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THE APPLICATION OF AIRBORNE AND GROUND GEOPHYSICAL TECHNIQUES TO THE SEARCH FOR MAGNETITE-QUARTZITE ASSOCIATED BASE-METAL DEPOSITS IN SOUTHERN AFRICA

Geoff Campbell and R. Mason
Johannesburg Consolidated Investment Company Ltd.
Johannesburg, South Africa

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Abstract

Within Southern Africa, much of the recent prospecting of Precambrian high grade metamorphic terranes has concentrated on the search for Cu-Pb-Zn deposits associated with highly aluminous host rocks and spatially related magnetite-quartzites (or banded iron formations). These orebodies comprise stratabound massive or (more commonly) disseminated sulphides which are essentially nonmagnetic, but are usually highly polarizable and in some cases highly conductive. The related magnetite-quartzites are of special prospecting significance in that they act as unique marker horizons for such mineralization, their strike extent appears to partly control the distribution of mineralization, and they yield readily identifiable magnetic responses.

During the period 1973 to 1975 the Johannesburg Consolidated Investment Company Ltd. conducted major exploration programs to locate deposits of this type, within the Damara Sequence of South West Africa and the Bushmanland Sequence of South Africa. Given the extensive overburden cover and lack of geological control, effective prospecting of these areas demanded a combined geophysical and geochemical approach with later geological mapping and percussion/diamond drilling.

The geophysical signatures of known deposits in the Bushmanland and Damara sequences were assessed, and were utilized in devising a search target model whose criteria were applied throughout the exploration program. As base-metal deposits were found to be characterized by fairly unique magnetic signals, the aeromagnetic technique was used as the prime reconnaissance prospecting tool in overburden-covered areas. Aeromagnetic anomalies designated as "significant" were ground checked by magnetometer surveys aimed at delineating potential magnetite-quartzite horizons, geochemical soil sampling being used initially to assess the base-metal potential of each magnetite-quartzite occurrence. Where preliminary results were encouraging, these were followed up by further ground geophysical surveys (i.e. EM, IP) to delineate possible sulphide zones, the resulting anomalies being first investigated by percussion drilling.

By late 1975, this exploration program had delineated several small orebodies, two of which reflected original grass roots discoveries.

Résumé

La plupart des travaux récents de prospection exécutés dans le sud de l'Afrique en terrains précambriens fortement métamorphisés ont consisté en bonne partie à chercher des gîtes de Cu-Pb-Zn associés à des roches encaissantes à forte teneur en alumine ainsi qu'à des quartzites à magnétite (ou formations ferrifères rubanées). Ces gisements comprennent des sulfures stratifiés ou (plus communément) disséminés qui sont essentiellement non magnétiques mais habituellement très polarisables et dans certains cas très conducteurs. Les quartzites à magnétite associés présentent un intérêt tout particulier pour les travaux de prospection puisqu'ils constituent des horizons repères uniques pour une telle minéralisation. L'étendue de leur direction semble contrôler en partie la répartition de la minéralisation et ils produisent des réactions magnétiques facilement identifiables.

De 1973 à 1975, la Johannesburg Consolidated Investment Company Ltd. a exécuté de grands programmes d'exploration afin de détecter des gisements de ce genre dans la séquence de Damara dans le sud-ouest africain et dans la séquence de Bushmanland en Afrique du Sud. Compte tenu de l'épaisse couche de morts-terrains et du manque de données géologiques, il a fallu, pour mener à bon terme les travaux de prospection, faire appel à des techniques géochimiques et géophysiques puis dresser des cartes géologiques et enfin effectuer des forages par percussion et au diamant.

Les sismogrammes de gisements connus dans les séquences de Bushmanland et de Damara ont été évalués et ont servi à établir un modèle de cible de recherche dont les critères ont été appliqués à tout le programme d'exploration. Étant donné que les gisements de métaux non précieux se sont caractérisés par l'émission de signaux magnétiques à peu près uniques, la technique aéromagnétique a été utilisée comme principal outil de prospection préliminaire dans les régions recouvertes de morts-terrains. Les anomalies aéromagnétiques considérées importantes ont fait l'objet de vérifications au sol au moyen de levés par magnétomètre afin de

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localiser les horizons possibles de quartzite à magnétite; l'échantillonnage géochimique du sol a servi à évaluer initialement le potentiel de métaux non précieux de chaque venue de quartzite à magnétite. Lorsque les résultats préliminaires s'avéraient encourageants, ils étaient suivis d'autres levés géophysiques (EM, IP) sur le terrain pour déterminer les zones possibles de minéraux sulfurés et les anomalies relevées étaient d'abord étudiées au moyen de forages par percussion.

Vers la fin de 1975, le programme avait permis de localiser plusieurs petits gisements de minerai dont deux reflétaient les découvertes initiales en surface.

INTRODUCTION

Major base-metal discoveries during the early nineteen-seventies of the Aggenys Pb-Zn-Cu-Ag deposit (Phelps Dodge) and the Gamsberg Zn deposit (Newmont) in the Northwest Cape Province of South Africa, and of the Otjihase Cu deposit (Johannesburg Consolidated Investment Company) near Windhoek in South West Africa, gave renewed impetus to the base-metal exploration activity initiated in Southern Africa following the Prieska Cu-Zn discovery) by Anglovaal in 1969. All these discoveries were made following diamond drilling of prominent surface gossan outcrops discovered by conventional prospecting. It was surprising to many explorationists outside Southern Africa that such prominent surface expressions of major mineralization had laid unrecognized for so long. The stratabound Aggenys – Gamsberg – Otjihase deposits are all closely associated with magnetite-quartzites (banded iron formations), and it is interesting to note that similar associations had already been recognized as exploration targets for a decade or more in Canada and Australia.

During the period 1973 to 1975, the Geological Department of Johannesburg Consolidated Investment Company Ltd (JCI) conducted a major exploration program aimed at locating deposits of this type within the Bushmanland Sequence of South Africa and the Damara Sequence of South West Africa. Extensive overburden cover and a consequent lack of geological control, resulted in the use of geophysical and geochemical surveys as the major prospecting techniques, with later back-up from percussion and diamond drilling. This paper discusses the contributions made to the exploration program by geophysical surveys over the two most significant (as subsequently determined) prospecting areas, namely the Pofadder East Block of the Northwest Cape Province, South Africa, and the Gorob Prospect of South West Africa (see Fig. 38.1).

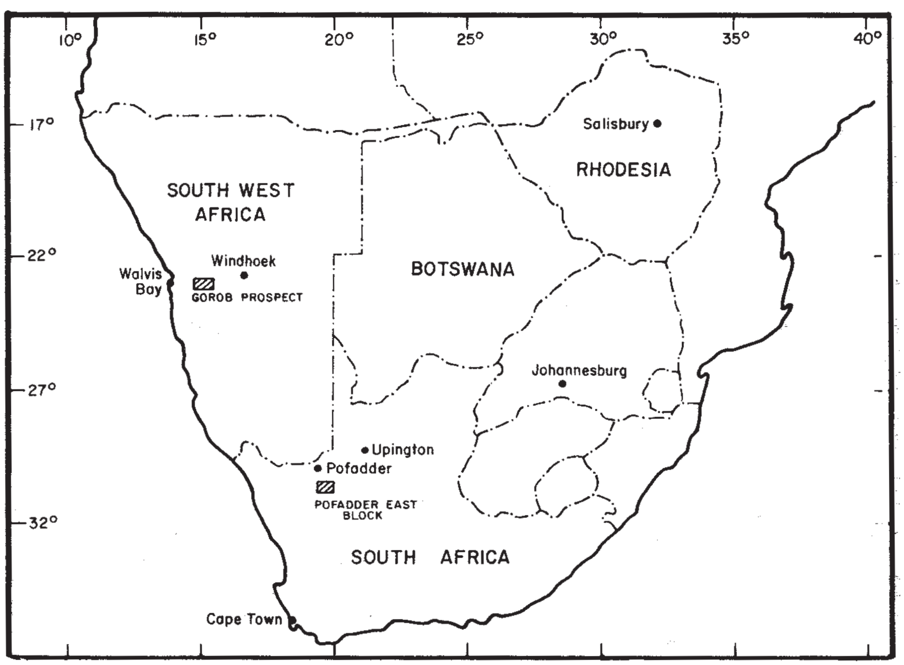

Figure 38.1. *Location map, Pofadder East Block and Gorob Prospect, Southern Africa.*

The Pofadder East Block, South Africa

The Pofadder East Block occupies a rectangular-shaped area some 17 km (N-S) by 31 km (E-W), the centre of which is approximately 40 km southeast of Pofadder and 90 km east of the Aggenys and Gamsberg base-metal deposits. The region is sparsely vegetated, semi-desert scrubland characterized by low relief. Outcrop is largely obscured by the presence of extensive sand and calcrete cover, maximum overburden thickness being approximately 15 m but more typically 2 to 7 m.

The ground was taken under option by JCI following an aerial reconnaissance exercise carried out to trace the Aggenys-Gamsberg lithological sequence eastwards towards Pofadder. This exercise was facilitated by tracing prominent metaquartzite ridges which occur close to the mineralized parts of the Bushmanland Sequence. Prior to this program, there were no reported instances of base-metal mineralization within the area. The so-called Putsberg copper deposit was subsequently located during the ground follow-up of aeromagnetic anomalies within the Pofadder East Block during 1974.

The Gorob Prospect, South West Africa

The Gorob Prospect falls within the Namib Desert of southwest Africa, and comprises a roughly rectangular-shaped block measuring some 20 km (NW-SE) by 80 km (NE-SW). The area lies some 70 km east of Walvis Bay and 200 km west of the Otjihase Copper mine near Windhoek. The prospect area is of minimal relief and has extensive alluvium and calcrete cover, increasing from approximately 2 m thickness in the southwest up to a maximum of 40 m thickness in the northeast.

Copper mineralization within the area was noted at the turn of the century, with subsequent small scale (and short-lived) workings being concentrated at the outcropping, so-called Gorob Mine. The latter and its associated deposits along strike, had previously been drilled by Rand Mines Limited and investigated in more detail by Penarroya, prior to the subsequent exploration by JCI. JCI's interest in the Gorob area was stimulated by the realization that its mineralization was related to a narrow belt of metavolcanic rocks called the Matchless Amphibolite Belt, with which were also associated the Otjihase – Ongeama – Ongombo copper deposits (discovered in 1970-71 by JCI. Follow-up work by JCI over major aeromagnetic anomalies, delineated two hitherto unknown deposits of cupreous pyrites.

Exploration Program

Aeromagnetic surveying was used as the major reconnaissance tool in prospecting these overburden covered areas, with the prime aim of defining the locale of magnetite-quartzite horizons, and hence, of potentially economic base-metal deposits occurring in close association.

Aeromagnetic anomalies deemed as significant were detailed by ground magnetometer surveys, and, where thick sand and/or calcrete cover was absent, geochemical soil sampling surveys were used to initially assess the mineralization potential of each "magnetite-quartzite" occurrence.

Where preliminary results were encouraging, EM or IP surveys were executed over and in the locale of the magnetic horizon, the resulting anomalies being first investigated by percussion drilling. The philosophy underlying the geophysical prospecting program is discussed later.

OUTLINE OF GEOLOGY

Pofadder East Block, South Africa

The Pofadder East Block forms part of the high grade Namaqualand metamorphic complex which straddles the lower parts of the Orange River valley in the Northwest Cape and in southern South West Africa. Throughout this metamorphic terrane a 100 to 500 m thick mid-Precambrian Sequence of gneisses, schists, metaquartzites and amphibolites (the Bushmanland Sequence) overlies a granitoid basement (Joubert, 1971). The Bushmanland Sequence is in recumbent fold complexes. Basal quartzofeldspathic gneisses are followed upwards by heterogeneous gneisses which may or may not be aluminous and/or siliceous; amphibolites of distinctive volcanic and hypabyssal types and aluminous schists with associated magnetite-quartzite horizons occur therein. This heterogeneous part of the Bushmanland Sequence contains all the significant base-metal mineralization discovered to date (Aggenys, Gamsberg etc.) and is overlain by prominent metaquartzite horizons, which become progressively more feldspathic in the areas east of Pofadder.

The Putsberg copper deposit occurs in a complex synformal zone of aluminous and graphitic schists, metaquartzites and amphibolites, which overlies the basal gneisses of the Bushmanland Sequence. The mineralization is intimately associated with thin siliceous horizons within biotite-sillimanite schists, and consists of chalcopyrite, minor pyrite, occasional sphalerite and rare galena. The mineralized horizon has been stretched and dismembered within the schists, and thicker intersections of it have been shown to be related to tectonic thickening in fold hinge zones (Paizes, 1975).

The resulting lack of coherency of the mineralization has made it difficult to evaluate, and it is currently considered subeconomic by the holding company in present circumstances.

Immediately below the mineralized zone at Putsberg there is a sequence of partly aluminous quartzo-feldspathic gneisses between 100 and 300 m thick which in turn overlie (structurally) a prominent zone of magnetite-bearing sillimanite gneisses with intercalated magnetite-quartzites. These are best developed in a position corresponding to the mineralization above.

Comparison has been made between the geology and mineralization of the Bushmanland Sequence and that of the Broken Hill area in Australia; the similarities are remarkable (R.L. Stanton, pers. comm.). It appears probable that the search model developed in this paper could be successfully applied to many other early to mid-Precambrian high grade metamorphic terranes elsewhere in the world.

Gorob Prospect Area, South West Africa

The cupreous pyrite deposits of the Gorob area are associated with a narrow belt of metavolcanic rocks situated within a flysch trough (the Khomas trough) of late Precambrian age, which forms part of the Damara mobile belt in South West Africa. Other cupreous pyrite deposits associated with the metavolcanic belt (the so-called Matchless Amphibolite Belt) include the Matchless Mine (Tsumeb Corporation), the Otjihase Mine, and the Ongeama, Ongombo and Kupferberg deposits near Windhoek (JCI Ltd.).

The Khomas Trough is intruded by a major granite batholith (the Donkerhoek granite) which has been partly unroofed by erosion along the northern edge of the Gorob Prospect area (Martin, 1965).

The Gorob deposits are situated around the rim of a major synformal structure which closes westwards near the Hope Mine (Fig. 38.8). The Hope – Anomaly deposits on the northern limb of the synform have been subjected to high grade contact metamorphism resulting from the intrusion of the granite to the north. Thus the predominant iron sulphide is pyrrhotite rather than pyrite, the mineralization is coarse grained rather than fine- to medium-grained, and the enclosing rocks contain upper-amphibolite facies mineral assemblages (the mineralization is confined within drag-folded sections of magnetite-quartzite horizons). The deposits on the southern limb of the synform (Gorob, Vendome and Luigi) are developed in magnetite-bearing quartz-sericite schists adjacent to barren magnetite-quartzite horizons. Ore shoots are contained within drag fold closures and the mineralization is predominantly pyritic with subordinate chalcopyrite, silver and minor sphalerite. All the orebodies at Gorob are characterized by well-developed pyritic-chloritic-aluminous lenses adjacent to the quartzitic rocks. While ore-grade deposits have been delineated within the Prospect, these are currently considered subeconomic by the holding company.

The geological setting and characteristics of the Gorob deposits are similar to those of many other late Precambrian-Phanerozoic pyritic ore deposits, and exploration for these could again follow the search procedure outlined in this paper.

EXPLORATION STRATEGY AND GEOPHYSICAL METHODS

The Search Target Model and Exploration Philosophy

Test aeromagetic surveys over economic orebodies associated with magnetite-quartzites, confirmed that their common denominator of well-developed, sympathetically correlating magnetite-quartzite horizons, yielded readily identifiable aeromagnetic anomalies of limited strike extent. Data released subsequent to the initiation of the exploration program have confirmed the results of the test surveys, and isomagnetic contour maps covering the Aggenys deposit in the Bushmanland Sequence and the Otjihase deposit in the Damara Sequence, are shown in Figures 38.2 and 38.3, respectively.

The magnetic contour map of Figure 38.2 is taken from a regional aeromagnetic survey (1976) of the Northwest Cape Province, executed on behalf of the South African Geological Survey. The survey was flown using a Geometrics

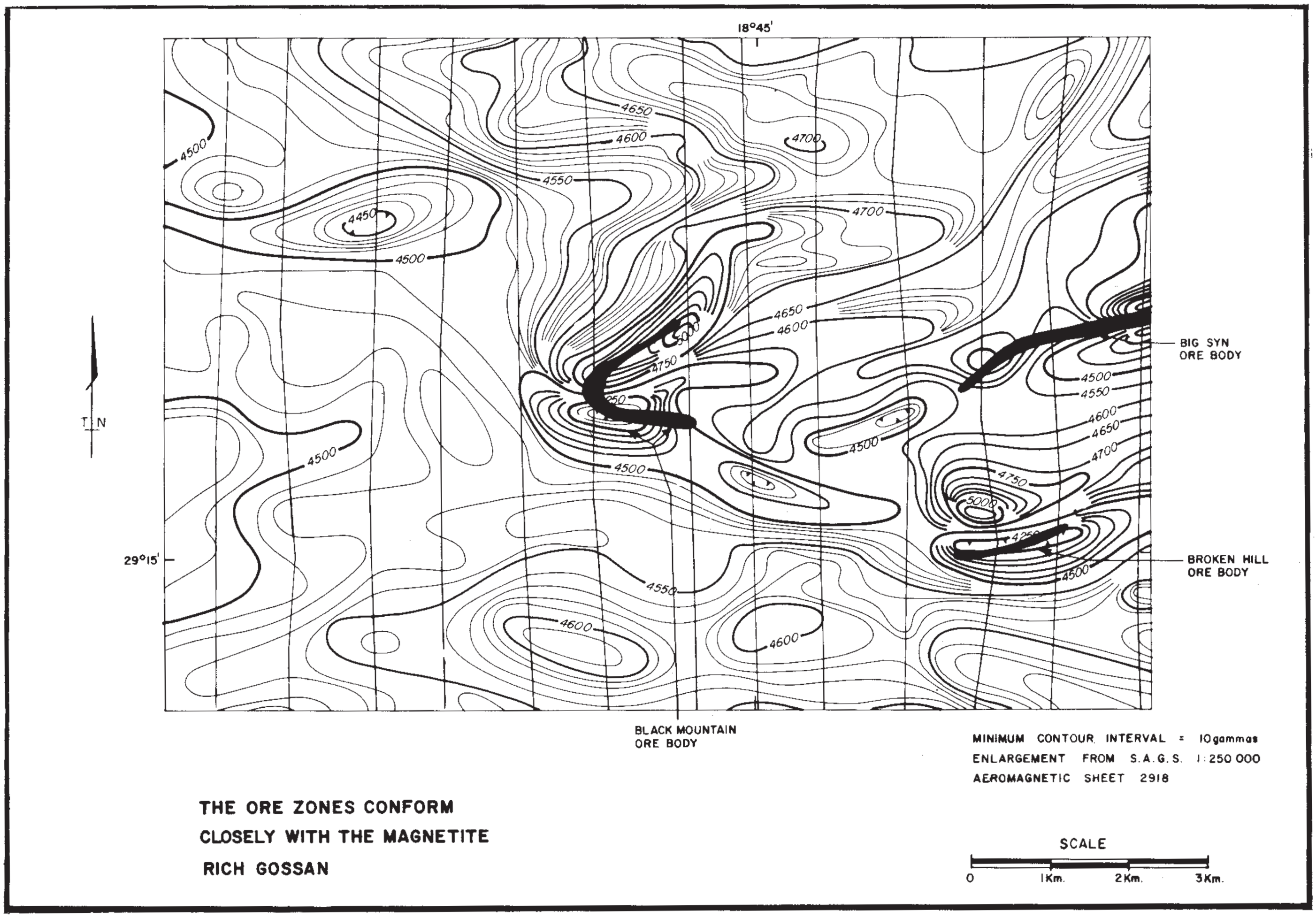

Figure 38.2. *Aeromagnetic contour map, Aggenys area.*

G803 proton – precession magnetometer at a mean terrain clearance of 150 m, along north-south flight lines having a separation of 1 km. The Aggenys ore zones are distributed around the closure of a synformal structure, the limbs of which can be readily traced via the magnetic responses of a major magnetite-quartzite horizon contiguous with the mineralization. Against a background of weakly magnetic schists and gneisses, the approximately 10 m thick magnetite-quartzite unit yielded an anomaly (maximum response ΔT=550 gammas) extending for 2-6 km from the nose. The predominantly positive anomaly along the northern limb and the low along the southern limb are consistent with tilted sheets magnetized by induction only in an ambient magnetic field of inclination I=-60°.

Figure 38.3 summarizes the results of an in-house JCI aeromagnetic survey (1974) over the Otjihase area; this survey was flown using a Geometrics G803 proton-precession magnetometer at a terrain clearance of 70 m, along north-northwest-south-southeast flight lines having a separation of 400 m. The ore-zone is characterized by a 3 km long, linear magnetic anomaly produced by the 3 m thick magnetite-quartzite horizon associated with the major sulphide zone. The predominantly negative response (maximum ΔT=100 gammas) is consistent with a sheet dipping approximately 20° to the north and magnetized by induction only.

From the results of the test surveys, it was concluded that orebodies of the search target type were characterized by narrow, linear magnetic anomalies having strike-lengths in excess of 1.5 km, but probably not greater than 5 km, with the anomalous horizon showing well-developed continuity along strike. Available evidence showed that such horizons had (i) magnetically identifiable widths in the range 10 to 50 m, but were generally not greater than 20 m, and (ii) a bulk magnetite content varying from 5 to 40 per cent by volume. While the strike-trace of the magnetite-quartzite units generally correlated well with the mineralized trace, inferring either contiguous horizons or an intimate association of both, one instance of a considerable separation (100 to 200 m) between ore horizon and magnetite-quartzite was noted at the Rozyn-Bosh Prospect, Northwest Cape Province. A discrete difference in stratigraphic levels between the sulphide mineralization and the magnetite-quartzites is a common feature of these types of deposits (Stanton, R.L. pers. comm.), and the phenomenon was incorporated into the final search model.

Whilst recognizing that the magnetite-quartzites do not always constitute the major ore-bearing horizons, their association with mineralization and their geophysical responses, were such as to render these units of prime prospecting significance in the search for Cu-Pb-Zn and cupreous pyrite deposits. In general, the magnetite-quartzites were assumed to act as unique marker horizons for such mineralization, and as discrete units their strike extent appeared to exert considerable control (albeit indirectly) on the spatial development of sympathetically correlating sulphides.

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Given the resultant magnetic signal responses of the search target mineralization, and the limited number of magnetite-bearing geological units within both prospect areas, the aeromagnetic technique recommended itself as the prime reconnaissance prospecting tool, both in terms of its cost-effectiveness and its fast-target generation capabilities. Furthermore, this strategy eliminated large areas with no economic potential (i.e. areas of little or no magnetic relief) at the outset. Thus, the initial prospecting approach was an indirect one, with areas of possible mineralization potential being selected on the basis of their proximity to interpreted magnetite-quartzite horizons.

At this stage of the program, little attempt was made to utilize any of the conventional geophysical prospecting techniques in defining the target sulphide zones themselves. Within the Northwest Cape area, the generally disseminated nature of the sulphide zones precluded their detection by airborne electromagnetic methods, whereas portions of the overburden-covered areas of the Gorob Prospect were known, from a previous Input EM survey executed on behalf of Penarroya, to be highly conductive, thereby negating the effectiveness of AEM surveys over a large portion of the area.

Regional geochemical sampling was not employed in the reconnaissance phase of the Northwest Cape program, due to doubts (since dispelled) as to its effectiveness in calcrete-covered areas, and its inferior cost-effectiveness/rate of coverage when compared to the aeromagnetic method. Geochemical surveys were utilized in the Gorob area, but proved ineffective in the deep calcrete-covered zones.

Selection of Potential Magnetite-Quartzite Horizons from Aeromagnetic Data

Because of their geometry, magnetite-quartzite horizons produce an anomalous aeromagnetic profile having the characteristic thin-dyke (i.e. sensor ground clearance >> dyke width) waveform (Gay, 1963; Reford, 1964). While this waveform is an important aeromagnetic parameter in identifying potential magnetite-quartzite units on the basis of their geometrical configuration i.e. differentiating between thick/thin dykes, plugs etc., it cannot be taken as uniquely diagnostic of the causative source. Other magnetite-bearing units (e.g. amphibolites) of long strike extent and widths not greater than the sensor ground clearance (i.e. about 100 m), may be expected to produce similar magnetic targets. The only additional criteria that can be utilized in separating significant horizons from those of lesser significance, short of ground checking, is an assessment of anomaly amplitudes within any one prospect area. However the amplitude parameter must be used with caution, as discussed below.

The magnetic response (peak-to-peak amplitude) of a magnetite-quartzite unit is not in itself significant in terms of (a) its identity and (b) the existence or otherwise of sympathetically correlating sulphide mineralization.

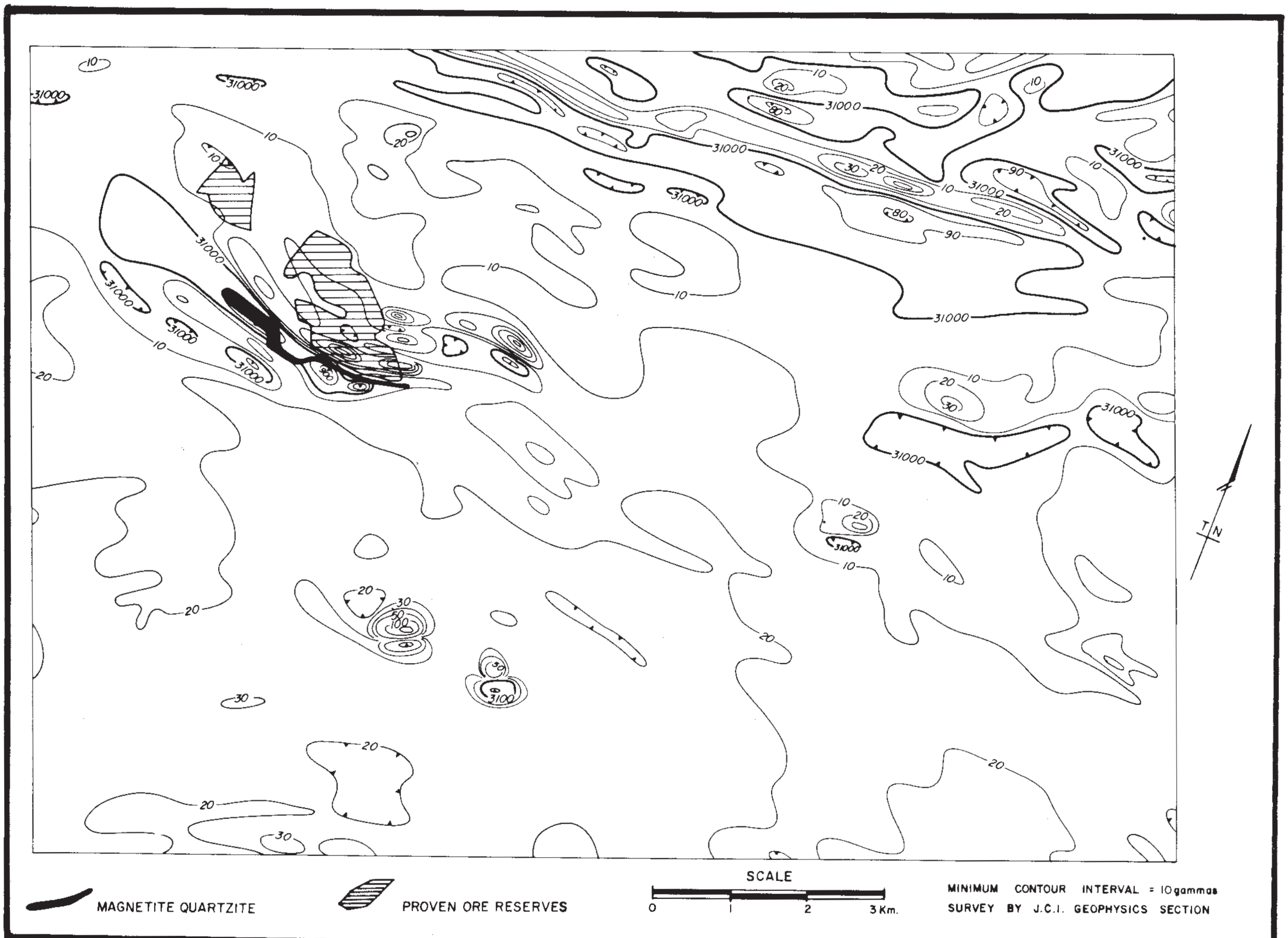

Figure 38.3. *Aeromagnetic contour map, Otjihase area.*

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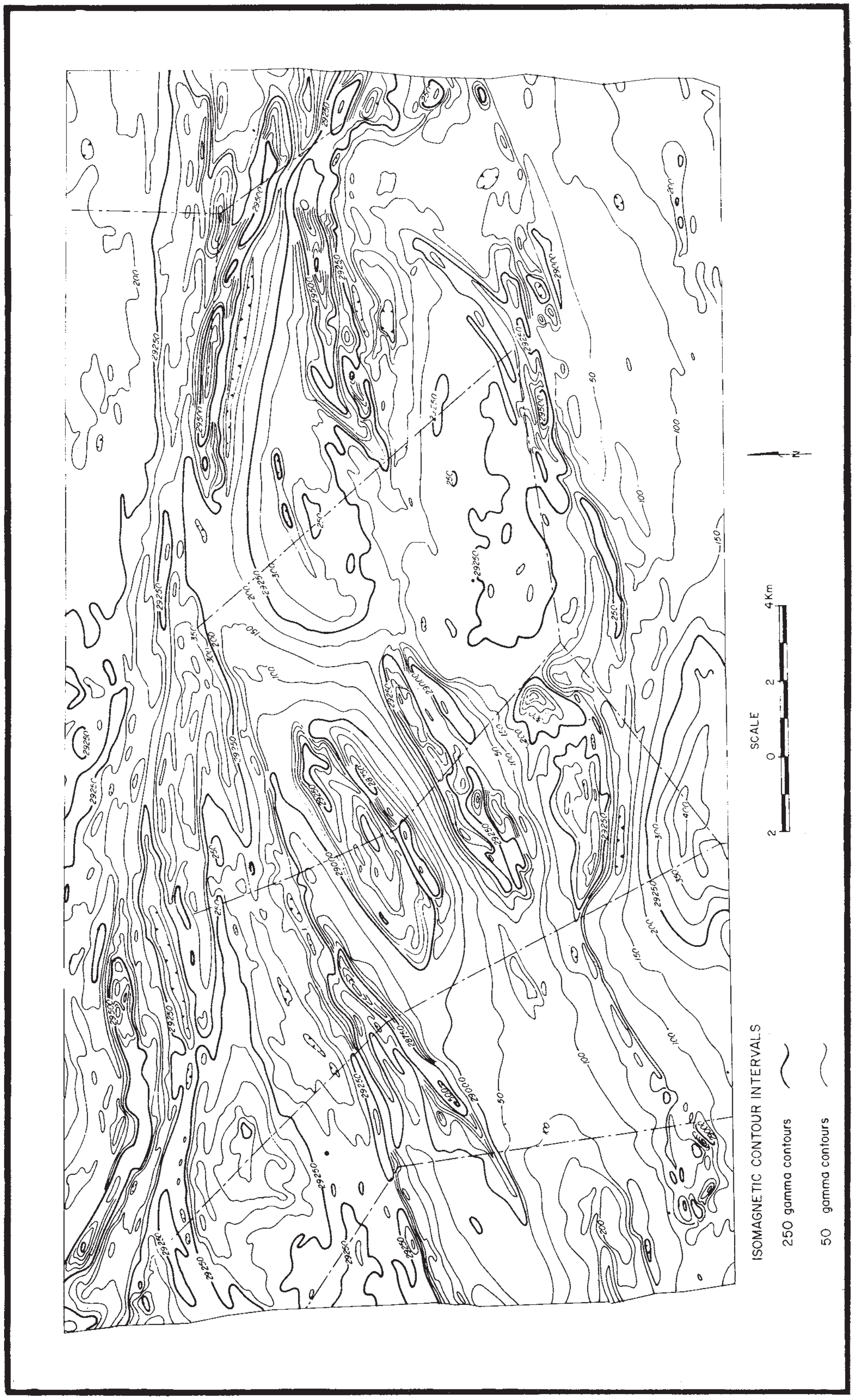

Figure 38.4. Aeromagnetic contour map, Pofadder East Block.

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Neglecting remanence, the amplitude of the magnetic response is mainly dependant on the product of the width and magnetite content of the horizon, and may vary by an order of magnitude, as shown by the test surveys over Aggenys and Otjihase, which demonstrated magnetite content (by volume) x width characteristics of the order of 300 m% and 20 m% respectively. The development of magnetite-quartzite units is of greatest significance, rather than their width or magnetite content, although the major orebodies do seem to be associated with higher magnetite contents in most cases.

In addition, localized tectonic thickening of the magnetite-quartzite unit e.g. drag folding, which in itself is a favourable indicator of possible contiguous sulphide deposition, will generally result in an increase in the apparent intensity of magnetization of this unit, producing an amplitude-enhanced magnetic response. Thus, given other favourable parameters, it remains a valid approach to assign high priorities to those horizons, or discrete strike sections, showing the greatest magnetic activity within an area.

Reconnaissance Phase – Ground Magnetometer Surveys

Ground magnetometer surveys were executed over selected airborne anomalies with the purpose of (a) accurately delineating the anomaly on the ground and (b) resolving ambiguities inherent in the selection of thin-dyke anomalies from the airborne data. Based on waveform analysis, (Martin, 1966; Koulomzine et al., 1970, and Am, 1972), the superior resolving power of the ground surveys permitted the rejection of heterogeneous magnetite-bearing units which had appeared as composite units from the air, plus those units which on inspection proved to have widths greater than 40-50 m. In outcropping areas, nonsignificant anomalies were rejected from geological considerations.

Follow-up Exploration Phase

Based on prior empirical observations, the search model adopted allowed for possible spatial separation between the magnetite-quartzite horizon and its associated mineralization. Thus the search for sulphide zones was not only restricted to the delineation of possible ore-bearing horizons contiguous with the pre-delineated magnetite-quartzite horizon, but recognized that such zones, while paralleling the former, might occur up to (say) 200 m away from it.

Magnetic horizons conforming to the search target type were accurately located on the ground, and were covered by detailed geochemical surveys aimed at assessing the base-metal potential of the horizon and adjacent area, up to 500 m on either side of the horizon. Soil and/or other surface material samples were taken at 10 m intervals along line, with the minus 80 mesh fraction being treated by total acid extraction and analyzed for Cu, Zn, and Pb on atomic absorption analytical equipment.

Within the Northwest Cape, geochemical sampling was followed by IP surveys over the same grids, with the aim of determining the sulphide potential of (a) prominent base-metal geochemical anomalies or (b) the entire grid, where reasonable doubt existed as to the effectiveness of the geochemical technique in any one area. Under favourable circumstances, the IP technique is capable of yielding polarization responses from sulphide zones having as little as 2 per cent sulphides by volume, and thus lent itself ideally to the search for what, in the main, were expected to be disseminated (about 5 per cent by volume) sulphides.

As the Gorob Prospect area was known to be typified by contiguous magnetite-quartzite and massive pyrite sulphide horizons, the search for the latter was initiated using the Turam electromagnetic technique. Interpretation problems arising from the use of Turam led to its early rejection, and except where geological problems dictated otherwise (see later), investigation of potential sulphide-bearing magnetite-quartzite horizons was undertaken by systematic percussion drilling.

GEOPHYSICAL RESULTS

The Pofadder East Block, South Africa

Aeromagnetic Survey

The aeromagnetic survey of the Pofadder East Block was flown using a Scintrex Map-2 proton-precession magnetometer at a terrain clearance of 70 m, along north-south flight lines having a separation of 300 m. An isomagnetic contour map covering the major portion of this block is shown in Figure 38.4. The original contour interval of 10 gammas has been coarsened in Figure 38.4 to 50 gammas for the sake of visual clarity. The corresponding magnetic interpretation map is shown in Figure 38.5.

Some 40 per cent of the total survey area is underlain by weak to moderately magnetic rock units, which show up as composite assemblages comprising closely-spaced, subparallel magnetic anomalies. The short wavelength nature of the latter indicates a near-surface origin for their causative sources, calculated depths of burial being in the range 0-20 m i.e. well within the depth penetration capabilities of the IP technique.

Major magnetic discontinuities, other than those due to contact-type sources, are not common within the area, and this implied scarcity of faults/shears has since been substantiated by later geological mapping (guided by the aeromagnetic data). While the major structure of this Block conforms to that of an easterly-plunging synform, the presence of a rapidly alternating series of subparallel antiformal and synformal fold axes is readily detectable from the data. Where such fold axes have been interpreted, the selection of an antiform or synform was based on the assumption of induced magnetization of the outer magnetic horizons.

Four major, magnetically identifiable rock units coded A to D (see Fig. 38.5) have been defined within the survey area, and are discussed below.

Unit A, which occupies the central portion of the survey area, is correlated with nonmagnetic biotite gneiss assemblages. Although these gneisses can be geologically subdivided, no such distinction is possible from the aeromagnetic data.

Unit B occupies some 40 per cent of the total survey area, and correlates with areas underlain by basal quartzofeldspathic gneisses which occupy interpreted antiformal structures. These weakly magnetic units generally exhibit a domal structure, and their nonconformable nature is apparent in the central portion of the survey area.

Moderately magnetic zones interpreted as Unit C occur within the central and eastern areas, and are correlated with discrete calc-silicate units falling within the topmost part of the local sequence. This is consistent with an interpretation of their association with east-west oriented synformal structures, and isolated units of this type presumably represent erosional remnants.

Unit D encompasses a fairly large zone in the northwest and western portions of the area, where it is geologically correlated with pink gneisses and biotite-schist units, which have associated magnetite-quartzites, metaquartzites and amphibolites. This moderately magnetic unit is the potentially mineralized portion of the Bushmanland Sequence in the Northwest Cape.

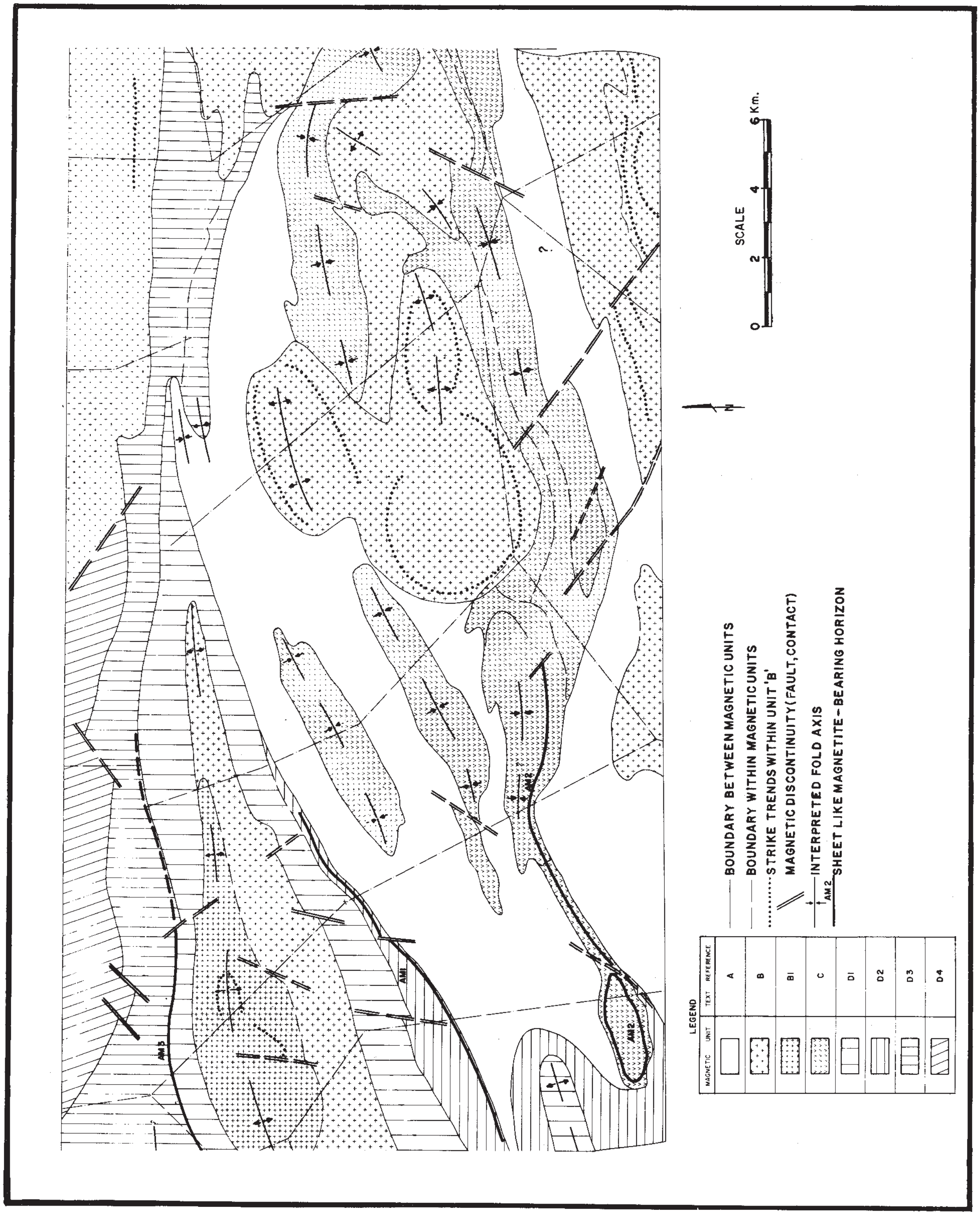

Figure 38.5. *Aeromagnetic interpretation map, Pofadder East Block.*

The weakly magnetic characteristics of units A and B were taken as precluding the presence of significant magnetite-quartzites therein. Based on the search target model, this automatically excluded some 50-60 per cent of the present area as having little or no economic potential, which subsequent ground checking proved to be correct.

The high density of magnetic horizons within units C and D, resulted in the selection therein of 18 priority areas covering aeromagnetic anomalies thought likely to reflect magnetite-quartzite horizons. True magnetite-quartzite units are now known to lie only within unit D, where they are identified by aeromagnetic anomalies AM1 and AM3 (see Fig. 38.5). Elsewhere, major magnetic responses are attributable to magnetite-enriched lenses within amphibolitic-type rocks, with the exception of AM2, which reflects magnetite layers in an intrusive metagabbroic sill within biotite gneiss country rocks.

AM1 and AM3 appear as predominantly negative anomalies which, given the confirmed near-vertical dip of enclosing strata, implies that remanent rather than induced magnetism must be taken as the dominant magnetization contributor, with the remanent magnetization vector being anti-parallel to the present earth's field inclination. As both the unit C and D rocks are characterized by normal induced responses only, it would appear these remanently magnetized magnetite-quartzite horizons must occupy a unique position within the local Bushmanland stratigraphy. AM3 was subsequently proven to have no base-metal sulphide associations.

The northeast-striking magnetic anomaly AM1 extends for some 10 km, and for a considerable portion of its length is spatially associated with a mineralized horizon at Putsberg. The Putsberg mineralized stratigraphic horizon parallels the magnetite-quartzite unit which has produced AM1 and occurs some 100-250 m to the south, where it lies close to an interpreted contact between units B and D. It appears significant in terms of mineralization control, that the aeromagnetic anomaly attains its greatest amplitude adjacent to the mineralized zone, indicating a marked increase in its width and/or magnetite content within this section. In fact it is a combination of increased width and increased magnetite content which produces the major anomaly. Magnetic discontinuities are apparent at the extremity of the highly anomalous section of the anomaly, and are related to local terminations of the magnetite-quartzite horizon.

Given its exploration significance, the magnetization characteristics of this anomaly may assume special importance. Insufficient evidence exists to establish any direct relationship between areas of possible mineralization and their association with remanently magnetized units, but it may be significant that the magnetite-quartzite at the Gamsberg zinc deposit is also reported to show a large negative remanent component.

Ground Surveys

The ground follow-up program over 18 selected aeromagnetic targets comprised ground magnetometer, geochemical soil sampling and induced polarization surveys carried out during the period August 1973 to July 1974. Magnetometer surveys were conducted at 20 m intervals along traverse lines having a spacing of 200 m, total coverage being 700 line kilometres. The instruments used were Scintrex MF-2 fluxgate magnetometers and Geometrics G816 proton-precession magnetometers. Induced polarization surveys totalling 100 line kilometres were carried out using a McPhar P660 frequency-domain unit, the preferred electrode configuration being dipole-dipole with an 'a' spacing of 25 m or 50 m (prior investigation had shown the thin overburden cover to be moderately resistive (about 300 Ωm) and the upper weathered layer to be less than 10 m thick).

Systematic deployment of the above techniques over and adjacent to selected aeromagnetic anomalies, resulted in the delineation of a zone of copper mineralization on the Putsberg farm. The ground magnetometer coverage of the significant portion of aeromagnetic anomaly AM1 (which first drew attention to the area) is shown in isomagnetic contour form in Figure 38.6b, along with the subsequently determined strike trace of the mineralized horizon.

The magnetic zone identified with AM1 extends for a distance of 6.5 km, from line 9000 in the southwest to line 15 500 in the northeast, and is flanked by nonmagnetic rock assemblages (with the exception of a narrow amphibolite horizon to the south). For the greater part of its length (lines 9000 – 12 800) its major component is a sharply peaking magnetic low (ΔT=1000-2000 gammas), which reflects a magnetite-quartzite horizon having a width in the range 15-25 m, and an average "depth to top" of 10 m. This unit is intercalated within a magnetite-rich sillimanite gneiss which averages about 60 m in thickness. Both causative sources exhibit remanent magnetization, with the polarization vector being anti-parallel to the earth's present field inclination (I Ω -60°).

Lying some 100-250 m south of, and paralleling aeromagnetic anomaly AM1, the metalliferous horizon was delineated by detailed IP surveys carried out over and along the projected strike trace of weak, discontinuous Cu-Zn geochemical anomalies.The copper anomaly is subdued and values between two and three times a background of 25 ppm Cu are the norm, with a maximum spot value of 260 ppm cu. The zinc is more erratic but values four to five times a background of about 80 ppm are common, and zinc values are sympathetic to the copper values.

Figure 38.6a shows two of the original magnetic/geochemical/IP discovery traverses over the mineralized zone. The 4 km-long IP anomaly reflects a narrow (about 20 m wide) steeply-dipping causative source having a shallow depth (< 15 m) to top, which was characterized by strongly persistent responses in the range 3 to 4.5 per cent PFE. The polarizable unit shows no unique correlating resistivity low, thereby largely precluding massive (conducting-type) sulphide mineralization. The hanging-wall biotite-gneisses/schists are characterized by resistivities of 200 Ω m, while the footwall grey/pink gneisses show values in the range 1000 to 3000 Ω m, thereby readily permitting mapping of their contact by the resistivity method.

Contemporaneous percussion drilling guided on site by the IP survey results, showed that the polarizable unit reflected a 4 km long, persistently mineralized horizon lying under 1-5 m of overburden, and containing erratic copper values of up to 4 per cent

Subsequent work has shown the polarizable horizon to contain finely disseminated pyrite (between 1 per cent and rarely 10 per cent by volume) within a 10 m thick assemblage of heterogeneous schists and thin siliceous beds. The major base-metal mineral is chalcopyrite which is present in sufficient quantity to generate subeconomic mineralized bodies at three sections along the mineralized horizon, between lines 10300-10500, lines 1100-11500 and lines 12100-12500. Because these ore zone sections are not characterised by a significant build up in sulphide content as such, the IP technique proved incapable of defining them uniquely within the boundaries of the mineralized horizon.

Geophysical Test Surveys over Putsberg Mineralized Horizons

In order to provide a more complete geo-electrical "finger-print" of the Putsberg mineralized horizon, test surveys were carried out over selected sections using the

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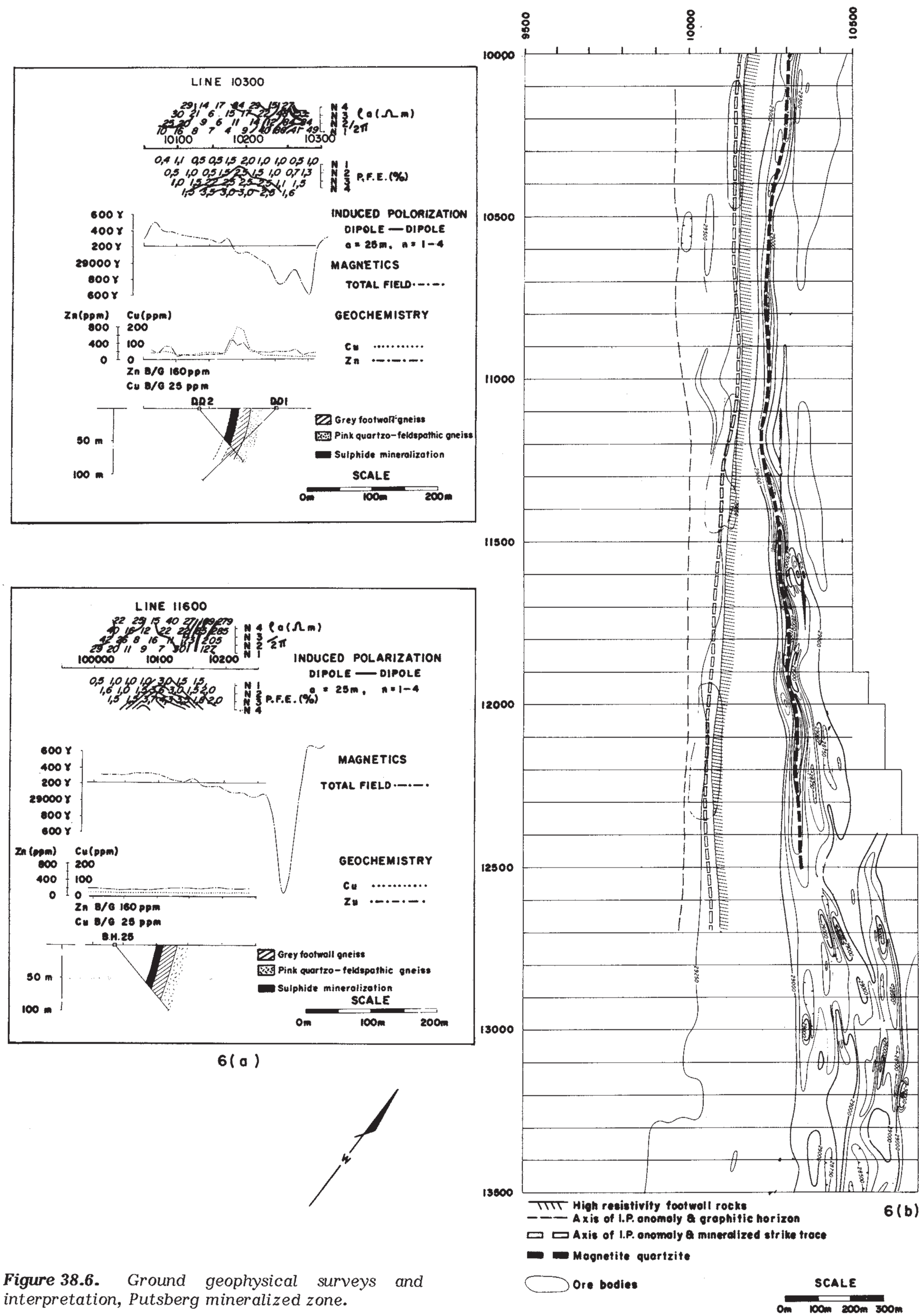

Figure 38.6. *Ground geophysical surveys and interpretation, Putsberg mineralized zone.*

self-potential, electromagnetic and time-domain IP methods, and an example of the results obtained is shown in Figure 38.7.

While consistently significant anomalies were obtained by both frequency and time-domain IP systems using a variety of electrode configurations, it is noteworthy (although not unexpected) that the sulphide horizon failed to generate distinct horizontal-loop EM and self-potential anomalies. Given the near-surface location (about 5 m depth) of the sulphides, this is of course directly attributable to the lack of massive sulphides in situ, thereby precluding any significant degree of electrical interconnection between sulphide grains.

Gorob Prospect Area, South West Africa

Aeromagnetic Survey

Figure 38.8 shows the results of an in-house JCI aeromagnetic survey over the major portion of the Prospect area, the original minimum contour interval of 2.5 gammas having been coarsened to 10 gammas for the sake of visual clarity. The survey was flown using a Geometrics G803 proton-precession magnetometer at a mean terrain clearance of 100 m, along northwest-southeast traverse lines having a separation of 400 m.

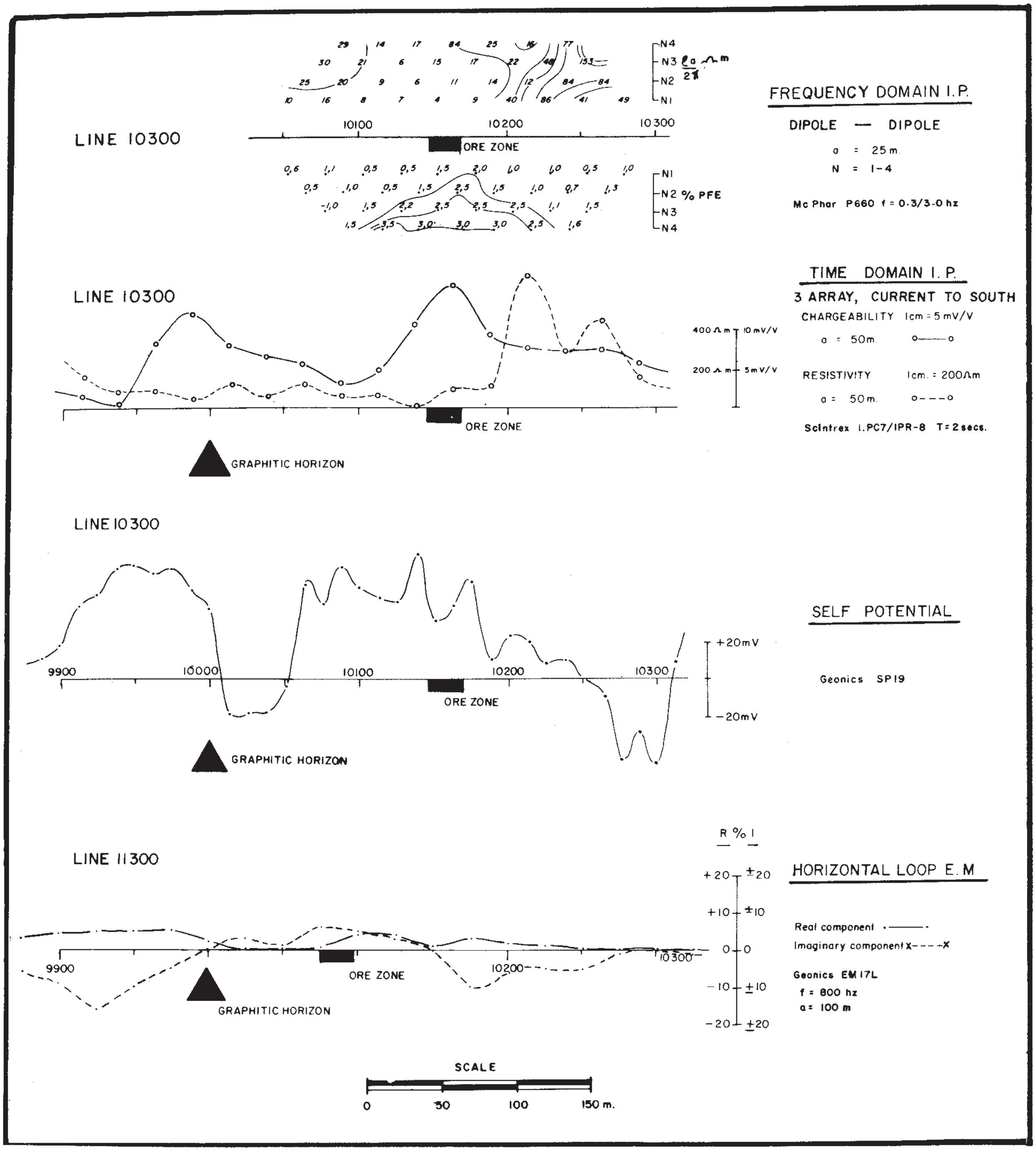

Figure 38.7. *Ground geophysical test surveys, Putsberg mineralized zone.*

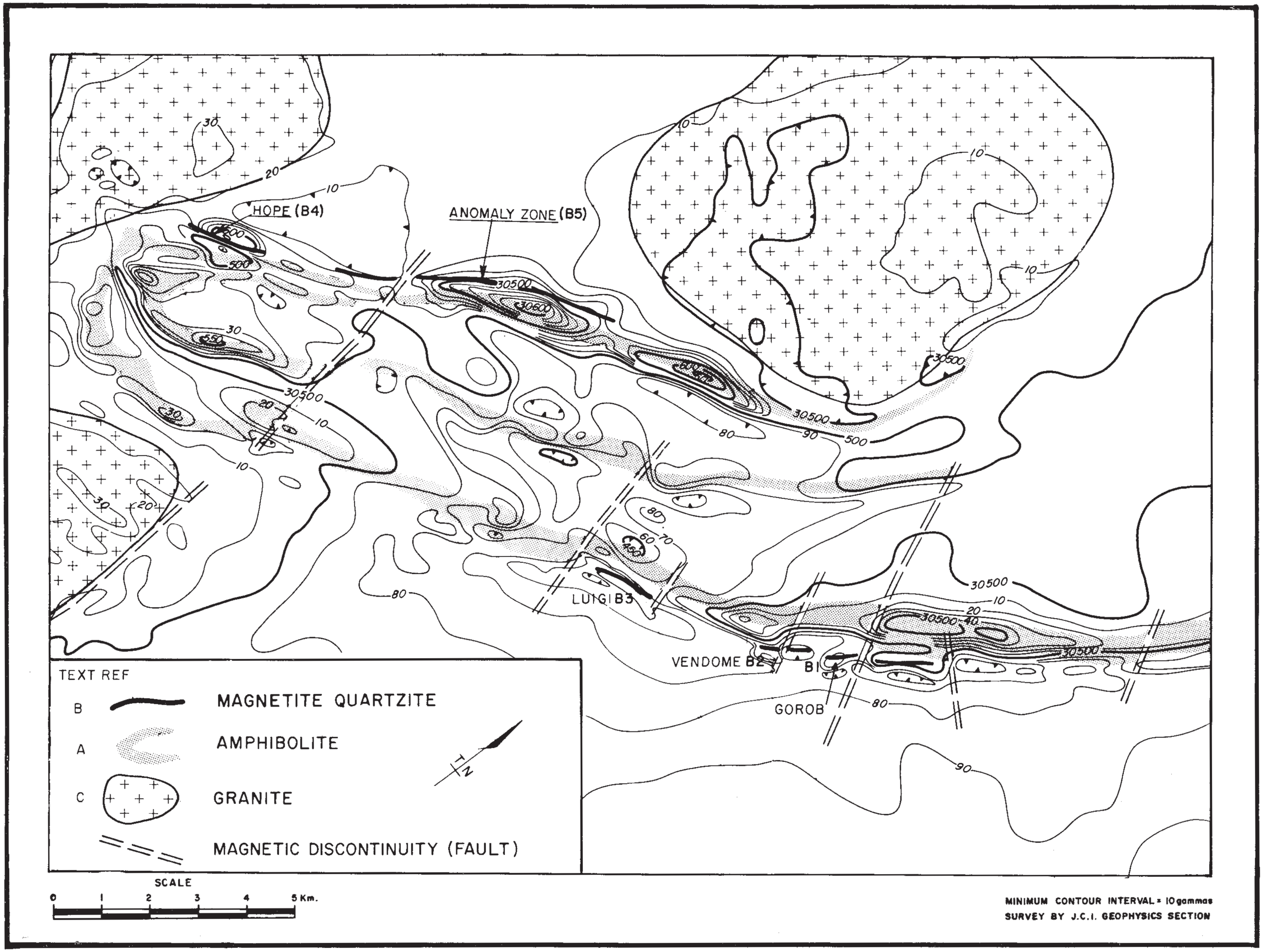

Figure 38.8. *Aeromagnetic contour and interpretation map, Gorob prospect.*

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Magnetic activity within the area is largely restricted to magnetite-bearing amphibolites of the so-called Amphibolite Belt, which fall within essentially nonmagnetic schists and gneisses. The magnetite-bearing nature of these amphibolites is in sharp contrast to those occurring in the vicinity of the Otjihase Mine, which contain little or no magnetite.

Major magnetic discontinuities trending north-northwest are apparent from the aeromagnetic map, and in most cases have been correlated with faults/shear-zones identified from photo-interpretation and geological mapping. The short wavelength nature of most magnetic sources indicates shallow to moderate depths of burial, ranging from at or near-surface in the south of the area, up to 50 m in the north.

Unit A reflects a nearly continuous and for the most part linear amphibolite horizon, whose strike trace delineates a major synformal structure in the western sector of the area. The amphibolites vary in thickness from 50 to 300 m, and have magnetite contents up to 5 per cent by volume. Their attitudes, as interpreted from the magnetic data and confirmed in the field, are consistent with a synclinal structure. Along the southern limb the amphibolites form an outcropping or sub-outcropping unit, whereas along the northern limb there is a marked variation in the "depth to top", ranging from sub-outcrop near the nose of the fold, up to a maximum to 50 m in the eastern extremity of the area, reflecting the increasing thickness of calcrete/alluvium cover in this direction.

The subdivided unit B reflects discrete magnetite-quartzite horizons lying structurally below the amphibolite unit, and separated from it (in plan position) by distances varying from 100 to 300 m. The magnetite-quartzites B1, B2, and B3 falling along the southern limb of the syncline, correlate with short-strike length (< 200 m) mineralized horizons delineated prior to the survey. B1 reflects a 500 m-long magnetite-quartzite horizon (maximum response ΔT=50 gammas) contiguous to the 150 m strike length pyrite orebody at the so-called Gorob Mine.

B4 reflects a 1.5 km-long magnetite-quartzite assemblage (maximum response ΔT=150 gammas) correlating, in part at least, with the oxidized outcrop of the mineralized zone of the "Hope Mine". The magnetite-quartzite associated with the mineralization is complexly drag folded in a tight synformal structure (plunging shallowly to the east-northeast) which, prior to the survey, had only been traced via sub-outcrop for a distance of about 300 m from the nose of the syncline. Subsequent work along that portion of the ore-carrying structure revealed by the magnetic survey results, has proved the existence of substantial sulphide mineralization along the down-plunge axis.

Unit B5, since renamed Anomaly Zone, reflects an approximately 4.5 km-long magnetite-quartzite horizon, paralleling and lying some 200-350 m north of the major amphibolite unit defining the northern limb of the syncline. Its aeromagnetic anomaly overlaps with that of the amphibolite horizon, such that it is only clearly distinguishable as a unique horizon from the original profile data. The magnetite-quartzite unit is now known to contain ore-grade copper mineralization within three discrete, short strike-length (about 500 m) sections. For the entirety of its strike-length, the Anomaly Zone magnetite-quartzite is overlain by some 2-40 m of surficial calcrete and gravels.

Unit C reflects weakly magnetic granitic intrusions, which have removed the eastward strike extension of the northern limb of the syncline in the northeast parts of the area.

Ground Surveys – "Anomaly Zone"

Ground magnetometer surveys along a 10 m by 50 m grid were carried out over the Anomaly Zone area, using a Geometrics G816 proton-precession magnetometer. Survey results were used to guide contemporaneous percussion drilling of the 4.5 km-long buried magnetite-quartzite horizon, and resulted in the early delineation of intercalated, narrow (less than 2 m wide) massive sulphide sections carrying traces of copper. In an attempt to define the mineralized horizons more precisely, and in particular to isolate those sections exhibiting the highest sulphide content, ground electromagnetic suveys were carried out over the magnetometer grid. These surveys utilized a Scintrex SE-71 Turam EM unit operating at a frequency of 400 Hz, loop dimensions of 1000 x 1000 m, and a receiver coil spacing of 25 m.

Magnetometer survey results over the entire Anomaly Zone grid, and representative Turam EM results from the grid are shown in Figure 38.9, along with relevant geological information, including the position of significantly mineralized zones proved by limited drilling.

The magnetic data indicate that the magnetite-quartzite unit shows considerable pinching and swelling along strike, with a maximum thickness of about 20 m. Drilling has shown mineralized sulphide zones of low-grade copper in three places, namely Anomaly West, Central and East. (In fact, Anomaly West and Central are contiguous and form the hinge zone of an easterly-plunging drag fold). It is significant that it is within these sections that the magnetite-quartzite unit attains its greatest thickness and/or magnetite content. Using the magnetic width(t) x susceptibility (k) product as an index, these 3 sections are characterized by k*t values in excess of 150 cgs units, vs an "average" value of about 70 cgs units (Koulomzine et al., 1970; McGrath and Hood, 1970; Paterson et al., 1975); the contribution from pyrrhotite may be significant here. In general the magnetic data show the magnetite-quartzite unit to have a near vertical to steep southerly dip, although in the locality of Anomaly West/Central this is reversed and a steep northerly dip is indicated (later verified by diamond drilling). Interpreted depths of burial range from 10-50 m.

The broad deep-seated anomaly to the west of Anomaly Central has proved to be related to an amphibolite lens detached from the main zone to the south.

The Turam EM survey delineated a continous 4 km-long conducting horizon, with an axis parallel and some 10-20 m north of the magnetite-quartzite horizon. The causative unit in general displayed a monotonously regular conductivity – thickness value averaging some 10 mhos, and, assuming a thin dyke source (Bosschart, 1964) an average depth of burial of 40 to 50 m. The electromagnetic data were disappointing in that no unique responses were obtained in the vicinity of the mineralized sections, which are now known to contain up to 40 per cent by volume of sulphides.

Given that massive sulphides are not present along the entire strike extent of the magnetite-quartzite horizon, the strike persistency and regular stratigraphic position of the conducting horizon, indicate that its major causative source must be attributed to conducting minerals other than sulphides in a zone flanking the magnetite-quartzite unit. In this instance, it thus appears that the EM results are not diagnostic of buried massive sulphides, but relate more to a wide lithological unit, probably graphitic schists which have been intersected in one of the few diamond-drill holes in this sector.

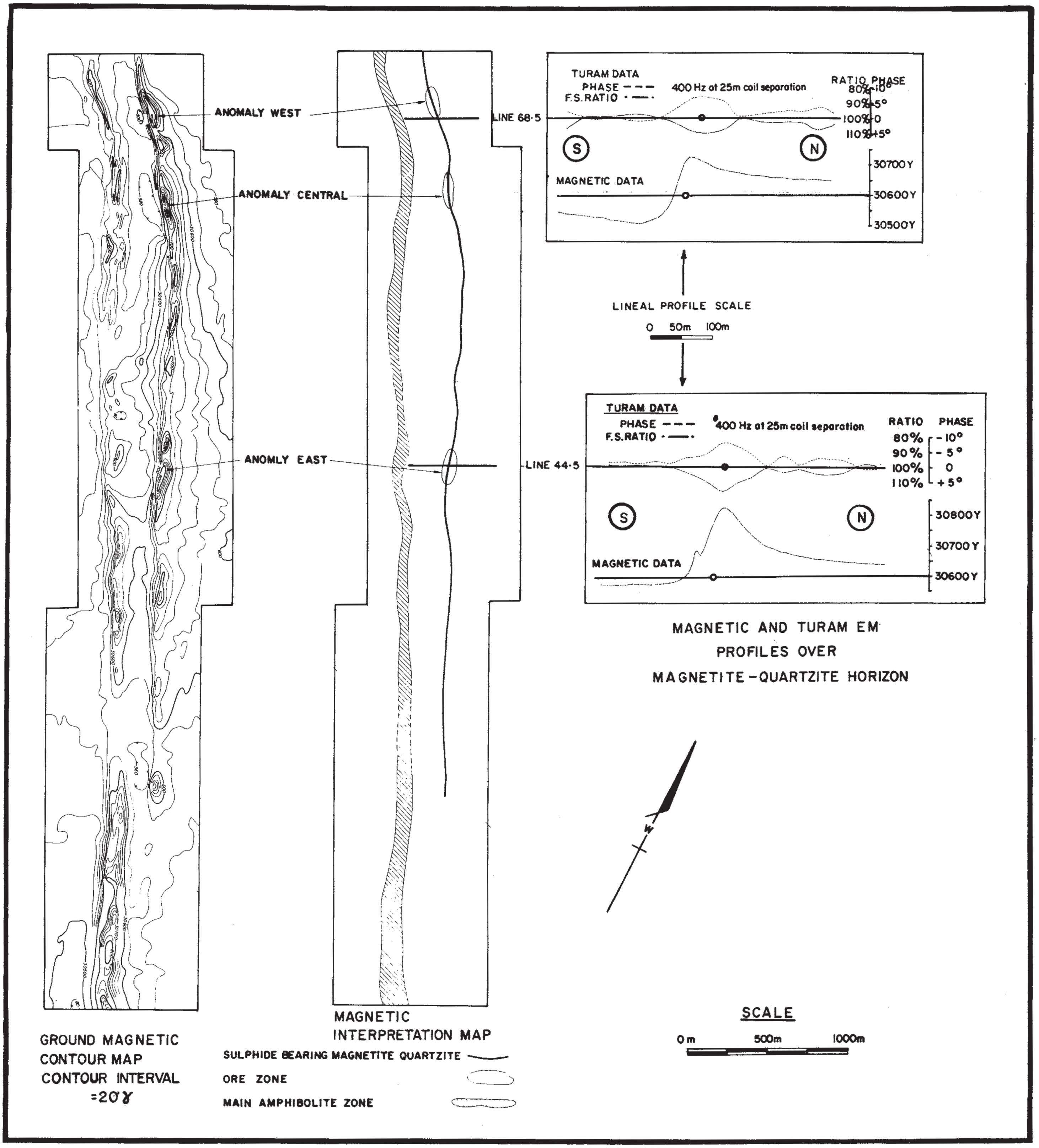

Figure 38.9. *Ground geophysical surveys and interpretation, Anomaly Zone area.*

Ground Surveys – "Hope Mine" Zone

Ground magnetometer data for this area are summarized in the isomagnetic contour map of Figure 38.10. Survey instrumentation and grid configuration were the same as for the Anomaly Zone area. The magnetite-quartzite horizon generates a maximum anomalous response of ΔT=3000 gammas in the locality of the synformal closure and diminishes eastwards in accordance with the shallow plunge in this direction. Individual anomalous centres relating to the northern and southern limbs, are clearly identified on the profile data for a distance of 200 m down-plunge from the fold closure. Thereafter, the increasing depth of burial of the magnetic units, and their close separation (about 40 m), combine to produce a single broad anomalous response which can be traced, albeit with some difficulty, for a distance of up to 1500 m along strike from the fold closure.

Early drilling along the synclinal axis (as interpreted from the magnetic data) indicated that ore-grade massive sulphide mineralization was distributed erratically throughout the refolded keel of the syncline, where it conformed to a near cylindrical mass with a diameter in the range of 30-50 m. Typical magnetic and geological cross-sections are shown in Figure 38.10b.

Magnetic profile data were interpreted using both the thick-dyke and ribbon models (Martin, 1966; Paterson et al., 1975), although it was recognized that the geometrical complexity of the magnetite-bearing units hardly accorded with either of these simple models. Theoretically the ribbon model should give the best approximation for a synformal structure of the type developed at Hope, but it was found in practice that the thick-dyke model yielded (a) the more internally consistent results and (b) depth and dip values closer to those revealed by later drilling. In all cases, induced magnetization was assumed, and simple field tests have confirmed a magnetization vector within 10° of the earth's present field inclination of -60°. In practice, the thick dyke model was used for determining the axis of the synclinal structure, which, when combined with the extrapolated plunge of the mineralized zone, allowed the designation of subsurface drilling targets.

Taking the magnetite-quartzite limbs as one composite magnetic source, the thick dyke interpretation showed the synclinal structure as having a shallow easterly plunge (<12°) and a steeply-dipping axial plane (>70°N/S). The thick dyke and ribbon interpretations were largely in agreement to the east of line 115W, with the latter generating a ribbon length greater than 1000 m in this sector i.e. the magnetite-quartzites did not appear to be significantly depth limited. West of line 115 the ribbon model inevitably exhibited greater depths of burial (by 20-50 m), with the ribbon at times (fortuitously?) intersecting the mineralized zone. Lack of practical necessity has precluded further investigation of the appropriateness of either model in such a complex geological situation, especially given that the magnetite distribution within the synclinal unit is known to vary considerably in both the horizontal and vertical planes.

In an attempt to define the highly localized ore-zone more closely, recourse was made to electrical survey techniques after core tests had shown the sulphide mineralization to be electrically conducting. A down-hole resistivity survey in drillhole Hope 5 (see Fig. 38.11) showed the upper 70 m of strata to have a resistivity of about 20 Ωm, resistivities down to 150 m being of the order of approximately 40 Ωm. These depressed resistivity values were attributed to heavy rains having generated highly saline groundwater, although similar values had not been observed in the adjacent Anomaly Zone. Given that the upper layer thus demonstrated a minimum conductivity x thickness value of 3 mhos, surface EM techniques were initially discounted, especially given their lack of diagnostic responses in the Anomaly Zone. The large depth to mineralization and limited dimensions of the sulphide zone, also militated against the use of the IP technique, leading finally to the employment of the mise-à-la-masse method (Parasnis, 1967).

Figure 38.11 shows the results of such surveys along the strike trace of the magnetic unit, utilizing energizing current electrodes in drillholes Hope 5, 9 and 17 respectively. Infinite current electrodes were set out 2 km to the north and south of the mineralized zone, and surface voltage potentials read (with respect to an "infinite" potential electrode) at intervals of 12.5 m along line. Instrumentation consisted of a Huntec 7.5 kw, time-domain Ip transmitter and a Scintrex IPR-8 receiver unit.

The isopotential data from Hope 5 and 9 (only discrete sections of which are shown in Fig. 38.11) confirmed the presence of a continuous, moderately conducting ribbon extending for a minimum distance of 700 m. Of particular note is the strike trace flexure in the locality of lines 115-114.5W. The relatively low values for the normalized potential field response over the mineralization and the lack of a sharply peaking response, are due to both the considerable depth of burial of the mineralization, and the thick, upper conducting layer above it, which acts to short-circuit and attenuate a major portion of the subsurface current flow.

The mineralized zone intersected by Hope 9 appears to terminate in the locality of line 114. Mineralization intersected by Hope 17 does not appear to be continuous with that intersected in Hope 9, nor exhibit significant longitudinal dimensions.

The results of the mise-à-la-masse survey are summarized, along with the magnetic data, in the geophysical interpretation maps of Figure 38.12. Results from a Pulse EM survey utilizing a Crone Pulse EM unit (see below) are also presented thereon.

An interpretation of the magnetic data using the thick dyke model shows the synclinal fold axis to be arcuate in outline and steeply dipping. The width of the structure determined is up to 60 m greater than that indicated by drilling, which is due to the presence of magnetite in the schists adjacent to the quartzite. Based on the "depth-to-top" of the magnetite-quartzites, the topmost portion of the synclinal structure shows a plunge of 4° along its western section, which steepens east of line 115W to an angle of 12°. The marked discontinuity in apparent plunge angles is most probably due to faulting believed to occur between lines 115 and 114W.

For the greater part of its known strike length and for depths of burial of up to 125 m, the mineralized zone is well delineated by both the Pulse EM and mise-à-la-masse data. Only the latter, however, provides information on the known northern flexure of the zone at its eastern extremity. The lack of continuity of the mise-à-la-masse conductive axis to the east of line 114.5W, presumably ties in with the fault indicated as occurring at this locality (from both magnetic and drilling information).

The contributions made by both magnetic and electrical methods to this particular search problem, comprising as they do a mixture of quantitative and qualitative data interpretations, are an effective testimony to the value of multi-technique geophysical surveys in assisting drilling programs aimed at assessing relatively small, discrete, and therefore difficult drilling targets at moderate depths of burial.

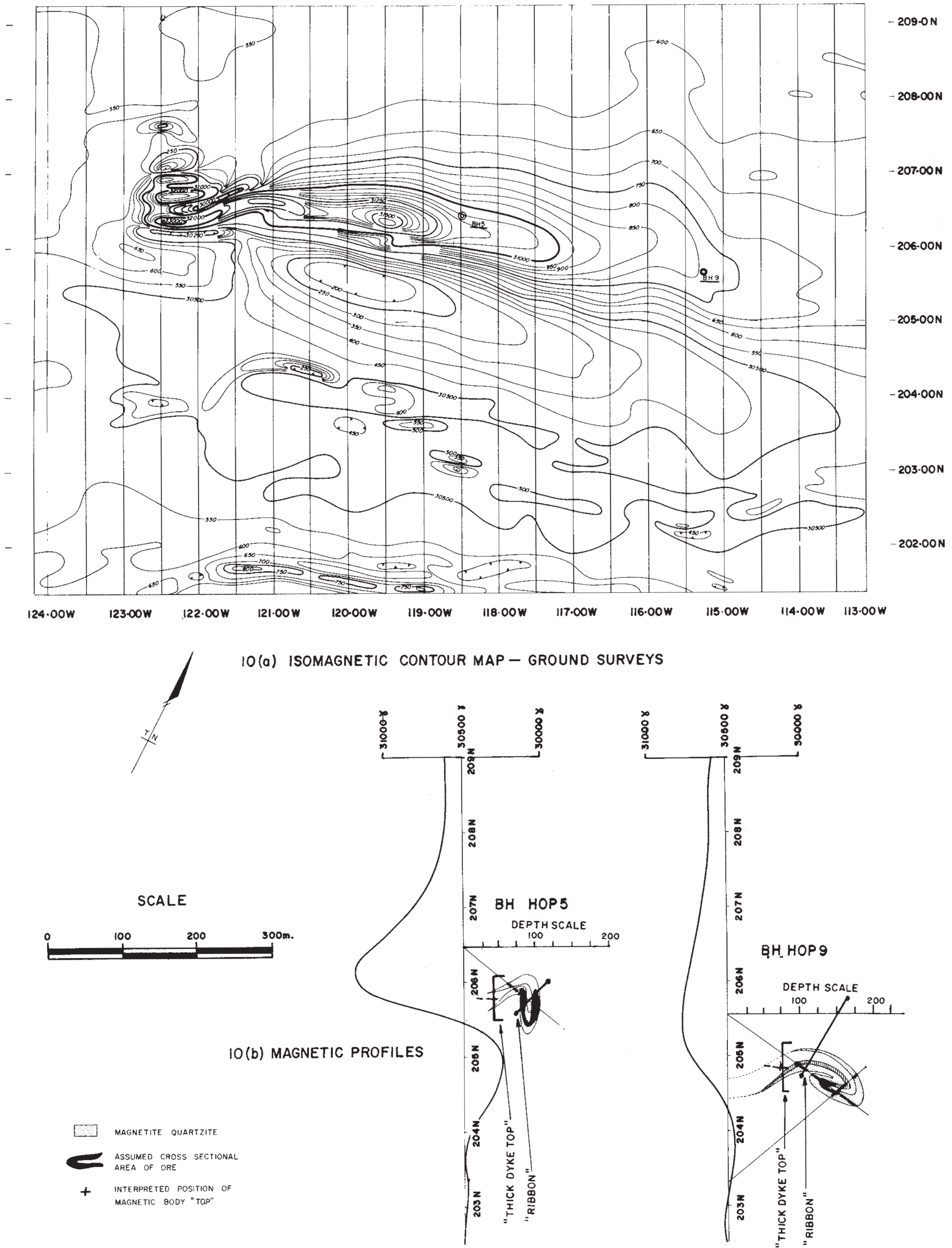

Figure 38.10. *Ground magnetometer surveys, Hope Mine Zone.*

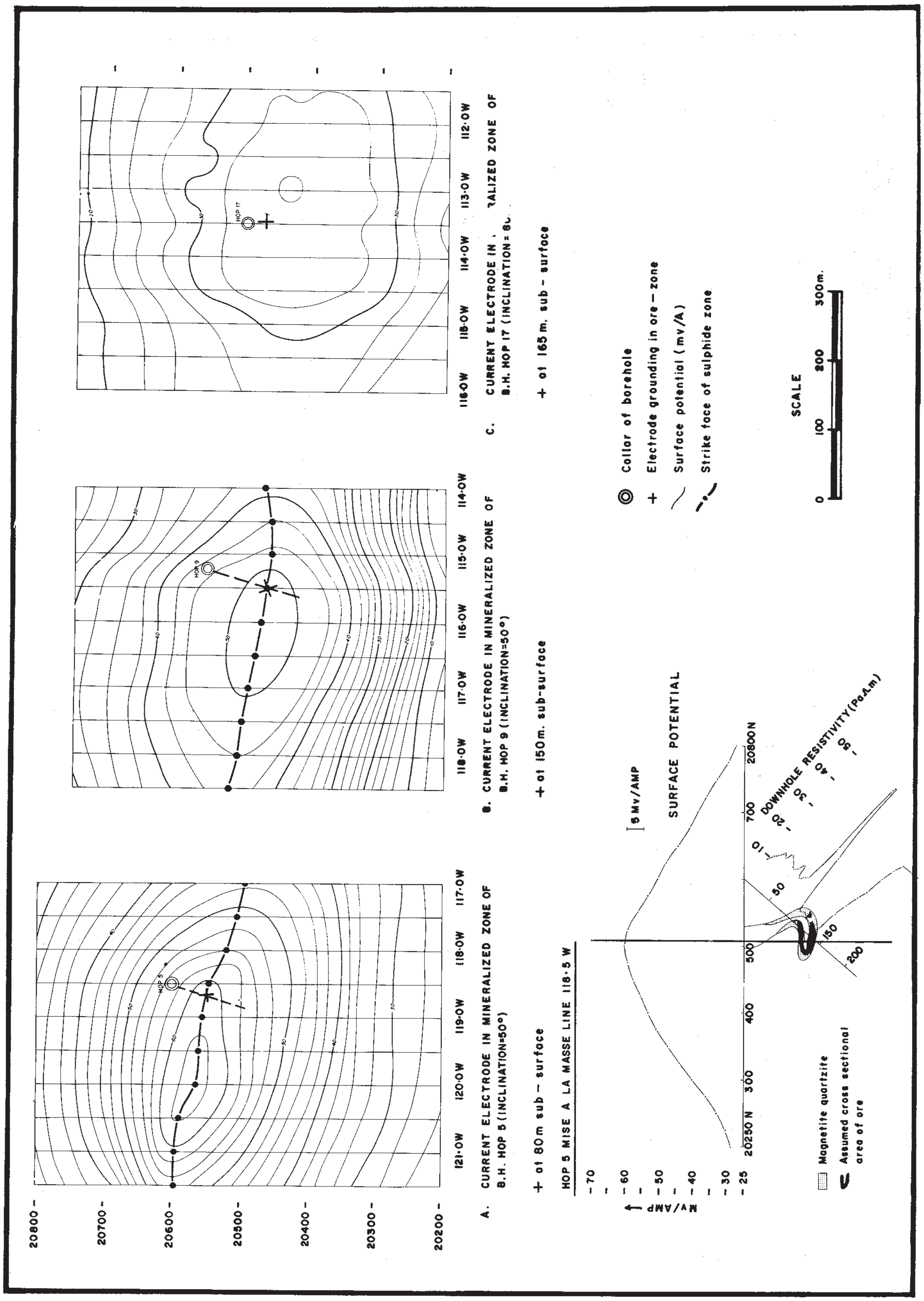

Figure 38.11. Mise-à-la-masse surveys, Hope Mine Zone.

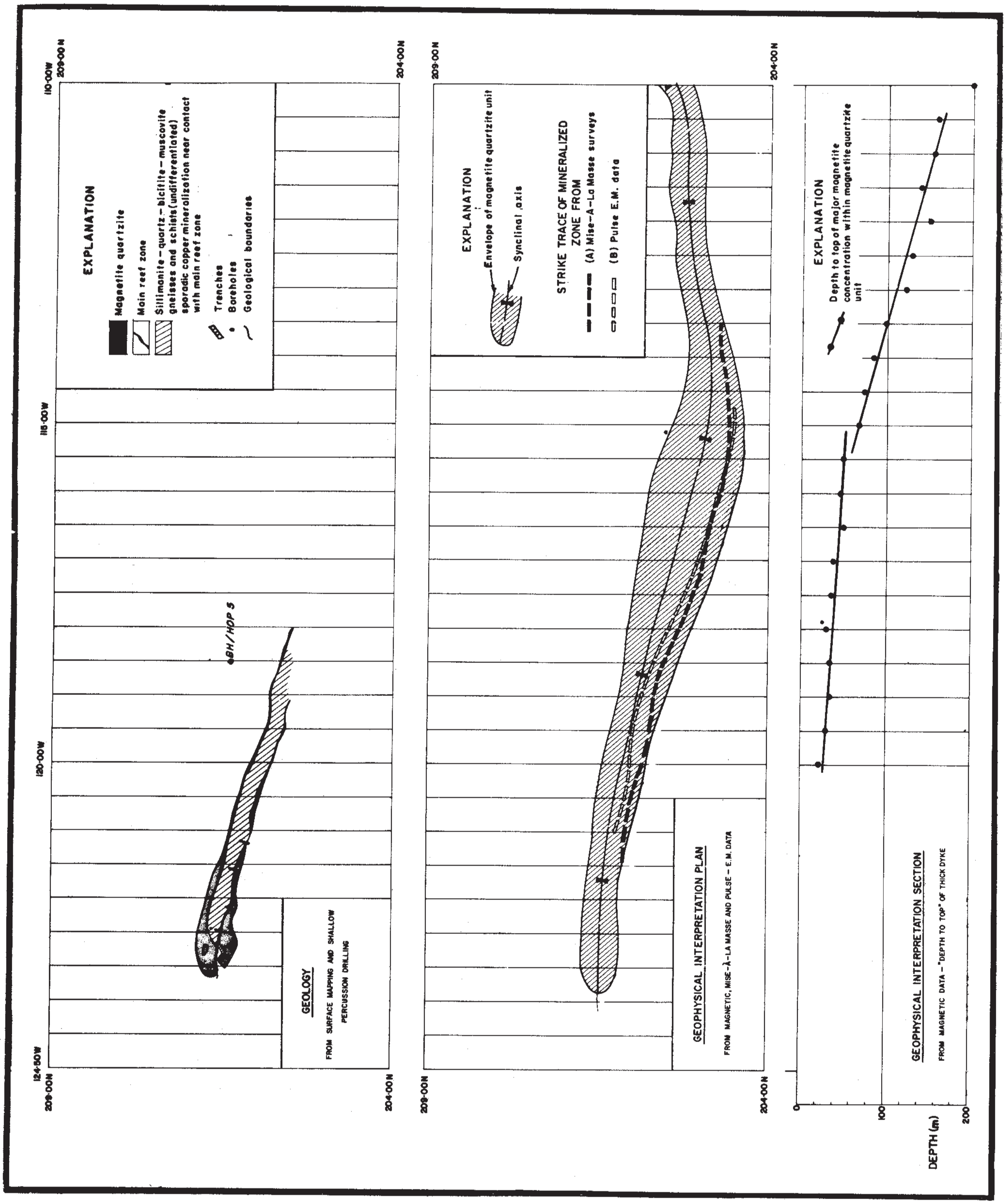

Figure 38.12. *Geophysical ground surveys interpretation map, Hope Mine Zone.*

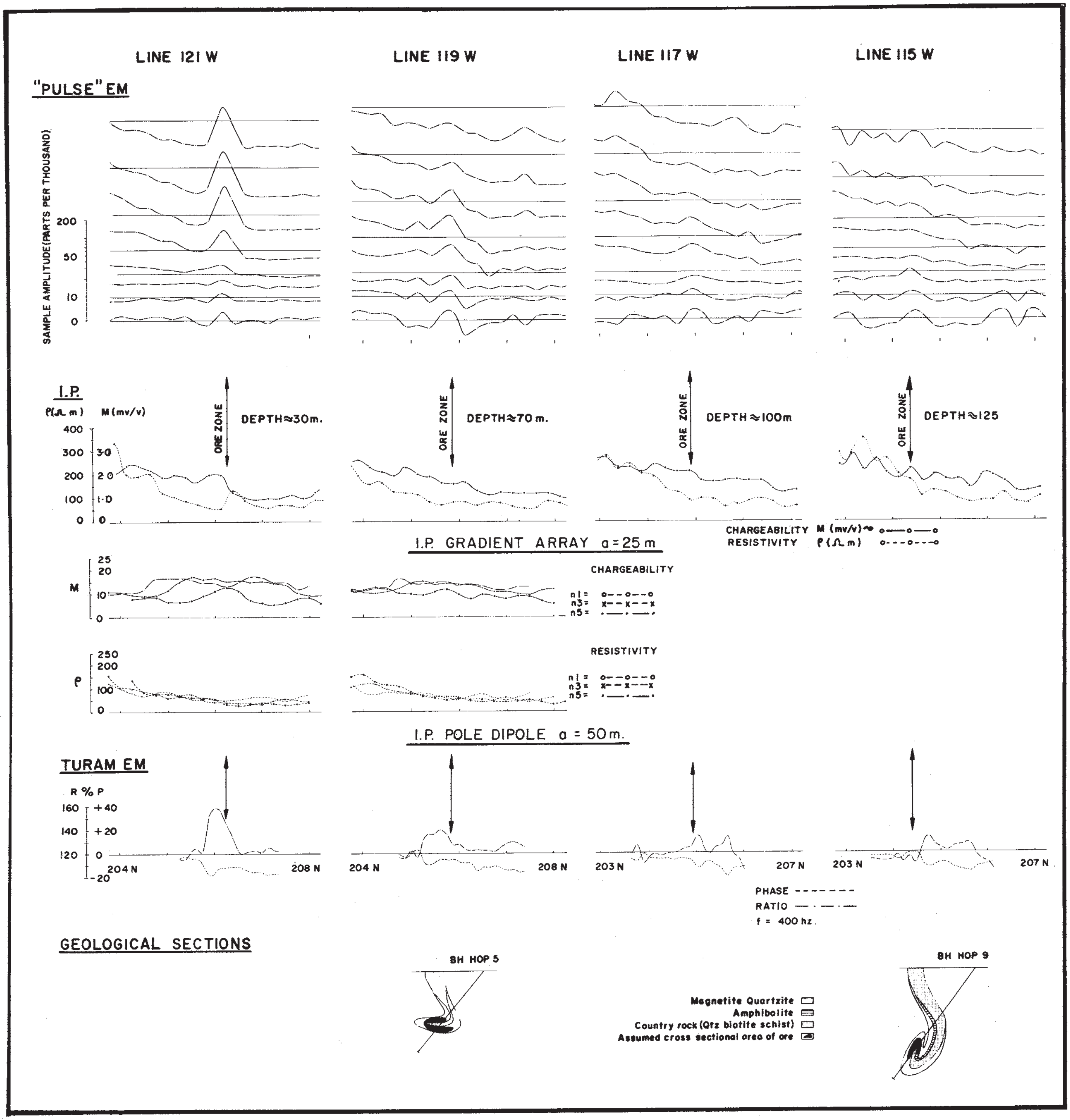

Figure 38.13. *Ground geophysical test surveys, Hope Mine Zone.*

Test Geophysical Surveys – Hope Mine Ore-Zone

Because of its limited lateral dimensions, large depth of burial, and relatively low conductivity (about 1mho/m), detection of this sulphide ore-zone presents a challenging geophysical search problem, especially given the conducting nature of the local country rocks. The postdrilling availability of a Crone Pulse EM system (through Geoterrex Ltd.) prompted the execution of a small test survey aimed at determining the time-domain EM response of the ore-zone. This was followed by a series of comparative surveys employing the IP, Turam EM and horizontal-loop EM (Geonics EM17L) methods, sample results from all except the latter being shown in Figure 38.13. The 600 m strike extent covered in these surveys reflected ore-zone depths of burial from 30 m (L121W) to 125 m (L115W).

The Crone Pulse EM equipment (Crone, 1976) comprised horizontal Tx/Rx dipoles having a separation of 75 m. Data are presented in the conventional manner as a logarithmic response functions (signal amplitude in ppt) for the 7 receiver sample channels, with channel 1 reflecting the shortest and channel 7 the longest time delays i.e. anomalies in the higher numbered channels reflect a progressively increasing conductivity of the causative source and/or more deep-seated responses.

The lack of a comprehensive interpretation scheme (at the time of the survey) precluded more than an assessment of the presence or otherwise of readily identifiable channel anomalies. While only line 121W (depth-30 m) yielded an anomaly with a good signal-to-noise ratio, it is possible to trace the ore-zone responses through, on progressively higher channel numbers, to the vicinity of line 115W (depth about 125m). However, the poor signal-to-noise ratios from line 117W eastwards, would most probably have precluded confident anomaly identification had the presence of a conducting zone not already been known. It is interesting to note that the horizontal-loop EM results (a=200 m, f=800 Hz), while being of inferior quality to the Pulse EM data, permitted delineation of the ore-zone up to line 117W.

In contrast, the Turam survey results failed to delineate the ore-zone past line 119W, and even on the latter did not conclusively resolve the nature of the causative source. The highly conducting surface layer proved a serious drawback in the field utilization of this method. While the nature of the search problem demanded small loop sizes (say 500 m x 500 m) and low frequencies (200 Hz on the Scintrex SE-71) (West, pers. comm., 1975), attenuation of the primary and secondary magnetic fields via the conducting layer, resulted in extremely poor signal-to-noise ratios, and almost complete loss of signal some 300 m from the leading edge of the loop. Field operations in this case were only practicable using a 1000 x 1000 m loop and a frequency of 400 Hz, with a coil spacing a = 25 m. The surprisingly large field-strength ratio (about 40 per cent) anomaly on line 121W may, in part, be due to the current-gathering anomaly effect (due to host rock conductivity) described by Lamontagne (1970), Lajoie (1973) and West (pers. comm., 1975). Elsewhere, minor anomalous features have been attributed to the heterogeneous surficial conducting layer.

Time-domain IP surveys were carried out using a Huntec 7.5 kw transmitter (2 sec. on/off) and a Scintrex IPR-8 receiver. Given the search target dimensions, the lack of significant anomalous IP responses along any of the sections traversed is not unexpected. The 5 mV/V IP anomaly on line 121W (gradient array + pole-dipole, n=1) presumably reflects the narrow, polarizable magnetite-quartzites. Host rock resistivities in the vicinity of the ore-zone are generally about 50 Ωm, confirming (in a qualitative sense) the results of the down-hole resistivity survey. The disparity in value (20 Ωm vs 50 Ωm) between the surface and down-hole surveys may be due to the combination of a thin, surface resistive layer, and the presence of conducting muds etc. in the borehole.

Given the discrete nature of a sulphide target, and its conductive geoelectrical environment, it would thus appear that its delineation by surface geophysical surveys can only be done by utilizing close-coupled EM techniques.

SUMMARY AND CONCLUSIONS

1. While no major base-metal discoveries resulted from the present exploration program, adoption of a pragmatic search target model did result in the discovery of several small orebodies, in particular the Putsberg grassroots discovery in the Pofadder East Block, South Africa, plus the Hope Mine and Anomaly Zone orebodies within the Gorob Prospect, South West Africa. At present all these deposits are considered subeconomic by the holding company, and thus are not being exploited.
2. Within the Southern African context, there is a valid correlation between magnetite-quartzites and spatially correlating base-metal orebodies of both the complex Pb-Zn-Cu-Ag and cupreous pyrite type, in the cover rocks of many metamorphic terranes.
3. Base-metal sulphides may be directly associated with the magnetite-quartzite horizons or may be spatially separated (up to 300 m) from these horizons.
4. Detailed aeromagnetic surveys are invaluable in the search for magnetite-quartzite horizons, especially in geological environments where magnetic activity is restricted to a limited number of lithological units. Cost-effective benefits include rapid target generation, the rejection of obviously nonpotential areas, and the building up of a semi-regional geological framework.
5. Interpretation of the aeromagnetic data should emphasize the selection of anomalies reflecting thin-dyke causative sources and should be based on interpretation of profiles rather than contour maps. Priority targets are those showing a structural discontinuity or an enhanced magnetic response resulting from tectonic thickening and/or an increased magnetite content.
6. In the first instance it is the presence of the magnetite-quartzite itself and its relative (and not absolute) magnetic response, which are significant in the search for associated base metal sulphides.
7. Ground magnetic surveys as a follow-up to aeromagnetic surveys serve (a) to accurately delineate the magnetic unit on the ground, (b) to reject those horizons which do not accord with the thin-dyke model, (c) to permit an accurate interpretation of the geometrical configuration of metalliferous zones in cases where the latter are intercalated with magnetite-quartzites and lie under substantial overburden cover, and (d) to provide an invaluable aid to interpretation of the geology of an area.
8. Having located the target using magnetics and geology (where possible), the next logical step is to assess the target geochemically where overburden is not an inhibiting factor, using a grid which permits coverage up to 500 m on either side of the axis of the magnetic target.
9. Thereafter significant geochemical anomalies should be followed-up using IP/EM techniques, bearing in mind that possible ambiguities may arise where sulphide mineralization is directly associated with the magnetite-quartzite.
10. Exploration of long strike-extent magnetite-quartzite zones is most cost effective when inexpensive percussion drilling can be used to probe the anomaly (i.e. where the depth to fresh sulphides is generally less than 40 m). In cases where IP anomalies are generated in areas covered by overburden and close to the search target-type of magnetic anomaly, percusison drilling will most cost effectively indicate whether significant mineralization is developed there or not.

The exploration model adopted here, and the geophysical techniques and interpretation schemes utilized, are deceptively simple. However, in the South African context they have proved very successful in exploration for the various types of mineralization which can occur in association with magnetite-quartzites. Close liason must be maintained between the geologist and geophysicist in order to control excesses which inevitably develop where one or the other adopts too prejudiced and/or dominant a role. There is no doubt in our minds that detailed, carefully interpreted aeromagnetic data over potentially mineralized areas still provide the most reliable guide to significant targets. Thereafter, carefully-planned exploration programs utilizing a variety of techniques to suit particular situations, can be adopted with a good expectation of success.

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