25.

SOME ASPECTS OF INTEGRATED EXPLORATION

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Coope, J.A., and Davidson M.J., Some aspects of integrated exploration; in Geophysics and Geochemistry in the Search for Metallic Ores; Peter J. Hood, editor; Geological Survey of Canada, Economic Geology Report 31, p. 575-592, 1979.

Abstract

For many years, regional techniques of mineral exploration incorporating airborne geophysical methods and other remote-sensing techniques applied to identify broad geological parameters have been used under a variety of geological and geomorphological conditions. Such use of disciplines has served to broadly classify areas based primarily on broad features such as physical properties and prospective mineral potential.

The better understanding of the geological processes leading to the formation of mineral deposits, together with the enterprising development of geophysical, geochemical and other types of exploration tools during recent years, has provided a basic framework for an integrated application of techniques on a more detailed scale and with the potential of improved cost and exploration effectiveness.

Variations in geophysical and geochemical backgrounds can provide critical data which serve to elucidate geological interpretation and the evaluation of anomalous conditions. The variations are commonly related to primary geological features or larger scale, ore-forming processes and can yield critical information when the connection is recognized and properly interpreted. Magnetic, resistivity, electrical, lithogeochemical and other selected techniques are particularly adaptable in this more detailed integrated application.

Different disciplines and data-gathering methods within disciplines can yield the same or equivalent information interpretable in a geological context. However, recognition of the physio-chemical fingerprint of an ore environment requires a multidisciplined, integrated approach when signatures observed from any one discipline are too subtle to generate adequate confidence levels by themselves. In any particular situation there is a sequence of application and areal coverage which will define targets at a minimum cost.

Résumé

Depuis plusieurs années, on utilise des techniques régionales d'exploration minière, intégrant des méthodes géophysiques aéroportées et autres techniques de télédétection pour définir des paramètres géologiques larges dans divers milieux géologiques et géomorphologiques. Ces disciplines ont servi à définir grosso modo des zones, surtout en fonction de leurs caractères physiques et de leur potentiel minier.

Une meilleure compréhension des processus géologiques qui engendrent des gîtes minéraux, et la mise au point ces dernières années de méthodes d'exploration géophysique, géochimique et autres, permettent d'intégrer les diverses techniques à une échelle plus détaillée et sans doute de réduire les coûts et de rendre l'exploration plus efficace.

Les variations du fond géophysique et du fond géochimique peuvent fournir des données essentielles pour l'interprétation géologique et l'évaluation des anomalies. Ces variations sont généralement liées à des éléments géologiques primaires ou, à une échelle plus grande, à des processus de genèse des gîtes minéraux. Elles peuvent aussi apporter des renseignements essentiels lorsque la corrélation est reconnue et proprement interprétée. Les méthodes magnétique, de résistivité, électrique, lithogéochimique et autres techniques appropriées peuvent facilement être intégrées, à une échelle plus détaillée.

Les différentes disciplines et les méthodes de recueil des données dans ces disciplines peuvent donner les mêmes renseignements ou des renseignements équivalents, qui peuvent être interprétés dans un contexte géologique. Cependant, l'identification des caractères physico-chimiques d'un milieu minéral exige que l'on adopte une approche pluridisciplinaire et intégrée, lorsque les observations recueillies au moyen d'une méthode particulière sont trop peu convaincantes. Dans toute situation, on peut adopter une série de procédés, et un mode de couverture aérienne, de manière à définir les objectifs d'exploration au coût le plus bas possible.

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Figure 25.1. *Total magnetic field map of part of NTS 31 F/7 southern Ontario. (Reproduced from Hood et al., 1976.)*

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DESCRIPTIVE NOTES

This total field contour map was compiled from date recorded during aeromagnetic survey operations by a self-orienting rubidium-vapour magnetometer which was installed in the tail stinger of a Beechcraft B80 Queenair aircraft. The data was digitally-recorded with a resolution of 0.02 gammas. A second boom mounted above the tail stinger at a distance of 2.08 metres forms a vertical gradiometer system.

Flight altitude was 500 feet above ground at 1000 feet average flight line spacing and double control lines were flown at an average spacing of 4 miles.

The data was edited, compiled, levelled and gamma values for contouring interpolated on a square grid (0.1" grid spacing at the published map scale) by automatic computer processes.

The automatic levelling process employs the two components of the double control line and the short segments of traverse which connect them where they are not exactly co-incident. This data is used to minimize and distribute non-geological contributions from the total magnetic field profile along the control line. The corrected control lines are used to level the traverse by a method of minimal sum-total adjustment.

The final grid was contoured and plotted using the automatic contouring program and digital plotter facilities of the Department of Energy, Mines and Resources, Computer Science Centre.

Airborne survey was carried out in April 1975 and digital compilation by Resource Geophysics and Geochemistry Division, Geological Survey of Canada. The Queenair aircraft of the Geological Survey of Canada was flown under contract to Kenting Earth Sciences Ltd.

No correction has been made for regional variation.

The photo and map base for this map was compiled by Survey and Mapping Branch, Department of Energy, Mines and Resources.

ISOMAGNETIC LINES (absolute total field)

50-100 gammas .... ≈
5 gammas .... ~
Magnetic depression .... ⌓
Flight altitude: 500 feet above ground level
Contour interval: 5 gammas

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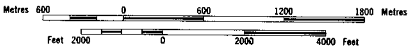
TOTAL MAGNETIC FIELD

Scale 1:25,000



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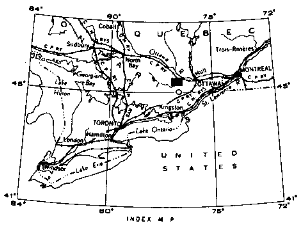

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INTRODUCTION

Effective "integrated exploration" requires communication and co-operation between the various mineral exploration disciplines. The concept of integrated utilization of exploration methods and tools can be applied on all scales – from the regional reconnaissance of large geographic areas to very detailed application in the search for extensions of known orebodies. A review of this broad field would require consideration of the techniques that have been reviewed during the Exploration '77 Symposium together with several exploration methods which have not. The latter methods include the practical application of trenching, percussion and diamond drilling, and isotope geology and geochemistry.

This paper makes general reference to some fundamental aspects of exploration integration, and numerous principles are reviewed and illustrated which are consistent with good exploration practice.

THE IMPORTANCE OF GEOLOGY

The predominant preoccupation of the Exploration '77 Symposium with geochemical and geophysical methods should not detract attention from the fundamental foundation of mineral exploration which is a knowledge and understanding of the geology of mineral environments. Significant advances in the geological understanding of mineral environments have been made in the past 20 to 25 years. These advances which reflect a greater understanding of the processes of mineralization and the localization of economic quantities of metals, provide the basic foundation for the development, refinement and sophistication of mineral exploration techniques. All interpretations, whether based on geophysical or geochemical measurements, must relate to geology to be meaningful and, consequently, neither the exploration geochemist nor the exploration geophysicist can function independently of the exploration geologist.

Exploration is progressive. In many parts of the world, the last two decades have been marked by the rapid development and application of many exploration geophysical and exploration geochemical techniques. Many of these developments have been extremely successful and have directly indicated sub-outcropping or near-surface orebodies and extended the search capabilities into areas of extensive cover and difficult accessibility.

This period of rapid development and success nurtured, among many, a reliance on the airborne EM method or the stream sediment method or some other technique to identify "anomalies" for detailed geological scrutiny. In some localities, e.g. the Bathurst Camp, New Brunswick, this approach to exploration led to the establishment of several mining operations in areas where the geological controls on the mineral deposits were poorly known or misunderstood. Follow-up studies in these areas have corrected this imbalance. As time progresses, and, as it becomes apparent that additional ore reserves in these regions will only be found in blind deposits at increasing depths beyond the limits of detection by conventional geochemical and geophysical methods, the importance of geology becomes overwhelming and new exploration tools have to be applied based on the latest geological understanding of the mineral environment of interest.

It has been proven many times that, for some combination of geological or other reasons, an orebody of the type sought will not respond dramatically to a specific exploration technique, and will not produce a prominent anomaly. Total reliance on a geophysical or geochemical tool as the leading technique in an exploration program is therefore predestined to imperfection.

The example provided by the discovery of the South Bay orebody at Confederation Lake in northwestern Ontario where a relatively weak airborne INPUT anomaly became enhanced by the interpretation of the geological relationships in nearby outcrops, illustrates the advantage of the integration of geological mapping and interpretation into the exploration sequence. Knowledge of geology and an understanding of mineral environments serves to classify anomalies detected by the application of geophysical and geochemical techniques much more satisfactorily than does reliance on the magnitude of a physical or chemical concentration.

To many, these comments will appear to be a statement of the obvious. Nevertheless, the fundamental consideration of geology must be emphasized in the context of good exploration practice. This contribution is intended to illustrate how thoughtful integration of geological expertise with the enterprising development and application of geochemical and geophysical

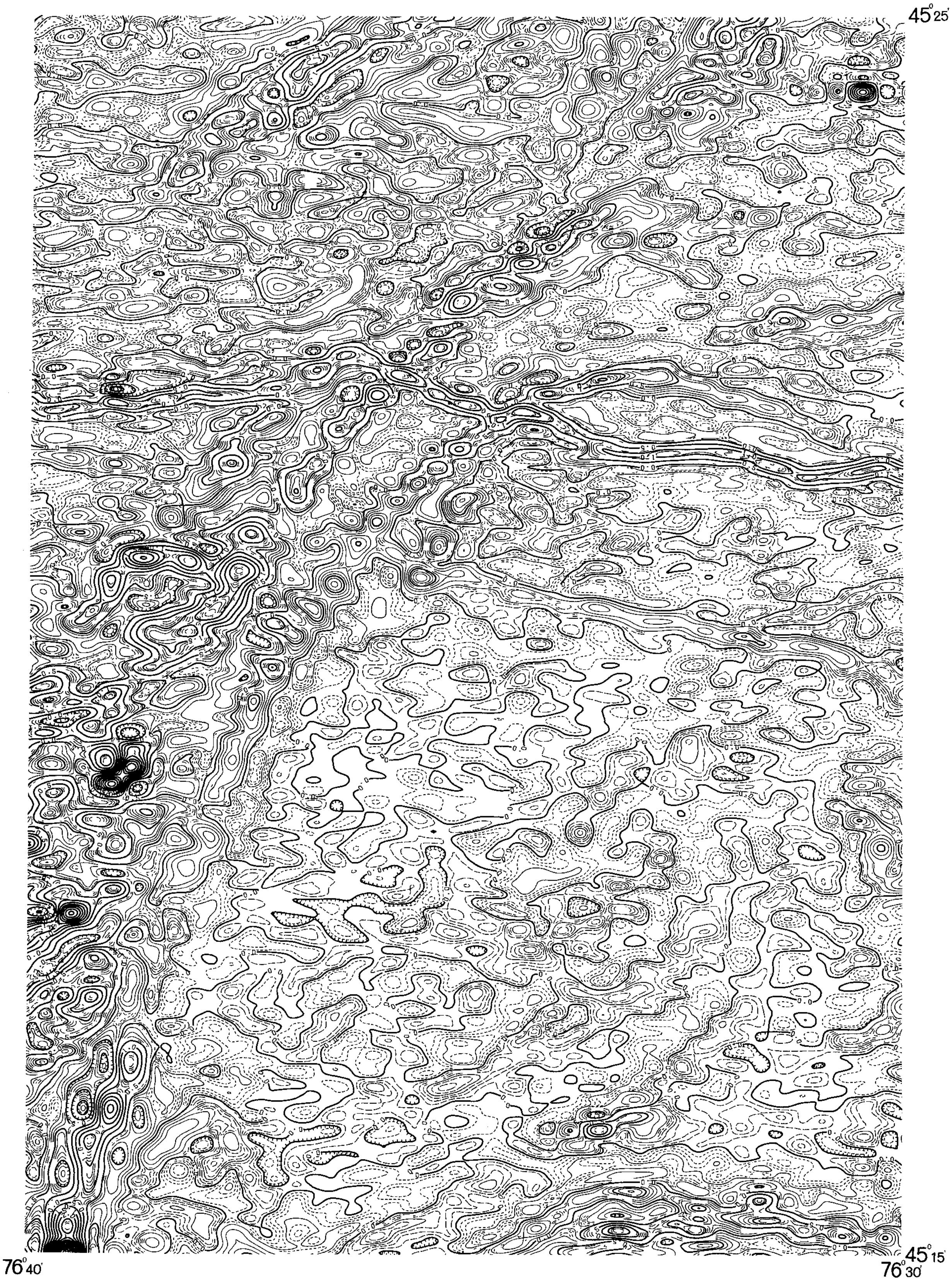

Figure 25.2. Vertical gradient magnetic map of part of NTS 31 F/7 southern Ontario. (Reproduced from Hood et al., 1976.)

DESCRIPTIVE NOTES

This map is based on in-flight digitally recorded high sensitivity aeromagnetic data obtained with two self-orienting Rubidium vapour magnetometers installed in twin tail booms inboard a Beechcraft B80 aircraft. The magnetometer heads are separated by a distance of 2.08 metres with each measuring the total magnetic field to a resolution of 0.02 gammas.

Flight altitude was 500 feet above ground at 1000 feet average flight line spacing and double control lines were flown at an average spacing of 4 miles.

The data was edited, compiled, levelled and gradient values for contouring interpolated on a square grid (0.1" grid spacing at the published map scale) by automatic computer processes.

The vertical gradient data was filtered with a digital operator to remove noise spikes and instrument hash. The vertical gradient data from the tie lines was not used to compile the map, instead each line was individually adjusted as required.

The final grid was contoured and plotted using the automatic contouring program and digital plotter facilities of the Department of Energy, Mines and Resources, Computer Science Centre.

Airborne survey was carried out in April 1975 and digital compilation by Resource Geophysics and Geochemistry Division, Geological Survey of Canada. The Queenair aircraft of the Geological Survey of Canada was flown under contract to Kenting Earth Sciences Ltd.

The photo and map base for this map was compiled by Surveys and Mapping Branch, Department of Energy, Mines and Resources.

EQUIPOTENTIAL LINES (vertical gradient field)

.5 gammas/meter	≈
.1 gammas/meter	～
.025 gammas/meter (above 0.0)	- -
.025 gammas/meter (below 0.0)	⋯
Magnetic depression	⊃

Flight altitude: 500 feet above ground level

Contour interval: .1 gammas/meter

Intermediate contour interval between +/-1.0 gammas/meter
:0.025 gammas/meter

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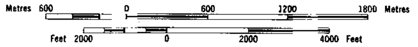
ONTARIO
VERTICAL GRADIENT

Scale 1:25,000



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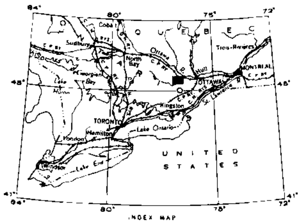

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methods can accommodate the demands of our expanding societies for the discovery of elusive economic mineral deposits in a selection of environments. In addition, examples will highlight how penetrative interpretation of geophysical and geochemical data can extend the understanding of geological relationships at depth or beneath overburden beyond the direct observation of the geologist.

INTEGRATED EXPLORATION

Opinions as to what constitutes "integrated exploration" vary widely. Actually, many who consider themselves to be adherents, are taking only partial advantage of the benefits and cost-effectiveness that full integration offers. True integrated exploration does not begin at some late stage in an exploration program after a geophysical or geochemical (or some other) survey has been completed. The full benefits can only be obtained when integration is effected at the earliest stage of the program. At this time the geologist should raise all the possible geological questions whose answers may be significant to the program, and the geophysicist and the geochemist should consider the various techniques which are capable of providing partial or complete answers to these questions under the conditions of the proposed survey. It is a rare case when a given type of geophysical or geochemical survey cannot provide answers to more than one geological question provided the survey planners are aware of these multiple questions in time to design appropriate field procedures.

Geophysical Aids to Geological Mapping

The geophysicist must convert field data into physical property representations that can be communicated and which are consistent with general geological principles and with whatever is known about the geology. The step from physical property maps to interpreted geology is best performed by the geologist and the geophysicist working jointly. To function efficiently in this fashion the geologist must be aware of the physical properties associated with various geological units, even to the extent of mapping these properties in the field regardless of whether or not they appear to be of economic significance. This would include such features as magnetite content, total sulphide content, the presence of bentonitic clays, graphite, magilmenite exsolution crystals, porosity and apparent resistivity contrasts. During the process of interpretation, the geophysicist is aware of the confidence levels associated with various physical property representations and is best equipped to modify these towards greater consistency with the emerging geological picture. The geologist, on the other hand, is best equipped to assess the confidence levels associated with the geological information and to formulate the overall geological model or models most consistent with all the observations.

Geophysical methods are often classified as "direct" when they are used to sense economic mineralization and "indirect" when they provide more general geological information. It is important to realize that this distinction is not inherent in the method but in the questions asked of the method. It is also important to appreciate that many anomalous responses which appear to mask or obscure the direct detection of mineralization are capable of yielding significant geological information. So called "geological noise" can be converted into a geological signal by merely asking the right question.

For example, consider a case where IP was being used to outline sulphide mineralizaiton in a thick sequence of dolomites. A large formational IP response in the general area of the known mineralization was found to be due to carbonaceous material in a black fetid dolomite. Recognizing that the depositional environment of the dolomite was ideal for the precipitation of metallic sulphides if the metal ions entered the reducing basin, the IP program was expanded with broad-spaced regional lines to locate and map paleochemical environments.

In the search for uranium-bearing roll fronts in sedimentary basins, the first phase is commonly groundwater hydrogeochemistry to establish areas of anomalous uranium and radon. The second phase could be resistivity surveying to map quickly and cheaply the meandering sand channels and establish sand thicknesses. In certain environments where pyrite has been deposited near roll fronts and where bentonitic clays are not ubiquitous, IP can be used to reduce the area where drilling is required.

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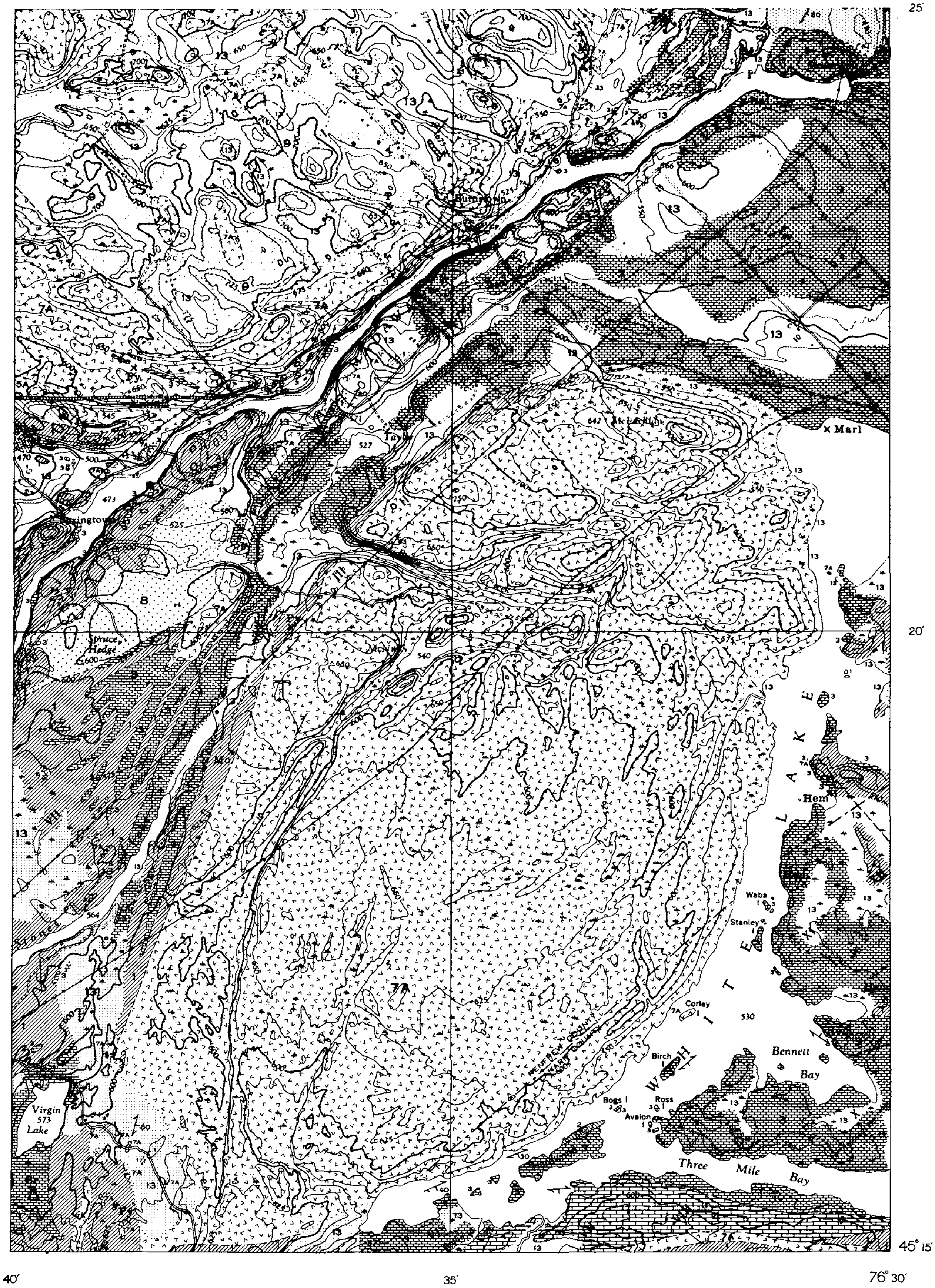
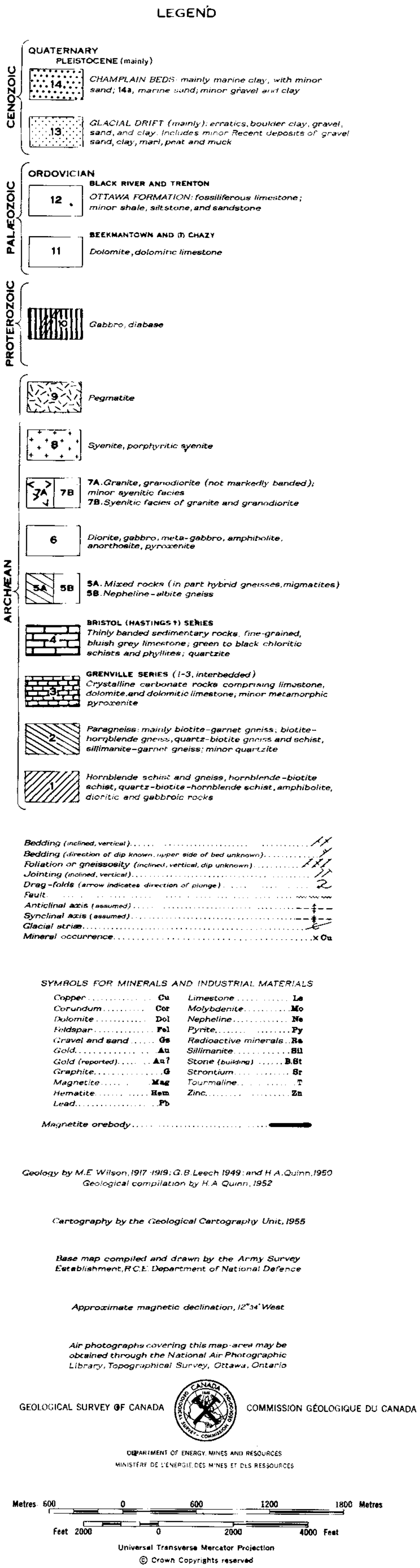


Figure 25.3. *Geological map of part of NTS 31 F/7 southern Ontario. (Reproduced from Hood et al., 1976.)*



Where there is lithological variation and major rock units can be classified according to resistivity contrasts, it is possible to map these units broadly with resistivity measurements made during the completion of routine IP surveys. Such an approach has a direct application in areas of extensive overburden where the distance between outcrops is such that geological units cannot be mapped with satisfactory accuracy.

Magnetic surveys have, of course, been widely used to aid in the geological mapping of areas where sufficient magnetization contrast exists between rock units. Two papers by Boyd (1969) and Morley (1969) in the 1967 Symposium documented the capability of the magnetic, gravity and seismic methods to provide significant geological information. Papers presented during the 1977 Symposium and published herein described the geological mapping capability of airborne techniques such as γ-ray spectrometry (for mapping alteration in some terranes) and the potential of E Phase, Radiophase and other VLF EM methods, and high resolution aeromagnetic surveys.

The magnetic gradiometer and gradient techniques are a positive development which permit resolution of composite or complex magnetic anomalies into their individual constituents and, on the same basis, automatically remove the regional magnetic gradient to better define shallower features which may be of interest. In practice the method allows a sharper delineation of geological units with contrasting susceptibilities. The illustrations in Figures 25.1 and 25.2 compare gradient magnetic data with total intensity magnetic data for an area in Southern Ontario (Hood et al., 1976) and it is immediately apparent that the gradient map reflects the geological details (Fig. 25.3) much more precisely. Late dykes, striking approximately west-northwest across the granite body, are prominent in the magnetic data but were not observed during the geological survey.

The three examples cited utilizing the IP and resistivity survey responses illustrate the adaptation of other geophysical techniques to similar mapping roles.

In a recent article, Pelton (1977) explained how a careful study of the position and magnitude of peaks in the plot of IP phase angle versus frequency can be used to discriminate between graphite and massive sulphide mineralization, magnetite and nickeliferous pyrrhotite and between barren pyrite halos and disseminated economic mineralization in some porphyry copper systems.

These few examples illustrate, in a general way, how a more objective interpretation and adaptation of conventional techniques can complement the broader geological picture and add information that is of direct and immediate value in the assessment of truly anomalous responses which may be related to ore.

There is an obvious requirement for the development of the "indirect" application of geophysical techniques in order to satisfy the need to carefully examine and geophysically characterize the large scale environment of known deposits. This expertise, when developed to a satisfactory level, can then be adapted to down-hole geophysical surveying as mine-finding exploration is extended below the first hundred metres.

Geochemical Aids to Geological Mapping

It has been noted that, as exploration progresses in areas where shallow mineral deposits have been found and the search expands to explore for blind deposits at increasing depths, knowledge and understanding of the geology of mineral environments becomes the basis for the development and application of sophisticated geochemical, geophysical and other techniques that may be used effectively in these advanced exploration programs.

As an example, one can trace the recent development of lithogeochemical exploration methods. It became apparent early in the history of geochemical prospecting that trace element backgrounds varied according to the lithology and composition of rock types. Nickel, for example, enters into the crystal structures of olivines and copper tends to be higher in certain pyroxenes.

Different background levels in geochemical data in areas uncomplicated by mineralization can be correlated with rock lithologies and, in greater detail, with mineralogical associations. This correlation is obviously more direct in the case of the lithogeochemical method but similar correlations are possible with certain soil, stream sediment and other data sets (Fig. 25.4). Multi-element data and computer programming can help refine these correlations.

The correlation between geochemical data and mineralogy is relatively easy to demonstrate and understand. Partial analysis or "speciation" of lithogeochemical sample material can be used to differentiate qualitatively elements in different mineral phases such as certain sulphides, silicates, and oxides.

For many years, geochemical exploration was concerned primarily with the measurement of trace element quantities. With the advance of analytical expertise, major element analysis has become incorporated into the exploration geochemical spectrum. More recent instrumental adaptation, particularly the XRD method, has allowed the quantitative measurement of minerals, and the work of Hausen and Kerr (1971), and Figures 25.5A to 25.5D and Franklin et al. (1975) has clearly shown the adaptation of this method to map quantitatively the distribution of alteration minerals.

Franklin and his co-authors (1975), utilizing XRD techniques, have identified a pipelike alteration zone characterized by manganiferous siderite extending at least 300 m directly below the Mattabi massive sulphide deposit. Copper and zinc are concentrated in anomalous proportions in the upper central part of the pipe. The distribution of siderite and dolomite is shown in Figures 25.6 and 25.7. Figure 25.8 is a composite illustration of the generalized distribution of alteration and mineralization based on the Franklin et al. studies.

Quantitative XRD geochemistry plus trace and major element data can geochemically describe a geological environment and complement geological observation and understanding by portraying subtle or invisible variations which might otherwise go unnoticed. In the mineralized environment of the volcanogenic massive sulphide deposit, for example, the portrayal would reveal alteration patterns of chloritic, sericitic, feldspathic, carbonate and silica intensity which are, in part, visible and, in part, invisible to the eye of a trained geologist plus major and trace element variations in primary dispersion patterns indigenous to or, superimposed on, geochemical backgrounds related to rhyolitic and andesitic volcanic products.

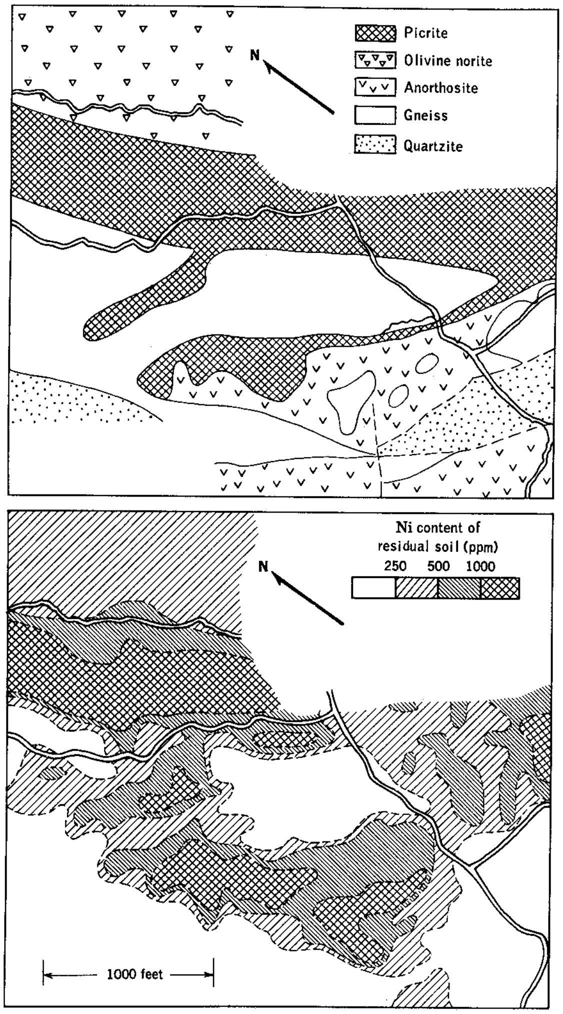


Figure 25.4. *Relationship between geology and the pattern of nickel in residual soil, Nguge Region, Tanzania. (Colluvial and alluvial overburden occur flanking main rivers.) After Coope (1958) Courtesy Hawkes, H.E. and Webb, J.S., (1962) 'Geochemistry in Mineral Exploration', Harper and Row, New York, N.Y.*

Such a geochemical overlay on the geological environment is of immense value to the geologist in the investigation of the genesis of volcanogenic mineralization. In turn, when this understanding is developed, these geochemical relationships can be applied in prospecting in other favourable geological situations. In such a prospecting effort, it will be apparent that the exploration geochemist will be dependent on the knowledgeable exploration geologist for guidance in selecting critical lithogeochemical samples.

The integration of the geochemical and geological disciplines has been illustrated by results from the Canadian Shield which indicate that, in certain mineralized districts, the felsic and intermediate formations in volcanic cycles hosting mineralization contain significantly higher background zinc contents than equivalent rocks in unmineralized cycles (Nichol et al., 1975) (Fig. 25.9).

A note of caution should be registered with respect to the geology and related geochemistry of volcanogenic environments. Conspicuous variations in the geology and alteration associated with productive deposits are frequently recognized from mining camp to mining camp. For example, the relatively restricted distribution of chlorite at Mattabi in the Sturgeon Lake Camp, (Franklin et al., 1975) and Figure 25.8, is not a feature of the Noranda Camp where chlorite is more common and is widely distributed in the footwall alteration zones. Consequently a parallel study to the Mattabi study by Franklin et al. on a Noranda Camp deposit would outline a footwall alteration zone and other distinctive features related to the host and enclosing rocks, but the distribution and dominance of chlorite would be strongly contrasting.

Similarly, the Confederation Lake-Woman Lake relationship (Fig. 25.9) may not necessarily be reproduced in other camps although based on a geological understanding of these environments relationships of this or allied types can be anticipated in other volcanogenic areas.

Illustrations of how geological knowledge of a mineral environment can indicate useful exploration techniques can be selected from papers in the literature dealing with volcanogenic environments.

It can be demonstrated that anomalous amounts of metal occur in exhalite horizons contemporaneous in age with volcanogenic massive sulphide deposits. In their study of the dispersion of metals from the submarine exhalative bodies in the Red Sea, Holmes and Tooms (1972) were able to demonstrate that dispersion of metals from the metalliferous brines is taking place through normal seawater. Furthermore, this dispersion is detectable in both a soluble form in the water and in suspended particulate matter (Fig. 25.10 and 25.11). The net effect of the dispersion process is reflected in the upper few centimetres of the surface sediments, (Fig. 25.12), and it is apparent that the distance of anomalous dispersion is measurable in miles.

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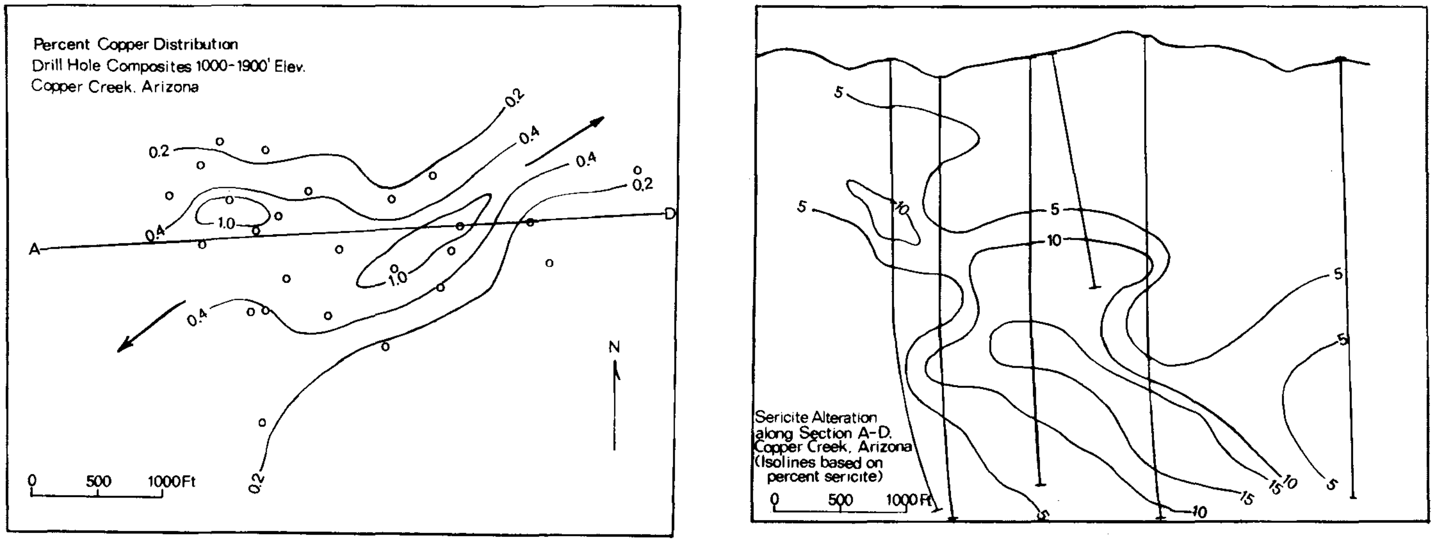
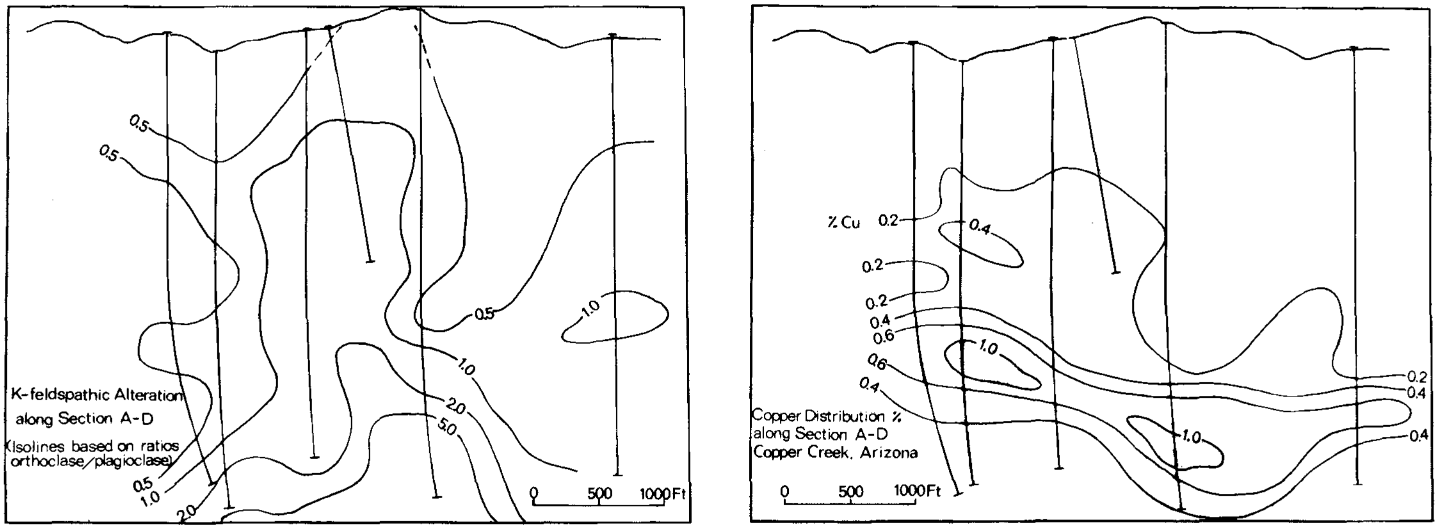


A. *Per cent copper distribution at Copper Creek, Arizona – drillhole omposites 1000-1900 ft. elev.*

C. *Sericite alteration along Section A-D, Copper Creek, Arizona (isolines based on per cent sericite).*



B. *K-feldspathic alteration along Section A-D, Copper Creek, Arizona (isolines based on orthoclase/plagioclase ratios).*

D. *Copper distribution along Section A-D, Copper Creek, Arizona.*

Figure 25.5. *Per cent copper, sericite alteration, K-feldspar alteration, Copper Creek, Arizona. (Reproduced from Hausen and Kerr, 1971.)*

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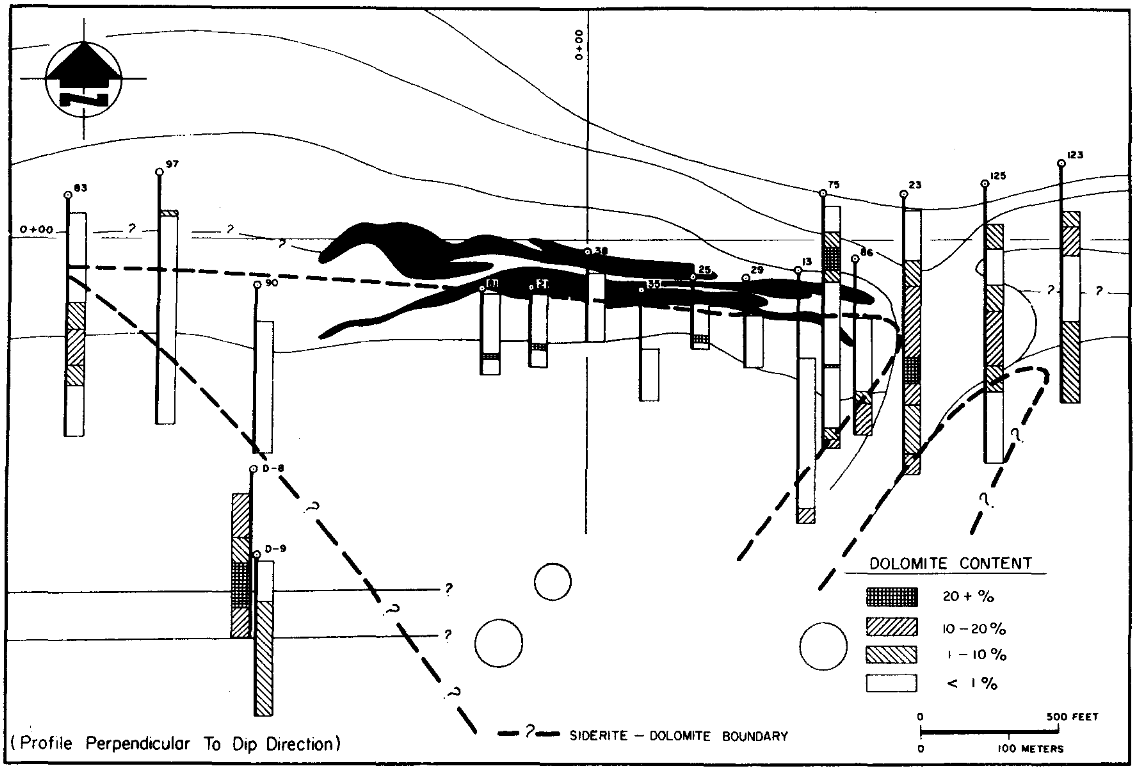

Figure 25.6. *Distribution of dolomite in the Mattabi Mine area. Reproduced from Franklin et al. (1975).*

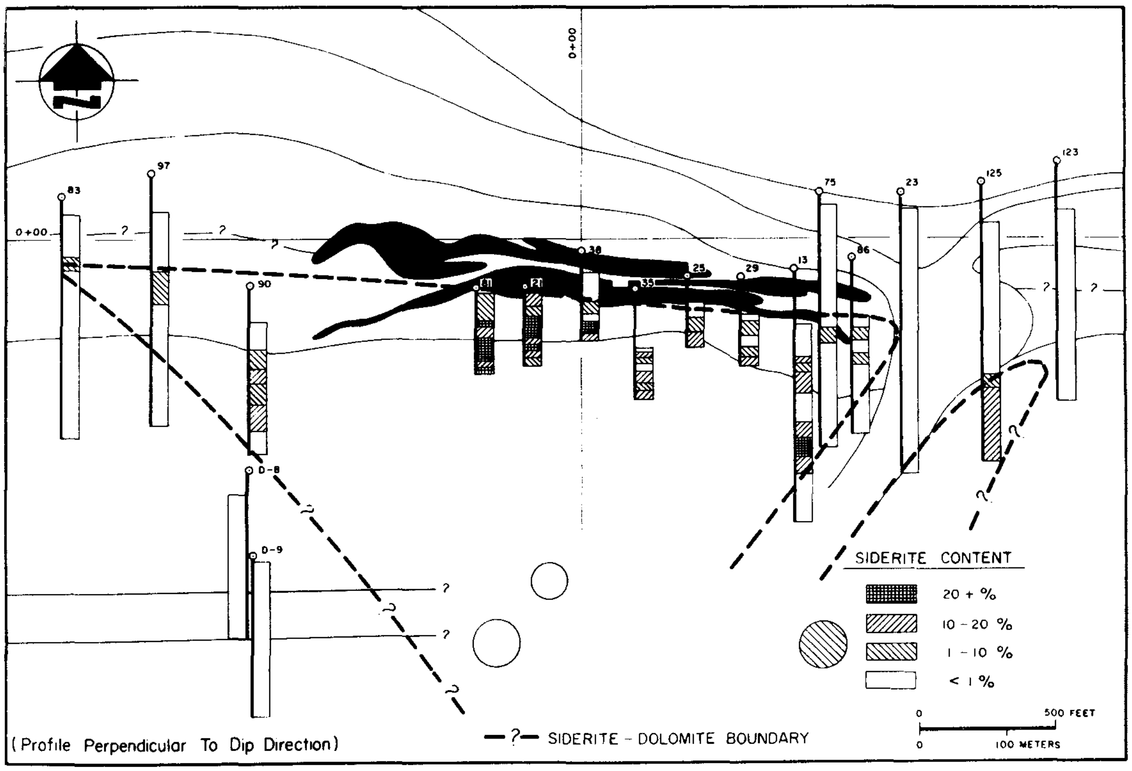

Figure 25.7.

Distribution of siderite in the Mattabi Mine area. Reproduced from Franklin et al. (1975).

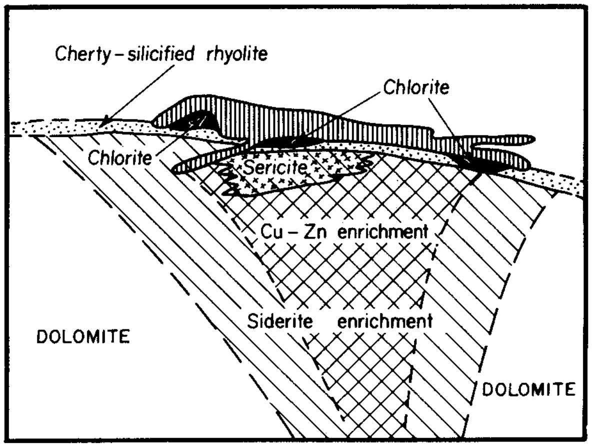

Figure 25.8.

Generalized distribution of alteration types in the footwall rocks of the Mattabi Mine. Reproduced from Franklin et al. (1975).

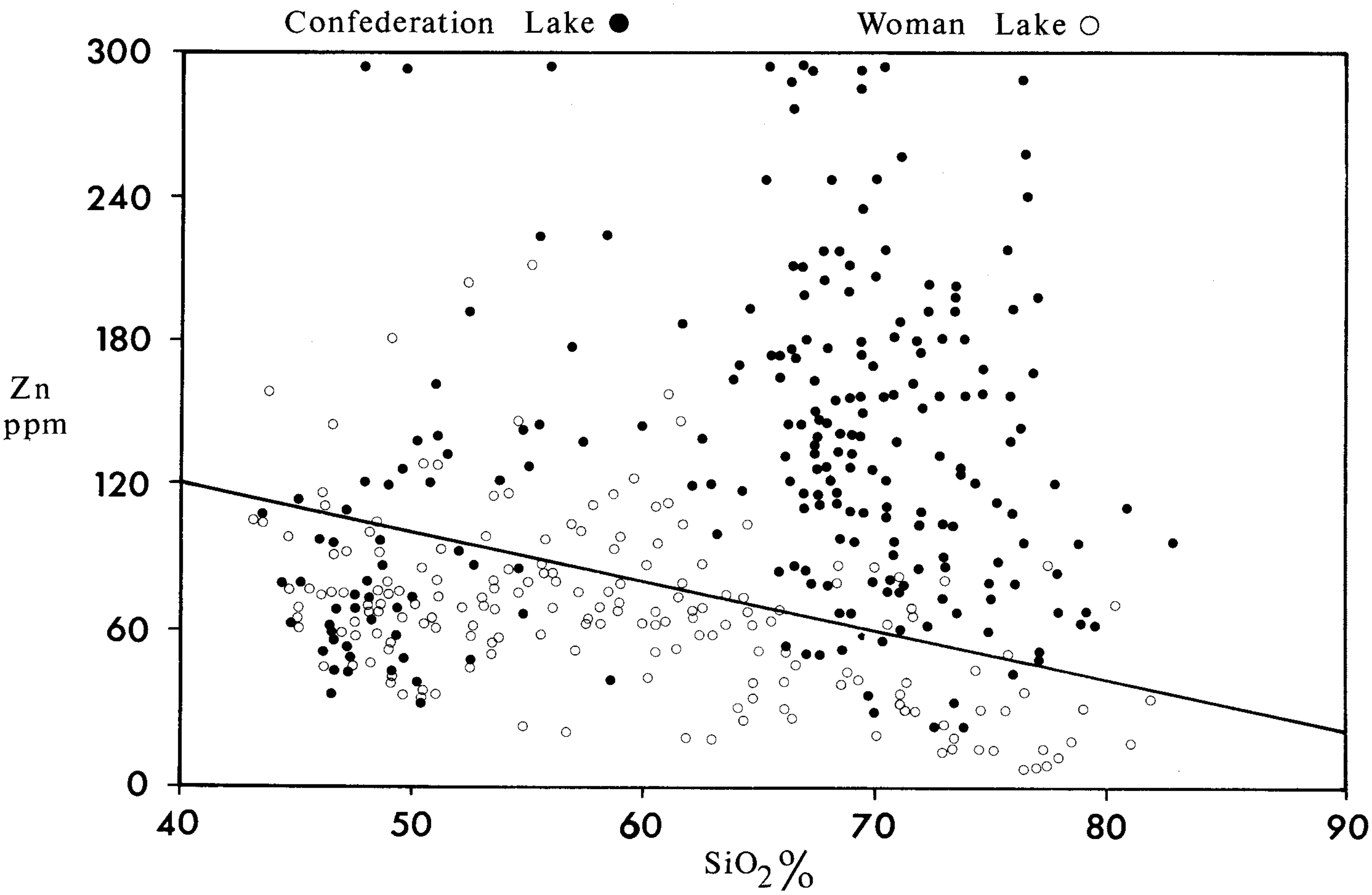

Figure 25.9. *Comparison of zinc with SiO₂ between the mineralized Confederation Lake Volcanic Cycle and the unmineralized Woman Lake Volcanic Cycle, Uchi Lake Area, Ontario. (After Govett and Nichol, 1978.)*

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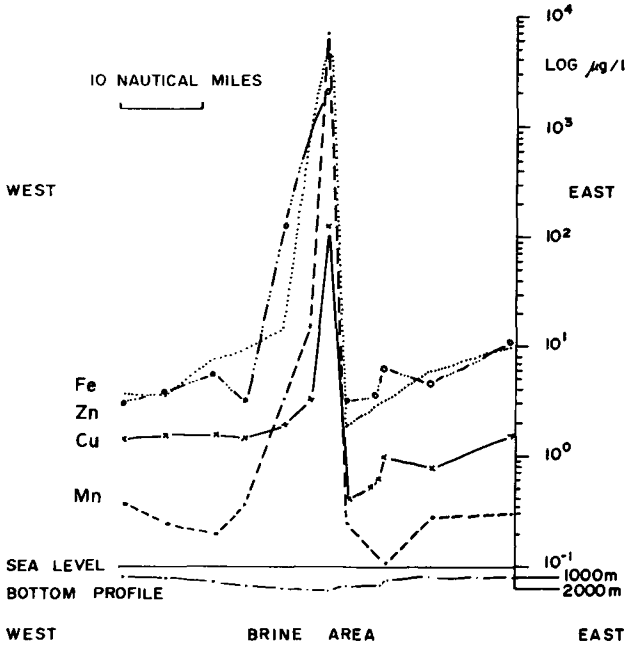

Figure 25.10. *Variation of dissolved metal species in near-bottom water, west-east across Atlantis II Deep (no samples from brine). (After Holmes and Tooms, 1972.)*

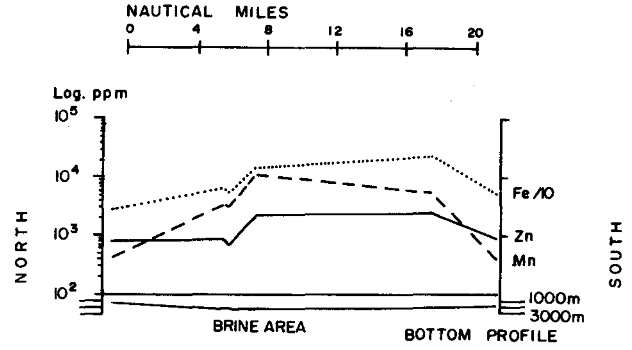

Figure 25.11. *Variation in particulate metal contents in near-bottom water, north-south across Nereus Deep. (After Holmes and Tooms, 1972.)*

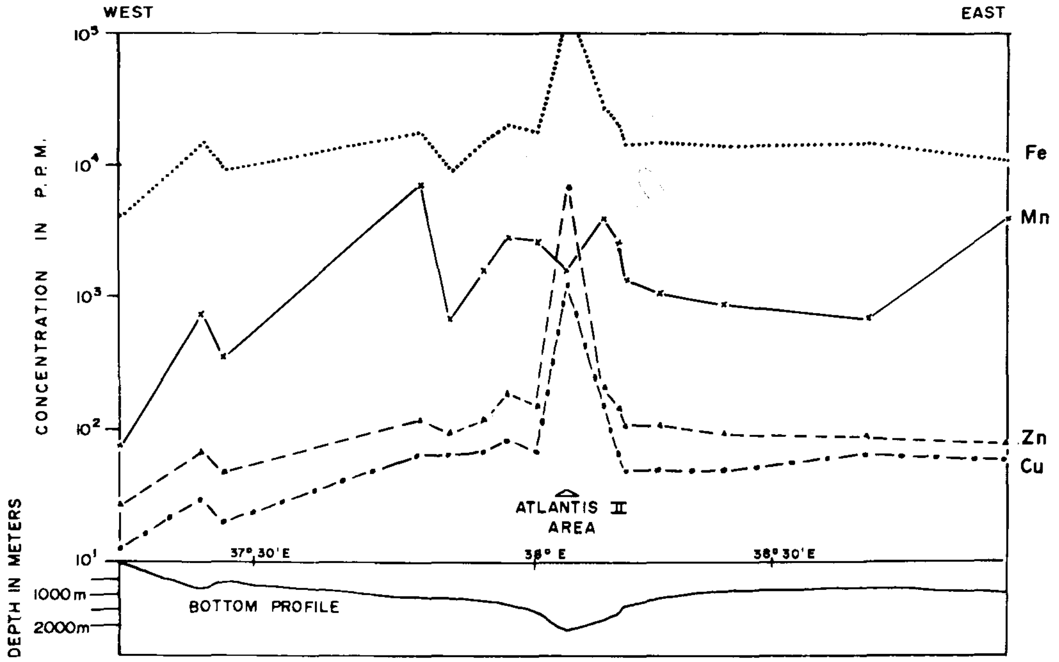

Figure 25.12.

Cu, Zn, Fe, Mn contents of surface sediments along traverse across Atlantis II Deep. (After Holmes and Tooms, 1972.)

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More recent work by Bignell (1975) and Bignell, Cronan and Tooms (1976), records anomalous geochemical halos of Fe, Mn, Cu, Zn and Hg detectable in surface sediments 3 km to 10 km from the metalliferous deposits in the Atlantic II Deep and the Nereus Deep (Fig. 25.13 and 25.14). Background values in these diagrams have been calculated from data from sediments collected along the axial valley sides within the Red Sea, away from the mineralized deeps.

The evidence from the modern environments of the Red Sea clearly supports the concept of the exhalative process advocated by numerous observers of massive sulphide deposits in ancient terranes and immediately suggests that contemporary sediments deposited at the same time as polymetallic massive sulphide mineralization in ancient exhalative environments could contain anomalous amounts of metals spatially related to economic mineral deposits. Such contemporary sediments include the chemically precipitated exhalites.

Figure 25.15 is a geological map published by Cameron (1977) of a volcanogenic massive sulphide deposit initially indicated in a lake sediment sampling survey in the Northwest Territories (Cameron and Durham, 1974a). The body is known as the Yava Syndicate or the Agricola Lake deposit. The exhalite horizon related to the mineralization, (known locally as the "B" horizon), is highly sericitized and the general geological relationships of the area are shown in Figure 25.16.

Sampling of rock outcrops beyond the limits of Figure 25.15 proved the presence of anomalous levels of Zn, Cu and Pb along the extension of the massive sulphide-bearing stratigraphy (Cameron and Durham, 1974b). Anomalous values for zinc occurring along or near the "B" horizon exhalite and its projection are located approximately 300 m and approximately 900 m beyond the suboutcropping massive sulphides (Fig. 25.17). Such anomalous dispersion most likely occurred during the exhalative period when the massive sulphide deposit was being formed.

There is an indication, therefore, that anomalous dispersion in horizons contemporaneous with massive sulphides is detectable in some Precambrian volcanogenic environments more than 300 m from the massive sulphides. This has significant implications with respect to the potential of lithogeochemistry in mineral exploration in that, in vertically dipping stratigraphy, indications of significant, blind massive sulphide concentrations buried to depths of 300 m or more could be detectable in samples of exhalite horizons from surface outcrops.

Russell (1975) described unusually high zinc values and anomàlous manganese values in an exhalative sedimentary iron formation and contemporaneous limestone facies 1 km to 7 km from the Tynagh base metal deposit in Lower Carboniferous rocks in Ireland (Fig. 25.18). Gwosdz and Krebs (1977) described somewhat similar dispersion extending 5 km from the Meggen deposit in Germany (Fig. 25.19).

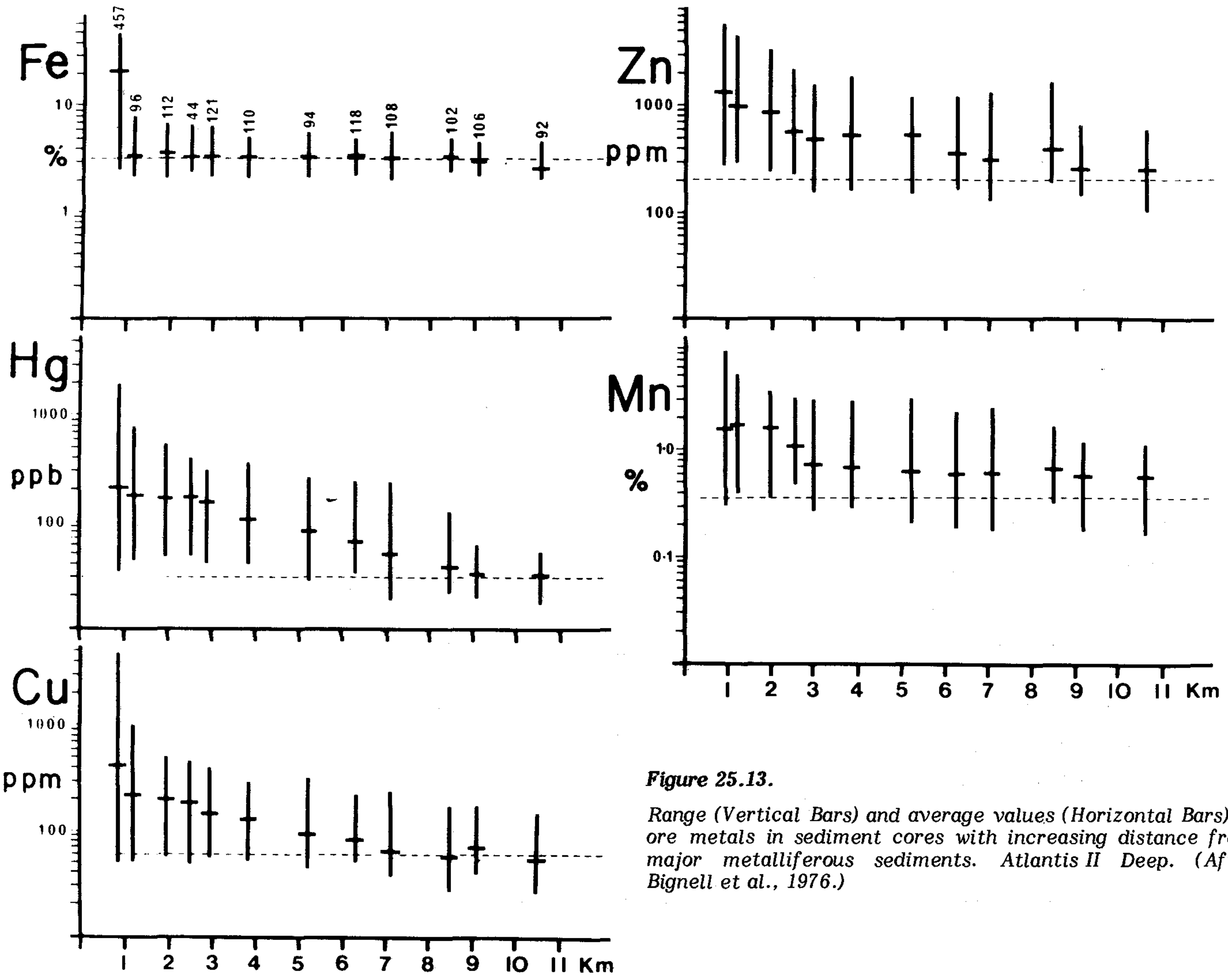

Figure 25.13.

Range (Vertical Bars) and average values (Horizontal Bars) of ore metals in sediment cores with increasing distance from major metalliferous sediments. Atlantis II Deep. (After Bignell et al., 1976.)

Contents

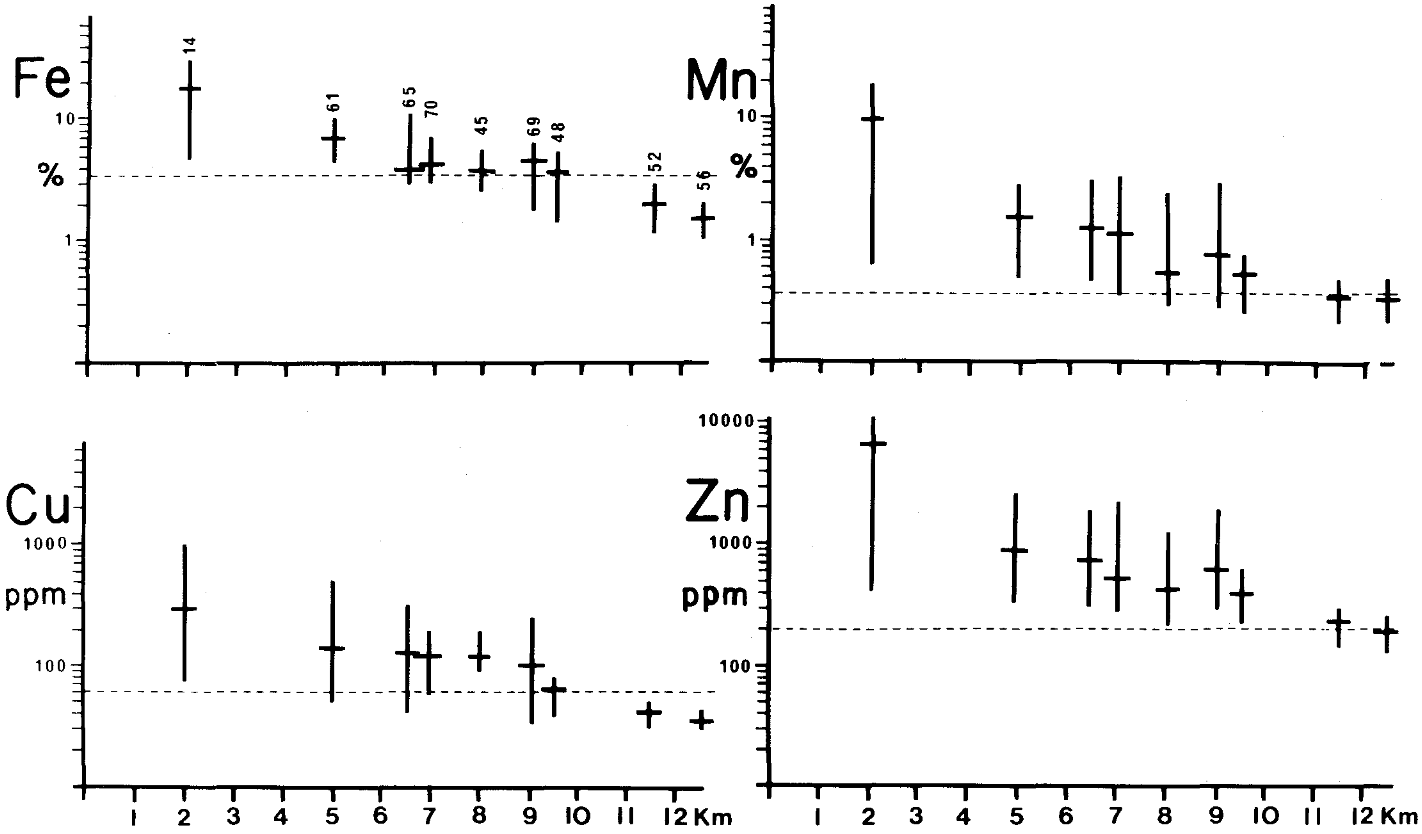

Figure 25.14. *Range (Vertical Bars) and average values (Horizontal Bars) of ore metals in sediment cores with increasing distance from major metalliferous sediments. Nereus Deep. (After Bignell et al., 1976.)*

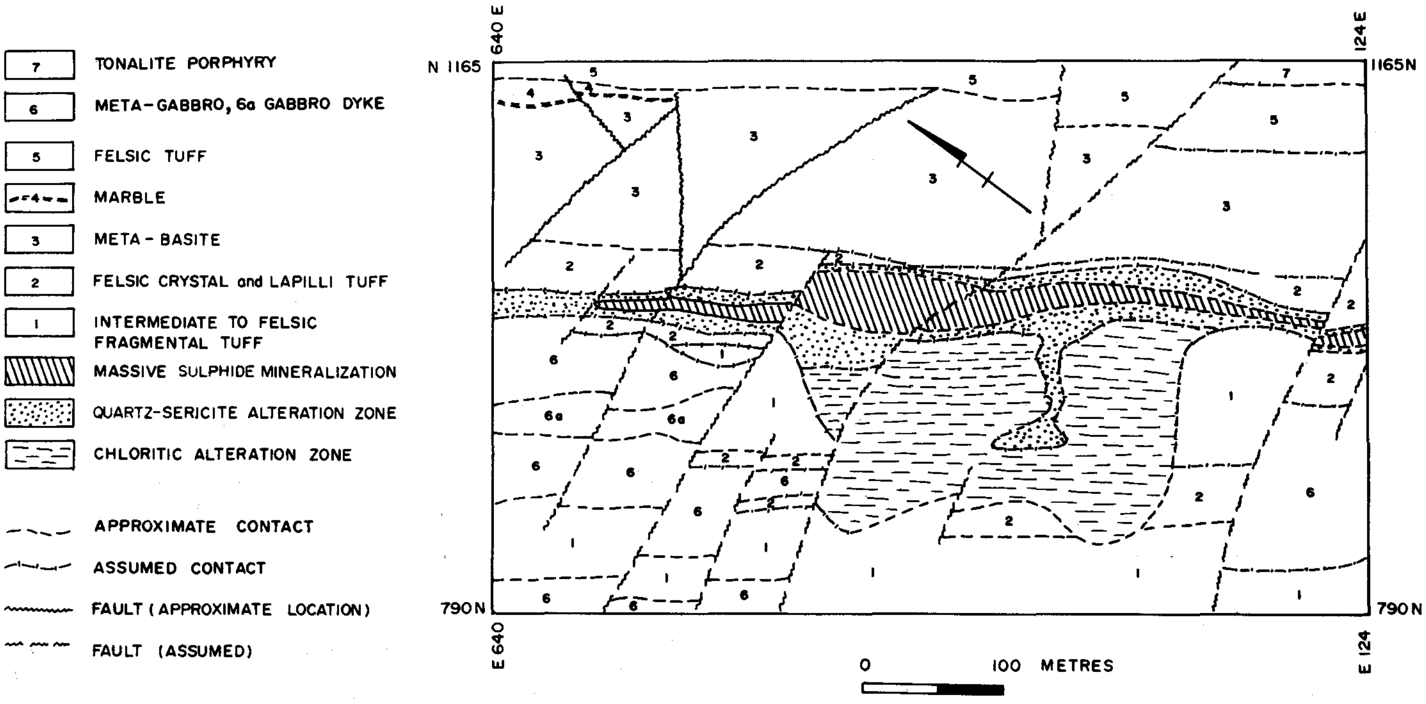

Figure 25.15. *Geology of the Agricola Lake deposit. (After Cameron, 1977.)*

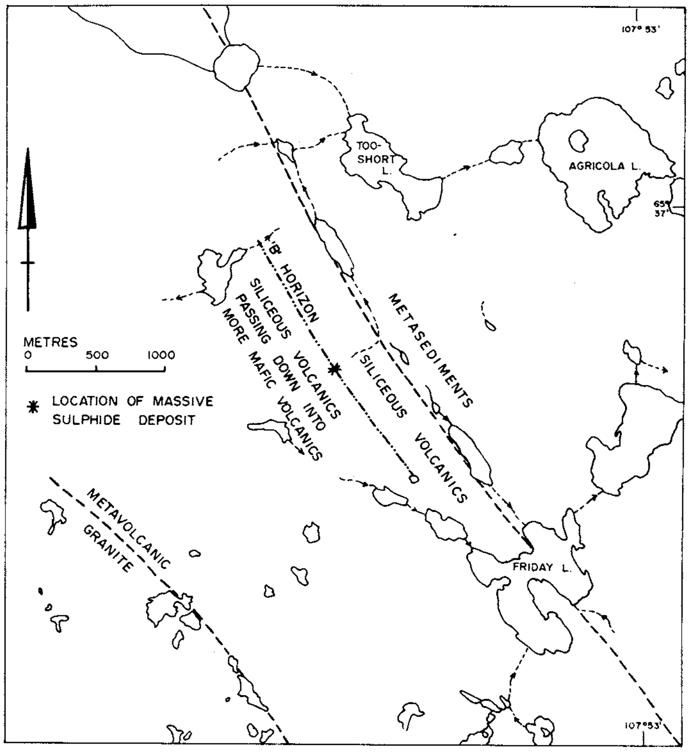

Figure 25.16. *General Geology-Agricola Lake area. (After Cameron and Durham, 1974b.)*

The dispersion patterns that are described are compatible with the volcanogenic model. Investigations involving careful sampling of exhalite horizons require the input and guidance of the exploration geologist familiar with the model and appreciative of the fact that the significant exhalite horizons can be thin and relatively inconspicuous.

The complete integration of the lithogeochemical technique with geology can be illustrated by noting the potential role of lithogeochemistry in the development and refining of geological concepts leading to a better understanding of the ore environments and ore genesis.

Potentially Useful Research Integrating Geophysics, Geochemistry and Geology

Pertinent information on mineralization genesis has been obtained from a geochemical study of active geological processes in such localities as hotsprings areas where mineral-bearing solutions are circulating, ocean floors where processes related to plate-tectonism are active, and areas such as the Red Sea and Vulcano where volcanogenic processes have deposited sulphide mineralization. As has been noted with reference to Red Sea data, geochemical observations in recent environments have served to confirm or explain conceptual mineralization processes advocated by observers of mineralized environments in ancient terranes. Parallel studies in other recent environments may provide pertinent information leading to a better understanding of the genesis of other types of mineral deposits, which, indirectly, will lead to the design of more effective exploration programs applicable throughout the geological succession.

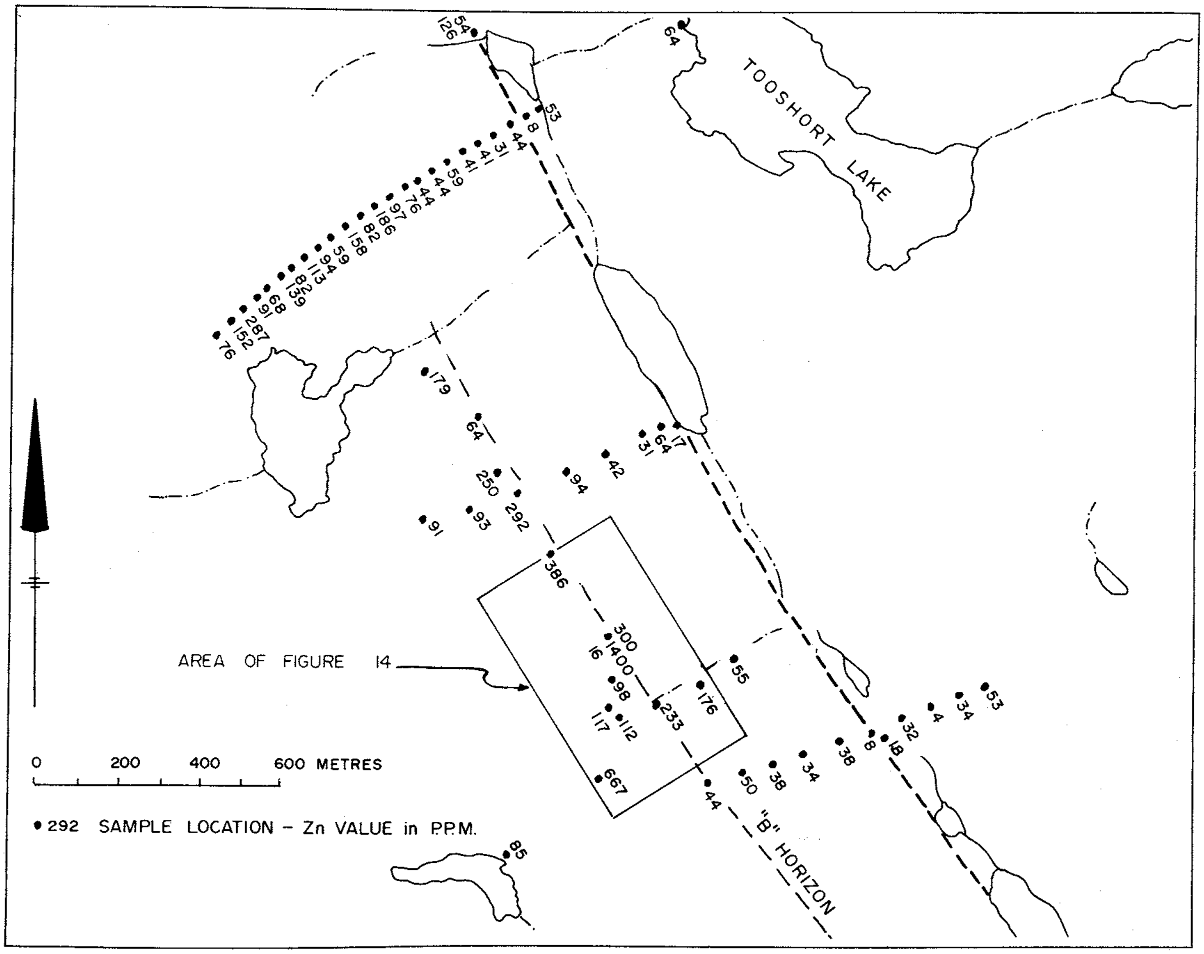

Figure 25.17. *Zinc content of rock samples from the Agricola Lake area. (After Cameron and Durham, 1974.)*

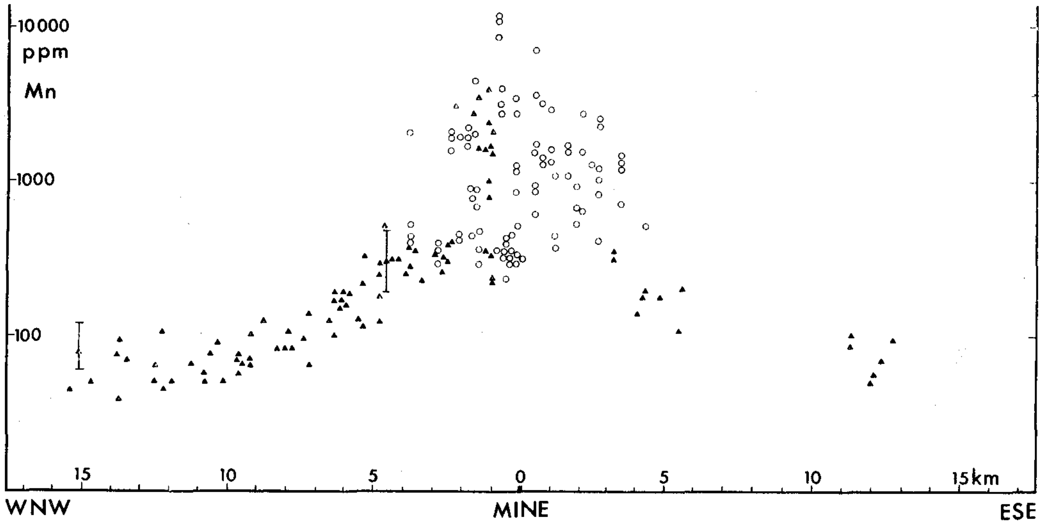

Figure 25.18. Manganese content of Waulsortian limestone horizon reflecting exhalative disperson around the Tynagh deposit (Mine). Circles represent drill core samples, triangles represent outcrop samples. (Reproduced after Russell, 1974.)

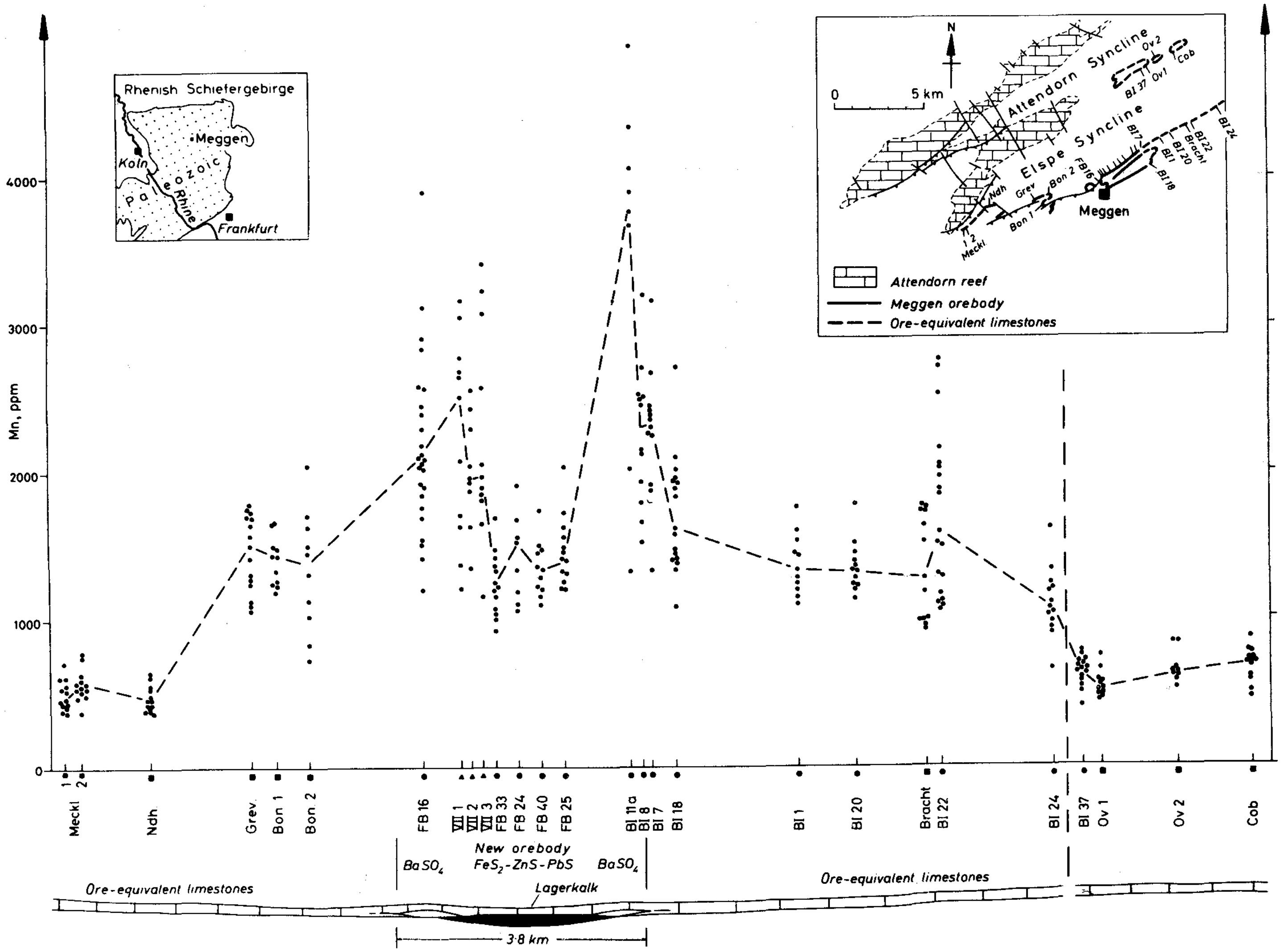

Figure 25.19. Manganese distribution in Lagerkalk and ore-equivalent limestones in area of Meggen ore deposit: southeastern flank of Elspe syncline separated from anticline structure between Elspe and Attendorn syncline by vertical broken line; other broken line links median values (■ quarry, ▲ underground working, ● drillhole). (Reproduced from Gwosdz and Krebs, 1977.)

An area where meaningful geophysical results might be anticipated would be research on the post-mineralization impact of a large sulphide mass on the host environment. In arid climates, the effect of acid weathering on the physical and chemical properties of the surrounding rock is poorly documented although there is some evidence that IP – responsive clay minerals are formed locally. Electrochemical effects driven by the oxidation of a sulphide mass may also produce post-mineral changes in the host rocks which are detectable at a distance. Such a mechanism for dispersion of elements is currently understudy and a considerable amount of interesting data is being accumulated (Govett, 1973; Govett et al., 1976; Bolviken and Logn, 1975). Comprehensive geochemical studies of the weathering zone overlying known mineralized environments similar to those described by Nickel et al. (1977) and those being carried out in other CSIRO programs in Australia, may also reveal important geochemical parameters which would be pertinent in the identification of favourable environments from surface observations.

Another area for fruitful investigation concerns the alteration mineralogy of the iron minerals. Magnetite and the various hematites are very difficult to distinguish by most analytical techniques including XRD, yet these minerals have relatively distinct magnetic properties and appear to be sensitive indicators of chemical environments. Some work of this type has been done by US Geological Survey personnel using high resolution susceptibility measurements to characterize the chemical environment of uranium roll fronts.

COST EFFECTIVENESS

Just as integrated exploration offers significant opportunities to the exploration geologist so the selection and application of the variety of available techniques presents an important challenge.

There are numerous examples on record of areas being systematically covered by one technique after another in the hope that the accumulation of data may reveal all significant geological secrets. This is a bland, unimaginative approach to exploration.

Cost-effectiveness is of prime importance in good exploration practice. Optimum cost-effectiveness is based on considering the incremental cost of obtaining additional information from each survey in an integrated program and on establishing the proper sequence of surveys, mapping and drilling so that each stage builds on the body of knowledge already obtained. Confirmation of geological information which has already been obtained with an adequate confidence level, is both time consuming and expensive.

The old adage "you will never find a mine until you break rock" cannot be denied and it should be the objective of all exploration teams to strive for the geological fact as expeditiously as possible and equate the cost of diamond drilling or other definitive and factual geological data acquisition against the added time and cost of additional discriminatory geophysical and geochemical data gathering.

Optimum cost-effectiveness requires a flexible approach consistent with the level of geological knowledge, and programming in which the various exploration decision points are carefully considered in advance. Within an integrated program, there are more stages at which to place a decision point which can take advantage of appropriate techniques to provide reliable negative or positive information.

The problem of differentiation of EM anomalous zones in Precambrian terranes of the Canadian Shield covered by extensive and complexly transported overburden, has been attacked in several ways. The high incidence of graphite in these regions has made systematic drilling of the EM zones expensive and unjustifiable. Various criteria based on the strength of the anomalies, and their length and position relative to broad, complex, major anomalous trends have also been applied with mixed and often negative results. Overburden drilling and sampling has been adapted to the problem and, by examination of trace element values and heavy mineral concentrates in basal tills, differentiation of graphite, barren sulphides and metal-bearing sulphides can be achieved under certain conditions. Favourable targets thus differentiated are then drilled.

Provided the parameters of size and depth of any desired massive sulphide deposit are properly defined, surface gravity techniques are capable of differentiating less dense graphitic sources from the denser, sulphide-rich sources which are more likely to be orebodies.

Overburden geochemical drilling, under favourable conditions, has the property of discrimination between barren and metal-bearing sulphide accumulations, but the cost of the geochemical drilling, especially in complex glacial overburden deeper than 30 m, becomes significant when anomalies are being investigated. The gravity technique, in concert with seismic and elevation surveys adapted for rapid, inexpensive coverage under Canadian Shield conditions, can quickly and relatively cheaply, eliminate anomalies related to graphite and other low density sources. Cost-savings achieved utilizing the gravity method at this stage of a program have been known to offset the additional diamond drilling costs required to examine remaining targets related to all higher density sulphide concentrations and also offset the extended time plus overburden drilling and related analytical costs that would be required to define the fewer targets by the alternative approach.

The principle of cost-saving and cost-efficiency is also illustrated by a much simpler example from Basin and Range Province areas where considerable exploration has been directed towards evaluation of pediment areas for buried porphyry copper deposits. Following a careful study of available geology, certain pediment areas have been selected for drilling to determine if significant features correlatable with porphyry copper mineralization in the pediment bedrock could be identified. Repeatedly, this approach proved unsuccessful and led to the abandonment of the property because, after acquisition of land, sometimes at a significant cost, holes were drilled thousands of feet without penetrating the valley gravels.

An integrated program has been developed with identical objectives but, instead of the first decision point in the program being the identification of a significant geological feature in pediment bedrock, the first decision point was based on an estimation of the depth of the pediment gravel. Relatively cheap gravity profiles carried out on public roads across the valleys quickly established the location of the Range Front faults bounding the pediments, and also provided adequate estimates of gravel thickness. In this integrated program every drillhole tested bedrock, and many areas were rejected on the basis of excessive depth of bedrock.

CONCLUSIONS

The strength of integrated exploration is the fact that the geophysicist and the geochemist can sense many aspects of a geological environment that the geologist cannot observe. The conversion of geophysical and geochemical data into geological information is usually ambiguous and imprecise without the input of the geologist and the objective of integrated exploration is to convert data into geological information at a satisfactory level of precision.

Integrated exploration does not come into being automatically. Exploration geophysics, exploration geochemistry and exploration geology have, to some extent, evolved separately from different roots, and competition, rather than co-operation, has been the norm. Much of the integrated exploration practiced today has resulted from the insistence of enlightened exploration managers rather than the natural tendencies of individuals. Fortunately, once integrated exploration has taken root under whatever impetus, most individuals have been quick to appreciate the benefits and have accepted the philosophy wholeheartedly.

The contribution of the geologist is important. Integrated exploration is dependent on geologists being able to formulate meaningful questions which relate to the environment of mineral deposits and which, in some way, can be answered by changes in physical and chemical properties.

Geophysical and geochemical techniques of today can be designed to be cost-effective in the detection of the relatively gross physical and chemical property contrasts associated with the direct detection of mineralization and in the provision of critical and useful geological information relevant to the environment of mineral deposits.

Objective application of this capability and expertise in advancing the geological understanding of the genesis of mineral deposits will perpetuate and improve the geological momentum which we have witnessed over the past 20 to 25 years. This will ensure the progressive development of our exploration capabilities in the face of the challenging demand of our various societies.

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