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REPUBLIC OF CYPRUS

MINISTRY OF AGRICULTURE AND NATURAL RESOURCES

GEOLOGICAL SURVEY DEPARTMENT

APPLICATION OF THE VARIABLE FREQUENCY INDUCED POLARIZATION METHOD IN MINERAL EXPLORATION IN CYPRUS

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CYPRUS

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Abstract

A number of geophysical methods, including the variable frequency induced polarization, have been used by the writer whilst being employed by the Geological Survey Department of Cyprus for the past 12 years in mineral exploration in Cyprus. The target of exploration has been medium to high grade cupriferous sulphide mineralization occurring mainly in the pillow lavas which form the upper part of the Troodos Igneous Complex.

The use for many years of conventional ground geophysical methods, like gravity, magnetics, electromagnetics and self-potential has not been very successful mainly as a result of the peculiar properties of the Cyprus sulphide orebodies and the enclosing host rock. Such properties included low resistivity of the lavas and high porosity (low bulk density) and non-magnetic nature of the sulphide orebodies. Other factors, such as geometry and depth of the orebodies also played an important role.

Sulphide mineralization is associated with tectonic zones of variable width and length occurring mainly in the form of fracture fillings and disseminations. The massive, saucer shaped, upper part of the largest known orebodies of Cyprus, formed in depressions of an ocean floor from hydrothermal solutions by means of an exhalative - sedimentary process may not have been developed in all cases or may have been removed at a later stage.

The numerous problems associated with conventional geophysical methods and the inability of such methods to respond positively to concealed occurrences of mineralization, compelled the Geological Survey Department to resort to induced polarization as a better indicator of mineralization with depth penetration comparable to that of gravity and superior to that of the electromagnetic method.

The induced polarization method, however, is not devoid of problems and limitations. Response to non-economic low grade mineralization, membrane effects, electromagnetic coupling and cultural effects are but some of the factors limiting the depth penetration and resolution of the method. Nevertheless the induced polarization method proved a powerful geophysical tool.

Table of Contents

Page

1. Introduction 1
2. The Induced Polarization Method 2
   2.1. The Variable Frequency I.P. Method 2
   2.2. Field Equipment 2
   2.3. Survey Procedure. 3
   2.4. Parameters Used in Frequency Domain I.P. Surveying 3
   2.5. Data Reduction and Presentation 4
   2.6. E.M. Coupling 5
   2.7. Cultural Effects. 7
   2.8. Topographical Effects 7
3. Geology of Cyprus 8
4. Mineralization Associated with the Troodos Ophiolite 13
   4.1. Mineralization Associated with the Troodos Plutonic Rocks 13
   4.2. Mineralization Associated with the Troodos Pillow Lavas 14
   4.3. Mode of Occurrence and Genesis of Sulphide Orebodies 14
5. Application of Geophysical Methods in Mineral Exploration in Cyprus 17
   5.1. Magnetics 18
   5.2. Gravity 18
   5.3. Electromagnetics. 19
   5.4. Self - Potential 20
   5.5. Induced Polarization 20
   5.6. Borehole Geophysics 21
6. Examples of the Application of the Variable Frequency I.P. Method in Mineral Exploration 22
   6.1. Geophysical Survey of Avdellero Area. 22
   6.1.1. Introduction. 22
   6.1.2. Geology of the Avdellero Area 23
   6.1.3. The Geophysical Results 24
   6.1.4. Conclusions 27
   6.2. Geophysical Survey of the Lythrodhonda Area 27
   6.2.1. Introduction 28
   6.2.2. Geology of the Lythrodhonda Area. 28

.../2

	Page
6.2.3. The Geophysical Results	29
6.2.4. Conclusions.	33
6.3. Geophysical Survey of the Ayios Ioannis (Agros) Area	33
6.3.1. Introduction	33
6.3.2. Geology	34
6.3.3. The Geophysical Results	35
6.3.4. Conclusions	38
7. Summary and Conclusions	38
8. References	41,42

List of Figures

Fig. 1 Geological Map of Cyprus.

Fig. 2 Sha (Strongyli) Line 15, Meshed Pseudosection

Fig. 3 " " " ", 100m Pseudosection

Fig. 4 " " " ", 50m Pseudosection

Fig. 5 " " " ", 50m Pseudosection

Fig. 6 Mathiati North Line 15, 100m Pseudosection

Fig. 7 " " " ", 100m Pseudosection corrected for topography

Fig. 8 Map Showing Distribution of the Most Important Mines of Cyprus.

Fig. 9 Sha (Strongyli) Mise-a-la-masse Survey, 25m Station Interval

Fig. 10 Sha (Strongyli) Mise-a-la-masse Survey, 5m Station Interval.

Fig. 11 Geological - Geophysical Map of Avdellero Area.

Fig. 12 Troulli-Avdellero Line 101, 60m Pseudosection

Fig. 13 " " Line 113, " "

Fig. 14 " " Line 117, " "

Fig. 15 " " Line 119, " "

Fig. 16 " " Line 121, " "

Fig. 17 " " Line 125, " "

Fig. 18 " " Line 129, " "

Fig. 19 Avdellero Area - Sulphur Distribution Diagrams.

Fig. 20 Avdellero Line 125, Max - Min. Profiles

Fig. 21 Geological - Geophysical Map of Lythrodhonda Area

Fig. 22 Lythrodhonda Line 1, 60m Pseudosection

Fig. 23 " Line 3, " "

Fig. 24 " Line 5, " "

Fig. 25 " Line 7, " "

Fig. 26 " Line 9, " "

Fig. 27 " Line 11, " "

Fig. 28 Lythrodhonda Line 13, 60m Pseudosection

Fig. 29 " Line 15, " "

Fig. 30 " Geological Cross - Sections and Sulphur Distribution Diagrams.

Fig. 31 Geological - Geophysical Map of Ayios Ioannis (Agros) Area.

Fig. 32 Ayios Ioannis (Agros) Line 12S, 200 ft Pseudosection

Fig. 33 " " " Line 4S, " "

Fig. 34 " " " Line 4N, " "

Fig. 35 " " " Line 12N, " "

1. Introduction

The present report describes briefly examples of the application of the variable frequency induced polarization method in mineral exploration in Cyprus. These examples include a variety of geological environments and different modes of sulphide occurrence.

The response of the variable frequency method under such circumstances is discussed in terms of the usual parameters, i.e. frequency effect, metal factor and apparent resistivity. A number of problems which in effect limit the applicability and usefulness of the method are presented and discussed.

Three examples of induced polarization surveys over mineralized zones are presented. The first example is of a survey over a relatively narrow mineralized fault zone in the pillow lavas. The problem of large E.M. coupling effects sets a limit to the useful depth of investigation. The lack of resistivity contrast between lavas and low to medium grade mineralization excludes the possibility of using this parameter in sulphide exploration over such rocks.

The second example is from an area of Basal Group mineralization. E.M. coupling effects over such rocks are minimal owing to their high background resistivities. Mineralized zones are usually associated with lower resistivities. The main problem is that of the high background polarization caused by the widespread weak pyrite mineralization in Basal Group rocks.

The third example is of a survey over a mineralized zone in gabbroic rocks. Large responses are obtained from this type of mineralization and background effects are generally low. A moderate resistivity contrast also exists between mineralized and unmineralized gabbro.

An example is given of the effect of topography on apparent resistivity. The sulphide bearing rocks of Cyprus weather to a rugged topography which affects the observed resistivities. As the dipole-dipole array is particularly affected by topography, such effects should be recognised and separated from true resistivity anomalies.

Examples are also given of a mise-a-la-masse survey and of a modified pseudosectional plotting technique which enables meshing of measurements obtained over the same line with different dipole lengths.

The report also includes an account of the geology of Cyprus with special emphasis on the sulphide bearing formations and a short introduction into the history of geophysical activity in Cyprus.

2. The Induced Polarization Method.

2.1. The Variable Frequency I.P. Method.

It has been observed that in rocks containing metallic minerals and clays, resistivity varies with the frequency of the applied electric field. This frequency dependence has been attributed mainly to electrode and membrane polarization phenomena. Owing to build up of polarization with time the resistivity of a polarized zone is found to decrease with increasing frequency. The same behaviour is shown by the voltage or impedance across a polarized zone.

In practice the I.P. phenomenon is measured by passing a controlled inducing current through the earth and observing resultant voltage changes with variations of inducing frequency. Measurements in the frequency domain are made in the frequency spectrum of 0.1Hz to 10Hz, usually at decade intervals, so that comparison of measurements taken at different frequencies can be readily made.

2.2. Field Equipment.

The equipment used by the writer is the McPhar Induced Polarization System, Model P660, which operates in the frequency domain and is driven by a 2.5 kw generator. The equipment is light and portable and has facilitated the execution of surveys in difficult terrain which might otherwise necessitate the use of extremely large lengths of transmitting cables.

The transmitter is a manually variable voltage source whose output current is regulated and kept constant for large load and input voltage changes.

.../3

The receiver is of the potentiometer type where the amplified and filtered signal is compared with a reference voltage.

2.3. Survey Procedure.

The dipole-dipole array of I.P. surveying has been routinely employed throughout. The dipole leght was 60 m for the detailed work and 100 m for reconnaissance or in cases where deeper penetration was required. The dipole separation was usually increased from 1 to 4 and more rarely from 1 to 6 for each receiver station.

The transmitter was centrally positioned on the survey line with an adjacent current electrode and four or more electrodes on either side. This transmitter set up was traversed by the receiver dipole in a way that allowed several check readings by interchange of receiver and transmitter dipoles.

The penetration and resolution achieved with the dipole-dipole array are quite good and information about the depth of conductors may be obtained qualitatively from the pseudosections. The amount of survey wire is minimum with this array.

The disadvantages of the system are the slow rate of coverage, complex interpretation and topographic distortions of the resistivity data. The signal to noise ratio is also poor with this array.

2.4. Parameters used in Variable Frequency I.P. Surveying.

These parameters are the per cent frequency effect, the metal factor and the phase angle and are defined below. The derivation of electrical resistivity is also given because this parameter is very useful although not directly related to rock polarization.

Per cent Frequency Effect, PFE.

This is defined as

$$PFE = \frac{\rho dc - \rho ac}{\rho ac}$$

/4

where ρdc is the resistivity measured with direct current and ρac the resistivity measured with alternating current of a certain frequency. Low frequency current is usually used instead of direct current. The resistivities are in fact apparent resistivities.

The PFE is usually given directly by the I.P. receiver.

Metal Factor, MF.

This is defined as,

$$MF = \frac{\rho dc - \rho ac}{\rho dc \, . \, \rho ac} \, . \, 2\pi \, . \, 10^5$$

and is expressed in units of conductivity. The 2π factor is believed to have been derived from the use of $\rho/2\pi$ for expressing resistivity. This factor was originally used but was later dropped by the writer.

Phase Angle.

This is the phase lag between the input and output sinusoidal waveforms.

Electrical Resistivity ρ.

In the case of the dipole-dipole array the resistivity is given by

$$\rho = \pi \frac{V}{I} \; n\,(n+1)\,(n+2)\,a$$

where V is the measured voltage across the receiver electrodes, I is the applied current, a is the dipole length and n is the dipole separation.

For inhomogeneous earth the measured resistivity is apparent.

2.5 Data Reduction and Presentation.

The parameters, per cent frequency effect, PFE, metal factor MF, and apparent resistivity, ρa, have been computed and presented in conventional pseudosectional fashion at a scale of 2cm = 1 electrode spacing.

.../5

Where lines or portions thereof have been surveyed with different dipole lengths the data is presented both in the conventional manner and meshed in the modified pseudosection as proposed by Edwards (1977). The Edwards pseudosections have the advantage of giving a better depth estimate of the source of an anomaly, whilst the degree of meshing is an indication of the accuracy of the results.

An example of a meshed pseudosection is shown on fig 2. The measurements come from a survey with 100 m and 50 m dipoles over the pillow lavas in the Sha area. The conventional pseudosectional plots of the same measurements are shown on figs 3,4 and 5. From the meshed pseudosection it is evident that agreement between measurements taken with different dipole lengths is fairly good, although the 50 m dipole measurements were taken at a later date. The significance of anomalous zones appears to be appreciated better on the meshed pseudosection.

I.P. measurements have been corrected for E.M. coupling whenever necessary, generally assuming uniform earth, and the corrections applied are shown on the pseudosections.

An approximate logarithmic contour interval has been used in most cases.

2.6. E.M. (Electromagnetic) Coupling.

E.M. coupling is the linkage of the transmitter and receiver circuits through electromagnetic wave propagation. At low frequencies, the E.M. coupling and the normal polarization effect of the subsurface material have similar functional behaviour with respect to the conductivity of the half-space, and their combined effect is recorded in an induced polarization survey. To study the normal polarizability of a mineralized body in its true perspective, therefore, it is necessary to eliminate the effect of E.M. coupling.

Expressions have been developed for computing the effects of E.M. coupling of collinear dipoles on a uniform half space (F.Millet,1967), at the surface of a two-layer earth (G.Hohmann, 1973) and over a multilayered earth (A.Dey and F.Morrison, 1973).

Tables and nomograms have also been published for the correction of E.M. coupling, although owing to uncertainty usually involved in such a process it would be preferable to try and avoid E.M. coupling effects during a survey.

For a particular rock resistivity, ρ, in order to decrease E.M. coupling effects it is necessary to decrease the electrode interval a, the electrode separation factor n, or the frequency f. In general I.P. prospecting should be carried with $\alpha/\delta < 0.1$ where δ is the skin depth and is given by

$$\delta = 502.4 \sqrt{\frac{\rho\text{(ohm. metres}}{f\text{ (hz)}}}$$

E.M. coupling is believed to have been one of the most serious problems and in general a drawback in an extensive application of the frequency domain method in I.P. surveying in Cyprus. The reason is evidently the very low resistivity of the pillow lavas, which generally varies between 10 and 20 ohm.m.

Frequencies of 0.3 Hz and 5Hz were originally used which produced large E.M. coupling effects even for dipole lengths of 60 m. The problem was most serious at electrode separations n = 3 and 4. In order to avoid such problems the operating frequencies in surveys over the lavas were later fixed at 0.125 Hz and 1.25 Hz which ensured coupling free measurements in most cases, even at n = 6. Use of lower frequencies, however, resulted in considerable reduction of the speed of the surveys and in some interference from telluric noise. E.M. coupling effects over the Basal Group and Gabbro are usually negligible for dipole lengths of 60 m and an upper frequency of 5 Hz owing to the higher resistivities of these rock units.

With 100 m dipole surveys, as have been used for deeper exploration, E.M. coupling effects have generally been low to moderate down to n=4 but rather excessive for larger electrode separation factors making measurements at deeper levels unreliable.

The correction for E.M. coupling has been based mainly on the assumption of uniform earth. This assumption appears to be valid in cases where apparent resistivities vary by a factor of less than two. In some instances it seems more appropriate to assume a layered earth model, although this would necessitate additional work in order to establish the true resistivity layering. According to G. Hohmann (1973) the simplified assumption of uniform instead of layered earth results in an overestimate of the coupling correction.

Lateral changes in resistivity have also presented difficulties in applying E.M. coupling corrections. For some such variations the E.M. coupling effects have resulted in negative frequency effects.

2.7. Cultural Effects.

The presence of an artificial conductor in the earth causes spurious IP anomalies mainly by leakage currents between transmitter and receiver circuits.

In Cyprus such effects have been produced by metal water pipes and mine dumps. Although these effects are usually recognized as such they are still very problematical in IP surveying because they are usually strong and may mask the effect of sulphide mineralization 100-200 m on either side of the source. Cultural effects are always shallow and can be usually recognized if the geology and mineralization of the area are taken into consideration.

The effects of linear conductors can be minimized by running traverses perpendicular to them or insulating them.

2.8. Topographic Effects.

Apparent resistivity varies with topography, this variation depending on the particular type of topographic feature and the dipole length with respect to the wavelength of this feature (Fox et al, 1980). Thus in rocks of uniform resistivity a hill will give rise to a resistivity high with flanking lows whilst the reverse is observed in the case of a valley. In general the terrain effect anomaly increases with increasing slope lengths and reaches a maximum between three and six dipole lengths.

It is clear that such effects should be recognized in order to avoid confusion with true resistivity variations or anomalies. During I.P. surveying in Cyprus numerous resistivity anomalies have been recognized as purely topographical in origin. One such case is shown on the pseudosection of fig. 6 which is from the Mathiatis N area, a short distance to the west of Mathiati mine. On this pseudosection the resistivity high with the associated flanking lows between 1800 and 2200 appears to be due to the effect of the hill that is present in the same area. A similar effect is reflected on the metal factor. The apparent resistivities of this profile have been corrected for topography at the Institute of Geological Sciences in London and are replotted on fig. 7. Most of the anomaly has disappeared, although higher than background values are still obtained under the hill, probably owing to the non-pillowed nature of the lavas.

Most topographic effects can be recognized qualitatively by correlating the observed resistivity pattern with the topographic profile of the same survey line. Although the pillow lava terrain is generally hummocky to rugged and is responsible for numerous cases of topographic effects on resistivity, it is doubtful whether this can be a very serious drawback because resistivity alone does not seem to be diagnostic of mineralization. This is not the case, however, for surveys over the Basal Group and Gabbro where there appears to be definite relation between resistivity and mineralization. In the examples of I.P. surveys over such rocks that are included in this report it is shown that resistivity and metal factor can be of value in defining zones of mineralization.

Topography does not generally have any effect on the observed frequency effects except in cases of definite sources because of variations in the distance between the surface electrodes and the source.

3. Geology of Cyprus.

Cyprus is divisible, topographically and geologically, into four roughly parallel belts which trend approximately east-west and are gently concave to the north (see fig. 1).

These belts are: a) The Kyrenia Range to the north, b) the Mesaoria Plain in the centre, c) the Troodos Massif in the south, and d) the Southwestern Foothill Belt occupying the extreme southwestern part of the island.

The Kyrenia Range runs parallel to the north coast and rises to elevations of 915 metres. It comprises four northdipping thrust arcs (Moore, 1960) of allochthonous Permian and Cretaceous limestones flanked mainly by flysch deposits of Middle Eocene to Middle Miocene age. Other associated deposits comprise marls and arenites, pelagic micrites and limestones. Two episodes of volcanic activity have been recognized, one of Maestrichtian and another of Palaeocene age (Baroz, 1978). These two kinds of volcanism have been considered as comparable to island arc volcanism. The Kyrenia Range is considered as the most southerly expression of the Tauro-Dinaric alpine belt.

The Mesaoria Plain separates the tectonically deformed sediments of the Kyrenia Range from the contemporaneous undeformed sediments flanking the Troodos igneous massif. It is occupied by flat lying Plio-Pleistocene to Recent marly and calcareous sediments. Deep drilling for oil and gravity and magnetic studies have shown that the Mesaoria Plain is floored by lavas of the Troodos Igneous Complex which are separated from the Kyrenia Range by the Kythrea wrench fault.

The Troodos Massif formed mainly of basic and ultrabasic igneous rocks of uppermost Cretaceous (Campanian) age (Mantis, 1970) occupies a roughly oval area of 3000 sq. km. Including the inliers of the Akamas peninsula in the west and Troulli in the east, it has an east-west extent of nearly 130 km and a width in a north-south direction of about 35 km.

The Troodos Massif constitutes the main structural and topographical feature of the island. The igneous rocks comprise a complete and undeformed ophiolite sequence ranging downwards from pillow lavas, overlain in places by ferromanganoan sediments through a sheeted dyke complex to cumulate gabbros and peridotites and to harzburgite tectonite. Extensive late Tertiary differential uplift, coupled with a serpentinite diapiric intrusion through an initially layered igneous sequence and concommitant deep erosion are responsible for the present domal structure of the Troodos complex.

The original upward succession of plutonic rocks-sheeted complex-pillow lava is now arranged in an outward succession, from centrally exposed plutonic rocks to sheeted dyke complex and peripheral pillow lavas.

To the north and south the Troodos igneous rocks are overlain by calcareous sediments (chalks, chalky marls, limestones and calcarenite) of Maestrichtian to Tertiary age. These sediments, which are thicker to the south, have a gentle radial inclination which has been imposed by the same central uplift that has affected the massif.

The mode of formation and emplacement of the Troodos ophiolite complex has been the subject of intensive research for the last two decades. The most widely accepted view at the present time is that the Troodos massif represents a subaerially exposed slice of oceanic lithosphere and underlying upper mantle generated at a constructive plate margin (Gass and Masson Smith 1963, Gass 1968, Moores and Vine 1971).

A three fold subdivision of the massif into the sheeted intrusive complex, the central plutonic complex and the peripheral pillow lavas has long been established.

Pillow Lavas

These form an irregular and incomplete ring around the periphery of the massif and have a thickness of 2-3 km. The pillow lavas represent the effusive phase of the magma that differentiated to form the plutonic rocks. The pillow lavas have been subdivided in upward succession into Basal Group, Lower Pillow Lavas and Upper Pillow Lavas. This subdivision was based on several criteria, such as local unconformable contacts, intrusive-extrusive abundance ratios and primary and secondary petrological, mineralogical and chemical differences.

The Basal Group, representing the earliest extrusive phase, consists of a host rock of pillow lavas which have been intruded by dykes. In its lower part the Basal Group, which contains about 10% pillows, has suffered greenschist facies metamorphism. In its upper part the Basal Group, with about 30% pillows, has suffered widespread hydrothermal alteration including silicification, argillization, chloritization and epidotization and weak pyrite mineralization.

The Lower Pillow Lavas consist mainly of submarine flows of oversaturated basalts with an equal proportion of dykes and sills formed contemporaneously or after the extrusives. The Lower Pillow Lavas are in unconformable contact with the underlying Basal Group. The primary minerals include plagioclase, clinopyroxene and magnetite. The lavas show a downward increase in metamorphism from zeolite to greenschist facies (Smewing 1975, Gass and Smewing 1973) with minerals such as zeolites, green celadonite, chalcedonic silica and montmorillonite).

The Upper Pillow Lavas consist mostly of well formed pillows dominantly olivine basalts with limburgites and picrites and lie unconformably on the Lower Pillow Lavas. Quite often they are found lying directly over the Basal Group. Primary minerals include plagioclase, clinopyroxene, olivine and magnetite. The lavas have suffered low grade zeolite facies metamorphism with the production of zeolites, montmorillonite and calcite. Feeder dykesusually account for less than 10% of outcrop.

The Sheeted Intrusive Complex.

The Sheeted Intrusive Complex, representing the greater part of the massif, consists of a dense dyke swarm of 100% dykes. The dykes are nearly vertical and trend in a general north-south direction. They range in thickness from less than one metre to five metres and are of basic to andesitic composition. Several phases of dyke intrusion have been recognized. The Sheeted Intrusive Complex has been subjected to greenschist facies metamorphism. The transition from Sheeted Intrusive Complex to the undelying gabbro is quite rapid, although the gabbro immediately below is cut by dykes which form 10 - 15% of the rock.

The Plutonic Complex

The Plutonic Complex of the Troodos ophiolite consists of two parts, one occupying the central core of the Troodos massif and another in the Limassol Forest area to the southeast of the main massif. Rocks of the Plutonic Complex range in composition from the base upwards from harzburgite and dunite through wehrlite and pyroxenite to gabbro and plagiogranites.

The harzburgite is considered as the residue of partial fusion of plagioclase lherzolite mantle from which basaltic liquid has been extracted (Greenbaum 1972). The harzburgite is mostly serpentinized and contains economic chrysotile asbestos deposits.

The harzburgite is followed in upward succession by a cumulate sequence of chromitite, dunite, wehrlite, pyroxenite and gabbro, the products of fractional crystallization and magmatic sedimentation of basaltic magma.

Higher up in the plutonic sequence are the high-level intrusives constituting the extreme products of fractional crystallization. These are mainly trondhjemites and tonalites collectively termed plagiogranites. They are exposed marginally in some areas between the gabbro and the Sheeted Intrusive Complex.

The Southern Foothill Belt in the southwestern part of the island consists essentially of gently folded Upper Cretaceous to Middle Miocene calcareous sediments also containing large inliers of the allochthonous Mamonia Complex. The Mamonia Complex consists of sandstones, shales and limestones with an associated volcanic suite of alkaline affinities of Triassic to Mid. Cretaceous age. The Mamonia Complex was brought into juxtaposition against Upper Cretaceous oceanic crust which now forms the Troodos Complex (Swarbrick 1979). The final deformation events involved the extrusion of massive serpentinite along major faults.

Structure of the Troodos Massif.

The Troodos ophiolite is characterized by three prominent structural features, i.e. block faulting, gravity slide faulting and thrusting (Searle and Panayiotou, 1979). The last two phenomena are characteristic of the southern Troodos zone and are absent from the northern flank.

The present structural pattern has resulted principally from the effects of block faulting and late normal faults and the subsequent tilting of the fault blocks. The Basal Group shows steeper dips, often in a different direction compared with later lavas. Fault directions aligned at 290° and 60° represent the earliest deformation and are associated with massive sulphide mineralization.

Later north-south faults intersect all previous structures. In an account of the form and formation of the orebodies of the Kalavasos mining distric of southern Cyprus, Adamides (1979) concludes that the mineralizing fluids occupied north-easterly fractures and faults whose orientation indicates that they are directly related to the evolution of the Lower Pillow Lavas and Basal Group. These faults are considered as being originally parallel to and dipping towards the spreading axis of a mid-ocean ridge.

Gravity slide faulting in the southern Troodos zone has developed from upthrusting of the Troodos and the sliding of large fault blocks to the south and southwest.

4. Mineralization Associated with the Troodos Ophiolite

4.1. Mineralization Associated with the Troodos Plutonic Rocks

The most well known occurrences of mineralization in these rocks are those of asbestos in the intensely serpentinized ultramafics and the economic chromite deposits in the dunite near its contact with the underlying harzburgite. Less well known are the sporadic occurrences of iron-copper-cobalt-nickel sulphide mineralization in the serpentinized ultramafics of the Limassol Forest Plutonic Complex (Panayiotou 1977) and the sulphide mineralization in the gabbros between Ayios Ioannis and Agros in the Pitsilia region of central Cyprus (Vokes and Constantinou 1964).

Economic chrysotile asbestos deposits occur over the eastern part of the serpentinized ultramafics (harzburgite) where the serpentinization has been more intense. The serpentinization has been brought about by the action on ultramafic rocks of large amounts of water, probably of meteoric origin (Magaritz and Taylor, 1974) at a very low temperature in a near surface environment.

Chromite is an accessory mineral in several olivine rich ultramafic rocks, although economic deposits are found in dunite close to its contact with the harzburgite. These deposits are of the podiform type and are considered as products of segregation of the magma that also produced the rocks of the Troodos Ophiolite Complex.

The sulphide mineralization in the gabbros, the most well known occurrence of which is located in the Ayios Ioannis-Agros area, is in the form of fracture fillings, sulphide veins and quartz sulphide veins and is associated with hydrothermal alteration controlled by faults and fracture zones in the gabbroic rocks. The predominant sulphide mineral is pyrrhotite with subordinate amounts of chalcopyrite, sphalerite, pyrite and marcasite. The hydrothermal alteration also included extensive chloritization and silicification of the host rocks.

4.2. Mineralization Associated with the Troodos Pillow Lavas.

The Troodos pillow lavas have formed the host rock for the formation of massive and disseminated sulphide orebodies most of which have been known and worked since ancient times. The Cyprus sulphide deposits are small by world standards, the largest being that of Mavrovouni of 15 million tons, with average sulphur and copper contents of 40% and 4% respectively. Most of the other sulphide deposits of Cyprus, which occur in clusters of four or more in five mining districts over the pillow lava outcrop, are generally much smaller in size, the second largest being that of Skouriotissa with 6 million tons.

A map with the most important mines of Cyprus is shown on fig. 8.

4.3. Mode of Occurrence and Genesis of Sulphide Deposits.

The Cyprus massive sulphide deposits have been considered as type examples of orebodies occurring in accretional ophiolite suites (Constantinou 1972). They are characterized by distinct vertical zoning with an upper zone of massive ore with more than 40% S underlain by a zone of sulphide with quartz with 30-40% S, and a stockwork zone underneath containing less than 30%S.

The massive ore consists in many ore deposits of blocks of solid sulphide embedded in a matrix of sandy, friable and highly porous ore. The predominant mineral is pyrite. Marcasite is highly variable and may be completely absent. Chalcopyrite is invariably present, particularly in the upper parts of some deposits, whilst sphalerite, although less common than chalcopyrite is invariably present.

The stockwork zone consists in its upper part of mineralized and hydrothermally brecciated lava grading downwards into pillow lava which is similarly altered. The stockwork zone, which represents the channelway through which the mineralizing solutions reached the surface of the ocean floor is generally much more extensive than the associated massive ore and extends to depths in excess of those reached in exploration drilling. In the stockwork zone the mineralization is in the form of sulphide and quartz-sulphide veins the thickness and proportion of which decrease with depth. Copper and zinc are rather erratic but generally decrease downwards.

The massive parts of the deposits usually have a saucer shape disposition which has been interpreted as indicating formation in fault controlled bathymetric depressions at the site of an oceanic ridge. The mode of formation has been envisaged as exhalative - sedimentary by the interaction between sea-water and hydrothermal solutions reaching the sea floor through fracture zones.

The deposits lie on hydrothermally altered lavas and on many occasions are overlain by unmineralized Upper Pillow Lavas. They are also intruded by later unmineralized dykes, feeders to the Upper Pillow Lavas. Usually there is an iron-rich ochreous sediment that may be associated with cherts, tuffs and siliceous limestone, interposed between the massive sulphides and the overlying Upper Pillow Lavas. This sediment has been interpreted as the product of oxidation and leaching of the underlying sulphides (Constantinou and Govett, 1972).

The stratigraphy, relative age and genesis of the sulphide orebodies has confounded Cyprus economic geology for many years. In the first notable study of the sulphide deposits by Cullis and Edge (1927) it was concluded that these were later than the sedimentary cover of the lavas (Miocene) and that the sediments acted as a barrier to the ascending mineralizing hydrothermal solutions which were considered to have formed the orebodies by replacement of the lavas. These ideas prevailed until the U.N.S.F. (United Nations Special Fund) project between 1963 and 1968 with the attendant research work on sulphide deposits shed considerable light on the matter.

The sulphide mineralization was unequivocally considered as synvolcanic and non-replacive except probably at the lower levels of the stockwork zone. There is still, however, a difference of opinion as to the exact position of the massive mineralization within the lava sequence. Constantinou and Govett (1972) and Constantinou (1972) consider the Cyprus sulphide deposits as being deposited in caldera-like depressions during a pause in volcanicity before a final olivine basalt phase. Searle (1972) on the other hand suggested that the sulphide mineralization occurred during the interval between Basal Group and Lower Pillow Lava volcanicity. These views evidently have considerable bearing on exploration.

The elongated, saucer shaped massive zones which are typical of the larger orebodies, such as Mavrovouni and Skouriotissa, have not been developed in all cases of known orebodies. In all cases, however, it is now certain that localization of the deposits was controlled by longitudinal fractures which formed part of the rift valley of a mid-ocean ridge. Recent studies by Heaton and Sheppart (1976) and Spooner (1976) have shown that deep circulating sea water is the main mineralizing fluid. The ore solutions, whilst pervasive and diffuse in nature in the lower parts of the volcanic sequence, become more localized in the longitudinal fractures upon reaching the ocean floor.

In geophysical and in general in mineral exploration for sulphide deposits knowledge of the mode of formation and occurrence of these deposits is of paramount importance as any programme of exploration will have to be based on such previous knowledge.

It is now well known that the size of the target sought is generally small and probably less than one million tons. This, together with a number of other variable factors, such as grade of expected mineralization, thickness of post mineralization volcanics and sediments, width and longitudinal extent of mineralized fracture zones and shape and geometry of orebody will determine the choice of geophysical methods and techniques to be employed in exploration.

5. Application of Geophysics in Mineral Exploration in Cyprus.

The application of geophysical methods in mineral exploration in Cyprus dates back to the 1920s when the mining industry of Cyprus was revived after many centuries of dormancy. The principal mining companies of Cyprus, including the Cyprus Mines Corporation, the Hellenic Mining Co and the Cyprus Sulphur and Copper Co carried out at various times geophysical surveys over their concessions employing various geophysical methods. A great deal of this geophysical work was carried out by contracting companies including McPhar Geophysics, Newmont Exploration, Lea-Cross Geophysical Co and Huntings Geology and Geophysics.

Originally the primary purpose of the geophysical work was the evaluation of mineralized occurrences, including numerous gossans. The geophysical methods used were mainly the self-potential and equipotential. The scope of exploration was later extended to the discovery of blind orebodies with the application of the gravity, magnetic, electromagnetic and induced polarization methods.

A sound basis for systematic geophysical exploration in Cyprus, however, was laid down during the U.N.S.F. project between 1963 and 1968 with the introduction of the main geophysical methods and the training of local personnel. The Hellenic Mining Co also started in 1970 systematic geophysical exploration with extensive application of the time-domain induced polarization method (Maliotis 1978).

From the results of the application of geophysical methods in mineral exploration in Cyprus for the past 20 years it can not be claimed that this application has been very successful. In most cases there have been serious limitations imposed by the properties of the orebodies and the enclosing host rocks, the geometry and size of the orebodies and the cover of post mineralization volcanies and sediments.

A short account is given below of the application of each geophysical method.

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5.1. Magnetics

This is a cheap and quick method and has been employed extensively by the Geological Survey Department. The magnetic variometer originally used by U.N.S.F. project was later replaced by a Geometrics G8[18] proton precession instrument.

The sulphide orebodies of Cyprus are generally non-magnetic and this is mainly attributed to sulphurization of magnetite in the mineralized lavas. In fact mineralized zones were expected to be associated with magnetic lows.

Although the magnetic susceptibilities of the three lava units are about the same these units differ in the amount of remanent magnetization, with the Basal Group showing the smallest intensity and the Upper Pillow Lavas the highest. This property has been employed for lithological discrimination and structural definition.

Alteration of the lavas results in decreased values of both the induced and remanent magnetization so that alteration zones, which may be related to mineralization are marked by magnetic lows.

5.2. Gravity.

Although occasionally applied by mining companies this method was essentially introduced by the U.N.S.F. project during which it was used extensively. Its use continued after the termination of the project in 1968, although to a smaller extent. The equipment used since 1965 is the Worden Prospector.

Like the magnetic method it has serious limitations owing to the small density contrast between the highly porous (Constantinou 1972) Cyprus sulphide deposits and the enclosing lavas and to certain other factors, such as interference from high density intrusives with specific gravities of about 2.5. The Basal Group with its uneven subsurface topography has also been responsible for numerous gravity anomalies that have been considered as being associated with mineralization.

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In such cases additional geophysical investigations with other methods are normally required in order to obtain more information on the nature of the anomalous bodies. In general the densities of the lavas increase with the amount of intrusive material.

Although of limited value in the direct detection of sulphides the gravity method has found application in the determination of the regional structure of an area.

5.3. Electromagnetics

Electromagnetic methods have been used at various times by the mining companies, but extensive use of the method has been made by the U.N.S.F. project and the Geological Survey Department. The technique mainly used is the Swedish Turam.

The surveys carried out at the outset of the U.N.S.F. exploration programme over known near-surface orebodies showed distinctive E.M. response. Further work, however, showed that not only the sulphides but also non-commercial electrolytic conductors caused by increased porosity and salinity of interstitial water within the lavas, agrillaceous alteration and faults were the source of the vast majority of E.M. anomalies. Separation of anomalies in most cases may be made only through comparison with other geophysical or geological methods.

Work by the Geological Survey Department has shown that sufficient conductivity contrast between sulphide mineralization and host rock is usually found for occurrences in the Basal Group whose conductivities usually vary from 0.02 to 0.01 mhos/metre. In the case of pillow lavas with much higher conductivities (0.02 - 0.1 mhos/metre) sufficient conductivity contrast exists only when the sulphur content of the mineralization is in excess of 30%.

The Pulse E.M. method, applied extensively by Noranda Exploration (Cyprus) Ltd during their exploration for sulphides between 1976 and 1978 seems to suffer from the same inherent problems as other E.M. methods.

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5.4. Self Potential.

This method appears to have found wide application only during the early days mainly for the evaluation of shallow mineral indications and gossans. It is used today in favourable circumstances, supplementary to other geophysical methods.

5.5. Induced Polarization.

Before 1970 this method was employed occasionally by the mining companies for sulphide exploration over their concessions. The first survey was carried out by McPhar Geophysics for the Cyprus Mines Corporation in 1962. There is not much information about this survey but there is more information about another survey carried out in 1968 by Huntings Geology and Geophysics for the Cyprus Sulphur and Copper Co. The gradient array was used throughout this latter survey.

Because of discouraging results of these early geophysical surveys the U.N.S.F. project did not apply the induced polarization method, although it was thought that this method might prove effective if it supplemented gravity and electromagnetics.

The Geological Survey Department, following the recommendation of the U.N.S.F. project purchased in 1970 a McPhar P660 variable frequency induced polarization system which, however, was infrequently used until in 1975 the writer took charge and started an intensive programme. This programme, although aiming mainly at discovering economic sulphides, also aimed at establishing the electrical and induced polarization properties of all the rock types involved.

The Hellenic Mining Co in cooperation with Leicester University initiated in 1970 an induced polarization project which was expanded in 1972 and put on a routine basis. The frequency domain method was originally used but it was replaced later by the time domain method making use of powerful generators. The Hellenic Mining Co has carried out since then extensive surveys some of which have led to the discovery of economic sulphides.

5.6. Borehole Geophysics.

Use has been made lately, by both the Geological Survey Department and the Hellenic Mining Co of borehole geophysical methods. The Geological Survey Department is cooperating with the BRGM (Bureau de Recherches Geologiques et Minieres) of France in the application of two methods, the mise-a-la-masse or applied potential method and the IP mise-a-la-masse method which is an adaptation of the first one. In this latter method the current electrode that is earthed in a borehole does not have to lie in conducting ore whilst the other current electrode is placed as usual at infinity. Measurements are taken of the electric field and frequency effect in two perpendicular directionswith a short receiving dipole along lines parallel to the transmitting dipole. Values of apparent resistivity and resultant frequency effect are computed for each station from meaaurements in two orthogonal directions.

These methods appear to offer certain advantages over similar ground methods, particularly in cases of orebodies lying at depths several times their diameters.

An example of a mise-a-la-masse survey is shown on figs 9 and 10. The example comes from a survey in the Sha area on the eastern flanks of the Troodos massif. In this survey one current electrode was earthed in borehole RF3/80 which encountered massive mineralization from 57 to 63 metres and the other current electrode at infinity. One potential electrode was also placed at infinity in a direction opposite to that of the current electrode.

Fig 9 is a map of the surface potentials obtained with the current electrode at 50 m depth, i.e. above the massive mineralization. Station spacing was 25 m and line spacing 50 m. The equipotentials are nearly circular indicating almost electrically isotropic earth. Except for the 100 mV equipotential the rest are nearly centred around the epicentre of the current electrode.

Fig 10 is a map of the surface potentials obtained with the current electrode at 59 m, i.e. in the massive mineralization. Station and line spacing was reduced to 5 m. The equipotentials are now definitely elongated, approaching an elliptical shape which reflects in some measure the geometry of the conducting body. The major axis of the ellipse indicates the approximate strike direction of the orebody.

The extent of the massive ore is not probably determined from the mise-a-la-masse survey alone. It is evident, however, that borehole RF9/81 which intercepted about 4m of massive mineralization coincides with the 87 m V equipotential whilst borehole RF3/80 with about 6 m of massive ore is associated with the 88.5 m V equipotential.

The above example indicates the usefulness of borehole geophysics in providing information regarding not only the presence but also the extent of an orebody. Surface induced polarization failed to reveal the presence of the orebody, probably because it occurs in a much more extensive zone of altered and weakly mineralized volcanics and probably because of its relatively small volume.

6. Examples of the Application of the Variable Frequency Induced Polarization Method in Mineral Exploration.

6.1. Geophysical Survey of the Avdellero Area.

6.1.1. Introduction

The Avdellero area occupies the south western corner of the Troulli Inlier where rocks belonging to the Troodos pillow lava series are exposed.

There is a long gossanized zone in this area (see fig 11) lying about 400 m to the southeast of Avdellero village which has attracted attention from time to time. Cyprus Mines Corporation sank several exploratory boreholes and pits over the western part of the gossan which encountered disseminated pyrite and propylite with maximum sulphur content of 5% .

Part of the area was surveyed in 1967 during the U.N.S.F. project by means of Turam which, however, failed to reveal any worthwhile anomalies.

The present induced polarization survey of the Avdellero area was initiated in 1978 and formed part of a more extensive geophysical survey which also included gravity, magnetics and electromagnetics and covered a large part of the Troulli inlier. In cooperation with the BRGM of France part of the Avdellero area was also surveyed in 1980 by the Max-Min electromagnetic method and borehole IP.

The geophysical work was followed by a drilling programme which included six boreholes sited on the basis of various geophysical anomalies. Borehole MR/P47/80 was drilled on a gravity anomaly, whilst borehole MR/P66/80 was drilled on a Max-Min anomaly. The rest of the boreholes were located on IP anomalies.

6.1.2. Geology of the Avdellero Area.

The Avdellero area forms part of the Troulli igneous inlier with the outcropping rocks belonging to the Upper and Lower Pillow Lavas (fig 11). The main structural feature is a near east-west trending fault zone which downthrows the Upper Pillow Lavas to the south.

The zone is mineralized and a notable gossan is observed over a considerable part of its exposed length. The mineralization, which is restricted to the Lower Pillow Lavas, is of the stockwork type, i.e. in the form of fracture fillings and disseminations. The mineralized zone appears to be narrow and typical of similar longitudinal mineralized fractures which are common in the Basal Group and Lower Pillow Lavas of Cyprus. To the west toward Avdellero village a later northeasterly trending fault seems to have caused a reversal in the dip of the structure.

The aim of the geophysical work in this area was to locate concentrations of mineralization in the vicinity of the exposed mineralized structure and in particular under the cover of fresh Upper Pillow Lavas.

The sulphide mineralization in the form of veinlets, fracture fillings and disseminations does not appear to contribute towards lowering apparent resistivity.

Topography does not appear to have affected seriously the observed apparent resistivity as the relief of the area is relatively gentle. The only notable effect is seen on line 113 where a marked resistivity high between - 180 and - 360 appears to be due, at least partly, to a hill with a wavelength of about 4 dipole lengths.

Frequency Effect.

The Upper Pillow Lavas are generally characterized by percent frequency effect of 1-2%. The Lower Pillow Lavas are also characterized on the main by PFE falling in the range of 1-2% although consistent deviations outside this range are apparent on several occasions. Thus PFE smaller than 1% are obtained over the extreme northeastern partions of most of the lines whilst values in excess of 2% and approaching 3% are obtained over the central parts of lines 117-121 down to a dipole separation n=2. It is believed that these variations in PFE reflect variations in the lithology of the Lower Pillow Lavas.

PFE over the mineralized zone are generally higher than 2%, reaching values of 5.4%. The highest values are obtained on lines 111-125 where the mineralization appears to be mainly concentrated. Sulphur distribution diagrams of boreholes drilled over this part of the zone are shwon on fig 19. It is evident that a peak PFE of 4.8% on line 119 corresponds to 5.4% sulphur and a peak value of 5.4% on line 121 to 16% sulphur. Membrane effects from the clay within the mineralized fault zone may also be responsible for part of the observed anomalous PFE response.

Metal Factor (MF).

Background MF for the Upper Pillow Lavas are 50-150 and for the Lower Pillow Lavas 50-200. Over the mineralized zone the MF is generally higher than 200 although lower values are obtained on certain lines where high apparent resistivities are also obtained.

The fact that the resistivity of mineralized zones in the Lower Pillow Lava is not determined by the sulphide content but rather by other factors, such as argillization and silicification diminishes the effectiveness of the M.F. as an indicator of mineral content. Any variations in apparent resistivity, either lithological or topographical are also reflected on the M.F. and considerable care should be taken when dealing with this parameter.

The Form of the IP Anomaly.

PFE is evidently the most diagnostic parameter of mineralization. Although in many cases resistivity is not indicative of mineralization it is still a useful parameter particularly when used in conjunction with PFE.

The PFE anomalies obtained along the Avdellero mineralized zone are generally narrow, of the order of one to two dipole lengths and quite shallow with anomalous values appearing on n=1. Most of the anomalies are symmetrical with anomalous values obtained when both the transmitting and receiving dipoles traverse the mineralized ground. The PFE pattern obtained on most of the lines is that of a central low with flanking highs which most probably indicates a limited depth extent of the source. This pattern is typicallydeveloped on lines 101,119 and 121.

Results of Other Geophysical Methods.

Borehole MR/P47/80 was drilled on the only important gravity anomaly that appeared in the Avdellero area. The borehole encountered only traces of pyrite but intercepted a thick basaltic intrusive below 12 m with specific gravity of 2.2 to 2.5.

The Turam and Max-Min revealed numerous, generally shallow anomalies, which are mostly related to electrolytic and clayey conductors. Borehole MR/P66/80 drilled on a strong Max-Min anomaly did not encounter any mineralization. Except for the top 12m of weathered and slightly oxidised Lower Pillow Lava, the rest of the intercepted rock is relatively fresh. The Max-Min profiles for line 125 are shown on fig 20.

.../27

6.1.4. Conclusions.

From the geophysical results from the Avdellero area it is clear that IP in contrast to other geophysical methods, is the only method whose anomalies are essentially associated with sulphide mineralization even of very low grades.

Gravity, magnetics and electromagnetics are more responsive to sources other than the sulphide mineralization. Higher density intrusives affect the gravity field, whilst electrolytic and clayey conductors are mostly the sources of the numerous anomalies usually obtained with the electromagnetic method.

On the other hand, however, it is doubtful whether mineralization of the grade encountered at Avdellero has sufficient density and resistivity contrast to the enclosing host rock to make it detectable by means of gravity and electromagnetics. From the resistivity results of the IP survey it is at least evident that there is not usually sufficient resistivity contrast and that in some cases the mineralization is of higher resistivity than the host rock.

The drawback of the IP method is probably that it responds even to very low concentrations of sulphides and that no estimate of the grade of mineralization can be made from the IP parameters so that many boreholes drilled on IP anomalies encounter uneconomic sulphides. It appears, nevertheless that an increase in grade should be expected with increase in PFE for shallow lying sources.

A serious limitation of IP surveying over low resistivity pillow lavas is that of the large E.M. coupling effects. For dipole lengths up to 60m this problem is eliminated with the use of the lowest possible frequencies of 0.125 Hz and 1.25 Hz. For larger dipole lengths, however, there is no way of avoiding E.M. coupling with the result that penetration is limited by this effect particularly rather than by the power and sensitivity of the equipment.

6.2. Geophysical Survey of the Lythrodhonda (Lakxiaes tou Penettou) Area.

6.2.1. Introduction

The Lythrodhonda (Lakxiaes to Penettou) area lies on the eastern foothills of the Troodos igneous massif, about 3km to west-southwest of the village of Lythrodhonda (fig 21).

A strong gossan, richly coloured with limonite, jarosite, hematite and friable silica attracted attention and the Hephaestus Mining Co which had the prospect for some time drilled in 1961 ten boreholes (AB1-AB10) and carried out investigations including geological mapping and a self-potential survey. The boreholes were reputed to have outlined a zone of mineralization containing 1.5 million tons of sulphides with an average sulphur content of 24%.

The area was resurveyed in 1968 during the U.N.S.F. project when it formed part of a more extensive survey area by means of magnetics and gravity. No response was obtained over the mineralization. Two boreholes (MR/7/69 and MR/16/69) were also drilled over a small gossan to the east of the main one which, after a thin cover of oxidized volcanics intercepted about 100 metres of silicified and brecciated Basal Group containing rare pyrite.

The Geological Survey Department, in an attempt to completely evaluate the prospect carried out in 1978 an IP survey and drilled in 1979 and 1980 seven additional boreholes (fig 21). Both the IP and drilling results showed that the mineralization did not extend beyond the limits originally outlined by the Hephaestus Mining Co.

6.2.2. Geology of the Lythrodhonda Area.

The outcropping rocks belong exclusively to the Basal Group. They are invariably iron stained and thick red soils have been developed at places. They have been subjected to widespread hydrothermal alteration including silicification, argillization and epidotization and weak pyrite mineralization.

Low to medium grade sulphide mineralization in the form of veins and fracture fillings has developed in the southern part of area.

.../29

Within each zone there are smaller variations due to changes in lithology and grade of mineralization.

The northern zone is characterized by resistivities varying between 100 and 800 ohm. metres, with the highest values appearing over the western part of the zone.

Over the mineralized zone much lower resistivities are obtained which generally vary between 20 and 200 ohm. metres. The Lowest values appear on lines 9 and 11 where the mineralization is of highest grade. The variations in resistivity due to mineralization are superimposed on a regional change which indicates increase in resistivity to the west. This latter variation appears to reflect litholggical changes particularly in the state of argillization and silicification.

The zone to the south is characterized by values varying between 70 and 270 ohm. metres which also indicate a general increase to the west.

The resistivity field in the Lythrodhonda area has revealed two important facts, a) that Basal Group rocks, unlike the overlying pillow lavas, generally have much higher resistivities owing to widespread silicification and large proportion of intrusive material and b) that mineralized zones within the Basal Group with 25-30% sulphur have resistivities as low as 20 ohm. metres. A large resistivity contrast may thus exist between mineralized and unmineralized Basal Group rocks, rendering the resistivity method an efficient geophysical tool. This phenomenon is not usually observed over the pillow lavas where both the mineralized and unmineralized rocks usually have similar resistivities.

Topography has probably affected apparent resistivity, although the extent of such effect cannot be known before a theoretical evaluation is made. Topographically the survey area is avalley wit slope angles generally in excess of 10° and slope lengths equal to 3-4 dipole lengths. According to Fox et al (1980) topographic effects reach maximum values under such conditions. The resistivity anomaly produced by a valley is that of a central low flanked by highs.

Frequency Effect.

The frequency effect field, like resistivity, also shows a similar threefold subdivision into three zones. The northern zone has values varying between 2% and 5%. The highest values are obtained on lines 5-13 and particularly in the area adjacent to the more intense mineralization. The PFE obtained over this zone appear to partly exceed the background values expected from Basal Group, but owing to the absence of any boreholes in this area the reason for this is not obvious.

The southern zone is characterized by generally lower values between 1% and 3%, which are typical background values for Basal Group.

The mineralized zone is characterized by PFE which are generally higher than 3% and as large as 8.7%. The highest values are obtained on lines 7,9 and 11 where the highest grades of mineralization have been found to occur.

The mineralization is generally shallow, lying at an average depth of about 10m below a limonitic gossan. On line 7 medium grade mineralization with sulphur contents of 20-30% occurs down to depths of about 85m in the area between boreholes AB2 and AB8, whilst borehole AB7 is mostly negative with only a thin zone of mineralization. The horizontal extent of the mineralization is equivalent to one dipole length.

On line 9 mineralization with sulphur contents of 20-30% occurs between boreholes AB1 and MR/17/79 as shown on fig 26. Mineralization of this grade is found down to 80m and over a horizontal distance of about 70m, i.e. nearly 1.5 times the dipole length. The grade of mineralization falls off sharply to the north and south as revealed by the results of boreholes AB3, MR/9/79 and AB9. Borehole MR/9/79 gave an average sulphur content of 5% down to 52m whilst boreholes AB3 and AB9 were considered by the Hephaestus Mining Co as barren.

The grade of mineralization also falls off to the east towards line 11. This is evident from the results of boreholes MR/31/78 (average S 11%) and MR/9/79 (average S 5%).

Borehole AB10 which falls quite close to line 11 did not encounter any economic mineralization and was considered as barren. The horizontal extent of the mineralization on line 11 is not exactly known but is not expected to exceed one dipole length.

A sharp fall off in the grade of mineralization is also evident to the west of line 7. Borehole AB6 still gives 20-30% sulphur down to a depth of 40m but boreholes MR/8/79 and MR/16/79 are much poorer averaging less than 5% sulphur.

From the above discussion it is evident that the PFE is proportional in a rather crude manner to the grade of mineralization. The rather high PFE obtained on line 11 relative to the grade of mineralization may be partly due to side effects from higher grade mineralization occurring to the west.

On lines 1-5 and 13-15 the PFE of the mineralized zone only slightly exceed the background values of the weakly mineralized Basal Group and appear to indicate slightly higher grades of mineralization.

Metal Factor.

The MF does not indicate any differences between the zones north and south of the mineralization, both of which are characterized by similar values which vary between 15 and 200. The zone of medium grade mineralization between lines 7 and 11 is characterized by values which are greater than 200 and exceed 3000 on line 9. Lower MF values are obtained over the rest of the mineralized zone and like PFE they appear to follow the grade of mineralization.

In IP exploration in Cyprus the value of MF as an indicator of mineralization is usually very limited except in cases like this where the resistivity of the host rock is higher than that of mineralization. This is typical of Basal Group mineralization.

The typical shape of both the PFE and MF anomalies over the mineralization is the "pant-leg" consisting of two anomalous limbs and a central, deep low. The anomalies are rather asymetrical.

Anomalous values are obtained on n=1, indicating the shallowness of the source. Although the highest values are obtained when the transmitting or receiving dipoles are over the mineralization it is evident that anomalous measurements are also obtained when both dipoles are at some distance from it on either side.

The resistivity anomaly is rather simpler in shape being essentially a zone of lower values. A small, deeper high is usually associated with this zone.

6.2.4. Conclusions.

The IP method appears to be quite effective in sulphide exploration over Basal Group rocks. In the Lythrodhonda area it has defined an area of mineralization with an average sulphur content of 25% where the gravity and magnetic methods had previously failed. It is probably a case where the electromagnetic method could give diagnostic results.

Definite PFE and MF anomalies are obtained over the medium grade mineralization, but where the sulphur content falls below about 5% the anomalies are not as definite. The background PFE are generally higher than those obtained for lavas because of widespread weak pyrite mineralization within the Basal Group.

The apparent resistivities of the Basal Group are generally much higher than those of the Lower and Upper Pillow Lavas as a result of widespread silicification and larger proportion of intrusive material. Much lower resistivities are, however, obtained over mineralized zones, a property that facilitates their detection. In pillow lavas, mineralization of this grade does not usually have any resistivity contrast to the host rock.

6.3. Geophysical Survey of the Ayios Ioannis (Agros) Area.

6.3.1. Introduction.

The Ayios Ioannis area lies between the villages of Ayios Ioannis and Agros in the Pitsilia region of central Cyprus, about 28 miles to the southwest of Nicosia and 16 miles north of Limassol.

Copper bearing mineralization within this area has attracted attention since ancient times as evidenced by old galleries found in the village of Ayios Ioannis.

In recent years prospecting in the area started by sinking a number of pits along mineralized zones which revealed some high assays for Cu, Au and Ag. These assays, coupled with the general geology of the area, were considered sufficiently encouraging for the U.N.S.F. project to initiate in 1964 a programme of detailed geological mapping with the aim of obtaining additional information regarding the mineralization. The geological mapping was followed by a self-potential survey and the drilling of one borehole (A.I.1.) which, however, for technical reasons, did not reach the anticipated depth (Constantinou 1964, Vokes 1964). Another borehole, MR/15/70, was drilled in 1970 by the Geological Survey Department and in 1977 Noranda Exploration (Cyprus) Ltd, which acquired interest in the area, carried out an IP survey and drilled one borehole. The IP survey was carried out by the writer whilst in employment by the Geological Survey Department. The prospect was later released by Noranda and at the present time the Geological Survey Department is carrying out a drilling programme based on the IP work with the aim to evaluate the potentialites of the area.

6.3.2. Geology (see fig 31).

A detailed account of the geology and mineralization of the Ayios Ioannis area can be found in Constantinou (1964) and Vokes (1964). According to these authors the Ayios Ioannis area lies on the southern border of a large area of gabbro which stretches northwards to Agros and has an east-west width of about 1.5 miles. The gabbro is medium grained with varying patches of coarse - grained to pagmatitic gabbro and is cut by dykes of microgabbro and microdiorite which mainly strike north-east.

Following the intrusion of these dykes the gabbroic rocks were subjected to a phase of chloritization by solutions ascending through fractures and low-angle fault planes. This resulted in the formation of extremely irregular bodies, dark to light green

Contemporaneously with the chloritization or a short time afterwards, sulphides and quartz were introduced along the same openings, forming replacement bodies and vein like fillings. The quartz is mostly confined to the chloritic bodies where it usually occurs in the form of sulphide bearing veins along the centres of dyke-like forms of the chloritic rocks and is found to much less extent in the gabbroic rocks.

The sulphides occur both within the vein quartz zones and in the chloritic rocks. In the quartz veins they occur in the form of grains, veins or irregular bodies. In the chloritic rocks they are found in the form of disseminations. The mineralization consists mainly of pyrrhotite with less common chalcopyrite and sphalerite.

The sulphides weather on the surface to a brown-yellow limonitic gossan which commonly exhibits a well developed box-work texture. In outcrop, also, the quartz veins are extremely weathered, rusty and porous due to oxidation of the sulphides which they invariably carry.

The chloritic rocks with which the sulphide mineralization is intimately associated form very irregular bands or zones in outcrop. Viewed as a whole, however, the chloritic bodies are contained within a zone more than 1.2 km long, trending north-south and stretching from the village of Ayios Ioannis to the Ayios Yeorgios locality. The zone dips to the southwest at about 40^{o}.

6.3.3. The Geophysical Results.

The IP coverage of the Ayios Ioannis area included nine lines placed at regular 400 ft intervals and trending east-west, i.e. perpendicular to the north-south mineralized zone of chloritic rocks (see map fig 31). The dipole-dipole configuration was employed with a dipole length of 200 ft and dipole separations n= 1-4. The operating frequencies were 0.31 Hz and 5 Hz. E.M. coupling effects have generally been negligible because of the relatively high background resistivities.

The IP results are discussed below with reference to four representative pseudosections for lines 12S, 4S, 4N and 12N shown on figs 32-35. These results show the presence of a frequency effect and metal factor linear anomaly which extends northwards from Ayios Ioannis village and coincides with the principal zone of chloritization (see fig 31). Over its strongest part the anomaly coincides with low apparent resistivities.

The behaviour of the three parameters, i.e. apparent resistivity, percent frequency effect (PFE) and metal factor (MF), corresponding to the unaltered and mineralized rocks is briefly discussed below.

Apparent Resistivity.

The apparent resistivity of the unaltered gabbroic rocks is highly variable with values of 120 to over 1000 ohm. ft/2π (230-1915 ohm. metres).

The same range of values is obtained for chloritic rocks which are either devoid of any sulphide mineralization or in which the mineralization is in the form of disseminations. This is the case for lines 16S, 12S, 12N and 16N along which the chloritic rocks, whose presence is apparent from geology and from slightly above background frequency effects, are not associated with different apparent resistivities.

The mineralized zone between lines 8S and 8N is associated with much lower resistivities which vary between 30 and 300 ohm.ft/2π (57-570 ohm. metres). It appears that the sulphide mineralization, in the form of interconnecting veins is mainly responsible for the observed decrease in resistivity.

The topography of the area is quite rugged and is expected to have influenced the resistivity field to a certain extent.

Percent Frequency Effect.

It appears that a three-fold separation of the rocks of the Ayios Ioannis area can be made on the basis of the observed PFE, i.e. the gabbro, the chloritic gabbro and the mineralized chloritic gabbro.

The gabbro is characterized by values of 0.1 - 2.0%. Although relatively unaffected by hydrothermal alteration the gabbro has suffered deep weathering which probably accounts for some of the observed variations in PFE. Other factors, such as ammunt of intrusive material and mineralogical differences such as presence or absence of olivine may also be responsible for polarization differences.

The chloritic gabbro appears to be associated with PFE values of 2-3.5%. These above background values may be due to the intrinsic membrane polarization of chlorite and partly to electrode polarization from disseminations of sulphides within the chloritic rocks. Examples of such occurrences can be seen on line 12S between stations 4E and 8E, on line 4S between stations 9E and 12E and on line 12N between the base line (BL) and station 3E.

The zone of mineralized chloritic gabbro is characterized by PFE values in the range of 5-18%. The zone is sharp and particularly strong on lines 8S to 4N weakening rapidly on line 8N with PFE generally below 5%. It appears that the observed polarization is governed mainly by the metallic sulphides pyrrhotite and chalcopyrite which the chloritic rocks contain. The magnitude of the response is also partly determined by the shallowness of the source. Borehole A.I.1, close to line 0, encountered mineralization from 21m to 29m depth (bottom of the hole) which averaged 0.45% copper. Similarly borehole MR/15/7^{0} intercepted weak sulphide mineralization in the form of veins and disseminations below a depth of 15m.

Metal Factor.

The MF values, like the PFE fall into three ranges which appear to correspond to different lithological types. The gabbro is characterized by values of 1-70, the chloritic gabbro by values of 50-160 and the mineralized gabbro by 120 to over 2000. There is good correspondence between PFE and MF although the latter parameter tends to follow rather the fluctuations of apparent resistivity.

The Ayios Ioannis IP survey, unlike similar surveys over the pillow lavas shows that the MF may be quite useful in delineating mineralized zones. The exact relation of MF to mineralization is, however, rather difficult to determine at the present owing to insufficient borehole information.

Like resistivity the metal factor appears to be quite sensitive to topography.

The shape of the frequency effect anomaly over the mineralized zone, although slightly different from line to line generally conforms to the "pant-leg" type. The anomalies are generally asymmetrical, with the eastern limb rather better defined. The anomalies are sharply defined and are several times the background values in magnitude. From the shape and extent of the anomalies it is deduced that the source is generally shallow, of the order of one dipole length in width and rather steeply dipping to the west.

The MF and resistivity anomalies are generally more complex in form. The MF anomalies are sharply defined, with large contrast to background values, but their shapes vary, being in general zones of higher values.

The resistivity anomalies are not as sharply defined and anomalous values may only be 2-3 times lower than background.

6.3.4. Conclusions.

It appears that the IP method responds positively to narrow zones of veined and disseminated sulphide mineralization in gabbroic rocks. This response is accentuated by the rather subdued response of the gabbroic host rock, although another reason for this may be the shallowness of the source.

The resistivity of the gabbroic rocks is generally high and a large resistivity contrast is observed between mineralized and unmineralized zones.

7. Summary and Conclusions.

Three examples of the application of the variable frequency I.P. method in sulphide exploration in Cyprus have been presented.

The examples cover three different geological environments, i.e. pillow lavas, Basal Group rocks and gabbro in which sulphide mineralization has developed. In all three cases the mode of occurrence is similar, i.e. in the form of veins, fracture fillings and disseminations along narrow structural zones. The depth of mineralization is generally shallow and in any case not greater than about 50 metres. The grade of mineralization can be considered as low to medium with sulphur contents of 2% to 30%.

An example is also given of a mise-a-la-masse survey for the delineation of a small (approx. 40m X 20m X 6m) orebody, as well as of a modified pseudosectional plotting technique which enables meshing of measurements obtained with different dipole lengths and which has a true vertical scale that permits more accurate estimate of the depth of I.P. sources.

The I.P. survey over the lavas in the Avdellero area has shown that the I.P. method responds positively to sulphide mineralization even of low grades and that anomalous responses due to sources other than sulphides are generally absent. This is a great advantage over other geophysical methods like gravity and electromagnetics which have failed to show the mineralization but have produced numerous anomalies some of which have been tested by drilling and found to be due to contrasts in density or conductivity in the host rock.

Problems in the unprohibited application of the IP method over the pillow lavas result mainly from the low resistivities of these rocks (10-15 ohm. metres) which match those of low to medium grade mineralization. Low resistivities increase E.M. coupling which limits effective penetration to depths generally less than 100 metres. Penetration is also limited by skin effects particularly at higher frequencies. Resistivity is generally non-diagnostic owing to lack of contrast between mineralization and host rock. Metal factor also is not helpful.

Deeper seated occurrences of mineralization than the one surveyed at Avdellero have given generally low to subtle I.P. responses which, however, owing to the low background response from the lavas, can usually be recognized. This shows that a cover of unmineralized lavas usually diminishes the I.P. response.

Owing to several problems associated with I.P. surveying over the pillow lavas it is believed that the I.P. method should be used in conjunction with other geological and geophysical methods in order to discard anomalies due to uneconomic sulphides or to other sources. BoreholeI.P. appears to offer certain advantages, particularly regarding depth of investigation and size of source in relation to its depth.

The I.P. method has also proved successful in the detection of low to medium grade mineralization in Basal Group rocks, which the gravity and magnetic methods had previously failed to indicate. From similar examples in other areas it appears that the E.M. method can also provide diagnostic results.

Resistivity is also a useful parameter as mineralized occurrences usually have a large contrast to the quite resistive host rock. The usefulness of this method is, however, diminished owing to effects from the rather rugged topography of Basal Group outcrops.

The main problem of I.P. surveying over the Basal Group is that of the large background frequency effects which are due to widespread weak sulphide mineralization. This effect may be larger or comparable to that expected from sources within the lavas and is quite troublesome, particularly considering the fact that many mineralized occurrences involve rocks of both the Basal Group and the pillow lavas. The large effect from Basal Group may mask the effect from sulphides in adjacent pillow lavas. Also the effect of Basal Group from under a cover of lavas may be confused with that of sulphide mineralization. Fortunately, in many cases the presence of Basal Group is recognized owing to its generally higher resistivity although occasions of Basal Group outcrops with apparent resistivities close to those of pillow lavas have also been encountered. The gravity and magnetic methods may also be used profitably for the clarification of such cases owing to the higher density and lower magnetization of the Basal Group rocks.

I.P. response from shallow sulphide occurrences in gabbroic rocks is generally high whilst background effects are low. Resistivity is diagnostic of mineralization, although the rugged topography of gabbro outcrops is responsible for distortions of the resistivity field. Mineralized occurrences in gabbroic rocks appear to be rather

8. References.

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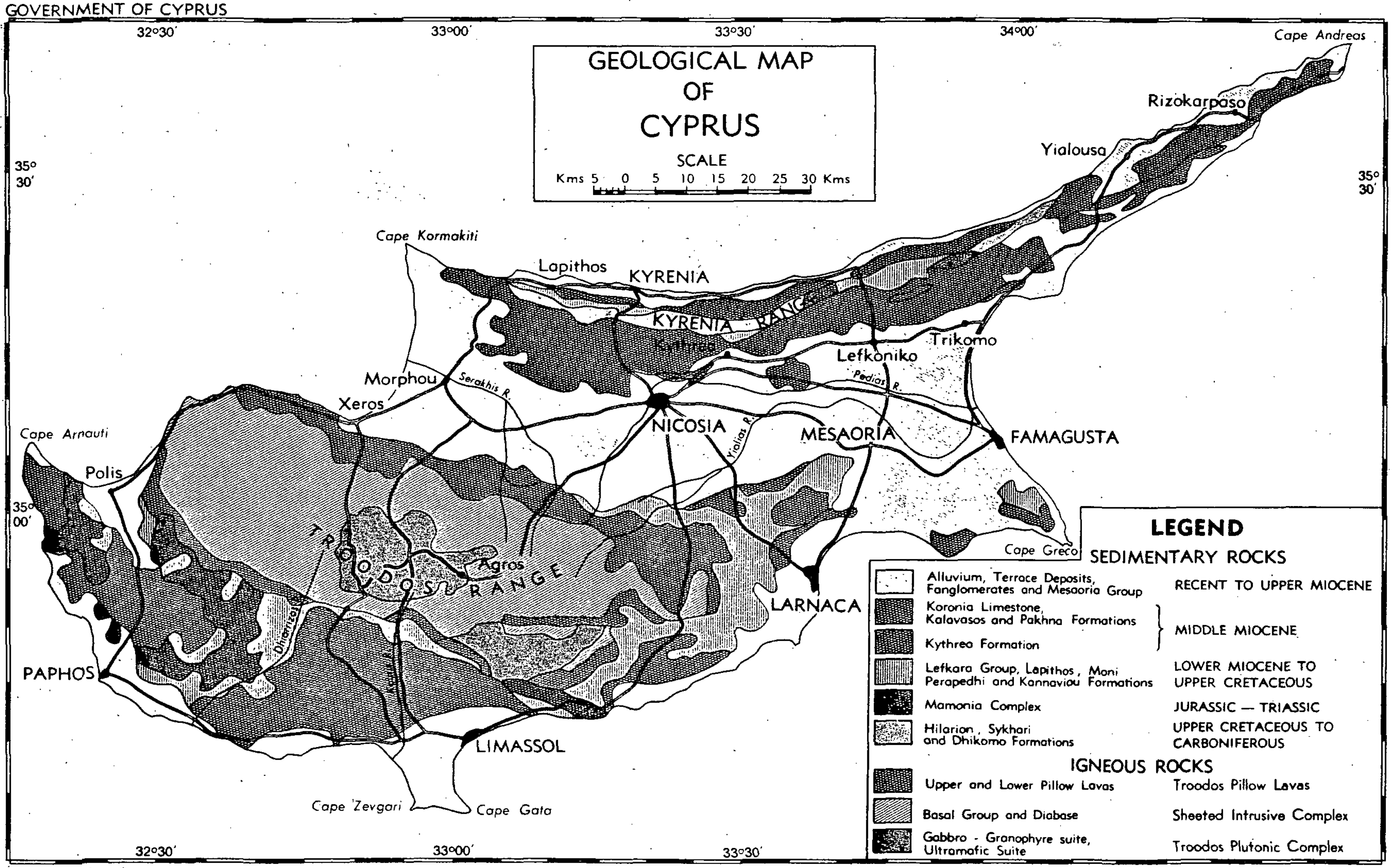
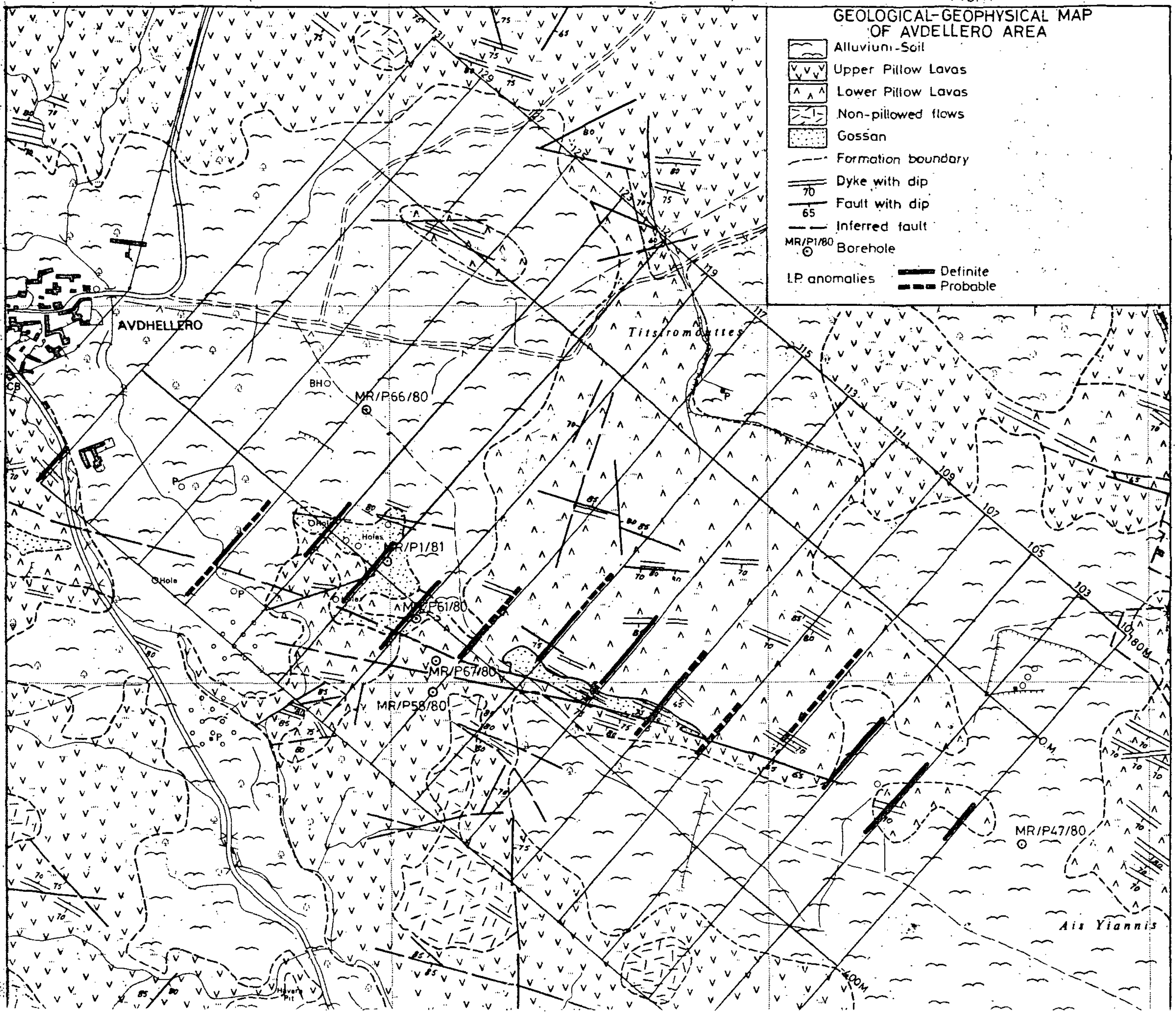
GOVERNMENT OF CYPRUS

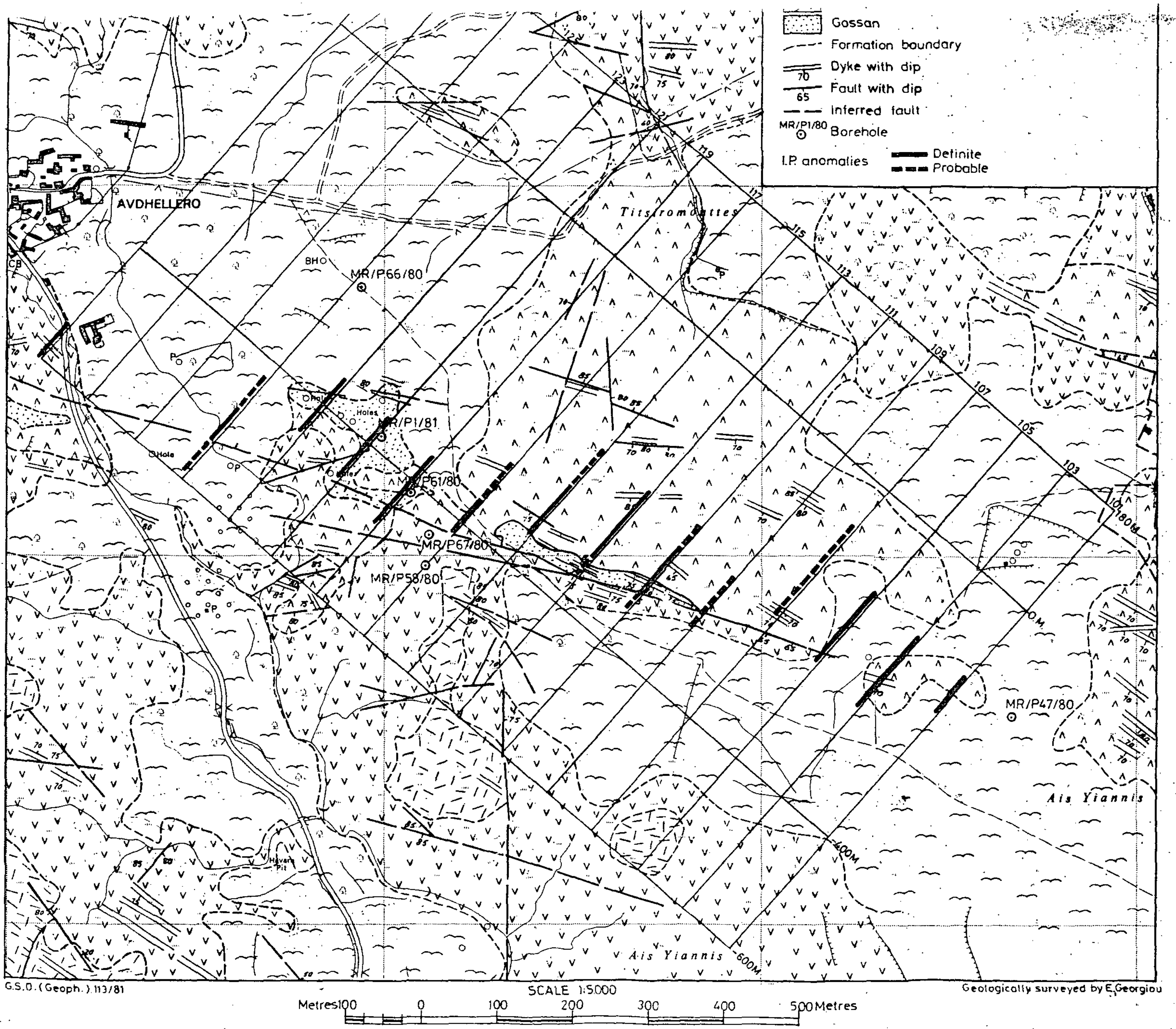


Compiled, drawn and photographed by Geological Survey Department,

Fig. 1

FIG. 11


GEOLOGICAL-GEOPHYSICAL MAP OF AVDELLERO AREA
Alluvium-Soil
Upper Pillow Lavas
Lower Pillow Lavas
Non-pillowed flows
Gossan
Formation boundary
Dyke with dip
Fault with dip
Inferred fault
Borehole
I.P. anomalies
Definite
Probable
AVDHELLERO
Titsiromouttes
MR/P66/80
MR/P1/81
MR/P61/80
MR/P67/80
MR/P58/80
MR/P47/80
Ais Yiannis



G.S.D. (Geoph.) 113/81

Geologically surveyed by E. Georgiou

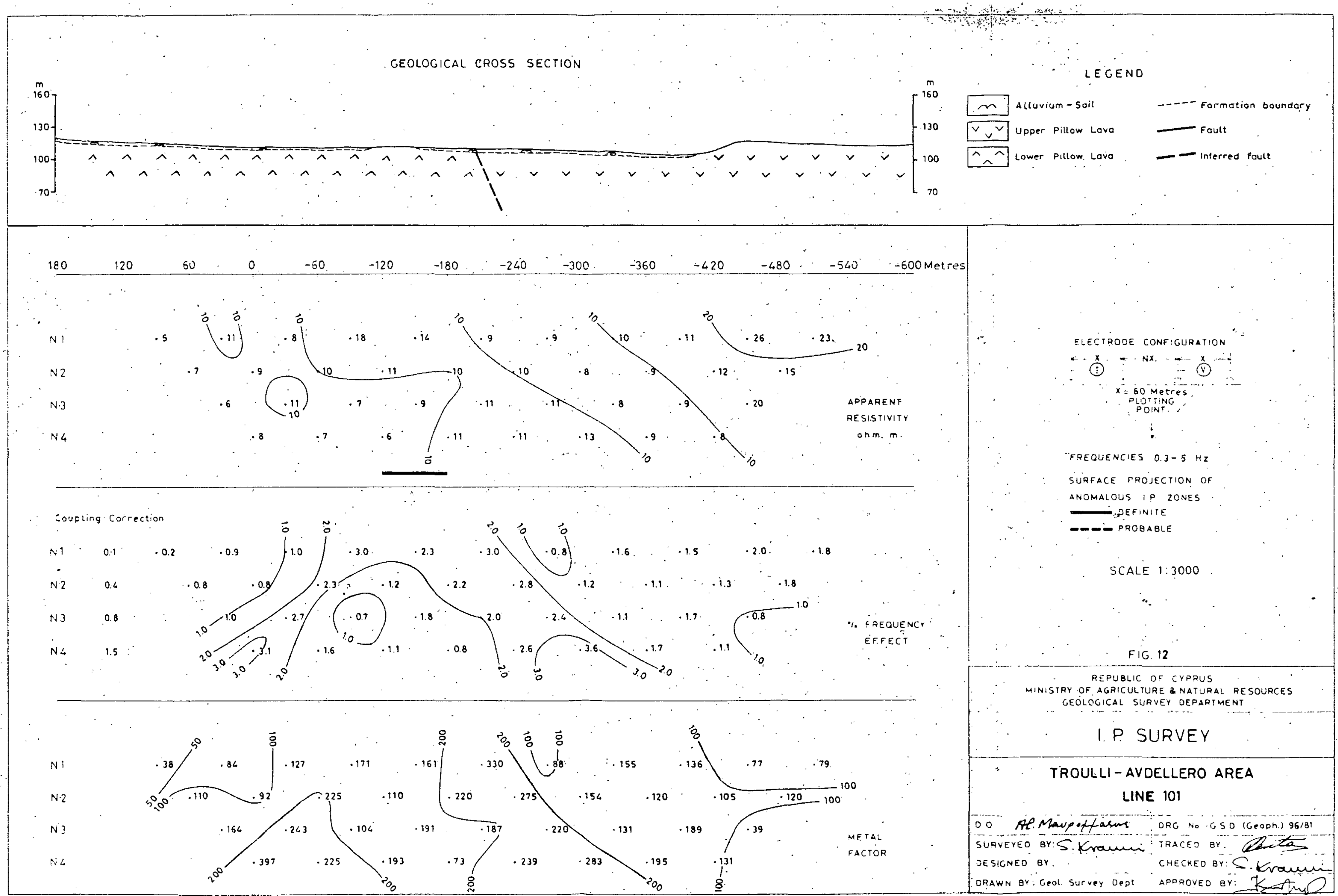
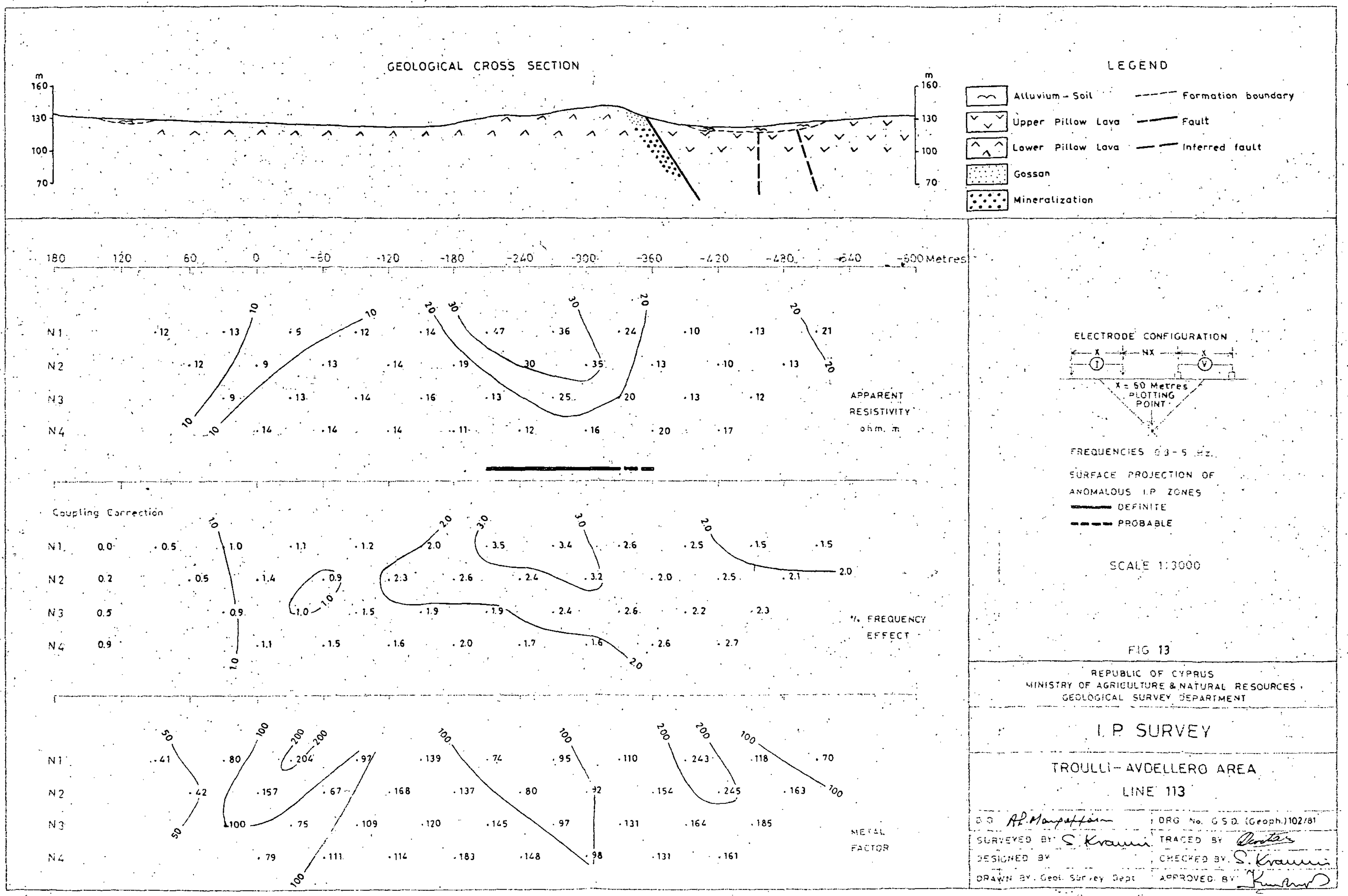

GEOLOGICAL CROSS SECTION
LEGEND
Alluvium - Soil
Upper Pillow Lava
Lower Pillow Lava
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
APPARENT RESISTIVITY ohm. m.
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 - 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
TROULLI - AVDELLERO AREA
LINE 101
DRG No G.S.D (Geoph.) 96/81
SURVEYED BY:
TRACED BY:
DESIGNED BY:
CHECKED BY:
DRAWN BY: Geol. Survey Dept
APPROVED BY:

FIG. 12


GEOLOGICAL CROSS SECTION
LEGEND
Alluvium - Soil
Upper Pillow Lava
Lower Pillow Lava
Gossan
Mineralization
Formation boundary
Fault
Inferred fault
Metres
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 - 5 Hz.
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
FIG 13
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
TROULLI - AVDELLERO AREA
LINE 113
DRG. No. G.S.D. (Geoph.) 102/81
SURVEYED BY
TRACED BY
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APPROVED BY

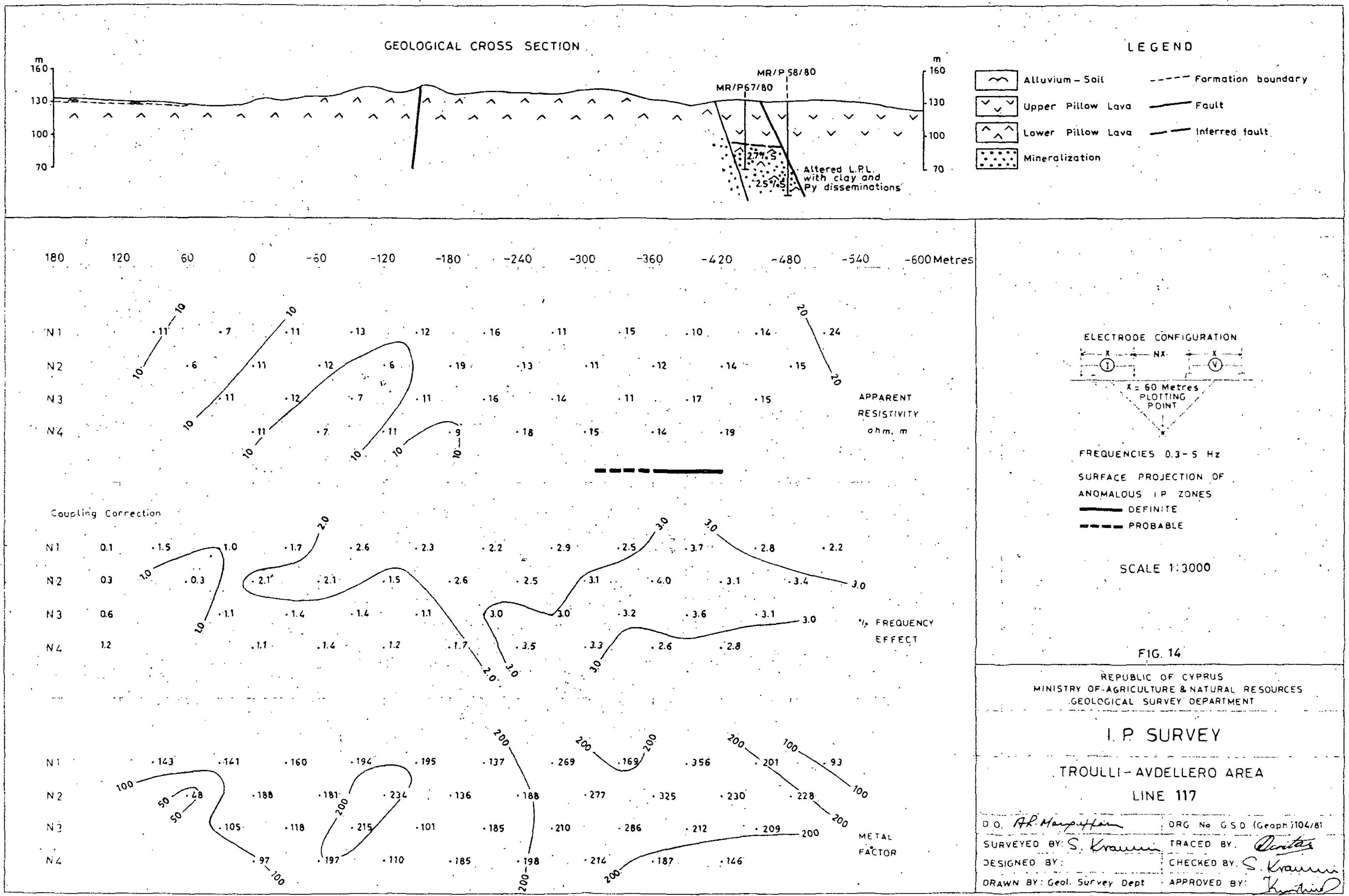
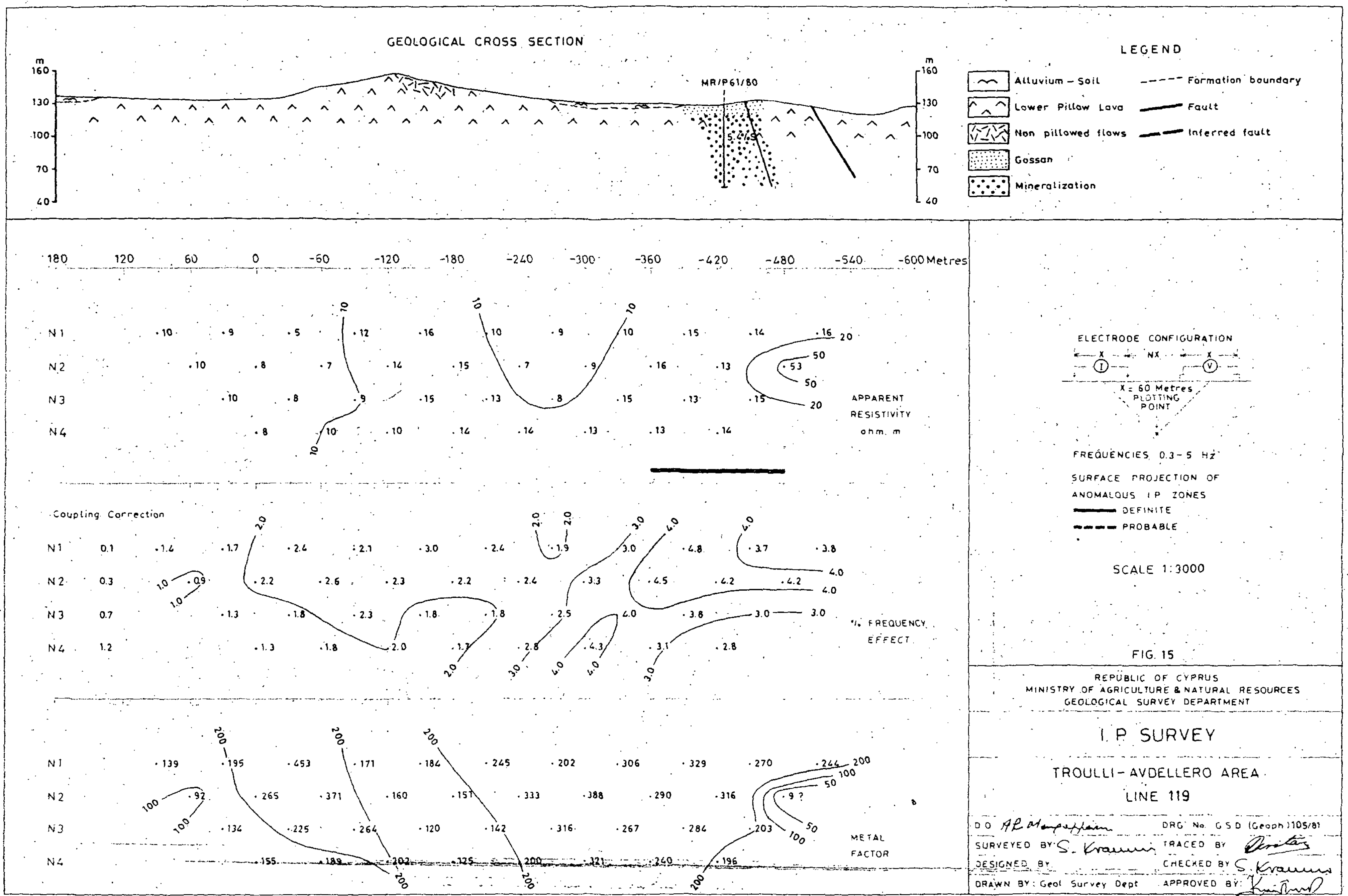
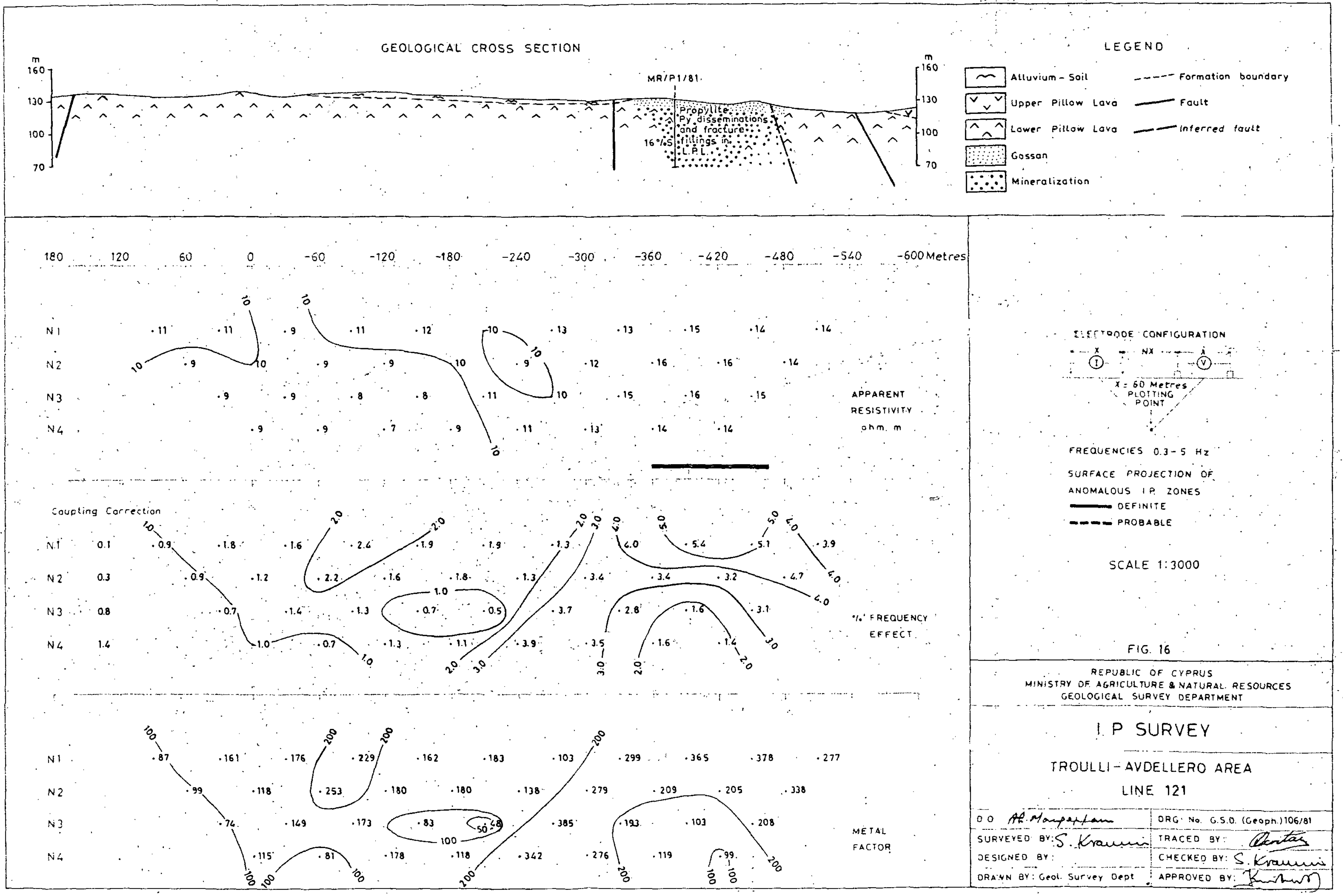
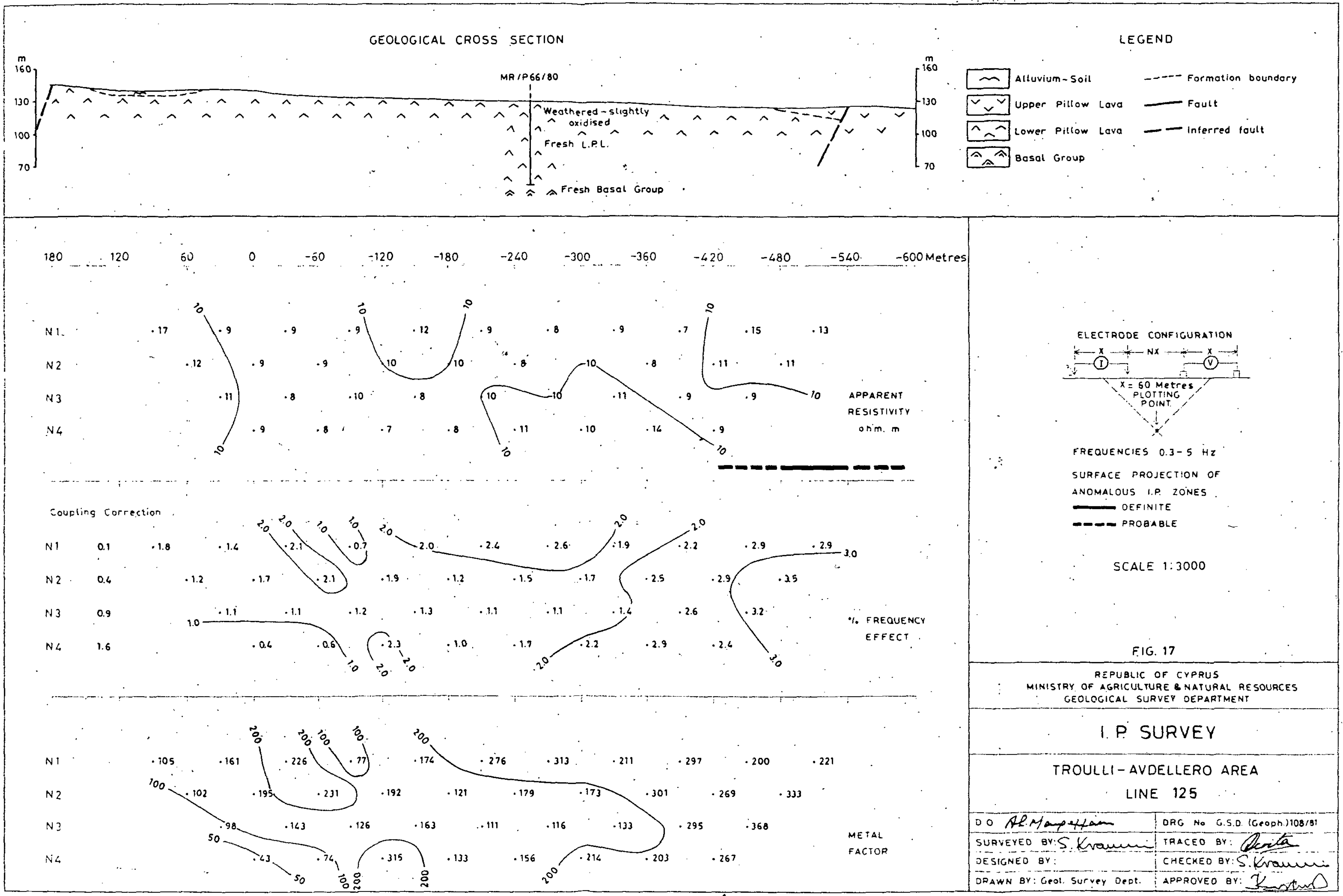

GEOLOGICAL CROSS SECTION
MR/P 58/80
MR/P67/80
Altered L.P.L. with clay and Py disseminations
LEGEND
Alluvium – Soil
Upper Pillow Lava
Lower Pillow Lava
Mineralization
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 – 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
TROULLI – AVDELLERO AREA
LINE 117
D.O.
ORG No G.S.D. (Geoph.)104/81
SURVEYED BY: S. Krauss
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Krauss
DRAWN BY: Geol. Survey Dept
APPROVED BY:

FIG. 14



GEOLOGICAL CROSS SECTION
MR/P61/80
LEGEND
Alluvium – Soil
Lower Pillow Lava
Non pillowed flows
Gossan
Mineralization
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 – 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
FIG. 15
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
TROULLI – AVDELLERO AREA
LINE 119
DRG. No. G.S.D. (Geoph.) 105/81
SURVEYED BY
TRACED BY
DESIGNED BY
CHECKED BY
DRAWN BY: Geol. Survey Dept.
APPROVED BY


GEOLOGICAL CROSS SECTION
MR/P1/81
Propylite Py disseminations and fracture fillings in L.P.L.
16°/S
LEGEND
Alluvium - Soil
Upper Pillow Lava
Lower Pillow Lava
Gossan
Mineralization
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 - 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
FIG. 16
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P SURVEY
TROULLI - AVDELLERO AREA
LINE 121
DRG. No. G.S.D. (Geoph.) 106/81
SURVEYED BY: S. Kraus
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Kraus
DRAWN BY: Geol. Survey Dept
APPROVED BY:



GEOLOGICAL CROSS SECTION
MR/P66/80
Weathered - slightly oxidised
Fresh L.P.L.
Fresh Basal Group
m
160
130
100
70
LEGEND
Alluvium - Soil
Upper Pillow Lava
Lower Pillow Lava
Basal Group
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
N1
N2
N3
N4
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 - 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
FIG. 17
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
TROULLI - AVDELLERO AREA
LINE 125
DO
DRG No G.S.D. (Geoph.)108/81
SURVEYED BY: S. Kramm
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Kramm
DRAWN BY: Geol. Survey Dept.
APPROVED BY:

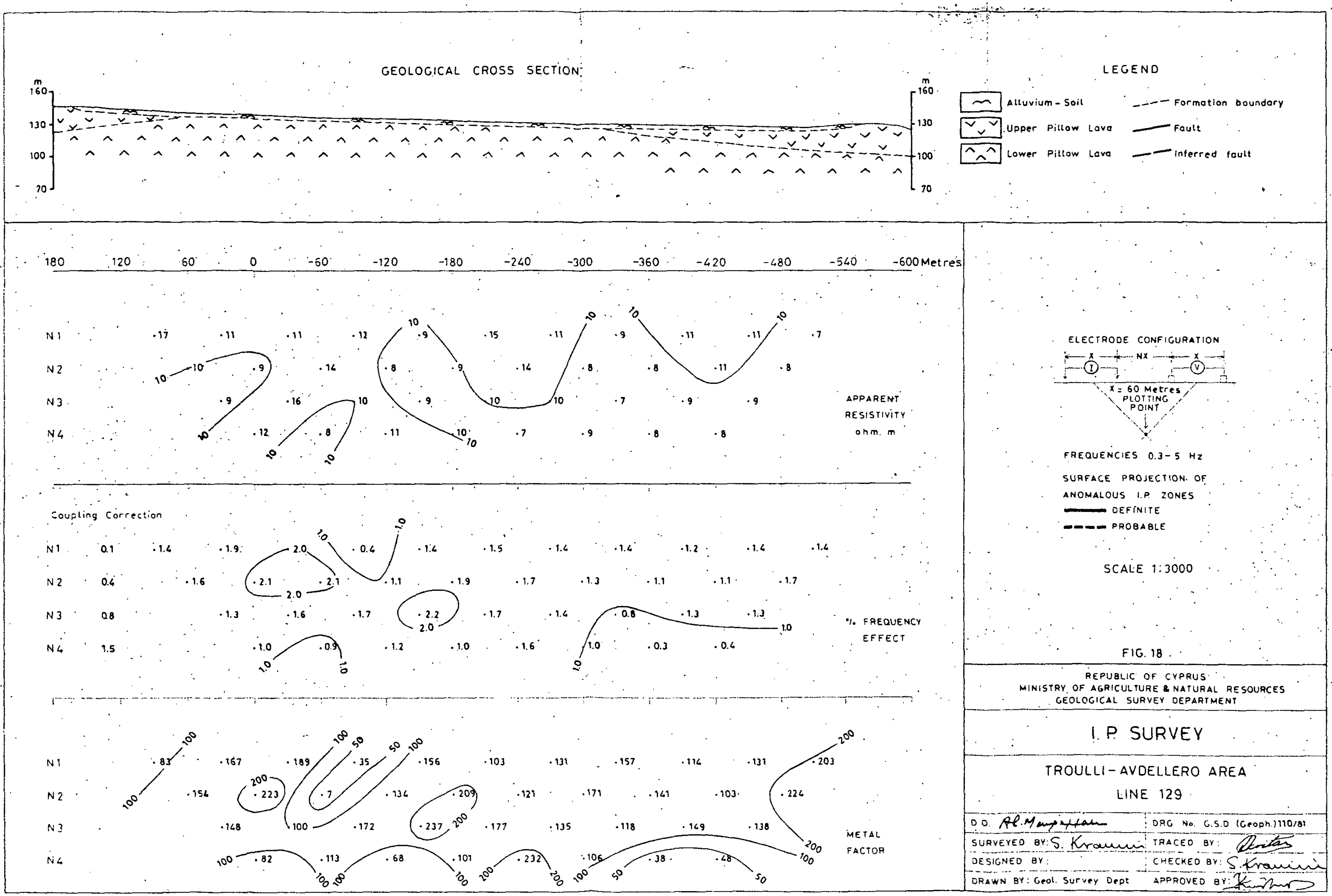
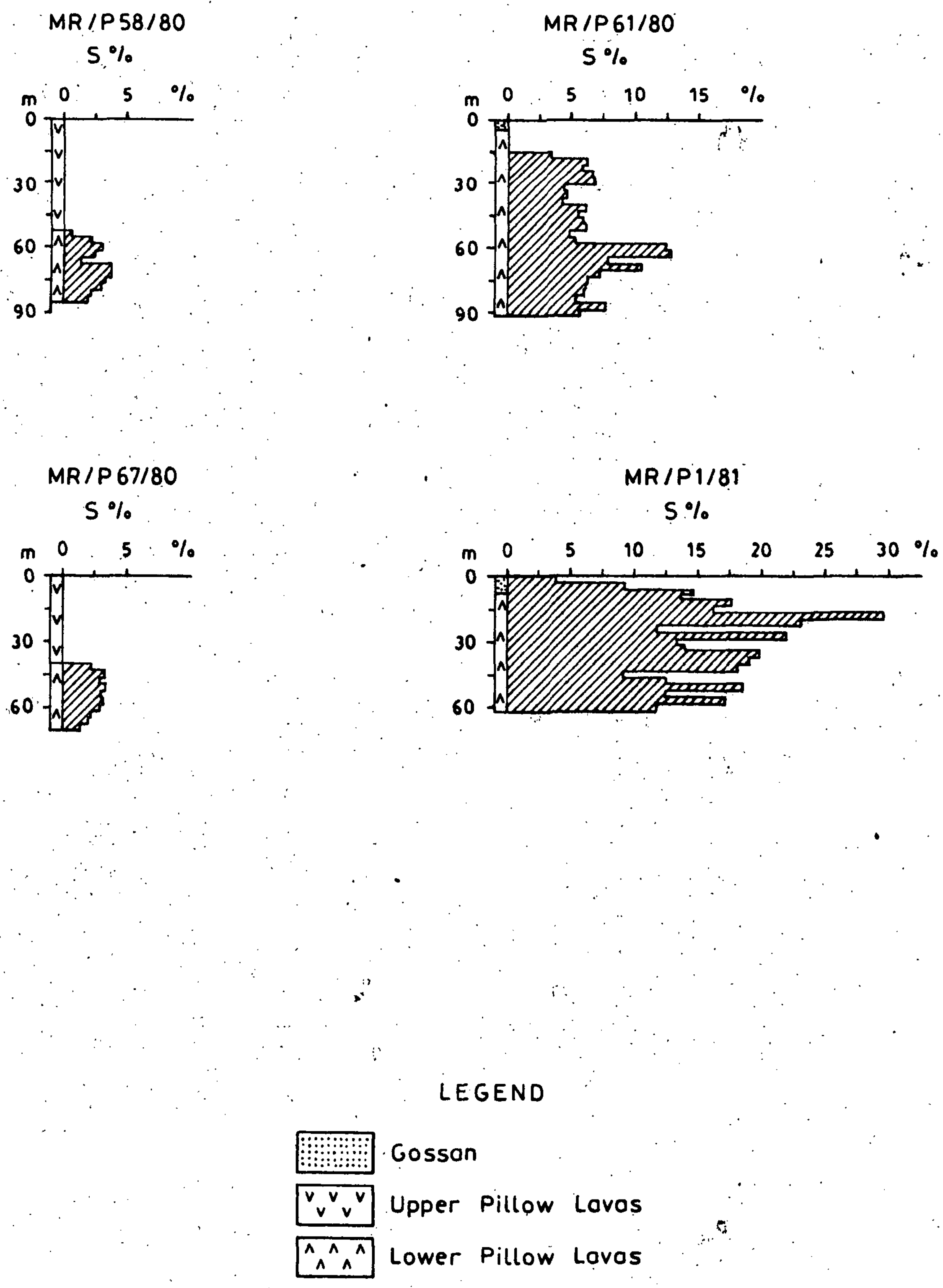

GEOLOGICAL CROSS SECTION
LEGEND
Alluvium - Soil
Upper Pillow Lava
Lower Pillow Lava
Formation boundary
Fault
Inferred fault
180 120 60 0 -60 -120 -180 -240 -300 -360 -420 -480 -540 -600 Metres
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 60 Metres
PLOTTING POINT
FREQUENCIES 0.3 - 5 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1:3000
FIG. 18
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I.P. SURVEY
TROULLI - AVDELLERO AREA
LINE 129
DRG No. G.S.D (Geoph.)110/81
SURVEYED BY: S. Krauss
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Krauss
DRAWN BY: Geol. Survey Dept
APPROVED BY:

FIG. 19

AVDELLERO AREA
Sulphur Distribution Diagrams
(Sludge Samples)



G.S.D. (Min.) 1/81

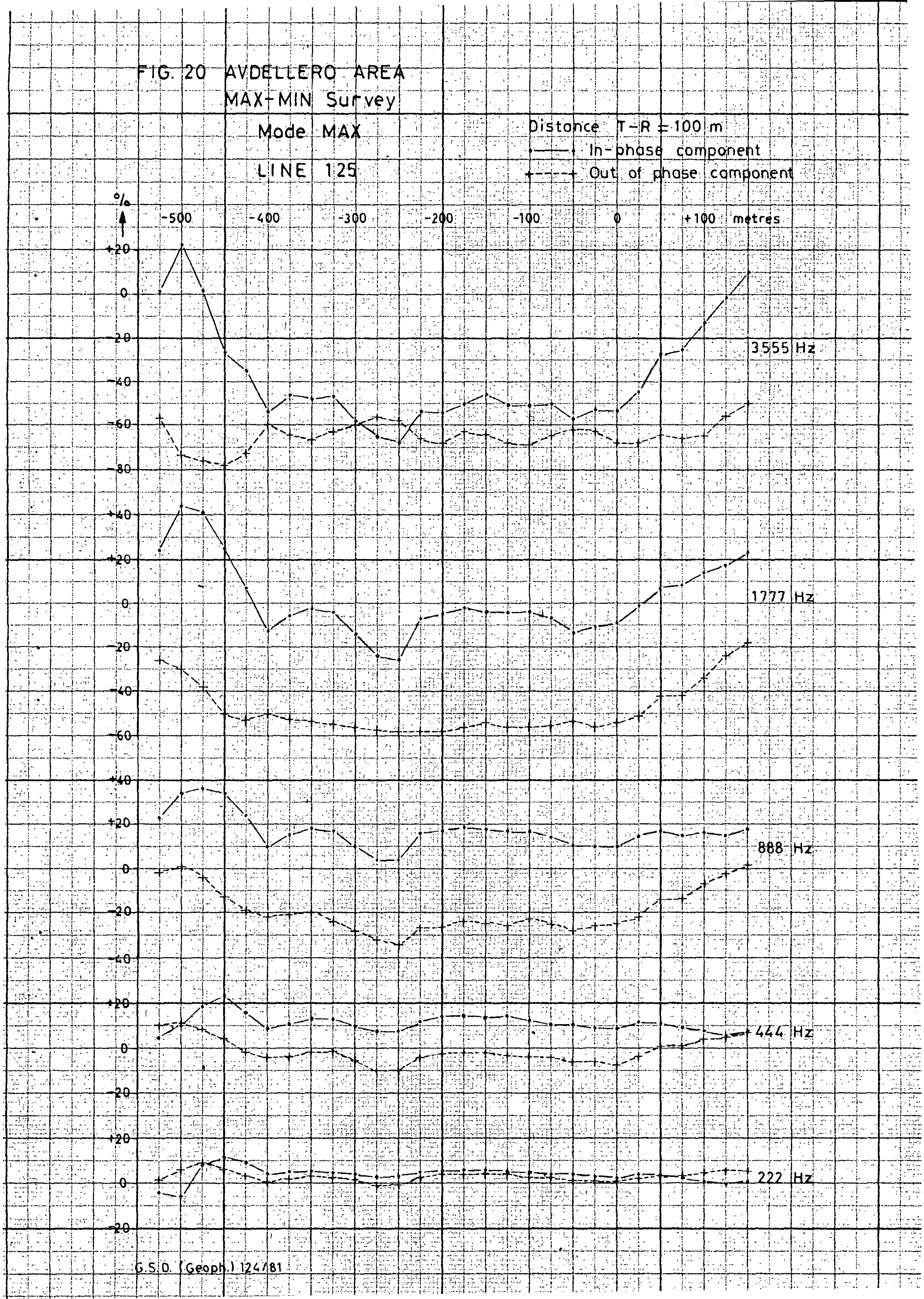
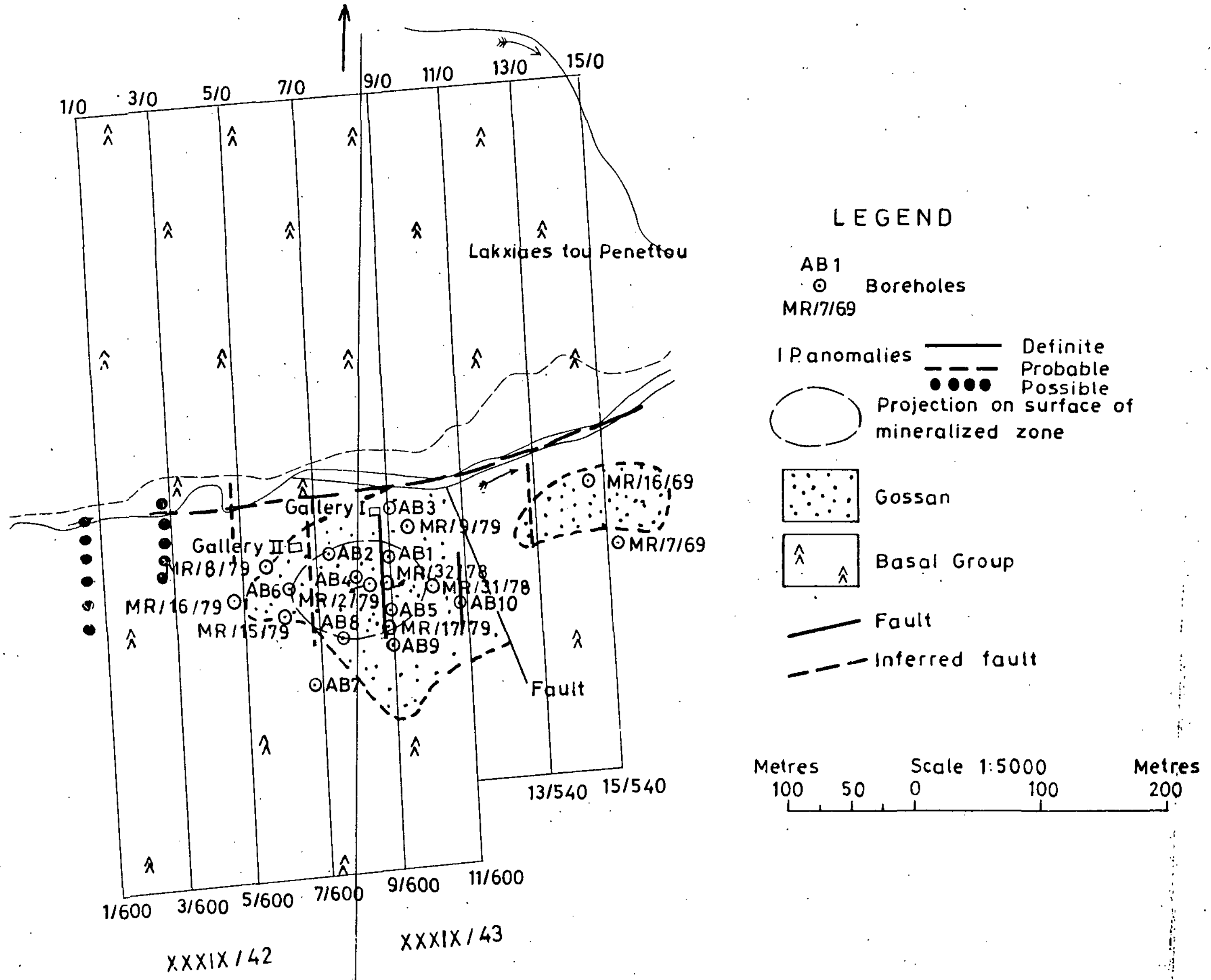


FIG. 20 AVDELLERO AREA
MAX-MIN Survey
Mode MAX
LINE 125
Distance T-R = 100 m
In-phase component
Out of phase component
%
-500
-400
-300
-200
-100
0
+100 metres
3555 Hz
1777 Hz
888 Hz
444 Hz
222 Hz
G.S.D. (Geoph.) 124/81

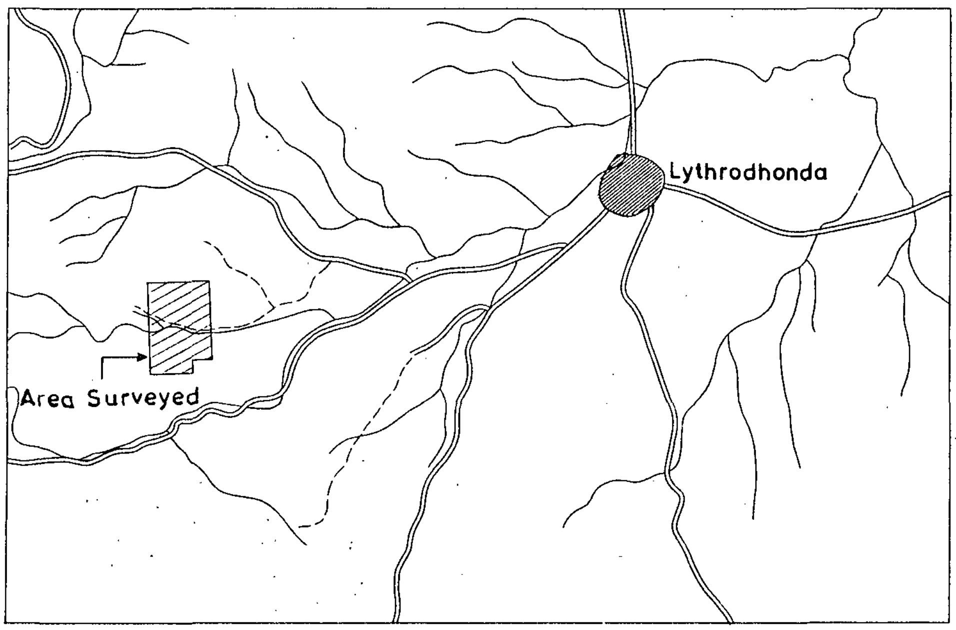
FIG. 21

LYTHRODHONDA (LAKXIAES TOU PENETTOU) AREA

I. P. SURVEY-GEOLOGICAL GEOPHYSICAL MAP



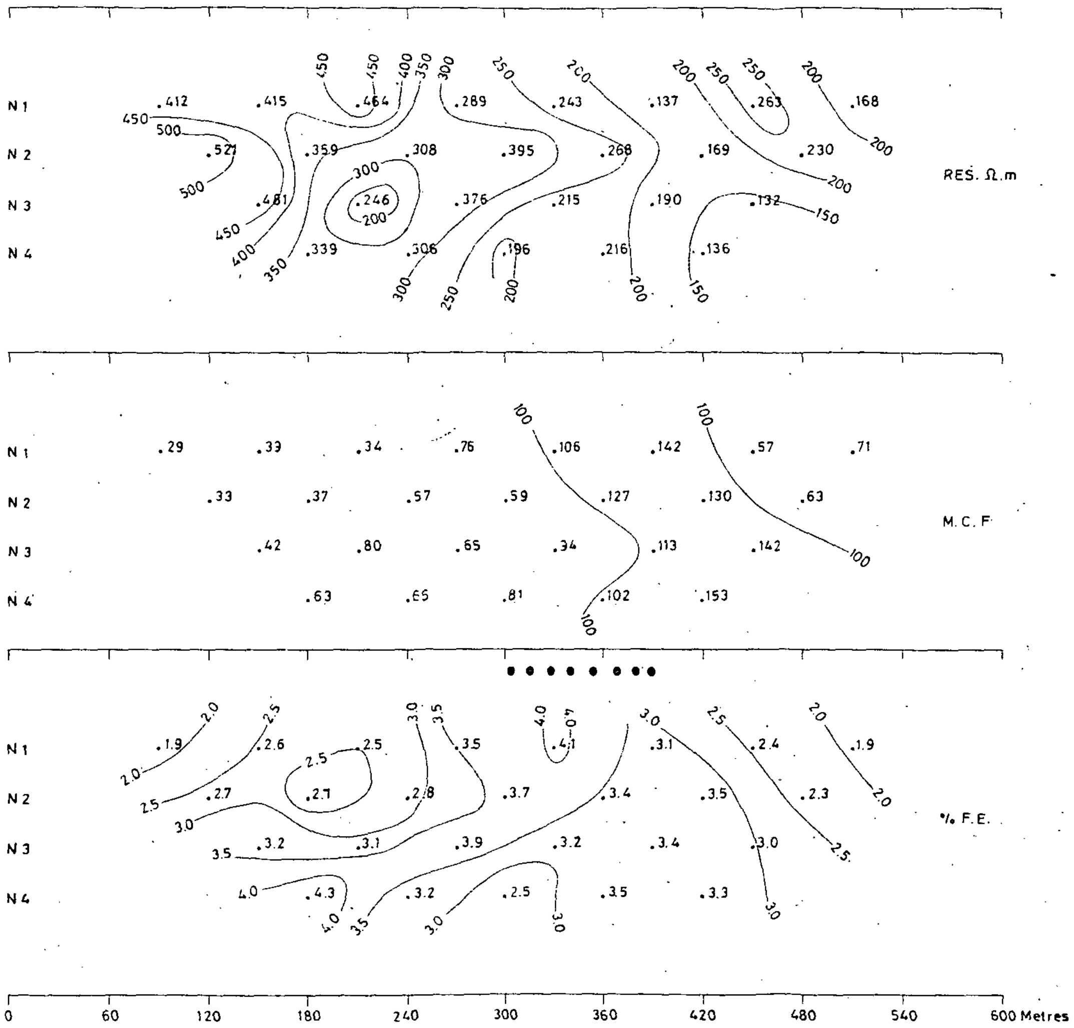
Location Map



Scale 1:50000

G.S.D. (Geoph.) 15/78

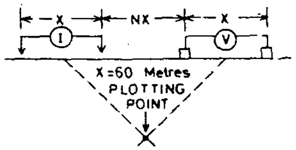
Drawn by Geological Survey Department
Surveyed by S. Kramvis



LINE No.: 1

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3–5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

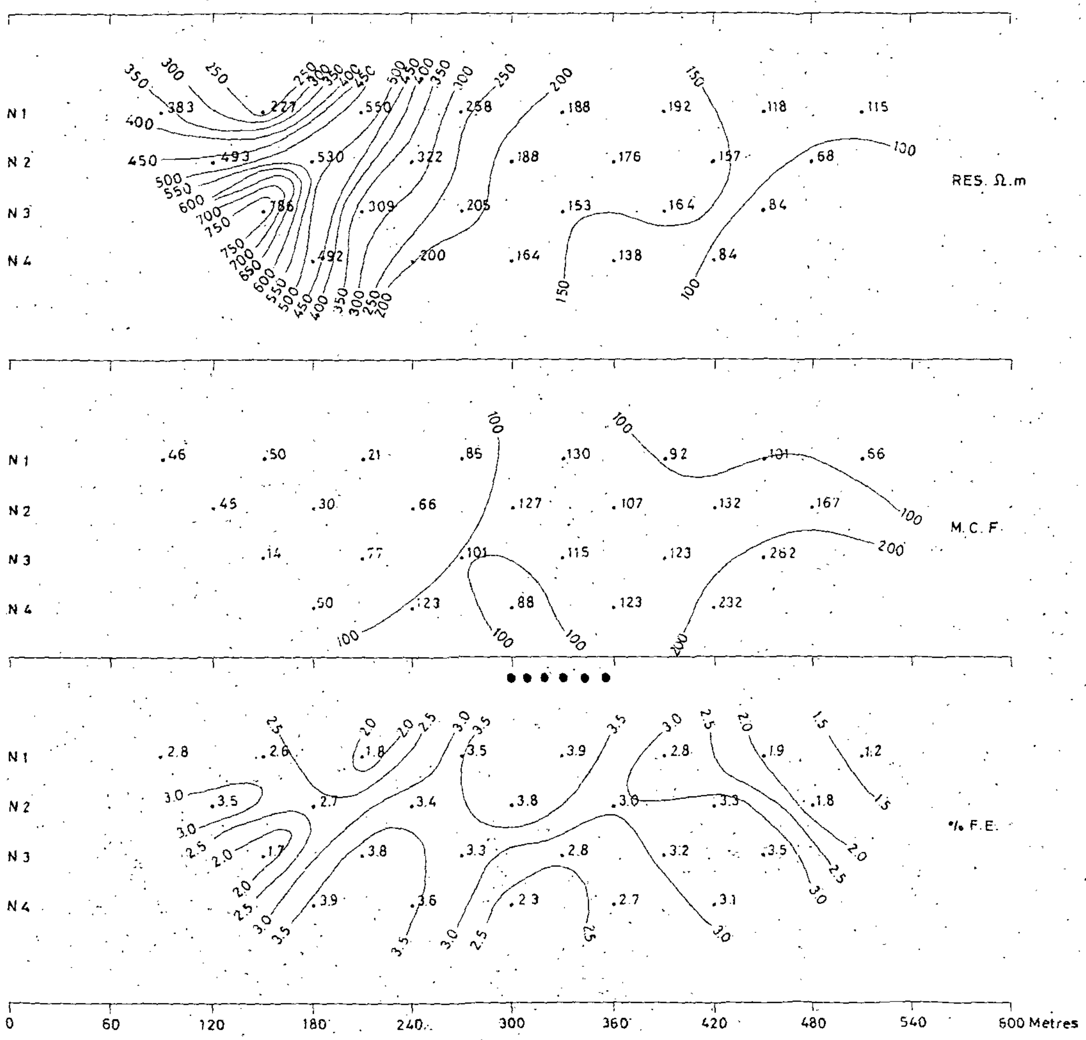
FIG. 22

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

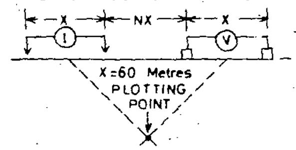
D.O. A.L. Mixpettasrs	DRG No. G.S.D.(Geoph.) 16/78
SURVEYED BY: S. Kramvis	TRACED BY: M.Georgiou
DESIGNED BY: S. Kramvis	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dep	APPROVED BY AG. DIRECTOR:



LINE No.: 3

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3–5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

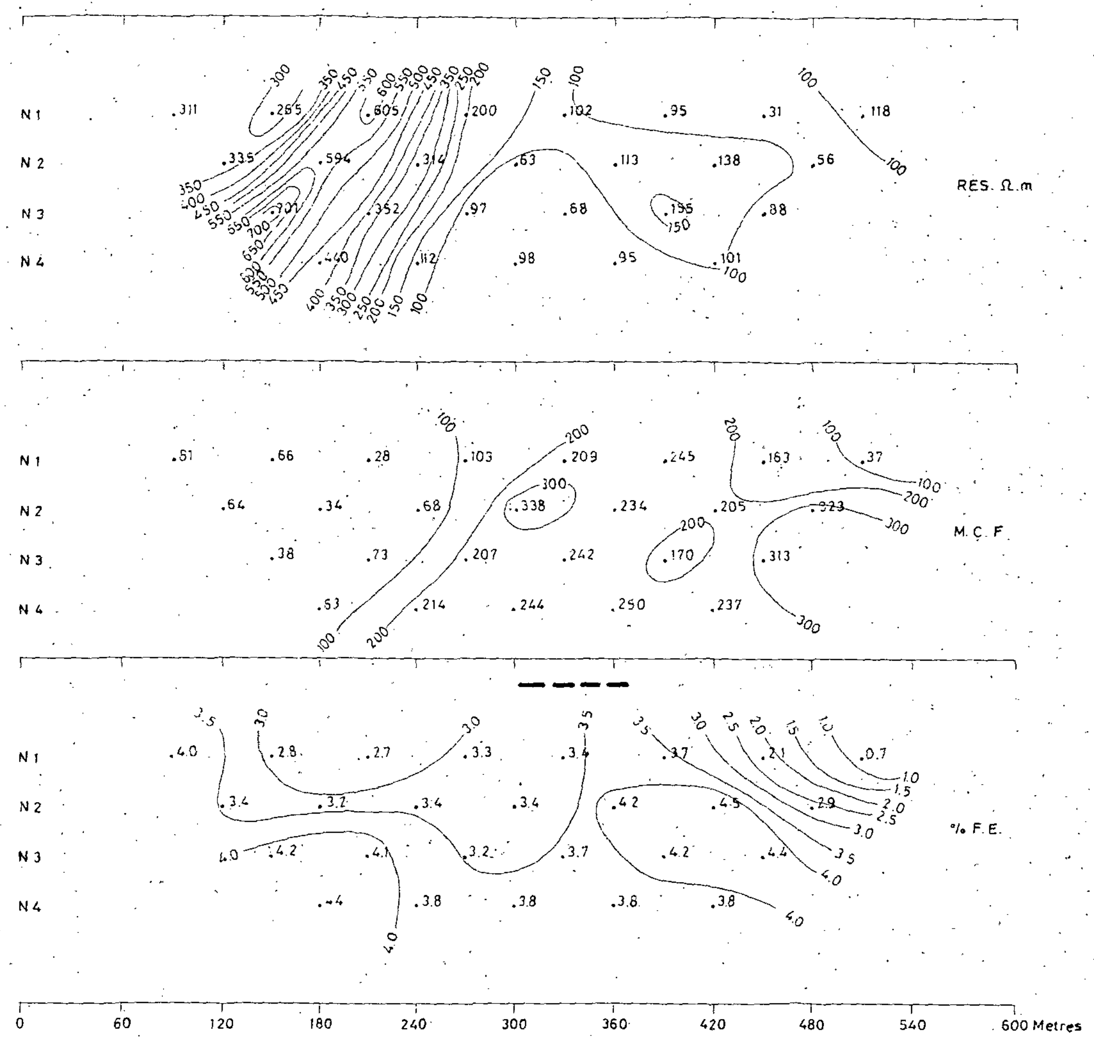
FIG. 23

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

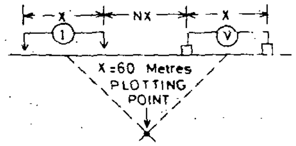
D.O. [illegible]	DRG No. G.S.D.(Geoph.) 17/78
SURVEYED BY: [illegible]	TRACED BY: [illegible]
DESIGNED BY: [illegible]	CHECKED BY: [illegible]
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR: [illegible]



LINE No.: 5

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3–5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

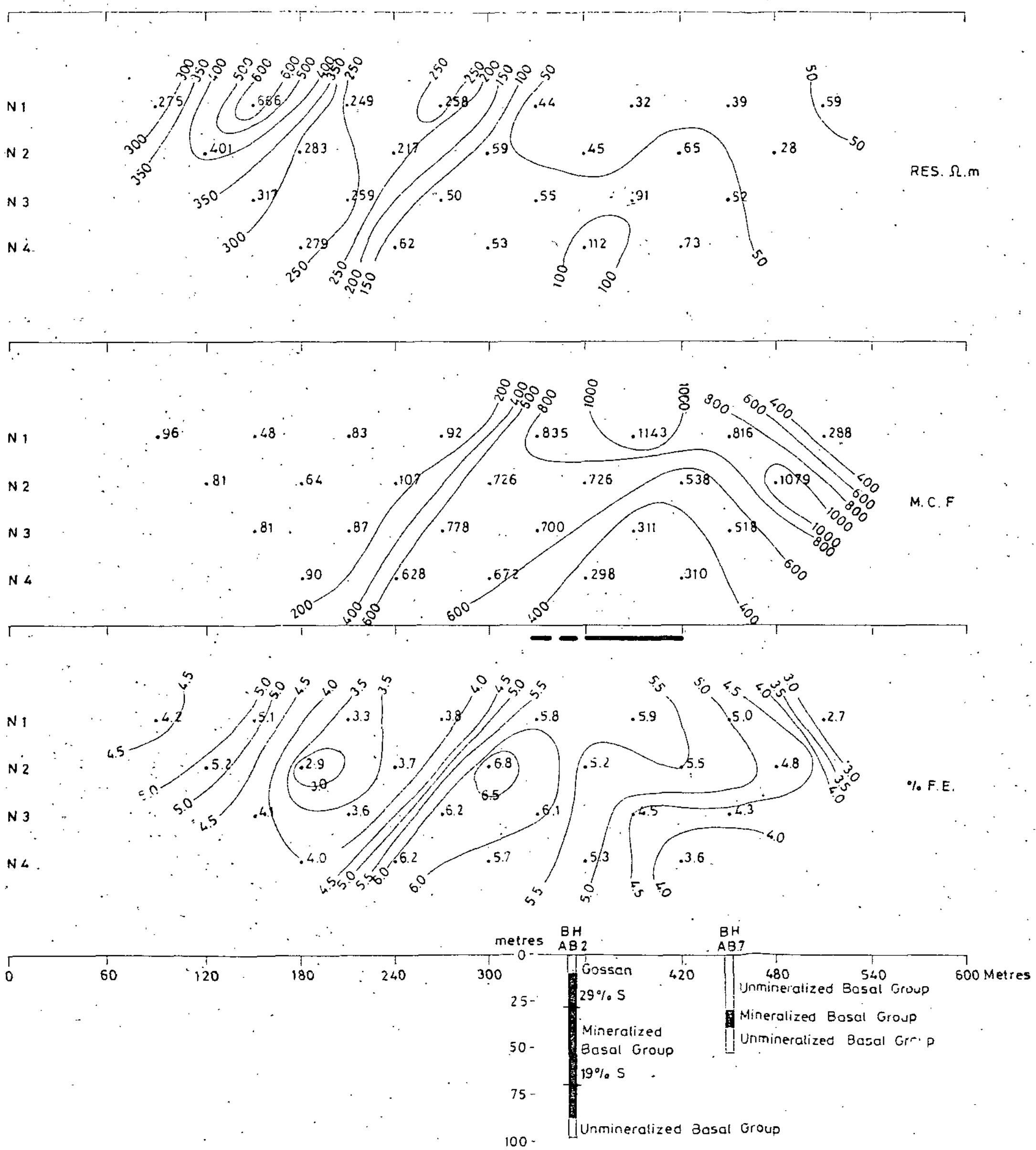
FIG. 24

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

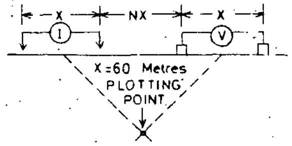
D.O. A. E. Μπουρλιάσης	DRG No. G.S.D. (Geoph.) 18/78
SURVEYED BY: S. Κραμβής	TRACED BY: Μ. Γεωργιάδου
DESIGNED BY: S. Κραμβής	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR: [illegible]



LINE No.: 7

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3-5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

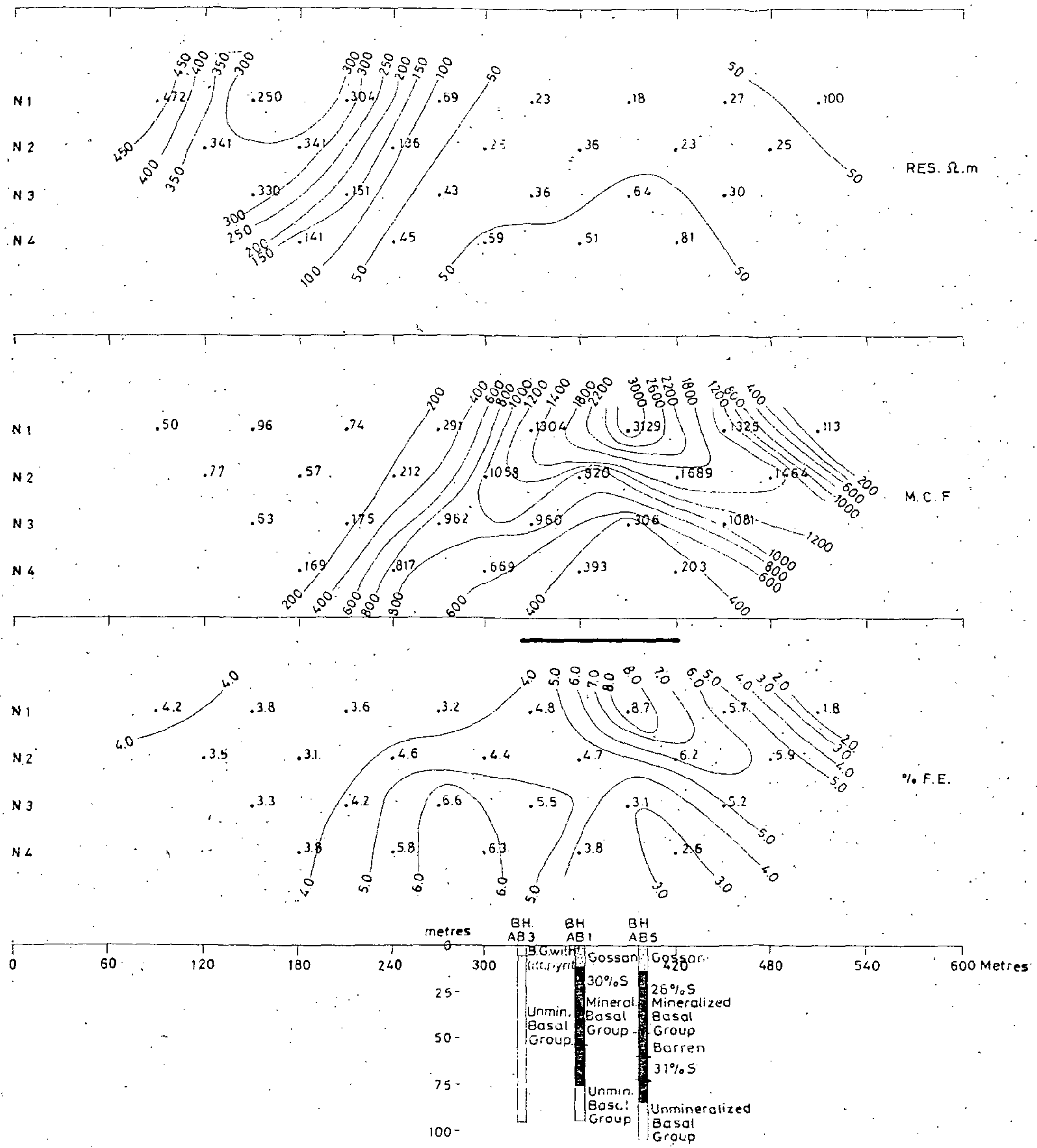
FIG. 25

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

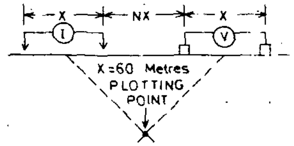
D.O. A. Malpetlas	DRG No. G.S.D.(Geoph.) 19/78
SURVEYED BY: S. Kramvis	TRACED BY: Georgiou
DESIGNED BY: S. Kramvis	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR:



LINE No.: 9

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3–5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

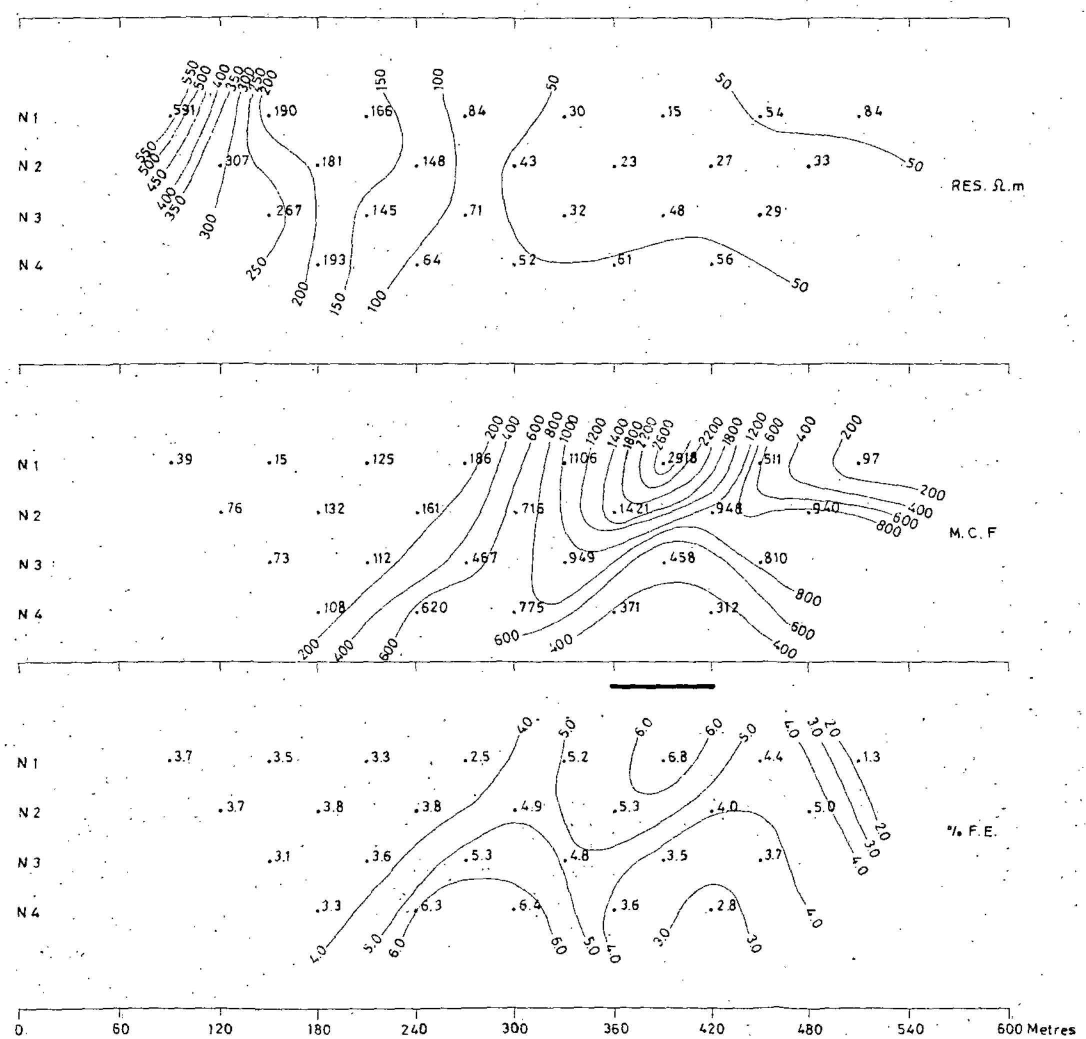
FIG. 26

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

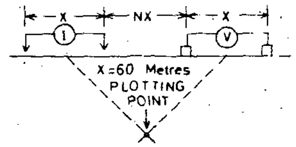
D.O. [signature]	DRG No. G.S.D.(Geoph.) 20/78
SURVEYED BY: S. Kramvis	TRACED BY: [signature]
DESIGNED BY: S. Kramvis	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR: [signature]



LINE No.: 11

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3-5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

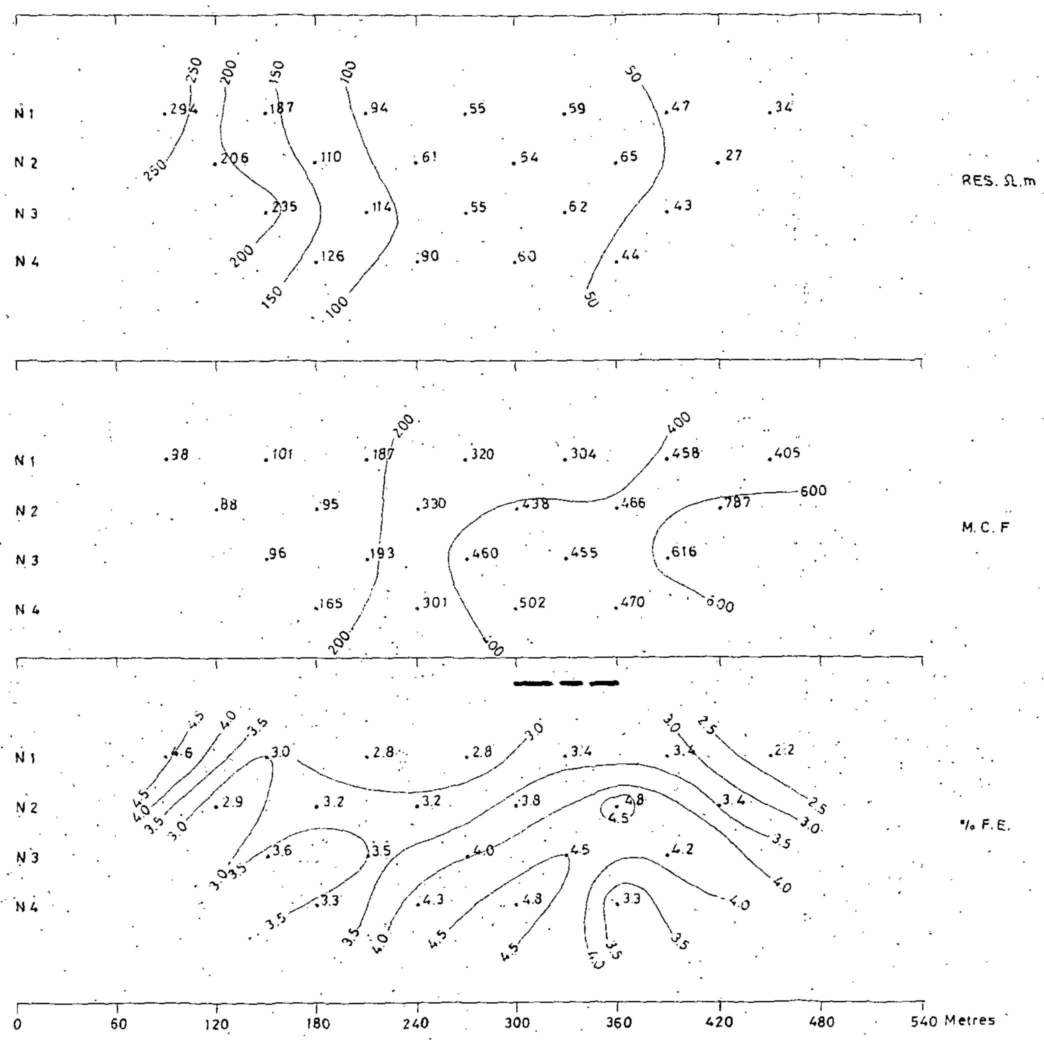
FIG. 27

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

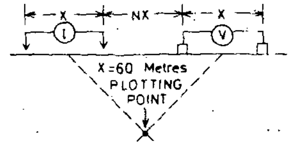
D.O.	DRG No. G.S.D.(Geoph.) 21/78
SURVEYED BY:	TRACED BY:
DESIGNED BY:	CHECKED BY:
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR:



LINE No.: 13

SCALE: 1:3000

ELECTRODE CONFIGURATION



FREQUENCIES 0.3-5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

FIG. 28

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

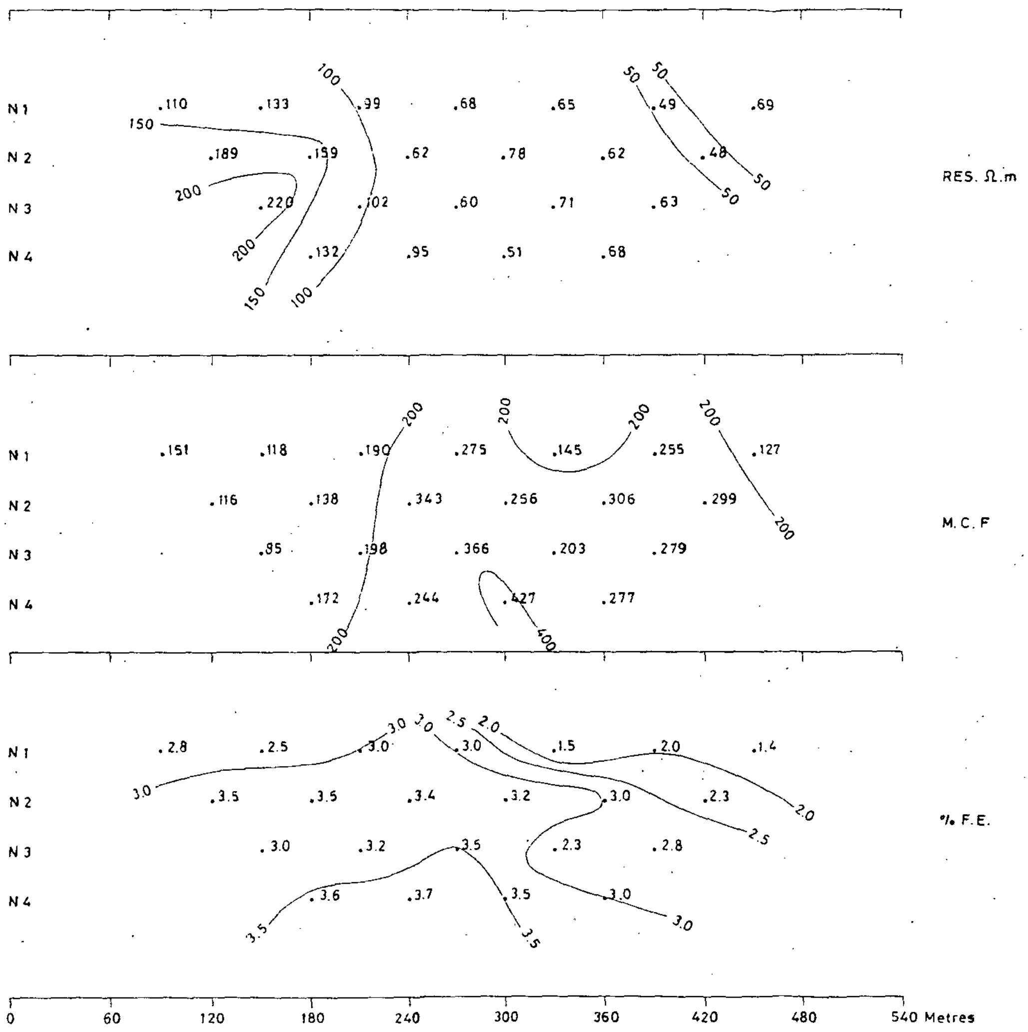
I.P. SURVEY

LYTHRODONDA AREA

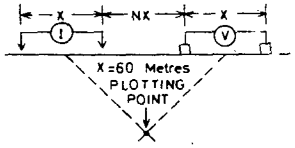
D.O. A. Miltiadous	DRG No. G.S.D.(Geoph.) 22/78
SURVEYED BY: S. Kramvis	TRACED BY: H. Georgiou
DESIGNED BY: S. Kramvis	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR:

LINE No.: 15

SCALE: 1:3000



ELECTRODE CONFIGURATION



FREQUENCIES 0.3-5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

— DEFINITE

- - - PROBABLE

• • • • • POSSIBLE

FIG. 25

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

LYTHRODONDA AREA

D.O. A. Michaelides	DRG No. G.S.D.(Geoph.) 23/78
SURVEYED BY: S. Kramvis	TRACED BY: [illegible]
DESIGNED BY: S. Kramvis	CHECKED BY: S. Kramvis
DRAWN BY: Geological Survey Dept.	APPROVED BY AG. DIRECTOR: [illegible]

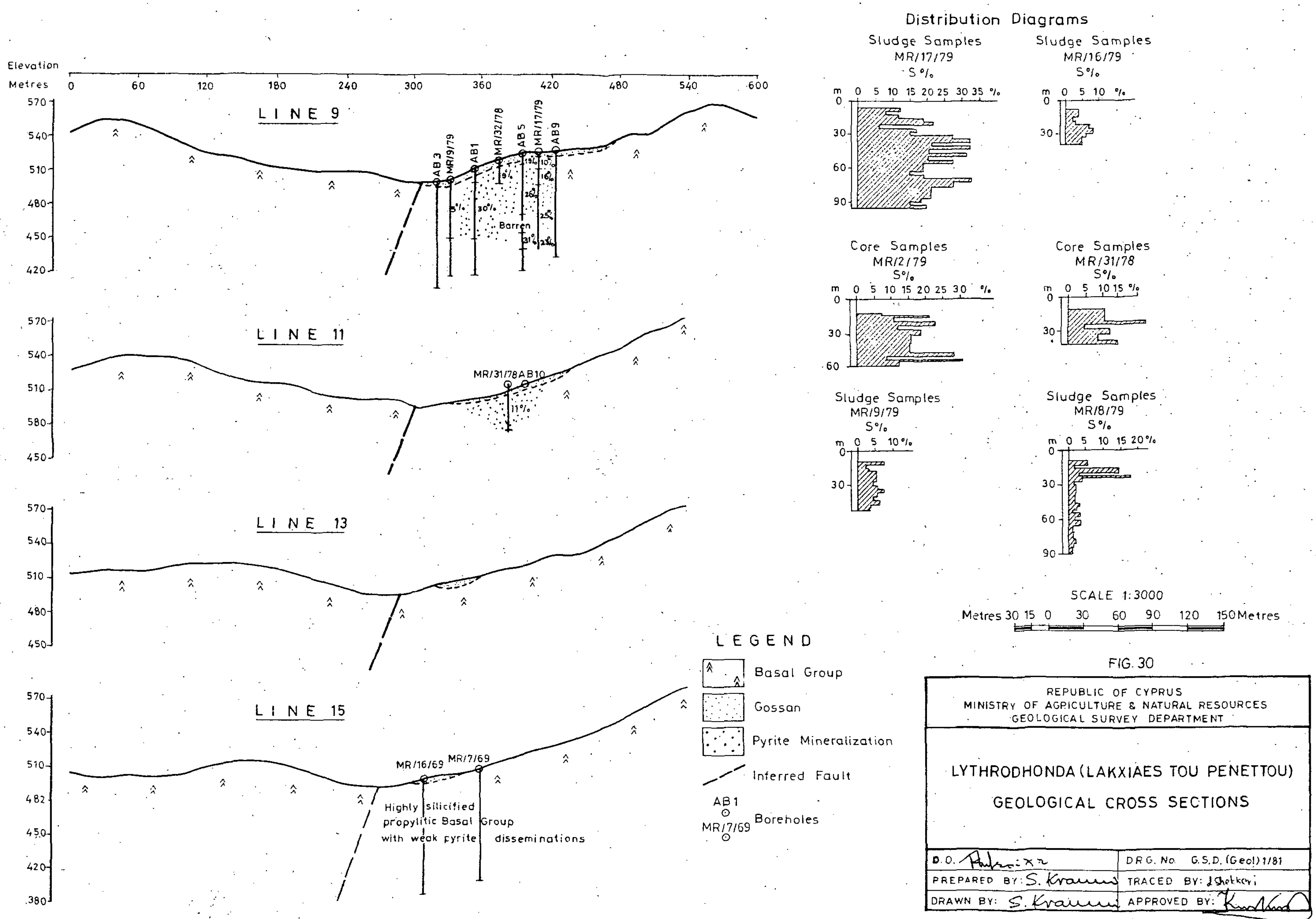


FIG. 30

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

LYTHRODHONDA (LAKXIAES TOU PENETTOU)
GEOLOGICAL CROSS SECTIONS

D.O.	DRG. No. G.S.D. (Geol) 1/81
PREPARED BY: S. Krauss	TRACED BY: J. Shekkeri
DRAWN BY: S. Krauss	APPROVED BY:

NE
m
400
350
300

LEGEND

- Soil
- Umber
- Upper Pillow Lava
- Non-pillowed flows-U.P.L.
- Formation boundary
- Fault
- Inferred fault

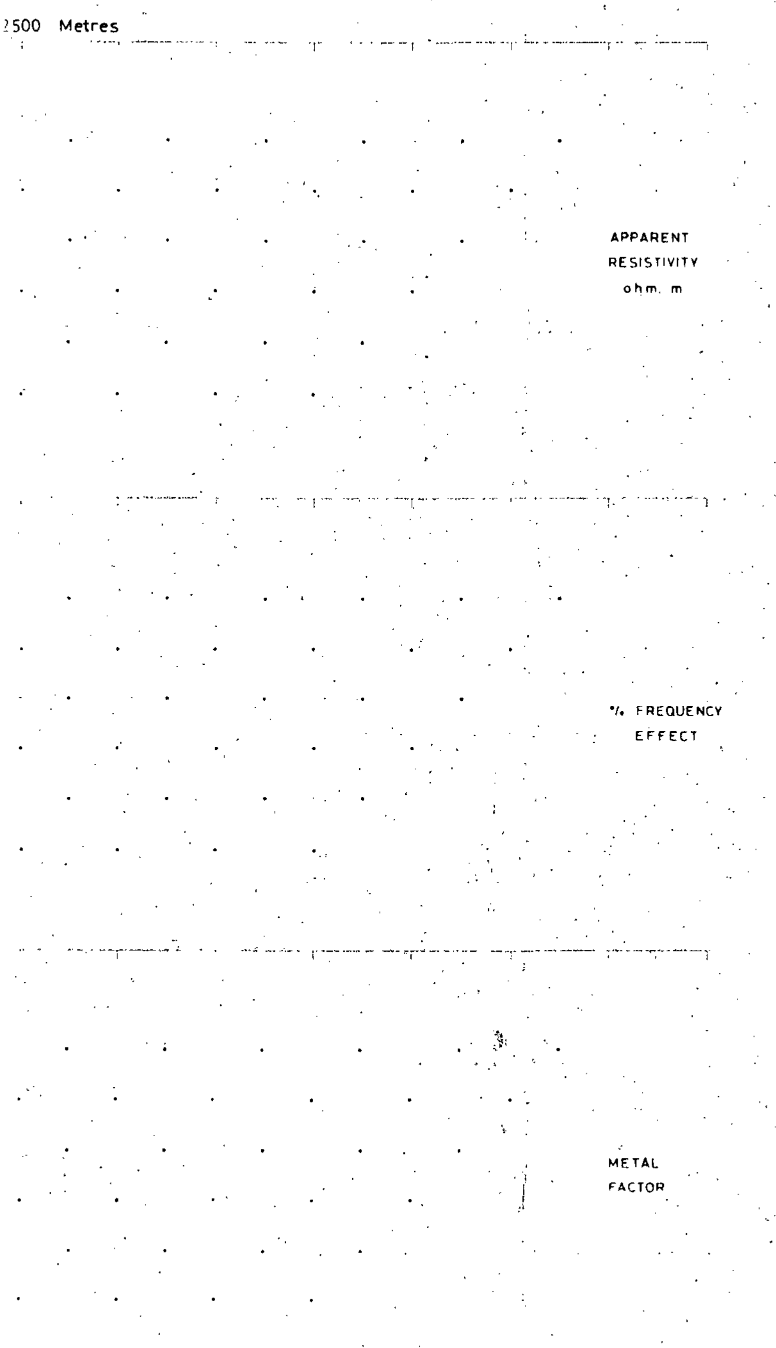
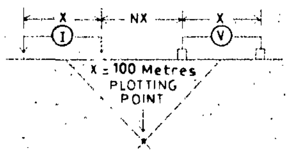


FIG. 6

ELECTRODE CONFIGURATION



FREQUENCIES 0.125 – 1.25 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- DUE TO BASAL GROUP

SCALE 1: 5000

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I.P. SURVEY

MATHIATIS NORTH AREA
LINE 15

D.O. Al Mavrojianis	DRG. No. G.S.D. (Geoph.) 13/81
SURVEYED BY: S. Krauni	TRACED BY: [signature]
DESIGNED BY:	CHECKED BY: S. Krauni
DRAWN BY: Geol. Survey Dept.	APPROVED BY: [signature]

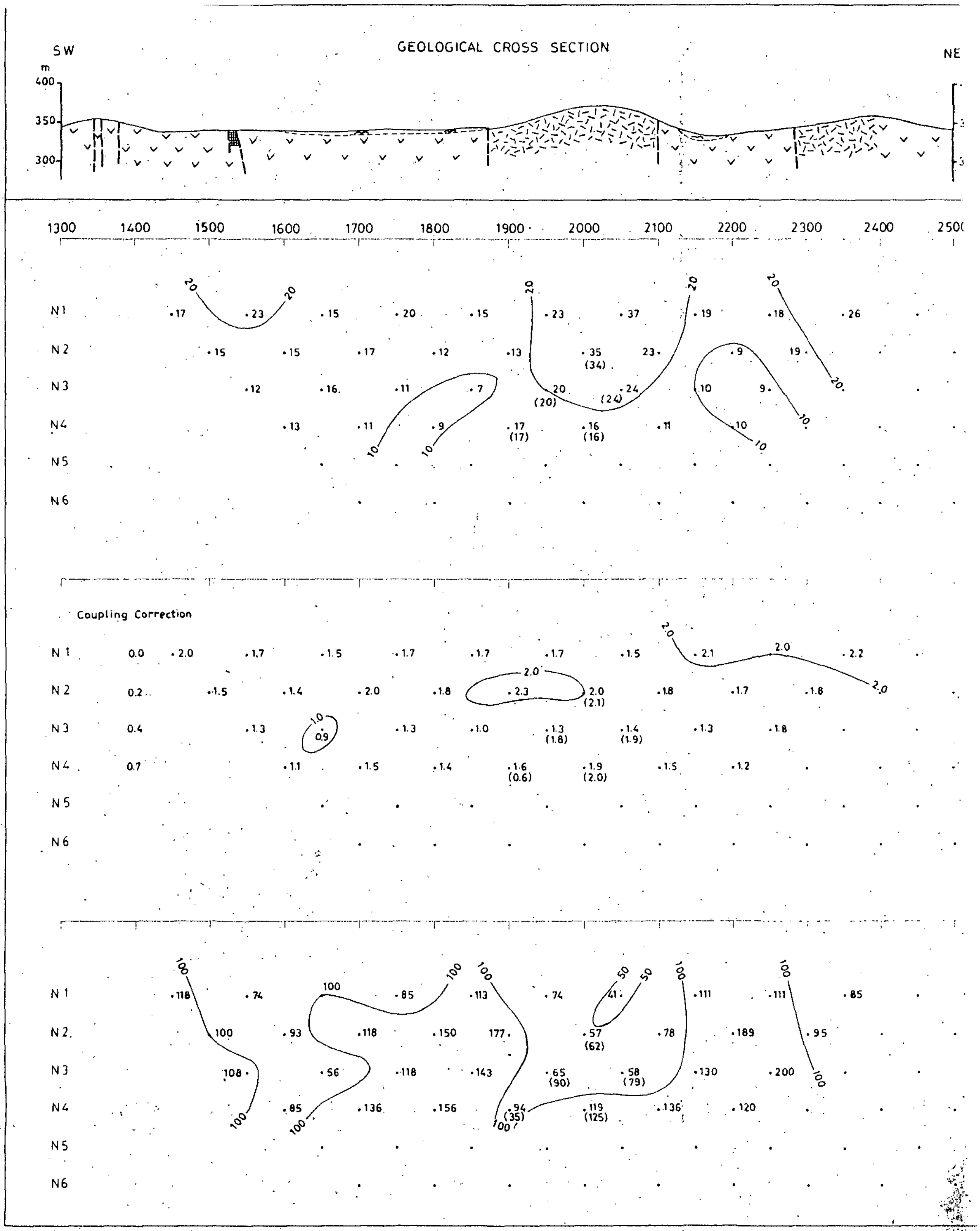

GEOLOGICAL CROSS SECTION
SW
NE
m
400
350
300
1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
N1 .17 .23 .15 .20 .15 .23 .37 .19 .18 .26
N2 .15 .15 .17 .12 .13 .35 (34) 23. .9 19.
N3 .12 .16. .11 .7 20 (20) .24 (24) .10 9.
N4 .13 .11 .9 .17 (17) .16 (16) .11 .10
N5
N6
Coupling Correction
N1 0.0 .2.0 .1.7 .1.5 .1.7 .1.7 .1.7 .1.5 .2.1 2.0 .2.2
N2 0.2 .1.5 .1.4 .2.0 .1.8 2.0 .2.3 2.0 (2.1) .1.8 .1.7 .1.8 2.0
N3 0.4 .1.3 1.0 0.9 .1.3 .1.0 .1.3 (1.8) .1.4 (1.9) .1.3 .1.8
N4 0.7 .1.1 .1.5 .1.4 .1.6 (0.6) .1.9 (2.0) .1.5 .1.2
N5
N6
N1 .118 .74 100 .85 .113 .74 41. 50 .111 .111 .85
N2 100 .93 .118 .150 177. .57 (62) .78 .189 .95
N3 108. .56 .118 .143 .65 (90) .58 (79) .130 .200
N4 .85 .136 .156 .94 (35) .119 (125) .136 .120
N5
N6

FIG. 9

STRONGYLI - SHA

Mise-á-la-masse survey

Map of surface potentials

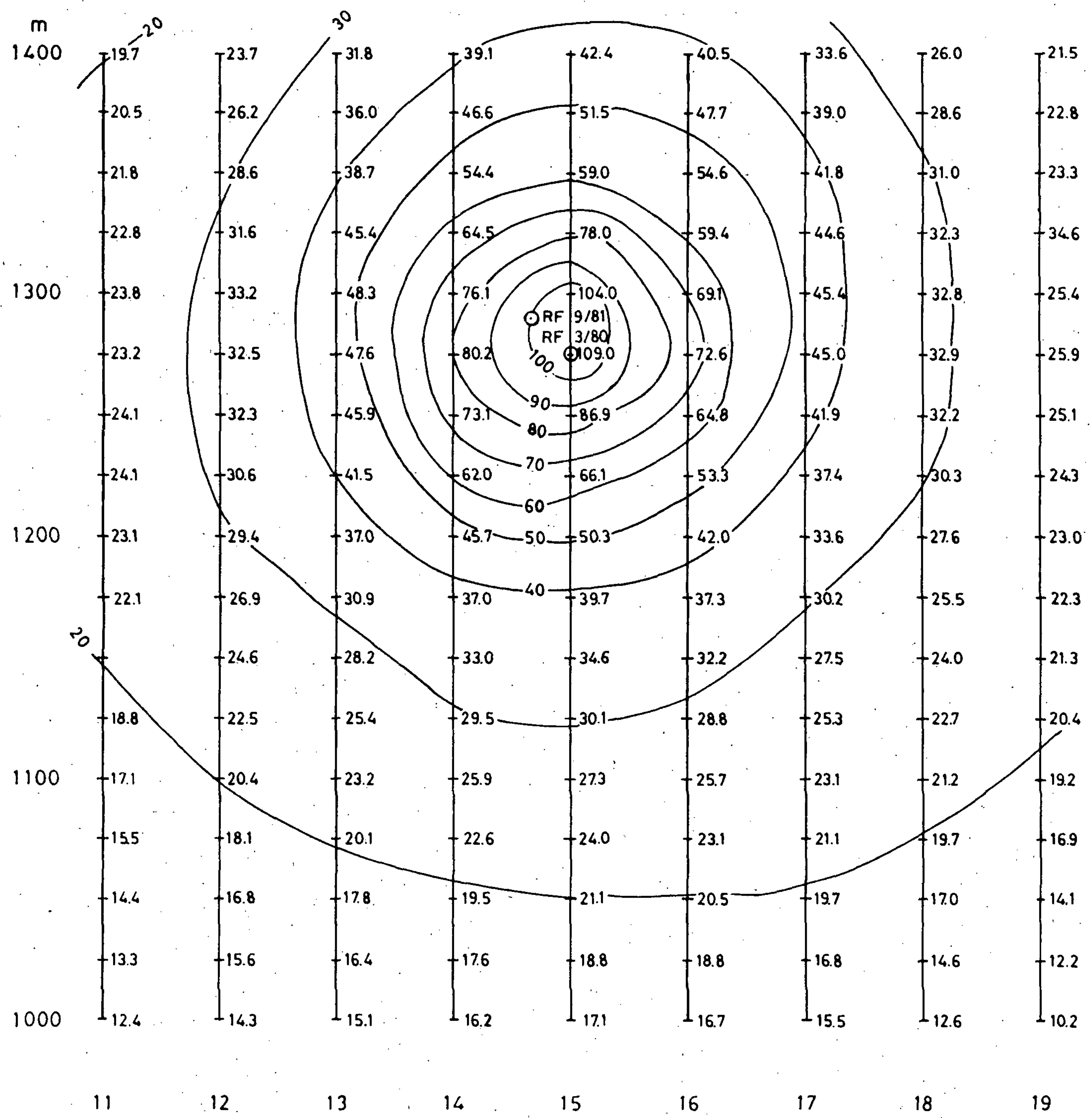
Electrode in BH RF 3/80

Depth below ground 50 m

Current 3 A

Contours in m Volts

Scale 1:2500



G.S.D. (Geoph.)49/81

FIG. 10

STRONGYLI - SHA

Mise-á-la-masse survey

Map of surface potentials

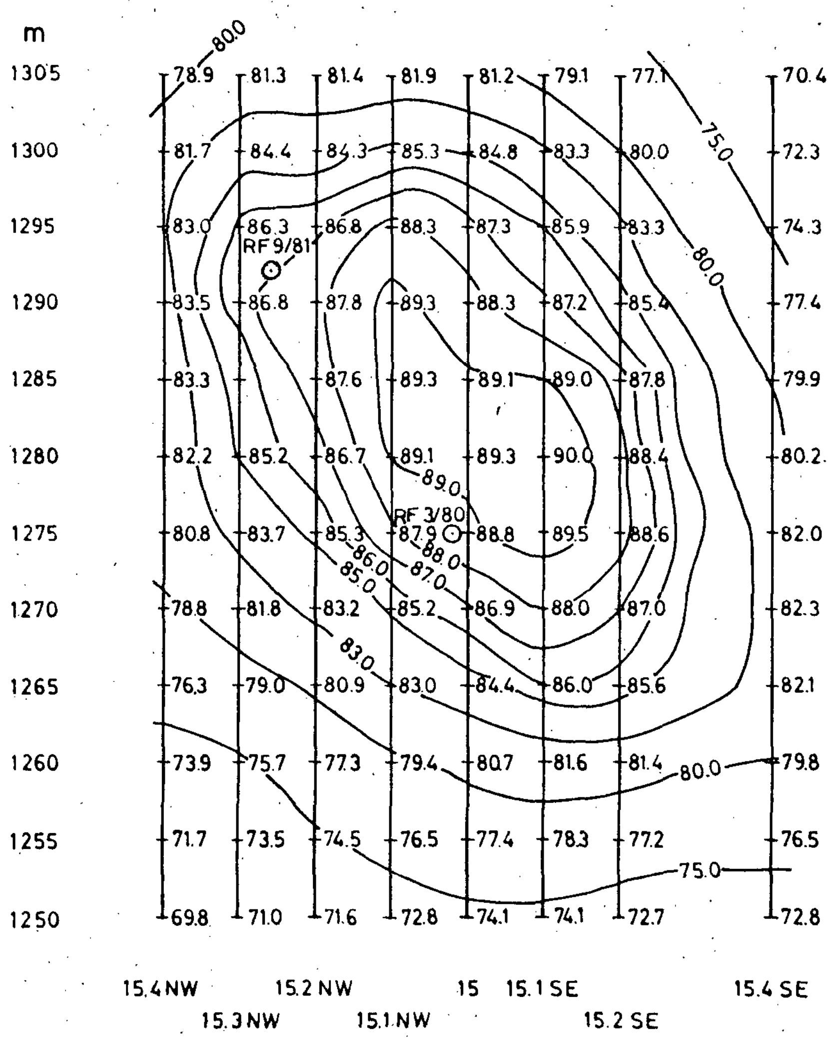
Electrode in BH RF 3/80

Depth below ground 59 m

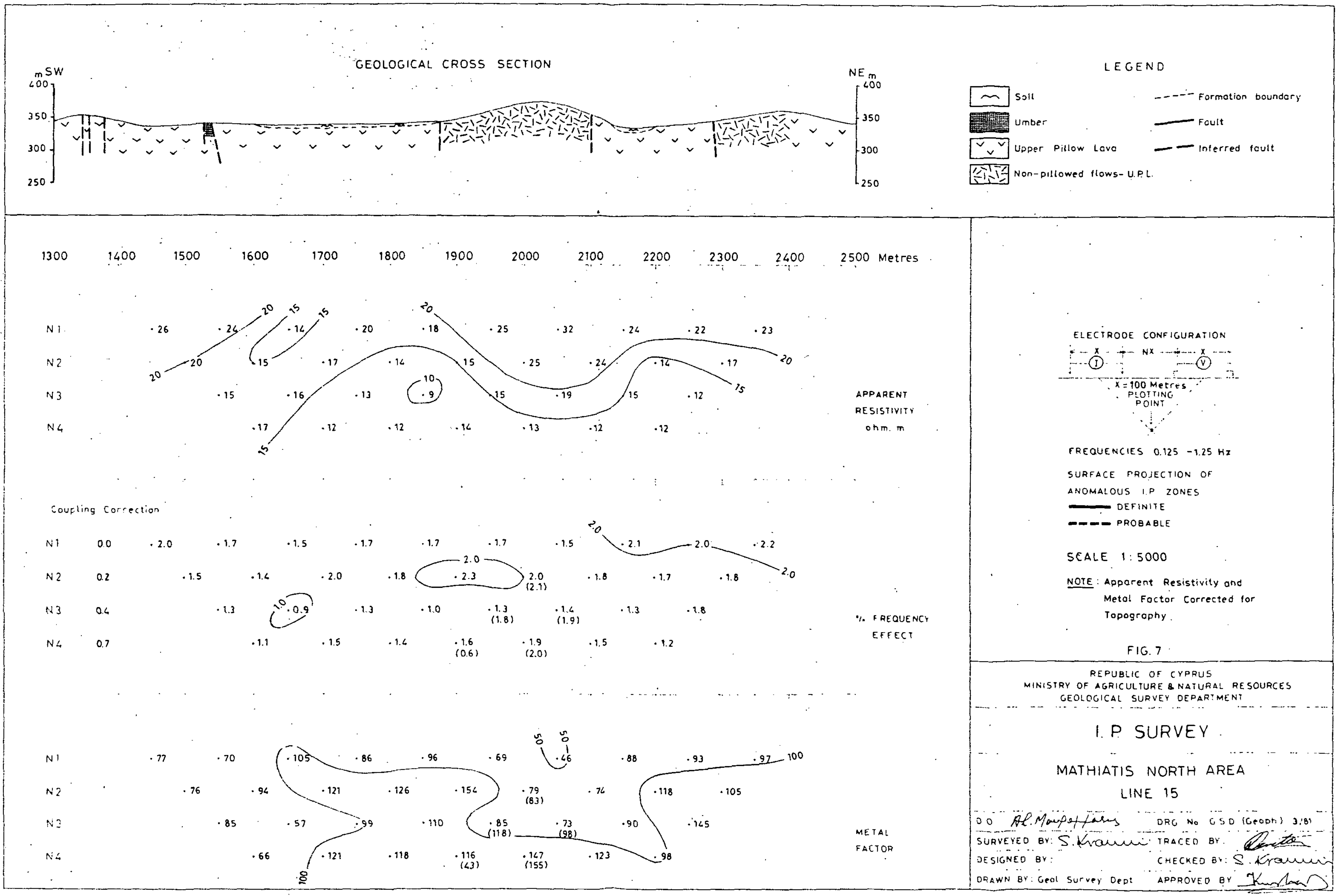
Current 2.5 A

Contours in m Volts

Scale 1:500



G.S.D. (Geoph.)50/81


GEOLOGICAL CROSS SECTION
m SW
NE m
400
350
300
250
LEGEND
Soil
Umber
Upper Pillow Lava
Non-pillowed flows- U.P.L.
Formation boundary
Fault
Inferred fault
1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 Metres
N1
N2
N3
N4
APPARENT RESISTIVITY ohm. m
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
ELECTRODE CONFIGURATION
X = 100 Metres
PLOTTING POINT
FREQUENCIES 0.125 -1.25 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
SCALE 1 : 5000
NOTE : Apparent Resistivity and Metal Factor Corrected for Topography.
FIG. 7
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
MATHIATIS NORTH AREA
LINE 15
D.O.
DRG. No. G.S.D. (Geoph.) 3/81
SURVEYED BY: S. Kramer
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Kramer
DRAWN BY: Geol. Survey Dept.
APPROVED BY

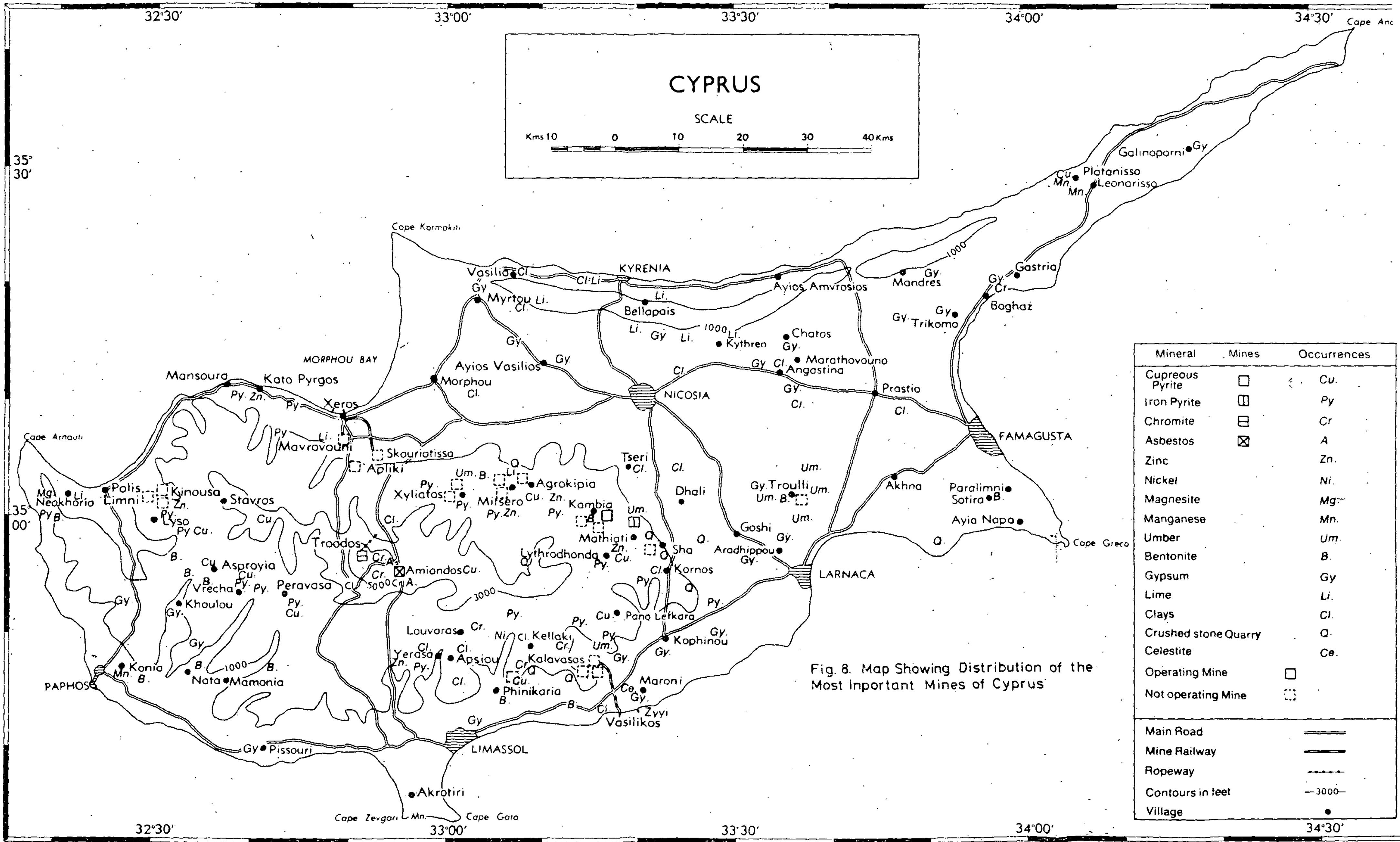


Fig. 8. Map Showing Distribution of the Most Inportant Mines of Cyprus

G.S.D. (Min.) D.P. 8/81

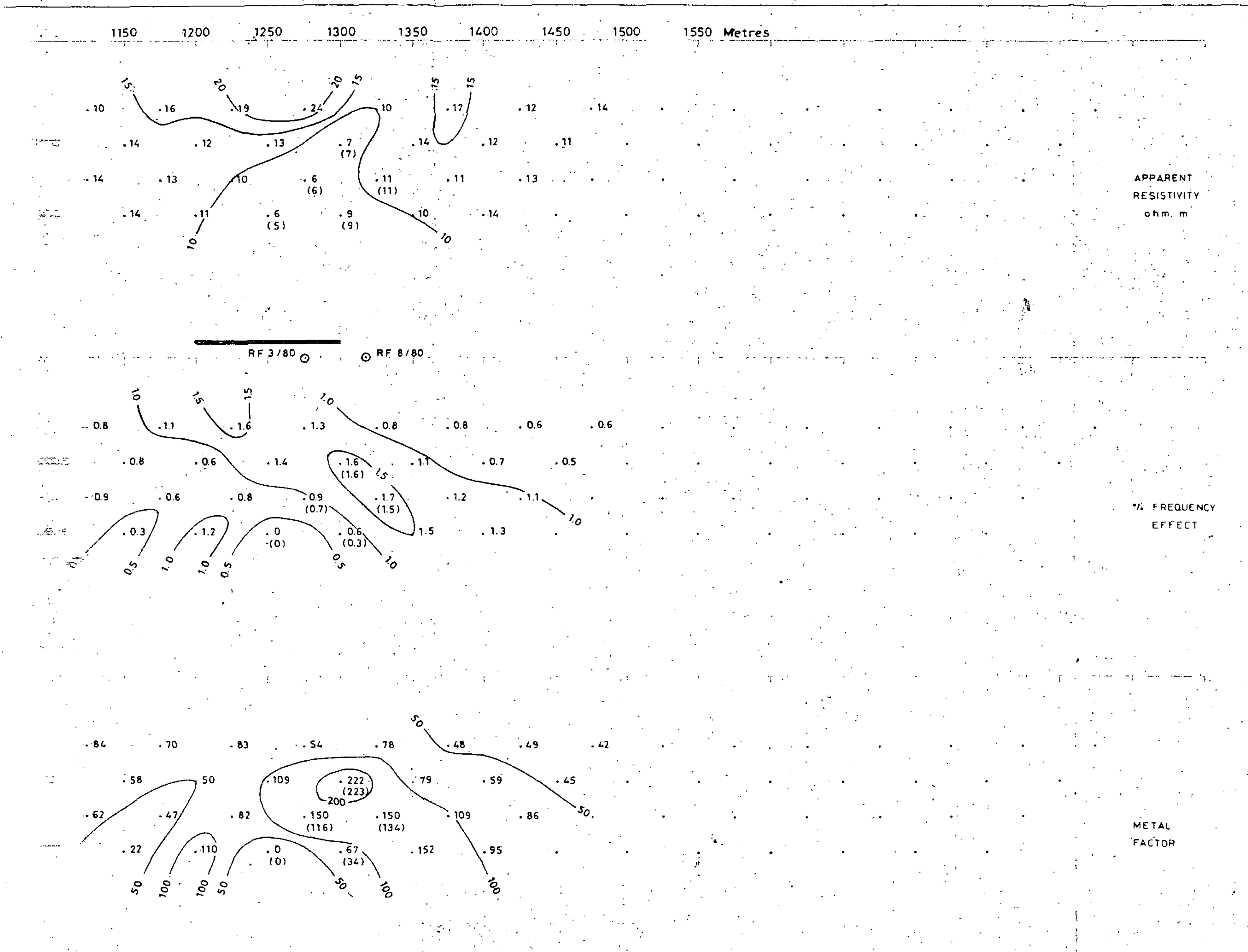
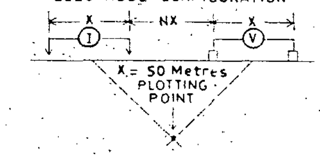


FIG. 4



FREQUENCIES 0.125 – 1.25 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- DUE TO BASAL GROUP

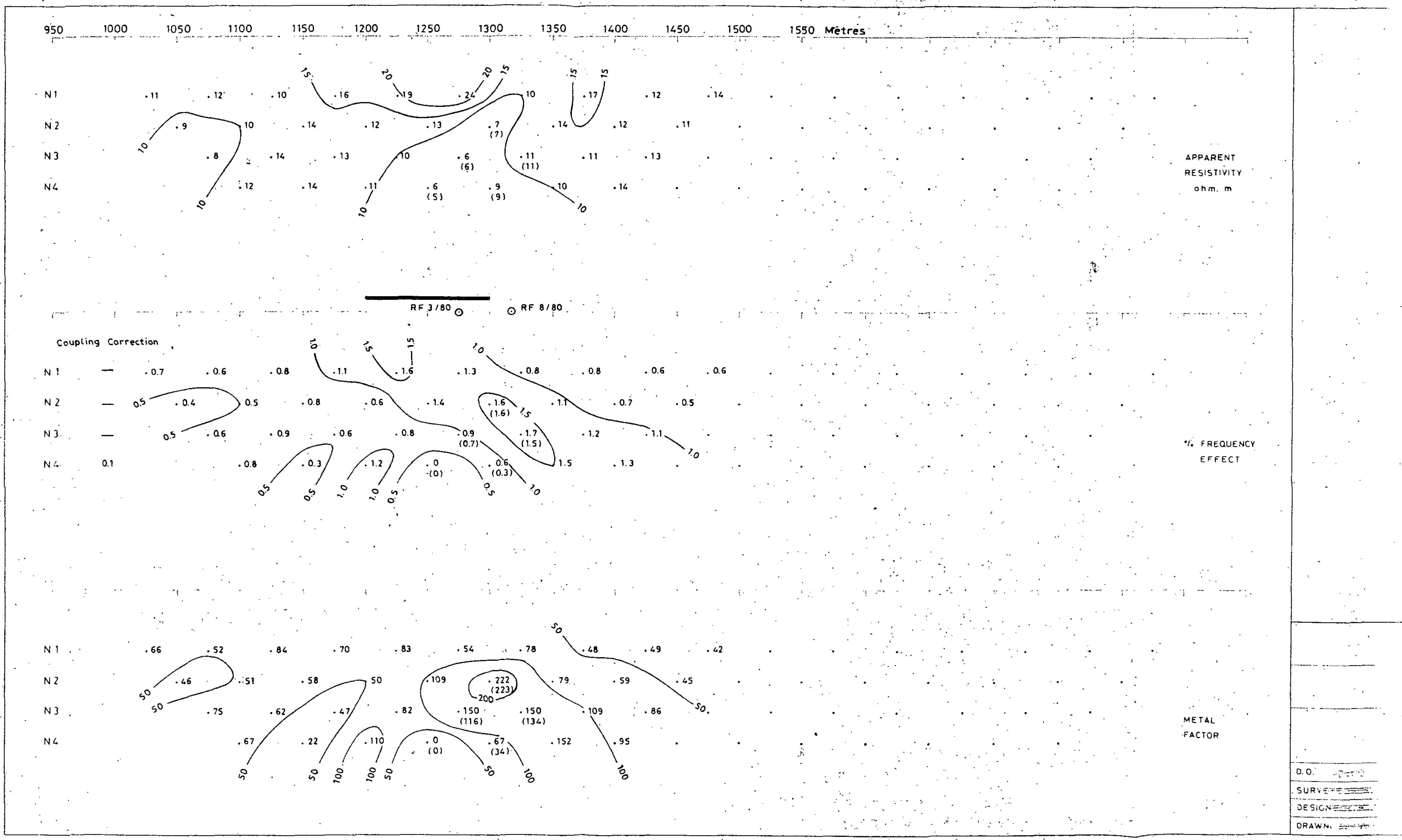
SCALE 1: 2500

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

I. P. SURVEY

STRONGYLI – SHA AREA
LINE 15

D.O. Al. Maupettons	DRG No G.S.D. (Geoph.) 30/81
SURVEYED BY: S. Kramer	TRACED BY: [signature]
DESIGNED BY:	CHECKED BY: S. Kramer
DRAWN BY: Geol. Survey Dept.	APPROVED BY: [signature]


950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550 Metres
N1
N2
N3
N4
APPARENT
RESISTIVITY
ohm. m
RF 3/80
RF 8/80
Coupling Correction
% FREQUENCY
EFFECT
METAL
FACTOR
D.O.
SURVEY
DESIGN
DRAWN

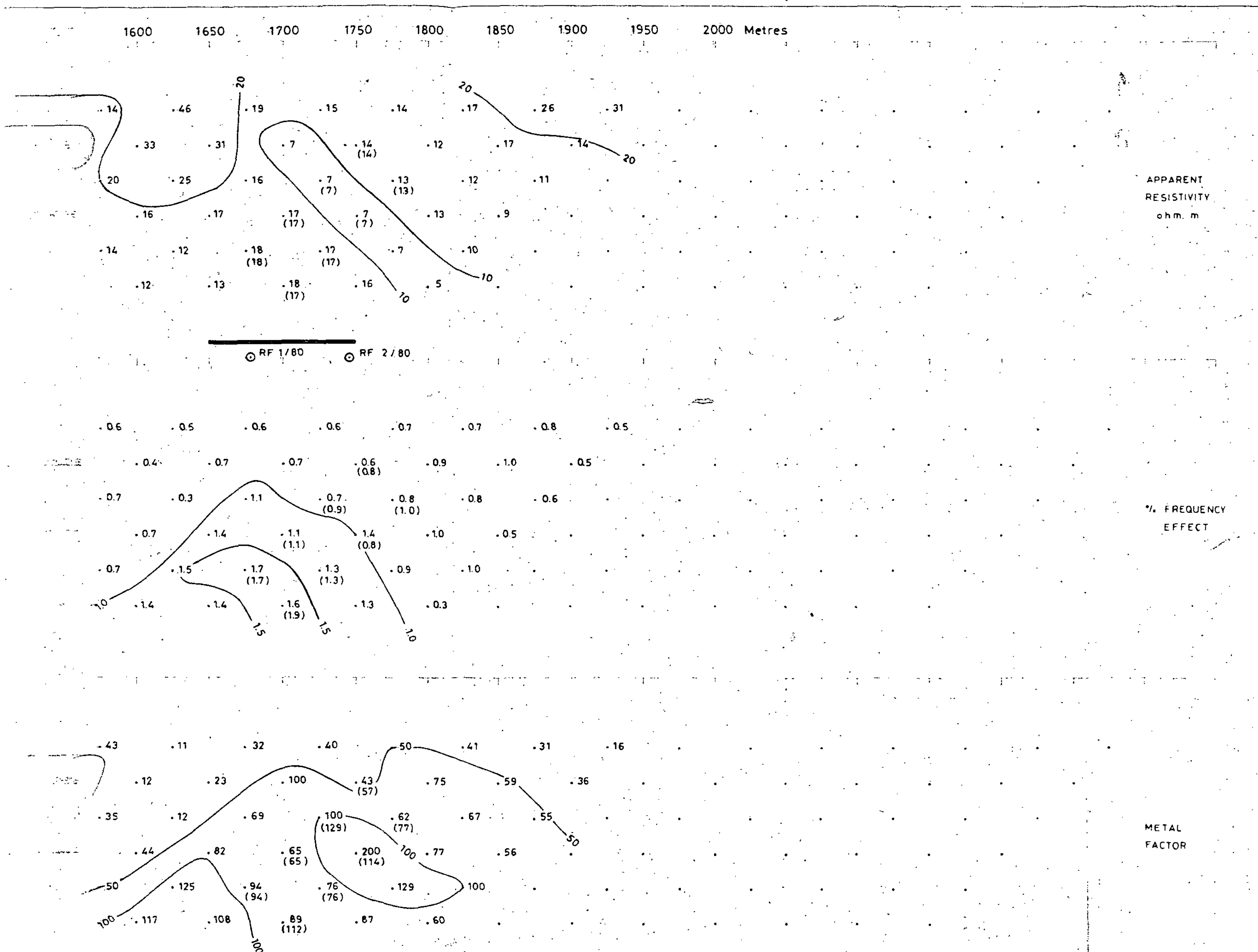
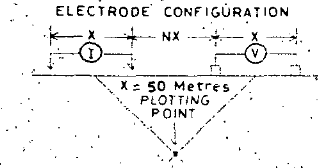


FIG. 5

ELECTRODE CONFIGURATION



FREQUENCIES 0.125 - 1.25 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- DUE TO BASAL GROUP

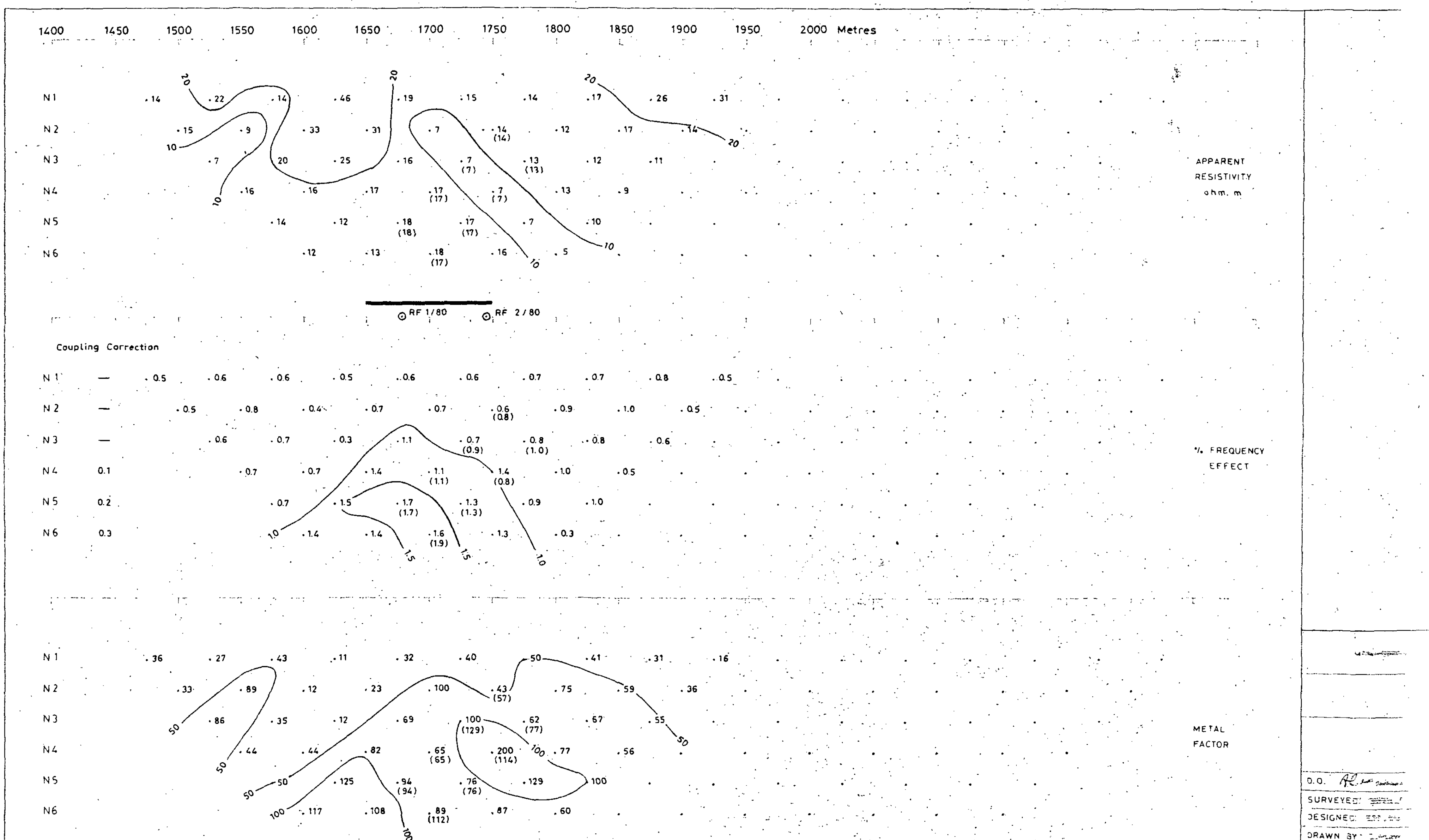
SCALE 1: 2500

REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT

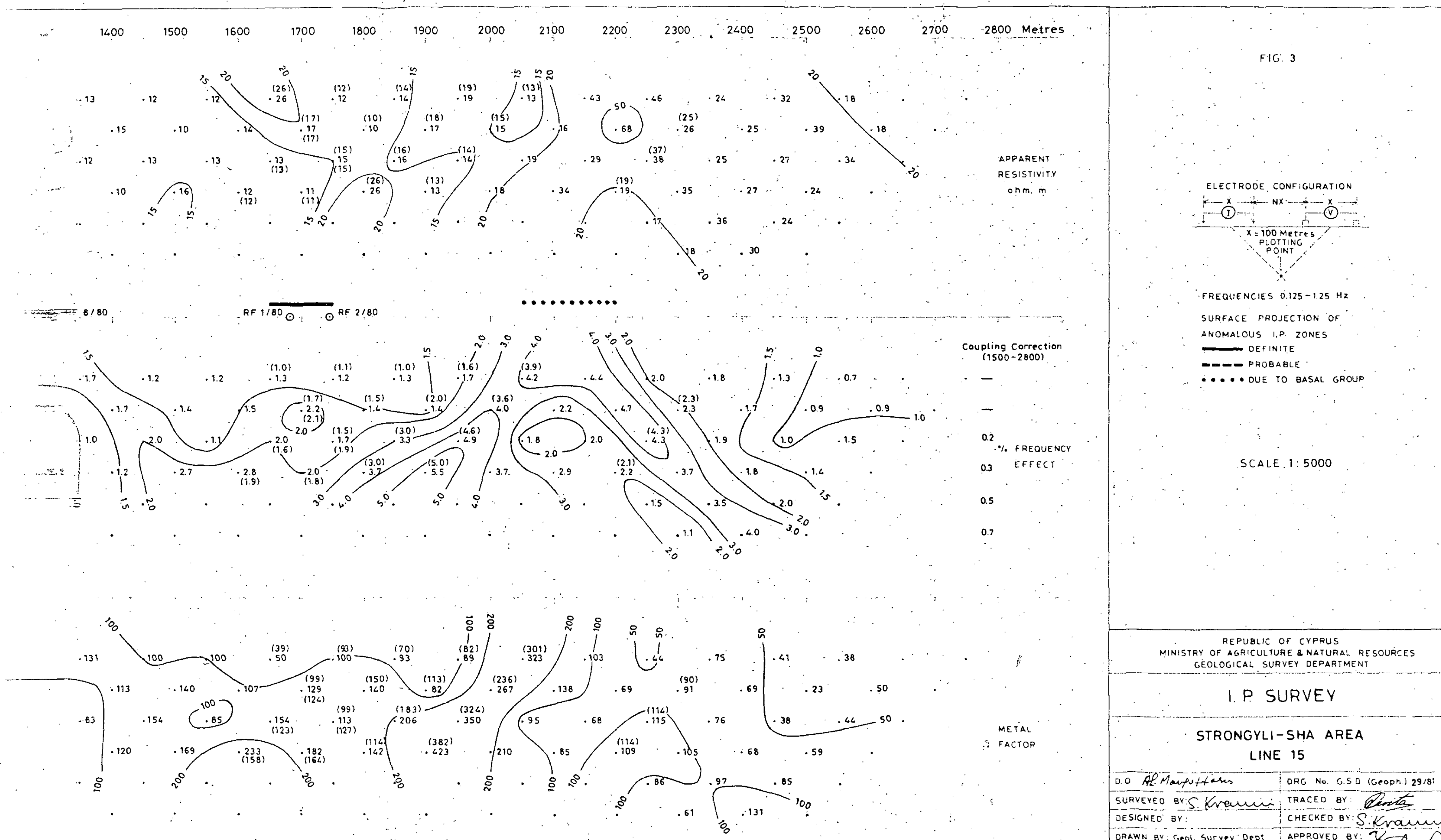
I. P. SURVEY

STRONGYLI-SHA AREA
LINE 15

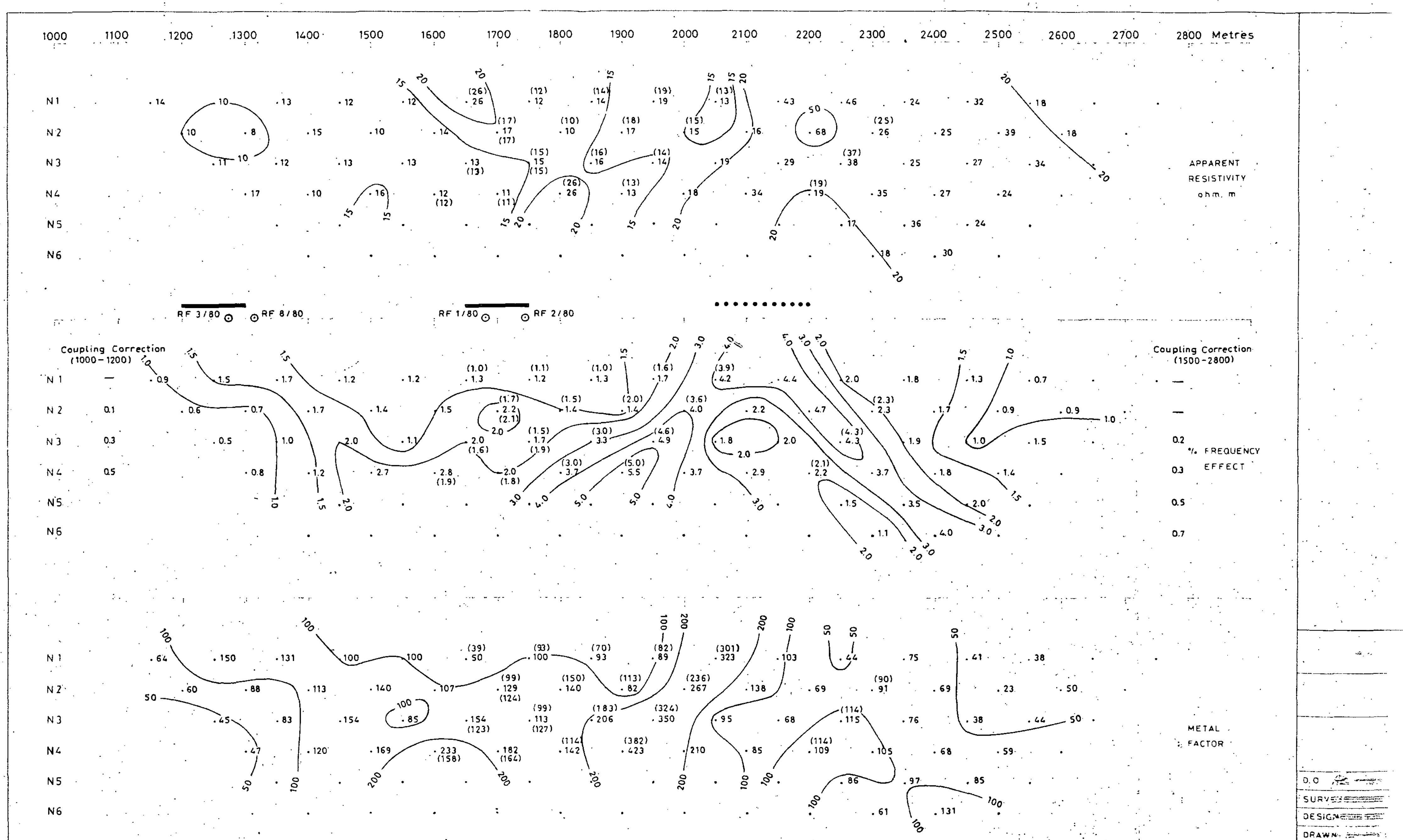
D.O. Al. Mavpoltou	DRG No. G.S.D. (Geoph.) 31/81
SURVEYED BY: S. Kramer	TRACED BY:
DESIGNED BY:	CHECKED BY: S. Kramer
DRAWN BY: Geol. Survey Dept	APPROVED BY:



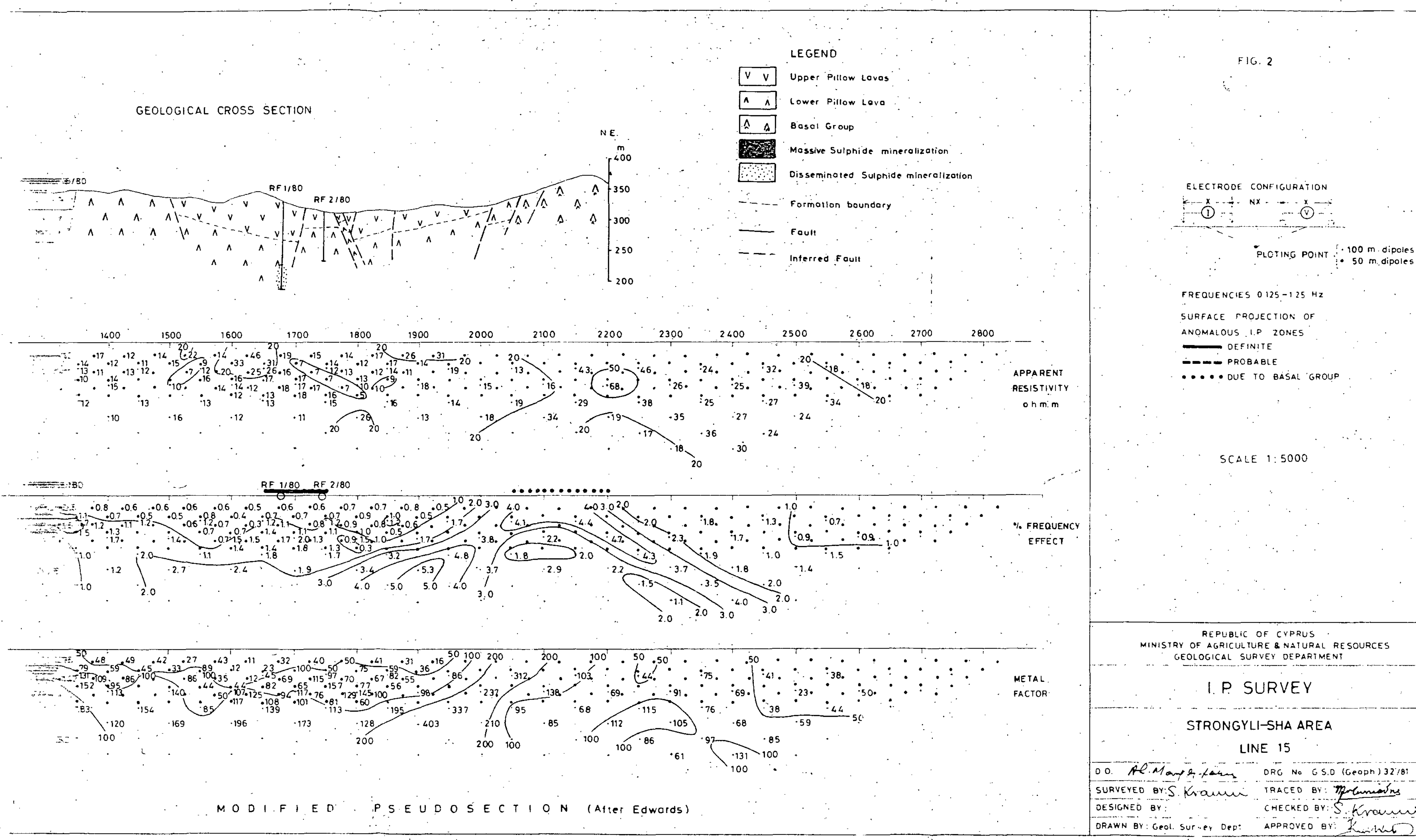
1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 Metres
N1
N2
N3
N4
N5
N6
APPARENT RESISTIVITY ohm. m
RF 1/80
RF 2/80
Coupling Correction
% FREQUENCY EFFECT
METAL FACTOR
D.O.
SURVEYED
DESIGNED
DRAWN BY

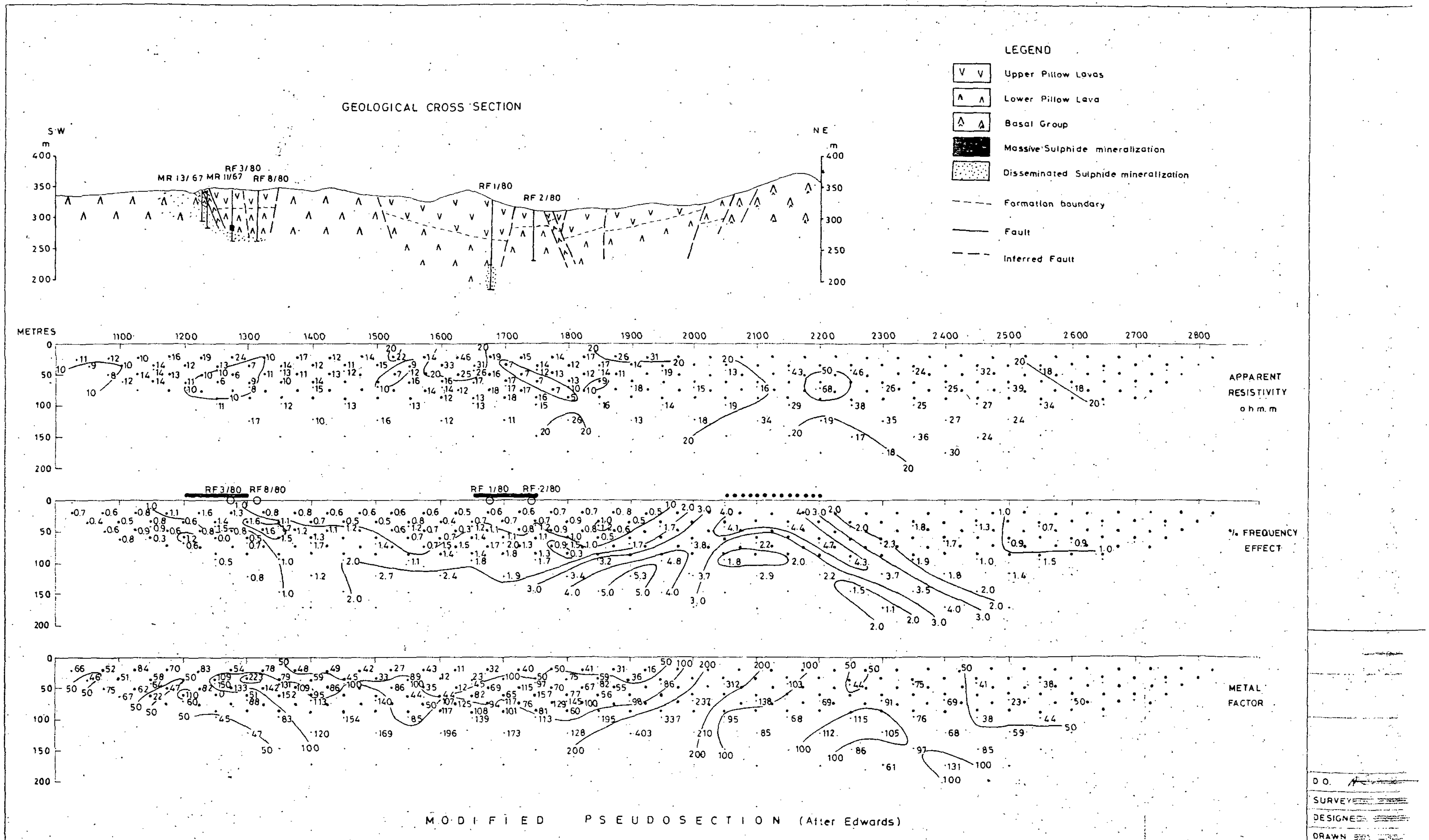


1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 Metres
APPARENT RESISTIVITY ohm. m
8/80
RF 1/80
RF 2/80
Coupling Correction (1500-2800)
% FREQUENCY EFFECT
METAL FACTOR
FIG. 3
ELECTRODE CONFIGURATION
X = 100 Metres
PLOTTING POINT
FREQUENCIES 0.125 - 1.25 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
DUE TO BASAL GROUP
SCALE 1: 5000
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
STRONGYLI-SHA AREA
LINE 15
D.O
DRG No. G.S.D (Geoph.) 29/81
SURVEYED BY
TRACED BY
DESIGNED BY:
CHECKED BY:
DRAWN BY: Geol. Survey Dept
APPROVED BY:



1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 Metres
N1
N2
N3
N4
N5
N6
APPARENT RESISTIVITY ohm. m
RF 3/80
RF 8/80
RF 1/80
RF 2/80
Coupling Correction (1000 – 1200)
Coupling Correction (1500 – 2800)
% FREQUENCY EFFECT
METAL FACTOR
D.O.
SURVEY
DESIGN
DRAWN


GEOLOGICAL CROSS SECTION
N.E.
m
400
350
300
250
200
RF1/80
RF 2/80
LEGEND
Upper Pillow Lavas
Lower Pillow Lava
Basal Group
Massive Sulphide mineralization
Disseminated Sulphide mineralization
Formation boundary
Fault
Inferred Fault
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
APPARENT RESISTIVITY
ohm.m
RF 1/80
RF 2/80
% FREQUENCY EFFECT
METAL FACTOR
MODIFIED PSEUDOSECTION (After Edwards)
FIG. 2
ELECTRODE CONFIGURATION
NX
PLOTING POINT
100 m. dipoles
50 m. dipoles
FREQUENCIES 0.125 - 1.25 Hz
SURFACE PROJECTION OF ANOMALOUS I.P. ZONES
DEFINITE
PROBABLE
DUE TO BASAL GROUP
SCALE 1:5000
REPUBLIC OF CYPRUS
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
GEOLOGICAL SURVEY DEPARTMENT
I. P. SURVEY
STRONGYLI-SHA AREA
LINE 15
D.O.
DRG No G.S.D (Geoph.) 32/81
SURVEYED BY: S. Kramm
TRACED BY:
DESIGNED BY:
CHECKED BY: S. Kramm
DRAWN BY: Geol. Survey Dept.
APPROVED BY:



GEOLOGICAL CROSS SECTION
S W
N E
MR 13/67
MR 11/67
RF 3/80
RF 8/80
RF 1/80
RF 2/80
LEGEND
Upper Pillow Lavas
Lower Pillow Lava
Basal Group
Massive Sulphide mineralization
Disseminated Sulphide mineralization
Formation boundary
Fault
Inferred Fault
METRES
APPARENT RESISTIVITY ohm.m
% FREQUENCY EFFECT
METAL FACTOR
MODIFIED PSEUDOSECTION (After Edwards)
D.O.
SURVEY
DESIGNED
DRAWN

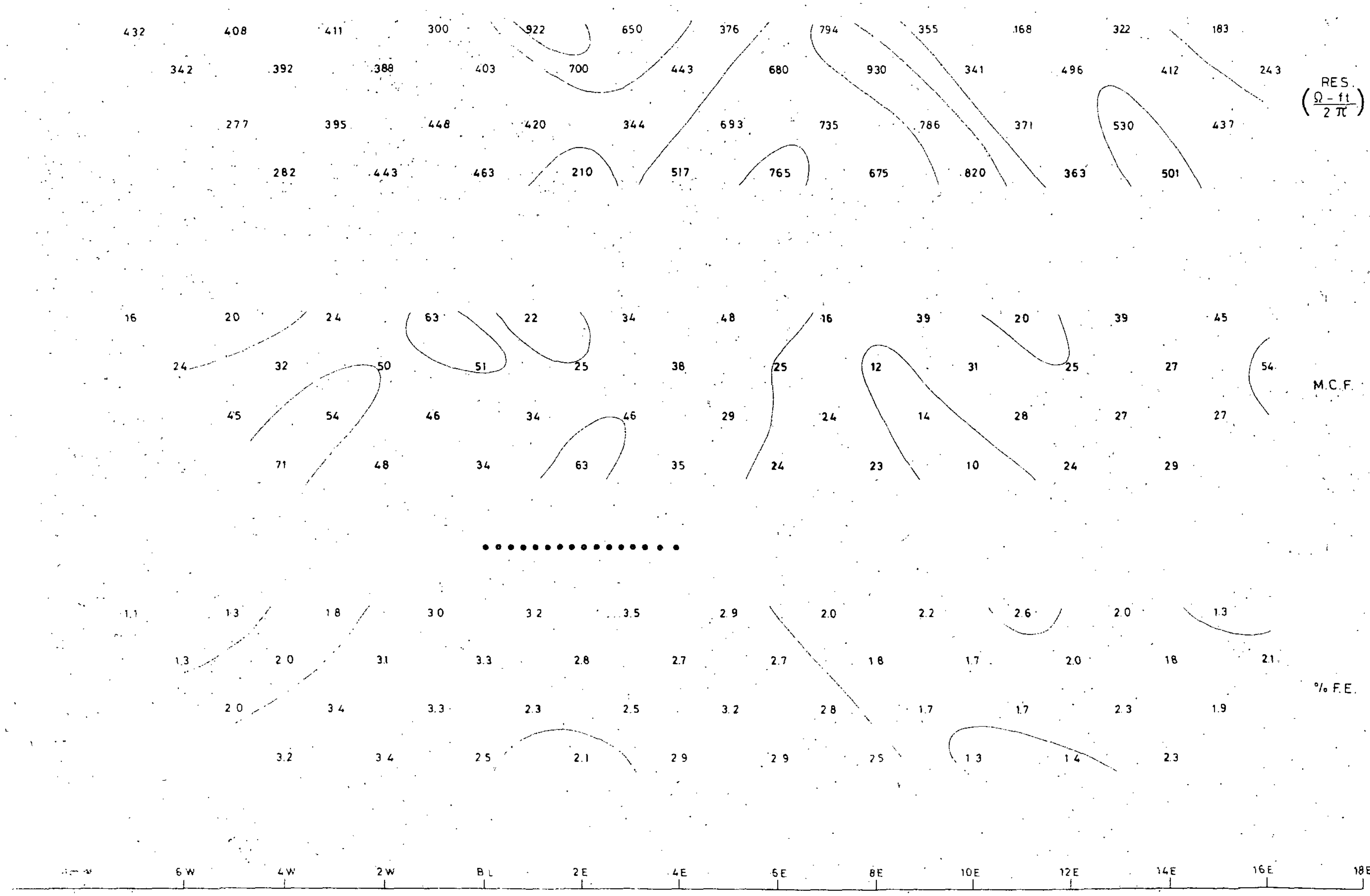


FIG. 35

I.P. SURVEY

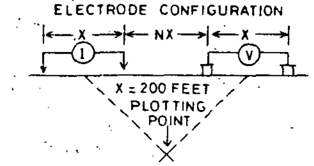
PROPERTY: AYIOS IOANNIS

PROJECT No.: 543

LINE No.: 12 N

SCALE: 1" = 200'

ELECTRODE CONFIGURATION



FREQUENCY 0.3 - 5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

- DEFINITE
- PROBABLE
- POSSIBLE

CONTOURS 1.0, 1.5, 2.5, 5.0, 7.5 ....

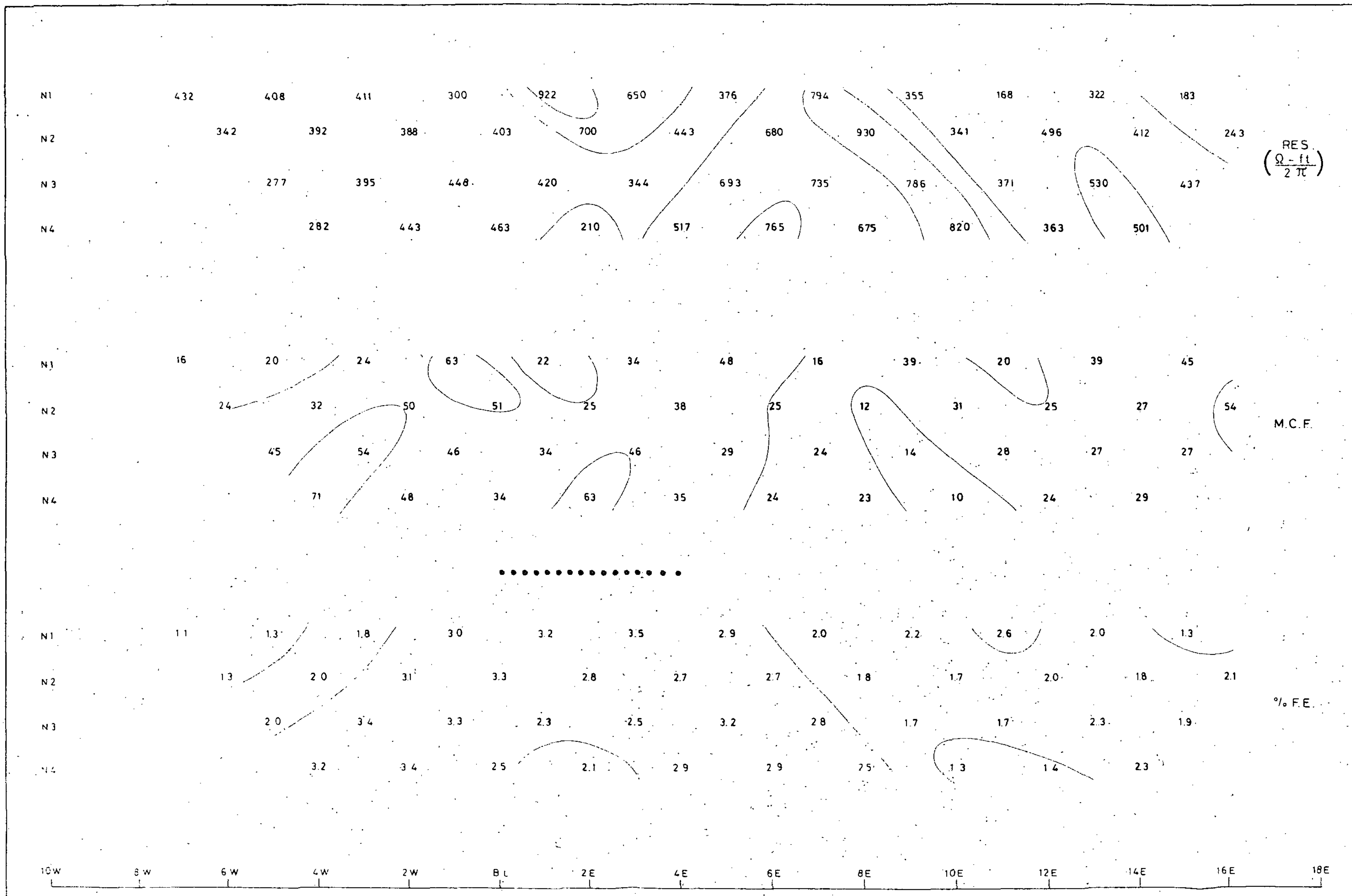
DATE SURVEYED: NOV. 1976

OPERATOR: KRAMVIS-SOLOMI

DRAWN BY: K.T.Z.

REMARKS: ______

APPROVED: ______



I.P.

PROPERTY:

PROJECT No.:

LINE No.: 12 N

SCALE: 1" = 200

ELECTRO

FREQUE

SURFACE

ANOMAL

CONTOUR

DATE SURVE

OPERATOR:

DRAWN BY:

REMARKS:

APPROVED:

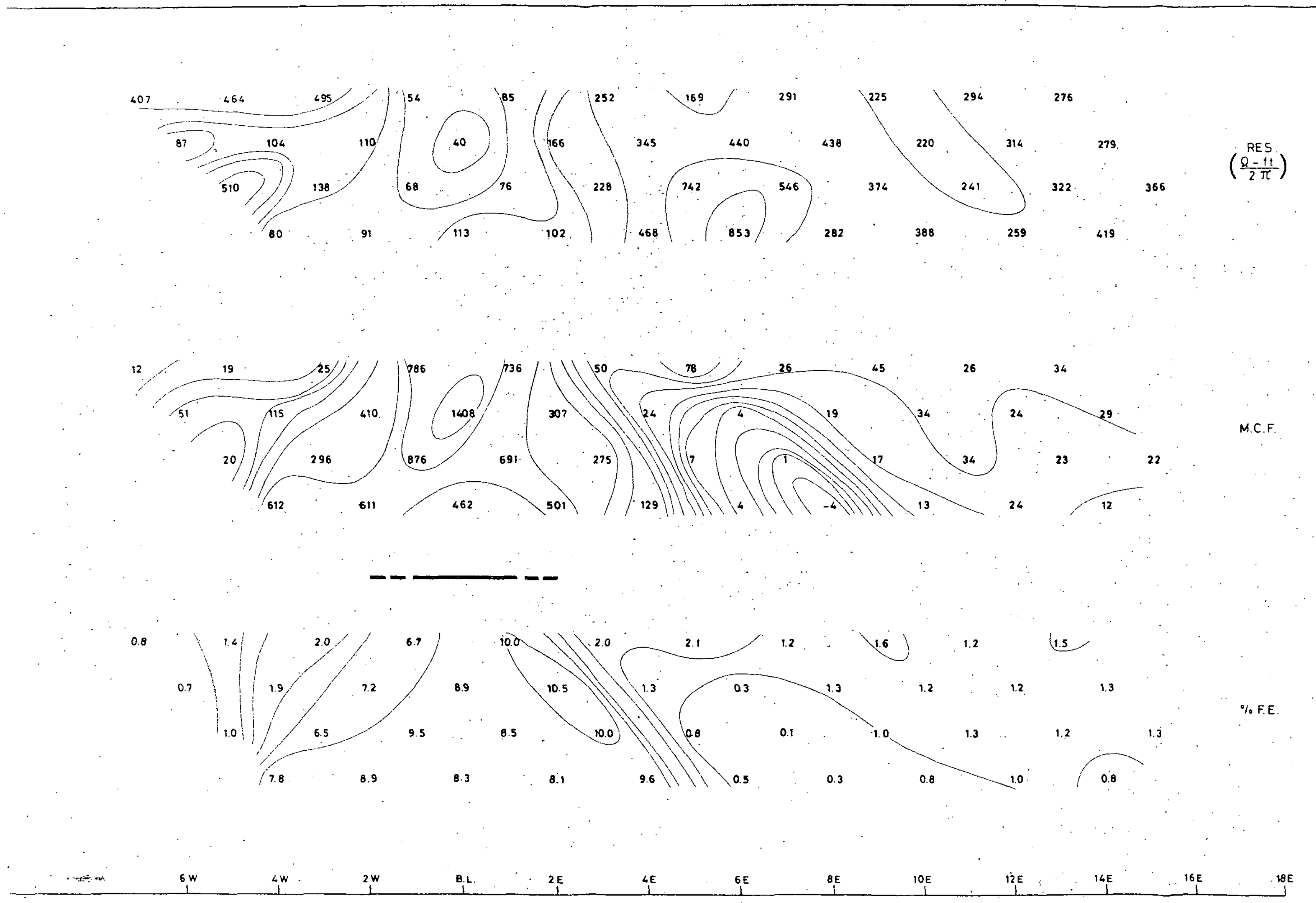


FIG. 34

I.P. SURVEY

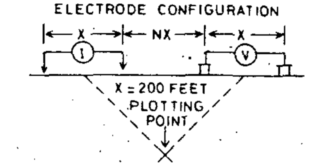
PROPERTY: AYIOS IOANNIS

PROJECT No.: 543

LINE No.: 4N

SCALE: 1" = 200'

ELECTRODE CONFIGURATION



FREQUENCY 0.3 - 5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

DEFINITE

PROBABLE

POSSIBLE

CONTOURS 1.0, 1.5, 2.5, 5.0, 7.5....

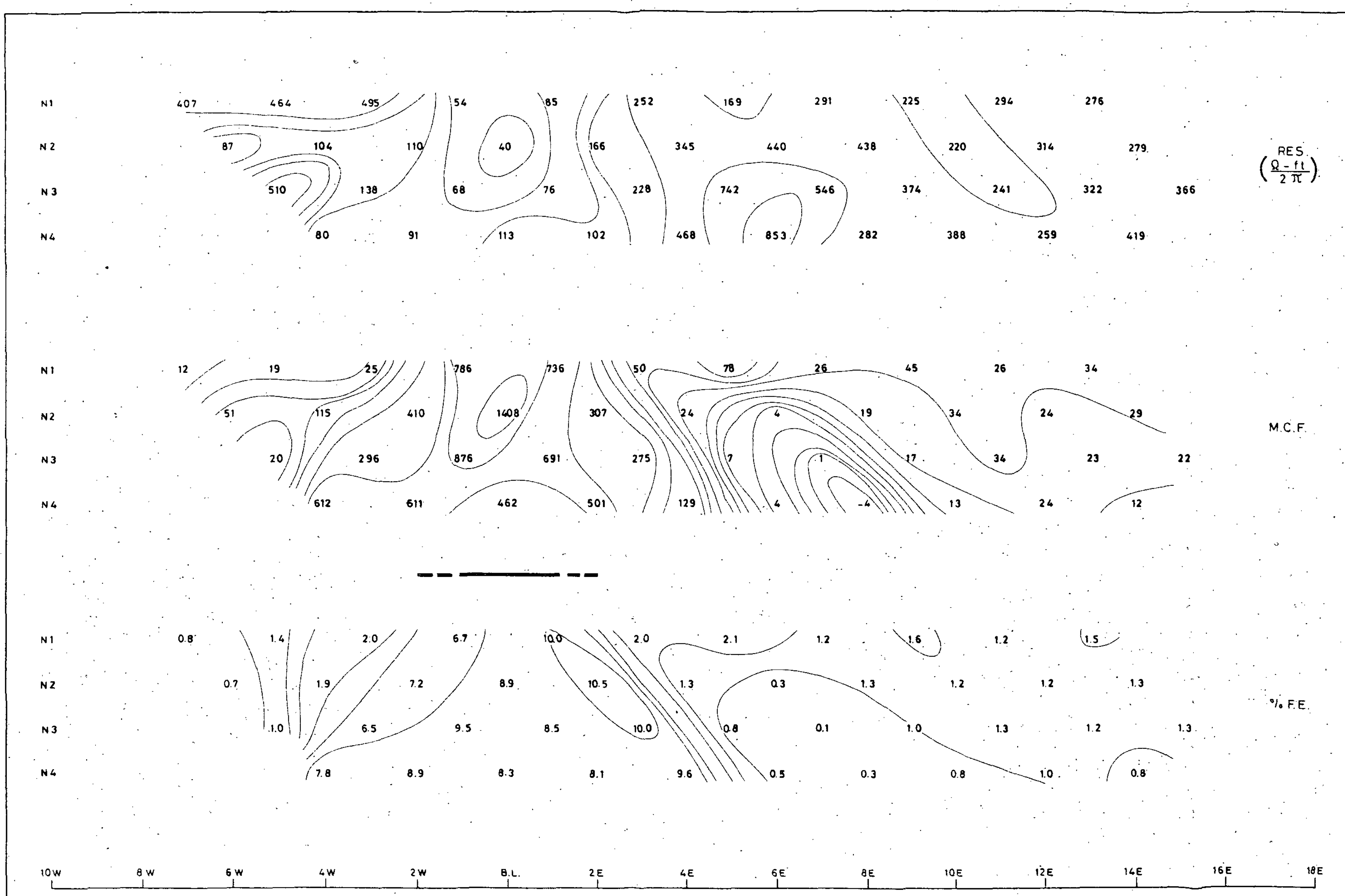
DATE SURVEYED: NOV. 1976

OPERATOR: KRAMVIS-SOLOMI

DRAWN BY: K.T.Z.

REMARKS: ________

APPROVED: ________



PROPERTY:

PROJECT No.:

LINE No.:

SCALE: 1"=

ELEC

FREQU

SURFACE

ANOMAL

CONTO

DATE SURVE

OPERATOR:

DRAWN BY:

REMARKS:

APPROVED:

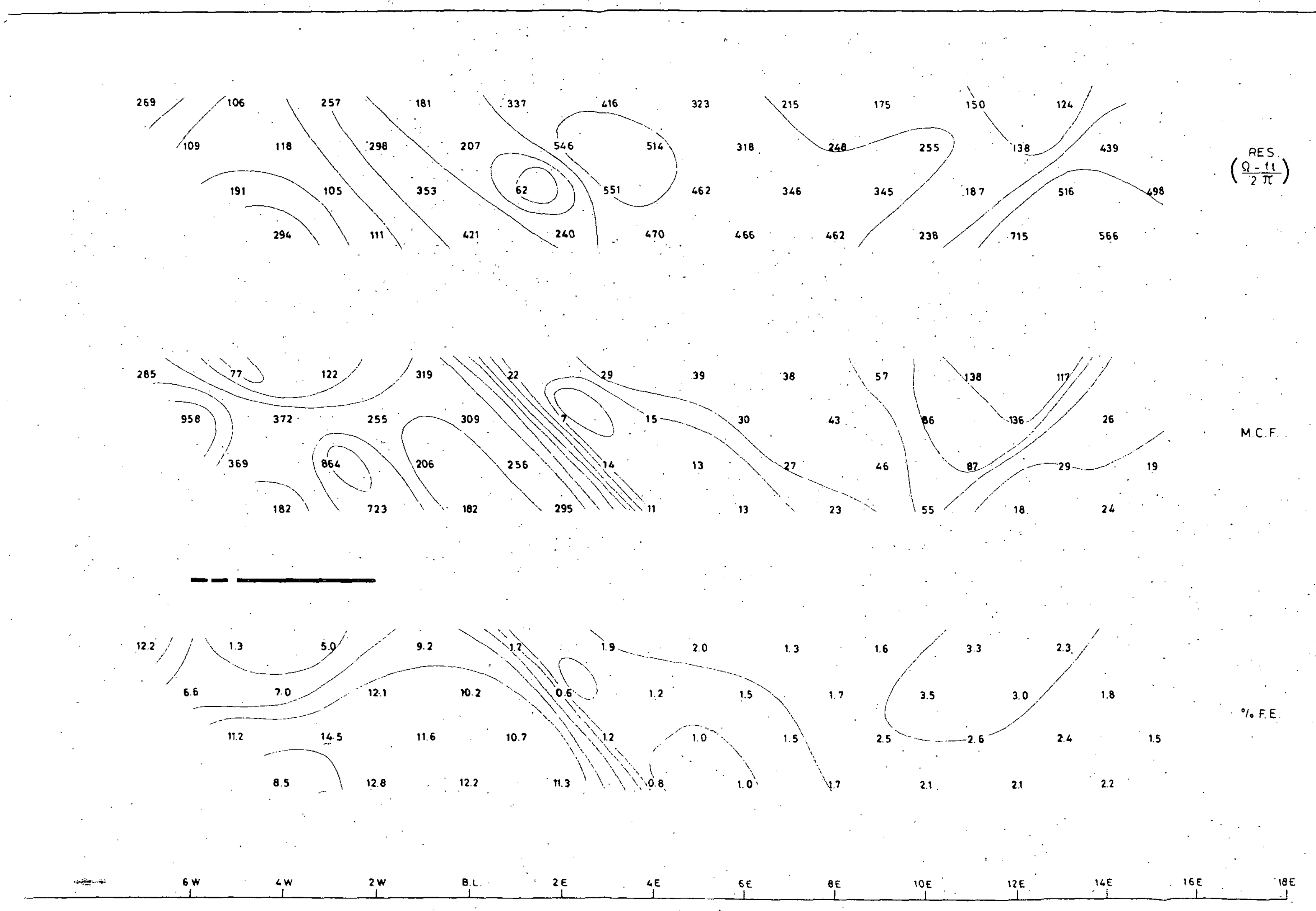


FIG.33

I.P. SURVEY

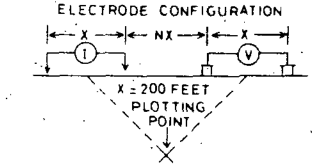
PROPERTY: AYIOS IOANNIS

PROJECT No.: 543

LINE No.: 4S

SCALE: 1" = 200'

ELECTRODE CONFIGURATION



FREQUENCY 0.3 - 5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

DEFINITE

PROBABLE

POSSIBLE

CONTOURS 1.0, 1.5, 2.5, 5.0, 7.5....

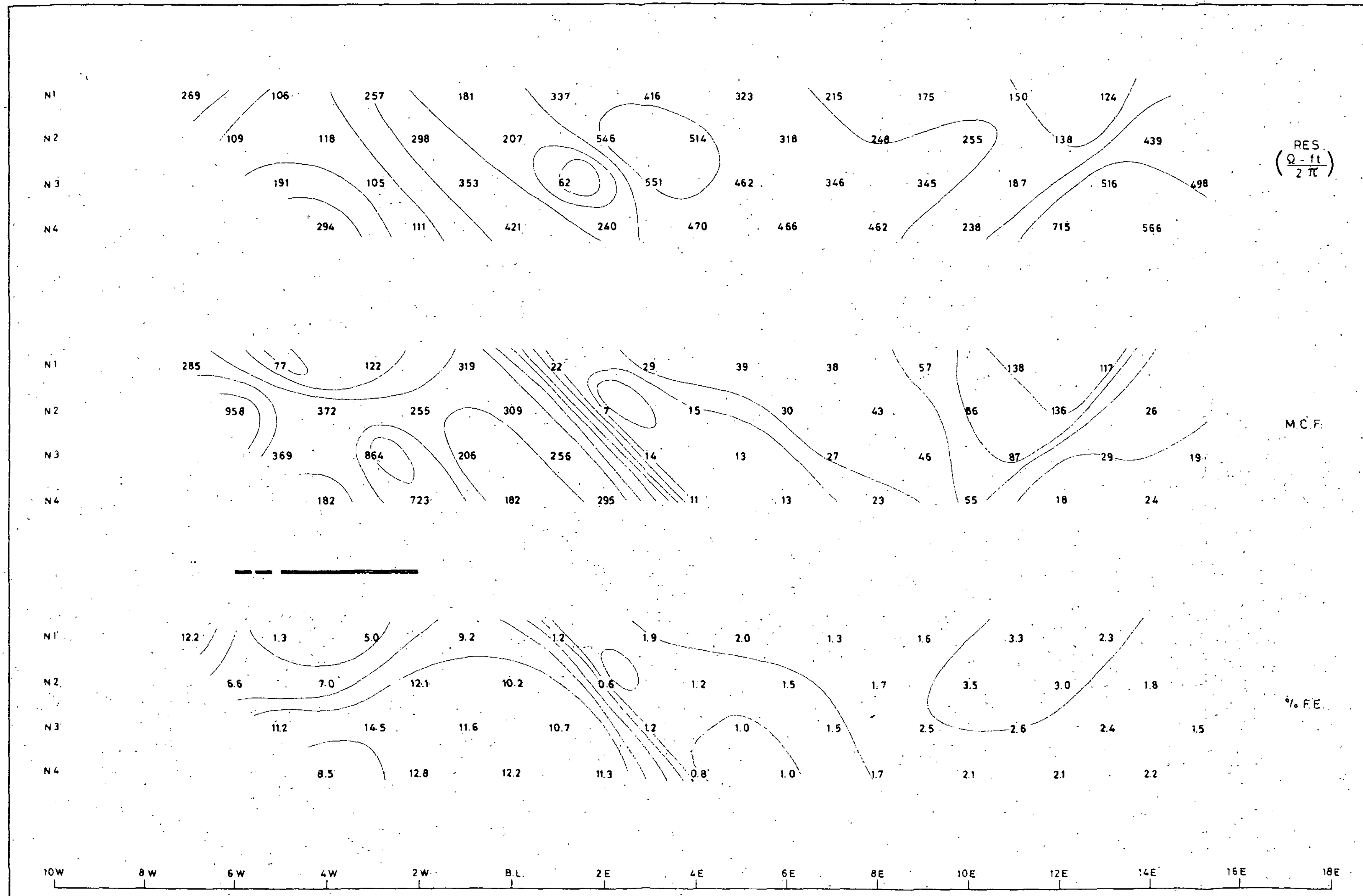
DATE SURVEYED: NOV 1976

OPERATOR: KRAMVIS-SOLOMI

DRAWN BY: K.T.Z.

REMARKS: ________

APPROVED: ________



I.P.

PROPERTY :

PROJECT No.:

LINE No.:

SCALE: 1"

ELECT

FREQUE

SURFACE

ANOMAL

CONTOUR

DATE SURVE

OPERATOR:

DRAWN BY:

REMARKS:

APPROVED:

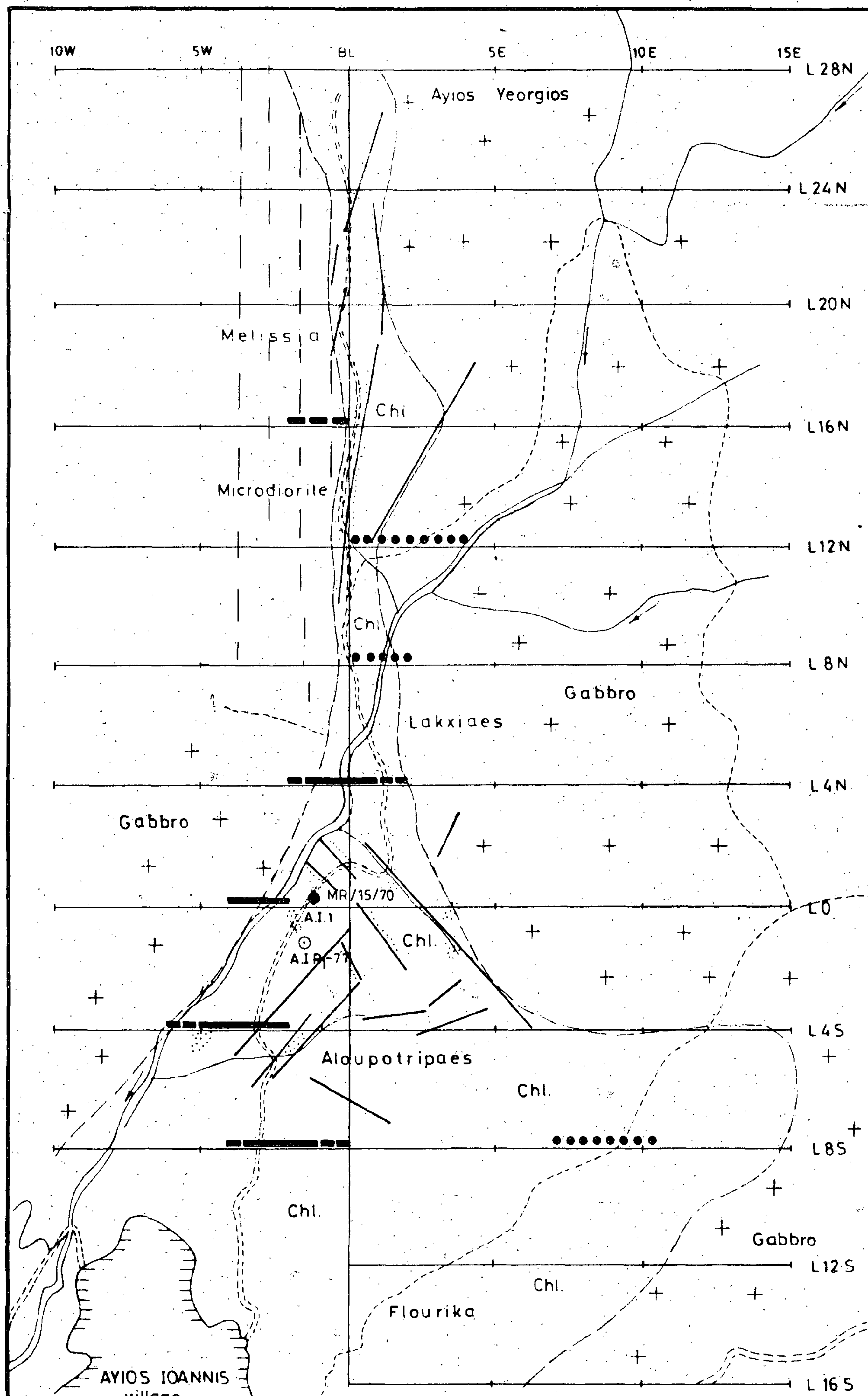


FIG. 31-AYIOS IOANNIS (AGROS) AREA

GEOLOGICAL-GEOPHYSICAL MAP

SCALE 1:5000

0 50 100 150 200 250 m

Chl Chloritic rocks

● A.I. 1 / ⊙ AIP$_1$-77 } Boreholes

Surface Projection of anomalous I.P. zones

Definite

Probable

Possible

G.S.D. (Geol. Geoph.) 1/81

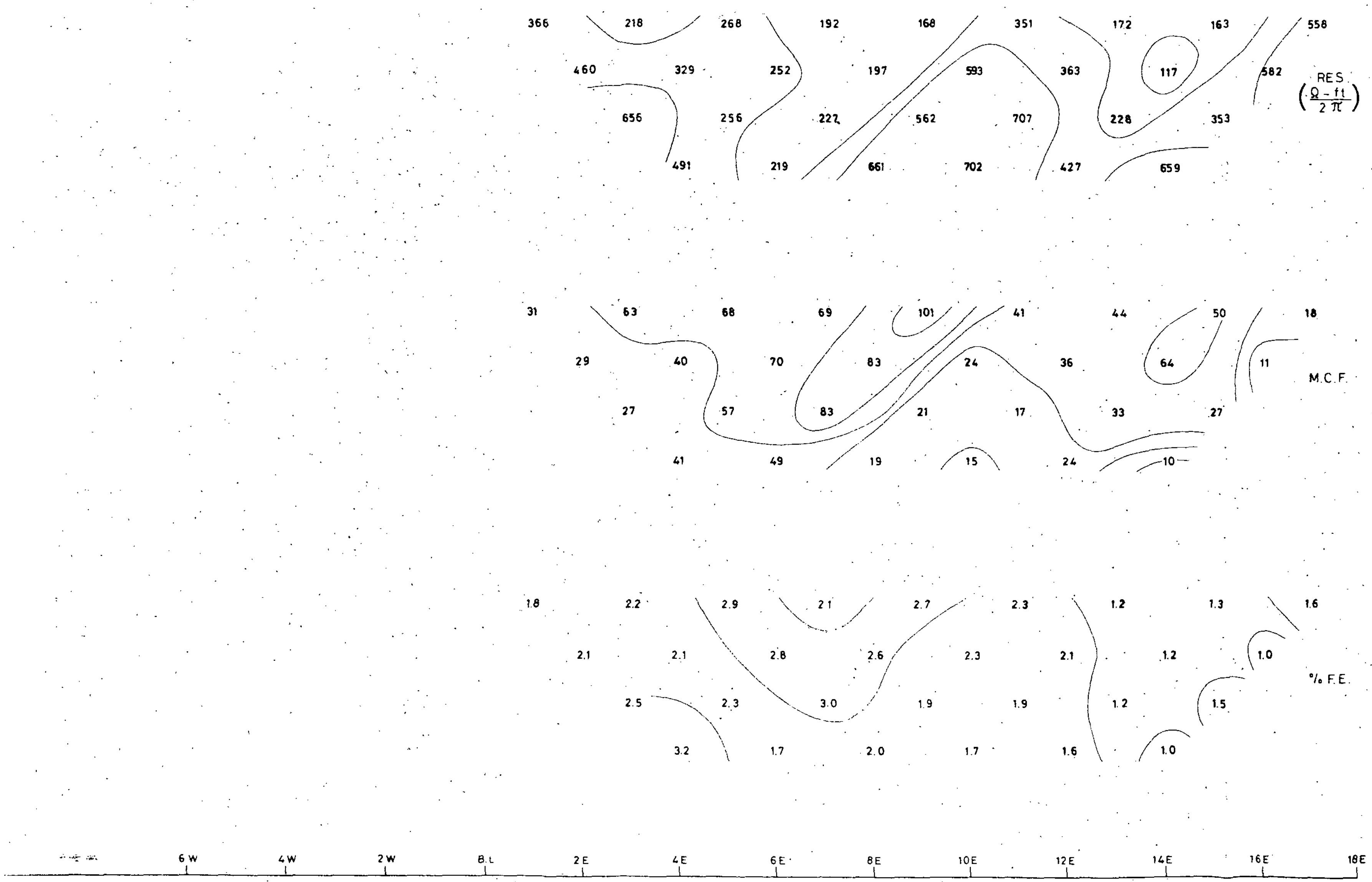


FIG. 32

I.P. SURVEY

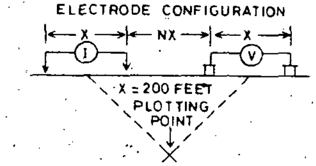
PROPERTY: AYIOS IOANNIS

PROJECT No.: 543

LINE No.: 12 S

SCALE: 1" = 200'

ELECTRODE CONFIGURATION



FREQUENCY 0.3 - 5.0 Hz

SURFACE PROJECTION OF ANOMALOUS I.P. ZONES

DEFINITE

PROBABLE

POSSIBLE

CONTOURS 1.0, 1.5, 2.5, 5.0, 7.5....

DATE SURVEYED: NOV. 1976

OPERATOR: KRAMVIS - SOLOMI

DRAWN BY: K.T.Z.

REMARKS: ________

APPROVED: ________

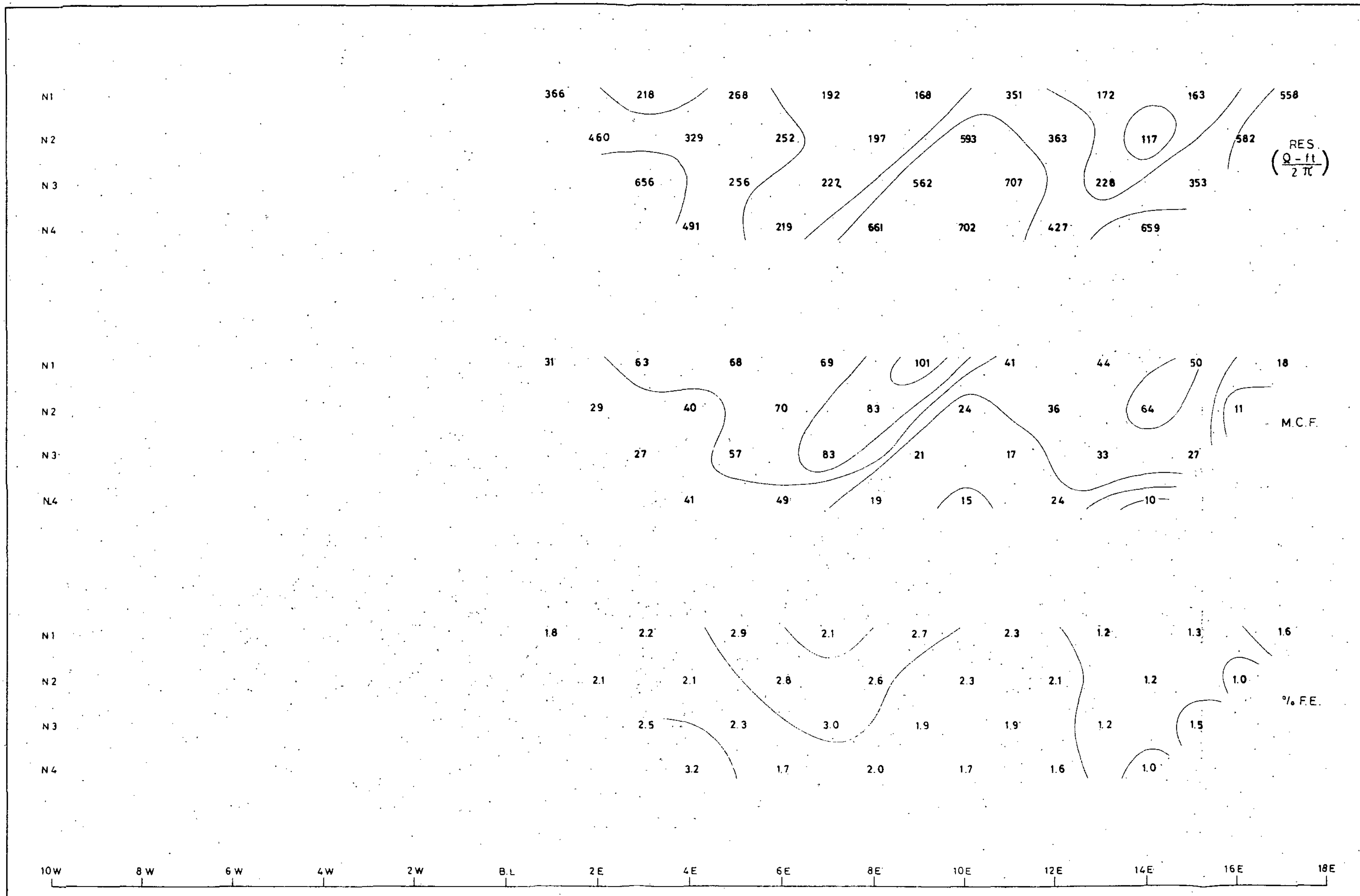


FIG.

I.P.

PROPERTY:

PROJECT No.:

LINE No.: 12 S

SCALE: 1" =

ELECTRO

FREQUENCY

SURFACE

ANOMAL

CONTOUR

DATE SURVEYED

OPERATOR:

DRAWN BY:

REMARKS:

APPROVED: