 to 50 m. In southeastern United States, Worthington et al. (1976) reported that soil geochemistry usually faithfully reflects metal concentrations in the bedrock despite the soils being leached. Anomalies are, however, weaker in the soil than in bedrock.

It is evident that all degrees of surface leaching can occur from insignificant to complete. When severe leaching is expected, routine geochemical practice is to analyze for associated or pathfinder elements such as gold, lead, molybdenum, arsenic, selenium, tin, tungsten and platinum which are less mobile or immobile under the conditions encountered and thus unlikely to be completely removed from the soil.

Calcrete

Calcrete or caliche is a commonly encountered soil development in arid areas, but has generally been ignored or avoided as media for geochemical sampling and its use is virtually unreported in the literature. Calcrete is composed of a cementing and/or replacing carbonate, usually calcite, which can form in almost any type of pre-existing soil by deposition from the soil water (Netterberg, 1971). Physically it can take many forms including powdery disseminations, nodules, pellets, boulders or massive layers. Furthermore, the relative proportions of calcite and host soil may vary considerably over short distances.

Figure 14.3 shows the results of sampling residual soils containing calcrete developed over copper-lead-zinc mineralization at Areachap in the desert environment of the Northern Cape Province of South Africa (Danchin, 1972). The nature of the calcrete varies from a dense massive variety containing occasional quartz and jasper pellets, through powdery to lumpy. There is also a well developed calcretized mixed zone above the bedrock containing relict bedrock

fragments in various stages of decomposition with oxidized copper sulphides and copper staining. This sequence was carefully sampled and analyzed for total copper and zinc. Sampling was also carried out through similar calcrete profiles over nickel-copper mineralization in ultrabasic rocks at Jacomyns Pan approximately 120 km from Areachap.

Profiles from both areas show similar results with concentrations of the ore elements decreasing steadily upwards from bedrock to the surface through the calcrete. However, the surface of the calcrete is still anomalous over the mineralization and systematic grid sampling of the uppermost layer of calcrete in these areas delineated the underlying mineralization. The situation is further complicated at Areachap where the top 15 cm of soil above the calcrete is largely composed of windblown material of remote origin which masks any geochemical response from the mineralization. (The complications of windblown sand are discussed in more detail in a later section.) Cox (1975) examined residual soil profiles containing calcrete over nickel-copper mineralization at Pioneer near Norseman, Western Australia. He found that systematic sampling and analysis of the upper surface of the calcrete reflected both the underlying mineralization and lithology. However, both here and in South Africa, the contrast between anomalies over mineralization and background is much lower in the surface calcrete samples than in samples of bedrock. In this case the calcrete horizon is 0.5 - 1.5 m thick.

Worldwide experience in the sampling and the analysis of calcrete in geochemical exploration is limited. However, it appears that certain generalizations can be made. The carbonate material is a secondary precipitate and acts as a dilutant to the original trace element content of the pre-existing soil. Thus in residual soils, as in the examples quoted, the presence of calcrete depresses absolute trace element values and leads to a reduced anomaly contrast. In areas of thin calcrete or where the carbonate represents only a minor portion of the total soil, anomalies related to mineralization and rock types are preserved in the near-surface soil. However, it is probable that where calcrete development is very thick or dominates in the soil, geochemical anomalies may be so depressed that they cannot be discerned using conventional techniques.
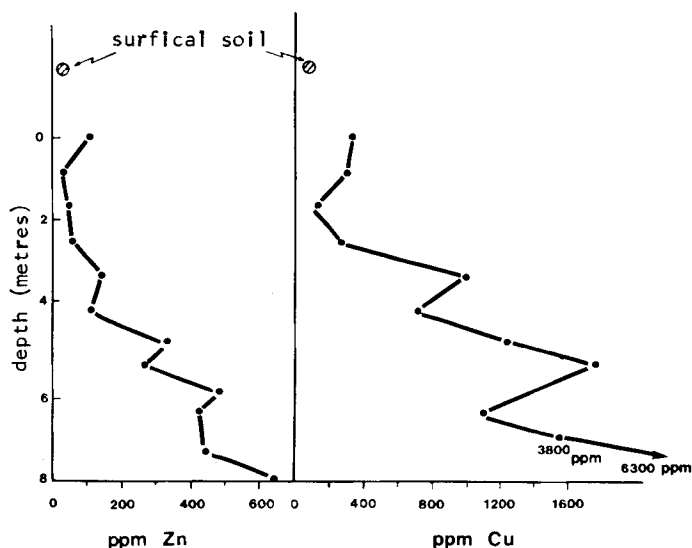

Figure 14.3. Distribution of copper and zinc in soil profile through calcrete over copper-zinc mineralization at Areachap, South Africa (with permission of the Anglo-American Corp.).

The problem can be further aggravated by the presence of several layers of calcrete in the soil. Usually it is only in the lowest calcrete horizon that a reliable geochemical response related to the underlying mineralization may be obtained.

In soils of transported origin (alluvium, colluvium, etc.) trace element distribution patterns will be determined by the composition of the parent material and modified by the presence of the carbonate material. Such soils will not normally show any geochemical patterns related to underlying mineralization.

Duricrust

The terms duricrust, ferricrete and canga are used to describe a hard indurated crust, cap, layer of pellets or nodules formed by dehydration of the upper part of a lateritic soil. The loss of water causes the collapse of the phyllosilicate (clay) lattice and results in a restructuring of the soil constituents into compact, hardened sesquioxides and iron-rich concretionary material. Duricrust forms preferentially on well-drained hills or at the margin of larger hills and plateau surfaces. In the latter situation, the duricrust commonly is thickest close to scarps at the margin of the upland surfaces and is progressively thinner away from the edge. The formation of duricrust is apparently an irreversible process and should drainage or climatic conditions change the duricrust will not revert to a lateritic or other new soil profile.

Duricrust commonly inherits the general geochemical characteristics of its parent material, usually with some modification in the absolute levels of trace elements. For example, Tooms et al. (1965) working in Sierra Leone found that the projection of mineralized veins could be traced in the duricrust horizon of lateritic soils as molybdenum maxima of similar magnitude to those in weathered bedrock. In nearby background areas, however, molybdenum levels are higher in duricrust than in underlying weathered bedrock and contrast between mineralization and background is much lower in the duricrust. In direct contrast the indurated portion of a lateritic profile may become leached and create the problems for geochemical exploration described earlier.

Duricrust resists weathering processes and tends to persist on hills and plateau surfaces as less competent unindurated soil is eroded. This can lead to the formation of fossil duricrusts perched, capping or surrounding younger soils as found over large areas of Western Australia (Butt and Sheppy, 1975). Prolonged erosion and scarp retreat result in the formation of transported detrital duricrusts covering pediment and plateau surfaces, notably in parts of Western Australia (Butt and Sheppy, 1975), central Brazil, and central Africa. Under such conditions geochemical continuity between the duricrust and adjacent residual soils is poor or nonexistent.

Direct comparison of duricrust and residual latosols and other unindurated soils is often difficult and may be impossible. For most routine surveys it is thus recommended that data obtained from duricrust soils be interpreted separately from other soils data.
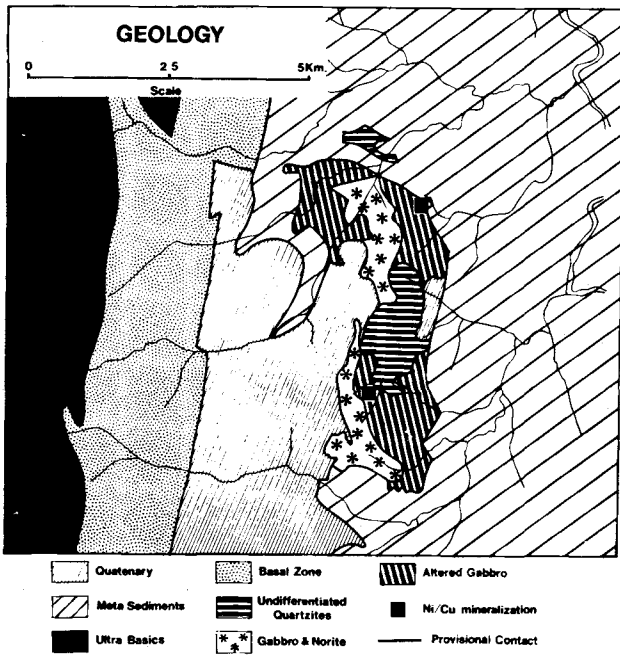
LITHOLOGICAL ANOMALIES OR FALSE ANOMALIES

The trace metal content of unmineralized rocks is usually uniformly low with respect to mineralization. However, this is not always the case. For example, the high content of nickel, copper and chromium in ultrabasic rocks, zinc and molybdenum in black shale and uranium in many granites, frequently gives rise to anomalies in residual soils which can have the same magnitude as anomalies related to potentially economic sulphide or oxide mineralization.

Although basic intrusives and shale are the most frequently encountered sources of false anomalies related to distinctive lithologies, rather than mineralization, they are by no means restricted to these rock types.
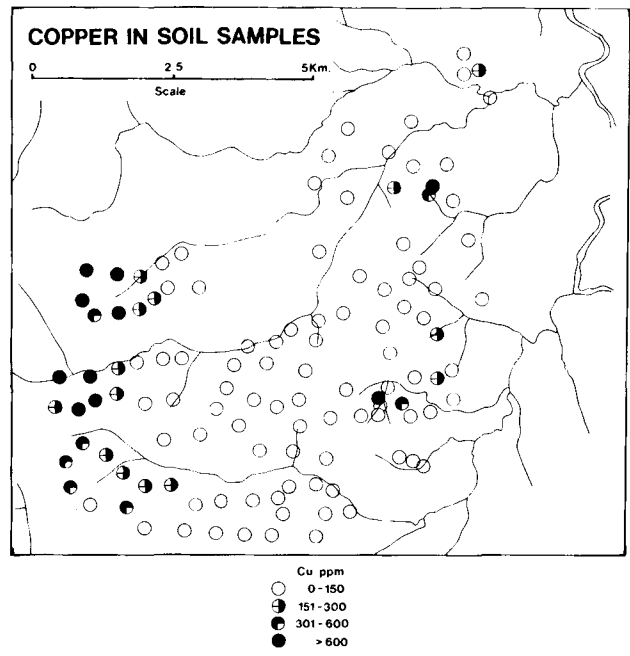
An example of soil anomalies related to both rock type and sulphides is provided by work from Brazil (modified from Thomson, 1976) in which soil sampling was carried out over part of the Niquelandia ultrabasic complex and a small altered gabbro body, both of which are intruded into Precambrian schists. Two small bodies of nickel-copper sulphide mineralization are known in the eastern gabbro at locations shown in Figure 14.4; no significant sulphide occurrences have been found in the ultrabasic rocks. The results for total nickel and copper in soils, also shown in Figure 14.4, reveal a very strong and areally large response over the ultrabasic rocks and much smaller and generally weaker anomalies related to sulphide occurrences. On the basis of individual metal distribution patterns alone, it is not possible to distinguish the barren ultrabasic rocks characterized by high concentrations of copper and nickel held, most probably, in the lattice of the silicate minerals from the nickel-copper sulphide mineralization. In this case, anomalies related to mineralization may be differentiated from those related to rock type by the use of metal ratios. In the Niquelandia area, the sulphides are high in copper with respect to nickel contrasting with the ultrabasic rocks in which the nickel is high with respect to copper. Consequently, a change in the copper-nickel ratios (Fig. 14.4) clearly identifies the sulphide mineralization with a further minor anomaly to the west over the ultrabasic rocks. (In the present case, the copper-nickel ratio anomaly in the ultrabasic rocks has not been followed up and its cause is not yet known. Nevertheless, the area of interest requiring follow-up has been significantly reduced by the use of metal ratios.) The fact that the soils in this area are residual is well demonstrated by Figure 14.5 which shows profile samples taken over barren schist, unmineralized altered gabbro, and sulphide mineralization. The profiles not only illustrate the difference in metal concentrations between contrasting rock types, but also demonstrate that there is no significant variation with depth.

Metal ratios as a means of distinguishing between anomalies related to mineralization and lithology have been used elsewhere. For example, copper-nickel ratios have been found useful in exploring areas of ultrabasic rocks over much of southern Africa and in parts of Western Australia (Cox, 1975; Wilmshurst, 1975).
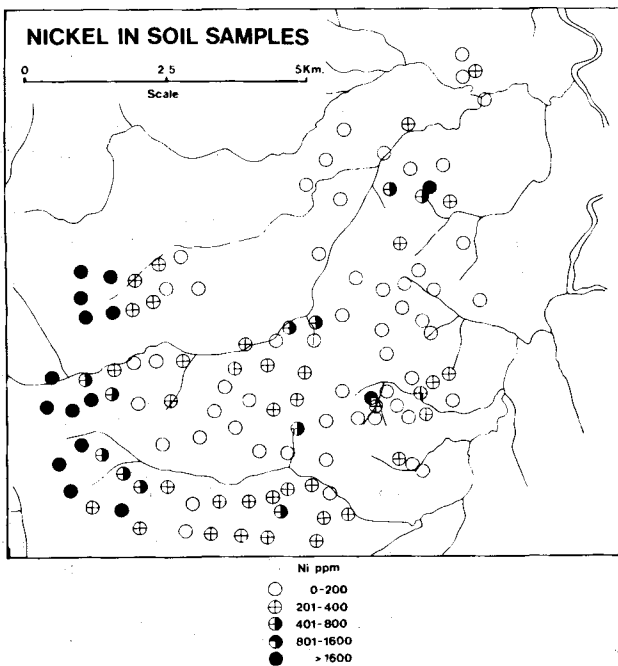
Further assistance in interpretation can frequently be gained by analyzing for elements uniquely associated with either potentially economic mineralization or the unmineralized metal-rich lithology. For example, in the case of nickel-copper mineralization in ultrabasic rocks, cobalt is frequently concentrated in the sulphides in contrast to chromium which occurs either with silicate minerals or as a separate oxide phase (chromite). Consequently, a nickel-copper anomaly high in cobalt, low in chromium, can be up-graded and a similar nickel-copper anomaly, low in cobalt and high in chromium could be downgraded. Wilmshurst (1975) working in Western Australia found platinum, palladium, arsenic and zinc useful pathfinders related to sulphide mineralization and unrelated to barren ultrabasic rocks. Clema and Stevens-Hoare (1973) also working in Western Australia, demonstrated multi-element relationships capable of differentiating leached cappings over nickel sulphides from those developed over unmineralized iron-rich rock types. Experience has shown that once metal associations have been established in one part of a mineral belt, the same associations apply throughout the whole belt and can be used with some reliability (Moeskops, 1977). However, while
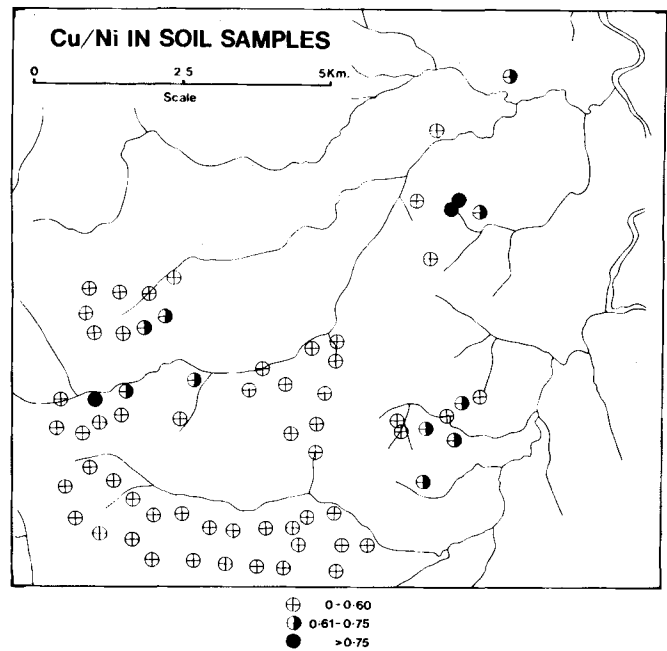
A

C

B

D

a. Geology
b. Distribution of nickel in near-surface soil samples

c. Distribution of copper in near-surface soil samples
d. Copper/nickel ratio in near-surface soil samples (after Thomson, 1976)

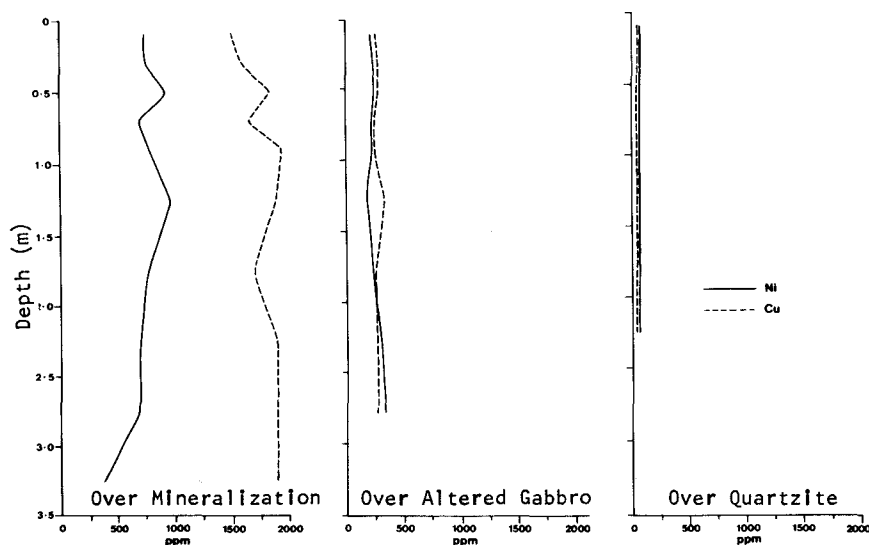**Figure 14.4.** The Niquelandia area, Goias, Brazil.

Figure 15.5. *Vertical distribution of copper and nickel in profiles through residual soils over copper-nickel sulphide mineralization, altered gabbro, and quartzite, Niquelandia area, Goias, Brazil (after Thomson, 1976).*

experience with one mineral belt can assist in determining which associated metals are likely to be of greater assistance in a new belt, these associations must always be confirmed before they are relied upon too heavily.

More recently, workers in Australia have found that the mode of occurrence of nickel and copper in lateritic soils derived from sulphide mineralization is different from similar soils developed over barren rock types. Smith (1977) reports that the association formed by nickel and copper with iron oxides in the lower part of lateritic soil profiles developed over sulphide mineralization is distinct from that found over barren rocks. The use of appropriate selective analytical extraction techniques permitted good discrimination between a sulphide and silicate origin for the raised concentrations of these metals in soil. Studies of this type will no doubt lead to better methods of discriminating anomalies in other geological and climatic environments.

TRANSPORTED SOILS AND BLIND MINERALIZATION

Geochemical Anomalies in Transported Overburden

Any material of remote origin, be it a cover of postmineralization rocks or transported detrital overburden, will usually mask all conventional geochemical expression of the mineralization in overlying soils. (The word conventional is stressed since techniques are under investigation which, at least in limited applications, have provided surface geochemical anomalies through significant thicknesses of bedrock and transported overburden.) The condition is illustrated in Figure 14.6, an idealized model of geochemical dispersion processes from mineralization covered by transported overburden.

There are very few published accounts of "negative" case histories in which soil geochemistry failed because of the presence of transported overburden or postmineralization cover although many certainly exist in company files. Ullmer (1978), however, reports that he found no geochemical response in surface soils over the Sacaton porphyry copper deposit in Arizona where the mineralization is covered by up to 20 m of transported sand and gravel.

The masking affects of an exotic covering thus require modifications in the application of exploration geochemistry techniques (Horsnail and Lovestrom, 1974 and Lovering and McCarthy, 1978) and soil sampling may have no role at all. It is of primary importance, however, that the presence of any cover be recognized otherwise totally erroneous interpretations will be made of soil geochemical data.

The presence of an exotic cover need not necessarily eliminate the application of soil geochemistry. The cover may be discontinuous permitting the positive application of soil sampling in the intervening areas of residual soil. Circulating groundwaters may reach the surface in seepage zones producing hydromorphically transported anomalies related to concealed mineralization. Alternatively, local dispersion processes may permit the upward migration of metal with soil water into the overburden to give anomalies in transported soils directly over mineralization such as those reported by Brown (1970). It is also possible that plants, penetrating the exotic cover, will bring metals up into their foliage which then accumulates in the topsoil when the plant dies giving rise to geochemical anomalies in surface soils over the mineralization.

Alluvium and Colluvium

Alluvium and colluvium are the most readily recognized and most frequently encountered forms of transported overburden. Both materials effectively mask any response from the bedrock and it is essential that the distribution of
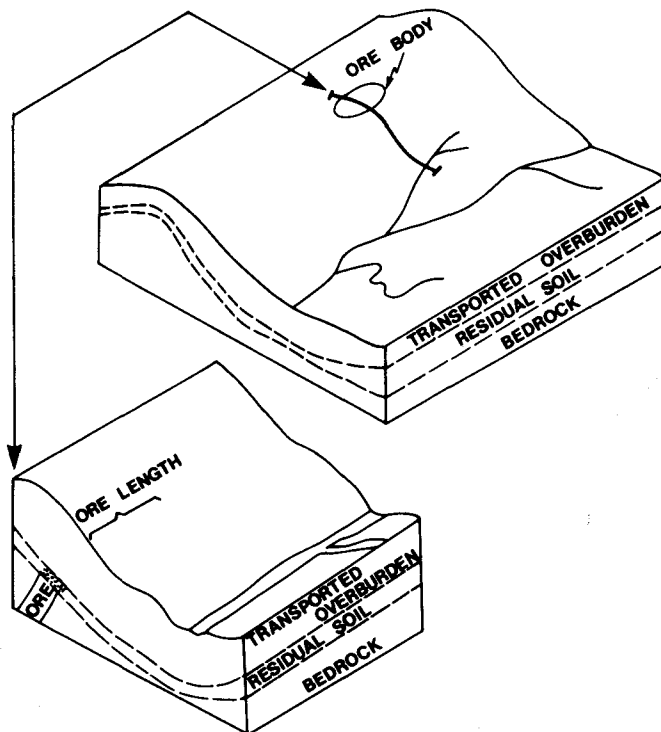

Figure 14.6. *Idealized diagram – geochemical anomalies in transported overburden over mineralization.*

any such deposits be determined before interpreting soil geochemical data. Chaffee and Hessin (1971) working in Arizona found that soil sampling and analysis for total copper and zinc faithfully reflected the distribution of metals about the Veikol Hill porphyry copper deposit where the soils are residual. However, as soon as 0.5 - 1.5 m or more of alluvial sand and gravel was encountered all response from the underlying mineralization was effectively masked.

Colluvium can be very much more variable than alluvium and range from a minor component of soil, diluting local geochemical patterns, to a complete cover masking all bedrock response. Cox (1975) noted that colluvial material, introduced by sheet wash, is present in some soils at Pioneer, Western Australia. This material dilutes metal values and reduces the contrast of anomalies over copper-nickel sulphides. At the other extreme, Leggo (1977) observed that landslip deposits of stabilized mud avalanche material below steep mountain slopes in Fiji completely mask part of an area of porphyry copper mineralization except where there are windows on ridges and beside streams that have cut through the cover.

Alluvial areas may coalesce to produce extensive valley gravel deposits such as those found in the southwestern United States or merge into lake beds. Playa lakes are found in arid environments 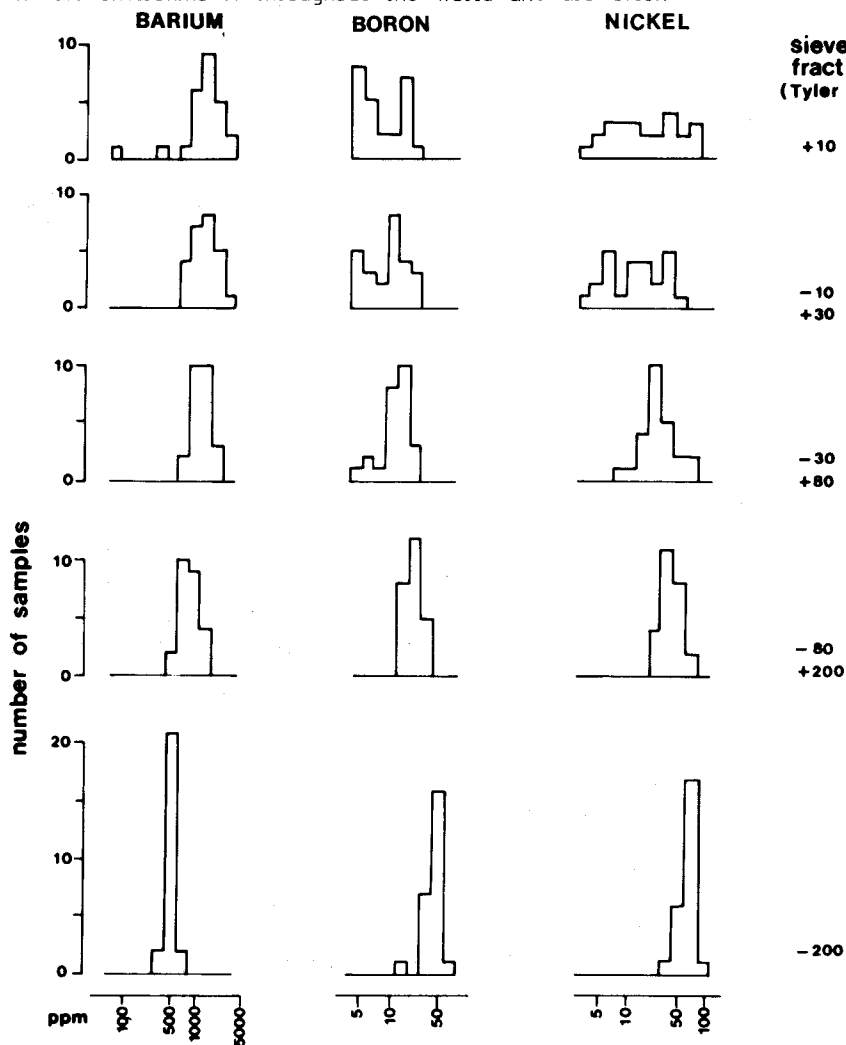throughout the world and are often characterized by Solonchak soils or the development of calcrete. Regardless of the degree to which secondary precipitates may cement or replace these soils it is important to realize that trace element patterns are primarily determined by the initial chemistry of the alluvial sediments. While this material may reflect the geochemistry of the catchmnet area it is unlikely to be able to directly delineate underlying mineralization and is not a useful medium for soil sampling.

Windblown Sand and Loess

Soils over large areas of the world contain at least a portion of windblown material. It must be stressed that, although the geochemical problems in areas of dune sand are obvious, soils in many semi-desert and open plain areas contain a high proportion of windblown material which can cause difficulties.

Aeolian or windblown material tends to be chemically uniform and is usually geochemically featureless. The main effect of the presence of this material in residual soils is to dilute the local geochemical patterns, (Bugrov, 1974; Cox, 1975; Scott, 1975). Bedrock sampling may be used in areas where this dilution is extreme or the overburden is composed entirely of aeolian detritus. However, soil sampling can continue to be of value if the effects of the aeolian material can be removed. Normally only the finer particles of soil (less than 200 μm or approximately 80 mesh) can be moved great distances by the wind. Thus, under most circumstances the effects of dilution by windblown sand can be removed by sieving out the fine fraction of soils.

The character of the problem is well illustrated by the work of Theobald and Allcott (1973) in Saudi Arabia. Figure 14.7 shows the results of analysis of different size fractions of surface samples collected along a traverse over the Uyajah Ring structure. The area is desert with little evidence of a true soil development and most surficial material is sandy-stony regolithic debris with local dune sand accumulations. The data shown in Figure 14.7 reveal consistent distribution patterns which are typical of all elements in the area. There is a conspicuous lack of variation in the finest size fraction which the authors attribute to the homogenizing effect of aeolian material which is predominant in the size range. In progressively coarser fractions there is an increase in the variability of the analytical data. This is interpreted as reflecting a steady increase in the proportion of material derived from the local geology. Indeed, subsequent regional sampling using the -10 +30 mesh fraction was found to reliably define the geology of the ring complex and remove the effects of dilution by windblown material. However, Theobald and Allcott (1973) found that anomalies related to molybdenum-tungsten mineralization could be further enhanced by analysis of nonmagnetic heavy-mineral concentrates recovered from the -10 +30 mesh size fraction. Bugrov (1974) and Bugrov and Shalaby (1975) report similar experience in the deserts of eastern Egypt using the -1 mm + 0.25 mm fraction (-20+70 mesh).

Figure 14.7. *Variation of barium, boron and nickel in surface debris as a function of size fraction, Uyaijah Ring Company, Saudi Arabia (from Theobald and Allcott, 1973).*

These results suggest that for soil sampling the effects of aeolian dilution can be removed by sieving out the fine fraction and anomalies enhanced by isolating the heavy mineral fraction. Experience has shown, however, that geochemical techniques may have to be adapted to suit local conditions. Bugrov (1974) draws attention to the problem of false anomalies produced by the secondary concentration of resistate heavy minerals in depressions in the desert surface. In direct contrast, Brown (1970) found that in areas with a cover of blown sand on the margin of the Kalahari Desert, copper anomalies were developed in the silt fraction of transported soils overlying copper sulphide mineralization. From an examination of the form and distribution of anomalous copper in the aeolian cover, Brown attributed the anomaly development to the seasonal upward movement of metal-bearing moisture through the overburden. Bugrov (1974) also noted an association of copper with clay-sized material in desert soils over mineralization in eastern Egypt.

In general, however, it appears that when aeolian detritus represents a minor portion of the total soil, the diluting effects may be removed by sieving out the fine fraction. Where windblown material is dominant at the surface alternative procedures may have to be applied and consideration given to sampling residual soil material below the aeolian cover or sampling the bedrock itself. The preferred sampling scheme is best defined by an orientation survey.

Volcanic Ash

A covering of volcanic ash is not commonly encountered in exploration programs since it is restricted to areas of active volcanism. It was, however, the principal source of confusion during early evaluation of the Panguna porphyry copper deposit on Bougainville Island (Mackenzie, 1973).
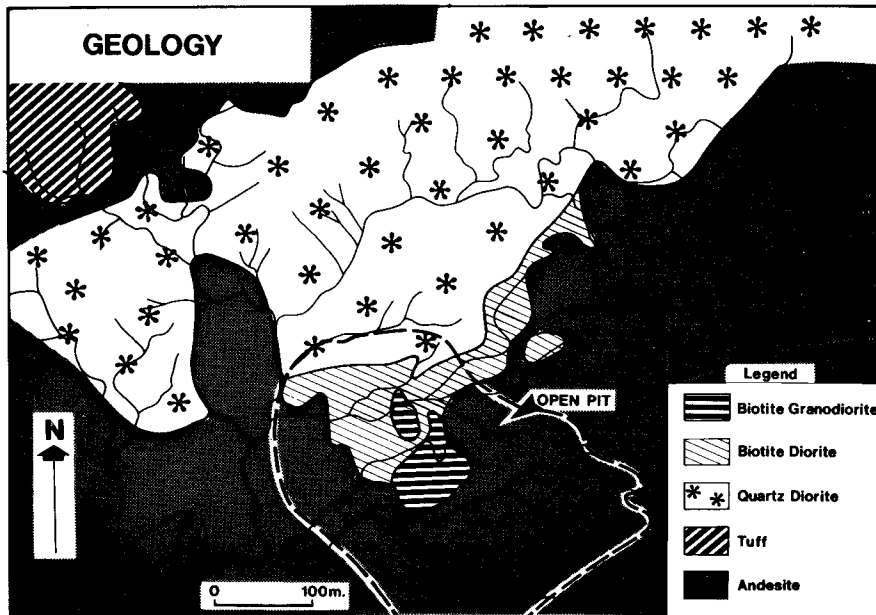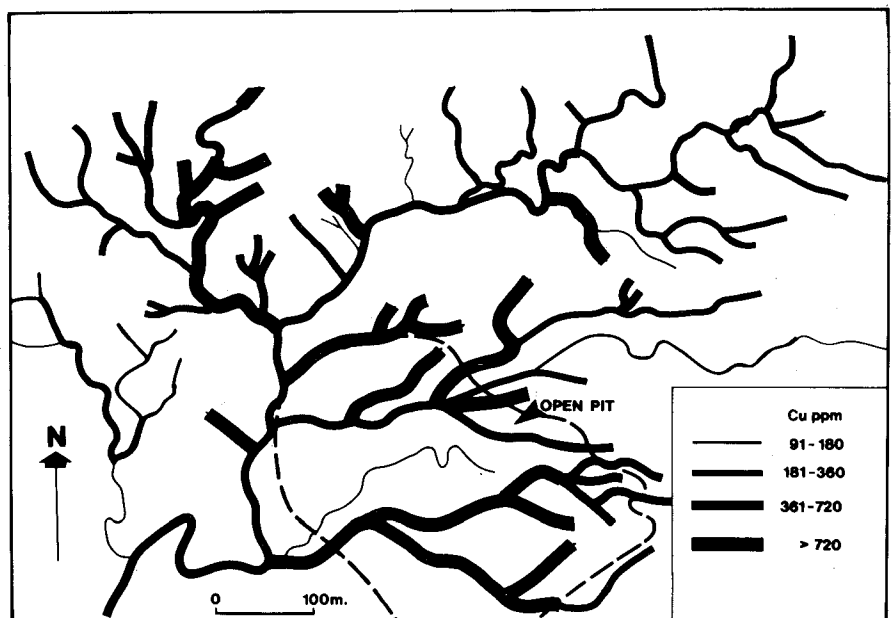

Figure 14.8

Geology of the Panguna area, Bougainville Island (after Baumer and Fraser, 1975).

Figure 14.9

Distribution of copper in stream sediments, Panguna area, Bougainville Island (with permission of RioFinEx).
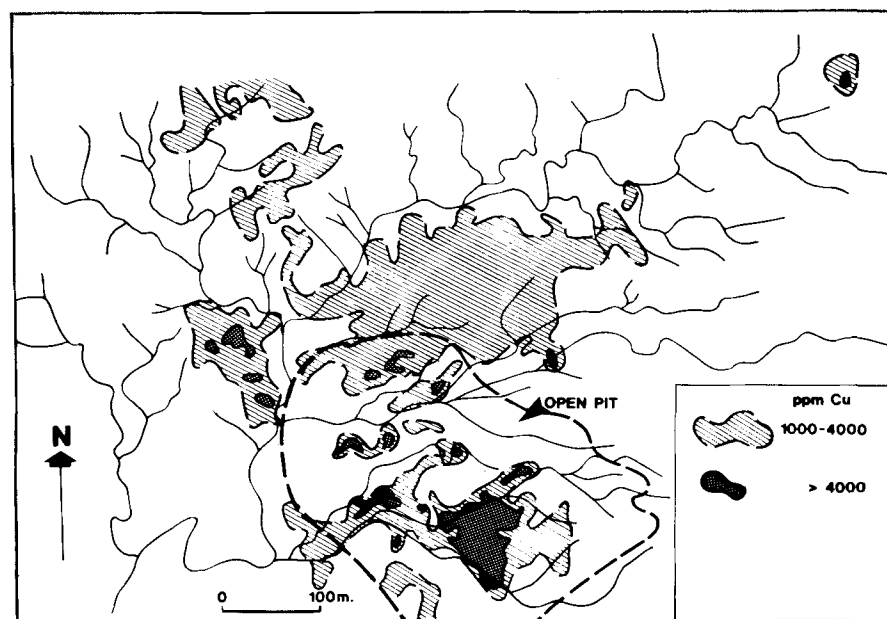
Figure 14.10. *Distribution of copper in soils, Panguna area, Bougainville Island (with permission of RioFinEx).*

FUTURE DEVELOPMENTS

A detailed discussion of new methods under investigation and future developments is outside the scope of this paper. However, it is probable that effort will be concentrated in certain directions including:

1. The further development of geochemical techniques for locating mineralization beneath a cover of transported overburden or post-mineralization rocks. This includes the identification of seepage of metals from depth, the use of gases which are able to migrate more freely through overburden, continued study of the role of vegetation in the development of anomalies and possible electrochemical dispersion processes.

2. The continuing study of the form and mode of occurrence of metals derived from potentially economic mineralization. The use of selective analytical techniques to isolate metal derived from particular primary or secondary mineral forms shows promise as a way of increasing specificity to mineralization in areas of high background, identifying false anomalies due to rock types and enhancing anomaly contrast where the metal related to mineralization is only a minor component of the total metal in the soil.

The challenge is to devise methods appropriate for problems encountered in the field. Success in developing any technique is dependent on correctly identifying the field conditions.

ACKNOWLEDGMENTS

The Panguna deposit is located in youthful mountain terrain covered with dense tropical rainforest. The general geology of the deposit is shown in Figure 14.8 together with the outline of the open pit which contains the principal concentration of mineralization. Weak disseminated copper sulphides extend over a much larger area. Detailed stream sediment sampling in the upper part of the Kawerong Valley reveals an extensive area of high copper values in the general area of the Panguna deposit (Fig. 14.9) which relates to the widespread low-grade disseminated copper mineralization. Soil sampling, however, gave a broken picture with several discrete anomalies (Fig. 14.10), most noticeably in the area of the present open pit separated by areas with low levels of copper. Initially the low copper values found on ridges within the area of anomalous steam sediments were attributed to surface leaching (Mackenzie, 1973). Subsequent investigations, deep augering and pitting, revealed the presence of the volcanic ash blanketing nearly all ridges and spurs to depths varying from a few centimetres to 24 m. The ash is of recent age and is a stratified brown clayey deposit which in a few places carries exotic boulders of agglomerate and breccia. During the early phase of exploration, soil samples were collected by auger at a depth of 0.5-2 m and field personnel were unable to see any visible difference between the clayey ash and clayey weathered bedrock. Later, it was found that the ash is thickest on slopes and in places extends onto alluvial boulder terraces beside the rivers so that the area of residual soils over the main deposit, as represented by the outline of the open pit, is relatively restricted (Mackenzie, 1973).

Once the problem had been recognized exploration methods were modified to cope with the ash cover. Deep augering was employed to sample weathered rock below the ash, and prior to drilling, efforts made to extrapolate the geology into the blind areas. Systematic drilling ultimately proved the presence of extensive mineralization below the ash cover and alluvial terraces of sufficient grade to sustain a mine (Baumer and Fraser, 1975).

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