THE USE OF GEOPHYSICS IN THE SEARCH FOR SULPHIDE DEPOSITS IN THE TROODOS OPHIOLITE COMPLEX, CYPRUS

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A B S T R A C T

The lack of pronounced geophysical contrast between the sulphide mineralization and the host volcanic rocks in the Troodos Ophiolite Complex, calls for a more systematic application of Geophysics in mineral exploration in Cyprus. This involves the conducting of regional studies with the interpretation of airborne aeromagnetic data for the mapping of the major tectonic zones and intrusive bodies responsible for the formation of the mineral deposits. Such studies could include also refraction seismic and gravity surveys. Having determined such broad targets areas, these are then mapped with TEM for a more detailed diagnosis of the distribution of the alteration phenomena. Subsequently, specific target areas are investigated with IP for the location of mineral deposits.

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Π Ε Ρ Ι Λ Η Ψ Η

Λόγω της έλλειψης έντονης διαφοράς μεταξύ των γεωφυσικών χαρακτηριστικών της θειούχου μεταλλοφορίας και των ηφαιστειακών πετρωμάτων που την περικλείουν στο οφιολιθικό σύμπλεγμα του Τροόδους, απαιτείται μια πιο συστηματική εφαρμογή των γεωφυσικών μεθόδων στη μεταλλευτική έρευνα στην Κύπρο. Σ' αυτή την προσέγγιση περιλαμβάνεται η διεξαγωγή περιφερειακών μελετών με την επεξεργασία αερομαγνητικών δεδομένων για τη χαρτογράφηση των κυρίων τεκτονικών ζωνών και διεισδύσεων μαγματικών σωμάτων που είναι υπεύθυνα για τη γένεση των θειούχων κοιτασμάτων. Τέτοιες μελέτες θα μπορούσαν να περιέχουν επίσης σεισμικές μεθόδους διάθλασης και βαρυτομετρικές έρευνες. Εχοντας καθορίσει τέτοιους ευρείς στόχους, εφαρμόζονται στη συνέχεια time-domain ηλεκτρομαγνητικές μέθοδοι (TEM) για τη λεπτομερέστερη μελέτη της κατανομής των φαινομένων αλλοιώσεως των πετρωμάτων λόγω της μεταλλογένεσης. Στη συνέχεια, περιοχές με ειδικούς στόχους ερευνώνται με τη μέθοδο πολώσεως δι' επαγωγής (IP) με σκοπό τον εντοπισμό κοιτασμάτων.

INTRODUCTION

Geophysical exploration for sulphide deposits in the Troodos Ophiolite in Cyprus is a difficult task because of the high conductivity of the host volcanic rocks and the small size of the deposits. The traditional methods have been found useful for the evaluation of the gossans and the environs of known deposits, but they are unable to locate new deeply seated targets. However, although the deposits themselves may be difficult to be observed geophysically (Busby et al., 1983), other major phenomena which controlled the genesis of these deposits are more easily identified in regional geophysical studies. Such phenomena are the major tectonic lineaments associated with the spreading centres and the intrusive bodies which sustained the circulating hydrothermal systems which produced the deposits.

In view of the above, a properly conducted exploration program in Cyprus should aim first in identifying these major phenomena in a particular region, and then concentrate in their detailed investigation for the localization of sulphide bodies which may be associated with them. In this respect geophysics have a new and enlarged role to play which calls first for the confirmation of the major phenomena controlling the mineralization and the identification of broad target areas. Having established this, these areas are explored in detail using both geophysics and geochemistry.

The purpose of this paper is to describe this approach as it is being applied in Cyprus by the Hellenic Mining Company Ltd. in collaboration with the Department of Geology of the University of Leicester, U.K.. The paper begins with an outline of the geology of the Troodos Ophiolite and the associated sulphide mineralization, and then describes the Regional and finally the Detailed geophysical studies.

THE GEOLOGY AND SULPHIDE MINERALIZATION OF THE TROODOS OPHIOLITE - AN OVERVIEW

The Troodos Ophiolite is the most prominent geological feature of the island. It is a well preserved and well exposed complex which exhibits the typical ophiolitic suite which comprises a Plutonic Complex at the bottom, the Sheeted Dyke Complex, and at the top the Pillow Lava Sequence. The latter is divided into the Upper and Lower units and hosts the sulphide mineral deposits.

Recent structural studies (Varga and Moores, 1985; Allerton and Vine, 1987) have identified three major graben structures which were named from west to east : the Solea, the Mitsero and the Larnaca Grabens, and postulated that these represent fossil axial valleys produced by the progressive eastward jump of a spreading centre.

Typically, the Troodos sulphide deposits consist of a layer of massive sulphide ore, predominantly of pyrite with lesser amounts of chalcopyrite, which represents the exhalative part of the mineralization. This is underlain by a pipe-shaped stockwork zone consisting of veined sulphide ore in brecciated and altered and silicified rock (Adamides, 1984). Some of the major deposits

are found to follow more or less this model and they are considered to have been structurally controlled by faults associated with the major grabens and are hence located along old spreading axes. Stratigraphically they are positioned in the Lower unit of the Pillow Lava sequence and are classified into the "Cyprus-type" sulphide deposits.

In a number of localities the sulphide mineralization is related to the Upper Pillow Lava (UPL) sequence (Maliotis and Cooper, in preparation). The recognition that mineralization occurs with the UPL deviates much from the hitherto supported theories for the formation of the Troodos deposits, but is in agreement with recent independent observations by other workers (Varga and Moores, 1985).

On the basis of the above, both the Cyprus-type and the UPL-hosted sulphide deposits must have been genetically associated with major fracture zones which provided the channelways of the mineralizing fluids. Such fracture zones must have been those related with the axial graben regions and the associated transcurrent faults and controlled the genesis of the Cyprus-type deposits. The second type of deposits, the UPL-hosted ones could have been formed in association with the already existing tectonic features, normal and transcurrent faults, which continued to exist after the spreading, as well as other tectonic lineaments which may have formed subsequently and generated by the rising high level intrusions.

From the above it becomes evident that the first stage of mineral exploration should involve the identification of the major graben related tectonic lineaments and the identification of the high level intrusions, and the second stage should concentrate in localizing mineral occurrences within more limited areas.

REGIONAL GEOPHYSICAL STUDIES

Aeromagnetic Surveys

The existing low altitude aeromagnetic data (Geological Survey Department, 1969), were re-examined over a limited area in the NE part of Troodos, Figure 1. From the analysis of the primary contour data and the study of the pseudorelief images, there became clear the sub-parallel NW trending anomaly belts. These are apparently displaced by NE oriented orthogonal lineaments. This interpretation appears to correspond to an extensional half graben and horst model distributed about two successive spreading axes. Such a model attributes the NW trending positive-negative anomaly belts to predominantly LPL thickness variations caused by block rotation during extrusion.

Figure 2 illustrates the structural model derived from the above interpretation. The NNW trending Solea Axis lies outside and to the west of the area examined, but its eastern flanks are marked by rotated half grabens. The younger NW trending Larnaca Axis and the related half grabens lie to the east of the area. On the same figure there are plotted also the positions of the major sulphide deposits which are found in the area. It may be observed that many of them are in close proximity to the axial and the transcurrent faults.

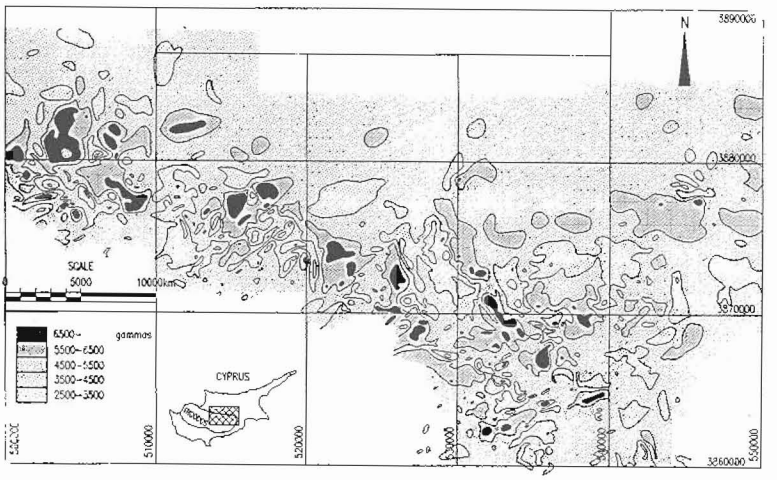

Fig.1. Low altitude aeromagnetic data over north-north east Troodos.

A high altitude aeromagnetic survey (Huntings, 1969) depicts some very prominent positive anomalies over the extrusive terrain, Figure 3. These anomalies were originally interpreted by Vine at al. (1973) as being areas with large thickness of the Lower Pillow Lava sequence. Having in mind the current ideas for the geological environment in axial regions, these highs have been interpreted by Maliotis and Cooper (in preparation) as representing major high level intrusive bodies which could have been emplaced either during or after the axial activity. This interpretation is supported by an earlier gravity survey which is described below. According to the current theories for the genesis of the mineral deposits, the existence of such intrusive bodies play a very decisive role in the formation and localization of mineral concentrations. In effect they are responsible for the driving of the circulation cells. They could also be responsible for the creation of a new structural pattern which results from the uplifting caused by the intrusion.

Gravity Surveys

As a regional exploration tool Gravity surveys have a dual role to play. The first is as a complementary method to the Low Altitude Aeromagnetic survey in the unravelling of the tectonic structure and the localization of the major tectonic lineaments which could host mineral deposits. In this respect gravity surveys are carried out in areas of suspected major lineaments.

The second role of the Gravity surveys has a more regional character and intends to confirm the existence of the high level intrusive bodies which are considered responsible for the origin

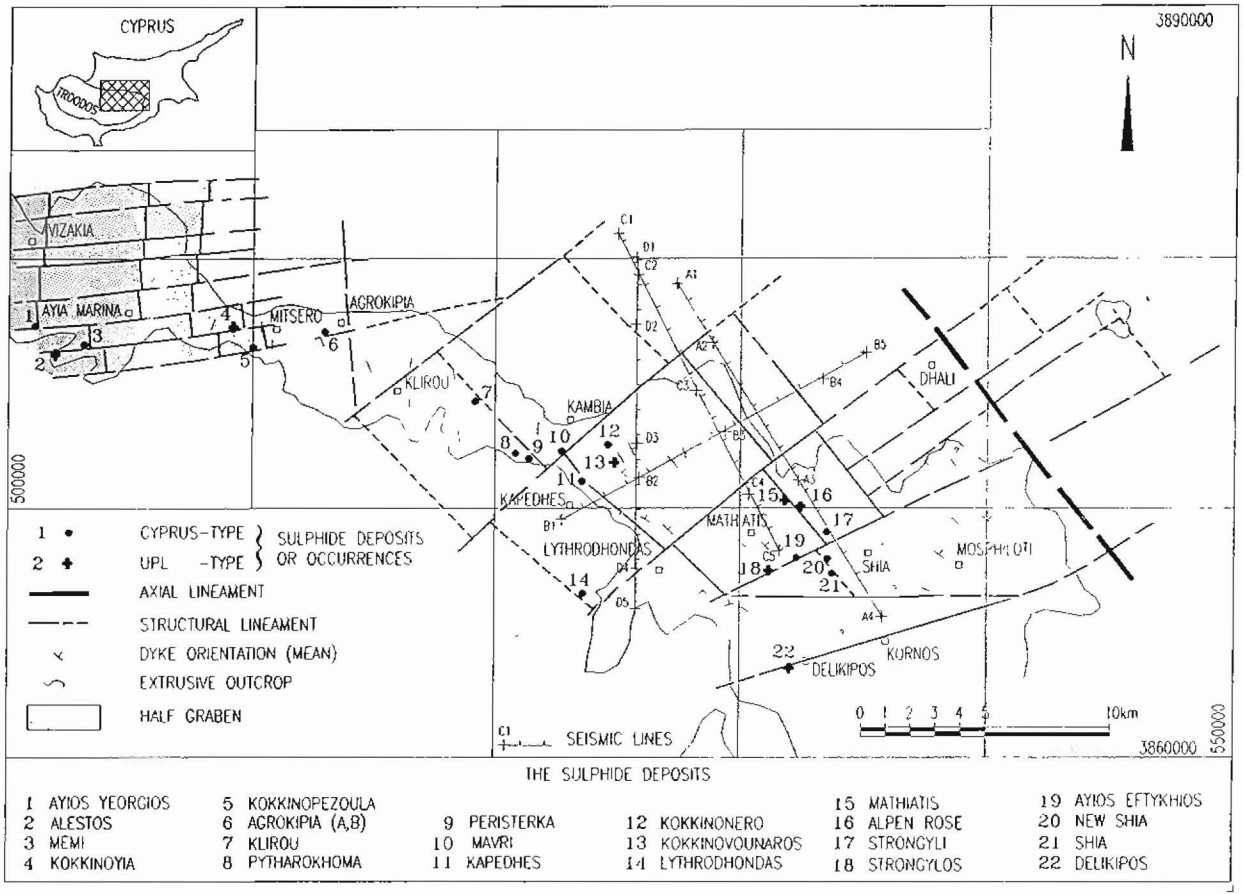

Fig.2. The structural interpretation of the low altitude aeromagnetic data over north-north east Troodos.

of the UPL-hosted deposits. As such there has been completed so far only a limited study for this purpose which concentrated over the high altitude aeromagnetic anomaly in the Shia area (see Figure 3). The results of this study are shown in Figure 4 and confirm the existence of a high level intrusive body in the area.

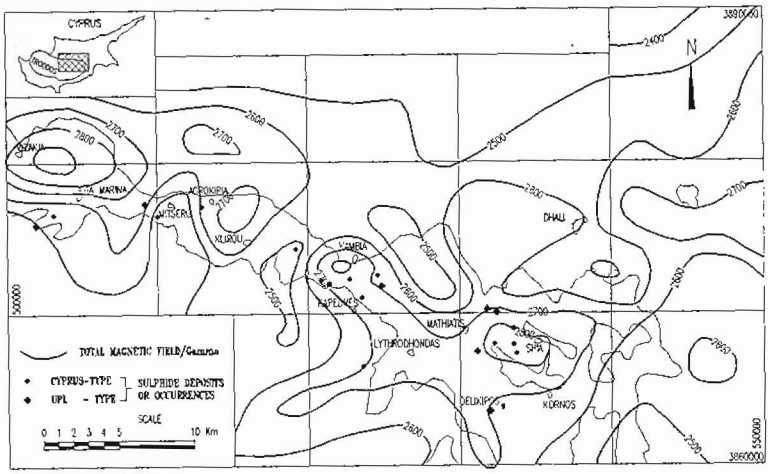

Fig.3. High altitude aeromagnetic data over north-north east Troodos.

Seismic Surveys

A Seismic Refraction survey has been carried out within the framework of the investigation of the proposed Larnaca extensional structure in the NE part of the Troodos Ophiolite. This survey intended to examine the validity of the low altitude aeromagnetic interpretation and identify with a better precision the position of the suspected major structures. The survey location is shown in Figure 2 and comprised four refraction lines, A, B, C and D, oriented parallel and perpendicular to the proposed NNW structural strike. All lines extended beyond the ophiolite - sedimentary boundary.

The forward model interpretation for the four lines together is summarised in Figure 5. This demonstrates at least three half graben blocks which are progressively downthrown to the east (Line B). Lines A, C and D illustrate the progressive downthrow of the ophiolite sequence to the NW by major tectonic structures which appear to run transcurrently to the axial direction.

DETAILED STUDIES

The Transient Electromagnetic Method (TEM)

An investigation into the applicability of TEM in Cyprus proved that the method is incapable to distinguish between the

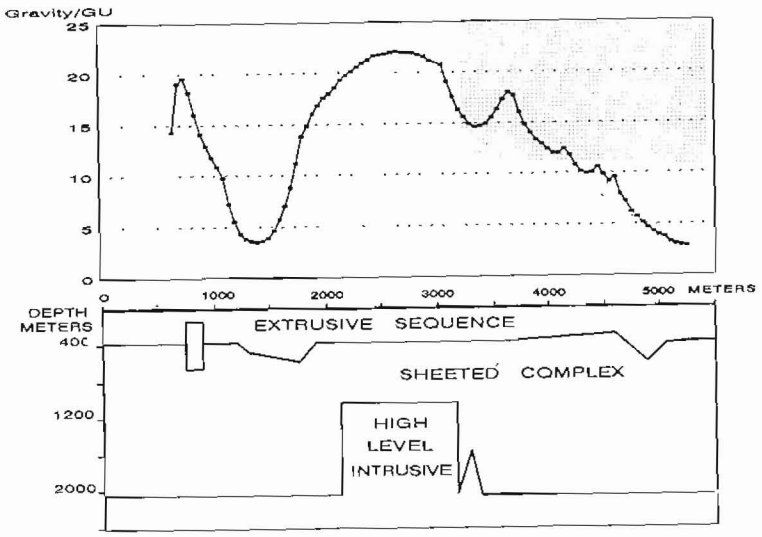

Fig.4. The gravity survey over the high level intrusive in the Shia area.

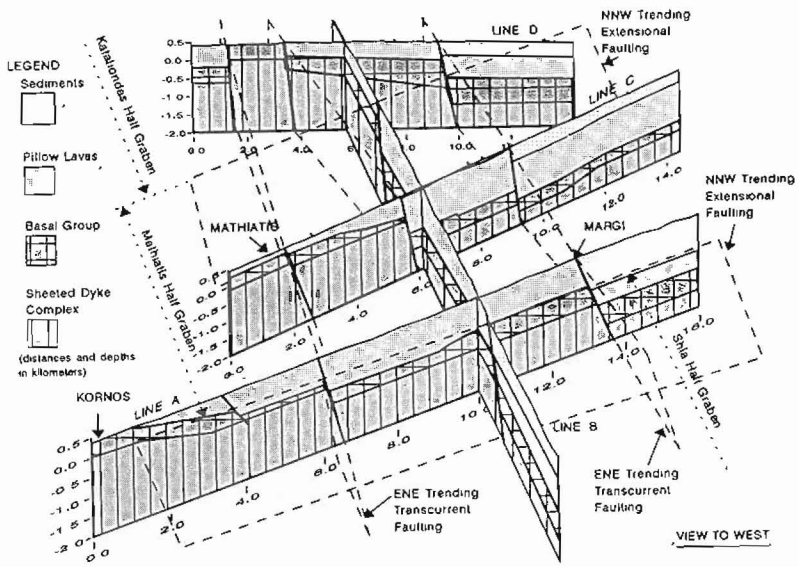

Fig.5. The interpretation of the seismic refraction lines.

mineralised and non mineralised ground because of the lack of resistivity contrast between the altered and silicified mineralization, and the altered pillow lava host rocks (Cooper, 1993). However, the method was found to be a very useful tool in the structural mapping of limited target areas and the

localization of possible mineral bearing structures. In a detailed TEM survey over the area between Mathiatis and Shia which measures nearly seven square kilometres, by employing an 100 meters coincident loop configuration, it was established that it was possible to map resistivity contrasts at depths of 350 to 400 meters. By compiling from successive inversion models the inverted one-dimensional sounding for successive stations, there are obtained pseudo-two-dimensional geoelectric images for each line which enable the identification of the major faults and the estimation of their throws. Figure 6 shows the example of Line 12. Furthermore, the inverted interface depths, after topographic correction, are plotted on an x,y grid to simulate lateral variation of structural interfaces.

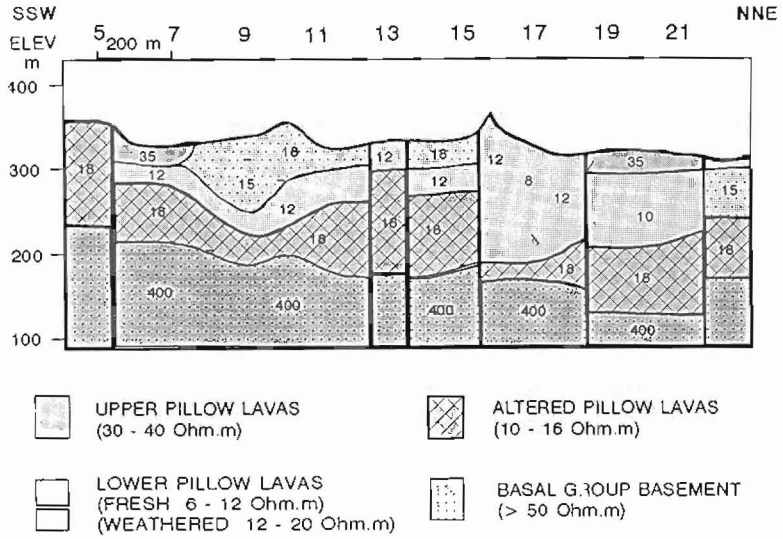

Fig.6. The tem pseudosection of line 12 in the Shia area.

One such interface which is of great interest in mineral exploration is the one which marks the top of the altered LPL and is produced by the silicic alteration caused by the mineralization. A structural interpretation based on the relative elevation of this interface from the one dimensional results in the Mathiatis - Shia area is shown in Figure 7. This shows the continuous elevation of that interface along the major Alpen Rose Fault which is considered to be related with the Shia, New Shia and Mathiatis deposits and the Alpen Rose mineral prospect. A similar but less prominent feature is observed to cut at right angles the Alpen Rose structure and be associated with the smaller Strongyli deposit.

The Induced Polarization Method (IP)

This method proved to be a reliable tool for the detailed investigation of prospect areas. Its applicability in Cyprus has been described previously by Maliotis and Khan (1980) and Busby et alia (1983). It has been used extensively since 1970 for the

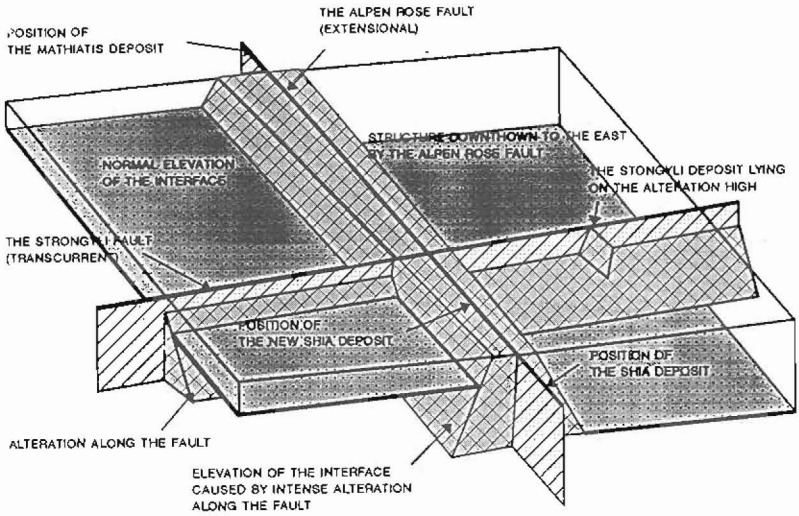

Fig.7. The TEM map of the altered lava interface.

evaluation of gossans and the investigation of the environs of known deposits. At present, and in combination with the previously discussed methods, it is used for the investigation of specific mineral target areas such as major tectonic lineaments which are expected to host mineral deposits along their strike. One such example is the discovery of the New Shia deposit; Figure 8 shows the IP anomaly along Line 3 which runs across the Alpen Rose Fault mapped with the TEM survey described above.

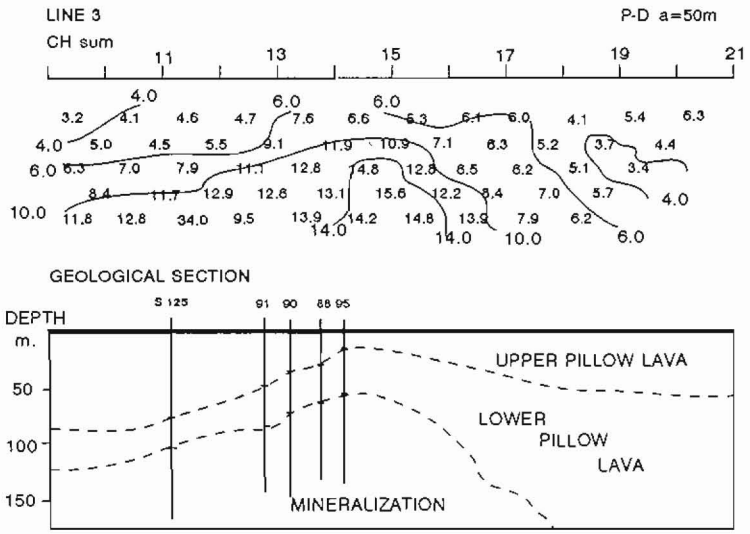

Fig.8. The IP results over the New Shia deposit.

CONCLUSIONS

The interpretation of the available aeromagnetic data over the northeastern Troodos Ophiolite, carried out in the light of the modern concepts for the genesis of the sulfide mineralization in Cyprus, lead to the identification of two suites of extensional and transcurrent faults which belong to the Solea and the Larnaca axial graben domains. Furthermore, there were identified areas which are believed to be underlain by high level intrusive bodies. These findings were verified by subsequent refraction seismic and gravity surveys. This structural and intrusive pattern explains the distribution of the known major deposits in the region and determines the areas for searching for new ones. This search is greatly facilitated by TEM surveys which succeed in the mapping of the alteration zones which in their turn are surveyed in detail by IP.

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