THE APPLICABILITY AND LIMITATIONS OF THE INDUCED POLARIZATION METHOD IN THE SEARCH FOR SULPHIDE MINERALIZATION IN THE TROODOS IGNEOUS COMPLEX, CYPRUS

VOLUME ONE

BY

GEORGE MALIOTIS

B.Sc., M.Sc., M.I.M.M.

Thesis submitted for the degree of
Doctor of Philosophy
University of Leicester

1978

THE APPLICABILITY AND LIMITATIONS OF THE INDUCED POLARIZATION METHOD IN THE SEARCH FOR SULPHIDE MINERALIZATION IN THE TROODOS IGNEOUS COMPLEX, CYPRUS.

By GEORGE MALIOTIS

ABSTRACT

The Pillow Lava sequence overlying the Troodos Igneous Complex of Cyprus contains sulphide mineralization within tectonic zones of variable width and extent, and some of these have been mined since ancient times. Previous I.P. and other geophysical work showed that the location of concealed zones presents considerable problems. In this study a new attempt using modern highpower equipment was made to assess the usefulness of the I.P. method in Cyprus. After an orientation survey over a sulphide body 125 m deep, Time-Domain I.P. and Resistivity surveys using the pole-dipole configuration with a spacing of 50 m were carried out over six different areas where the mineralization occurs in different modes and grades.

The data were plotted on pseudosections which conveyed very useful information on the location, extent and depth of the polarizing body.

The resistivities of the barren rocks were generally low, between 5 and 30 ohm-meters. The zones of high grade sulphide mineralization had equally low resistivities which increase with decreasing sulphide content. The N.T.I. was found to attain high values over the mineralization. The amplitude varied mainly according to the size, depth and location of the body with respect to the geophysical grid. The highest anomalous values were observed when both poles of the receiver were over concealed or exposed mineralized bodies. This clearly imposes limitations on the detection of narrow zones, particularly at depth.

The values of the I.P. voltage were observed at sixteen times between 0.035 and 0.78 sec. for n = 2 on all the lines. The I.P. decay was investigated both as an exponential decay and as a log time decay. In the first the electromagnetic and true chargeability components were found to attain in general high values over the mineralization but without any significant variations between the disseminated and higher grade mineralization. On the log time axis the I.P. decay was found to consist of a short and fast decaying linear component, and a later and slower curved component. Some of the parameters which describe this shape were found to have much different values over the different grades of mineralization implying thus a distinction between disseminated and high grade mineralization on the basis of the decay curve.

TABLE OF CONTENTS

/ IV. PRACTICAL

CHAPTER THREE

THE SCOPE OF THE PRESENT RESEARCH

CHAPTER FOUR

ON THE GEOPHYSICAL RESULTS
OF THE MATHIATIS (MITSERO) AREA

/ III. THE

CHAPTER FIVE

ON THE GEOPHYSICAL RESULTS OF THE KLIROU AREA

/ CHAPTER

Page

CHAPTER SIX

ON THE GEOPHYSICAL RESULTS OF THE KOKKINOVOUNAROS AREA

Page

CHAPTER SEVEN

ON THE GEOPHYSICAL RESULTS OF THE VRECHIA AREA

CHAPTER EIGHT

Page

ON THE GEOPHYSICAL RESULTS OF THE PETRA AREA

CHAPTER NINE

ON THE GEOPHYSICAL RESULTS OF THE KAMPIA AREA

CHAPTER TEN

THE APPLICABILITY AND LIMITATIONS OF THE INDUCED POLARIZATION METHOD

CHAPTER ELEVEN

SUMMARY AND CONCLUSIONS

The Tables and Figures are presented in Volume Two.

CHAPTER ONE

INTRODUCTION

The purpose of the present Thesis is to investigate the applicability and the limitations of the Induced Polarisation (I.P.) method in the search for sulphide deposits in Cyprus. Although this method is applied extensively throughout the world for the search of sulphide mineralization, particularly porphyry copper deposits, it was realised that under the conditions this mineralization is found in Cyprus, the method would suffer from certain limitations. These were essentially based on the fact that the Cyprus deposits are relatively small by world standards. They are generally associated with tectonic zones and represent effectively concentrations of sulphide minerals within those zones. Evidently their width is relatively small but they could have considerable longitudinal extents. The mineralization is found within a series of volcanic rocks which were covered by further volcanic extrusions and later by sedimentary rocks.

From the above it is evident that the aim is to locate generally narrow bodies of mineralization at a variable depth, which could be variably mineralized, either in the form of economic concentrations or of lower grade mineralization, which itself would assist in locating potential orebearing lineaments. An important implication of the Cyprus sulphide mineralization is the fact that the cupriferous mineralization is almost always associated with high sulphur concentrations. This immediately implies that the disseminated mineralization has no economic significance as it consists primarily of pyrite. It is under these conditions the I.P. method is being applied in Cyprus, and the purpose of this Thesis is to investigate its applicability as well as its limitations.

/ To

To achieve this, I.P. surveys were carried out over a number of areas where the mineralization is found in certain typical modes of occurrence. These modes are essentially the depth in which the mineralization is found, its size and its average grade. For this, seven different mineralized areas were studied and their results are described individually in separate Chapters. The location of these areas is shown in Fig.1.

The Thesis is divided into the following Chapters:

Chapter Two reviews the I.P. method describing the current theories on its origin, practical considerations regarding its application in the field and interpretation, together with a review of previous work on the I.P. transient shape.

Chapter Three defines the scope of the present research. First it describes the general geology of the orebearing volcanic rocks followed by a detail description of the sulphide mineralization and presents examples of two orebodies. Further there is a definition of the problems of an I.P. survey in the search for this type of mineralization together with a description of the parameters and instrumentation used throughout this research. This is followed by a review of the applicability of other common ground geophysical methods applied over this type of mineralization, including past work with the I.P. Finally there presented the results of an orientation study carried out over the deeply seated Agrokipia B Orebody. This study defined the values of a number of field parameters which were used throughout the present research.

Chapters Four to Nine present and discuss the geophysical results of the I.P. surveys over the different areas. In addition to the I.P. results there is an account of the Resistivity results obtained in each area since this method usually accompanies I.P. Chapter Four describes

/ and

and compares the results over a small and shallow, high grade seated deposit and a parallel running zone of low grade disseminated mineralization which occurs in the Mathiatis Area.

Chapter Five describes and compares the results of the Klirou Area which includes disseminated exposed mineralization and two concealed higher grade deposits, one at a depth of about ten meters and the other at a depth of about one hundred meters.

Chapter Six describes the geophysical work over a long and widely exposed zone of mineralization in the Kokkinovounaros Area.

Chapter Seven describes and compares the geophysical results over a small and shallow seated sulphide deposit and an exposed lower grade mineralization in the Vrechia Area.

Chapter Eight examines the geophysical results over a sulphide deposit of the Petra Area localised at the intersection of two major structures, one of them representing the feeder of the mineralising solutions.

Chapter Nine describes the geophysical results over a partly exposed narrow mineralized zone in the Kambia Area which was responsible for the formation of a nearby massive sulphide deposit.

Chapter Ten examines the results obtained from each of the above areas and discusses the applicability and limitations of the I.P. method under these conditions. Attention is paid on the possibility of discriminating between disseminated and higher grade mineralization on the basis of the I.P. transient curve in the light of the results of Chapters Four to Seven. In addition this Chapter discusses the applicability of the Resistivity method in this type of exploration and its usefulness in combination with I.P.

/ Chapter

Chapter Eleven summarises the present research and presents its conclusions. Further it recommends on further research on the subject particularly on the establishment of field parameters which would enable the discrimination of disseminated from higher grade mineralization on the basis of the I.P. decay curve shape.

The present research is based primarily on the geophysical and geological data obtained during the exploration activities of the Hellenic Mining Company Ltd. For this the author expresses his graditude to Mr. P. Paschalides, President, and Mr. S. Loisides, Managing Director of the Hellenic Mining Company for their permission to utilise these data and also use some of the facilities of the company.

The present study was supervised by Dr. M.A. Khan to whom the author is grateful for his encouragement and guidance.

Sincere thanks are also due to Professor L. Mousoulos, Technical Consultant of the Hellenic Mining Company, and to my colleagues Messrs N. Adamides and I. Christoforou, for useful discussions particularly with regard to the nature of the sulphide mineralization in Cyprus.

Thanks are also due to the Geophysical Field Crews of the Company and in particular their leaders Messrs I. Aristodemou and A. Heliades for their assistance in the field. Thanks also go to Mr. I. Vouniotis for drafting the figures and to Miss N. Panayidou and Miss L. Diakonou for typing this Thesis.

The author wishes to acknowledge Noranda Exploration (Cyprus) Ltd for the geological information which they made available on the Vrechia Area.

Finally sincere thanks go to my wife for her encouragement and patient during the period of this study.

CHAPTER TWO

A REVIEW OF THE INDUCED POLARIZATION METHOD

I. INTRODUCTION

Historically the Induced Polarization method was first attempted by the Schlumberger brothers (Schlumberger 1920) but it was abandoned in favour of the self-potential method. The first recognised work is that of Bleil (1953) for a Ph. D. Thesis. The method was first applied in prospecting by the Newmont Exploration (Brant 1959).

The name induced polarization is derived from the fact that it is mostly concerned with detecting the electrical surface polarization of metallic minerals induced by electric currents applied to the ground. When the pore passages of the rock are blocked by these minerals the electric current must overcome an electrochemical barrier in order to flow through the interface between the metallic minerals and the solution filling the pores of the rock. The forces opposing the flow of the current are said to polarise the interface. The added voltage necessary to drive the current accross the electrochemical barrier is known as "overvoltage". When the energizing current source is turned off, this voltage decays with time. This phenomenon is equivalent to the decrease of the resistivity of the rock with increasing frequency.

When the induced polarization is studied by measuring the decay of the voltage after the interruption of a steady current flow, the measurements are said to be made in the Time Domain. If instead alternating currents are used and the resistivities corresponding to various frequences are determined, the measurements are said to be made in the Frequency Domain.

/ All

All minerals that are electronic conductors are expected to show induced polarization effects. For this reason sulphide minerals are found to have polarization effects in contrast to pore fluids which are ionic conductors. Table 1 lists the more common minerals giving induced polarization effects (Madden and Cantwell 1967). Clay minerals can also show polarization effects.

TABLE 1

Common minerals giving polarization effects.

Oxides	Sulphides	Other
Magnetite	Pyrite	Graphite
Pyrolusite	Pyrrhotite	Native Copper
Cassiterite	Marcasite	
	Galena	
	Chalcopyrite	
	Molybdenite	
	Pentlandite	
	Cobaltite	
	Argentite	
	Bornite	
	Chalcocite	
	Enargite	

The I.P. method is at present the most widely applied geophysical method in the search for sulphide deposits. Particularly it is used extensively in prospecting for porphyry copper deposits. However, in spite of its presently wide application, compared with the other major geophysical methods, not much has been published so far. The actual origin of the phenomenon is still being discussed and there is no direct method of quantitative interpretation, and by far, no qualitative interpretation.

/ The

The purpose of the present Chapter is to present a short review of the I.P. method. First there is a discussion on the origin of the I.P. phenomenon followed by a description of the different parameters with which this phenomenon is recorded in the field for exploration purposes. Further there is a discussion on practical field considerations - in particular the different electrode arrays and the various coupling effects - followed by a brief description of the currently used instrumentation. This is followed by a short discussion on the different methods of I.P. interpretation currently applied. Finally, there is a review of the work carried out so far on the transient shape together with a brief discussion on the actual nature of this curve.

II. THE ORIGIN OF THE I.P. PHENOMENON

The I.P. phenomenon can be exhibited in two different ways. One, as a decrease of the electrical impedance with increasing frequency, and the other as a transient decay after the cessation of the energizing current. As it will be discussed in a different section these two effects are the manifestations of one and the same phenomenon. These two effects could be accounted for by displacement currents as they occur in ordinary dielectric properties of materials, but as pointed out by Madden and Cantwell (1967), they are observed at too low frequencies indicating that they must be attributed to different phenomena.

Mayper (1959) enumerates a number of possible causes of the I.P. effect. These are the normal dielectric effects, the electrokinetic response of air bubbles in the rock pores, the electrode polarization and the membrane polarization. However, the first two causes are discarded as not contributing appreciably to the I.P. phenomenon which is therefore solely attributed to the electrode and membrane polarization (Marshall and Madden 1959, Keevil and Ward 1962, Ward and Frazer 1967). These two phenomena will be described briefly below:

A. Electrode Polarization

Before any further discussion it is important to examine the electrochemical conditions at the interface between a metal electrode and an electrolyte when no current is passing through the interface. Immediately adjacent to the solid layer there is an adsorbed layer of fixed ions - the so called "fixed layer". Adjacent to this there is the "diffuse layer", see Fig.2, made of related mobile ions in a zone in which the anomalous number of ions decreases exponentially from the fixed layer. The potential drop across this diffuse layer is termed the zeta potential. The properties of

/these

these two layers differ. The first is stable and the ions can only be removed after the application of strong physical force, whereas the diffuse layer thickness varies according to the dielectric constant of the medium, the valency of the ions, the ion concentration in the electrolyte, and the temperature (Ward and Frazer 1967).

The passage of current through an electrolyte in contact with a metal can be accomplished through two paths, the so called "faradaic" and "non-faradaic" paths. In the first the current is carried across the interface by electrochemical transfer of charge which involves oxidation or reduction of some ion, thus involving the diffusion of ions towards or away from the metal-electrolyte contact, by conversion of an atom to an ion or vice versa. In the non-faradaic path the current is transferred because of the condenser-like behaviour of the double layer. Therefore the non-faradaic path can be represented by a capacitance as far as the variations of its impedance is concerned. In the faradaic path, however, the ion diffusion impedance cannot be represented satisfactorily by a combination of capacitors or resistors, and is thus customarily referred to as "Warburg impedance", W. The magnitude of W varies inversly as the square root of frequency. Fig.3 depicts the two paths faradaic and non-faradaic as equivalent electrical circuits.

Ward and Frazer (1967) have suggested a simplified equivalent circuit for the representation of the faradaic and non-faradaic charge transfer through an interface between a metal electrode and an electrolyte. This is shown in Fig.4. The behavior of the conductivity of this circuit with variable frequency is shown in Fig.5. The central portion of this curve is known as the "Warburg region". The slope of this is the I.P. frequency response which when divided by the resistivity is the Frequency Effect. This idealised conductivity-frequency spectrum was found by Ward and Frazer (1967) to show significant similarities with actual rock spectra.

/ Membrane

B. Membrane Polarization

This is the second important cause of polarization in rocks differing from the electrode polarization in that there is no charge transfer by the faradaic and non-faradaic processes as in the first case but it is due to ion mobility variations. As a result of adsorption of negative charges on the surfaces of rock minerals when in contact with pore fluids, positive ions are repelled away. Thus, if the pore passages are small, then there is a decrease in mobility of the negative ions as they cannot pass through the cationic clouds, Fig.6. This phenomenon of restricted mobility is more pronounced when the pore passages are extremely small as in the case of clay minerals present in the rock. This mobility reduction is more effective for lower than higher frequencies (Ward and Frazer 1967), indicating that the conductivity of the rock increases with increasing electrical frequency.

Madden and Cantwell (1967) have suggested that in order to observe these polarization effects two conditions must be satisfied: First, the membrane zones must be alternated with non-restrictive zones, and second, the length of the alternating zones must be small. Consequently, massive clay zones do not show polarization effects whereas dirty sands in which clay particles are dispersed within pore passages show very marked effects. Apart from dirty sands other rock types, such as those containing fibrus and layered minerals, could show these effects, e.g. serpentinites which possess the necessary properties which give rise to membrane-type polarization effects. The same authors (Madden and Cantwell, 1967) have also pointed out that the membrane type polarization could also be caused by metallic minerals where mobile positive ion species could block the current flow giving a much larger polarization than the usual membrane polarization materials.

III. PARAMETERS USED IN I.P. MEASUREMENTS

Basically the I.P. effect, although a dimensionless quantity in theory, is measured in practice as a voltage change with frequency or time, depending on the method applied. Fundamentally the two methods are similar. For practical purposes during field surveys a number of parameters were developed. These are defined below.

A. Frequency Domain Measurements

1. Percent Frequency Effect (P.F.E.).

This is defined as:

$$PFE = \frac{\rho_{dc} - \rho_{ac}}{\rho_{ac}} \times 100 \qquad (1)$$

where ρ_{dc} is the resistivity at a direct current and ρ_{ac} is the resistivity at an alternating current. In practice the dc. is replaced by a very low frequency current. The resistivities are apparent resistivities calculated according to the electrode configuration.

2. Metal Conduction Factor (M.C.F.).

This is defined as:

$$MCF = \frac{\rho_{dc} - \rho_{ac}}{\rho_{ac} \times \rho_{dc}} \times 2 \times 10^5 \qquad (2)$$

If the resistivities are expressed in ohm-meters the dimensions of the MCF are in (Ohm-meters) $^{-1}$. In practice the direct current is again replaced by a very low frequency current.

3. Phase-angle measurement.

This is defined with reference to Fig.7.

/ It is

It is the phase lag b between two sinusoidal waveforms, the input and the output.

B. Time Domain Measurements

In the Time Domain the I.P. effects are measured by recording the voltage decay following the interruption of the energizing current. Fig. 8 shows the transient decay of electric field strength in a rock sample. The electric field will quickly drop to a value Vo, a small fraction of the energizing field Ve; it will then decay slowly over a long period of time.

For practical purposes the following parameters are used.

1. I.P. Effect (I.P.E.).

This is the ratio of the residual voltage V(t) in mV at time t after the current was interrupted to the voltage Ve in V while the current was flowing. This is expressed in mV/V.

2. Normalised Time Integral (N.T.I.).

The decay curve is registered over a length of time and the area under it between two time limits is determined as shown in Fig. 9. This is expressed in mV sec. The time integral measure of the I.P. is given by dividing this by the steady voltage Ve, mVsec/V.

3. Chargeability M.

This was introduced by Siegel (1959). It is given by:

$$M = \frac{Ve - Vo}{Vo}$$

where Ve and Vo are as defined in Fig 8. For practical purposes Vt taken a very short time after the cut-off is used instead of Vo.

/ C. Relationship

C. Relationship between Frequency and Time Domain Measurements

The Frequency Domain and Time Domain measurements are related through the Fourier transformation. An account of this relationship lies beyond the scope of this review. Madden and Cantwell (1967) have shown that the frequency effect at a frequency J is proportional to the step function decay voltage at time $t = 1/2\pi J$. In the usual units of PFE and IPE, the PFE at frequency J is given by:

$$\text{PFE} = \frac{1}{10} \times \text{IPE at } t = 1/2\pi J.$$

IV. PRACTICAL CONSIDERATIONS

A. Electrode Configurations

There is a number of electrode configurations which can be used in I.P. field surveying. These can be broadly divided into profiling and sounding arrays. The first are the most commonly used in exploration. The second group are employed for depth probing about a stationary point, or rarely for profiling using a fixed spacing.

The profiling group of arrays includes mainly the dipole-dipole, the pole-dipole and the gradient. These arrays are shown in Fig,10 with the standard nomenclature for current potential and spacings.

The most commonly used sounding arrays are the Schlumberger and Wanner arrays also shown in Fig.10.

The choice of the electrode configuration to be employed in a given I.P. project is one of the most important decisions the geophysicist has to make. Certainly the choice of the proper array depends on the actual purpose of the survey-reconnaissance or detail. Another important consideration is the geological environment and the type of target the survey is aiming to detect and locate. And depending on the target, the choice of the array depends on the amount of information desired to be obtained from the survey. There is a number of factors which are considered according to the nature of the survey. These are mainly:

1. The Magnitude of the Response.
2. The Resolution of the different structures.
3. The Overburden Penetration.
4. Geometry - dip determination of a structure.
5. The Inductive Coupling.

The most commonly used arrays were studied by many researchers with respect to the above factors. The most recent contributions are those of Coggon (1973) and Dey et alia (1975). Lately Sumner (1976) has presented a detail comparison of the various arrays. Below there is given a brief discussion of the characteristics of the commoner profiling arrays with . respect to the above factors (1 to 5).

1. Magnitude of Response.

The largest response for a given structure is given by the dipole-dipole array. The pole-dipole array gives a slightly lower response than the dipole-dipole. The smallest response is given by the Gradient array. The same holds true for the resistivity responses.

2. The Resolution of different structures.

The dipole-dipole is considered to give the greater overall resolution-separation of effects of adjacent structures compared with the pole-dipole. However, the gradient array is far superior than the other two. For single structures the pole-dipole gives a broader anomaly than the dipole-dipole resulting in a decrease in the lateral resolution for locating the exact position of a structure.

3. The Overburden Penetration.

The conductive overburden results in reductions in the I.P. values of all three arrays. There is a slightly greater reduction in the dipole-dipole arrays than the pole-dipole and gradient which are approximately equally reduced by the overburden masking.

4. Geometry-dip determination of a structure.

The greatest effect is shown by the gradient array anomaly shape.

/ There

There is an I.P. anomaly peak downdip and a trough updip. The resistivity pattern shows the peak updip and the trough downdip. Certainly these criteria are applied only near the middle of the current electrodes. For this the gradient anomaly is considered as being indicative of the presence and direction of dip.

The dipole-dipole and pole-dipole patterns are also indicative of the presence of dipping structures. This is shown by the asymmetry of the pseudosectional patterns in which, for both arrays, the strongest portions dip opposite the structure. It must be noted that the asymmetry is more pronounced for small dips until in the horizontal case (0° dip) the pseudo-sectional pattern is strongly asymmetrical.

5. The Inductive Coupling.

Although this is discussed in a different section below, it is pertinent to mention that the dipole-dipole array suffers the least effects from the inductive coupling. The next is the pole-dipole with generally longer effects than the dipole-dipole. The gradient suffers more than the other two arrays under similar conditions.

In addition to the profiling and sounding arrays there is a number of different electrode configurations which are applied for subsurface surveying by the utilization of boreholes. In general the borehole arrays can be divided into two groups. The first includes the logging arrays which are used for the study of the properties of in-place rock and the recording of the resistivity and I.P. characteristics of the drilled rocks for correlation purposes. The second group includes the exploration arrays which are effectively applied in order to expand the effective usefulness of a borehole much beyond the actual dimensions of the hole.

/ In the

In the first case two or more electrodes are placed in the hole at usually small and predetermined spacings and measurements are taken at different points along the borehole constituting thus a borehole "log". Fig. 11 shows a number of such logging configurations.

In the second group one electrode, usually the current, is put into the borehole and the distribution of the electrical field pattern resulting from this is investigated with surface potential electrodes. Measurements of the electrical field are made along radial lines from the borehole, see Fig. 11. The borehole electrode can be either in barren rocks or in mineralization. The second case constitutes the Mise-a-la-masse (excitation of the mass) method. By energizing the encountered mineralization in this way it is possible to establish its lateral extensions by surface measurements along radial lines. In another type of borehole array the current electrodes are placed at a distance of three quarters the depth of the hole on either side of it on the surface, and the potential is loged with one potential electrode placed at the collar (stationary) and the other moving along the borehole. By changing the azimuth of the current electrodes about the hole it is possible to establish the location and geometry of a neighbouring polarizing body. It is worth noting that between the two Domains, the most preferable is the Time Domain which suffers the least electromagnetic couplings due to the proximity of the current and potential wires in a borehole.

One of the most important problems in the use of all the above arrays is the presentation of their results. This problem has already been settled for the sounding arrays where the results are presented in a manner similar to that employed in the resistivity methods. Equally simple is the presentation of their results for the borehole electrode configurations in which only one dipole, usually the receiving, is moved whereas the other is stationary. The subject of the point of assignment of a measurement has been discussed in detail by Habberjam (1972). The most problematical presentation is that of the pseudosectional plotting employed in the dipole-dipole and pole-dipole configurations. Perhaps the term "pseudosection" does not describe how pseudo (false) indeed this section is. Certainly with the increase of the distance between the transmitting dipole (or pole) and the receiving dipole, a depth probe is carried out and therefore each n-value represents different depth of penetration. However, this is not the only effect involved. Quick (1973) discussed this problem in some detail. He listed five different effects taking place as the value of n changes. These are:

1. The effect of deeper horizontal layers is increased.
2. Vertical or inclined inhomogeneities are crossed.
3. A large volume of ground is sampled and thereby resolution is decreased.
4. With the different positions of the current dipole (or pole) the inhomogeneities or discrete bodies are polarised differently.
5. With the different positions of the potential dipole, the potential field created by a polarised body is measured at a different section.

As pointed out by Quick (1973) these five considerations merely imply that "a pseudosection is a very complex set of data which cannot be readily evaluated". However, the present writer believes that if it is accepted and fully understood that the shape of the pseudosectional contoured pattern does not correspond directly to the subsurface structure but it obeys its own rules and limitations, then the pseudosectional plotting is a very useful way of presenting the field data.

/ B. Coupling

B. Coupling Effects

1. Electromagnetic Coupling.

Electromagnetic coupling is the result of the coupling of the transmitter with the receiver through electromagnetic wave propagation. In this the two units with their wirings behave like the primary and secondary windings of a transformer. This coupling can affect the I.P. readings in both the Frequency and Time Domain methods.

The Electromagnetic coupling effects were investigated by a number of authors the most nobable being Sunde (1949), who has put the theoretical foundations for the investigation of this phenomenon, Millet (1967), Hohman (1973) who calculated two layer solutions for the dipole-dipole array, and Dey and Morrison (1973) who expanded the solution to multilayered media for both the Frequency and Time Domains.

The electromagnetic effects can be both positive or negative i.e. in the same sense as the true I.P. effect or opposite to it. Evidence of the existence of this form of coupling is given by the strong departure of a frequency spectrum in higher frequencies in the Frequency Domain, or by the departure of the decay curve from a logarithmic response on early recording times in the Time Domain. Therefore, it is easier to avoid the electromagnetic effects in the Time Domain by simply recording the curve after a certain delay from the instant of the cessation of the energizing current.

Some authors presented tables and monographs for the correction of the electromagnetic coupling effects from the field readings (Millett (1967) and Ness (after Sumner 1976)). Wynn and Zonge (1974) have described a method for removing this effect. However, as pointed out by Sumner (1976) because of the uncertainty which arises in attempting to correct I.P. field data for the coupling effects, it is advisable to try and avoid these effects as much

/ as possible

as possible during the field survey. This can be achieved by investigating beforehand the value of the ratio a/d, where a is the electrode spread and d the skin depth given by the formula $d = 502.4 \sqrt{\frac{\rho(\text{ohm-meters})}{f(\text{Hz})}}$ meters. By keeping this ratio below 0.1 then the coupling effects may be considered as being negligible. Further, from the formula of the electromagnetic coupling due to two wire segments given by Sunde (1949), it is evident that the coupling effects become minimal as the angle between the two segments approaches the 90°. Thus by applying perpendicular than collinear arrays the electromagnetic coupling may be minimised.

2. Capacitive coupling.

This type of coupling may also influence the polarization voltages. In this phenomenon the transmitter is coupled to the receiver through wire to wire or wire to ground capacitance.

Capacitive coupling can occur in three ways.

(a) Leakage of current from the transmitting wire picked up at the receiving electrode.

(b) Leakage of current from the transmitting electrodes picked up by the receiving wire.

(d) Direct wire to wire leakage.

Madden and Cantwell (1967) have shown that the FE expected from transmitting wire leakage in the dipole-dipole configuration is given by:

$$FE = (\frac{L}{2} n(n^2-1) \quad ln \frac{n^2}{n^2-1}) \frac{I_1}{I}$$

where I_1 is the leakage current per unit length. Assuming leakage capacitance to ground as 0.005 µf/1000 ft at 3 cps, the same authors have shown that the PFE FOR $L = 1000$ m ranges from 0.025 at $n = 1$ to 0.07 at $n = 4$. Capacitive coupling is therefore relatively unimportant for this configuration. The same

/ would

would be true for the pole-dipole array (Madden and Cantwell 1967).

For the Schlumberger array they have shown assuming, a = 10 m, b = 1000 m and electrode-wire distance equal to 3 m,

$$FE = -1.4 \text{ percent at 3 cps.}$$

According to the same authors this represents very nearly the worst case but it is not a significant change over normal background effects. A more detail discussion is given by Wait (1959).

In general it may be concluded that capacitive coupling is unlikely to cause any significant effect provided care is taken during the field survey. A minimum distance of 10 m between wires and electrodes has been suggested by Madden and Cantwell (1967). In drill hole surveys shielded wire must be used.

3. Cultural Coupling.

Cultural coupling comprises the effect from a number of man-made objects which interfere and create problems during the execution of a field survey. Such objects are usually powerlines, metal fences and metal power lines. The presence of one of these in the vicinity of an orebody could easily mask any evidence of its existence.

The electromagnetic noise from the transmitted current through a powerline is filtered out by special electronic devices fitted to almost any modern I.P. receiver. The frequencies involved are usually 50 or 60 Hz. However, for lighting protection power transmission lines are usually well grounded simulating thus a large grounded fence.

Pipelines and fences could show anomalous values sometimes as much as five times the background (Wynn and Zonge, 1974) demonstrating on anomalous pattern, similar to that due to a polarizing dyke, in the pseudosectional

/ plottings

plottings. If the survey line is parallel to or near the pipeline or a fence then the resistivity results could also be effected, whereas if it is perpendicular they show no effect.

Wynn and Zonge (1974) have suggested two possible explanations for the origin of these effects. The first is that the anomalous fields are produced from non-linearities in the current behaviour in the vicinity of a fence or pipeline due to current focussing. The other explanation is that the fence acts as a grounded antenna which collects and transmits the survey signals with a resultant phase lag.

C. Telluric Noise

The telluric noise is the term for the electric noise observed particularly in the time domain receivers due to the so called telluric currents which flow continually in the earth. These currents are generally parallel to the earth's surface but their direction can vary due to local subsurface resistivity or even due to the polarization of the incoming waves. These currents are caused by low-frequency energy which strikes the earth's surface as micropulsations (Sumner 1976). These micropulsations which are observed as small magnetic field variations or as small electric currents in the earth, are caused by the low-frequency electromagnetic radiation produced by the effects of the solar wind or the magnetosphere.

There is a wide distribution of frequencies of the telluric currents but their greater proportion is made up of the low frequency energy. Fig.12 shows the power density of the telluric function of frequency taken after Cantwell (1960). From this figure it is evident that the noise increases with decreasing frequency imposing therefore a lower limit to the frequencies which can be used for field measurements.

/ In the

In the field, the elimination of the telluric noise can be achieved by some kind of filtering, either mathematical or electrical. The first requires a great deal of computation making it impracticable in the field. Electronic filters on the other hand are bulky. However, there is a number of measures which can be taken in order to eliminate or reduce to the minimum this noise. These are the following:

a. By increasing the current sent by the transmitter. Currents of up to 5 Amps can be used but higher currents create other problems.

b. By increasing the signal at the receiver for given current values. This can be achieved with certain electrode configurations such as the pole-dipole and the Schlumberger which give higher signals for a given current.

c. If the transmitting and receiving dipoles are on different resistivities the telluric noise will be minimised by placing the receiving dipoles on the low resistivity ground.

d. By reducing the potential electrode resistivities to the minimum by improving the electrical contacts.

e. By averaging a number of readings taken at the same position.

D. <u>Signal -to- Noise Ratio</u>

During an I.P. survey due care must be given to the amount of noise which is expected at the receiver and measures must be taken to reduce this to the minimum. The signal voltage for a given array and spacing is given by the apparent resistivity formula:

$$Vs = \frac{\rho I}{\varphi}$$

where φ is the geometric factor of the array which is a function of the electrode spacing and separation. The noise voltage Vn is given by equation:

/Vn

$$Vn = Ka\sqrt{\rho} \qquad \text{(Summer 1976)}$$

where K is a filtering constant depending on the receiver and a the electrode spacing. The signal-to-noise ratio is then given by the equation:

$$\frac{Vs}{Vn} = \frac{I\sqrt{\rho}}{\varphi K\, a}$$

This equation shows the relationship between the signal-to-noise ratio and the different parameters which can affect it. It is obvious that in low resistivity areas the signal-to-noise ratio will be low. This can be increased to the maximum by applying a higher current and a low-noise configuration (small φ) and the lowest electrode spacing depending on the purpose of the survey.

V. I.P. FIELD EQUIPMENT

Basically there are two different types of equipment for measuring the I.P. phenomenon, one for the Time Domain and the other for the Frequency Domain method. These two different types of instrumentation were developed rather simultaneously by various research institutions and instrument manufacturers. The most notable is Newmont Exploration Limited who developed both time domain and frequency domain equipment and demonstrated the equivalence of pulse, frequency and phase angle I.P. measurements (Dolan and McLaughlin 1967). Other valuable contributions to the development of I.P. instrumentation were those of Madden and his coworkers at the M.I.T., McPhars and Geoscience for the Frequency Domain, and Huntec and Scintrex for Time Domain instrumentation.

An I.P. unit of either type (frequency or pulse) consists essentially of three different components. The first is the power supply which can be either a battery device or a generator, the second is the current transmitter, and the third, and most important, the I.P. receiver.

A. The Power Source

The type of the power source depends on the output of the system. Small I.P. units up to 250W are powered by rechargeable batteries which are often enclosed in the transmitter console itself. More powerful units are powered by high frequency (400Hz) AC generators. The reason for using a high frequency AC current is that it can be easily stepped up and regulated. Further it requires a much lighter transformer than a low frequency current.

The generators are usually powered by two or four cycle engines depending on their power.

B. The I.P. Transmitter

The transmitter is that part of the I.P. instrumentation which converts the electric power provided by the generator or battery to the desired current waveform. Fig.13 is a generalised block diagram after Sumner (1976) of an I.P. transmitter for both frequency and time domain work.

The main difference between the two types of transmitters (frequency and pulse) is basically in the form of the transmitted current. In both cases silicon controlled rectifier networks are used which can synthesise any desired waveform. In the frequency domain this is a low frequency sinusoidal wave produced by the phase-control method of current control. The time domain pulse is essentially a square wave which can easily be formed by the combination of two full square waves with a 90 degree phase difference.

C. The I.P. Receiver

1. The Time-Domain Receiver.

In the time domain the receiver measures essentially the amplitude of the transient voltage at one or more predetermined times after the cessation of the energizing current, and compares them with the voltage measured during the transmission of the current. In the older types the synchronization of the receiver with the transmitter was being accomplished with direct wire connection of the two units which was consequently imposing some problems during field work. In the new receivers the instrument is triggered remotely by sensing the "off" instant of the transmitter voltage. In this way the receiver records the I.P. voltage during the transmitter's off time period.

An example of a time domain receiver is shown in Fig.14 which depicts the block diagram of the IPR-8 receiver of Scintrex. Some of the important

/ parts

parts of this receiver are the S.P. bucking which eliminates any potential difference due to S.P. across the receiving electrods, and the 50 (or 60) Hz filters which filter out powerline frequencies. The A.S.P. (automatic S.P.) circuit takes into account and corrects for any possible S.P. change during the taking of the measurements. The programmer generates all the necessary control signals required for the automatic operation such as the timings of the recording of the transient amplitudes. The memory allows the simultaneous recording of this transient voltage at more than one times and the sequential display of the results.

The popular Huntec MK3 Receiver is described in much detail in Chapter Three of this Thesis as it was used extensively throughout the present study.

2. The Frequency Domain Receiver.

This is essentially a specialised, sensitive, low frequency voltmeter. Fig.15 shows a simplified block diagram of a typical frequency domain receiver (after Sumner 1976). In this type of receiver the voltage of two or more frequencies are measured separately. In the case of sequential transmission, the different voltages are measured separately and then compared to give the frequency effected. In the dual frequency simultaneous transmission the voltages of the two frequencies are measured simultaneously and the frequency effect is immediately displayed on a meter. A phase reference system is required for the measurement of the different frequencies. In the past this was achieved with direct wire link. New instruments have overcome this limitation with special electronic circuits.

/ VI. I.P.

VI. I.P. INTERPRETATION

The purpose of the interpretation of an I.P. survey can be considered as two-fold. The first is the conventional geophysical interpretation in which the geometry and depth of a polarizer are determined. The second involves the approximate establishment of the nature of the conductor in terms of mineralogical composition and grade.

In the first case there is a number of methods currently used. One group includes all those indirect methods which are actually a comparison of the field data with case histories, physical model studies, and master curves. The second group comprises the direct interpretation methods such as numerical modelling. Below each method in briefly reviewed.

A. Case Histories

In this method the field data are compared with previously obtained results over structures which were either known before their I.P. surveying, or have consequently been drilled and their structure and geometry verified. Such case histories have been puplished in the geophysical litterature. Geophysical contractors, such as McPhars, release regularly case histories from their surveys over the world.

It is understood that by this method of interpretation it is not expected that an identical case will be available to match with the results being interpreted. However, the present author feels that whenever possible some form of case histories must be established for a particular environment of ore occurrence by orientation surveys over previously known structures in the same environment. This has been applied by the author and proved to be of much use.

/ B.

B. Physical Model Studies

In this method the I.P. responses of particular structures, geometries and polarizers have been studied with the use of models, and the field results are compared as in the case histories with available model data. Such model studies have been carried out by Hallof (1967) of McPhars for various sizes and geometries of polarizers. In these model studies he used a plastic model block impregnated with graphite as the polarizing body in an alkaline solution. Real polarizable materials have also been used by other researches on a small scale to simulate real conditions. Quick (1973) in a Ph.D. thesis has presented a large variety of model cases particularly for the gradient array. Small scale experiments were also described by Bertin and Loeb (1974).

C. Theoretical I.P. Curves - Master Curves

In this method the I.P. results are treated in a similar manner to that of the resistivity interpretation methods with the use of theoretically computed master curves. There is a number of mathematical techniques which are applied for the computation of these curves. The applicability of the curve matching method in I.P. interpretation was discussed in Patella (1971). Elliot is marketing a library of I.P. master curves for all the commonly used electrode arrays.

D. Numerical Modelling

With this method geometric shapes can be investigated mathematically with the use of numerical techniques. Obviously such methods require the use of digital computers. The most commonly used methods are the finite difference which is based on the Taylor series expansion of a function of two variables, and the finite element method which can deal with more irregular boundaries and heterogenous models. Examples of this method are given by Coggon (1971 and 1973).

/ E. Direct

E. Direct Interpretation Methods

The direct methods use the field potentials to come to a direct solution of the subsurface structure. This procedure is not being applied as much as the methods described above. Dieter et alia (1969) have first developed a method for the direct interpretation of the I.P. data for the pole-dipole array in terms of a sphere.

The possibility of direct interpretation was discussed by other authors who suggested a number of criteria for interpretation. Komarov (1967) has suggested that for the gradient array the depth to the center to a conductor can be determined by placing one of the current electrodes over a previously determined anomaly. Then the distance of the anomaly from this current electrode equals the depth to the center of the anomalous body.

Quick (1973 and 1974) has proved that the direct techniques of total or vertical magnetic field interpretation can be applied for the gradient chargeability results. He has also presented a number of empirical equalities for the interpretation of gradient array profiles over a number of geometries.

/ VII. A

VII. A REVIEW OF THE WORK ON THE TRANSIENT SHAPE

A. The work of Wait (1959)

The first attempt to investigate the shape of the I.P. transient was that of Wait (1959), who has studied the shapes of rock sample decays. In his study he used three different parameters:

1. The Rate of Decay.
2. The Decay Curvature.
3. The Rate of Change of Curvature.

1. The Rate of Decay.

This was studied at different points on the decay curve given, by the formula

$$Pn = \frac{Mn-1 - Mn+1}{Mn}$$

where M are decay amplitudes at successive times. This numerical formula is according to Wait (1959), closely akin to the first derivative of the curve divided by its response at the central point.

He has found that the mineralized samples he studied were characterised by generally higher rates of decay compared with the non-mineralized ones.

2. The Decay Curvature.

This parameter is considered by Wait (1959) to be closely akin to the second derivative with respect to $\log_e t$ divided by the magnitude of the response at the central point. It is considered to be a measure of the departure of the decay curve from a $\log_e t$ type of decay. It is given by the formula:

$$N = \frac{M1+M3-2M2}{M2}$$

/ Wait

Wait (1959) considers this criterion as more truly characteristic of the curve shape alone. He stated that a positive N value implies a decay curve which is "concave-down" at the point in question.

From his experimental work he had found that the non-mineralized samples had mostly negative N values whereas the mineralized samples had always positive values. The overlap of the range of values for the two was found to be almost zero and it was thus considered to be characteristic.

3. The Rate of Change of Curvature.

This parameter, considered by Wait (1959) to indicate how the curvature changes along the curve, is given by the formula:

$$Q = \frac{-M1 + 2M2 - 2M4 + M5}{M3}$$

The numerator of this formula is akin to the third derivative at M3 time. He has concluded that the mineralized samples had lower values (of Q) than the non-mineralized.

4. General Conclusions on Waits study.

Wait has plotted all these parameters with respect to the response at 1 sec, and has drawn the medians for the mineralized and non-mineralized samples separately as the lines with equal number of readings above and below them. Then he estimated the percentage of the mineralized points that lie below the median non-mineralized line.

The results were as follows:

P 0.3	75%	N 0.3	83%	Q1	66%
P 1	66%	N 1	100%		
P 3	91%	N 3	66%		

/Since

Since 100% of the mineralized samples were under the N1 non-mineralized median, he considered the N1 as the "best quality from this standpoint". Further, Wait (1959) has examined the variation of these parameters with respect to the mineralization content of the samples. He has observed no relationship except for a vague trend in N1.

In his concluding remarks he states:

(a) The rate of decay at 3 sec, P3, to be "seemingly diagnostic".

(b) The curvature, N, at 1 sec to be a "very good criterion".

(c) The mineralization content could not be estimated from properties of the I.P. curve.

B. The work of Collet (1959)

Collet (1959) has presented some results of laboratory studies of the transient curves carried out by Newmont Exploration Ltd. He has demonstrated for the first time that the different minerals show different decay curves. The main part of his experimental work, however, was the investigation of the decay changes with respect to variations of the primary voltage, the amount of the electrolyte, type of electrolyte, concentration of electrolyte, temperature, particle size and relative particle volume.

C. The work of Ebell (1965)

Ebell (1965) in a paper describing some time-domain field trials where he has suggested new parameters for the presentation of I.P. results, has also studied the transient decay curve. He has not found any difference in the shape of the curves over sulphide and graphitic polarizers and he has thus concluded that the curve shape "hardly offers any possibility of separating graphite and sulphide conductors". Further he introduces the parameter IP(2)/ IP(0.4) (transient value at 2 secs divided by transient value at 0.4 sec) which he has found constant in neutral areas but increasing markedly over both sulphide and graphitic mineralization.

/ D. The

D. The work of Bertin (1968)

Bertin (1963) in a paper on I.P. has made some remarks on the decay curves. In a statistical study of "apparently simple decay curves" he has calculated the parameters $\frac{P2}{P1}$, $\frac{P4}{P1}$, $\frac{P8}{P1}$, where Pt denotes the transient amplitude at secs. On plotting numerous such results versus the response at 1 sec he has found that each of these parameters were distributed in alignment and with an absolute dispersion of ± 5%. He has concluded that in a rough estimate and for the interval of 1 to 8 secs, "that the decay curves have the same time constants and that one point is sufficient to determine their amplitude".

Bertin (1968) has also observed complex decay curves and also negative I.P. phenomena. In the first case he has noted that the complex decay was the result of the superposition of a short duration effect on a major effect of longer duration. In the case of the negative I.P. he has explained tentatively the phenomenon as occurring in an outcropping polarizable layer where the surficial depolarization currents are in the opposite direction to the primary current. The negative I.P. has also been explained in the case of a burried polarizable body as again being caused by depolarization currents resulting from the position of the polarizing body in depth. In this way he explained the negative flanks which are observed in shallow seated polarizers of limited lateral extent.

E. The work of Scott and West (1969)

Scott and West (1969) in studying the I.P. of synthetic high resistivity rocks, have touched upon the subject of the decay curve. They have observed that their curves were linear when plotted on a $\log_e t$ base and linear potential axis. On a log-log plot they observed that there was a suggestion of two linear segments, the second beginning at about 0.5 sec with a more rapid fall-off than the first.

/ With

With regard to the decay shape they have observed no obvious change or change in the rate of decay with increasing current density. In the quartz-loaded specimens - no sulfides, the decay curves had the same general form as those of the sulphide loaded specimens, although they observed a tendency for a slightly more rapid fall-off.

F. The work of Siegel (1970)

Siegel (1970) claims that it has been known since 1950 that "useful secondary information is available in the shape of the transient decay curve". He also believes that this information is related primarily to two factors, first, the average metallic particle size, and second, the presence of electromagnetic transients. Further he argues that it has been established through laboratory measurements that metallic conductors with large average particle size produce long time decay curves, whereas small particle size conductors produce short time decay curves.

For the investigation of the decay curve shape, Siegel (1970) proposed the L/M parameter, originally introduced by Newmont Exploration (McLoughlin 1967). The definition of L and M is given in Fig.16. Siegel (1970) considers this ratio as a sensitive indication of the shape. In the barren areas it was found to be constant to within 20%. Any departure implies abnormal conditions which may be due to either anomalous metallic polarization responce, or electromagnetic, or interline coupling. Further Siegel (1970) argues that:

(a) A significant increase in L/M implies abnormally short time constant which he considers as due to small particle size polarization or positive electromagnetic effect (Fig.17a).

(b) A decrease in L/M implies an increase in the time constant which is due either to large particle size metallic polarizers or negative electromagnetic effect (Fig.17b).

/ (c) Significant

(c) Significant reduction in L/M is indicative of electromagnetic transients of large amplitude and reversed polarity (Fig.17c).

(d) Negative L/M values imply a longer term reversal with prominent negative electromagnetic effect (Fig.17d).

C. The work of Grant (1971)

Grant (1971) believes that the shape of the decay curve "conveys geologically usefull information". He claims that valuable data are therefore discarded because of ignorance and failure to observe them. He considers a number of advantages in being able to monitor the entire decay curve. First, it will permit the identification and thus separation of E.M. transient effects. Second, it might enable the separation of overvoltage from background I.P. or differentiation between responses of different kinds of rocks with substantially different time constants, which might eventually lead to criteria to distinguish between effects from metallic and non-metallic substances. Finally he argues that since the response from small particles is of longer amplitude and shorter duration than the massive concentrations, then it might allow the distinction between massive and disseminated ores.

Further, Grant states that the I.P. decay rates change from point to point and this change does not depend on the chemistry of the polarizable rocks but only on the gross shapes and the electrode configuration. In discussing the effect of the shapes of the polarizable bodies he argues that "the gross envelope of the polarizable medium must have some effect upon the relaxation time because it determines how widely the ions must seek for alternative routes around the blocking grains".

By adopting the model first proposed by Wait (1959) to represent a polarizable medium, Grant (1971) investigates the effect of the shape of the envelope and of the changing electrode positions. For the shape of the

/ envelope

envelope he estimated the decay curve for different values of the d.c. admittance of the film, q, for both parallel and perpendicular to the strike. The results indicate that the decay is steeper for higher q and that it becomes steeper as the direction of the field changes from perpendicular to parallel with respect to the long axis of the body, Fig.18. He has observed that the partial integrals which are usually taken in I.P., vary much differently from the changes in the apparent chargeability. For the changing of the electrode positions he has shown that by changing the positions of the current electrodes, the overall decay of the curve changes, Fig.19.

H. The work of Moeskops and Quick (1971)

Moeskops and Quick (1971) in a study of the I.P. effects of sepertinised ultramafic rocks have used the ratio $\Delta V1/\Delta V5$ (=R) (i.e. transient amplitude at one second, divided by the amplitude at 5 seconds) as a measure of the curve shape. By treating their results statistically they concluded that if $R > 2.43$ then the decay is certainly due to membrane polarization, whereas if $R < 2.43$ the type of polarization is uncertain.

I. The work of Quick (1973)

Quick (1973) has investigated the shape of the transient decay for core samples, tank samples and scale models. As a measure of the decay he has used the parameter R, as in Moeskops and Quick (1971). It is evident that high values of R denote rapid decays, and low values slow decays. At first, Quick (1973) has tested the becaviour of R with respect to the current density variation and has found no relation between them. However, he has found that R was related to the charging time with longer decays for longer charging times. In addition he has found no significant correlation between polarizability and R and also not with resistivity.

After a statistical treatment of his results he concluded that metallic

/ and

and possibly graphitic polarizers very rarely have R values in excess of 2.43 and few are likely to exceed 2.36. The membrane polarizers can exceed these values, but also commonly have lower values indistinguishable from metallic polarizers.

In the scale model cases Quick (1973) has found that the time constant of the transient decay varied both from place to place for constant geometry of polarization and with changing geometry of polarization. He has found no effect due to body geometry – as expected from Grant's (1971) work, but he attributed this to possible experimental errors.

Finally, in a discussion on the complex and negative transients he accepted that they really exist, but other effects such as electromagnetic coupling and SP drift may produce such results. He argued that in the real asymmetric transients there may be some geometric information.

J. The work of Phillips and Richards (1972, 1974, 1975)

Phillips and Richards have published a number of papers on the variation of the transient decay curves. In their first paper (Phillips and Richards 1972) they discussed the results over a weakly mineralised area where there was an I.P. anomaly with negative transients flanking the mineralization. The main subject of the paper was the fact that by interchanging the current and potential electrodes the shapes of the decay curves over a particular area were different. In other words they proved that reciprocity did not hold as far as the shape of the I.P. transient is concerned, at least in areas close to mineralization.

In a second paper Phillips and Richards (1974) have studied more extensively the I.P. transient curves obtained over a reciprocal dipole-dipole configuration. They compared the results from a similar work over the same area but with porous pots instead of steel stakes as current electrodes.

/ They

They concluded that the differences they have noticed, and in particular the negative polarization, which was prominent only in the steel current electrode reciprocal arrays, was due to negative polarization on the current electrodes. Although they have noted that the negative effects could be eliminated with higher current densities, they attributed their observations to the decrease of the specific surface resistance of pyrite as the current density was increased, as noted by Anderson and Keller (1964). However, they accepted that this did not hold true for their phenomenon.

In a third paper (Phillips and Richards 1975) they have studied the I.P. decay characteristics of some sulphide and graphite deposits. With their studies they reached the conclusion that the I.P. transient decay was more akin to a $\log_e$ time decay than an exponential decay. The slopes of the regression lines of the $\log_e$ decay were found to parallel closely the magnitude of the I.P. at 1 msec after switch off. In order to compare the slopes of the regression lines, they normalised to the value at $\log_e t = 3$. In general they have found that in traverses across a mineralized zone there was no significant change in the slopes of the normalised regression line. They have observed, however, some difference in the slope of this normalised regression line over a sulphide mineralization compared with a graphitic mineralization and they attributed these differences to the nature of the mineralization.

K. The work of Swift (1973)

Swift (1973) in a theoretical study of the behaviour of the L/M parameter rejected the initial claim that this ratio is indicative of the grain size of the metallic particles. He has suggested that an anomalous L/M value could only be interpreted as evidence of coupling (Gedde and Hawland Rose, 1970). Further he points out that although the L/M recording instruments have the ratio to be equal to unity for normal values, the most typical field values of L/M was found to be between 0.7 and 0.8.

/ L. The

L. The work of Bertin and Loeb (1974)

Bertin and Loeb (1974) have discussed the decomposition of the transient curve of I.P. into different exponential factors. They have assumed that:

$$DV(t) = a_1 e^{-t/T1} + a_2 e^{-t/T2} + \ldots a_n e^{-t/Tn}$$

For their field results in which they recorded the curve for 80 secs after switch off, they decomposed the transient into three factors in a way which appeared to be similar to that suggested by Hutchins (1971).

Bertin and Loeb (1974) have introduced the following parameters which they claimed to be of some significance in the interpretation of field results. These are the parameters $A1 = a_1/DV$ and $A2 = a_2/DV$, where a_1, a_2 and DV are defined in the equation above, and the quotient A1/A2. On the basis of their field evidence, they argued that the A1/A2 ratio is of more diagnostic value than the actual I.P. measurement. They concluded that the rapid decay coefficient (one to several seconds) is related to the polarization of bodies containing metallic minerals, whereas the slow discharge factor (ten to dozens of seconds) is related to rocks with purely electrolytic conductivity.

M. Discussion and Conclusions on the Transient Shape

Many researches examined on which form of plotting the I.P. decay is linear. Wait (1959) observed that the transient curves are approximately straight lines when plotted against $\log_e$ time base, and so did Keller (1959).

In discussing the shape of the decay curve, Ebell (1965) observed that on neutral ground it is more rapid and has nearly an exponential form, i.e. linear with linear time axis and $\log_e$ potential axis. The curves over mineralized ground, however, were considered to be composed of two parts, one following the exponential decay and the other decreasing very slowly remaining

/ almost

almost constant during the recording time. He has suggested that the decay curve could be represented by:

$$\frac{IP(t)}{RP} = Ne^{-t/T} + L$$

where N is the normal overvoltage amplitude with a decay constant T of the order of 1 sec, and L the persisting part which depends largely on the duration of the current pulse. Scott and West (1969) observed that over the time interval used in their experiments, the decay curves were mostly nearly linear when plotted with a logarithmic time axis and a linear potential axis. On a log-log plot they have observed a suggestion of two linear segments, the second beginning at about 0.5 sec with a more rapid falloff than the first. Siegel (1962) also observed that the decay was approximately linear for a reasonable length of time when plotted on a logarithmic time axis and linear potential axis.

Hutchins (1971) and Bertin and Loeb (1974) consider the I.P. decay to be exponential and in fact the sum of series of exponential functions of the form $Ae^{-\alpha t}$. Hutchins (1971) presented a graphical method for factoring the decay curve into the two components

$$e(t) = Ae^{-\alpha t} + Be^{-\beta t} + \text{constant}$$

Phillips and Richards (1975) suggested that the transient voltage values fall close to a straight line when plotted on a $\log_e$ time scale.

From the review presented above, it is evident that it was soon recognised that the I.P. decay curve could disclose useful information regarding the type of polarization, and also the grade of the metallic polarizers. Collet (1959) went a stage further and suggested that each mineral was characterised by different transient shapes. Some of the early workers, such as Wait (1959), Ebell (1965) and Bertin (1968), in their attempt to investigate and use the decay shape, devised various crude parameters for

/ representing

representing the decay curve shape. Siegel (1970) introduced a more elaborate parameter - the L/M ratio, which found some application in routine surveys, adopted even by some instrument manufacturers such as SCINTREX. Serious objections regarding this parameter were later expressed by Swift (1973).

An important contribution towards the study of the decay curve shape was the work of Hutchins (1971) who described it as the sum of exponential functions and devised a method for their computation. This method was adopted by a number of researchers such as Phillips and Richards (1972 and 1974) and Bertin and Loeb (1974), who demonstrated that at least some of these parameters are indicative of the mineralization. For this reason, it was decided during the present research to investigate further the applicability of these parameters particularly in an attempt to establish their usefulness as mineral grade indicators. The present research examines also the possibility of a $\log_e$ time linear curve. For this purpose, a number of parameters describing this shape were devised by the present author. These are described in the following Chapter.

CHAPTER THREE

THE SCOPE OF THE PRESENT RESEARCH

I. INTRODUCTION

Mining in Cyprus has been going on for centuries with the exploitation of numerous shallow seated or partly exposed and oxidised sulphide deposits. A single deposit could have been mined at different times by different people, beginning with the ancients, each taking what was considered to be economic (ore) at his time. Therefore, although the mining history of the island is long, the number of orebodies exploited so far is small, or more correctly the total tonnage of ore produced is relatively small. In the last decades, however, as a result of a number of interelated factors such as the mechanization of the mining methods and the reduction of costs, the reduction of the cut-off grades with the increase in the metal prices, the rate of production has increased considerably. Consequently the necessity for the concurrent increase of the reserves has become more apparent. In the past during the low production years, mineral exploration was being carried out at a slow rate. It was concentrated in the location of extensions or dislocated parts of an under exploitation orebody, or over a gossan. In the latter, the aim was the investigation of the underlying rocks by drilling which was usually preceeded by some form of small penetration geophysics such as S.P.

An important characteristic of the low production years, was that the geology of the environment in which the sulphide mineralization occurs - the volcanic succession of the Troodos Igneous Complex, was not well known. Similarly, the mining geology of the sulphide deposits had not yet been

/ clarified

clarified. Although there were some notable contributions to the subject during those years, each worker restricted his observations within the limits of his area without relating it with other similar environments in other parts of the island.

At present the situation is different. The exploitation of the ore deposits is carried out with higher production rates and exploration has to follow in the same pace. In addition, almost all known orebodies have been mined out and all other mineral indications have been thoroughly investigated. At the same time, however, the geological environment where these deposits occur and their geological features were studied and clarified, indicating that there may be other potential areas than those of the gossans, either hidden under the volcanics or the younger overlying sediments. This finding has justified and dictated the extension of the mineral exploration activities to deeper levels under the surface. Thus the role of geophysics has become more important than in the past where it was merely used for the evaluation of gossans.

For the fulfilment of these new requirements, the geophysicists had to utilise the new and modern techniques which enable the investigation of the subsurface properties at greater depths than before. One of the new methods which has found wide application throughout the world is the Induced Polarization method. The purpose of this thesis is to examine the applicability and limitations of this method in the search for sulphide mineralization in Cyprus.

The purpose of this Chapter is to describe the geological environment where the Cyprus sulphides occur, with a more detail description of their own characteristics, together with an outline of the different geophysical activities which took place in the past. Further, its purpose is to define the scope of the present research and the methods and means with

/ which

which it was accomplished. For these, the Chapter begins with a general outline of the geology of the island of Cyprus followed by a more extensive description of the Troodos Igneous Complex where the sulphide mineralization occurs. This is followed by a detail description of the sulphide mineralization and the geological environments where this is found. This is exemplified by two orebodies which are described in some detail particularly as geophysical targets. Following this there is a definition of the scope of the present research and the different geophysical problems it attempts to clarify, together with a description of the field methods used to resolve them. The next section describes the instrumentation used in this study. This is followed by a brief review of the applicability and limitations of the different ground geophysical methods applied in the past. The previous work with the I.P. method is described in a separate section. The final section presents the results of an orientation study which was carried out over the known deeply seated Agrokipia B orebody. It was on the basis of this study that the various field parameters used in the present research were chosen.

II. THE GENERAL GEOLOGY OF CYPRUS

The island of Cyprus has an areal extend of about 9000 square Kilometers and is situated in the northeastern corner of the Mediterranean Sea. Both topographically and geologically it can be divided into four parallel belts running about east-west. These belts are from north to south:

a. The Kyrenia Range which consists mainly of Carboniferous to Miocene sediments and is considered to be the southernmost arc of the Alpine Chain.

b. The Mesaoria Plain which consists of undeformed sedimentary rocks of Miocene to Pliocene age of a total thickness of about 2700 meters.

c. The Troodos Igneous Massif which is the major topographic and geological feature of the island covering about one fourth of its total area. The sulphide mineralization is found in this igneous complex. For this its geology is described in some detail in the following section.

d. The Southern Foothills which consists of sediments of Campanian to Pliocene age.

A sketch map summarizing the above geological and topographic features of Cyprus is shown in Fig. 20.

III. THE TROODOS IGNEOUS COMPLEX

A. Introduction

The Troodos massif is an elliptical shaped dome which occupies the central and southern parts of the Island of Cyprus. It has a WNW-ESE extent of about 60 miles and its width ranges from 15 to 20 miles. It covers an area of about 900 sq. miles, nearly a fourth of the total area of the island.

The massif is formed by three main groups of Igneous rocks. These are (i) the Sheeted Intrusive Complex, a swarm of diabase dykes occupying the major part, (ii) the Pillow Lavas fringing the Sheeted Intrusive Complex and (iii) the Plutonic Complex. Fig. 1 is a geological map of the Troodos massif.

Exceptionally large positive gravity anomalies (of 240 mgal) have been recorded over the island. The axis of these anomalies lies over the Troodos massif, and it is believed that they are due to the presence of a high density material, probably of the Upper Layers of the Mantle, and the absence of the sialic crust.

B. Geography

The relief of the massif is controlled by the differential weathering of the rocks. The Pillow Lavas which form the periphery, weather easily usually by exfoliation, giving rise to rounded hills and in general a low hummocky surface. The major part has a youthful topography and steep relief resulting from the resistant rocks of the Sheeted Intrusive Complex. Finally the Plutonic rocks have a relatively smooth relief.

The ground rises from sea level in the western side of the massif to 1950 m. on Mount Olympus; the bulk of the massif lies above 600 m.

/ The

The area is drained by about twenty major river systems which have their sources along the Troodos ridge-line. The valleys have been rejuvenated in the recent uplift, and the rivers are in their youthful stage flowing along V-shaped scree-covered valleys forming numerous rapids and waterfalls.

C. Petrology

The rocks of the Troodos massif are classified as follows:

VOLCANIC	Upper pillow Lavas Lower pillow Lavas	THE TROODOS PILLOW LAVA SERIES
INTRUSIVE	Basal Group Diabase	THE SHEETED INTRUSIVE COMPLEX
PLUTONIC	Granophyres Gabbros Ultrabasic	THE TROODOS PLUTONIC COMPLEX

This table shows the structurally highest rocks (Upper Pillow Lavas) at the top and the lowest at the bottom (basic rocks of the Troodos Plutonic Complex).

1. The Troodos Pillow Lava Series.

The Troodos Pillow Lavas fringe the massif with an exception on the N.W. side where the underlying diabase outcrop extends to the coast. They crop out over a relatively low relief country between the Sheeted Intrusive Complex and the overlying sediments. They exhibit a pillow structure with the diameters of the pillows ranging from a few centimeters to a few meters.

The series is subdivided according to the intrusive material into:

a. The Upper Pillow Lavas.

b. The Lower Pillow Lavas.

/ a. The

a. The upper Pillow Lavas.

They consist of uniform accumulations of basalt, olivine-basalt, limburgite and picrite-basalt submarine flows although in certain areas sills and dykes occur. The Upper Pillow Lavas rest on the undulatory upper surface of the Lower Pillow Lavas. The contact between the whole series and the Sheeted Intrusive Complex below is faulted in many places while in others there is an unconformity between them.

b. The Lower Pillow Lavas.

They consist of submarine flows of andesite and dacite with an equal proportion of dykes and sills of basic composition formed contemporaneously with the extrusives. The intrusives are sub-divided into:

(i) Irregular minor intrusions - relatively narrow irregular intrusions cutting the pillow lavas without any preferred orientation, and

(ii) Major dykes - considerably thicker intrusions with a regular north-south trend.

2. The Sheeted Intrusive Complex.

The Sheeted Intrusive Complex forms the greater part of the massif cropping out between the overlying Pillow Lava Series and the Plutonic Complex. The major part of the complex is formed by a swarm of basic dykes, individuals of which are from 0.5-3 m thick. The dykes which are basic in composition exhibit a very good sheeted structure with a dominant N-S trend and very steep dip which usually exceeds 60°.

According to the host rock the complex is divided into:

a. The Diabase-with structureless host rock occurring in the form of thick sheets between the dykes, and

/ b. The

b. The Basal Group - with pillow lavas as host rock.

a. The Diabase.

This shows a characteristic uniform sheeting structure with parallel joint planes, separated by layers of structureless host rock. It has a splintery fracture and weathers easily forming extensive screes along the sides of the valleys. The diabase is a microcrystalline rock composed essentially of plagioclase feldspar, amphibole, chlorite and quartz, the accessories being sphene, iron oxide and epidote. The relative proportion of these minerals varies according to the degree of metamorphism the rock suffered during the emplacement of the plutonic rocks. This variation is easily observed in quartz which in the outer margins occurs in small quantities, while in the inner margins near the Plutonic complex it becomes abundant.

b. The Basal Group.

The Basal Group has a host rock of pillow lavas which have been intruded by andesitic or basaltic dykes 1 to 3 m. thick forming the major part of the group. The pillow structures occur as screens usually 2 to 3m. wide between the dykes. The dykes and pillow lavas have a similar mineralogical composition ranging from that of an altered basalt or andesite to diabase.

3. The Troodos Plutonic Complex.

The Troodos Plutonic Complex crops out on Mount Olympus, in the central part of the massif, occupying an area of about 95 sq. miles and in the Limassol Forest, in the S.E. part, over an area of 55 sq. miles. It consists of rocks ranging from ultrabasic to granophyric types. According to their composition they are classified as follows:

/ a. The

a. The Ultrabasics.

b. The Gabbros.

c. The Granophyres.

The Ultrabasic rocks in Mount Olympus occupy the central dome and are surrounded by the Gabbros which outcrop over a relatively large area. In the Limassol Forest area the Ultrabasics exceed the Gabbros. The Granophyric group is exposed over a small area. In particular on Mount Olympus it occurs as a narrow zone around the Gabbros.

D. The Structure

The regional structure of the Troodos Massif is of an anticline running in an east-west direction formed by the recent uplift of the area. North-south compressional forces during the uplift produced innumerable fracture zones in the incompetent volcanic rocks. The first fault zones are dated from pre-Upper Pillow Lava times when the Sheeted Intrusive Complex and the Lower Pillow Lavas were subjected to high pressures. Numerous other faults also developed, mainly along the sheeting planes of the diabase. Intense faulting also took place during the emplacement of the plutonic rocks in the Alpine orogenic movements. Low hading and tear faults are the predominant types; there is also a number of extensive thrust faults in the diabase outcrop area. The Ultrabasic rocks have been uplifted with regard to the surrounding Gabbro by peripheral fractures. These fractures are well developed in the north, south and eastern margins of the plutonic rocks giving rise to an extensive breccia zone in the bastite-serpentine rock outcrop. The diabase sheets and the dykes have a predominant north-south trend and a low dip to the east, indicating that their structural pattern may be due to east-west tensional relief.

/ IV. THE

IV. THE SULPHIDE MINERALIZATION OF THE TROODOS IGNEOUS COMPLEX

A. Introduction

Massive sulphide ores are known to occur in the Troodos Pillow Lava Series. These deposits are generally small by world standards. The largest Maurovouni was 15 million tons with an average of 40.0% S. and 4.0% Cu. This, together with the second in size, Skouriotissa of 6 million tons, were exceptionally large. The rest of the deposits are smaller. Table 2 gives the size of all known deposits in Cyprus. Fig. 1 shows their distribution throughout the Troodos Igneous Complex.

TABLE 2

Table giving the Size of the Cyprus Orebodies

Mavrovouni	15,000,000 tons
Skouriotissa	6,000,000
Apliki	1,600,000
Kalavassos (Mavridhia)	2,500,000
Mousoulos	1,500,000
Mavri Sykia	750,000
Lantaria	500,000
Pareklishia	200,000
Kokkinonero (Kambia)	2,000,000
Mathiatis (North)	3,000,000
Agrokipia A	500,000
Agrokipia B	5,700,000
Kokkinoyia	1,000,000
Memi	1,500,000
Peravasa	100,000
Ambelikou	16,000
Limni	4,100,000
Kynousa	500,000
Vrechia	300,000
Mathiatis (Mitsero)	200,000

/ The most

The most notable contributions to the study of the Cyprus sulphide mineralization before 1960 were those of Gullis and Edge (1922) and much later of Mousoulos (1957). A strong impetus to the study of these deposits was given by the United Nations Special Fund (Now U.N. Development Programme), which in collaboration with the Cyprus Geological Survey Department has undertaken a survey of the mineral resources of the island. One of the main tasks of this project was the study of the sulphide deposits and the understanding of their mineralogy, genesis, stratigraphic position and relationship with the enclosing pillow lavas. The findings of this project have been presented in numerous reports of the Cyprus Geological Survey, the most important being those of Searle (1968), Searle and Constantinou (1967 and 1968), and Searle and Panayiotou (1968). The Cypriot sulphide mineralization is described in a number of publications such as Hutchinson and Searle (1972) and Searle (1972). A significant contribution to the purpose of that project was the work of Constantinou (1972) for a Ph.D. Thesis. The latest published contribution particularly to the controls of mineralization was that of Adamides (1975) who related the mineral deposits to the structural field developed at a mid-ocean rise, following Moore and Vines (1971) theory that the Troodos Complex was developed on a mid-ocean ridge.

B. <u>A Description of the Sulphide Deposits.</u>

In general, at present, there may be said to be an agreement among the different workers as to the origin and mineralogy of the sulphide deposits, although this was much debated in the past. Their stratigraphic position, however, which is such an important factor in mineral exploration is still being discussed.

The source of the mineralising fluids is considered as being magmatic reaching the surface through fumarolic vent systems. This mode of formation is responsible for the zonation of the orebodies into a number of zones with

/ different

different grades and mineralogy. The top zone consists of massive sulphides corresponding to an exhalative-sedimentary mode of deposition. The massive sulphides comprise hard angular blocks of pyrite with chalcopyrite in a matrix of soft friable pyrite. This zone is underlain by the stockwork zone which is that part of the vent system which was within the pillow lavas during the genesis of the deposit. It consists of highly altered and silicified lavas in which pyrite occupies fractures and cavities. This zone has a lower sulphur content than the higher levels, which diminishes downwards. Fig. 21 is a generalised section showing this zonation and other characteristics of the Cyprus sulphide deposits.

The dominant ore mineral is pyrite accompanied in some cases by marcasite. The main copper mineral is chalcopyrite which occurs in variable amounts. Other copper minerals are covellite, bornite and chalcocite. Sphalerite is present in variable amounts reaching in some cases economic grades.

As mentioned above, the stratigraphic position of these deposits within the volcanic sequence is still being debated. The first dating of the mineralization was that of Gullis and Edge (1922) who studied the Skouriotissa orebody which is directly overlain by sedimentary rocks. They concluded that the mineralization was post-sedimentary with the sediments acting as a barrier to the ascending ore fluids. Mousoulos (1957) and later Bear (1963) have advocated the same age of mineralization. An important finding of the U.N. Development Programme - Geological Survey Department joint project mentioned earlier, - was the realization that the mineralization was intervolcanic. There are, however, different opinions as to where exactly within the lavas it took place. Hutchinson and Searle (1970), Constantinou and Govett (1972) and Constantinou (1972) consider it as predating the olivine basalts of the Upper Pillow Lavas. Searle (1972) has later

/ suggested

suggested that the mineralization took place during the interval between the Basal Group and the Lower Pillow Lavas. The present author believes that the mineralization took place after the extrusion of the lower parts of the Upper Pillow Lavas, the limburgites, and before the extrusion of the overlying olivine basalts.

C. The Environment of Ore Occurrence

1. Introduction.

As described above, the localization of these deposits is considered to be controlled by fracture systems in the volcanic rocks which acted as passage ways to the mineralizing fluids. Obviously these systems were related to major tectonic events in the history of the Troodos Massif. The philosophy of exploration is essentially based on this model.

2. The Mineralized Zones.

The recognition of the existence of mineralized zones is attributed to Prof. Mousoulos (1971) who classified the ore deposits, from the exploration point of view, into two types. The first type includes those deposits which are found within those zones in the form of local sulphide concentrations, and the second those which represent the exhalative part of a fumarolic system. This second type was essentially formed only in those cases where the vent system reached the surface of the volcanic rocks. This model has guided the exploration activities of the Hellenic Mining Company Ltd.

Such zones of mineralization were recognised in many parts of the Troodos volcanic series explaining in all cases the occurrence of sulphide mineralization. An important characteristic of these zones is their small width and a large extent. The width is generally less than 100 meters decreasing towards the higher parts in the case of a blind zone into a very

/ thin

thin zone which could have the appearance of a mineralised fault and in some cases even a narrow fault. An example of such a zone is the Kokkinovounaros-Kambia mineralised zone which in the lower parts of the volcanic succession attains a width of about 100 meters decreasing gradually to a mineralised fault and later to a fault before it is covered by the post mineralization volcanics. Where these zones are seen to extend down to the Basal Group, they widen with minor sulphide mineralization in the form of thin veins and impregnations and is heavily iron-stained at the surface. In some occasions these zones can also be traced into the Diabase which again appears to be ironstained on the surface, with impregnations and minor veins of sulphides. Since these zones were preexisting fractures, their present boundaries with the country rocks must have characteristics of both the tectonic fracturing and the effect of sulphide mineralization. In general, it can be stated that their boundaries are clearcut. However, in their lower parts they are usually found to extend outside these clearcut boundaries in the form of alteration of the country rocks. On the surface this appears as an ironstaining occurring as a thin halo surrounding a more intensive mineralization. In the higher parts these boundaries are usually clearcut faults enclosing between them the mineralization with no effect at all on the surrounding rocks. Examples of these two cases are the Kokkinovounaros and Kambia areas which are described in detail in Chapters Six and Nine of this Thesis.

The longidutinal extent of the zones also merits discussion. Being originally tectonic zones the faults must have had certain extents. The mineralization along these zones was concentrated in those parts of the fracture system where brecciation was more intensive. For this reason the mineralised zones do not extend throughout the whole of the presently exposed volcanic succession but terminate within it and link with the underlying volcanics at depth. Further, the mineralization also occupies other

/ complementary

complementary structures of the original fault system and give rise to offshoots of the mineralization. The extent of these offshoots could be limited or extended according to the intensity of the faulting and the mineralization itself.

An important aspect of this type of mineralization is the localization of sulphide concentrations. This is essentially controlled by the mineralising fluids themselves, and the T-P conditions. The amount of brecciation, however, also plays an important role. Evidently if a second fault system intersects the mineralised fault zone some concentration of sulphides would occur at their junction. Within the zone itself there may be some concentrations resulting from local variations in these conditions. In addition an offshoot may be found to contain high grade mineralization resulting from the lack of any further passage of the rising fluids.

The intersection of the mineralised zone with other major structures could be the most important factor in the localization of sulphide concentrations rather than the feeder structure itself. Such an explanation was given by Adamides (1978) for the Kalavassos Area where the main feeder was found to be a major fault, the Mavridhia Fault, considered to be a complement of a transform fault (TF, Fig. 1) extending all along the south of Cyprus, and the mineralization was concentrated in contemporaneous tectonic zones trending at right agles to the Mavridhia Fault.

So far it has been assumed that fracture zones are continuous. It has been observed, however, that in the case of the Kokkinovounaros-Kambia zone there are two zones arranged an enhelon. This arrangement of large scale tectonic structures has been reported in the litterature (Badgley 1965).

An important implication is the effect of post mineralization tectonics. According to the stress field the mineralised zones could be cut and displaced

/ to various

to various extents. The mineralized zones are usually found to be affected by cross cutting faults which would result to a successive downthrowing of the mineralization to lower levels. An example of this is the Kokkinoyia Ore - zone which is described below as an example of an orebody.

The utilization of existing planes of weakness must also be expected during a post mineralization tectonic disturbance. With this it is justified to expect some movements along the faults which enclose the mineralized zone. These could either uplift the mineralization forming a horst structure or downthrow it into a graben. The best examples of a horst structure is the Mathiatis North Orebody which is described below as an example of a sulphide deposit. The only example of mineralization occurring in a graben that the author is aware of, is perhaps the Vrechia deposit. This is not certain, as the area has not been mapped in sufficient detail.

3. The Types of Oredeposits.

From the preceeding description of the Cyprus sulphide mineralization, it is evident that economic sulphide deposits could occur in a number of different but closely related modes. Fig. 22 summarises the different environments in which sulphide mineralization could be found, all originating from the same general mechanism i.e. a fracture zone acting as channelway for hot mineralizing fluids.

From the exploration point of view there are a number of important effects which could impose serious limitations on a geophysical program. The first is of course the depth to the top of the mineralization. This is related with another very important aspect, the size of the mineral deposit. Both these effects play together an important role in the applicability of a geophysical method. The existence of parallel running extensions of a mineralized zone or even a limited offshoot which could have economic

/ concentrations

concentrations should also be demonstrated by a geophysical method. This imposes immediately problems of resolution. One of the most important problems encountered in exploration is the grade of mineralization. From the preceding description it is evident that disseminated mineralization could be found extensively along a zone. This is generally unwanted since it is not usually cupriferous but it gives rise to strong I.P. anomalies. Cupriferous disseminated mineralization is only known to occur in the Basal Group and the Diabase.

D. Examples of Orebodies

1. Introduction.

In the preceding pages there was given a general account of the sulphide deposits of Cyprus and their different modes of occurrence which are the result of erosion, intensity of fumarolic activity, post mineralization tectonic movements and overlying rocks. For a better understanding of these different modes of ore occurrence, there is given below a description of two orebodies, the Mathiatis (North) orebody and the Kokkinoyia orebody. Both the orebodies are under mining at present, the first by opencast and the second by underground method. Other mineralized areas-orebodies where I.P. surveys were carried out during this present research are described in other Chapters of this Thesis.

2. The Mathiatis North Orebody.

a. Introduction.

This is located about 27 kilometers south of Nicosia, see Fig. 1. The exploitation of this orebody started during the Roman times as evidenced by the presence of an ancient slag heap in the viscinity. In 1952 the Cyprus Mines Corporation carried out a drilling programme over and around the gossan, which proved the existence of a pyrite body of about 3 million tons with an

/ average

average grade of 33% S. and 0.24% Cu. In 1964 the Hellenic Mining Company acquired the Mining Lease and since then it mines the orebody periodically. The orebody was studied by a number of workers the most important being Searle and Panayiotou (1968) and Constantinou (1972). The present author mapped and studied it in detail and investigated its possible extent particularly in depth (Maliotis 1974).

b. The Shape of the Orebody-Tectonics.

The shape of the orebody is controlled by two parallel faults which enclose the mineralization. Fig. 23 is a geological map of the orebody at its present state. It shows clearly that it is bounded to the northwest and southwest by two parallel trending normal fault zones in a direction of 300°. To the east there is a third normal fault bounding the orebody on this side. To the northwest the contact is normal-younger lava flows overlie the mineralization. As a result of the tectonic movements the orebody was tilted by 40° to the northwest. The surrounding rocks on all sides are younger and fresh Upper Pillow Lava flows appear in contact with the mineralization. Fig.24a is a section across the orebody demonstrating its horst form.

c. The Mineralization.

The Mathiatis (North) mineralization attains the typical sulphide zonation described earlier in this Chapter. However, as a result of the tilting this has at present a different-oblique, attitude and is exhibited well on a horizontal plane. This is shown in Fig.23 and in Fig. 24b, which is a longitudinal section of the mineralization. The massive ore which grades more than 40% S. has a thickness of 15 meters and consists of sandy and friable pyrite with blocks of solid pyrite embodied in it. It is underlain by a medium grade ore zone having a thickness of about 30 meters, with 30% to 40% S, and consisting of hard sulphides with white silica. Below there is a stockwork zone with a variable S content, beginning with 30% at the top and

/ decreasing

decreasing downwards. It consists of sulphide mineralization in the form of veins in brecciated, altered and pyrite impregnated lavas. In general the mineral assemblage is pyrite and marcasite with rare chalcopyrite and sphalerite. The high grade is overlain by a three to eight meters thick bed of ochre which was formed by the subaqueous alteration of the high grade ore before the extrusion of the Upper Pillow Lavas (Constantinou, 1972).

3. The Kokkinoyia Orebody.

a. Introduction.

The Kokkinoyia orebody is situated about 17 kilometers southwest of Nicosia, see Fig. 1. This body was first mined by the Romans or even possibly by the Phoenicians who exploited the mineralization directly under a colourful gossan. In 1962 the Hellenic Mining Company Ltd. who held the prospect since 1937 initiated a drilling programme to investigate the lateral extend of this mineralization. As a result of this it was realised that the zone of mineralization had a northeasterly direction plunging by about 30^{o} under the Upper Pillow Lavas. Three high grade concentrations were located during this drilling programme and their underground mining started in 1973. The original ore reserve estimates have indicated an orebody of about 1.0 million tons with over 1% Cu.

The Kokkinoyia orebody was studied and described by Searle and Constantinou (1968) and later by Constantinou (1972) using only the drilling records. Christoforou (1975) mapped and studied the underground workings in detail. Recently, Maliotis and Christoforou (1976) studied the tectonics in the Kokkinoyia Mine in an attempt to clarify the extension of the zone to the northeast.

/ b. The

b. The Shape of the Orebody.

This is essentially a mineralized zone with a SW-NE direction. This is exposed in the southwestern end where it forms a colourful gossan in the Lower Pillow Lavas. Further south this gossan grades into iron-stained Basal Group rocks. To the northeast the zone plunges by about 30^{o} below post-mineralization volcanics. The boundaries of this zone are two parallel running and opposite dipping faults. These are considered as being the original boundaries of the tectonic zone. There is evidence that some movement has also taken place along these fault planes at a later stage. Fig. 25 is a tectonic map of the 400 m level of the Kokkinoyia Orebody compiled from underground mapping and borehole information. This demonstrates the existence of the bounding faults F1 and F3, the plunging of the zone indicated by the convergence of the two faults, and the post mineralization cross cutting tectonics.

In general the sulphide mineralization of this zone does not demonstrate any recognizable zonation. Instead of grading into a hard and silicified ore, it grades into a soft, altered and pyrite impregnated lava - the propylite. Three main separate bodies of high grade ore were found and exploited in this orezone. These are considered as local concentrations of mineralization within the orezone. There is strong evidence that they were displaced by post mineralization tectonics. Their contacts with the lower grade are always faulted and it appears that these high density bodies "sunk" into the plastic propylitic mineralization.

c. The Mineralogy of the Orebody.

Mineralogically the orebody consists essentially of pyrite with subordinate amounts of chalcopyrite, bornite, chalcocite and sphalerite. In the high grade concentrations the sulphur content could be as much as 45

/ to 50%

to 50%. In the propylitic mineralization the sulphide mineralization which is essentially pyrite occurs in impregnations and thin veins. There is some evidence of silicification in this lithology.

E. Conclusions on the Sulphide Mineralization

In the preceding pages there was given a description of the Cyprus sulphide mineralization, its origin, mineralogy, original form and stratigraphic position in the volcanic sequence. Due consideration was given to the environment in which economic grades could be found and their different implications as geophysical targets. Two general types of economic deposits are recognised, the first is that of a high grade exhalative body underlain by stockwork mineralization. This is generally found to be overlain by the olivine basalts of the Upper Pillow Lavas. The second type is that which occurs mainly in the Lower Pillow Lava terrain, associated with major tectonic zones which acted as passages to the ore fluids. These deposits could either be the roots of the first type exposed at a lower level due to erosion, or even the higher parts of a vent system which did not reach the lava surface during the fumarolic activity. Such deposits could be covered by fresh rocks of the Lower Pillow Lava series. There were given two examples of oredeposits,which together with their geological characteristics they have demonstrated the importance of the post-mineralization tectonics.

/ IV. THE

IV. THE SCOPE OF THE PRESENT RESEARCH

A. Introduction

As described above the economic mineralization in Cyprus is intimately associated with fracture zones which occur in the Lower Pillow Lavas and can extend up to their contact with the overlying olivine basalts of the Upper Pillow Lavas. An exploration project could therefore have different targets. First it could aim at locating such zones in a Lower Pillow Lava terrain which are blind, or suspected to occur from the sparse indications of mineralization along a major fault. Second, it could have the purpose of investigating the extent of such zones which outcrop but terminate within the Lower Pillow Lava terrain. Third, it could be carried out in the Upper Pillow Lava terrain in order to investigate the extent of such zones up to the contact with these lavas (U.P.L.). It should be remembered that if such a vent system reaches the top of the Lower Pillow Lava then there is a strong possibility of an exhalative type sulphide deposit. A fourth possibility is to look for concealed zones parallel to an exposed one, or even concealed offshoots of an exposed mineralized zone.

B. The Scope of the Thesis

The purpose of the present Thesis is to examine the applicability and limitations of the I.P. method in the search for such targets. An important question to be answered is whether all these different targets can be detected with the I.P. method. Further, it is essential to establish the conditions for locating these targets in different field situations. Another major subject to be discussed is the problem of the interpretation of the geophysical data over these targets with respect to their geometry and grade. Since the mineralized zones may have grades ranging from disseminated to massive sulphides, it is of the utmost importance to be able to distinguish

/ between

between anomalies caused by each of these two types of mineralization.

The present research project utilised some of the field results obtained during the course of the I.P. exploration by Hellenic Mining Company carried out since 1972. All the problems enumerated above were evident from the start and for this the work was not concentrated only on routine exploration but also on a considerable amount of research both in the field and in the office using the collected data. In a number of occasions test surveys were carried out over known targets.

The first project described in this Thesis is that carried out in the Mathiatis (Mitsero) area in the Tamassos Mining Lease. In this area it was known from past drilling of the existence of a small tabularly shaped sulphide body occurring in the Lower Pillow Lavas. During the course of the I.P. project to investigate the responses and extensions of this body, a second parallel and blind zone was located. On drilling this anomaly it was discovered that this second zone was of the disseminated type. Research was therefore concentrated in this area to establish criteria for distinguishing between the two types of mineralization.

The second project was carried out in the Klirou area to investigate the applicability of the method over (a) an exposed low-grade and extensive mineralized zone, (b) a higher grade concealed offshoot of this zone occurring at a depth of about 10 meters under fresh volcanics and (c) over a third mineralization of high grade occurring at a depth of about 100 meters below fresh volcanics. This was actually discovered during the present survey. Particular attention was given on the possibility of discriminating between the different grades of mineralization.

The third project investigated the responses of a typical example of a mineralized zone which is exposed at the surface in the Kokkinovounaros

/ area

area. Attention was given to the interpretation problems of the geophysical results over this type of target particularly the exact location of the mineralization boundaries.

The fourth project examined the applicability of the I.P. method in the Vrechia area which includes a small high grade deposit occurring at a variable depth and a parallel exposed lower grade mineralization. Together with the interpretation problems of such a geometry there was an attempt to discriminate between the grades of mineralization.

The fifth project investigated the applicability of the method over the Petra mineralization which was localised near the intersection of a major feeder fault structure with a minor fault perpendicular to it in which the mineralization was concentrated.

The sixth project investigated the applicability of the I.P. method over a partly exposed narrow zone of mineralization occurring in the Kambia area.

C. Method of Study - Parameters Investigated

The parameters studied during the present research include the N.T.I. which is normally recorded in a routine Time Domain I.P. field survey, together with a number of other parameters which describe the shape of the transient decay. Those parameters include the Decay Factors, the Bertin and Loeb (Modified) Functions and a group of parameters introduced by the present author which describe the characteristics of a $\log_e t$ plotted decay curve. In addition to this the apparent resistivity value was computed from the field data expressed as $\rho/2\pi$ ohm-meters in the tables and pseudosections.

The N.I.T. and resistivity were recorded in all areas covered by the present study. The field parameters were kept constant throughout the survey.

/ The

The electrode configuration used was the pole-dipole with an electrode separation of 50 meters. Readings were taken on electrode separations (n) from 1 to 4 and in some occasions 5. These values were plotted on pseudo-sections in the conventional way.

The shape of the transient decay curve was studied in four areas, namely Mathiatis, Klirou, Kokkinovounaros and Vrechia. This was recorded on the $n = 2$ dipole separation by measuring the transient amplitude at sixteen different points on the time axis. It is important to note that the different parameters which express the shape of the decay curve fall in two categories in agreement with the two different current opinions on the shape of the decay. The first category is that which assumes an exponential decay. This includes the Decay Factors and the Bertin and Loeb's (Modified) Functions. In the latter these functions are normalised to the corresponding resistivity value. The second category includes parameters which consider that the decay is close to a linear decay on a logarithmic time axis and linear potential axis.

The electrodes consisted of stainless steel stakes and porous pots with copper sulphate electrolyte for the transmitter and receiver respectively.

1. The Normalised Time Integral (N.T.I.).

This is defined as the area under the decay curve between two time limits. In the instrument used (Huntec MK3 Receiver, see section on Instrumentation below), the amplitude of the decay was being recorded at four different times normalised to the primary voltage, and the N.T.I. values were computed by multiplying by the width of each area. This normalised amplitude was designated as Mi ($i = 1-4$) and the normalised integral was being expressed in Msec i ($i = 1-4$). This notation was used in this study.

/ The

The different times this M value was being registered were 55, 130, 280 and 580 msecs after the termination of each pulse. The corresponding widths of each area under the decay curve were 50,100, 200 and 400 msecs. These parameters are also explained in Fig. 26.

2, The Decay Factors.

It was assumed by some workers, originally by Roussel (1962) and later by Hutchins (1971), that the I.P. decay could be represented as a sum of a number of exponential factors being therefore in the form:

$$e(t) = Ae^{-\alpha t} + Be^{-\beta t} + Ce^{-\gamma t} + \ldots \qquad (1)$$

where $\alpha > \beta > \gamma$. Hutchins (1972) suggested a graphical method for the determination of the first two factors, the first being the inductive coupling contribution and the second the chargeability contribution. This method is described below in some detail, since it was used extensively, together with a minor alteration introduced by the present author.

For the Huntec MK3 Receiver which includes an automatic S.P. cancellation loop, equation (1) for two factors only, includes a constant P which is the residual chargeability at the S.P. sampling time. Therefore, for a true value e(t) this datum shift must be subtructed from the field readings. The function is then written:

$$y(t) = f1(t) + f2(t) + P \qquad (2)$$

$$\text{where } f1(t) = Ae^{-\alpha t} \text{ and } f2(t) = Be^{-\beta t}$$

Assuming that at the S.P. cancellation time

$$f1(tsp) \ll f2(tsp)$$

$$\text{then } P \simeq Be^{-\beta tsp} \text{ and therefore,}$$

$$y(t) = f1(t) + f2(t) + f2(tsp) \qquad (3)$$

/ Taking

Taking logarithms of both sides:

$$\log_e y(t) = \log_e \left[f1(t) + f2(t) + f2(tsp) \right]$$

Let q being the last time a point has been recorded by the instrument, and being fairly large it may be assumed that

$$f1(q) \ll f2(q)$$

Then,

$$\log_e y(q) \simeq \log_e \left[f2(q) + f2(tsp) \right] \qquad (4)$$

The derivative of equation (4) evaluated at q is

$$\mathring{y}(q) = - \frac{\beta}{1+e^{-\beta(tsp-q)}} \qquad (5)$$

$\mathring{y}(q)$ is the slope of a tangent drawn to the curve y(t) at time q.

Factor β may be obtained by solving equation (5).

Factor β is given by equation

$$y(q) = B \left[e^{-\beta q} + e^{-\beta tsp} \right]$$

Lastly,

$$Ae^{-\alpha t} = y(t) - \left[Be^{-\beta t} + Be^{-\beta tsp} \right]$$

The determination of these factors A, α, B and β is rather simple. It requires first to plot the M readings on semi-log paper as $\log_e$ M versus linear time.

In solving equation (5) Hutchins (1972) has suggested tabulation and plotting of the function for different values of (tsp-q). Below is presented another way of solving equation (5) which was used during the present research. If both sides of equation (5) are multiplied by (tsp-q)

/ then

then

$$\mathring{y}(q)\,(tsp-q) = \frac{\beta\,(tsp-q)}{1+e^{-\beta(tsp-q)}} \qquad (6)$$

let $z = \beta(tsp-q)$ and $C = \mathring{y}(q)\ (tsp-q)$

Then equation (6) may be written as

$$C = \frac{z}{1+e^{-z}} \qquad (7)$$

This function has been plotted for different values of z and equation (7) can be solved by using this plot shown here in Fig. 27. The value of β is then given by the relationship

$$\beta = \frac{z}{t(sp-q)}$$

The advantage of this graphical solution of equation (5) is that Fig. 27 can be used for any combination of values tsp and q.

An example of factoring the decay curve into the function $y(t) = Ae^{-\alpha t}+Be^{-\beta t}+P$ using the above method of Hutchins (1972) is given in Figs 28 and 29. Fig. 28 shows the graphical steps in a log-normal plotting and Fig.29 the calculations in a form prepared and used in the present research project.

3. The Decay Characteristics of a $\log_e t$ Plotted Transient.

A number of parameters were introduced by the present author in order to describe the characteristics of the transient voltage plotted against $\log_e t$. Strong evidence is presented in the following chapters that these curves are not linear as suggested by a number of workers in this field (Scott and West, 1969, Siegel, 1970, and Phillips and Richards, 1975). These new parameters are defined as shown on Fig. 30. As it will be demonstrated in the following Chapters, these curves consist of two components: an early linear and

/ rapidly

rapidly decaying, and a later slow decaying and curved (Fig. 30). The parameters used to describe such a transient shape are:

a. R1 - the rate of decay per $\log_e$ decade of the first component.

b. R2 - the rate of decay per $\log_e$ decade of the second component (measured always in the interval of 100 and 1000 msecs).

c. R1/R2 - the ratio of the above two factors.

d. t_d - the time the second component begins to deviate tangentially from the first component.

e. V_d - the potential value at which this deviation begins.

f. d(0.5) and d(1.0) - these are measures of the deviation of the second component from the first linear one and are expressed as the distance in msecs measured between the first and second components at the potential values of 0.5 mV and 1.0 mV respectively.

4. The Bertin and Loeb's (1974) Functions (Modified).

Bertin and Loeb (1974) also factored the I.P. transient into a form similar to Hutchins (1971) and introduced the parameters A1 and A2 and their ratios A1/A2, where A1 and A2 are defined as:

$$A1 = \frac{A}{DV} \quad \text{and} \quad A2 = \frac{B}{DV}$$

where A and B are defined by:

$$y(t) = Ae^{-\alpha t} + Be^{-\beta t} + P$$

and DV is the primary energizing voltage measured at the receiving electrodes. This, of course, assumes a constant energizing current and electrode geometry. In the present study these parameters were "modified" into

$$A1 = \frac{A}{\rho/2\pi} \quad \text{and} \quad A2 = \frac{B}{\rho/2\pi}$$

since the energizing current is not always the same.

/ An important

An important difference between the original parameters of Bertin and Loeb (1974) and those computed in the present study, is that they recorded the transient in the interval between one to twenty seconds after the interruption of the energizing current, whereas in the present study this interval is between 0.035 and 0.78 secs.

5. The Apparent Resistivity.

This was computed from the primary voltage recorded across the receiving electrodes and the amplitude of the energizing current read on the transmitter.

VI. INSTRUMENTATION

The I.P. equipment used throughout the present survey consisted of a HUNTEC MK2 7.5 KW Time Domain Transmitter and a HUNTEC MK3 Receiver. Below there is a thorough description of the above instruments.

A. The Transmitter - HUNTEC MK2

This unit has a maximum output of 3250 Volts in 10 steps with a maximum current of 16 Amps D.C. The pulse duration of the instrument could be varied as follows: 0.5, 1, 2 and 4 secs. The on/off ratio could have the following values: 1.0, 1.46, 1.91 and 2.55.

Throughout this study instead of the pulse duration, the cycle duration was used which includes two signals of opposite polarity and two off periods and designated as tc. Thus the available tc values of the Transmitter were 2, 4, 8 and 16 secs. The 8 sec cycle time was applied throughout the present work.

The transmitter is powered by a 208V Ac, three phase, 400 Hz generator driven by a 35 HP Perkins diesel engine.

B. The Receiver - HUNTEC MK3

The MK3 Receiver measures the amplitude, M, of the decay curve at several times after the cessation of the energizing current. During a single reading it measures four different M values together with the steady state voltage. The position in time where the M values are recorded are defined by the values of two parameters, the delay time, td, and the integration period, tp. There are five selectable values of both these parameters which are easily changed by subpanel switches. There are therefore 25 sets of td and tp values allowing thus the recording of the transient amplitude 100

/ different

different times. However, there is a considerable overlap in these values which reduces them to 70. Fig. 31 defines the time position of the four M readings with respect to the td and tp parameters. From the same figure it is evident that the M value read by the receiver is at the center of the corresponding integrating period. Table 3 gives the middle values in msecs of the different integrating periods as defined by td and tp.

The processing of the signal in the receiver is described below with reference to Fig. 32 (after Hutchins 1971). The resistance of the electrodes is determined by a buffer amplifier (1) to more than three megohms. The input attenuator (2 and 3) and the manual S.P. are adjusted so than the meter (10) shows a level of 1 to 3 volts symmetrically about zero. Further the signal is filtered for its 50 (or 60) Hz component by filter (4) and then amplified by (6). At that stage the amplitude of the signal at the end of the measuring cycle is sampled every half period by the sample and hold memory register (7), (18) and (8), and is cancelled out by means of the feedback loop around amplifier (6). The signal then passes through electronic switches which are actuated by the synchronizing system (16) of the receiver. This system which has replaced the old wire and radio link between transmitter and receiver, detects the zero time reference point. The inputs of this system are the td, tp, tc and the on/off ratio of the pulse, and the outputs are different voltages which actuate a number of electronic switches. Voltages X and Y actuate the first switch (11), which commutes the signal amplifier output every half cycle. Voltage tn+1 actuates the switch of the sample and hold memory register mentioned above. Voltage To-δ actuates switch (13) which gates a reference voltage VR(12) to the reference integrating register. The same voltage actuates switch 13 B which gates the Vp voltage to the memory register. Voltages t1 to t4 actuate switches 13C-13F during the sampling period which gate the corresponding integrating registers.

/ At

At each half cycle all the registers acquire an increment of

$$Ki \int_{t1}^{t2} e(t)\, dt$$

where Ki is the gain of each integrator and t1 and t2 the integrating time interval as defined in Fig. 31. After L periods the content of each register will be

$$Qn = Ki \sum_{n=1}^{L} \left| \int_{t1}^{t2} e(t)\, dt \right| n$$

In the reference register the value of e(t) is constant, VR, and the content of the register can be written as

$$QR = i \quad L\, V \quad tp$$

(since t1 - t2 for the reference register equals tp). In the Vp register which has a similar value of t1-t2 = tp (see Fig.31), the charge stored in the register will be

$$Qp = \sum_{1}^{L} Kp\, \bar{Vp}\, tp = L\, Kp\, \bar{\bar{Vp}}\, tp$$

In all the other registers, the stored charge at the end of L samples is

$$Qi = \sum_{1}^{L} Ki \int_{t1}^{t2} e(ti)\, dt$$

$$= \sum_{1}^{L} K1 \quad (t1-t2)\ e^{-(ti)}$$

$$= L\, Ki\ (t1-t2)\ \bar{\bar{e}}\ (ti)$$

The gain of the different registers is inversely proportional to the integration times. Therefore,

/ Kr =

$$Kr = K$$
$$Kp = K$$
$$K1 = K$$
$$K2 = K/2$$
$$K3 = K/4$$
$$K4 = K/8$$

Also, as explained in Fig. 31, the duration of the integration times is:

	VR register		=	tp
	Vp	"	=	tp
first	M	"	=	tp
second	M	"	=	2tp
third	M	"	=	4tp
fourth	M	"	=	8tp

Thus the charge at the different M registers at the end of the respective integration times is:

$$Q1 = LK\ \bar{\bar{e}}\ (t1)\ tp$$

$$Q2 = \frac{LK}{2}\ \bar{\bar{e}}\ (t2)\ 2tp$$

$$Q3 = \frac{LK}{4}\ \bar{\bar{e}}\ (t3)\ 4tp$$

$$Q4 = \frac{LK}{8}\ \bar{\bar{e}}\ (t4)\ 8tp$$

When the DVM switch is set at the different positions after the completion of the measurement, this will show the following values:

/ Vp

$$Vp = \frac{Qp}{QR} = \frac{\overline{\overline{Vp}}}{VR}$$

$$M1 = \frac{Q1}{Qp} = \frac{\overline{\overline{e}}}{\overline{\overline{Vp}}}$$

$$M2 = \frac{Q2}{Qp} = \frac{\overline{\overline{e}}\ (t2)\ \%}{\overline{\overline{Vp}}}$$

$$M3 = \frac{Q3}{Qp} = \frac{\overline{\overline{e}}\ (t3)\ \%}{\overline{\overline{Vp}}}$$

$$M4 = \frac{Q4}{Qp} = \frac{\overline{\overline{e}}\ (t4)\ \%}{\overline{\overline{Vp}}}$$

It is understood that the number of samples (L) is the same for all registers.

VII. A SHORT REVIEW OF THE APPLICABILITY AND LIMITATIONS OF THE DIFFERENT GROUND GEOPHYSICAL METHODS APPLIED FOR SULPHIDE EXPLORATION IN CYPRUS

A. Introduction.

The application of geophysics in sulphide exploration in Cyprus started from the early years of this century with the renewal of the mining activity. However, the purpose of the geophysical prospecting at that time was not the location of blind orebodies or extensions of known ones, but the evaluation of the numerous gossans without the necessity of much drilling, which at that time was costly, tedious and time consuming. The only institutions involved in such exploration at that time were the two major and older mining companies, the Cyprus Mines Corporation and the Hellenic Mining Company Ltd.

Although almost nothing is known about the activities of the C.M.C., the Helco archives are available to the author, suggesting that numerous methods were tried and put into a routine basis with relatively satisfactory results.

The first methods tried and applied by H.M.C. were the Self Potential and Equipotential. Both these methods were found useful in the evaluation of prospects with gossans. In fact a number of orebodies, e.g. Kokkinopezoula, were first detected in this way. The Equipotential method found a lesser application than the Self Potential but it was extensively applied in the Mining Leases.

In 1948 the H.M.C. acquired a Nörgaard Gravimeter which was used extensively throughout the prospects held by the company. Later, in 1963 a Vertical Loop Electromagnetic unit was added to the geophysical instrumentation but this had only a limited application. A year later with the

/ initiation

initiation of the U.N. Special Fund - Geological Survey project the geophysical prospecting for sulphides received a strong impetus with the experimenting and application of a number of methods. These were the Magnetics, Gravity, Electromagnetics and Resistivity.

The Pulse Electromagnetic Method (P.E.M.) was first attempted by Newmont Exploration for C.M.C. in 1962 and was recently reintroduced by Noranda Exploration (Cyprus) Ltd.,who together with other methods applied it in sulphide prospecting.

A brief account of the applicability of the different methods is given below.

B. The Magnetic Method

The first known application of Magnetics in sulphide exploration is that of the U.N.S.F.-G.S. project as an auxiliary technique which consisted of measurements of the vertical magnetic intensity. From the beginning of the survey it was evident that the method could not offer much since the sulphide ores are not magnetic and in addition the alteration of the volcanics associated with the mineralization could lower the values of both the remanent and induced magnetization. In fact it was expected that the mineralised zones would be characterised by magnetic lows.

The magnetic susceptibility of the Basal Group, Lower and Upper Pillow Lavas and the intrusives does not differ much having all an average of about $2,000 \times 10^{-6}$ cgs units (U.N.S.F.-G.S. 1970). These rock units, however, show a much greater variation in the remanent magnetization. The Basal Group and the intrusives have the smallest values with directions approximately paralleling the present magnetic field. Stronger values of remanent magnetization are found in the Lower Pillow Lavas, again with almost parallel direction to the present day field. The strongest values of remanence are

/ those

those of the Upper Pillow Lavas with similar direction. As pointed out (U.N.S.F.-G.S. 1970) the magnetic pattern over the volcanic rocks is determined by the magnitude and direction of the remanent magnetization. Stronger variations are also the result of the present attitude of the rocks as a result of the tectonic movements.

In conclusion the magnetic method could not have a direct application in the search for sulphide mineralization.

C. The Gravity Method

The Gravity method is known to have been applied first by H.M.C. in 1947 with their Nörgaard Gravimeter. The method was put on a routine basis and an extensive amount of surveying was carried out as a part of the exploration efforts of the company. As a result of this work, however, a large number of anomalies over fresh pillow lavas were located, which after drilling were found to have no association with sulphide mineralization. Eventually the method was abandoned.

During the U.N.S.F.-G.S. project, the gravity method was applied again on a routine basis using a Worden Gravimeter. The method was again found to have its limitations. In many occasions the gravity anomalies were proved to be due to high density intrusive rocks in the pillow lavas.

It is interesting to discuss briefly the possible effects on the gravity field of the different types of mineralization described elsewhere in this Chapter.

The most decisive factor in this method is of course the density contrast between the mineralization and the enclosing rocks. During the U.N.S.F.-G.S. project a number of density measurements were made using the standard procedure of weighing samples in air and water, for all the related

/ rock

rock formations. The results are shown in Fig. 33. It is observed that there is an increase in the density values from the Upper Pillow Lavas through the Lower Pillow Lavas to the Basal Group. It is interesting to note also the high density of the pillow lava intrusives and the low density of the altered and propylitised lavas. Fig. 33 shows also the theoretical density curve for pyritic ores with respect to their sulphur content. The lowest value must be taken to be about 2gr/cc which is the average value for the propylitised and altered lavas, and the maximum is around 50 gr/cc which is the specific gravity of pyrite (53.4%S). Before going into further discussion it is interesting to point out that the Upper Pillow Lavas have densities equivalent to those of a 17% S mineralization, the Lower Pillow Lavas to a 20% S mineralization and the intrusives up to a 27% S mineralization.

Constantinou (1972) in describing the different orebodies has made a number of interesting observations on the porosity of the mineralization. For the Skouriotissa orebody which consists of conglomeratic ore embedded in sugary matrix which could be as much as 75% of the volume of the ore, the matrix was described as being very porous. The solid blocks are also very porous "and very often they have a 'pumiceous' appearance". Their cavities vary in size "from less than one millimeter to several centimeters". A similar situation was described by the same author at Mathiatis and Mousoulos orebodies. In the later, density measurements of the massive ore made for mining purposes has not exceeded the 3 gr/cc (H.M.C. private files) whereas theoretically it will be from 4 to 5 gr/cc. Christoforou (1975) has reported a similar amount of porosity for the massive ore of Kokkinoyia Orebody.

Constantinou (1972) carried out qualitative measurements of the total surface area covered with pores on polished sections of both the sugary and solid sulphides from the Skouriotissa, Mathiatis and Mousoulos orebodies. He has found that the porosity of the sandy ore varied between 44% and 90%, and

/ for

for the solid sulphides from about 10% to 30%. Fig. 34 shows the effect of porosity on rock density for pyrite (5 gr/cc) for both water saturated and dry, estimated with the use of the formulae:

$$dr = dg(1-P) + P \quad \text{for water saturated}$$

$$\text{and} \quad dr = dg(1-P) \quad \text{for dry}$$

(after Nettleton 1971)

(dr=bulk density, dg=grain density, P=fractional porosity).

It is observed that the density decrease should be significant. A 50% porosity can reduce the density of the high grade ore down to 3 gr./cc.

Taking into consideration that the orebodies are usually small, not exceeding often the three million tons, the high grade ore could be a small fraction of this body. The main part of an orebody consists of lower grade mineralization ranging from 30% to 10% S. Ignoring the porosity of this ore in the form of fractures, theoretically, it will have a density between 2.5 and 3 gr/cc. In conclusion it may be stated that the Cypriot deposits, due to their limited size, zonation and porosity of both the high and lower grade mineralizations, have overall densities which are not significantly different from those of the enclosing rocks. It could be suggested therefore, that in Cyprus the gravity method has serious limitations in sulphide exploration.

D. The Self Potential Method

The Self Potential method was probably the first geophysical method applied in Cyprus. It has found extensive applications since 1930 for the evaluation of mineral indications and gossans. The method was apparently first applied by H.M.C. using an instrument designed and made by Stern (1935).

The method has gained considerable reputation after a number of successes, the most notable being the discovery of the Kokkinopezoula Orebody.

/ In fact

In fact the S.P. anomaly coincided with an extensive gossan which was capping the mineralization. At present it has almost no application since most of the exploration activities are aiming at deeply seated deposits.

E. The Equipotential Method

This method was applied extensively by H.M.C. in the period of 1940-1950 and it was primarily used for prospect evaluation over gossans. It was found to be a useful technique and it was usually applied in combination with the S.P. method. As with the S.P., the Equipotential method was not applied in the search for deeper deposits. However, the author believes that there is scope in investigating its applicability in these conditions particularly with the new powerful current transmitters now available.

F. The Resistivity Method

The applicability of the Resistivity method was first investigated by H.M.C.'s staff over a number of shallow seated orebodies in the early 1940's. In the course of this investigation a number of probes were carried out over the gossans overlying mineralized ground.

The method was re-examined during the U.N.S.F.-G.S. project. The resistivities of the main rock types were determined by test probes. The results are shown in Fig. 35. The Lower Pillow Lavas have the lowest values with minimum of 10 Ohm-meters. Somehow higher resistivities are shown by the Upper Pillow Lavas ranging from 30 to 70 Ohm-meters and even higher by the Basal Group from 60 to 120 Ohm-meters. The silicified lavas show a much wider range with values from 60 to 500 Ohm-meters. The altered lavas have the lowest values from 7 to 10 Ohm-meters. The same figure shows the resistivity of the sulphide mineralization as a function of its grade in sulphur content. It is interesting to note that up to 30% S the values are similar to those of the Lower Pillow Lavas. The higher grades, however, show

/ much

much lower resistivities compared with the unmineralized lavas indicating to the applicability of the method.

At present the Resistivity method is applied in prospecting together with the I.P.

G. Electromagnetic Methods

The Electromagnetic methods were tried at about the same time by both the H.M.C. and the U.N.S.F. - G.S.project in 1963.

The H.M.C. has investigated the applicability of the Vertical Loop EM using a McPhars 70 and 300 cps system. The results were discouraging and the method was soon abandoned. A study of their field data has revealed that the distance between the transmitting and receiving coils has exceeded in most times the permissible maximum of 1200 feet for the instrument. (This figure of 1200 feet was not mentioned in the manual of the instrument but only in the manufacturers general catalogue).

The U.N.S.F.-G.S. project has used two methods, the Turam,and to a lesser extend the Minigun. Their initial investigations over known near-surface orebodies had positive results. It was later proved, however, that most of the anomalies were not due to sulphide mineralization but to argillaceous alteration and fault structures within the lavas. And the anomalies from these two different sources could not be distinguished between them. In fact the Turam method was later used for the detection of fault structures during the course of water prospecting in the volcanic terrain.

H. The Pulse Electromagnetic Method

The first major ground instrumentation for P.E.M. was designed specifically for exploration in Cyprus by McLaughlin in 1962. This was applied by Newmont exploration in the Skouriotissa area under contract by

/ Cyprus

Cyprus Mines Corporation (Crone 1975). The results were discouraging at that stage and in addition it was expensive and restricted to areas of easy mobility. (The power was delivered by 90 automobile batteries!).

Recently the method was reintroduced and applied extensively by NORANDA Exploration (Cyprus) during their recent exploration programme in Cyprus. It was soon realised that the method was more capable of locating faults than massive sulphide zones as might have been expected. Many spectacular anomalies were drilled without locating any mineralization at all.

VIII. PREVIOUS WORK ON THE I.P. METHOD

A. Introduction

The I.P. method was first attempted by McPhars for the C.M.C. in 1962 on a contract basis. The results of that work were never revealed except for a case history over the Mavrovouni Orebody which was published by Hallof (1963). Later, in 1967, Huntings Geophysics carried out I.P. measurements for Limni Mines Ltd., but the results are again unknown. Apparently in both cases they had discouraging results. This is reported in the U.N.S.F. G.S. project report (1970) where it is written: "The I.P. work was not applied by the project because of previous discouraging results in Cyprus. It was found to respond to clay patches in the volcanic rocks and to poor disseminated pyrite". They have both applied the Frequency Domain method with a 2.5 KW transmitter. However, the Cyprus Geological Survey following the Project's recommendations, acquired in 1971 a 2.5 KW McPhars F.D. unit for their prospecting activities.

The third known attempt to use the I.P. Method after C.M.C. and Limni, was made by Dr. M.A. Khan of the Department of Geology of the University of Leicester, and the present author. This was an experimental study in the Kalavassos Mining Lease of H.M.C. in summer 1970 using the Frequency Domain technique and the Leicester University 1.5 KW McPhars unit. This work followed a laboratory study of mineralized and unmineralized core samples from Cyprus made by the present author at the University of Leicester in 1969 as a part of an M.Sc. degree. Following the 1970 project at Kalavassos, the H.M.C. has adopted the method on a routine basis by purchasing first a 7.5 Kw Huntec Time Domain unit in 1972, and later in 1976, due to the intensification of the exploration activities, a 15 Kw Scintrex Time Domain unit.

The results of the author's laboratory study and the Kalavassos

/ experimental

experimental project together with Dr. M.A. Khan are briefly outlined below.

B. The Laboratory Study

The purpose of the laboratory study was to investigate the properties of the pyritic bodies and their host rocks and to discuss the applicability of the method in the search for sulphide bodies in Cyprus. The results were presented in an M.Sc. Dissertation (University of Leicester, Maliotis, 1969).

The suite of core samples used at this project consisted of seven mineralized and three unmineralized specimens from Kambia Mine and its surrounding unmineralized rocks. The apparatus used was developed by Dr. D.H. Quick for his own project and is described in Maliotis (1969) and Quick (1973).

In the Frequency Domain the project included measurements of the resistivity of the samples at seven frequencies between 10 and 1000 cps and the calculation of the P.F.E. according to the formula:

$$PFE = \frac{\rho_{10} - \rho_f}{\rho_f} \times 100$$

The M.C.F. was also calculated according to the formula:

$$MCF = \frac{\rho_{10} - \rho_f}{\rho_{10} \times \rho_f} \times 2 \times 10^{-5}$$

In the Time Domain the whole transient voltage was recorded as follows:

a. At constant charging time of 15 secs and different energizing currents from 0.1 to 32 mA, and

b. at constant energizing current of 0.5 mA and different charging times from 1 to 480 secs.

The d.c. resistivity of the samples was calculated from the steady state voltage.

/ The

The results of the Frequency Domain are shown in Figs. 36 to 39. The P.F.E. (Fig. 36) and the M.C.F. (Fig. 37) show low values in low sulphide content samples but the highest values do not correspond to the richest sulphide mineralization. Two of the rock samples show both negative P.F.E. (Fig. 38) and M.C.F. (Fig. 39) below the 1000 and 4000 cps, whereas the third behaves similarly to the ore samples.

In the Time Domain the results for the ore samples with the variable current are shown in Fig. 40. It is clearly observed that although the low sulphide samples show low responses, the sulphide rich samples do not show a regular distribution. The variation of the I.P.E. with increasing charging time is shown in Fig. 41, demonstrating a behaviour comparable with that of the variable energizing current. The rock sample responses parallel that of the Frequency Domain. The same two samples show negative I.P. effects whereas the third behaves normally, but in contrast to the Frequency Domain, it has much lower values than the ore samples (Figs 42 and 43).

The D.C. resistivity of the ore samples was generally low varying between 6.3 and 18.0 Ohm meters. The two rock samples with the negative I.P. responses had resistivity values falling in this range, whereas the third had a much greater resistivity value. Table 4 summarises the results of this project.

In discussing the applicability of the I.P. method in Cyprus on the basis of these results, the author concluded that the P.F.E. contrast between mineralization and barren rock was not very pronounced, whereas the M.C.F. and better the I.P.E. could indicate more clearly the presence of mineralization within the rock.

/ C. The

C. The Kalavassos Project

This project consisted mainly of measurements over two areas of mineralization in the Kalavassos Mining Lease. The first was over the shallow seated Mavri Sykia orebody and the second over a deeper conductor in the Mavridhia area, see Fig. 44. Measurements were taken with the dipole-dipole electrode configuration with a spacing of 50 feet.

The Mavri Sykia contoured geophysical section and drilling data are shown in Fig. 45. There are two distinct anomalies along this line, the first between stations 17 and 22 corresponding with the shallow seated mineralization under a cover of about six meters of gossanised material. The second is about two hundred meters to the west between stations 7 and 8. The resistivities range from 10 to 50 Ohm-feet with two regions of low values, one between stations 6 and 8 and the other between stations 19 and 20. In the PFE the two anomalies have maximum values of 22% and 9% respectively. The two anomalies are displayed even more convincingly in the MCF pseudosection. The MCF values range from 150 to 1200 with the highest values around the two anomalies described above, see Fig. 45.

The Mavridhia orebody lies at a greater depth, 50 meters under fresh Upper Pillow Lavas. The contoured geophysical sections and drilling data are shown in Fig. 46. There is a distinct anomaly shown in all three parameters in the region of stakes 6 to 10. This corresponds with the more extensive part of the mineralization along the line of survey. The resistivity values are lower than those of Mavri Sykia ranging between 2 and 25 Ohm-feet with the lowest between stations 6 and 10. The PFE values are again lower than Mavri Sykia ranging from less than 1% to more than 10%. The highest values were recorded in the larger electrode separations, also between the same stations (6-10). The MCF values range between 100 and 2000, the highest coinciding with the resistivity and PFE anomalies.

The observations at these two bodies of sulphide mineralization provided a convincing demonstration of the applicability of the I.P. method to sulphide exploration in Cyprus. This prompted further I.P. investigation with exploration over two areas which have not been drilled before. These were the Livadhia Area and the Vasa Triagle both in the Kalavassos Mining Lease. Although no significantly high results were recorded in these two areas, all anomalies were drilled and found to be due to low grade mineralization with about 3% S.

The outcome of this project together with the different implications encountered during the field work, convinced the H.M.C. to apply the I.P. method on a routine basis. It was for these reasons that the present programme of work was initiated.

IX. ORIENTATION STUDY - THE AGROKIPIA B OREBODY

A. Introduction

Before the commencement of any I.P. exploration, it was considered pertinent to carry out an orientation study over a known deeply seated deposit. The purpose of this orientation study was first to illustrate the applicability of the method and thus justify its use in sulphide exploration. Second, it intended to investigate the effects of a number of field parameters such as the type of electrode array and the electrode spacing, and also the charging time and on/off ratio of the energising current. For this purpose the Agrokipia B Orebody occurring at a depth of over one hundred meters of pillow lavas was considered as an excellent target. This orebody occurs in the Tamasos Mining Area, Fig. 1. The whole orientation study was carried out over a single line directly over the orebody. In the following pages there is given first a brief description of the geology of the orebody. In the next part there is given an account of the geophysical results, followed by a discussion and conclusions on the various parameters.

B. The Geology of the Agrokipia B Orebody

The Agrokipia B Orebody is totally covered by a series of pillow lavas with a minimum of 125 m. in thickness. The location of this orebody is shown on the geological map of the area illustrated on Fig. 47. This body is considered essentially as representing the highest parts of a typical Cyprus-type deposit. It is believed that this was formed in a mineralized fracture zone with the lower parts to the south, and the higher parts to the north. Thus, the body is considered as an almost complete Cyprus-type which is at some degree tilted to the north. Fig. 48 is a geological section across the orebody along the line surveyed geophysically. The occurrance of the high grade cupreous ore in the northern boundaries of the body demonstrate its tilting in that direction.

/ From

From the drilling it appears that all the known contacts of the orebody with the unmineralized rocks are tectonic. The top of the orebody is defined by a low angle fault bringing in contact the mineralization with fresh volcanics. The northern boundary consists of two parallel normal faults which downthrow the highest parts of the mineralization to the north. From the drilling results there is not much evidence with regard to the western and eastern boundaries of the mineralization. The Agrokipia B Orebody exhibits the grade and mineral zonation known for the Cyprus deposits. The highest part of the orebody is cupreous with high values of sulphur. Towards the south the grade decreases with traces of copper and lower sulphur content. Further south the mineralization is of the stockwork type with pyritic veins and disseminations in silicified and propylitised rocks. In general this orebody is characterised by high values of zinc distributed erratically in the deposit. The size of the orebody has been estimated to the 5.7 million tons with an average grade of 20% sulphur.

C. <u>The Geophysical Results</u>

The geophysical work over the Agrokipia line included an investigation of the N.T.I. responses obtained with the three common profiling arrays i.e. the dipole-dipole, pole-dipole and gradient array, together with an investigation of the effects of the cycle time and the on/off ratio of the energising current, on the same responses. Three different cycle times were investigated: 4, 8 and 16 secs and also four on/off ratios: 1.0, 1.46, 1.91 and 2.55. The results are presented below.

1. Comparison of the electrode arrays.

The dipole-dipole and pole-dipole configurations were applied with a cycle time of 8 secs at an on/off ratio of 1.0 and an electrode spacing of 50 meters. The gradient array presented serious problems related to the

/ function

function of the I.P. receiver, and it was therefore applied only with a 16 secs cycle time.

a. The dipole-dipole results.

These are illustrated in Fig. 49. The presence of the orebody appears from the first integral, Msec 1, which attains high values in the n = 4 electrode separations in the region of stakes 11 to 13. The presence of the orebody is more strongly indicated in the higher integrals. On the pseudo-sectional pattern the highest values correspond well with the position of the orebody, see also Fig. 48.

b. The pole-dipole results.

The results for this configuration are illustrated on Fig. 50. The presence of the mineralization is suggested from the first integral values, Msec 1. The anomaly is again better defined in the higher integrals. In the Msec 3 for example, the 250 contour corresponds well with the location of the orebody. Fig. 50a illustrates the resistivity results over this line. Slightly higher values were recorded over the orebody, and much higher in the area of the Upper Pillow Lavas.

c. The gradient array results.

The current base for this array had a length of 1000 meters with the Agrokipia orebody falling in its central part. Readings were taken with a spacing of 50 meters. The results are illustrated in Fig. 51. It is important to note that because of the very low signals in the central parts of the current base, together perhaps with some distortion of the input waveform due to electromagnetic effects, the receiver operation could not synchronise with the transmitted signal and thus the receiver could not function at all. The results presented above (Fig. 51) were taken with a 16 sec cycle time and this was achieved with extreem difficulty. For this

/ purpose

purpose the gradient array was not considered further. From the results of Fig. 51, however, it is apparent that high I.P. responses were recorded over the orebody. Anomalous values were also recorded in the northern part of the line. These could be attributed again to downfaulted mineraliztion in this area.

d. Discussion on the different arrays.

From the above results it is evident that the only arrays which could be considered were the dipole-dipole and the pole-dipole. A comparison of the results obtained with these two different arrays, Figs 49 and 50 respectively, indicates that the presence of mineralization is more clearly indicated by the pole-dipole array. In this, the responses due to the mineralization are generally higher than those of the dipole-dipole array. In addition it appears that the amplitudes over the unmineralized rocks are lower in the pole-dipole array resulting in this way to a better definition of the anomaly. Comparing for example the Msec 4 values over the mineralization taken with the two arrays, it is observed that the highest value on the pole-dipole is about 450 whereas in the dipole-dipole it just exceeds the 350. For the same reason the presence of the orebody is more strongly indicated on the pole-dipole pseudosectional pattern than the dipole-dipole pattern. Considering the magnitude of the responses in the region of the stakes 14 to 17 on the pole-dipole results, these appear in most cases to be lower than the corresponding ones in the dipole-dipole results. For these reasons the pole-dipole array was considered superior to the dipole-dipole and it was therefore adopted. Another advantage of the pole-dipole configuration is the simpler wire handling in the field compared with the dipole-dipole array.

2. Comparison of the charging time.

This comparison was made with the pole-dipole configuration with a spacing of 50 meters. The on/off ratio was kept constant at 1.0.

/ a. The

a. The 4 sec results.

The results for this parameter are illustrated in Fig. 52. Anomalous values in the area of the orebody are evident from the first integral, Msec 1, beginning from the second dipole separation, n = 2. The anomalous pattern becomes more evident in the higher integrals. On the pseudosectional pattern the high values coincide well with the location of the orebody. However, almost equally high values were recorded on larger electrode separations to the north of the orebody, in the region under stakes 9 to 7. Similarly high values were recorded in the southern end of the line. These values do not correspond to any known mineralization in that area, although it is expected that the lower parts of this orezone must extend in depth over that area. The northern anomalies are most likely due to the faulted and dislocated parts of the orebody described above.

b. The 8 sec results.

These results were presented above on the comparison of the electrode arrays. They are illustrated in Fig. 50.

c. The 16 sec results.

The results for this parameter are illustrated on Fig. 53. As with the previous results the orebody begins to appear from the first integral, Msec 1. The anomaly is defined better in the higher integrals and corresponds well with the position of the orebody. It is interesting to note that anomalous values on the n = 4 dipole separation were recorded only on the northern end of the line which were considered previously as being caused by the down-faulted blocks of the main orebody.

d. Discussion on the different cycle times.

Below there is a detail comparison and discussion on the results

/ obtained

obtained with the different times. Each N.T.I. value is examined individually.

(i) The Msec 1 values.

Figure 54(a) shows the comparison of the Msec 1 values over the Agrokipia orebody for the three different charging times used, 4, 8 and 16 seconds. The results are plotted on the position of the current electrode at which each reading was taken.

At the n = 1 position there appears to be a uniformity, the higher results corresponding to the higher charging times (16 sec). Similarly the lower results correspond to the lower charging time (4 sec). The 8 sec results fall between the two. At the current positions 16, 18 and 19 there seem to be a slight departure from the parallelism of the values. In the first stake (16) the 8 sec result equals the 16 sec. In the second (18) the same approaches the 16 sec value, and in the third (19) it gets lower than expected approaching the 4 sec value.

At the n = 2 position there is again a uniformity in the results with the 16 sec values being the highest and the 4 sec the lowest. There is however a reversal between the 16 and 8 sec results at the 18 stake position. As with the n = 1 values in the northern parts of the line which are over the orebody (region of stakes 11 to 14), the Msec 1 values are higher than on the southern part and they are always regular.

At the n = 3 position the 16 sec results are higher in most of the stakes except for the 12 and 19 positions. In the first it is just below the 8 sec results and in the second it is below the 4 sec result. Other departures are noted on the following stakes. At stake 13 the 8 sec equals the 4 sec result. At stake 15 the 8 sec equals the 16 sec result. At stake 16

/ again

again the 8 sec equals the 4 sec result, and in the following stakes it remains below this: stakes 17, 18 and 19.

At the n = 4 position the results are not as simple as they were in the lower n values. The 16 sec results are the highest in the region of stakes 10 to 15 which includes the area of the high readings corresponding to the mineralization. In the same area (stakes 10 to 15), the 8 sec results fall between the 16 and 4 sec values except for the readings at stakes 10 and 14, where it attains the lowest value. In the region of stakes 16 to 19 the results are always irregular (i.e. do not follow the sequence 16, 8, 4 secs) except for stake 17. At stakes 16 and 18, the 8 secs result has the highest value and the 16 sec the lowest. At stake 19 the 16 sec result has the highest value and the 8 sec the lowest.

(ii) The Msec 2 values.

These are shown on Fig. 54(b). At the n = 1 position the values are uniform, i.e. the higher the charging line the higher the recorded value. However, there are two exceptions, one at stake 13 where the 4 sec result is lower than the 4 sec, and at stake 18 where the 8 sec is higher than the 16 sec result.

At n = 2 position the values are uniform in the region from stake 10 to 17, except for stake 16 where the 8 sec value equals the 4 sec value. At stakes 18 and 19 there is a reversal in the relationship between the 8 and 16 sec results.

At n = 3 electrode position there is a uniformity in the results from stake 10 to 16, except for two minor departures at stakes 10 and 15 where the 8 sec value gets greater than the 16 sec, and lower than the 4 sec respectively. In the region of stakes 17 to 19, the 8 sec values are the lowest and in the last two (18 and 19) the 16 sec values are lower than the 4 sec.

/ In the

In the n = 4 position the results are less uniform than in the lower dipole separation values. Irregularities occur at the following current electrode positions. As stake 10 the 4 sec value is higher than the 8 sec. Similarly at stake 12. At stake 16 the 16 sec value becomes lower than both the 8 sec and 4 sec values. Similarly at stakes 18 and 19.

(iii) The Msec 3 values.

These are illustrated in Fig. 55. At the n = 1 electrode position the values are uniform, the highest the charging time the higher the Msec value. There is, however, a slight discrepancy at the last stake where the 8 sec value equals the 4 sec one.

At the n = position the results are uniform from stake 10 to stake 17, except for stake 16 where the 8 sec value approaches the 4 sec value. In the last two stakes (18 and 19) the 8 sec values are higher than the 16 sec ones.

At n = 3 the 16 and 8 sec results seem to parallel each other except for stake 10 where they are equal, but the 4 sec results are less uniform. At stake 15 it is higher than the 8 sec value, and similarly on stakes 17 and 18. At stake 19 the 4 sec value is higher than the 16 and 8 sec results.

At n = 4 the picture is more complicated. Uniform results were recorded only at the following current positions: stake 11, 13, 14, 15 and 17. In the rest the results are irregular. At stake 10 the 8 sec value is lower than the 4 secs, and similarly at stake 12. At stake 16 the 16 sec value is the lowest. At the last two stakes, 18 and 19, there is a reversal with the 4 sec results being the highest, the 16 sec the lowest and the 8 sec in the middle.

/ (iv) The

(iv) The Msec 4 values.

The results for this values are illustrated in Fig. 56. At the n = 1 position the results are rather regular except for the stakes 13, 16 and 17. In the first, the 4 sec value is higher than the 8 sec, in the second stake (16) the 8 sec equals the 16 sec, and in the third stake (17) the 8 sec is again lower than the 4 sec.

In the n = 2 current positions the results are uniform from stake 10 to 17 although they do not parallel each other well, especially at stake 16 where the 16, 8 and 4 sec values are equal. At the last two stakes the 8 sec values are higher than the 16 sec ones.

At the n = 3 position the results are uniform in the following stakes: 11 to 14, 16 and 18, whereas in the rest they are irregular. At stake 10 the 8 sec value is higher than the 16 sec one. At stakes 15 and 17 the 8 sec value is lower than that of the 4 sec. At stake 19 the 4 sec is higher than both the 8 and 16 secs.

At the n = 4 position the picture is quite irregular. Uniform readings, i.e. following the order of the charging times, were only recorded at the 13, 14, 15 and 17 stakes. In the first three stakes (10 to 12) the 8 sec values are lower than the 4 sec ones. At stake 16 the 16 sec value is the lowest, and in the last two stakes (18 and 19) there is a reversal, i.e. the 4 sec values are the higher and the 16 sec the lower.

e. Conclusions.

From the preceding analysis of the results it may be concluded that in the lowest electrode separation, i.e. n = 1 there is generally a uniformity in all the normalised integral values with the 16 sec results having the highest values and the 4 sec results the lowest. In the next electrode

/ separation

separation the results are generally in the above order except for those readings taken near the end of the line. In the n = 3, and more pronounced in the n = 4 electrode separation, the anomalous results show generally higher values in the 16 sec and lowest in the 4 sec charging time, whereas in the readings taken away from the mineralization, near the edges of the line the 16-8-4 order in the results does not hold. The 4 sec results could be higher than the 16 sec, see for example the reading in the 19 stake at n = 4.

In general it can be concluded that the 16 sec charging time defines more clearly the anomaly with much higher values in the anomalous region and much lower in the fringes than the 8 sec or 4 sec charging lines. For the same reason the 8 sec is superior to the 4 sec charging time.

3. Comparison of the on/off ratio.

This comparison was made again with the pole-dipole configuration with a 50 m. electrode spacing. The cycle time was kept constant at 8 sec.

a. The 1.0 results.

These results were presented above and are illustrated in Fig. 50.

b. The 1.46 results.

The results for this parameter are shown in Fig. 57 in the usual pseudosectional plotting. The anomaly due to the presence of the orebody is again evident from the first integral, becoming stronger in higher integrals. As with the results described above the anomaly is centered in the region of stakes 10 to 12 coinciding well with the actual position of the orebody. Again, high values but not as high as those corresponding to the main body were recorded in the northern end of the line.

/ c. The

c. The 1.91 results.

The results for this parameter are illustrated on Fig. 58. The presence of the orebody is suggested from the first integral value, centered as above in the region of stakes 10 to 12 corresponding with the actual position of the orebody. Similarly with the other data presented above, high values were recorded in the northern end of the line.

d. The 2.55 results.

The results for this parameter are illustrated on Fig. 59. As with the rest of the cases described above, the anomaly is evident from the first integral becoming stronger in the higher integrals. The anomaly is again centered in the region of stakes 10 to 12 coinciding with the orebody.

e. Discussion on the different on/off ratios.

Below there is a detail comparison and discussion on the results obtained with the different on/off ratios. Each N.T.I. value is examined individually.

(i) The Msec 1 values.

Fig. 60(a) compares the Msec 1 values for the different on/off ratios.

At the n = 1 position the first four current electrode positions, 10-13, show that the magnitude of the Msec 1 value is proportional to the magnitude of the on/off ratio. These four electrode positions are over the mineralization. Away from it (in barren rocks) this order is not followed. In general however the highest readings are those of the 2.55 ratio and the lowest are those of the 1.0 ratio.

At n = 2, in the readings over the mineralization (i.e. the anomalous ones), the 1.91 ratio results give the highest values, the lowest being

/ those

those of the 1.0 ratio. Over the barren rocks there does not seem to be a uniformity in the results.

Similarly at the n = 3 position in the anomalous readings, the 1.91 ratio has the highest Msec 1 values, whereas in the readings away from the mineralization the highest results are those of the 2.55 ratio

At n = 4 this does not seem to hold. Over the mineralization the highest readings are those of the 2.55 ratio, although at the 11 and 13 positions these are just below the 1.91 ratios. Over the barren area the results show that the 2.55 reading is higher than the other readings.

(ii) The Msec 2 values.

Fig. 60(b) illustrates the comparison of the Msec 2 values.

The n = 1 readings show that in the anomalous area, the 2.55 results attain the highest values and the 1.0 the lowest. Away from the mineralization the 2.55 result is in most cases the highest but the magnitude of the different readings is not proportional to the on/off ratio.

At the n = 2 readings over the mineralization, the highest values in the different positions are attained by both the 2.55 and the 1.91 ratio results. Again, over the barren area there does not seem to be any regularity in the results with regard to the on/off ratio.

In the n = 3 readings it is immediately evident that the highest results over the mineralization are those of the 1.91 ratio, whereas in the rest of the line the highest readings are those of the 2.55 ratio.

At the n = 4 position the 2.55 results are generally the highest all along the line. As described above, some discrepancies in the order of magnitude with regard to the on/off ratio appear in the readings on the barren rocks.

/ (iii) Th-

(iii) The Msec 3 values.

The results for the Msec 3 values are plotted on Fig. 61.

At the n = 1 position the mineralization is characterised by a regularity in the order of the readings following that of the charging time values, i.e. the highest are the 2.55 readings and the lowest the 1.0. Away from the mineralization this order is not followed and the highest readings do not always correspond to the highest on/off ratio.

At the n = 2 position it is observed that the two lowest on/off ratios, i.e. 1.0 and 1.46, show some regularity over the mineralization, the higher results being those of 1.46, but the other two on/off ratios show about the same magnitude without any regular difference between them. Over the barren area the results do not seem to follow any order.

At the n = 3 position the highest reading was recorded with the 1.91 on/off ratio, whereas in the rest of the line the 2.55 ratio gave the highest results in almost all the locations. The two lowest ratios (1.0 and 1.46) do not show the regularity demonstrated before in the n = 2 results over the mineralization, but their magnitudes can be equal or even reversed.

In the n = 4 results the 2.55 values appear to be the highest in the mineralized area except in two places where they are below the 1.91 and 1.46 values. In the barren area the results are again irregular in order, as in the previous cases.

(iv) The Msec 4 values.

The results for the Msec 4 values are shown in Fig. 62.

At the n = 2 position over the mineralization, the magnitude of the values follows the order of magnitude of the on/off ratios. In the rest

/ of the

of the line this order is not followed although the 1.0 ratio results are always the lowest.

In the n = 2 results over the mineralization, the two lowest ratio values follow some order, the 1.46 having higher results than the 1.0. The other two, however, do not seem to show that difference, but they are close to each other. In addition the highest values are those of the 1.91 on/off ratio. In the barren area the results do not show any regularity in their magnitude.

In the n = 3 results the highest reading was recorded on the 1.91 on/off ratio, the 2.55 ratio giving a lower value on the same position. In almost the whole of the line, i.e. on both the mineralization and the barren area, there does not seem to be much regularity on the results with regard to their order of on/off ratio magnitude.

On the n = 4 position, over the mineralization the 1.0 and 1.46 results show some order, which, however, is not followed in the barren area readings. The highest value over the mineralization was recorded on the 1.91 ratio. It is evident that over the mineralization this ratio gave the highest values, whereas over the non-mineralized ground the 2.55 ratio had higher values.

f. Conclusions.

From the analysis of the results presented above it may be concluded that the N.T.I. values are not independent of the on/off ratio. In the small electrode separation (n = 1) it is evident that in the anomalous readings the N.T.I. values are proportional to the on/off ratio value. However, in the barren area this proportionality does not hold. In the n = 2 and n = 3 electrode separations, the highest value over the mineralization was recorded by the 1.91 on/off ratio. In the n = 4 the 2.55 ratio values appear to

/ superseed

superseed the 1.91 ratio values, but the first shows much higher values over the barren rocks. It may be concluded that the 1.91 ratio although not always higher than the 2.55 ratio values gives a more distinct anomaly.

D. Conclusions

The presently described orientation study indicates that the I.P. method is capable in demonstrating the presence of a pyritic deposit occurring at a depth of over one hundred meters under fresh pillow lavas. This immediately implies that the application of the I.P. method in sulphide exploration in Cyprus is indeed well justified.

On the basis of the results of this study a number of field parameters were decided. Among the three electrode configurations examined, it was decided to apply the pole-dipole, than the dipole-dipole and the gradient array. This was based primarily on the fact that the pole-dipole array was found to be superior to the dipole-dipole, indicating more clearly the presence of the Agrokipia B Orebody. The gradient array was not considered any more for instrumental reasons. The electrode spacing of 50 meters was considered to be satisfactory for the size of the mineralized bodies.

Regarding the charging time and the on/off ratio of the energising current, it was demonstrated that the 16 sec cycle and the high on/off ratios (1.91 and 2.55) could enhance the anomalies due to mineralization. However, the 8 sec charging time and the 1.0 on/off ratio could also demonstrate sufficiently the mineralization. Having in mind that these are the most commonly used values in the Time Domain method throughout the world, it was decided to adopt them during the field surveys. This would enable the comparison of the results over the Cyprus mineralization with results from other parts of the world. This is very important, particularly in the study of the shape of the I.P. decay curve.

CHAPTER FOUR

ON THE GEOPHYSICAL RESULTS OF THE MATHIATIS (MITSERO) AREA

I. INTRODUCTION

The Mitsero Area falls in the Tamassos Mining Lease of the Hellenic Mining Company in a lower Pillow Lava terrain. The mineralization in this area was known since 1935, and since then one exploratory shaft and sixty vertical boreholes were drilled over the outcropping (gossanised) part of the mineralization or very close to it. As a result of this drilling it was known that a small body of about 200,000 tons, beginning from the surface (below the gossan) with Copper and Zinc values, existed in this area.

An extensive amount of I.P. work consisting of a total of 7.0 kilometer lines was carried out in this area in order to investigate the behavior of the known mineralization, and in particular its extensions in all directions especially along its strike. As a result of this work it was found that the known mineralization is confined in a zone less than 100 meters wide, apparently almost vertical, with a strike of about N60^{o}E. During the course of this work a second mineralized area was discovered to the east and parallel to the known one. This was given particular attention due to its higher anomalous values than the first mineralization and for this, five holes, three vertical and two inclined, were drilled into it. All holes intersected dessaminated pyritic mineralization with the amount of sulphur not exceeding the 2%. For this it was decided to study the responses of the two mineralizations in detail and investigate whether the I.P. transient shapes could distinguish between the two types of mineralization. In the following pages there is an extensive account of the I.P. work in this area. Together with the

/ normal

normal four I.P. readings carried out with the pole-dipole electrode arrangement, the whole decay using sixteen readings was recorded at the n = 2 electrode positions.

II. THE GEOLOGY OF THE MATHIATIS AREA

The Mathiatis area falls well within the Lower Pillow Lava terrain, the Upper Pillow Lavas are about 1.5 kilometers to the north and the Basal Group about 0.5 kilometers to the south. The occurrence has attracted the attention in the past from the small and colourful gossans. There are two areas of mineralization. One to the west which is the main Mathiatis mineralization, hence called the western mineralization. The other is to the east of this, hence called the eastern mineralization, discovered during the course of the present I.P. exploration, and covered by fresh pillow lavas. This is in the area of boreholes MΘ 18, 19, 20, 21, 26 and 27, see Fig. 63.

Both the eastern and western mineralized zones have similar origins. They are considered to be structurally controlled and deposited in fracture zones in the Lower Pillow Lavas. It must be emphasized that such types of mineralization in other parts of the island have given rise to economic deposits. The problem from the exploration point of view is whether such zones or parts of them have disseminated pyrite mineralization only or whether they enclose lenses with higher grade. Below there is a description of the geology of the two mineralized bodies in the area particularly the western for which there is considerable information from the numerous boreholes sunk in the area.

A. The Western Mineralization

The geological map of the area is shown in Fig.63 together with the geophysical lines. From the map it is evident that the western mineralization reaches the surface forming a small but colourful gossan lying to the north-east of the geophysical lines. The main part of the mineralization occurs under a variable thickness of unmineralized Lower Pillow Lavas in the area immediately southwest of the gossan where most of the boreholes are concentraded (Fig. 63).

/ From

From the drilling results it became evident that the mineralization in this area represents another example of a mineralized body bounded by opposite dipping normal faults resulting to a typical horst structure trending NNE. Fig. 64 shows three geological sections along the geophysical lines. These sections demonstrate the tectonic picture described above together with an indication of the grade of mineralization from the average values of sulphur shown on each borehole through the mineralization. A comparison of the three sections indicates that the horst is plunging gently to the south occurring at deeper levels over line 3. Fig.65 shows three longitudinal geological sections along this horst structure. These figures demonstrate the tectonic disturbances of the mineralized horst by cross cutting faults, which appear to be responsible for the uplifting and appearance on the surface of the mineralization in the north, and its displacement to a greater depth in the south. The geological sections of Fig. 65 show also the position of the first three geophysical lines. From these it becomes evident that lines 1 and 3 were located near the edges of uplifted blocks of the mineralized horst whereas line 2 lies almost in the middle of an uplifted mineralised block.

Mineralogically the mineralized ground consists of propylitised and silicified lavas with pyrite chalcopyrite and sphalerite. As shown in the sections of Figs. 64 and 65 the grade of mineralization, which is expressed by its sulphur content, varies from weakly mineralized to massive pyrite with over 40% sulphur values.

B. <u>The Eastern Mineralization</u>

This mineralization was investigated by only five boreholes. A sixth borehole sited on the northeastern extensions of the geophysical anomalies gave negative results all along its depth.

/ Geologically

Geologically little is known about this mineralization because of the limited exploration carried over it. From the drill cores, however, which were taken at some intervals along these holes, it was observed that the rock was variably altered and propylitised with thin veins of pyrite running along the centers of thicker silica veins. The rock was also disseminated with pyrite. The grade of mineralization was found to show little variations, averaging just over 1% sulphur.

The depth to the top of this mineralization varied as shown on Fig. 64. On lines 1 and 2 it was found in depths of 70 and 60 meters respectively whereas on line 1 it lies at a depth of only five meters. In general, it is believed that this mineralization corresponds to a mineralized fracture zone which has a northeasterly trend and was intersected by the boreholes at different depths.

III. THE GEOPHYSICAL RESULTS

The area was covered by seven parallel geophysical lines running at 310^{o} and about at right angles to the strike of the known mineralization. The layout of the lines is shown in Fig. 63. The I.P. survey consisted of a pole-dipole survey along the lines at an electrode spacing of 50 meters with readings taken at the n = 1 to 4 electrode separations. The line spacing was 75 meters. The charging period was 8 seconds at an on/off ratio equal to 1.0. At n = 2 the decay curve was recorded at 16 different points. The I.P. transient was normally recorded at four positions: 55, 130, 280 and 580 msecs from the time of the interruption of the energizing current.

Below there is an analytical description of the geophysical results and studies in the following sequence:

A. The Normalised Time Integral.
B. The Decay Factors.
C. The Shape of the $\log_e t$ Plotted Decay Curve.
D. The Bertin and Loeb's (Modified) Functions.
E. The Resistivity Results.

A. <u>The Normalised Time Integral</u>

The N.T.I. was estimated for each of the four readings according to the method described in Chapter Three. The results for each line are presented and discussed below.

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig. 66.

The presence of the mineralized ground is evident from the first integral value, Msec 1, for both the western and eastern mineralizations. In

/ the western

the western, the first integral shows particularly strong readings in the receiving dipoles 6-7 and 7-8. In the other integral values it appears that the overall shape of the anomaly is asymmetrical, centered in the region of stake 7. This is more clearly shown in the Msec 4 pattern where the 350 contour value has also been included.

In the eastern mineralization the anomaly is again evident from the first integral value recorded mainly on the 15-16 receiving dipole. The patterns remain about the same in the higher integral values, although in the Msec 4 it may be considered as having a very asymmetrical shape with the stronger values remaining on the receiving dipole.

b. Line 2.

The results for this line are illustrated in Fig. 67. The first mineralized area is clearly shown from the first integral values (Msec 1) by the high readings recorded at the 6-7 receiving dipole and less in the adjacent dipoles. In all integral value patterns the anomaly remains with an apparent dip to the west.

The second anomaly appears from the beginning (Msec 1) to have a symmetrical shape. High readings began from the 11-12 receiver dipoles. The symmetry is more clear in the Msec 3 readings centered under position 12. The receiving dipole 12-13 has given the highest readings together with the transmitting pole 12.

c. Line 3.

The results for this line are illustrated in Fig. 68.

In the area where the line crosses the western mineralization, the readings are slightly higher than background values, but not as high as in the previous lines. It is apparent from the first integration values that these highs are associated with the transmitting poles 3 and 4 and not with the receiving dipoles at all. In all Msec values it is observed that the highest values are on the n = 1 to n = 3 positions only.

The eastern mineralized area appears distinctly on this line, the high values beginning from receiving dipole 11-12. From the first integration values it is observed that the pattern approaches a "boomerang" shape with an area of lows under the area of 13-14. However, the highest readings are on the receiving dipoles 12-13 and 13-14 forming the left leg of the boomerang, the right leg being formed by lower values from the 13 transmitting pole.

d. Line 4.

The results for this line are illustrated in Fig. 69.

The western mineralization is clearly absent from this area indicating that it does not extend this far to the south. It may not be insignificant, however, that under the area of stakes 6 to 7 there is a decrease in the values from the background.

The eastern mineralization is shown by a much broader area of higher values. These begin from the receiving dipole 12-13 but they also appear on the n= 4 position of the two previous dipoles (10-11 and 11-12). The pattern shown by this mineralization appears to be asymmetrical, centered about the receiving dipole 15-16.

e. Line 5.

The results for this line are illustrated in Fig. 70.

This line shows no evidence at all for the western mineralization.

The eastern mineralization appears as a very broad zone of high values, but certainly lower than those of the previous lines. This pattern is slightly asymmetrical following again the receiving dipoles. This is centered about the receiving dipole 17-18.

f. Line 6.

The results for this line are illustrated in Fig. 71.

This line has covered the region of stakes 8 to 20 only, i.e. of the southern extend of the eastern mineralization. Although the contoured patterns in all integration times show no spectacular anomalies as in the previous lines, there is however, an indication of a slight increase of the results in the deeper parts (n = 3 and n = 4) getting shallower in the region of the receiving dipoles 17-18, 18-19 and 19-20.

g. Line 7.

The results for this line are illustrated in Fig. 72.

This line shows almost no anomalies at all, but there are two interesting pictures apparently coinciding with the southward extensions of the two mineralizations. The first is a rather broad area of lows centered about the stakes 5-6. It is interesting to note that these values seem to be independent of any pole or dipole positions, but it is rather symmetrical. To the left of this low there is a series of high readings, which seem to be related with the transmitting poles 1 (n = 1 and n = 2) and 2 (n = 1-4).

The second pattern is evident again in all integration times and is an increase of the values in a broad sense, centered about stake 15. In the higher times, Msec 3 and Msec 4, there is a slight but definite indication of an increase of the values at the receiving dipole 13-14.

2. Discussion.

From the results presented above it is immediately evident that the

/N.T.I.

N.T.I. attains higher values over the different mineralizations. In the following lines there will be a discussion on these results by examining the responses and shape of the anomalies, separately for each mineralization. Then there will be a comparison of the results from these two mineralizations.

The western mineralization has been detected by lines 1 and 2 and to a much lesser degree by line 3. The anomaly in line 1 (Fig. 66) is controlled basically by the receiver dipoles 6-7 and 7-8. As a result, the anomalous pattern has a westerly dip because of the conventional plotting. On some of the Msec plottings it becomes immediately evident from the intervals contoured that the transmitting pole 7 has also given slightly anomalous values. The highest N.T.I. values in the Msec 4 integral recorded on this line is 492. Values over 400 were recorded on both receiver dipoles 6-7 and 7-8. In general the anomaly on this line has an asymmetric boomerang shape with an area of lows centered in the region of stake 7.

Comparing this anomaly with the geological section along line 1 (Fig. 64), it is evident that the low area bounded by the two areas of higher values coincides with the actual location of the mineralized block.

Line 2 (Fig. 67) shows a slightly different picture with the anomalous readings recorded only on the 6-7 receiver dipole. No other dipole has shown Msec 4 values above 400 and no transmitting pole has given any significantly higher values strong enough to be apparent on the pseudosectional pattern. However, on the 200 contour of the Msec 4 results in the region of stakes 8 and 9, there is a slight inflexion, but this is not strong enough to be considered as solely due to transmitting pole 7.

Comparing the above pattern with the geological section of the line, it is observed that the receiving dipole which gave the highest values (6-7) is the closest to the mineralized block. In addition it is observed that

/ although

although dipole 7-8 is close to the mineralization, the responses are much lower than those of the 6-7 dipole.

Line 3 has given a completely different picture. The pseudosectional pattern (Fig. 68) shows much lower values with maximum Msec 4 values not exceeding the 300, concentrated mainly in the small dipole separations. In addition the shape of the anomaly does not appear to be controlled by any receiver dipole or transmitting pole.

From the geological section along this line (Fig. 69), it is observed that the mineralization under it extends as much as on the other lines. But from the geological sections of Fig. 65 it is observed that this body does not extend much to the south of the line, but it terminates almost below the geophysical line by a cross cutting fault running about parallel to the line.

Comparing the three lines between them, having in mind their geological structure, it is evident that the mineralization of line 1 gives a much stronger anomaly than line 2 because of the very shallow depth to the mineralization under this line. Equally high readings were given by both dipoles on either side of stake 7 which overlies the mineralization. However, the receiver dipole 5-6 has also given results sufficiently high to be considered as anomalous. The mineralized block of line 2 although apparently wider than that of line 1 at a depth of only 20 meters below fresh volcanics, is demonstrated by a more limited anomalous pattern than that of line 1. Again the highest values were recorded at the receiver dipole which is closest to the mineralization, but anomalous values were also recorded on the neighbouring dipoles. The results of line 3 cannot be compared with those of the other two lines.

The eastern mineralization was recorded at various degrees on lines 1 to 6. Line 1 (Fig. 66) gives a very well defined anomaly centered on the receiver dipole 15-16. There is no strong evidence for a control by any transmitting pole although pole 16 has given slightly higher values. The

/ highest

highest values recorded on the Msec 4 integral exceeds the 800. Line 2 (Fig. 67) has also shown a well defined and strong anomaly which is centered on the receiver dipole 12-13. Equally high values were also recorded on the transmitter pole 12. The highest recorded Msec 4 is 760. Line 3 (Fig. 68) has recorded a slightly stronger anomaly centered on dipoles 12-13 and 13-14, and also on the transmitting pole 13. The highest Msec 4 value on this anomaly is about 850.

Although there is not sufficient geological information on this mineralization except for the five boreholes and the low grade of sulphur in all of them, the position of these boreholes will be examined with respect to the actual centers of the I.P. anomalies on each line. Borehole 20, see Figs 63 and 64, was located outside the anomalous receiver dipole 15-16, within dipole 14-15 and closer to stake 15. The mineralization in this borehole was intersected at a depth of 74 meters. It is expected, therefore, that this depth is not necessarily the minimum depth, but the mineralization could be found shallower at some place within the receiver dipole 15-16. On line 2 borehole 18 was located within the anomalous dipole 12-13 and intersected the mineralization at a depth of only 5 meters. On line 3 the borehole was sunk within the receiver dipole 12-13 and struck the mineralization at a depth of 60 meters. Line 4 has also shown a relatively strong anomaly but there is no drilling information in this area. In the rest of the lines the anomaly becomes much broader with much lower values indicating an increase of the depth to the top of the mineralization. Line 7 shows no effect due to the eastern mineralization at all.

From the preceding discussion for both the western and eastern mineralizations and their respective I.P. anomalies it becomes evident that the actual location of the mineralizing body which gives rise to the I.P. anomalies, both laterally and in depth, is indicated with relatively good

/ accuracy

accuracy by the anomalous pattern. The lateral location of the mineralization is shown by the receiver dipole results. The highest part of a mineralized body is located within the receiver dipole which gives the highest readings. If two adjacent dipoles give equally high readings, then the center of the mineralized body is very close to the common stake. A good indication of the depth to the mineralization is certainly given by the amplitude of the I.P. responses. However, it was observed in both cases that when the mineralization is at a shallow depth, high I.P. values are also recorded on the transmitting pole which is the closest to the mineralization.

Comparing the anomalies obtained from the two mineralizations it becomes immediately evident that the eastern one has given much stronger responses than the western mineralization. Having in mind the fact that these two mineralizations differ primarily on their grades, it appears that the low grade mineralization gives much stronger I.P. responses than the higher grade mineralization. This, however, can also be attributed to the fact that the two bodies of mineralization are significantly different in their size.

3. Conclusions.

From the preceding discussion it is clear that the N.T.I. attains much higher values over the mineralization compared with their values over the barren rocks. The highest values are recorded on the receiver dipoles which are closer to the mineralized body. If this is very close to the surface then high responses are also recorded on the transmitting pole which is closer to the mineralization.

B. <u>The Decay Factors</u>

The I.P. decay was recorded at the n = 2 positions over lines 2 to 7 (except for line 3 where it was recorded at n = 3). In fact the transient

/ amplitude

amplitude was recorded at the following times (in msecs) after the switch-off of the energizing current: 35, 55, 90, 95, 130, 150, 180, 215, 240, 280, 360, 420, 455, 580, 720 and 780.

The transient results were plotted on a linear time axis and a logarithmic potential axis and factored according to the method proposed by Hutchins (1971) and described in detail in Chapter Three of this Thesis. The results for each line are presented and discussed below.

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig. 73 and tabulated in Table 5.

The A-factor. High values are shown in both mineralized areas being slightly higher in the eastern one. It is interesting to note that the ground between them also shows some high values.

The B-factor. Much higher values have been recorded in the eastern mineralization than in the western, with almost similar values to that of the western mineralization recorded between the two. In other words this factor does not differentiate between the western mineralization and the barren area between the two mineralizations.

The α-factor. In both mineralizations it appears that the lowest values of this factor correspond to the highest values of A and B.

The β-factor. In general this factor does not show significant variations. Over the two mineralizations it appears to decrease, particularly over the western one.

The P-factor. This factor attains high values over the mineralizations, particularly over the eastern one.

/ b. Line

b. Line 2.

The results for this line are illustrated in Fig. 74 and tabulated in Table 6.

The A-factor. Significantly high values are shown over both the mineralized areas.

The B-factor. This shows clearly the two anomalies although the western does not have a significantly high value.

The α-factor. This shows both high and low values in areas corresponding to high A and B values over the two mineralizations. It is noted that there is a significant difference between the values of two mineralizations.

The β-factor. The first mineralization shows low readings, whereas the second shows both high and low values. Again the lows correspond to the highest A and B values.

The P-factor. This factor attains high values over the two mineralizations, the highest over the eastern one.

c. Line 3.

The results for this line are illustrated in Fig. 75 and tabulated in Table 7.

The A-factor. This shows distinctly the eastern mineralization with a much lower, but definitely over background value over the western mineralization.

The B-factor. Similarly this shows clearly highly anomalous values over the eastern mineralization with a slight increase only in the area of the western mineralization.

/ The

The α-factor. Over the eastern mineralization there is a significant decrease of the values. Some variation is also shown in the area over the western mineralization but this is not as profound as in the eastern one.

The β-factor. Low values were recorded again in the region of the eastern mineralization and slightly higher in the western mineralization.

The P-factor. This attains high values over the eastern and slightly over background over the western mineralization.

d. Line 4.

The results for this line are illustrated in Fig. 76 and tabulated in Table 8.

The A-factor. Distinctly high values are shown over the eastern mineralization.

The B-factor. Similarly, distinctly high values were recorded over the eastern mineralization.

The α-factor. The profile is much smoother than those of the previous lines showing a low region over the eastern mineralization. It must be noted that there is no direct correspondence between the eastern mineralization and the low values.

The β-factor. Again, in the area of the eastern mineralization there is a decrease in the readings which does not coincide exactly with the high values in the A and B factors.

The P-factor. This shows significantly high values over the eastern mineralization.

/ e. Line

e. Line 5.

The results are illustrated in Fig. 77, and tabulated in Table 9.

The A-factor. The results show almost no anomalous values. There is a slight increase, however, in the area of the eastern mineralization.

The B-factor. Similarly, this is low with very slightly higher values in the area of the eastern mineralization.

The α-factor. This shows low values in the area of the eastern mineralization.

The β-factor. Low values were recorded in the eastern mineralization as well as in two other places in the western half of the line.

The P-factor. This factor shows a smooth profile with only a very slight increase in the area of the eastern mineralization.

f. Line 6.

This line was surveyed only along its eastern half, in the region where the second mineralization was expected to extend. The results are illustrated in Fig. 78 and tabulated in Table 10.

The A-factor. This shows a smooth profile with almost no anomalous values.

The B-factor. Similarly, no anomalous values were recorded on this factor, the profile being very smooth.

The α-factor. A rather high value was recorded at stake 11. There are two lows one at 12 to 13 and the second at stake position 17, corresponding to a slight increase in the P values.

/ The

The β-factor. This shows also two lows as in the α-factor the second corresponding to a P-factor increase.

The P-factor. This is generally low with a slight increase in the areas of stakes 13 and 17.

g. Line 7.

The results of this line are shown in Fig. 79 and tabulated in Table 11.

The A-factor. The results are generally low with a slight increase in the area where the eastern mineralization could extend. There appears to be a slight increase at the beginning of the line as well.

The B-factor. This also shows generally low values with a slight increase in the region of the eastern mineralization. Similarly with the A-factor, there is an increase at the beginning of the line.

The α-factor. Low values are shown at the beginning of the line and also further along, but they do not coincide with any high values of the rest of the factors. In the area of the eastern mineralization they are generally high.

The β-factor. This is similar to the α-factor showing low values at the beginning, a second low further along, and a variable profile without significantly low values in the area of the eastern mineralization.

The P-factor. This shows slightly high values at the beginning of the line and also in the area of the eastern mineralization.

2. Discussion.

From the results presented above it is evident that some of the decay factors show positive responses over the mineralization. In addition there appears to be a difference in the amplitudes of their responses obtained from

/ the two

the two anomalies. Below there is a discussion on these results with particular emphasis on the possibility of discriminating between the two mineralizations which differ significantly in their grade.

From the results from each line presented above, it becomes evident that the A-factor is clearly indicative of the mineralizations. For the barren areas, i.e. line 2 from stake 8 to 11, line 4 from stake 3 to 13, line 5, from stake 3 to 15, the whole of line 6 and the whole of line 7, the A-factor has a value between 0.5 and 1.0. On line 1 over the western mineralization it attains a value of 2.17, and over the eastern the values reach the 2.5. On line 2 over the western mineralization A attains a maximum value of 2.05, and over the eastern mineralization it has a maximum value of 2.3. Similarly high values are recorded over line 4, on the eastern mineralization, the highest being 2.0. . Slightly high values were recorded on line 5.

In general it appears that the A-factor is indicative of the mineralization. Any values below 1.0 characterise barren rock, whereas mineralized ground gives values exceeding 2.0. . Comparing the two mineralizations on lines 1 and 2, it appears that the eastern mineralization has slightly higher values than the western mineralization.

Similarly the B-factor (the true chargeability) appears to discriminate very clearly between barren and mineralized areas.

Over the barren areas the B-factor is generally below 1.0, most commonly around 0.5, e.g. line 2, 4 and 7. Lines 5 and 6, however, show in general higher values over the barren areas not exceeding though 1.0.

Over the mineralization, B-factor attains values generally higher than the average value of the unmineralized (0.5). Over line 1, the western mineralization is characterised by a value of just under 1.0, whereas the second by much higher values up to 2.3. Similarly line 4 shows the second

/ mineralization

mineralization by high values up to 1.5. Some values higher than 1.0 are shown in line 5.

It may be concluded that the B-factor is clearly indicative of mineralization. It is worth noting that the eastern mineralization has higher values than the richer (in sulphur content) western mineralization. This is rather important as it allows the discrimination between the two types of mineralization.

The properties of the α-factor which describes the rate of decay of the first factor ($Ae^{-\alpha t}$) of Hutchins' equation, are rather difficult to assess from the present results. Some conclusions can be drawn, however, which indicate that low α-values suggest proximity to mineralization. The barren areas such as around stages 8-12 for line 1, 8-10 of line 2, stakes 5 to 13 of line 4, 5 to 12 of line 5 and parts of lines 6 and 7, show values usually higher than 8.0. Areas with lower values i.e. lower than 8.0 are from stake 14 to 20 on line 1, on stakes 11 and 14 and 6 to 8 of line 2, close to the two mineralized regions. Over the second, however, there are also high values in the region of stakes 14 to 17.

A low area is also shown on line 4 in the region of the eastern mineralization. Similarly on line 5, again over the eastern mineralization, low values were recorded. It appears therefore, that the α-factor attains low values over the mineralized regions with rather higher values over the barren. It also appears, but far from being certain, that the disseminated mineralization has lower values than the rather richer mineralization.

Rather more obscure appear to be the properties of the β-factor which is the slope of the true I.P. effect. In general the value of β ranges between 0.5 and 1.0. There appears to be no significantly higher or lower values, above the mineralized ground. Over both the barren and the two mineralizations there are both high and low readings.

/ The responses

The responses of the P-factor will certainly be the same as the Msec values. As it is expected therefore, over the barren area it attains low values, of about 0.1.

Over the mineralized ground it is certainly higher, above 0.3 over the western mineralization and above 0.5 over the eastern on line 1, just over 0.3 over the western mineralization on line 2, and over 0.4 over the eastern mineralization on lines 2 and 4. In general it is higher over the eastern mineralization.

3. Conclusions.

From the above discussion it is evident that some of these factors do not even show distinctly the presence of mineralization, but they seem to be able to discriminate between the two types of mineralization. Table 12 summarizes the values obtained by these factors in the Mathiatis area. The A-factor shows very clearly the presence of both grades of mineralization. The B-factor, however, shows distinctly lower values over the high grade than those over the lower grade, thus discriminating between the two types of mineralization. The α-factor is also indicative of mineralization by being lower than the barren rocks, and there is an indication that it attains much lower values over the disseminated eastern mineralization than over the higher grade western mineralization. This however is not as clear as in the case of the B-factor. The β-factor does not show up the mineralized zones very clearly. The P-factor is also indicative of the mineralizations with higher values over the disseminated.

C. <u>The $\mathrm{Log}_e t$ Decay Factors</u>

The decays recorded at the $n=2$ dipole positions of lines 1 to 7 were also plotted on a $\log_e$ time axis and normal potential axis and the characteristics of such plottings as described in Chapter Three were studied. The results for each line are presented and discussed below.

/ 1. Presentation

1. Presentation of Results.

a. Line 1.

The results are illustrated on Figs 80(a, b) and tabulated in Table 13.

The rate of decay of the first component - R1. From the profile of this parameter it is evident that the eastern mineralization shows higher values than the western.

The rate of decay of the second component - R2. This is similar to the R1 showing again higher values over the disseminated zone than over the higher grade.

The ratio R1/R2. It appears that both mineralized zones show slightly lower values. It is noted that some very high values were recorded in the first three readings.

The time the second component begins $-t_d$. It appears that there is no correlation between this parameter and the mineralization. In general the values of t_d vary between 60 and 95 msecs.

The potential at which the second component begins - V_d. This parameter shows clearly that the mineralized ground shows higher values. It is important to note that the disseminated (eastern) mineralization shows higher values than the western.

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter shows high values on both mineralizations, with significantly higher over the eastern one.

The deviation d(0.5) of the second component at V(t)= 0.5. This also shows high values over the mineralizations with significantly higher over the eastern.

b. Line 2.

The results for this line are illustrated in Figs 81(a,b) and tabulated in Table 14.

/ The

The rate of decay of the first component - R1. It is evident that both mineralizations are characterised by high rates of decay. In the western, however, the values are much lower than in the eastern mineralization.

The rate of decay of the second component - R2. This parallels the R1, with low values over the western mineralization and higher over the eastern.

The ratio of R1/R2. This ratio shows low values over the eastern mineralization compared with the western and the barren areas.

The time the second component begins - t_d. No definite conclusion can be drawn from the profile of this factor.

The potential at which the second component begins - V_d. This parameter shows high values over the mineralization. From the two, the eastern shows higher values than the western.

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter shows high values over the eastern mineralization. Over the western the values are very low, almost equal to those of the barren rocks.

The deviation d(1.5) of the second component at V(t) = 1.5. This parameter is similar to the previous one with significantly higher values over the disseminated mineralization.

c. Line 3.

The results for this line are tabulated in Table 15 and illustrated in Figs 82 (a,b).

The rate of decay of the first component - R1. This parameter shows increased values over the eastern mineralization. Except these, it also shows three

/ peaks

peaks in its profile, the lowest one corresponding to the western mineralization.

The ratio R1/R2. The results of this parameter are rather irregular. Over the eastern mineralization, however, it shows uniform low values.

The time the second component begins - t_d. This profile does not show any significant variations over any of the mineralizations.

The potential at which the second component begins - V_d. This shows clearly a significant increase over the eastern mineralization. In the area of the western mineralization a slight increase is observed on the profile.

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter shows almost no anomalies at all except for a definite increase in its values in the region of the eastern mineralization.

The deviation d(0.5) of the second component at V(t) = 0.5. This parameter shows again very high values over the eastern mineralization together with a slight but definite increase in the region of the eastern mineralization.

d. Line 4.

The results for this line are tabulated in Table 16 and illustrated in Figs 83(a,b).

The rate of decay of the first component - R1. This parameter shows high values over the eastern mineralization. In the western half of the line the profile is irregular.

The rate of decay of the second component - R2. This shows a smooth. profile with high values in the area of the eastern mineralization only. (It is reminded that the western mineralization terminates at about line 3).

/ The ratio

The ratio R1/R2. This ratio appears to attain low values in the area of the eastern mineralization.

The time the second component begins - t_d. This parameter shows a rather irregular profile but without significant variations in its values.

The potential at which the second component begins - V_d. This parameter shows a smooth profile attaining high values in the region of the eastern mineralization only.

The deviation d(1.0) of the second component at V(t) = 1.0. The profile of this parameter illustrates a well defined anomaly in the area of the eastern mineralization.

The deviation d(0.5) of the second component at V(t) = 0.5. Similarly a well defined anomaly is demonstrated by this parameter over the eastern mineralization.

e. Line 5.

The results for this line are tabulated in Table 17 and illustrated in Figs 84(a,b).

The rate of decay of the first component - R1. This parameter shows a broad area of slightly higher values, the highest being in the area of the eastern mineralization.

The rate of decay of the second component - R2. This parameter shows a very smooth profile which attains slightly higher values over most of the eastern half of the line, the highest being in the area of the eastern mineralization.

The ratio R1/R2. This parameter has a rather irregular profile with its lowest values in the area of the eastern mineralization.

/ The time

The time the second component begins - t_d. This has an irregular profile but without significant variations in its values.

The potential at which the second component begins - V_d. The profile of this parameter has a broad area of slightly higher values in most of its length, culminating over the eastern mineralization.

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter attains higher values than those of the barren rocks, over a broad area having its maximum in the region of the eastern mineralization.

The deviation d(0.5) of the second component at V(t) = 0.5. This parameter has a similar profile with the above, attaining its highest value in the area of the eastern mineralization.

f. Line 6.

The results of this line are tabulated in Table 18 and illustrated in Figs 85(a,b).

The rate of decay of the first component - R1. This shows generally low values with a slight increase in the eastern end of the line.

The rate of decay of the second component - R2. The profile of this parameter shows constantly low values, except in the last values in the eastern end of the line.

The ratio R1/R2. Although the profile of this parameter is irregular, it does not show any significant features.

The time the second component begins - t_d. This parameter has an almost constant value all along the line.

The potential at which the second component begins - V_d. This also has a smooth profile with a slight increase in the eastern end of the line.

/ The deviation

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter shows very low values, increasing slightly in the eastern end of the line.

The deviation d(0.5) of the second component at V(t) = 0.5. The profile of this parameter almost parallels the previous one with an increase in the eastern end of the line.

g. Line 7.

The results for this line are tabulated in Table 19 and illustrated in Figs 86(a,b).

The rate of decay of the first component - R1. This parameter shows a rather smooth profile with a slight increase in its values at the beginning, over stake 8, and in the eastern half of the line corresponding to the extension of the eastern mineralization on this line.

The rate of decay of the second component - R2. This parameter shows an almost totally smooth profile with very slight increases in some areas as in the R1 factor.

The ratio R1/R2. This has an irregular profile, the most significant feature being the high values in the area of the eastern mineralization.

The time the second component begins - t_d. This parameter shows a slightly irregular profile but without any significant variation in its values.

The potential at which the second component begins - V_d. This shows a smooth profile with an increase at the beginning of the line, and a very broad and low anomaly which reaches its highest value in the area of the eastern mineralization.

The deviation d(1.0) of the second component at V(t) = 1.0. This parameter almost parallels the previous one with slight but not insignificant

/ increases

increases in its values at the beginning of the line and over the eastern mineralization.

The deviation d(0.5) of the second component at V(t) = 0.5. Similarly this parameter attains higher values at the beginning of the line and also over a broad area centered about the eastern mineralization.

2. Discussion.

From the results presented above, it is evident that some of the factors which express the shape of the decay curve plotted on a logarithmic time axis, show positive responses over mineralization. In addition some of these factors appear to attain significantly different amplitudes over the two mineralizations in the area, which as described previously, differ considerably in their grade. Below there is a discussion on the amplitudes of the factors presented above with particular attention to the possibility of discriminating between the two mineralizations, the disseminated eastern and the higher grade western mineralization.

From the results presented above for each line, it is evident that the R1 factor attains high values over the mineralized ground. Over the barren areas - where the N.T.I. values are low - the R1 factor attains values around 1.5 as for example the western halves of lines 4, 5 and 7. Over the mineralization the values of R1 are generally higher. High values, reaching a maximum of 2.99, were recorded over the eastern mineralization of lines 1, 2 and 4, and also on the extension of this mineralization to the south up to line 7. It is interesting to note that the western mineralization does not show significantly high readings - lines 1 and 2. The highest is below 2.0 on line 1, and just under 1.5 on line 2, which does not differ much from the values recorded over the non-mineralized ground on these lines. In general it appears that this factor shows high values over

/ disseminated

disseminated mineralization and lower values over the barren and rich mineralization. This is a very important observation as it discriminates between disseminated and richer mineralizations.

The R2-factor also appears to be indicative of the mineralization. In the barren ground R2 is generally about 0.5, as seen on the first halves of lines 4, 5 and 7.

Over the mineralizations, however, it attains values higher than 1.0. In the eastern mineralization it reaches 1.9 on lines 1 and 2, and over 1.5 on line 4. On line 5 it is just over 1. On lines 6 and 7 it is generally low because of the depth to the mineralization.

The western mineralization shows a value of just over 1.0, lines 1 and 2, which is higher than the average value of the barren and also lower than that of the disseminated. This is important as it discriminates between the two types of mineralization. In general it appears that values about 0.5 are indicative of barren, values of 1.5 represent disseminated mineralization, whereas intermidiate values of 1.0 are of higher grade mineralization.

With regard to the R1/R2 ratio it appears that the mineralized ground is characterised by low R1/R2 values. The barren areas such as the first half of lines 4,5 and 7, and also those parts of the lines which have shown no I.P. effects, e.g. line 6 and the rest of line 7, show R1/R2 values higher than 2.0.

The mineralized areas and in particular the whole of lines 1 and 2 and the eastern halves of lines 4 and 5 show low values, lower than 2.0.

It appears therefore that this ratio attains slightly lower values over the mineralized ground than over the barren. There does not appear to be any significant difference between the values for the disseminated

./ and

and richer mineralization although, however, it appears that the disseminated shows slightly lower values.

In the results presented above for each line, no special significance appeared for the factor t_d. A rather irregular picture is shown over line 2 all being over 100 msecs. Low values were recorded not only over the eastern mineralization but also over other parts of the lines. Similarly a rather high reading was recorded over the western mineralization but equally high readings were found over barren parts of the line. The rest of the lines show rather smoother results and in almost all cases between 50 and 100 msecs. In general it may be stated that the time the second component begins, t_d, does not appear to reflect the mineralization of the rocks. By contrast, however, the potential value, V_d, at which it begins does seem to be related to the polarizability of the medium. Over the barren areas such as the first half of lines 4, 5 and the whole of 7 the values of V_d do not exceed 1.0 and are usually less than 1.0

Over the mineralized ground - and in particular the eastern mineralization - this value is quite high, usually over 2.0, and reaches a maximum of 3.8 on line 3. In lines 5 and 6 it is lower, almost certainly because of the increased depth to the mineralization. The western mineralization shows relatively low values compared with the disseminated mineralization for which V_d does not exceed 2.25. This is important as it is a major difference between the two types of mineralization.

The factors which describe the deviations of the second component from the first, are actually measurements of the distance between the first linear component and the second component along the time axis at a given potential value. In the results presented above for each line, this was estimated at the potential values of 1.0 and 1.5 for line 2, and 1.0 and 0.5 for the rest of the lines. The reason it was not estimated at 0.5 for line 2

/ is because

is because of the high amplitude of the curves and would have required long extrapolations. From the results it is evident that over the mineralized areas there is a significant increase in the values of d.

Considering first the value of d(1.0) over the barren regions of the lines, the deviation at this amplitude is very low and in some cases zero. This is demonstrated on lines 4, 5 and 7, and also on parts of lines 1 and 2. Over the mineralized ground and in particular over the disseminated, this parameter increases, considerably. On line 1 it has a peak value of over 1600 msecs, on line 2 of 2200 msecs, line 4 over 1500 msecs, dropping then significantly on the rest of the lines, is at 150 msecs on line 5, just over 50 msecs on line 6 and over 25 msecs on line 7. It is interesting and quite important to note that the western mineralization on lines 1 and 2 shows up with a maximum value of 350 msecs, significantly lower than for the disseminated mineralization on the same lines.

Considering the value of d(0.5) this shows values of under 300 msecs in the region of the barren rocks. However, in the mineralized ground, particularly the disseminated, it attains extremely high values. Over line 1 these are at about 6500. On line 2 these values were similarly high but they were not estimated since they would have been the result of long extrapolations. On line 4 it has a maximum value of 6700 msecs, dropping on line 5 to about 1100, 600 on line 6 and 400 on line 7. Over the richer western mineralization of lines 1 and 2, the deviation attains a value of over 2000 msecs, much lower than the disseminated mineralization. Examining the deviation at the potential value of 1.5, d(1.5), which was estimated only for line 2, it is evident that the western mineralization is characterised by significantly lower values than the eastern disseminated mineralization. The values for each one have maxima of 5 and 320 msecs respectively.

/ 3. Conclusions

3. Conclusions.

From the results presented above and the discussion which followed, it is clear that some of the parameters which describe the various characteristics of the $\log_e t$ plotted decay curve attain much different values over the mineralized ground as compared with values over barren ground.

Table 20 summarises the values (where possible their ranges) of these parameters attained over the two mineralized areas and the barren rocks. From this Table it can be concluded that significant differences are evident in the amplitudes attained by some of those parameters over the two mineralizations. It can be generally concluded that the rates of decay of both components of the I.P. decay curve, and the potential value where they separate, attain higher values over the disseminated eastern mineralization than over the higher grade western mineralization. However, more significant differences are observed in the parameters which measure the deviation of these two components from each other. The disseminated mineralization attains distinctly higher values than the higher grade mineralization.

D. The Bertin and Loeb's (Modified) Functions

The decay curves recorded on the Mathiatis lines were also studied according to the method proposed by Bertin and Loeb (1974). In this, the quotients A1 and A2 are computed where $A1 = A/\Delta V$ and $A2 = B/\Delta V$ where A and B are as defined on the equation $y(t) = Ae^{-\alpha t} + P$, and ΔV is the primary potential recorded at the receiving electrodes. (It is assumed that Bertin and Loeb's readings were taken at a constant geometrical factor and energizing current). During the present study the A1 and A2 factors were estimated as $A1 = A/\rho/2\pi$ and $A2 = B/\rho/2\pi$ which is equivalent to the original formula of Bertin and Loeb but normalised to equal energizing current. The results are presented and discussed below.

/ 1. Presentation

1. Presentation of Results.

a. Line 1.

The results for this line are tabulated in Table 21 and illustrated in Fig. 87.

The A1-factor. On this factor much higher values were recorded over the western mineralization than in the eastern which shows almost no difference from the barren rock.

The A2-factor. A similar picture is shown in these results with the eastern mineralization not distinguished from the barren rocks whereas the western is well indicated by its higher values.

The A1/A2 ratio. Again there appears to be a difference between the two mineralizations, the eastern showing lower values. It must be noted that a very high ratio was computed for the third stake corresponding to the highest value of the A1. Compared with the other parameters described above no anomalous readings were recorded at this position.

b. Line 2.

The results for this line are tabulated in Table 22 and illustrated in Fig. 88.

The A1-factor. On this parameter the western mineralization shows a well defined anomaly whereas over the eastern mineralization the values are only slightly higher than those of the barren rocks.

The A2-factor. A rather similar picture but not so well defined, is shown by this factor in which higher values are recorded over the western mineralization and lower over the eastern mineralization, and even lower over the barren rock.

/ The A1

The A1/A2 ratio. In this the results are rather inconclusive. However, significantly different values are observed in the two mineralizations - higher over the western and low over the eastern mineralization.

c. Line 3.

The results for this line are tabulated in Table 23 and illustrated in Fig. 89.

The A1-factor. This shows a high value over the area corresponding to the western mineralization together with another slightly lower value in the region of the eastern mineralization.

The A2-factor. This factor shows two almost equal peaks each corresponding to the two mineralizations in the area.

The A1/A2 ratio. The results are rather inconclusive showing two peaks at stakes 2 and 5 which do not correspond with any high values on the A1 and A2 profiles.

d. Line 4.

The results for this line are tabulated in Table 24 and illustrated in Fig. 90.

The A1-factor. This shows a rather smooth profile along the line, the highest value being at stake 8 which corresponds to barren rock. It is interesting to note that no significant anomaly appears over the eastern mineralization, the results being lower than the average.

The A2-factor. Similarly this shows a smooth profile with no anomalous values. The eastern mineralization is again characterised by lower than average values.

/ The A1

The A1/A2 ratio. This profile does not show any significant variations except for slightly lower values in the region of the eastern mineralization.

e. Line 5.

The results for this line are tabulated in Table 25 and illustrated in Fig. 91.

The A1-factor. This factor shows a smooth profile along the line but with lower values over the area of the eastern mineralization.

The A2-factor. Similarly there is a smooth profile with again slightly lower values in the area of the eastern mineralization.

A1/A2 ratio. The values of this ratio are low in the area of the mineralization and high on either side. This low concides with the lows shown by A1 and A2.

g. Line 7.

The results for line 7 are tabulated in Table 27 and illustrated in Fig. 93.

The A1-factor. This shows an irregular profile but without any significant variation.

The A2-factor. This shows a smooth profile but also with no significant variations.

The A1/A2 ratio. This is irregular but again without significant variations.

2. Discussion.

From the results presented above which actually took into account the

/ resistivity

resistivity of the rocks, it became evident that the two mineralizations are characterised by different amplitudes of these factors. Below there is a discussion on these results. Evidently attention is paid to the possibility of discriminating between the two mineralizations i.e. the disseminated - eastern, and the higher grade - western, mineralization on the basis of these factors.

The A1-factor over the areas of the barren rocks, such as the western halves of lines 4 and 5, the western end of line and the whole of line 7, has values of about 0.2. Over the disseminated eastern mineralization in all lines, the A1-values are generally below 0.2. Over the richer-western mineralization which is crossed mainly by lines 1 and 2, the A1-factor shows significantly high values ranging from 0.4 to 0.6.

It appears therefore, that the A1-factor is capable of discriminating between the two types of mineralization, with high values in the high grade and much lower in the disseminated. The barren rock values fall between the two but are generally closer to the disseminated mineralization values.

Over the barren rock the A2-factor shows values rarely exceeding the 0.1, such as the whole of line 7 and the western half of line 5. The barren areas of lines 4 and 6, however, show values close to or exceeding the 0.2. Over the eastern disseminated mineralization the A2-values are generally below 0.2. Comparing the values of the different lines where this mineralization is encountered, these become lower in the southern lines (4, 5, and 6). This is certainly due to the increase in the depth of the mineralization as indicated by the H.T.I. values. Over the richer - western mineralization, the A2 values are higher than 0.2, reaching the value of 0.3 on line 2. It appears therefore that the A2-factor discriminates between the two types of mineralization showing high values in the rich and lower values in the disseminated mineralization. Intermediate values are shown by the barren rocks.

/ The results

The results of the A1/A2 ratio are rather obscure compared with those of the A1 and A2 factors. Over the barren areas such as the western halves of lines 4 and 5 and the whole line of 7, the values it attains are generally above 1.5 and in some cases even higher, as much as 2.8 on line 5. The eastern mineralization shows values ranging between 1.0 and 2.0. The higher grade western mineralization, however, attains higher values reaching a maximum of 3.1. In general it may be stated that the A1/A2 ratio attains higher values over the western mineralization than those of the eastern one and the barren rocks.

3. Conclusions.

From the preceding discussion it can be concluded that the functions investigated above demonstrate different values over the two mineralizations in the area and the surrounding barren rocks. Table 28 summarises the Bertin and Loeb's (Modified) Functions over these different lithologies in the Mathiatis area. From these figures it can be concluded that with the use of these functions, particularly the A1 and A2, it is possible to discriminate between disseminated and higher grade mineralization, the first being characterised by lower values than the second. The ratio A1/A2 also appears to be capable to do this differentiation, again with higher values over the higher grade and low values over the disseminated mineralization.

E. <u>The Resistivity Results</u>.

The resistivity values were computed for all lines using the field data from the I.P. survey. These results are expressed in $\rho/2\pi$ values in ohm-meters and are presented and discussed below.

1. Presentation of Results.

a. Line 1.

The results of this line are illustrated in Fig. 94(a).

/ In general

In general the pseudosectional plot of the resistivity values shows an increase of the values from the west to east. In the western end the values are low corresponding to the fresh rocks in the area. Further east over the western mineralization (receiving dipole 6-7) the resistivities are slightly higher, but they appear to follow the general trend. It is interesting to note that this trend is disturbed by the values of the transmitting pole 6 which are slightly lower than those of the adjacent ones. Further east, the resistivities continue to increase up to the area of stakes 13 to 15 where the values of $\rho/2\pi$ exceed 20.0 ohm-meters. These certainly correspond to the eastern mineralization with the highest resistivity values in the 15-16 receiver dipole. Further east there is a decrease in the resistivity values centered on the 17-18 receiving dipole.

Compared with the N.T.I. values of the same line (Fig. 60), it is observed that the low resistivities in the western end of the line correspond to the low N.T.I. values. Over the western mineralization there is no similarity between the patterns of the two parameters. Further east there is in both parameters a trend towards an increase in their values which reached maxima at the 15-16 receiver dipole.

b. Line 2.

The results for this line are illustrated in Fig. 94(b).

The resistivity values of this line appear in general to increase from west to east. The lowest values were again recorded in the area of the barren rocks at the western end of the line. Going further to the east the values increase steadily without showing any significant change in the area of the western mineralization, except for a small inflexion indicating a decrease of the values in the readings of the transmitting pole 7. Further east the resistivity values increase up to the area of the eastern

/ mineralization

mineralization, except for a decrease in the area around the receiver dipole 14-15 where the resistivities attain slightly lower values.

Comparing the resistivity with the I.P. results (Fig. 67), it is observed that the low resistivities in the western end correspond to low N.T.I. values. However, the increase in the 6-7 receiver dipole of the N.T.I. values does not become apparent in any way on the resistivity results except for the fact that the values increase steadily to the east. In the area of the eastern mineralization the high resistivities correspond to high N.T.I. values but there does not appear to be a coincidence of their highest values. In the N.T.I. results the highest values are centered about the receiver dipole 12-13 and the transmitting pole 12. On the resistivity pattern no such variations are observed at these positions.

c. Line 3.

The results for this line are illustrated in Fig. 94(c).

This line shows relatively different results from those of lines 1 and 2. In this line there is a well defined area of lower resistivity values in the western half of the line. This resistivity low extends from the small dipole separation in the region of stakes 7 to 9, to the large dipole separations in the area of stakes 3 to 5. This resistivity low region has minimum values below 3.0 ohm-meters, whereas the surrounding area has slightly higher values averaging about 5.0 ohm-meters. It is worth noting that the shape of this resistivity low pattern does not seem to be controlled much by any receiver dipole or transmitter pole. Further it must be remembered that the western mineralization does not extend much beyond this line. Beyond this there is a significant inflexion in the pattern due to the increase in the values of the large dipole separations of the transmitting pole 5. After this there is a steady increase of the resistivity values towards the eastern mineralization culminating in the small dipole

/ separations

separations of the receiving dipole 14-15. Further east there is a decrease in the values, increasing again in the last receiver dipole. As with the previous lines there appears to be in general a decrease in the resistivities with increasing dipole separation.

Comparing the resistivity and the N.T.I. results of the same line (Fig. 68), it is observed that there is no correlation of the resistivity low with any significant pattern on the I.P. results. On the contrary, in the latter there is a high N.T.I. region which has an opposite arrangement on the pseudosectional pattern beginning from the small dipole separations of the receiver dipoles from stake 3 to 6 and extending up to the large dipole separations in the region of stakes 6 and 7. Over the eastern mineralizations there is of course a general correlation between the high N.T.I. values and the high resistivity values but there is no direct comparison of the patterns produced by these parameters.

d. Line 4.

The results for this line are illustrated on Fig. 94(d).

This line shows generally low values in the western half of the line. After the receiver dipole 10-11, the resistivities increase gradually towards the east, reaching their highest values in the small dipole separations of the receiving dipoles 15-16 and particularly 16-17, and also on the transmitting pole readings of pole 17.

Comparing the resistivity results with the I.P. results of the same line (Fig. 60), it is again evident that the low resistivities correspond with the low N.T.I. and the high resistivities with the high N.T.I. values. But again there does not appear to be any similarity between the two patterns. The I.P. anomaly is very clearly observed to be centered about the receiver dipole 15-16. The resistivity anomaly, however, is observed to be displaced

/ in some

in some way further east being centered on the adjoining dipole 16-17.

e. Line 5.

The results of this line are illustrated in Fig.95(a).

The western half of this line which is believed to correspond to barren rocks, is characterised by a uniform pattern with low resistivity values. The eastern half which includes the eastern mineralization, is generally characterised by higher resistivity values. These begin to increase from the receiver dipole 13-14 attaining their highest values in the area of stakes 16 to 18. From the resistivity pseudosection it is observed that high values were recorded on the 16-17 receiver dipole and the 17 transmitter pole, as well as on the large dipole separations in the region of stakes 16 to 19. Further east the resistivity values begin to decrease.

Comparing the resistivity and the I.P. results over the same line (Fig. 70), it is observed again that there is a sympathetic relationship between the two parameters. But this is not strictly followed as suggested by the results over the eastern mineralizations where the centers of the two anomalies do not coincide. In the I.P. results the highest values were recorded in the large dipole separations in the region of stakes 14 to 16, whereas in the resistivity results this is shifted to the area of stakes 16 to 19.

f. Line 6.

The results of this line are illustrated in Fig. 95(b).

This line was surveyed only in its eastern half. From the western end of the line to the receiver dipole 14-15 the resistivity values are generally low. After this dipole there is an increase culminating in the 17-18 receiver dipole. This area of high resistivities corresponds to the southward extensions of the eastern mineralization.

Comparing the resistivity and the I.P. results from the same line (Fig. 71), it is observed that the low N.T.I. values in the western part of the line correspond to the low resistivities in the same area. The slight increase of these I.P. values in the eastern end of the line over the eastern mineralization is accompanied by a more significant increase in the resistivity values.

g. Line 7.

The results for this line are illustrated in Fig. 95(c).

This line shows generally higher values than the previous ones in most of the region of the western half. There are two distinct areas with high resistivities in this part, the first centered about the receiver dipole 4-5 and the second on the receiver dipole 9-10. Further west the values decrease in the region of stakes 9-10 and increase again on the transmitting pole readings of stake 10. An increase of the resistivities is also observed in the region which could be considered as corresponding to the southward extension of the eastern mineralization in this line.

Comparing the resistivity and I.P. results of the same line (Fig. 72), it is observed that the N.T.I. values also show an irregular pattern in the western half of the line whereas on the previous lines this region shows a smooth non-anomalous pattern. However, there does not appear to be any similarity between the resistivity and the N.T.I. patterns. Over the eastern half of the line where there is a definite increase of the resistivity values, the N.T.I. results show only a very slight increase which is observed mainly on the large dipole separations.

2. Discussion.

From the results presented above it is evident that the resistivity values over the different areas along the Mathiatis lines attain different

/ amplitudes.

amplitudes. The significance of these values is discussed below.

For those parts of the lines which are believed to be underlain by barren rocks - as indicated by their low I.P. responses, the resistivity values are generally low. From the values recorded in the western ends of lines 1 and 2 and the western halves of lines 4, 5, 6 and in some areas of 7, it is observed that the resistivity values range from about 1.5 to almost 6.0 ohm-meters. Some areas, however, such as the 4-5 and 9-10 receiving dipoles of line 7 show higher values than these, but it is not certain that these are due to barren rocks. This is discussed below.

Lines 1 and 2, which run over the western mineralization, in the first line being only at a shallow depth (see Fig. 64), there does not appear to be any significant change in the resistivity pattern. The only changes are the slight variations in the general pattern which are observed in the readings corresponding to the transmitter poles 6 and 7 on lines 1 and 2 respectively. In both cases they suggest a decrease of the resistivity values. An interesting pattern is observed on the pseudosectional plot of line 3 and particularly on the transmitting pole 5. This shows an increase in the resistivity values which appears not to conform with the general trend in the area. From the above it is evident that the resistivity values recorded over the western mineralization do not differ much from those of the enclosing barren rocks.

A different picture is observed over the eastern halves of almost all lines. In those parts of each line, the resistivities attain much higher values than those of the barren rocks, reaching in some cases values of 20.0 ohm-meters. This resistivity increase parallels the increases in the N.T.I. and the other I.P. parameters described in the previous sections, in that they are not sharp increases limited on a number of consecutive dipole readings, but they extend over almost the whole eastern half of each line (except for

/ lines

lines 6 and 7). These higher values attain, however, maximum values on certain receiver dipole readings and also transmitting pole readings. It must be noted that in general these maximum value dipoles do not coincide with the dipoles which gave the maximum I.P. responses. It is interesting to note that the N.T.I. results of lines 5, 6 and 7, show in general smoothly contoured patterns which are interpreted as being due to the increase depth to the mineralization. On the contrary, the resistivity patterns of these lines show rather sharply defined anomalies. Any attempt to explain these phenomena must certainly take into account the nature of the mineralization in question. As described earlier in this Chapter, the eastern mineralization is of a disseminated type which was accompanied by intensive silicification of the rocks which appears on the drill cores as silica veins of variable thicknesses. Evidently the two phenomena, i.e. sulphide mineralization and silicification, although having the same origin, have different spatial extends. And both these are considered as giving higher resistivities than normal unmineralized rocks (Parkhomenko 1967). It is proposed, therefore, that the high resistivity values recorded in lines 5, 6 and 7, could correspond to rocks which have been silicified during the general mineralizing activity, this silicification extending beyond the centers of the mineralization where the sulphides were mainly deposited.

3. Conclusions.

From the preceding discussion it can be concluded that the resistivity method can convey useful information which can assist an I.P. exploration project substantially. From the above results it is concluded that the resistivity values of both the barren rocks and the western mineralization have almost similar amplitudes. This suggests that their discrimination on the basis of resistivity only is problematic if not impossible. The eastern mineralization on the other hand which corresponds to disseminated pyrite in silicified rocks, gives much higher resistivities. These high values are

/ attributed

attributed to both the impregnated nature of the mineralization and the silicification of the rocks.

F. Conclusions

The geophysical results presented and discussed above include the investigation of I.P. parameters which are applied in a routine exploration project together with parameters which describe the variations of the shape of the I.P. decay curve. Together with these, the present study included an investigation of the Resistivity method.

From the discussion which followed each investigation and the conclusions which were drawn, it can be stated that the I.P. method in general appears to be capable not only to discriminate between mineralized and unmineralized rocks assisting in this way the location of mineralization, but also to discriminate between disseminated and higher grade mineralization. The N.T.I. which is the routine recorded parameter, demonstrated that over the disseminated eastern mineralization it attains much higher amplitudes than over the higher grade western mineralization. It must be noted that the conditions at which these two mineralizations occur when they are compared are similar i.e. of about the same depth.

From the factors which describe the shape of the I.P. transient curve, most of them appear to respond positively over the mineralization. The A and B factors which represent respectively the amplitude of the electromagnetic and true I.P. component of the transient decay, attain higher values over the mineralization than over the barren rocks. Similarly the P-factor which is a measure of the amplitude of the decay at a time much longer than those recorded on the N.T.I. readings. From these it appears that the B-factor which is in fact the true chargeability, attains lower values over the higher grade western mineralization and higher over the disseminated eastern one.

/ A number

A number of other parameters which describe the shape of $\log_e t$ plotted decay curve were also investigated. It was demonstrated that the I.P. decay is formed of two components which become apparent when the decay is plotted on a $\log_e$ time axis. The first being a rapid decaying linear component and the second a slower non-linear component. The parameters which describe this picture and which were investigated over the Mathiatis area, are the rates of decay of each component, R1 and R2 respectively, their ratio R1/R2, the time and the potential values at which they separate, t_d and V_d, and their degree of deviation from each other along the time axis measured at two different potential values. From the results obtained in the Mathiatis area, it can be concluded that the R1 and R2 factors attain high values over the mineralizations and particularly over the disseminated mineralization, suggesting that a discrimination between the two grades could be possible on the basis of these two factors. A similar picture is shown by the potential value at which the two components begin to separate from each other. Again the values over the disseminated mineralization are higher than those over the higher grade mineralization. The most striking difference between the two mineralizations at Mathiatis is shown by the deviation factors. From the results presented above there is no doubt that the values these factors attain over the two mineralizations are significantly different from each other. Even lower values were recorded over the barren rocks.

Other parameters related to the decay curve shape are the Bertin and Loeb's (Modified) Functions which demonstrated again different values over the two mineralizations, low over the disseminated and higher over the high grade mineralization.

Together with the various I.P. parameters investigated above, the resistivity of the various lithologies was studied and compared with the I.P. responses. It was concluded that the resistivity values of the barren rocks

/do not

do not differ significantly from those of the higher grade western mineralization. The disseminated mineralization, however, is characterised by much higher values.

/ IV. GENERAL

IV. GENERAL CONCLUSIONS

The present Chapter described and discussed the geophysical results from the Mathiatis area. This area encloses two grades of mineralization in a geological environment similar to that of almost all economic deposits exploited so far, i.e. in the Lower Pillow Lavas. The most important characteristic of this area as a whole, was the fact that it included two types of geophysical targets, both of them showing anomalous responses on I.P. parameters which are recorded in a routine exploration project. One of these targets is characterised by grades of mineralization which are comparable with those of other economic deposits, whereas the other had only a very low concentration of sulphides. The main purpose of the research carried out over the area was to establish criteria which would enable the geophysicist to decide whether an I.P. anomaly recorded during an exploration project is likely to correspond to a certain grade of sulphide mineralization, and thus to decide whether it is likely to be of economic interest or not. Irrespective of the sulphur grade of the mineralization, the geophysicist wishes to be in a position to decide whether the mineralization encountered after drilling a borehole or two is that which produced the geophysical anomalies, so that no further drilling or other exploration is carried out over a non-economic target.

From the research carried out on the Mathiatis results it is believed that some progress was made towards the establishment of such criteria. It was demonstrated that the routine recorded I.P. parameters (the N.T.I.) give anomalous readings over any grade of mineralization. And if an exploration project as a whole is to proceed to its next stage, all those targets must be drilled. However, from the study of the characteristics of the I.P. decay curve it was established that its shape varies according to the grades of sulphides included in the rocks. It was proved that in fact some of the

/ factors

factors which describe the shape of the decay, attain significantly different values over disseminated mineralization as compared with those over higher grade mineralization which is more likely to be of economic significance. From the study of the resistivity results which were recorded together with the I.P., it was demonstrated that at least in the higher grade mineralization of the Mathiatis area, the resistivities of the enclosing rocks could be as low as those of the mineralization. However, the non-economic mineralization in the area was shown to be characterised by much higher resistivities than those of the higher grade mineralization. This phenomenon is certainly related to the mineralizing mechanism in general and its overall effect on the country rocks.

/ CHAPTER FIVE

CHAPTER FIVE

ON THE GEOPHYSICAL RESULTS OF THE KLIROU AREA

I. INTRODUCTION

The Klirou area occurs in the northern foothills of the Troodos Massif. Its location is shown on Fig. 1. Its main feature is a series of colourful gossans all aligned in a north-south direction. The terrain is Lower Pillow Lavas close to the boundary with the Upper Pillow Lavas.

Ancient mining activity on a small scale, is evident from small patches of ancient slags. The colourful gossans were exploited for gold later, during the 1940's, but again on a small scale. During the United Nations Development Program in 1964 some attention was paid on these gossans which were drilled, without disclosing any significant grades of cupreous or even non-cupreous mineralization. Recently, in early 1976, the Noranda Exploration (Cyprus) in collaboration with the Hellenic Mining Company Ltd. carried out a geophysical survey of the area with I.P. and P.E.M. and on consequent drilling discovered a shallow seated concealed mineralization to the east of the gossans. After this, it was considered pertinent to carry out a research I.P. program over the two mineralizations - gossan and concealed, in order to investigate further the I.P. method. For this the area was covered with five parallel lines of east-west direction which crossed both the gossans and the concealed mineralization. This research program .lead to the discovery of another concealed mineralization at a greater depth lying again to the east of the gossans and to the north of the second mineralization.

The present Chapter begins with a description of the geology of the

/ Klirou

Klirou area. This is followed by a detail analysis of the geophysical results and closes with some conclusions with regard to the applicability of the method and the significance of the various parameters investigated.

/ II. THE

II. THE GEOLOGY OF THE KLIROU AREA

The Klirou area together with its mineralized ground presents an excellent example of mineralized zones in the Lower Pillow Lava terrain. As described in an earlier Chapter, these zones are considered as mineralized fracture systems which correspond to the lower parts of a Cyprus-type deposit, the highest being the rich volcanic exhalative mineralization.

Fig. 96 is a geological map of the area covered during the present project showing also the layout of the geophysical grid. The background consists of andesitic flows and intrusions which belong to the Lower Pillow Lava Series. The proportion of the intrusions which have a north-west trend increases to the south towards the Basal Group which outcrops outside the area. The pillow lavas appear to plunge to the northeast. The Upper Pillow Lavas are found in the northeast outside of the area. They are thin and consequently they are found in small outliers.

There are three different zones of mineralization recognised at Klirou, see Fig. 96. The first occurs to the west, occupying the prominent Kokkinorotsos (red-rock) hill. This is referred to below as the western mineralization. The second occurs to the south-east of this hill in the area of boreholes HKL-1 to HKL-27 referred to below as the southern mineralization. The third occurs in the northeastern part of the area in the region of bore-holes HKL-34 to HKL-57 referred to below as the northern mineralization.

A. The Western Mineralization

This outcrops on the surface forming the colourful gossans of Kokkino-rotsos. These gossans have a prominent north-south direction being controlled by parallel faults, see Fig. 96, which enclose the mineralized ground in the form of a horst through the unmineralized volcanics. This horst has been cut and dislocated along its length by a later east-west structure. Fig. 97

/ is a

is a geological section across this mineralization along the geophysical lines, demonstrating its structure. The same figure illustrates the grade of this mineralization as indicated from borehole KLCH-18. This hole proved that the grade does not exceed the 7.0% in sulphur with very low values of copper and zinc. Mineralogically it consists of silicified and propylitised lava with pyrite and minor amounts of chalcopyrite. To the west of these gossans, and in some cases in faulted contact with them, see Fig. 96, the Lower Pillow Lavas are intensively iron-stained with a very low degree of mineralization in the form of disseminations of pyrite which do not exceed the 1% in sulphur. This type of mineralization is seen to grade to the west into fresh Lower Pillow Lavas. For description purposes this lower grade mineralization is included in the western mineralization.

B. The Southern Mineralization

This is concealed by unmineralized volcanics which range in thickness from 15 to 50 meters. The extensive drilling proved that the mineralized ground occurs in a narrow zone about 80 meters wide running in a north-south direction, see Figs 96 and 97. The boundaries appear to be gradational passing from unmineralized volcanics to very slightly mineralized, to propylitised lavas with rich grade, occasionally massive, see for example boreholes HKL-8 and HKL-4 in Fig. 97(b). To the west, the boundary dips by about 50^{o} and is apparently connected in depth with the western mineralization, Fig.97. The eastern boundary is most probably steeper with an almost vertical dip as indicated by borehole HKL-17, Fig.97. Similarly, the zone is delimited to the south and to the north as it was indicated by the drilling results. In conclusion the southern mineralization has a flattened pipe-like shape with almost vertical attitude. It can be interpreted as an example of a blind mineralization in the Lower Pillow Lavas, being an offshoot of a mineralized fracture zone.

/ The primary

The primary mineral is pyrite in the form of vein and cavity filling. There are subordinate amounts of chalcopyrite and sphalerite. The sulphur content is occasionally rich reaching 50% - massive pyrite.

C. The Northern Mineralization

This is also a concealed mineralization occurring at a depth of over 80 meters within the Lower Pillow Lavas, Fig.97. This mineralization is located to the northeast of the southern mineralization and it was discovered during the presently described I.P. project after drilling the N.T.I. anomalies in these parts of lines 3, 4 and 5. The drilling results indicated that this mineralization extends to the north beyond line 5 up to borehole HKL-40, Fig. 96. Its northern boundary appears to be tectonic. The overall shape of this mineralization appears from the drilling results to be one of a northerly trending zone occurring in depth within the Lower Pillow Lavas. It was originally considered to be a dislocated part of the southern mineralization,cut and displaced both vertically down and laterally. However, there is no sufficient geological information to support this. It is more likely a parallel zone displaced on enchelon with respect to the western and southern mineralizations.

The sulphide content of this mineralization varies from a few percent sulphur to massive. The latter appears to occur in concentrations within the lower grade. The primary mineral is pyrite with subordinate amounts of calcopyrite and sphalerite.

III. THE GEOPHYSICAL RESULTS

The whole area was covered by five parallel lines (1-5) trending east-west 950 meters each, with a line spacing of 60 meters, see Fig.96. These lines covered the gossans in the west and crossed also the two concealed mineralizations. Readings on these lines were taken with the pole-dipole array on electrode separations n = 1-4 and at a spacing of 50 meters. On lines 1 to 4 the whole I.P. transient decay was recorded on the n = 2 dipole separation. The period of the energising current was 8 sec at an on/off ratio of 1.0 and the I.P. transient was being recorded at four positions: 55, 130, 280 and 580 msecs from the time of interruption of the energising current.

Below there is an analytical description of the geophysical results and studies in the following sequence:

A. The Normalised Time Integral.

B. The Decay Factors.

C. The $Log_e t$ Decay Factors.

D. The Bertin and Loeb's (Modified Functions.

E. The Resistivity Results.

A. <u>The Normalised Time Integral</u>

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig. 98 which is a pseudosectional plotting of the N.T.I. values. In all Msec sections there is evidence of two different mineralizations. The first is indicated by the anomaly recorded with center the receiving dipole 9-10. High values were also recorded on the adjoining dipoles. It is evident on all Msec values that the anomaly is asymmetrical being controlled by the receiver dipoles. The

/ dipole

dipole 11-12 has given much lower values in all dipole separations. Further west there is a significant increase in the Msec values. In the region of stakes 15 to 13 these high values are concentrated in the low dipole separations n = 1-2, whereas on the 15-16 receiving dipole results all dipole separations show high readings. Thus the anomaly attains an asymmetric boomerang shape dipping to the west.

The first anomaly, dipole 9-10, is attributed to the southern mineralization which is found in the area under about 30 meters of fresh Lower Pillow Lavas. The second anomaly is due to the exposed mineralization (gossans) which outcrops in the region of stakes 13 to 17.

b. Line 2.

The results for this line are shown in Fig. 99. On all Msec values and particularly the Msec 4, there is evidence of two anomalous regions. The first is in the area of stakes 9-11 where the anomaly has an asymmetric shape, resulting from the fact that it has been recorded on the receiving dipole 9-10. The 10-11 dipole also shows high values. After a dipole of low values, 11-12 except for n = 1, there is a broad area of high values in the region of stakes 13-16. Further west the 16-17 dipole has also recorded moderately high values.

In general the shapes of the anomalies are controlled by the receiving dipoles. The first anomaly can certainly be attributed to the southern concealed mineralization which in the area of this line is in a depth of about 10 meters under fresh Lower Pillow Lavas. The second anomaly is the result of the exposed western mineralization extending from stake 13 to 19.

c. Line 3.

The results for this line are shown in Fig. 100. On the pseudo-sectional plottings of all N.T.I. values there are clearly two regions of

/ anomalous

anomalous results. On the Msec 4 pattern there is an indication of a third anomalous area as well. This third area is shown by the readings of dipoles 3-4 and 4-5 on the n = 3 and n = 4 dipole separations. The second area of high readings is shown by the results of the dipole 7-8. To the west of this dipole there is a continuation of the high values with a minor drop in the 9-10 results. Further west anomalous readings were recorded by the dipoles from 12 to 15. Again the anomaly appears to be dipping to the west. Further along the line the readings on the low dipole separations remain high until the end of the line.

The first anomaly in the region of stakes 3-5 cannot be attributed to any known mineralization. The second anomaly is certainly due to the northern mineralization which was discovered after drilling it at a depth of about 100 meters. The anomaly in the region of stakes 12-15 is certainly due to the outcropping western mineralization.

d. Line 4.

The results for this line are shown in Fig. 101. The pseudosectional plottings for this line show two regions with anomalous N.T.I. values. The first is a broad region of values higher than those in the eastern end of the line, beginning from the region of stake 6. The highest values were taken on the receiving dipole 7-8. Further to the west beginning from the region of stake 12 the values begin to increase forming a second broad anomaly having a V-shape. The eastern leg of this V is rather broad defined by the readings of receiving dipoles 12-13 and 13-14. The western leg is stronger with high values corresponding to the transmitting poles 19 and 18.

The first anomaly which was interpreted as being due to a deeply seated conductor was proved by drilling to be due to mineralization - the northern mineralization at a depth of about 100 meters. The second anomaly is caused by the outcropping western mineralization in this part of the line.

/ e. Line

e. Line 5.

The results for this line are shown in Fig. 102. In view of the fact that line 4 has shown high values in the n= 4 separation, line 5 was surveyed up to n = 5 in its eastern half.

All N.T.I. values show two broad areas with anomalous values. The first is in the region of stakes 4 to 10. In the Msec 1 to Msec 3 pseudo-sections there appears to be a single peak anomaly whereas in the Msec 4 pseudosection there is evidence for a second peak recorded on the receiving dipole 4-5. The first peak has been recorded by the 6-7 receiving dipole. After an area of lower values in the dipole readings 8-9 and 9-10, the Msec values increase and remain almost constant in the region of stakes 12 to 16. Further, on the receiving dipole 16-17 there is a notable increase in the values. A single high value was also recorded in the n = 3 separation between stakes 16 and 17. This is related to the transmitting pole 18. This anomaly has a boomerang shape centered about stake 17. As stated earlier, the first anomaly is the response of the deeply seated northern mineralization. The western anomaly is certainly due to the exposed mineralization.

2. Discussion.

The geophysical survey described above, indicated three different anomalous areas, each corresponding to a different mineralization. The first and most noticeable anomaly is that of the exposed - gossan, referred to above as the western mineralization; the second anomaly is caused by the concealed mineralization in the region of boreholes HKL 1-HKL 33 immediately east of the gossans (Fig. 96) referred to as the southern mineralization, and the third is the broad and deeply seated anomaly in the region of boreholes HKL 34 to HKL 40 to the north of the previous mineralization, referred to as the northern mineralization. In the following pages there will be a discussion on the N.T.I. responses over these three conductors.

/ a. The

a. The Barren Rocks.

The barren rocks have generally given low N.T.I. values. These have their lowest magnitude on the smallest dipole separation being about 100, and their maximum on the highest with values around 250 in the Msec 4 integral. From Fig. 98 for example (line 1), it appears that the magnitude of the N.T.I. is gradually increasing as the mineralization is approached. With the southern mineralization in the area of stake 9, the values of N.T.I. seem to begin to increase from the region of stake 5, two hundred meters away.

b. The Western Mineralization.

This mineralization can be divided into two grades, the poorly disseminated ($S < 1\%$) and the richly disseminated ($S = 1-5\%$) as described above. All lines have crossed both these two grades. The poorly disseminated mineralization appears in all cases to give generally lower values than the other grade of the mineralization. The magnitude of the Msec 4 response appears to be generally around eight hundred and in many cases even lower, except for line 4 where readings over one thousand were recorded on the current stake 19. The richly disseminated mineralization is indicated with much higher values over one thousand and in some cases over fifteen hundred. This is generally true for lines 1, 2 and 3. On lines 4 and 5 the rich western mineralization has not given very strong amplitudes as on the first three lines. Their values are generally low approaching the values of the poorly disseminated mineralization.

In conclusion, it is evident that the N.T.I. parameter gives anomalous responses over both the two grades of mineralization. On the individual lines there appears to be some difference in the magnitude of this response with respect to the grade of mineralization which produce it. However, this cannot be generalised as both grades can give both high and low N.T.I. values.

/ c. The

c. The Southern Mineralization.

The I.P. responses over this mineralization are shown on Figs 98 and 99 corresponding to the results of lines 1 and 2 which crossed the mineralization in question. The highest results on line 1 were recorded in the receiving dipole 9-10 (Fig. 98). Anomalous values were also encountered on the adjacent dipoles (8-9 and 10-11). The maximum value in the Msec 4 integral is 981 on the n = 3 dipole separation. The first dipole separation gives a value of 620. It should be remembered that in this line the mineralization is of high grade (massive pyrite) and it begins from a depth of about 13 meters.

The responses of the second line are shown in Fig. 99. The highest values were recorded on the 9-10 receiving dipole and the Msec 4 integral exceeds the one thousand on the n = 3 dipole separation. High values were also recorded on the adjacent dipoles (8-9 and 10-11). It is reminded that in the region of line 2, the mineralization is slightly shallower than line 1, about 10 meters deep, but with much lower grade with an average of about 4% sulphur (HKL-14, HKL-17).

From the comparison of the pseudosectional patterns of Figs 98 and 99, both between them and with the corresponding geological sections, a number of conclusions can be drawn. First there appears that the massive mineralization, line 1, has given slightly lower N.T.I. values than the lower grade mineralization of line 2. Second, the highest values on both lines were recorded by the receiving dipole which was closer to the top of the mineralization. And the values on this dipole (9-10 on both lines) are not high on all dipole separations. In the first separation the value is much lower although the thickness of the unmineralized rocks over the mineralization does not exceed the 15 meters. It is interesting to note that the values recorded on the next receiving dipole (10-11) are much lower than those of the 9-10 dipole. The mineralization in this region (10-11) is at a depth extending

/ from

from 15 meters (HKL-4) to 50 meters (HKL-21) for line 1, and 25 meters (KLCH-14) to 40 meters (KLCH-16) under line 2.

Assuming that by increasing the dipole separation the depth of penetration increases, it would have been expected at least on the n = 3 and 4 separations of the dipole 10-11, that the I.P. responses would have been almost as high as the responses of the 9-10 separation since they "approach" the deeper mineralization. This is not the case, although some effect of the dipole separation with regard to the depth and the magnitude of the response is indicated by the n = 1 results of the 9-10 receiving dipoles on both lines. It can therefore be concluded that the responses at each dipole are more dependent on the proximinity of mineralization to that dipole when this is used as a receiving dipole, than the dipole separation value.

Another important conclusion which can be drawn from the preceding discussion, although it has been assumed in all the previous discussions, is the fact that the anomalous responses seem to depend considerably on the receiving dipole than the transmitting pole. For this, the anomalies although corresponding to conductors of well defined geometrical shapes, in this case almost vertical, they seem on the pseudosectional pattern which accounts for both the position of the receiver and transmitter, as dipping 45^{o}. (The amount of dip, 45^{o}, and the direction, results from the conventions applied in the pseudosectional plotting). The importance of this conclusion is realised when is to be decided to drill such an anomaly. From the above it is strongly emphasised that the most appropriate position is in the middle of the dipole which "received" the anomalous responses; in the case of lines 1 and 2 the dipoles 9-10 for both of the lines.

d. The Northern Mineralization.

Responses of this mineralization have been recorded mainly by lines 4 and 5 and perhaps even by line 3. In general the responses are low, the

/ highest

highest in the Msec 4 integral being over six hundred. From the pseudosectional patterns, see Figs 101 and 102, it is evident that the highest responses were recorded when the receiving dipole was over the mineralization. This implies that the mineralization was not only indicated by the anomalous values in the large dipole separations but also by slight increases in the values in the lower dipole separation. Collectively this appears on the pseudosectional pattern as a rising of the contour values towards the center of the receiving dipole which was located over the cause of the anomalous values. An example of this phenomenon was the siting of the first borehole on the northern mineralization (HKL-34) which was sunk on stake 7 of line 4. On the pseudo-sectional pattern of this line (Fig. 101), the values of the N.T.I. in this area are generally low.

3. Conclusions.

From the preceding presentation of results and the discussion which followed, it may be concluded that all three mineralizations at Klirou were recorded on the N.T.I. results. Certainly the shallower seated, exposed, western mineralization has given the strongest anomaly. By comparing the results over this exposed mineralization it appeared that the rich dissemin-ations (1-5% S) have given higher responses than the poorly disseminated mineralization. This was observed on lines 1, 2 and 3, whereas on lines 4 and 5 the 1-5% S grade has given responses as low as the lower grade and vice versa.

The southern mineralization was indicated very clearly on both lines (1 and 2). An important conclusion drawn from the anomaly of this mineral-ization is that the highest values were recorded when the receiving dipole was directly over the mineralization. On the pseudosectional plotting this appears as a series of high values which give rise to 45^{o} dipping contoured anomalies. The same conclusion was also drawn from the northern mineraliza-tion as well. This latter mineralization, although at a depth of about one

/ hundred

hundred meters was shown relatively well by the N.T.I. results.

B. The Decay Factors

The I.P. transient decay has been recorded at the n = 2 dipole positions over line 1 to 4. In fact the amplitude has been recorded at the following times (in msecs): 35, 55, 90, 95, 130, 150, 180, 215, 240, 280, 360, 420, 455, 580, 720 and 780. These transient results were factorised according the Hutchins' (1971) method described in detail in Chapter Three of this Thesis. The results for each line are presented and discussed below.

1. Presentation of Results.

The results for the Klirou lines are tabulated in Tables 29 to 32 and illustrated in Figs 103 to 106. From these it is observed that the A and B-factors attain high values over the exposed western mineralization and the concealed southern and northern mineralizations, compared with the values over the barren rocks. The α-factor appears to show in general low values in the region of the different mineralizations, whereas the β-factor shows no significant variations over the mineralized ground. Finally the P-factor values are higher over the mineralization than over the barren rocks.

2. Discussion.

From the preceding presentation of the results it is concluded that most of the factors of the decay equation indicate in some degree or another the presence of mineralization. It is interesting to examine the amplitudes of these factors from the individual mineralizations.

a. The Barren Rocks.

Although readings over barren volcanics were taken over many parts of the lines, their amplitudes are likely to be affected due to proximity to

/ mineralization.

mineralization. For this, only the values of the eastern ends of lines 1 and 2 were accounted as barren areas. The A and B-factors are respectively 1.3 to 2.0 and 0.33 to 0.9. For the α and β-factors the values range between 8.9 and 17.0, and 0.52 and 1.8 respectively. The P-factor is generally low ranging from 0.02 to 0.24.

b. The Western Mineralization.

This is divided into two grades. The very poor disseminations with less than 1% S and the richer disseminations ranging from 1 to 5% S. From the results presented above it is evident that in the poor disseminations the A-factor attains values between 2.3 and 3.3. Over the richer mineralization (1-5% S) this factor has values ranging from 3.0 to 7.6. The B-factor has a value between 0.73 to 2.2 in the poor disseminations, whereas in the richer western mineralization the values of B are generally higher ranging from 1.6 to 4.0. The α-factor, as it was stated above, shows low values over the mineralizations and higher over the barren rocks, although these low results do not correspond well to the respective high A and B values. Over the poor disseminations it has values ranging from 7.8 to 13.7 whereas over the richer grade (1-5% S) it ranges between 7.2 and 13.0. The β-factor has values ranging from 0.5 to 0.76 in the poor mineralization, and 0.63 to 0.88 in the higher grade. The P-factor attains low values in the poorly disseminated mineralization ranging from 0.29 to 0.57, and higher values in the richer western mineralization ranging from 0.5 to 1.22.

c. The Southern Mineralization.

This was encountered only by lines 1 and 2. The A-factor ranges from 2.5 to 4.3. The B-factor has values ranging from 1.77 to 2.42. The α and β-factors attain values ranging between 9.1 and 9.8, and 0.65 and 0.73 respectively. The P-factor ranges from 0.5 to 0.75.

/ d. The

d. The Northern Mineralization.

This is deeply seated under a cover of about 100 meters of unmineralized volcanics. Although the responses of this mineralization cannot be compared with those of the shallow ones, their decay factors are included in this discussion for comparison with the barren rocks. The A-factor ranges from 1.7 to 2.7 and the B from 0.82 to 1.5. The α, β and P-factors have respectively the following ranges: 11.0 to 13.4, 0.9 to 1.13 and 0.11 to 0.17.

3. Conclusions.

Table 33 summarises all the above results. The results of the western and southern mineralizations can be compared between them as they are both from exposed or very shallow seated conductors.

The lowest value of A is shown as expected by the barren rocks. Between the western and southern mineralizations the very poor disseminations show the next range of values, whereas the 1-5% S mineralization (rich disseminations) show values higher than the more massive southern mineralization. The deeply seated northern mineralization shows values slightly above those of the barren rocks.

The B-factor, the true chargeability, has naturally the lowest range of values over the barren rocks. The highest is that of the rich disseminations which is higher than the southern (richer) mineralization. The lowest between the three mineralizations is that of the poor disseminations (1%). The northern mineralization has values ranging almost outside the range of the barren rocks.

The α-factor ranges of values over the different targets seem to overlap considerably. However, it is obvious that the barren rocks could show much higher values than the mineralizations. In addition it appears

/ that

that the western mineralization could have lower values than the richer southern mineralization which shows a more narrow range. The northern mineralization range of values falls within the western mineralizations' ranges.

A similar picture is shown also by the β-factor. The widest range with the highest value is shown by the barren rocks. The three shallow mineralizations attain about the same range of values, whereas the northern one shows clearly higher values.

The P-factor has properties similar to those of the A and B-factors. The highest values are those of the rich disseminations followed by those of the southern mineralization. The poor disseminations show even lower values but almost outside the range of the barren rocks which show the lowermost values. The values of the northern mineralization fall in the range of the barren rocks.

In conclusion it appears that the A, B and P-factors could be capable of distinguishing between the three mineralizations i.e. poor disseminations (1% S), rich disseminations (1-5%), and richer mineralization. The highest values are attained by the rich disseminations and the lowest by the poor disseminations. The richer mineralization values fall between these two. The α and β-factors show rather inconclusive results. However, it is evident that they attain lower values over the mineralized ground than over the barren areas.

C. The $Log_e t$ Decay Factors

The transient decays recorded at the n = 2 dipole separation of lines 1-4 were plotted on a log_e time axis and normal potential axis. The characteristics of such plottings as described in Chapter Three, were studied and the results are presented and discussed below.

/ 1. Presentation

1. Presentation of results.

The results are tabulated in Tables 34 to 37 and illustrated in Figs 107 to 110. The R1 parameter is generally higher over the mineralization than over the barren rocks. Similarly the R2 parameter, but with lower values than the R1. Their ratio appears to decrease over the mineralized ground. The t_d parameter varies about 100 msecs with an apparent increase in the areas adjacent to the mineralizations and a decrease over them. The V_d parameter attains generally higher values over the mineralized ground. The deviation parameters d(1.0) and d(0.5) also show high values over the different mineralizations.

2. Discussion.

The results presented above indicate that the three different mineralizations can be delimited by most of the $\log_e t$-plotted decay factors. Below there is a discussion on the responses attained over the barren rocks and the different mineralizations.

a. The Barren Rocks.

The areas with the barren rocks and without any suspected anomalies not already drilled, show generally different values than those over the mineralizations. The R1 and R2 factors are low with ranges 1.20-1.45 and 0.5-0.9 respectively. The R1/R2 ratio ranges from 1.2 to 3.2. The V_d-factor is again low with a range 0.7-1.0. The t_d-factor has a narrower range than over the mineralized ground with values between 90 and 105 msecs. The deviation factors are also low, the d(0.5) having a range of 30-630 and the d(1.0) a 0-50 msecs.

b. The Western Mineralization.

This consists of two different grades, a poorly disseminated with less than 1% S and a richly disseminated with 1 to 5% S. (Their distribution is

/ shown

shown in Fig. 96). From the results presented above it is evident that both the R1 and R2 factors attain high values over the western mineralization. It is also evident, however, that the 1% S mineralization shows lower values than the richly disseminated one (1-5% S) in both R1 and R2. They show respectively over the poorly disseminated a range of values of 2.2 - 2.95 and 1.4 - 2.1, whereas in the richly disseminated mineralization the corresponding ranges are 3.1 - 5.3 and 2.1 - 4.15. It is noted that there is no overlap of these ranges. The ratio R1/R2 has almost equal values over both the mineralizations. The range of values it attains over the two types is 1.4 - 1.57 over the 1% S and, a slightly lower range of 1.2 - 1.51 over the richer disseminations (1-5%).

The V_d values over the two different grades appear to be significantly different. The poor grade attains a range of 1.9 - 3.2, whereas the richer grade a higher one of 3.3 - 7.5. As for the case of the R1 and R2 factors, it appears that the V_d-factor can distinguish between the two different grades. The t_d-factor presents rather inconclusive results. The range of values it attains in the 1% S mineralization is narrow, 120-140, included in the much wider range of the richer disseminations, 78-170. It appears therefore that the t_d-factor can attain lower and higher values over the richer mineralization than over the poor grade.

The two factors describing the deviation of the second component from the linear d(0.5) and d(1.0) attain high values over both the mineralizations. However, their ranges of values seem to differ for each of the two grades. In the first factor d(0.5), the poor mineralization (1%) has a range of 800-2000 msecs whereas the richer ranges from 1900-3200 msecs. These two ranges show only a small overlap of 100 msecs. The second factor d (1.0), shows no overlap at all in its ranges of values. The poor mineralization has values ranging from 180-900 msecs, whereas the richer disseminations have a range of 1200-2300 msecs.

/ c. The

c. The Southern Mineralization.

The values of some of these factors over this mineralization are generally above the background values. The presence of the mineralization is indicated by the R1 and R2 factors with ranges of 2.28-3.6 and 1.79-2.68 respectively, whereas their ratio does not show any significant variation along the profiles.

Similarly, the presence of the southern mineralization is indicated by the V_d-factor. This attains values between 2.9 and 4.5 which as seen on the different profiles are well above those of the barren rocks. The t_d-factor attains values ranging between 105 and 125 msecs without presenting any significant change over the mineralization.

The factors measuring the deviation of the decay curve from the linear are also indicating clearly the presence of the southern mineralization. The first one, d(0.5), has ranges between 2100 and 2400, whereas the second, d(1.0), has a range of 900-1300. The ratio of these two factors has values ranging from 1.84 to 2.66.

d. The Northern Mineralization.

The deeply seated northern mineralization was also indicated by most of the above factors. Both the R1 and R2 factors attained values over this mineralization ranging above the background values. These ranges are respectively 1.75 - 2.38 and 1.18 - 1.52. The ratio of these two factors ranges between 1.39 and 1.95.

The V_d-factor also indicated slightly higher values over the region of the northern mineralization, its values ranging from 1.16 to 2.3. The t_d-factor showed a wide range of values, from 95 to 170 msecs.

The measures of the deviation of the decay curve from linear d(0.5)

/ and d(1.0)

and d(1.0) indicated more conclusively the presence of the northern mineralization. They attained respectively values ranging from 600 to 1050 and 50 to 300.

3. Conclusions.

Table 38 summarises the results discussed above. Comparing the results over the western and southern mineralizations, which are both shallow seated, it can be concluded that with the R1 and R2 factors the richly and poorly disseminated mineralizations can be distinguished as they attain values differring from each other. However, the higher grade southern mineralization has values falling between these poorer grades. This is observed also in the V_d and d(0.5) and d(1.0) factors. . The ratios of R1 and R2 show some differences in the values of the two disseminated mineralizations but in general there is an overlap of the two ranges. The t_d-factor does not seem to offer any useful criterion. In conclusion, the richly disseminated ... shows higher values than the poorly disseminated and the rich grade. It can also be concluded that a deeply seated mineralization,like the northern one in this case,can be shown by these factors. Their values over the barren rocks are generally low. It is worth noting that the t_d-factor seems to have a rather constant value of around 100 msecs in the areas of the barren rocks, whereas over the mineralized ground its values have a considerable range.

D. <u>The Bertin and Loeb's (Modified) Functions</u>

These functions are the ratios $A1 = A/\rho/2\pi$ and $A2 = B/\rho/2\pi$, where A and B are defined in the equation $y(t) = Ae^{-\alpha t} + Be^{-\beta t} + P$. These functions were computed for the n = 2 dipole separations of lines 1 to 4 where the whole transient decay was recorded. The results are presented and discussed below.

/ 1. Presentation

1. Presentation of Results.

The results of these lines are tabulated in Tables 39 to 42 and illustrated in Figs 111 to 114. The A1 and A2 factors show in general higher values over the mineralization and lower over the barren areas. Their ratio A1/A2 demonstrates the opposite with higher values over the barren rocks.

2. Discussion.

From the results presented above it is evident that all the mineralization (western, southern and northern) are shown in some degree by these factors. It is interesting to discuss the responses recorded over these different grades and the non-mineralized rocks.

a. The Barren Rocks.

Non-mineralized ground was encountered on all lines over their eastern ends. Excluding the single high value on current stake 6 of line 1, in all cases the A1 factor is around 1.0. The A2 factor is more variable ranging between 0.2 and 0.6. The A1/A2 ratio is also quite variable in its values ranging from 2.0 to 5.0.

b. The Western Mineralization.

As described earlier, this mineralization is divided into two parts. The first consists of poorly disseminated pyrite reaching a value of about 1% S and the second is of slightly higher grade ranging between 1% and 5% S. The extent of these two types is depicted on Fig. 96. In all four lines their western ends correspond to readings over the poorly disseminated (max. 1% S) mineralization. From the results described above, it is noted that the A1 values recorded with the receiving dipoles over this grade are generally low not exceeding the value of 0.6. Over the higher grade of the western mineralization the A1 values are slightly higher ranging between 0.9

/ and 1.65

and 1.65, except on the readings of current stakes 17 on both line 3 and line 4 which gave values of 0.4. It is noted, however, that in both cases the current electrode was in barren rocks (see Fig. 97). It appears, therefore, that the very poor sulphide mineralization (1% S) shows much lower values than the higher grade (1-5% S) in the A1 factor.

The A2 factor shows again low values in the 1% S mineralization ranging from 0.15 to 0.4. The richer mineralization, however, shows higher values with a minimum of 0.4 and a maximum of 1.07. As with the A1-factor, the readings on lines 3 and 4 with the current stake 17 located in the barren rock are much lower than the other values. The A1/A2 ratio attains values over 2.0 over the 1% S mineralization, whereas over the 1-5% S it appears to have lower values down to 1.5.

c. The Southern Mineralization.

This was encountered by the current poles at stake 12 on both lines 1 and 2. In both cases the value of A1 is high exceeding the 2.0. The A2-factor shows values ranging from about 1.0 to 1.19. In both cases the A1/A2 ratio is about 1.8. It should be remembered that this mineralization lies at a minimum depth of 10 meters under fresh volcanics and the grade ranges from below 10% to over 50% S (massive pyrite).

d. The Northern Mineralization.

This was encountered by line 4 and also indicated slightly by line 3. As mentioned above this is at a depth of about 100 meters under fresh volcanics with grades reaching the 40% S. The A1-factor shows values above background, about 1.4. The A2-factor shows the presence of mineralization more clearly with values reaching the 0.73. The values of A1/A2 ratio corresponding to the high A1 and A2 values are about 2.0.

/ 3. Conclusions

3. Conclusions.

Table 43 summarises the results discussed above. The results over the western and southern mineralizations can be compared as they are respectively from exposed to very shallow seated mineralizations. The northern mineralization, however, is very deeply seated and it is expected that the responses will be much lower.

From Table 43 it can be concluded that the A1 factor shows discriminate values over the different grades. It may be noted that the barren rocks show values higher than the poorly disseminated mineralization. The A2-factor shows again a gradual increase in its value from the poor to the richer mineralization but there is a small overlap in the three groups. It is noted that the barren rocks show values which are close to those of the very poor (1% S) mineralization. The A1/A2 ratio seems to show distinct values, the highest being those of the barren rocks followed by the poor mineralization. The next two grades, however, do not seem to be indicated by values which follow this trend. The next lower value is that of the southern mineralization. The 1-5% S grade is represented by a lower value.

The deeply seated northern mineralization is only shown with certainty by the A1-factor, compared with barren rocks. The A2-factor has values which overlap slightly with those of the barren rocks.

In a final conclusion it could be stated that the A1 factor is capable of distinguishing between the different grades encountered at Klirou. Factor-A2 could also distinguish the three grades but with less reliability than A1. The A1/A2 ratio does show the mineralization but it does not seem capable of distinguishing between grades.

E. The Resistivity Results

1. Presentation of Results.

a. Line 1.

The resistivity results of this line expressed in $\rho/2\pi$ ohm-meters are illustrated on the pseudosection of Fig.115. The eastern half of this figure shows generally low values corresponding to the barren rocks occurring in this area. The western half which corresponds to the exposed mineralization has generally higher values.

Compared with the I.P. results (Fig. 98), it is observed that the resistivity lows correspond to the N.T.I. low values. Further along the line it is evident that the southern mineralization recorded on the 9-10 receiver dipole in the I.P. survey does not appear to give any significantly different responses on resistivity. Further west the broad I.P. anomaly due to the western mineralization coincides with the broad area of high resistivity values. It is interesting to note that there is a similarity between the two patterns. Both attain their highest values on the 15-16 receiving dipole and on the small dipole separations in the region of stakes 14 to 16.

b. Line 2.

The results of this line are illustrated on Fig. 116. This pseudosection shows an area of generally low values of $\rho/2\pi$ ohm-meters in the eastern half of the line. In the second half the resistivity values are generally high. There is a region of highs appearing on the pseudosection under dipole 13-14. Further west this is followed by a region of lower values, but before the end of the line, centered about the receiving dipole 16-17, there is an increase in the resistivity values.

Compared with the I.P. results (Fig. 99), the region of low

/ resistivities

resistivities in the eastern half of the line corresponds to the low I.P. values in the same area. Further along the line the resistivity results do not show any significant change in the 9-10 receiver dipole, which on the I.P. results has given a significant anomaly due to the southern mineralization. The high resistivity region in the western half coincides with the high I.P. results, both corresponding to the western mineralization. It is interesting to note that the highest values on the I.P. data are observed in the readings of the 13-14 receiver dipole. In the resistivity results this dipole has shown the lowest values in this generally high valued region. On the 16-17 receiving dipole, however, both I.P. and resistivity have given high values.

c. Line 3.

The results of this line are illustrated on Fig. 117. This line shows generally a similar picture, i.e. low values in the eastern and high in the western half. In the western half there is a high resistivity area corresponding to the readings of the receiver dipoles 11-12 and 12-13. In the next receiver dipole, 13-14, the resistivity values drop and increase again in the following dipoles. The highest values were recorded on the small dipole separations in the region of dipole 15-16.

Compared with the I.P. results (Fig. 100), it is observed that there are no significant variations in the eastern half of the line and particularly in the 7-8 receiver dipole. Further west, there appears to be a general coincidence between the high resistivity and the high N.T.I. values in the western half of the line corresponding to the western mineralization. It is interesting to note however that the highest N.T.I. results recorded on the receiver dipole 13-14 correspond to the lowest resistivity values recorded with this high resistivity region.

/ d. Line

d. Line 4.

The results for this line are illustrated on Fig. 118. This line shows a resistivity low area in the eastern half and a resistivity high area in the western half. In the first, there appears a slight increase in the 3-4 and 4-5 receiver dipole readings. Further west there is a gradual increase of the values with a localised increase in the large dipole separations in the region of the dipole 10-11. Further west over the western mineralization, the resistivity values continue to increase. The highest values were recorded in the small dipole separations in the region of stakes 15 to 18.

Compared with the I.P. results (Fig. 101), the eastern half of the line has generally low resistivity values except for the local increase in the large dipole separations in the region of the dipole 11-10, which do not necessarily correspond to the broad area of high N.T.I. values in the large dipole separations extending from stake 6 to stake 11. Further west, the two anomalies coincide broadly but they do not show any similarity in their patterns.

e. Line 5.

The results of this line are illustrated in Fig. 119. This line shows again the same general results as the previous ones, with low resistivity values in the eastern half of the line and high values in the western half. In the eastern half, however, there is a broad area of slightly higher values in the large dipole separations extending from the region of stake 6 to stake 10. Another region with similar values is observed in the region of stakes 3 to 7 particularly in the small dipole separations. In the western half of the line the resistivity values are generally high. From the pseudo-sectional plot it can be observed that higher values were recorded on the 12-13, 14-15 and 16-17 receiver dipoles, and lower values in the dipoles between them, i.e. 13-14 and 15-16.

/ A comparison

A comparison with the I.P. results (Fig. 102) suggests that the broad resistivity increase in the large dipole separations in the eastern half of the line, corresponds to the N.T.I. anomaly in the same region which was later proved by drilling to be caused by the northern mineralization. The western anomalies which evidently correspond to the western mineralization, do not show any similarity in their patterns indicating that there is no particular correspondence between the resistivity and N.T.I. values for each receiving dipole.

2. Discussion.

In the presentation of the resistivity results given above, the resistivity values were broadly divided into two groups, the low resistivity values, generally below 2.0 x 2π ohm-meters and the high resistivity values above this datum. In the discussion which follows it will be attempted to investigate the resistivity values of the different mineralization grades and rocks known to occur in the Klirou Area.

a. The Barren Rocks.

The eastern ends of lines 1 and 2 are in areas of barren rocks. From the results of these lines it is observed that the resistivity values of these rocks are generally low, not exceeding the 2.0 ohm-meters ($\rho/2\pi$).

b. The Western Mineralization.

This is divided into two different grades, the poorly disseminated (S = 1%) and the richly disseminated (S=1-5%) as described above. This mineralization is crossed by all lines, but in the present discussion attention will be paid on lines 1 and 2 which define the richly disseminated mineralization within a single pair of faults. From the geophysical results of these lines, Figs 115 and 116, it is observed that the richly disseminated grade which occurs in the region of stakes 13 to 15 (see also the geological

/ map,

map, Fig. 96), is shown very clearly by the 13-14 and 14-15 receiving dipole readings to occur as a region of lower values in the n = 3 and 4 separations, surrounded by higher values. The next dipole in the west shows significantly higher resistivities. In the adjacent dipole to the east the resistivities are higher only in the large dipole separations. In the n = 1 and also n = 2 dipole separations in the results of these two dipoles (13-14 and 14-15), it is observed that the resistivity values are higher than in other separations. This can be attributed to the surface alteration of the mineralization which in these cases varies between 10 and 20 meters. This alteration which results into the formation of limonite must certainly increase the resistivity of the altered rock. In deeper levels, however, it is observed that the resistivities are generally below 4.0 x 2π ohm-meters. This is considered as the representative value of this mineralization. In the next two receiving dipoles to the west which cross the poorly disseminated mineralization, the resistivity values as seen on both lines 1 and 2 (Figs 115 and 116) attain higher values generally above 5.0 x 2π ohm-meters. Almost the same picture is observed to the east of the richly disseminated grade, where the resistivity values as observed on the receiving dipoles 12-13 and 11-12 on both lines 1 and 2, are generally above 3.0 x 2π ohm-meters. These high values could certainly be attributed to the very low grade mineralization, below 1% sulphur, located by drilling in depth between the western and southern mineralizations.

A similar picture, i.e. with low resistivity values (below 4.0 x 2π ohm-meters) in the large dipole separations, is observed in the receiving dipole results of the other lines where they crossed the richly disseminated mineralization. On line 3 it is observed on the 13-14 dipole, on line 4 on the 15-16 dipole, and in a better way on lines 5 on the dipoles from 13 to 16. In all these cases the low dipole separation results are characterised by high resistivities attributed to the surface alteration.

/ c. The

c. The Southern Mineralization.

From Fig. 97 (geological sections) it is observed that this mineralization occurs in the area around stake 10 of both lines 1 and 2, and perhaps a small distance further to the east. On both lines the pseudosectional plots show that in this area the resistivity values are generally above 2.0x2π ohm-meters. However, they do not demonstrate any pattern which would suggest a control by the receiving dipole, except for dipole 7-8 of line 1 which is not known to correspond to any mineralization. It can therefore be concluded that the southern mineralization is characterised by values which range between 2.0 x 2π and 3.0 x 2π ohm-meters.

d. The Northern Mineralization.

This occurs in the eastern halves of lines 4 and 5 at a depth of about 100 meters. From the resistivity results of these lines it is observed that this mineralization, which is of a similar overall grade as the southern mineralization, i.e. high grade ore enclosed in richly disseminated mineralization, is indicated by resistivity values between 2.0 and 3.0 x 2π ohm-meters. The resistivity values above 2.0 recorded in the small dipole separations near the eastern ends of lines 4 and 5 cannot be attributed to any known mineralization.

3. Conclusions.

From the resistivity results presented above and the discussion which followed, it can be concluded that the different Klirou mineralizations attain higher resistivity values in comparison with the enclosing barren Lower Pillow Lavas. The later are characterised by resistivity values generally below 2.0 x 2π ohm-meters.

By comparing the resistivity results over the different Klirou mineralizations it can be concluded that the highly disseminated western mineralization is characterised by resistivity values as high as 4.0 x 2π

/ ohm-meters

ohm-meters, whereas the richer southern and northern mineralizations are characterised by resistivity values not exceeding the $3.0 \times 2\pi$ ohm-meters. Much higher resistivity values were recorded in the poorly disseminated part of the western mineralization exceeding the $5.0 \times 2\pi$ ohm-meters. Another rock type which appears to give high resistivity values is the oxidised surface part of the mineralized rock. In this respect the high values could either be from the oxidation products such as limonite and hematite, or due to the incomplete degree of oxidation of the conducting minerals in the region between the fresh mineralization and the weathered. In this region the sulphide content would drop to values corresponding to those of the disseminated mineralization. Certainly this explanation is tentative.

As a general conclusion it can be stated that in all cases the different types of sulphide mineralization found in the Klirou area are characterised by higher resistivity values than the surrounding barren rocks.

F. <u>Conclusions</u>

The parameters presented and discussed above include both routine I.P. parameters which are recorded during a normal I.P. survey including resistivity, and also parameters which express the shape of the transient decay curve. The purpose of the presently described project was to examine the responses of the various parameters over the Klirou mineralizations, and attempt to establish criteria which, under similar conditions, would enable the distinction between mineralizations of different grades.

The N.T.I. which may be considered as the parameter recorded directly in the field, has shown well defined anomalous responses over all the three different mineralizations. As expected the highest values were those due to the exposed and the lowest those due to the deeply seated mineralization. From the magnitude of the N.T.I. even under similar conditions, it appears that it would be impossible to obtain an indication of the grade of the pyritic mineralization. There is evidence, however, that the poor and sparse disseminations give lower responses than higher disseminated grades.

The Decay Factors, the electromagnetic component of the I.P. curve, A, and the true chargeability, B, show higher values over the mineralizations as compared with the barren rocks. But in addition they are capable of distinguishing between the three different grades, attaining their highest values over the richly disseminated and their lowest over the poorly disseminated mineralization.

The decay curves were plotted on a logarithmic time axis and it was proved once again that they can be considered as consisting of two components, a rapidly and a slowly decaying one. From the different parameters which characterise this two-component curve, the rates of decay of the two components, the amplitude at which they separate, and the magnitude of their deviation, show all high values over all the mineralizations as compared with the barren rocks. With regard to grades, these parameters can assist in distinguishing between the poorly disseminated and the richly disseminated mineralizations offering also indications of higher grades of mineralization.

The Bertin and Loeb's (Modified) functions introduce the resistivities of the different grades and suggest that a distinction can be made between the different grades particularly based on the A1-function.

The resistivity results indicated very clearly that the mineralization is characterised by higher resistivity values compared with the enclosing barren rocks. In the mineralized rocks the resistivity value appears to increase with decreasing sulphide content.

/ IV. GENERAL

IV. GENERAL CONCLUSIONS

The Klirou area presented an excellent example of a mineralized area found in Cyprus. The geological background consists of Lower Pillow Lavas which were the last volcanics before the mineralization. Thus the latter is found either exposed or under a variable thickness of fresh volcanics of the same composition as the host rocks. In addition the rich zones of mineralization are well defined with relatively sharp contacts. These are certainly tectonic, but the age of tectonism with regard to the mineralization is uncertain. Current opinion considers these bounding faults as pre-mineralization defining the boundaries of the fractured vent system which formed the passages to the mineralizing fluids. The adjacent ground has also been mineralized but with much lesser intensity.

The targets encountered at Klirou may be considered as typical for the Lower Pillow Lava terrain. Limonite stained rocks containing sparse pyritic mineralization not exceeding the one percent in sulphur were found in contact with richer mineralization again of the disseminated type. Both these mineralizations are known to give high I.P. responses during a routine geophysical survey. Another interesting feature of the Klirou area was the existence of two zones parallel to the exposed one, at different depths into the host rocks. In this occasion it was interesting to determine that a routine I.P. survey, i.e. with spacings and configurations usually applied in the field, is capable of resolving the three zones. The discovery of the third zone at a depth of about twice the spacing applied, has given an indication of the capability of I.P.

The major part of the Klirou project was the investigation of the responses from the different grades of mineralization. This investigation was based primarily on the information which is believed to be concealed in the shape of the I.P. transient. From the results of this investigation it has

/ been

been established that although the amplitude of the normalised time integral may be similar in the different grades, other parameters which describe the transient shape show different amplitudes. It may be concluded therefore that with careful examination of the values of these parameters some indication of the possible grade of the mineralization can be obtained without the necessity of drilling each anomaly. Certainly these criteria can only be applied with caution particularly when the field conditions are not uniform. In addition to these parameters, it was also found that the resistivity of the mineralized rocks varies according to their sulphide content.

/ CHAPTER

CHAPTER SIX

ON THE GEOPHYSICAL RESULTS OF THE KOKKINOVOUNAROS AREA

I. INTRODUCTION

The Kokkinovounaros area occurs in the northern foothils of the Troodos Massif. Its location is shown in Fig. 1. Its main features are two elongated gossans which appear to be aligned in a north-south direction. The geological background are Lower Pillow Lavas close to their boundary with the Upper Pillow Lavas.

The two colourful gossans were prospected for precious metals in the 1930's. The northern one yielded a significant tonnage of auriferous ore of exceptionally high grade. A lesser amount was mined from the southern gossan. During the United Nations Development Programme in 1965-1968, the area was explored for sulphides by drilling. This did not reveal any significant grades. Tentative estimates have suggested a body of one million tons with 11% sulphur and insignificant ($\simeq$ 0.3%) values of copper.

The Kokkinovounaros mineralization is considered as a typical example of the Cyprus-type mineralization which is controlled by older tectonic fracturers, which are at present bounded by clearcut faults forming a mineralized horst as described in Chapter Three of this Thesis. For this it has been decided to investigate the I.P. responses over this type mineralization with a number of lines at right angles to its strike.

The present Chapter begins with a description of the geology of the Kokkinovounaros area. This is followed by a detail analysis of the geophysical results and closes with some conclusions with regard to the applicability of the method and the various parameters investigated.

/ II. THE

II. THE GEOLOGY OF THE KOKKINOVOUNAROS AREA

The Kokkinovounaros area includes two elongated gossans in line with each other, with a total length of about 700 meters and an average width of 130 meters. Fig. 120 is a geological map of the area showing also the layout of the geophysical lines. The geological background is Lower Pillow Lavas consisting of andesitic flows and intrusives. Petrologically they appear to be uniform all over the area exhibiting their usual characteristics, such as celadonite filled vesicles and stainings. Upper Pillow Lavas outcrop along a narrow strip to the north of the Kokkinovounaros gossans. They are typical olivine-basalt flows.

The northern gossan exhibits colourful oxidation products ranging from white leached lavas to hematite red and limonite. Two grades of mineralized (oxidised) rock were recognised and mapped. The first is a limonite stained Lower Pillow Lava which forms a halo to the west and south of the gossan (see Fig. 120). This is considered as representing the outermost part of the mineralized lavas which have therefore been affected only slightly by the mineralizing fluids. The second grade appears on the surface to occupy the inner part of the gossan and represents the main body of mineralization. . The structure of this mineralization is depicted on Fig. 121(a) which demonstrates the horst structure of the mineralization.

The southern gossan shows again two different grades, one of limonite stained Lower Pillow Lavas forming a complete halo around the more strongly mineralised linner part. The geological structure is depicted on Fig. 121(b) which demonstrates again that the mineralization is bounded on its two sides by faults.

Both mineralizations have been thoroughly drilled by the Hellenic Mining Co. Ltd. and the Geological Survey (United Nations Development

/ Programme

Programme). The location of these holes is shown in Fig. 120. From their results it is concluded that the northern mineralization is generally of low grade consisting of disseminated pyrite in propylitised lava. The highest value is 5.9% sulphur in borehole MR 27/65 which averages 2.4% S. In general it may be concluded that the mineralization under the northern gossan falls in the range 1-5% S.

The southern gossan was more extensively drilled yielding higher values of sulphur. Since this mineralization was traversed by a number of lines, the grades of sulphides will be described according to their proximity to the geophysical lines. With regard to line 2, all boreholes near it were barren. The nearest borehole with some values is the MR 25/65 which averages 1.9% S. The next line (3) runs over a higher grade of sulphides. Borehole KB 15 averages 11.3% with a maximum of 19% S, borehole MR 61/68 averages 4.8% with a maximum of 10.1% S, borehole MR 61A/68 averages 4.3% with a maximum of 11%, and borehole MR 47/68 averages 6.0% with a maximum of 11.1% S. All these holes were in the vicinity of stake 9 of this line. Borehole MR 59/68 near stake 8 of the same line has intersected a much lower grade (there are no assays) described as "weak mineralization". Such a description corresponds to grades below 3% S. Further southeast towards and over line 4, the grades of the mineralization as encountered in the different holes are: borehole MR 43A/68 with an average of 7.8% and a maximum of 20% S, borehole MR 45/68 with an average of 4.5% and a maximum of 13.8% S, borehole KB 14 with an average of 7.3% and a maximum value of 19.0% S, borehole MR 39/68 has an average of 6.9% with a maximum of 20.7% S, and borehole MR 44/68 an average of 5.3% with a maximum of 9.4% S. It may therefore be concluded that the mineralization crossed by line 4 is generally well above 5%. This is concentrated in the eastern part of the gossan. Towards the west the grade decreases as indicated by boreholes MR 44/68 and MR 62/65. The latter is described as having only disseminated pyrite. Further south near line 5 borehole

/ MR 42/63

MR 42/62 has intersected mineralization with an average of 5.1% reaching a maximum of 16.9% S. The southernmost hole MR 64/68 drilled down to 100 meters is barren.

From the above description it is evident that in the Kokkinovounaros area the geophysical survey was carried out over a variety of sulphide grades. Line 7 was over barren rocks, lines 2 and 6 were run very close to low grade mineralizations. Line 1 was run over low grade mineralization, and lines 3, 4 and 5 were run over sulphide mineralization generally above the 5% S. In general the mineralization in the area is defined as of low grade in sulphur. No borehole has intersected any massive pyrite.

From the preceding geological description it can be concluded that the Kokkinovounaros mineralization represents an example of a mineralized zone in the Lower Pillow Lavas which was later affected by tectonic movements probably on existing planes of weakness.

III. THE GEOPHYSICAL RESULTS

The Kokkinovounaros hill was covered by seven lines, 750 meters each, trending at right angles to the strike of the mineralization. The line spacing was 100 meters. The layout of the lines with respect to the geology is shown in Fig. 120. Readings on these lines were taken with the pole-dipole configuration on electrode separations n = 1-4 and an electrode spacing of 50 meters. The period of the energising current was 8 secs at an on/off ratio of 1.0, and the I.P. transient was measured at four positions 55, 130, 280 and 580 msecs from the time of interruption of the energizing current, except for the n = 2 dipole separation where the transient decay was recorded by measuring its amplitude at 16 different positions.

Below there is an analytical description of the geophysical results and studies in the following sequence:

A. The Normalised Time Integral.

B. The Decay Factors.

C. The $\log_e t$ Decay Factors.

D. The Bertin and Loeb's (Modified) Functions.

E. Resistivity Results.

A. The Normalised Time Integral

1. Presentation of Results.

A. Line 1.

The results of this line are illustrated on Fig. 122 which is a pseudosectional plotting of the N.T.I. values. From the first integral value, Msec 1, there is apparent an anomaly in the center of the line in the region of stakes 7 to 10. In the higher integrals this anomaly is more well defined,

/ being

being centered about the receiving dipole 8-9. High values were also recorded on the receiving dipole 9-10. Lower values but still higher than background were recorded on the receiving dipoles 10-11 and 7-8. It is interesting to note that in the area of stakes 6 and 7 the readings on the pseudosection are slightly higher than the background values. From the 350 contour on the Msec 4 integral, it appears that the anomaly has a boomerang shape centered about the dipole 8-9, but it is much stronger on the eastern side. This asymmetry is attributed to the position of the electrodes with respect to the mineralization. When the receiver electrodes were over the mineralization the readings were much higher than when the transmitter pole was in the mineralized ground. As a consequence to this, the area directly under the mineralization appears on the large electrode separations of the pseudosectional plotting with low values, in the case of line 1 lower than the background values.

b. Line 2.

The results for this line are illustrated in Fig. 123 which is a pseudosectional section of the N.T.I. values. An area of anomalous values appears in the center of this line being evident from the first integral. The highest values were recorded on the 7-8 and 8-9 receiving dipoles. Lower values but still above background were recorded on the 9-10 receiving dipole. To the west, in the region of stakes 6 and 7, there is an area of high values. As in the first line these results are due to the location of the transmitting pole on the mineralization. In general the anomaly of this line appears on the highest integral value (Msec 4) to have a distorted asymmetric boomerang shape. This distortion can be attributed to the presence of two different mineralized bodies in close proximity to this line, see Fig. 120.

In the western end of the line the 2-3 receiving dipole has recorded a weak but definite anomaly. This becomes more apparent in the higher N.T.I. values.

/ c. Line

c. Line 3.

The results of this line are illustrated on the pseudosectional plot of Fig. 124. From the first integral, Msec 1, the anomalous pattern shows an asymmetric boomerang shaped anomaly centered about the dipole 8-9. The anomaly is stronger in the side of the receiver readings, i.e. readings taken when the receiver dipole was on the mineralization. The weak part of the anomaly corresponds to the transmitting pole positions over the mineralization. Analytically, anomalous readings were recorded on the receiver dipoles 8-9 and 7-8, and much lower on the 9-10. The transmitting pole gave high readings on the positions 8 and 9.

In the western end of the line, the last receiving dipole 1-2 recorded slightly higher readings than the background values.

d. Line 4.

The results of this line are illustrated on Fig. 125. This line shows also an asymmetric boomerang shaped anomaly centered about the dipole 7-8. As with the previous lines the strong leg of the anomaly corresponds with the readings taken with the receiving dipole over the mineralization and the weak leg with the transmitting pole over the mineralization. Anomalous values were observed on the receiving dipoles 7-8 and 6-7, and the transmitting poles 6 and 7.

In the western end of the line the last receiving dipole (1-2) recorded slightly higher values than background.

e. Line 5.

The results for this line are illustrated on the pseudosectional plots of Fig. 126. This line shows an anomaly centered about the dipole 6-7 with high readings also on the dipole 5-6. The general shape of the anomaly

/ is again

is again one of an asymmetric boomerang with higher values in the receiving dipole readings than on the transmitting pole. The receiving dipole 11-12 has also recorded values slightly higher than background.

f. Line 6.

The results for this line are illustrated on Fig. 127. This pseudo-sectional plot shows two distinct areas with high values. The first is centered about the receiver dipoles 6-7 and 5-6 and the second about the receiver dipole 2-3. It is interesting to note that the anomaly does not have a second leg due to the transmitting pole. This is attributed to the fact that no electrode was placed in the mineralized ground. This is discussed below. In the eastern half of the line the N.T.I. values appear to be in general higher than background.

g. Line 7.

The results for this line are illustrated on Fig. 128. This line shows three areas with high readings. The first is in the center of the line about the receiving dipoles 6-7 and 5-6. The readings are not as high as in the previous lines and are only concentrated in the n = 3 and 4 dipole separations. These can certainly be attributed to the exposed mineralization one hundred meters away from this line. The second area is the stronger anomaly recorded on the 2-3 receiving dipole. The third anomalous area extends from the region of stake 10 to 15. In this area the N.T.I. values are generally higher than background particularly on the receiver dipoles 10-11 and 13-14.

2. Discussion.

The Kokkinovounaros mineralization is a typical example of a Cyprus-type mineralized zone. It is narrow with a significant lateral extend and with well defined - tectonic, boundaries. The geophysical results presented

/ above

above represent an example of routine I.P. exploration. From these there is no doubt that the I.P. method can successfully record the presence of such zones of mineralization. It will be interesting, however, to discuss the anomalous responses along the different lines with regard to the grade of the mineralization in their vicinity, and also the shape of the geophysical anomalies obtained over this target. An important conclusion which can be drawn from such a discussion is the validity of the interpretation of these results since the shape of the target is known from the geological data.

Lines 1, 3 and 4 run over the mineralization whereas lines 2, 5, 6 and 7 are close or at some distance from it. As described in the section on the geology of the area, the mineralization in the vicinity of line 1 is generally of low grade in sulphides averaging below 5% in sulphur. On the contrary lines 3 and 4 were run over a higher grade of mineralization with maximum values exceeding the 15% in sulphur. On the average the grades intersected by the boreholes in this southern mineralization are low, since the deeper parts of the mineralization, usually consisting of disseminated pyrite, were also taken into consideration. A comparison of the I.P. responses recorded over these lines (1, 3 and 4) suggests that in all cases the maximum values of the N.T.I. are about the same. In other words the maximum responses of line 1 do not differ significantly from those obtained over the other two lines which have much higher sulphide content. In general it is observed that irrespective of the grade, the responses obtained along the lines crossing the exposed mineralization are almost equal. It should be recalled that the mineralization is covered by oxidised rock not exceeding 10 meters in thickness.

The maximum responses from the other lines (2, 5, 6 and 7) are lower than those described above. This is certainly due to the distance from the mineralization. In the case of line 2, the anomalous responses were generated

/ by the

by the nearby northern mineralization and to a lesser extent by the southern mineralization. In the region of line 5 the grade of mineralization near the surface decreases with evidence of high grade in depth (borehole MR 42/68). This explains the low anomalous responses obtained in the small dipole separations in this line followed by a higher response in the n = 3 dipole separation. Line 6 also shows a decrease in the anomalous responses which is explained by the increase in the depth to the mineralization. Similarly on line 7 there is some evidence of the presence of the southern mineralization but the responses are generally low because of the distance between the mineralization and the line.

The second important aspect which calls for discussion is the shape of the anomaly obtained over this type of geological target. In all lines the highest readings were obtained when the receiver dipole was over the mineralized ground. The result is that on the pseudosectional convention of plotting,in the present case where the target is narrow, the anomalous readings appear on a line dipping with 45° and corresponding to a certain receiver position. It is also important to note that in the case where the mineralization was exposed or gossanised, relatively high responses were recorded when the transmitting pole was located over it. In this case the anomaly is strongly asymmetrical with the highest values in the 45° dipping line corresponding to the receiving dipole(s) over the mineralization, and lower values in the 45° dipping line in the opposite direction corresponding to the transmitting pole(s). Much lower values even lower than the background values, appear on the pseudosectional plot between these two high legs and directly under the stakes which correspond to the mineralization. It is important to remember that the pseudosectional plots do not reflect geological sections exactly, but they do provide patterns which the experienced observer can interpret.

In the preceding discussion it was stated that anomalous readings are taken when the receiver dipole is over the mineralization. It is important

/ to note

to note that if one of the two electrodes is in barren ground, the I.P. responses are low enough not to be called anomalous. An example of this is the response of the dipole 9-10 compared with that of 8-9 on line 3, Fig. 124. Although stake 9 is over the mineralized ground, the receiving dipole 9-10 gave very low responses. Another example is the 8-9 receiver dipole on line 4, Fig. 125, compared with that of the 7-8 dipole. The importance of this observation is that the position of the mineralized target can be put very accurately for further investigation such as drilling. In this case the conductor is exposed. There are many cases, however, where the conductor is covered by a thin layer of soil or drift.

3. Conclusions.

From the discussion on the N.T.I. responses obtained over the Kokkinovounaros mineralization, it can be concluded that this factor which is used in a routine I.P. exploration project, is capable of locating a mineralized target. No distinction can be made with regard to the grade of mineralization on the basis of the N.T.I. responses. With the pole-dipole configuration the shape of the anomaly in the pseudosectional method of plotting is an asymmetrical boomerang. The exact position of the mineralized target can be decided on the basis of the receiving dipole and transmitting pole anomalous readings.

B. <u>The Decay Factors</u>.

The I.P. transient decay has been recorded at the n = 2 dipole positions on all the lines. The amplitude has been recorded at the following sixteen time positions (in msecs): 35, 55, 90, 95, 130, 150, 180, 215, 240, 280, 360, 420, 455, 580, 720 and 780. Each transient decay has been factorized according to Hutchin's (1971) method described in detail in Chapter Three of this Thesis. The results for each line are presented and discussed below.

/ 1. Presentation

1. Presentation of Results.

The results for all the Kokkinovounaros lines are tabulated in Tables 44 to 50 and are illustrated in Figs 129 to 135. In general the A-factor attained high values when the receiving dipole or the transmitting pole were over the mineralization. The B-factor attained its highest values in about the same positions as the A-factor. The α-factor shows in general anomalous profiles along the lines which cross the mineralization, but there is no correspondence with the high values of the A and B-factors. Similarly the β-factor shows some variations along those lines which cross the mineralization but there is no direct relationship between them. The P-factor attains in general high values over the mineralization and low over the barren rocks.

2. Discussion.

The results presented above indicate that at least some of the decay factors are indicative of the presence of the mineralization. It is important to examine and discuss the amplitude of these factors with particular attention to the grade of mineralization.

a. The A-factor.

In all lines which cross or run close to the mineralization, this factor attains high values in two ways. First, when the receiver dipole is on the mineralization and second when the transmitter pole is on the mineralization. In the first case the values are usually higher than in the second. From the results it is evident that over the mineralized ground the A-factor attains in general values above 2.0. The highest values were recorded on lines 1, 2 and 3 (3.2, 3.1, 3.1 respectively). From the description of the mineral grades given earlier in this Chapter, the mineralization in the vicinity of these lines is generally low - maximum average of a hole is

/ 6% S

6% S, and maximum assayed value of 19% S (in borehole KB 15) near line 3. Line 4 which runs over somehow higher grade of mineralization has a lower value of A (2.68). It appears therefore that at least on lines 1 and 3 which run over or close to lower grade mineralization, the A-factor attains higher values than over line 4 which is over a higher grade. The values obtained on lines 2 and 5 cannot be compared directly with those of the other lines, since the mineralization is not exposed along their length as in the case of the previous lines.

b. The B-factor.

This factor also responds positively over the mineralization. The results presented above indicate in general that over the barren areas the values are around 0.6, increasing to over 1.0 on the mineralization. It is worth noting that over the first mineralized area which is crossed by line 1 and which has the lowest grade in sulphur than the other lines, the B-factor attains its highest value, 2.08. Lines 3 and 4 attain lower maximum values 1.60 and 1.93. It appears, therefore, that the B-factor, which is the true chargeability (at t = 0), has lower values over the higher grade mineralization than over the lower grade.

c. The α-factor.

From the analytical description of the results presented above for this factor, no conclusive remarks can be drawn for it, except that in those lines where there is mineralization, its profile is highly irregular. Over line 7 (Fig. 135) for example, which does not have in its vicinity any mineralization, except for some minor indications in the N.T.I. readings in the western half, the profile of the α-factor is smooth. In the rest of the lines which cross the mineralization or are close to it, the α-factor profiles are indeed irregular. In conclusion it can only be suggested that an

/ irregularity

irregularity in this factor is indicative of the presence of mineralization.

d. The β-factor.

As with the α-factor, the results for all the lines presented earlier in this section do not indicate any conclusive remarks for this factor. Comparing the results obtained over lines 7 and 6 which are not over the exposed mineralization, with those of the rest of the lines, it appears that the β-factor has smooth profiles over the barren lines and slightly anomalous over the mineralized. In the first case its values are about 0.7, whereas in the mineralized lines their values increase slightly reaching the 1.0. Therefore, the β-factor which is a measure of the slope of the chargeability component of the recorded transient, attains an irregular profile in areas of mineralization and a smooth profile with slightly lower values in barren areas.

e. The P-factor.

In the results presented above it was evident that this factor is indicative of the mineralization. It should be remembered that P is in fact the normalised value of the transient decay at 1.75 secs from the interruption of the energising current. From the tables and profiles it appears that in the barren area P is about 0.2, whereas in the mineralization it attains higher values up to 0.6. Comparing its values over lines 1, 3 and 4, the highest value is on line 3, and the lowest on line 1, but their differences are not significant. In conclusion the P-factor indicates very clearly the presence of mineralization but it does not assist in any discrimination of the grade.

3. Conclusions.

Table 51 summarises the results over the Kokkinovounaros lines. From these and the discussion which followed, it can be concluded that the

/ factors

factors of the decay curve can be useful in exploration. Some of its factors, in particular the electromagnetic and chargeability components at zero time, are always indicative of the presence of any mineralization. Their slopes, however, factors α and β, do not suggest any direct usefulness, but the disturbance of their smooth profiles suggests proximity to mineralization. The P-factor parallels the A and B-factors showing in almost equal degree the mineralization. Some indication about the possible distinction between the different grades has been suggested by the present results. It appears that both the A and B-factors' values are in antipathetic relationship with the grade of mineralization. It must be admitted, however, that in the Kokkinovounaros area the grades of mineralization do not differ much as in the case of the Mathiatis and Klirou areas described in earlier Chapters.

C. The $\log_e t$ Decay Factors

The transient decays recorded on the n = 2 dipole separations of all lines were plotted on a $\log_e t$ axis and a normal potential axis. The characteristics of such plotting as described in Chapter Three were studied and investigated and are presented and discussed below.

1. Presentation of Results.

The results for all lines are tabulated in Tables 52 to 58 and illustrated in Figs 136(a,b) to 142 (a,b). The R1-factor attains generally high values over the mineralization, particularly on the receiving dipole than the transmitting pole. The R2-factor almost parallels the R1 but with lower amplitudes. Their ratio R1/R2 shows in general a decrease in its values in the region of the mineralization. The t_d-factor shows inconclusive results. Its values appear to increase slightly in the viscinity of the mineralization, but there is no direct relationship between the high values and the location of the mineralization. The V_d-factor, however, demonstrates

/ the presence

the presence of the mineralization very convincingly attaining high values over it. Similarly the two deviation parameters d(0.5) and d(1.0) which attain much higher values over the mineralized than over the barren rocks.

2. Discussion.

The factors presented above describe the variation of the shape of the decay curve as well as its amplitude across a mineralized zone enclosed in barren rocks. It is pertinent to discuss the values of these parameters and examine their usefulness in mineral exploration.

a. The rate of decay of the first component - R1.

This parameter attains generally higher values over the mineralization than over the barren rocks. From the profiles and the values presented above it is evident that the mineralization, even in those lines which are at some distance from the zone, is characterised by values of R1 generally above 2.0. The highest values recorded over the mineralization exceed the 3.0. Values below 2.0 characterise the barren rocks. It can be concluded, therefore, that over the mineralization the first component of the transient curve has a greater rate of decay than over the non-mineralized rocks. Although the grade of mineralization over the different lines which crossed the mineralized zone does not differ considerably, from the results presented above, it is difficult to establish any relationship between the grade of mineralization and the magnitude of the R1 parameter.

b. The rate of decay of the second component - R2.

The parameter appears to parallel the previous one with high values over the mineralization and low over the barren rocks. From the profiles and the values presented, it is evident that the mineralization is generally characterised by values over 1.0. The highest value recorded is just over 2.0. It can therefore be concluded that this parameter indicates very clearly

/ the

the presence of mineralization.

With regard to the grade of mineralization, although there is not much difference between the different lines, the R2 value over line 1 is the highest, 2.02. It will be recalled that the mineralization in the area of this line has lower grade than lines 3 and 4. Over these lines the highest value of R2 are respectively 1.84 and 1.96. It is interesting to note that the parallelism of the R1 and R2 parameters which was observed in most of the lines, does not appear to be applied for lines 5 and 6. In these two lines the highest values of R1 do not correspond to the same dipole position with those of the R2.

c. The ratio R1/R2.

This parameter appears to show a decrease in its values in the area over the mineralized ground. In general it appears from the data presented above that values of R1/R2 below 2.0 are usually recorded in the mineralized part of the lines. Line 5 and 6 have high values over the mineralization reflecting the fact that the R1 and R2 parameters do not parallel exactly each other as mentioned above.

d. The time the second component begins - t_d.

The profiles and values presented for this parameter appear generally rather inconclusive. The value of this parameter is generally below 100 msecs. From lines 7 and 6 it appears that in the barren area the average value is around 75 msecs. This value appears to increase slightly in other lines, and particularly in the region of the mineralization. The best example is shown on line 2 (Fig. 137(a)). In the rest of the lines which cross the mineralized zone, the t_d profile appears to exceed in some cases the 100 msecs, but these high values do not always coincide with the mineralization.

/ e.

e. The potential at which the second component begins - V_d.

This parameter appears from the profiles and the values presented above to indicate very clearly the presence of mineralization. The background values over the barren rocks are generally below 2.0. In all cases where the mineralization is crossed, this parameter attains higher values exceeding 3.5. In general this parameter is indicative of the mineralization .

f. The deviation,d(1.0),of the second component at Vt = 1.0.

Significantly high values were computed for this parameter over the mineralized areas, as compared with those over the barren rocks. In the latter the values are generally low not exceeding the 300 msecs. In the mineralization,. however, they are significantly high generally over 1000 msecs. It is interesting to note that although on lines 1, 3 and 4 the mineralization is exposed in the same way, the computed value for this parameter over the first line is 1000 msecs compared with 2550 and 2380 on lines 3 and 4. It appears therefore that this parameter does not only demonstrate very clearly the presence of mineralization but it also appears to show different values over the different grades.

g. The deviation,d(0.5), of the second component at Vt = 0.5

This parameter parallels the previous one. It shows significantly different values over the barren and mineralized rocks. In the first the computed values are generally below 2000 msecs whereas in the mineralization this deviation reaches the 10000 msecs. Comparing the values over the three similarly exposed lines, 1, 3 and 4, there is a significant difference between line 1, max. value 4750, and those of the other two lines which is about 10000 msecs.

/ 3. Conclusions

3. Conclusions.

Table 59 summarizes these results. From the discussion presented above it can be concluded that most of the parameters which describe the properties of the decay curve on a $\log_e t$ plot can discriminate very clearly between mineralization and barren rocks. The rates of decay of the two components R1 and R2 attain generally higher values over the mineralized ground, but not significantly higher than the values over the country rocks. More convincing seem to be the values of the V_d parameter again higher over the mineralization. The t_d parameter does not seem to present any important variations which could render it useful in exploration. On the contrary the parameters which describe the deviation of the second component of the decay curve from the first, appear to present a significant distinction between mineralized and non-mineralized ground.

D. <u>The Bertin and Loeb's (Modified) Functions</u>

These functions are the ratios $A1 = A/\rho/2\pi$ and $A2 = B/\rho/2\pi$ where A and B are defined in the equation of the decay curve $y(t) = Ae^{-\alpha t} + Be^{-\beta t} + P$. They were computed for the n = 2 dipole separation where the whole transient decays were recorded. The results are presented and discussed below.

1. Presentation of Results.

The results for all lines are tabulated in Tables 60 to 66 and are illustrated in Figs 143 to 149. The A1-factor has in general higher values over the mineralized ground. However, equally high values were also recorded in some lines in those parts which correspond to the position of the bounding faults. The A2-factor also attains higher values over the mineralization. Their ratio, A1/A2, attains low values over the mineralized ground than over the barren rocks.

/ 2. Discussion.

2. Discussion.

From the results presented above it is evident that these three factors attain in many cases different values over the mineralization compared with those over the barren rocks.

a. The A-1 factor.

This parameter shows generally an irregular profile with highs and lows, which (highs) in some cases do not correspond to any known mineralization. The best defined anomaly is over line 2 which does not run over any exposed mineralization but over the barren pillow lavas. Over this line, high values were recorded on both the receiving dipole and the transmitting pole when they were located over the mineralized ground. The highest value on line 4 does not correspond to the receiver dipole which is located on both sides on the mineralization, but on the adjacent one. This holds also for line 5. From the geology of the area, these dipoles of lines 4 and 5 (8-9 and 7-8) cross one of the bounding faults of the mineralization, which in that area are relatively well developed. This is also exhibited on the resistivity results for these lines, see Tables 64 and 65, which attain low values increasing therefore the value of the A1-factor. For this the A1-factor does not appear to correspond solely to the mineralization but also to the tectonics of the area.

b. The A2-factor.

This parameter appears to demonstrate more convincingly the presence of mineralization. Well defined anomalies appear on all lines which run over the mineralized ground. It is interesting to note that over line 2 which does not have any exposed mineralization there were computed two peaks, one corresponding to the receiver reading and the other to the transmitted pole. A well defined anomaly is also shown on line 4.

/ c. The

c. The A1/A2 ratio.

This parameter shows generally low values in the region of the mineralization on each line. However, low values on the profiles appear also in areas without any known mineralization and most certainly barren. From the examination of the different profiles, it is difficult to decide as to which value of this ratio could correspond to mineralization. On lines 1 and 2 the low is about 1.75. On line 3 the lowest value over the mineralization is about 2.0. On line 4 the lowest value is 1.25. In the rest of the lines, however, the values of most part of each line are as low as 1.5.

3. Conclusions.

Table 67 summarises the above results. From the discussion presented above it can be concluded that these factors do not seem to be able to discriminate very clearly between mineralized and non-mineralized rocks. The A1-factor offers the least between the two. It is affected by the faults which as stated in an earlier Chapter, can be of significant importance in the formation and later emplacement of the mineralization. The A2-factor generally shows the mineralization, but its profiles are not as clear as of other parameters presented earlier, most probably due to its dependance on resistivity. Similarly the A1/A2 ratio although in some cases it attains low values over the mineralization, equally low values can be computed from readings taken over non-mineralized ground.

E. The Resistivity Results

The resistivity was computed for all the Kokkinovounaros lines using the field data collected during the I.P. survey. Therefore, the resistivity survey was conducted with the same field parameters (electrode array etc) with the I.P. survey. The results are presented in pseudosections as $\rho/2\pi$ ohm-meters. The results for each line are presented and discussed below.

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated on Fig. 150(a). This shows primarily an increase in the resistivity values in the region of stakes 8 to 10. The highest values are concentrated in the small dipole separations and decrease in the larger separations. From the contouring it appears that there is a small dependance on the receiver dipole readings, i.e. readings taken with a certain potential dipole show a parallel increase (or decrease) compared with adjacent ones.

A comparison of the resistivity results with the N.T.I. results (Fig. 122) indicates a coincidence of the high N.T.I. values with the high resistivity values, both anomalies centered about the receiving dipole 8-9. It is observed, however, that I.P. anomalous values were recorded on all dipole separations, whereas on the resistivity results the anomalous values are concentrated on the small dipole separations.

b. Line 2.

The results of this line are illustrated on Fig. 150(b). The pseudo-sectional plot of these results demonstrates the recording of a resistivity high, not exceeding twice the value of the background resistivity, centered about the receiver dipole 7-8. The dependance of the resistivity reading on the receiving dipole is very well indicated by the contouring.

Compared with the N.T.I. results (Fig. 123), it is evident that the two anomalies coincide with each other. The only difference is that the N.T.I. values on both the 7-8 and 8-9 receiver dipoles are equal, whereas in the resistivity results the 7-8 has much higher values than the 8-9 dipole.

c. Line 3.

The results of this line are illustrated on Fig. 150(c). This figure shows a resistivity high in the region of stakes 7 to 9. High values were recorded on all dipole separations of the 6-7 receiver dipole. There is also an indication from the contouring that the transmitting pole 9 gave high resistivities. These anomalous values are generally much higher than those of the previous lines.

Compared with the N.T.I. results (Fig. 124), it is observed that the N.T.I. anomaly was centered on dipole 8-9. A similarity between the two plots is that their highest reading was recorded on the same pole-dipole and in addition they both show some control of the anomaly by the transmitting pole 9.

d. Line 4.

The results for this line are illustrated on Fig. 150(d). This line shows also a resistivity high in its central part but with maximum values much lower than those of the previous line. From the pseudosectional pattern it is directly evident that the anomaly is controlled by the receiver dipoles. The highest values are those of the 5-6, followed by the 6-7 and 7-8 dipoles.

Compared with the N.T.I. results (Fig. 125), it is observed that the I.P. anomaly is centered on the 7-8 receiver dipole,whereas the resistivity anomaly on the 5-6.

e. Line 5.

The results for this line are illustrated on Fig. 151(a). This line shows a resistivity high area centered about the receiver dipole 5-6 and with much lower values, but still higher than background on the adjacent dipoles. It is worth noting the well defined resistivity low on the 7-8 receiver dipole which could be attributed to the major fault structure which is crossed by

/ this

this dipole (see Fig. 120).

Compared with the N.T.I. results of the same line (Fig. 126) it is observed that although the two anomalies coincide broadly with each other, their highest values were recorded on different receiving dipoles. In this case the N.T.I. highest values are on the 6-7 receiver dipole, with slightly lower on the 5-6 dipole. In the case of the resistivity, the highest values are on the 5-6 receiver dipole with significantly lower on the 6-7 dipole.

f. Line 6.

The results of this line are illustrated on Fig. 151(b). This line shows a low amplitude, but well defined anomaly concentrated on the 9-10 receiver dipole. A moderate resistivity high was also recorded on the 5-6 receiver dipole.

Compared with the N.T.I. results (Fig. 127), it is observed that there does not appear to be a very significant coincidence in the patterns of the I.P. and resistivity. The 9-10 receiver dipole which gave the high resistivity showed no I.P. anomaly. However, the adjacent dipole 10-11, recorded the highest N.T.I. values in a broad area of moderately high N.T.I. results. The I.P. survey recorded a well defined anomaly on the 5-6 and 6-7 receiver dipoles concentrated on the large electrode separations. This appears to coincide with the resistivity low centered on the 5-6 receiver dipole. The N.T.I. anomaly on the 2-3 receiver dipole coincides with a slight low in the resistivity results on the same dipole.

g. Line 7.

The results of this line are illustrated on Fig. 151(c). This figure does not show any significant resistivity increase as in the previous lines. There is a broad area of very slightly higher resistivity values extending in the region between stakes 8 and 12.

/ Compared

Compared with the N.T.I. results over this line (Fig. 128), it is observed that the area with higher resistivities mentioned above coincides partly with a broad I.P. anomaly which extends in the region of stakes 10 to 15. The I.P. survey has also shown two more anomalous areas one on the large dipole separations of the receiving dipoles 5-6 and 6-7, and the other on the 2-3 receiving dipole. The resistivity results, however, do not show any significant variations on these dipoles.

2. Discussion.

From the results presented above it is observed that in all cases the mineralization attained high resistivity values compared with those of the enclosing rocks. In the first case the resistivity could have values up to 7.6 x2π ohm-meters, whereas the background values appear to be generally below 1.5 x2π ohm-meters. From the results over the Kokkinovounaros mineralization it can be concluded that all resistivity values above 2.0x2π ohm-meters could be attributed to mineralization.

An important aspect to discuss is the comparison of the resistivity anomalies with the I.P. anomalies presented earlier. From the results presented above it appears that there is not always a direct coincidence between the centers of the I.P. anomalies and the centers of the resistivity anomalies. On line 2 the I.P. anomaly attains its highest values on the 8-9 receiver dipole, whereas on the I.P. the results obtained on this receiver dipole are just over the background values. Similarly on line 3 the I.P. anomaly is centered about the receiver dipole 8-9, whereas on the resistivity results the anomaly is centered on the 6-7 receiver dipole which on the I.P. gave low anomalous values. On line 4 where the I.P. anomaly was recorded on the 7-8 receiver dipole, on the resistivity, the same dipole gave results

/ over

over the background values, but the most anomalous values on these lines were recorded on the 5-6 receiver dipole, which on the I.P. gave no significantly anomalous values. On line 5 the resistivity anomaly is centered about the 5-6 receiver dipole, whereas on the 6-7 dipole the values are significantly lower. On the I.P. the highest values were recorded on the 6-7 receiver dipole with slightly lower on the 5-6 dipole. The same difference can be observed on line 6 regarding the results obtained in the area of the known mineralization. A similar shifting of the anomalies is observed in the eastern half of the line where the broad I.P. anomaly centered (on the small dipole separations) about dipole 10-11, appears on the resistivity pseudo-section on the 9-10 dipole. On line 7 the known mineralization was recorded on the I.P. on the large dipole separations of the 5-6 and 6-7 receiver dipoles, but on the resistivity results there is no indication of a significant difference in this part of the line. Similarly, the broad area of relatively higher I.P. values in the eastern half of the line and the sharp anomaly recorded on the 2-3 receiver dipole, do not appear at all on the resistivity results.

A comparison of the resistivity results with the geological map of Fig. 120, suggests that the resistivity highs tend to concentrate on the western edge of the mineralization, particularly on lines 3 to 6. On line 2 it is also centered on the dipole immediately west of the dipole which gave the high I.P. responses. All these dipoles appear on the geological map to be close to a major north-south trending fault which apparently played an important role in the localization of the mineralization. It could be suggested therefore, that the high resistivity values do not necessarily show the location of the mineralization, as with the case of the I.P. method, but other geological structures which could be related to the ore genesis as for example higher concentrations of gangue minerals, such as silica, in those parts of the mineralized block. This explanation is of course tentative and requires further research.

/ 3. Conclusions

3. Conclusions.

From the above discussion it can be concluded that the mineralization is demonstrated by high resistivity values with respect to those obtained in barren rocks. In general, values above 2.0x2π ohm-meters can be attributed to mineralized rocks. From the comparison with the I.P. results it can be concluded that the anomalous results obtained with the two methods do not coincide, indicating that what gives high resistivity responses, does not necessarily give anomalous I.P. responses. This phenomenon also requires further attention and investigation.

E. Conclusions

The parameters presented and discussed in this section include both routine I.P. parameters which are recorded during a normal I.P. survey, and parameters which express the shape of the decay curve, which are computed in the office on the basis of the field results. The project in the Kokkinovounaros area intended to examine the applicability of the method and the usefulness of its various parameters in a relatively narrow but well defined mineralized fracture zone, exposed on the surface along most of its length.

The N.T.I. demonstrated well defined anomalous responses not only over the exposed mineralization, but also in the cases where this is at some distance from the surveyed lines. The anomalies obtained with the pole-dipole configuration were generally sharp particularly in the exposed mineralization. Significantly high readings were obtained when both the receiver electrodes were in the mineralized ground as compared with readings taken with only one receiver in the mineralization. This results in the sharp anomalies which can therefore pinpoint precisely the position of the mineralization with respect to the electrode positions. For this, although the

/ pseudosectional

pseudosectional method of plotting does not demonstrate the true geometry of the mineralization, the presentation of the actual figures taken with each dipole is certainly of great assistance in determining the exact position of the mineralization.

From the Decay Factors, the electromagnetic and chargeability components at zero time, A and B, attained higher values over the mineralization than over the barren rocks. Their slopes, however, factors α and β, did not seem to present any definite responds over the mineralization, except that their profiles along a line which crosses mineralization were irregular with both high and low values, as compared with a profile of the same parameters along lines which run solely over barren rocks. This irregularity suggests that these two factors do respond in some way which, however, from the collected results does not become apparent. This requires further research.

The decay curves were also plotted on a logarithmic time axis. From this plotting which demonstrates the fact that the I.P. decays consist of two components, it was found that the rates of decays of the two different components, the amplitude at which they separate and the magnitude of their deviation, attained all higher values over the mineralization as compared with values over barren rocks.

The Bertin and Loeb's (Modified) Functions which introduced the resistivity function, were also indicative of the mineralization, particularly the A2-function.

From the resistivity results over this area it was concluded that the mineralization is characterised by higher resistivity values than the barren rocks.

In general, it can be concluded that some of the parameters investigated over the Kokkinovounaros mineralization are indeed capable in

/ distinguishing

distinguishing between mineralized and unmineralized rocks, whereas others can achieve this to a lesser extent or not at all. Those which respond positively can certainly be used in an exploration programme as additional information.

/ IV. GENERAL

IV. GENERAL CONCLUSIONS

As it was stated earlier in this Chapter, the Kokkinovounaros area is a typical example of a mineralized zone occurring in the Lower Pillow Lavas, with a significant lateral extend and sharply defined boundaries. This zone, exposed in most of its length, offered an excellent opportunity to test the applicability of the I.P. method under these conditions.

From the results presented and discussed above, it can be concluded that this type of exploration target can easily be detected by the presently applied exploration method. The routine I.P. parameters under the applied field conditions (electrode arrays, spacings etc) demonstrate very convincingly the presence of mineralization. Similarly the transient decay of the I.P. phenomenon varies significantly over the mineralized ground as compared with its shape over barren rocks. Therefore, parameters which described this transient shape may also assist in geophysical exploration.

CHAPTER SEVEN

ON THE GEOPHYSICAL RESULTS OF THE VRECHIA AREA

I. INTRODUCTION

The Vrechia area occurs in the southwestern foothills of the Troodos Massif. Its location is shown on Fig. 1. The area is known for its small and shallow seated pyritic deposit, which was located by drilling and trenching a small, but intensively strong gossan in 1950. Small patches of slag indicate that the area was known to the ancients, who apparently extracted some amounts of cupreous ore from this locality. Noranda Exploration (Cyprus) Ltd. acquired an option of the Vrechia prospecting permit and carried out an extensive amount of prospecting, including drilling of the previously known targets, in order to establish the geology, grade and reserves of the area.

The Vrechia mineralization was considered as a suitable target for testing the applicability of the I.P. method and in particular examining the possibility of obtaining information on the shape of the I.P. transient over mineralization with known grades. For this, three parallel geophysical lines were carried out in this area, centered about the small Vrechia pyritic deposit, and crossing also a lower grade mineralization occurring to the east of this deposit.

The present Chapter begins with a description of the geology of the Vrechia area. This is followed by a detail analysis of the geophysical results and a discussion on the applicability of the I.P. method and the significance of the various parameters expressing the I.P. transient investigated over this mineralization.

/ II. THE

II. THE GEOLOGY OF THE VRECHIA AREA

The Vrechia area is another example of sulphide mineralization occurring in the Lower Pillow Lavas in the form of mineralized zones. As mentioned earlier, these zones are considered as representing fracture systems which formed the passageways of the rising mineralizing fluids. This type of environment is observed in the Vrechia area where the mineralization appears to be defined within such zones.

Fig. 152 is a geological map of the Vrechia area showing also the geophysical lines. The background consists of andesitic flows and intrusives belonging to the Lower Pillow Lava Series. From the amount of intrusive rocks and the proximity of the Basal Group which outcrops to the north just outside the area, it is concluded that geologically the area falls in the lower levels of the Lower Pillow Lava Series. The fresh Lower Pillow Lavas are observed in many places to grade into limonite stained rocks, which themselves pass in some places into strongly oxidised rocks.

The Vrechia deposit appears in a shallow pit in the area of boreholes DH-2 and DH-3 surrounded by a strong oxidation. This is the highest part of the deposit. To the north of this point the mineralization is covered by fresh Lower Pillow Lavas the thickness of which increase towards the north. A similar situation is observed towards the south where the mineralization is capped by fresh Lower Pillow Lavas but of smaller thickness than to the north. Fig. 153 illustrates three geological sections across this mineralization and along the three different geophysical lines. From the drilling results it is evident that the mineralization has not been delimited in any direction. It is believed that the eastern and western extensions of the mineralization are not far beyond the area drilled, but it extends both north and south. In other words the mineralization is confined in a

/ zone

zone of a width of just over 100 meters trending approximately north-south and extending beyond the geophysical lines.

The grade of the main Vrechia mineralization is shown on the sections of Fig. 153. The highest grade was found in the vicinity of line 2 where it reaches a maximum of 40.8% S. The rest boreholes along this line have values about 20% S. The mineralization encountered along the other two lines is of lower grade. In the north (line 1) it does not exceed the 12% S whereas in the south (line 3) it does not exceed the 14% S. The main sulphide mineral is pyrite with subordinate amounts of chalcopyrite and sphalerite.

The geophysical lines extended over two more mineralized areas. The first is in the area of boreholes CH-20, 21 and 23, see Fig. 152, in the eastern ends of the lines. This mineralization is indicated on the surface by the extensive strong oxidation occurring in this area, which appears to be in faulted contact with fresh lavas to the west. Undoubtly this extends further north up to the area of boreholes CH-6 and CH-7. The grade of this mineralization is generally low. As indicated on the geological sections of Fig. 153, the average sulphur content of the boreholes in this area is below 8%.

The third area is near stake 14 of line 1, and is indicated on the surface by a strong oxidation. The average sulphur content of borehole CH-22 drilled on this mineralization is 8.7%, see Figs 152 and 153.

/ III. THE

III. THE GEOPHYSICAL RESULTS

The area was covered by three parallel lines, the first (line 1) 650 meters, and the rest two (lines 2 and 3) 600 meters in length. The direction of these lines was east-west and their spacing 60 meters. These lines were surveyed with I.P. and resistivity with the pole-dipole array at an electrode spacing of 50 meters and electrode separations n= 1-4. At n=2 the I.P. transient was recorded at 16 different times to enable the reconstruction of the I.P. decay.

Below there is an analytical description of the geophysical results and studies in the following sequence:

A. The Normalised Time Integral.

B. The Decay Factors.

C. The $\mathrm{Log}_e t$ Decay Factors.

D. The Bertin and Loeb's (Modified) Functions.

E. The Resistivity Results.

A. <u>Normalised Time Integral</u>

1. Presentation of Results.

a. Line 1.

The results of this line are illustrated on the pseudosectional plottings of Fig. 154. In all Msec values there is evidence of three different anomalous areas. The first corresponds to the readings of the receiving dipoles 3-4, 4-5 and 5-6 corresponding to the mineralization exposed in this area. In the next dipole 6-7 there is a significant drop in the N.T.I. values to increase in the following receiving dipoles from stake 7 to 11 and particularly the receiving dipole 8-9, corresponding to the pyritic deposit. As indicated by the lower Msec results particularly

/ Msec 1

Msec 1 and Msec 3, the high values of this anomaly are also controlled by the transmitting pole results from stake 14. This is due to the exposed mineralization in the region of this stake (14). This mineralization appears strongly on the receiver dipole results in the western end of the line.

b. Line 2.

The results of this line are illustrated in Fig. 155. This figure shows two different anomalous areas. The first is at the beginning of the line centered about the receiving dipoles 4-5 and 5-6. This anomaly appears on all Msec values. In the next receiving dipole (6-7) there is a significant drop on all the dipole readings. On dipoles 7-8 and 8-9 the large dipole separations, n = 3 and 4, gave low readings, whereas the small n values gave higher responses. In the next two receiving dipoles 9-10 and 10-11, there is a significant increase of the N.T.I. on all dipole separations. The highest was recorded on the n = 1 of the 9-10 dipole. In the following two dipoles 11-12 and 12-13, the I.P. responses drop significantly and increase slightly in the last few readings in the western end of the line.

The first anomaly is attributed to the exposed low grade mineralization whereas the second anomaly is certainly due to the main mineralization in the area. The slight increase in the values after stake 13 is due to the iron stained i.e. very weakly mineralized rocks exposed in this part of the line.

c. Line 3.

The results of this line are illustrated on Fig. 156. This line also shows two anomalous areas the first at the beginning of the line recorded on the first two receiving dipoles, 4-5 and 5-6. The next dipole, 6-7, has lower values decreasing with increasing dipole separation. In the next two dipoles, 7-8 and 8-9, the values recorded on them are higher than in the previous one (6-7) but they again decrease with increasing dipole separation. In the following dipoles, 9-10 and 10-11, the I.P. responses attain hign values on all dipole separations. In general the I.P. anomaly recorded over this main mineralization is controlled mainly by the 9-10 and 10-11 receiving dipoles but it also has high values on the small dipole separations of the 7-8 and 9-10 dipoles. The anomaly attains therefore an asymmetrical boomerang shape. Further west, beyond this anomaly, the N.T.I. values decrease significantly.

2. Discussion.

From the results presented above and the geology of the area described earlier, it is evident that the geophysical survey in this area covered two different mineralizations. The first at the beginning of the lines is a low grade mineralization exposed on the surface, in fact under a thin cover of oxidised rock, and the second, the main Vrechia mineralization located at about the center of the lines, with higher grade and variable thickness of overburden. In the following lines there will be a discussion on the amplitudes recorded over each mineralization, the shape of the I.P. anomalies over the main mineralization where its shape is known from the drilling results, and a comparison between the responses obtained over the two different mineralizations which differ with regard to their grade.

The mineralization at the beginning of the lines has only been recorded by the receiving dipoles since the lines did not extend far enough to cover the mineralization completely. In fact this mineralization extends for a considerable distance to the east. In all lines the anomalous results were recorded on the receiver dipoles and the anomalies on the pseudosections appear to have a westerly dip due to the conventional plotting. Comparing the responses of the different Msec values of each line separately, it is

/ observed

observed that the main form of the anomaly begins to appear from the first N.T.I. value, i.e. Msec 1. Taking the Msec 4 values, it can be stated that these range between 700 and 900. It is reminded that the grade of this mineralization is generally low not exceeding the 10% S.

The next to discuss are the characteristics of the anomalies obtained over the main target in this area, i.e. the Vrechia deposit. The shape of the anomalies as plotted with the pseudosectional convention appear in all cases to be controlled by the receiving dipole results. On line 1 anomalous values were recorded on the receiving dipoles 11-10 and 9-10 over the known mineralization (see Fig. 153). It is interesting to note that the anomaly indicates very clearly the presence of unmineralized rocks over this mineralization by the low amplitudes in the first dipole separations. Another interesting point which corresponds with the depth to the mineralization, is the fact that the anomalous values of the 10-11 dipole are "shallower" on the pseudosectional plot than the values of the 9-10 receiver dipole. A careful examination of the geological section along this line indicates indeed that the mineralization appears to dip to the east, becoming deeper in the area of the receiving dipole 9-10. Further east on dipole 8-9, the N.T.I. values become stronger suggesting an extension of the mineralization over this area and at a higher level than under the previous dipole (9-10). It is unfortunate that there are no drilling results in the area of this dipole to prove or not the above. However, an examination of the drilling results along line 2 (see Fig. 153), suggests a fault structure between boreholes CH-18 and CH-9 with an uplift of the eastern side. Such a fault would have a northeasterly trend passing approximately from the region of stake 9 of line 1. South of line 2 this would be expected to occur between boreholes DH-3 and CH-5 and CH-15 and DH-4 of line 3. Indeed, by examining these two pairs of boreholes it is observed that borehole DH-3 intersected the mineralization almost from the beginning whereas borehole CH-5 at a depth of 15 meters.

/ Further

Further south along line 3 there is a significant change in the depth to the mineralization between boreholes CH-15 and DH-4 (see Fig. 153). All these suggest that there is a hinge fault running from about stake 9 of line 1 towards borehole CH-15 of line 3. Therefore there would be expected an uplift of the mineralization in the region east of stake 9 of line 1. Further east the results of the receiving dipole 7-8 suggest that the mineralization gets deeper east of stake 8, and disappears before the dipole 6-7. The anomaly due to this main mineralization is slightly affected by the transmitting pole readings of the low grade mineralization exposed in the area of stake 14.

The anomaly on line 2 is centered about the receiver dipole 9-10 and 10-11. The very high N.T.I. value recorded on the n = 1 position of the 9-10 dipole is attributed to a small heap of massive pyrite occurring between stakes 9 and 10, and closer to 10. (This was piled up during a past exploration activity over the main body). The remaining values of these two dipoles are generally high and increase with increasing dipole separation. High values were also recorded on the small dipole separations n = 1 and 2 of the 7-8 and 8-9 receiving dipoles, but these are attributed to the weakly oxidised ground occurring in this area, which apparently does not extend much in depth. The geological section of this line is shown on Fig. 153. It is interesting to note that although borehole DH-9 is located midway between dipole 11-12 and has intersected significant mineralization at a depth of 12 meters, the I.P. survey has not recorded any significantly anomalous values on this dipole. Although the extent of the mineralization to the west has not been determined accurately since all boreholes drilled on this side intersected mineralization, it is believed that the mineralization does not extend much beyond borehole DH-9. Borehole CH-13 (Fig. 152) has also struck mineralization at a depth of 13 meters. The fact that the receiving dipole 11-12 has not recorded any significantly high values, as

/ for example

for example dipole 9-10, suggests that the I.P. responses do not increase unless both potential electrodes are over mineralized ground. If one of them is not, i.e. the mineralization does not extend all along the dipole, then the responses are not anomalous. The same can also be said about the receiving dipole 11-12 of line 1 (Fig. 154). The mineralization on this line could not be considered as terminating on borehole CH-2 or before stake 11. This is a very important observation.

The anomaly on line 3 due to the main mineralization is also controlled by the receiving dipoles 9-10 and 10-11. The highest values are on the first dipole. Anomalous values following the receiving dipoles were also recorded on the 7-8 and 8-9 dipoles on their small dipole separations. These are attributed to the exposed mineralization around stake 8 (Fig. 152). Comparing the I.P. results with the geological section of this line (Fig. 153), it is observed that the mineralization in borehole CH-15 had a significant thickness and it is justified to expect it to extend beyond stake 11. However, dipole 11-12 on this line has not given any anomalous values. This effect was discussed above for both lines 1 and 2.

In general on all the lines it was observed that the anomalous responses were only obtained on the receiving dipole readings. The transmitting poles did not give any significantly high readings when crossing the mineralization. This indicates that the transmitting poles do not give anomalous readings when located on non-mineralized ground even if they are very close to it. The only case where the transmitting pole affected slightly the anomalous pattern was when a transmitting electrode was located at stake 14 of line 1 which is in mineralized ground. In fact the fresh mineralization is at a depth of 2 meters under an oxidised layer.

In all three lines it is observed that the anomalous pattern obtained at different integration periods, i.e. different Msec parameters, are very

/ similar

similar to each other and can all give a satisfactory shape of the anomalous pattern. Considering the Msec 4 values it can be stated that the anomalous values over the main mineralization range from just over 700 in the deeply seated mineralization on line 1, to over 1100 in the cases where the mineralization is very close to the surface.

Comparing the two different mineralizations and the I.P. anomalies which they gave rise to, it is observed that the first (eastern) mineralization is generally of lower grade than the second (main) mineralization. In addition the first is almost exposed being under a thin cover of oxidised mineralization. The I.P. responses given by these two different types and environments appear to differ between them. The poor and exposed mineralization is characterised by values just exceeding the 900 on the Msec 4 integral, whereas the richer main mineralization has higher values exceeding the 1100 even when the mineralization is at a depth under fresh volcanics.

3. Conclusions.

From the preceeding discussion it can be concluded that both mineralization in the Vrechia area gave anomalous responses. The main mineralization in the area crossed by all three lines gave the highest I.P. responses. In all cases the shape of the I.P. anomaly is controlled by the receiving dipoles. An important observation made on the results of these three lines, was that a receiving dipole could only give anomalous readings when the concealed mineralization extends all along under the dipole. Thus, if the boundary of the mineralization with the enclosing rocks occurs within a certain dipole, this dipole will not give any anomalous values. This phenomenon is not observed when the mineralization is exposed. If the exposed boundary is between a given dipole, this dipole will give anomalous values. From the anomaly of line 1 and the geological information available for this line, it can be concluded that some relative indication of the

/ depth

depth to the mineralization can be obtained from the pseudosectional plotting of the results. Comparing the two mineralizations it can be concluded that the richer one, the main Vrechia mineralization with higher grade than the eastern mineralization, gives higher N.T.I. responses.

B. The Decay Factors.

The I.P. transient decay has been recorded on the n = 2 dipole positions. In fact the amplitude has been recorded at the following times (in msecs): 35, 55, 90, 95, 130, 150, 180, 215, 240, 280, 360, 420, 455, 580, 720 and 780. These transient shapes were factorised according to Hutchins' (1971) method described in detail in Chapter Three of this Thesis. The results for each line are presented and discussed below.

1. Presentation of Results.

The results for the Vrechia lines are tabulated in Tables 68 to 70 and illustrated in Figs 157 to 159. Both the A and B-factors attain high values over the different mineralizations in the area, and lower values over the barren rocks. The α-factor shows some notable variations along the geophysical lines with both high and low values in the viscinity of the mineralized areas. The β-factor demonstrates generally very little variations along the lines. Finally, the P-factor is generally indicative of the mineralization attaining higher values over it.

2. Discussion.

The results presented above indicate that the different factors which describe the decay curve respond in some degree or another to the presence of mineralization. In the following lines there will be a discussion on the responses of each of these factors.

The A-factor always responded positively over the mineralized ground,

/ attaining

attaining high values over them. Beginning with the outcropping eastern mineralization it is observed from the results presented above, that its values range from 2.8 to 3.7. The main mineralization has also values above 3.0, up to 3.6, but these were obtained only in those parts of the line where the mineralization was very close to the surface, such as on dipole 10-11 of line 2. Much lower values were computed for dipoles 9-10 and 10-11 of line 1 where the mineralization is concealed under a thickness of 23 to 53 meters of fresh volcanics. The responses in this case have values as low as 2.2. These are generally higher than those of the barren rocks which have values ranging from 1.2 to 1.8. The mineralization exposed in the vicinity of stake 14 of line 1 has values falling within the range of the previous mineralizations. In general it appears that the A-factor is capable to distinguish between the barren and mineralized rocks since it attains distinctly different values on each type. Comparing the mineralizations between them, it appears that the responses obtained over the main mineralization which is of relatively higher grade than the eastern mineralization, fall within the range of the low grade mineralization. In other words, it appears that this factor cannot give any assistance in distinguishing between a mineralization of 5% to 10% sulphur and a richer one.

The B -factor which is a measure of the actual chargeability at zero time also responds positively over the different mineralizations. In the eastern mineralization the values range from 1.9 to 2.5. In the main mineralization the values of this parameter range from 1.65 on line 2 to 2.8 on line 3. On the barren rocks it ranges from 0.8 to 1.4. It is interesting to note the following regarding this parameter. On line 1, the 8-9 receiving dipole although with a peak on the A-factor, shows a relatively low B-factor value. In other words not differring much from the values obtained in the next dipoles which are believed to correspond to mineralization at a greater depth. Another interesting point is that on the receiver dipole 10-11 of

/ line

line 2 which has approached very closely the main mineralization at its highest grade, has a very low value of B of about 1.6. Comparing the B values over the two different mineralizations, it appears again that in general it is not possible to distinguish between them. However, comparing the values obtained over different parts of the main mineralization, it is observed that the 10-11 receiving dipole of line 2 which crossed the highest grade of this deposit and at a minimum depth, has given a low value of B, 1.65, as compared with that obtained over the 10-11 receiving dipole of line 3, with 2.4, which as shown on Fig. 153, the geological sections along the lines, is in the area of lower grade mineralization and at a depth of 10 meters below unmineralized volcanics. From the above it can be concluded that the B-factor appears to present some assistance in distinguishing between different grades. From this it can also be concluded that the grade of mineralization suspected to occur at some small depth in the area of dipole 8-9 of line 1, must be of relatively higher grade compared with that of line 3.

The α-factor shows in general profiles which cannot be compared with those of the previous factors. In the eastern mineralization its values range from 6.9 to 9.2, and in the main mineralization from 7.2 to 9.4. In the barren areas the values range from 6.2 to 7.5. From the above ranges it is evident that the mineralizations are characterised by higher values than the barren rocks. Comparing these ranges with the grade of mineralization it is observed that as a whole it is not possible to distinguish between the two mineralizations, the eastern one being of lower grade than the main one. Comparing results obtained from different parts of the main mineralization, as for example from dipoles 10-11 of lines 2 and 3, it is observed that in the high grade, line 2, the α-value is about 8.0 whereas on line 3 is slightly higher, about 8.3. This suggests at first that the α-value increases with decreasing sulphur content. However, looking at dipole 9-10 of line 2, it is observed that this does not increase compared with dipole

10-11 of the same line, but decreases indicating that the above observation is not valid.

The β-factor does not appear to present any significant variations along the three lines. On the eastern mineralization its values range from 0.55 to 0.8. On the main mineralization the β-values range from 0.5 to 0.8, and on the barren rocks from 0.6 to 0.8. From these three ranges it is observed that the β-factor could attain almost similar values over these three different rock types. Comparing for example the values obtained in dipoles 10-11 of lines 2 and 3 which as described above show significantly different grades of sulphur, it is observed that they are both about 0.65 which for example is approximately the value of the 13-14 dipole of line 2 which is 0.62 and corresponds to almost fresh volcanics.

The P-factor always responded positively over the mineralizations. Over the eastern mineralization its values ranged from 0.53 to 0.75. In the main mineralization the P-values ranged from 0.72 to 0.84, except for the deeply seated parts of line 1 where the values drop to about 0.5. The barren rocks are characterised by values ranging from 0.28 to 0.45. In general it is observed that the mineralization, even in depth as in the case of line 1, has always higher values than the barren rocks. Further, the high grade mineralization of line 2, dipole 10-11, attained higher values than the lower grades. The fact that the values are higher could also be due to the close proximity to the surface of this part of the mineralization.

3. Conclusions.

From the results presented above and the discussion which followed, it can be concluded that some of the different decay factors investigated above can distinguish very clearly between mineralized and non mineralized rocks. Table 76 summarizes the ranges of each factor in the different

/ environments

environments. From this table and the previous discussion it can be concluded that the A-factor can distinguish very clearly between mineralized and unmineralized rocks with higher values over the first, but it cannot give any indication of the grade of the mineralization. The B-factor is also capable of distinguishing between mineralized and unmineralized rocks attaining higher values over the first type. There are also indications, however, that this factor can give some assistance in distinguishing between different grades. It appears that under similar conditions this factor attains lower values over a high grade mineralization than over a low grade mineralization. The α-factor does not appear to be of any assistance since there is some overlap in the ranges of its values in the different types (see Table 71). There are indications, however, that it has higher values over the mineralized ground. The β-factor is of no help as indicated by the coincidence of the ranges of its values in the different types. The P-factor attains higher values over the mineralization compared with those over the non-mineralized rocks. With regard to the grade of mineralization it does not give any definite evidence than it can be of any assistance.

In general, it can be concluded that the A, B and P factors attain higher values over the mineralization than over barren rocks. Further, the B-factor appears to have lower values over the high grade and higher over the low grade of mineralization.

C. The $\log_e t$ Decay Factors

The transient decays recorded at the n = 2 dipole separation were plotted on a $\log_e$ time axis and normal potential axis. The characteristics of such plottings as described in Chapter Three were studied and investigated. An important modification in the study of these results in the Vrechia area is that the deviation of the second component of the I.P. decay from the first component, was investigated at the potential values of 1.5 and 2.0

/ compared

compared with 0.5 and 1.0 in the other areas. This was essential due to the very high responses which were recorded at Vrechia, otherwise the values describing this deviation would have been estimated after long extrapolations. The results for each line are presented and discussed below.

1. Presentation of Results.

The results for all Vrechia lines are tabulated in Tables 72 to 74 and illustrated on Figs. 160(a,b) to 162(a,b). The R1 and R2 factors attain always high values over the mineralizations and low over the barren rocks. Their ratio R1/R2 attains both high and low values over the different mineralizations. The t_d parameter shows in general smooth profiles with a poor indication of slightly lower values over the mineralized ground. The V_d parameter shows always higher values over the mineralization. Similarly the two deviation parameters d(1.5) and d(2.0).

2. Discussion.

In the results presented above it is indicated that at least some of the parameters which describe the shape of the transient decay on a $\log_e t$ plot are indicative of the presence of mineralization. In the following lines there will be a discussion on the responses of each of these factors.

The R1-factor is observed on all lines to show high values over the eastern mineralization. These values range from 2.7 to 3.5. The mineralization at stake 14 of line 1 has a value of 3.0 falling within this range. The main mineralization where it is very close to the surface or exposed, as on dipole 10-11 of line 2, has R1 values ranging between 3.1 and 3.4. In the deeply seated mineralization of line 1 the R1 values fall in the range of 2.2 to 2.9. The barren rocks have values below 2.0 (1.2 to 1.8), except for line 2 where dipole 12-13 gives a higher value of 2.15. In general, it is observed that this parameter has significantly different values over

/ the mineralization

the mineralization even at some depth, compared with those of the barren rocks. Comparing the results obtained over the different mineralizations, it is observed that these do not differ significantly, suggesting that this factor does not show much different responses over different grades of mineralization. In addition, by comparing the values obtained over dipole 10-11 of line 2 with that of dipole 10-11 of line 3, in the first the mineralization being almost exposed and of a high grade, whereas in the second concealed under a thin layer of fresh volcanics and at much lower grade, it is observed that the R1 values are not significantly different. The line 2 (higher grade) value even with the exposed mineralization has a slightly lower value than the concealed mineralization of line 3.

The R2-factor is also high over the mineralized ground. In the eastern mineralization it has values ranging between 1.9 and 2.6. Over the main mineralization its values fall within the range of 2.5 to 2.75, becoming as low as 1.7 in the concealed mineralization of line 1. In the stake 14 mineralization on line 1 it is 2.05. Over the barren rock the values are much lower ranging between 0.9 and 1.6. From these results it is evident that this factor can indicate very clearly the presence of mineralization. Comparing the results obtained from the different mineralizations - the main and the eastern, it is observed that the responses are about the same although the overall grades of these mineralizations differ from each other. The results over the 10-11 dipoles of lines 2 and 3 show respectively 2.75 and 2.7, indicating no significant difference between them. However, it must be noted that the 2.7 value corresponds to concealed mineralization of a lower grade.

The R1/R2 ratio gave on all three lines smooth profiles. On line 1 this appears to vary about a mean value of about 1.3 with slight increases over the three mineralizations of this line. These higher values are 1.37 -

1.4 for the eastern, 1.35 for the main, and 1.45 for the stake 14 mineralization. On the barren rocks it appears to attain a lower value down to 1.22. On line 2 the mean value is about 1.25 but the readings corresponding to the mineralizations are lower than this mean, about 1.2, contrary to what is observed for line 1. Similarly the barren rocks show higher values than the mean, up to 1.35. Line 3 is even more confusing showing higher values over the eastern mineralization and lower over the main mineralization. The mean value is about 1.2 and the eastern has values of 1.28, and main mineralization values as low as 1.14. The barren rocks have high values reaching the 1.3. From the above results it can be concluded that this ratio does not attain distinctly different values over the mineralization compared with those over the barren rocks.

The t_d-factor also shows profiles which cannot present any direct conclusions. On line 1 this profile shows lower values over the three mineralizations of this line, 103 to 90 msecs for the eastern, 95 for the main and 100 for the stake 14 mineralization. In the barren areas it reaches a value of 130 msecs. On line 2 the eastern mineralization still shows low values, 100 to 110 but the main mineralization has values ranging from 110 to 130. In the barren areas, as for example on dipoles 8-9 and 12-13, the t_d-factor has values of 140 and 122 respectively. On line 3 the picture is slightly different. It appears that the t_d-factor has a "regional trend" which decreases from the beginning to the end of the line. The values obtained over the different mineralizations are: 145 over the eastern and 125 to 140 over the main mineralization. On the barren rocks such as on dipole 12-13 the t_d-factor has a value of 110. From these results it appears that the t_d-factor does not show any significantly different values on the mineralized rocks as compared with those of the barren rocks.

The V_d-factor responded in all cases positively over the

/ mineralization

mineralization. The eastern mineralization has values ranging from 3.4 to 4.5. The main mineralization has values ranging from 4.2 to 4.6 in the exposed and near surface dipoles, and 3 to 3.8 in the deeper mineralization of line 1. The mineralization at stake 14 of line 1 has given a value of 3.5 and the barren rocks values ranging from 1.6 to 2.4. These figures indicate that the V_d-factor can certainly distinguish between mineralized and unmineralized rocks. The different grades of mineralization in the area, however, do not appear to give any significantly different responses which would assist in distinguishing between them. Comparing for example the responses from dipoles 11-10 of lines 2 and 3 which correspond to different grades, it is observed that the differences are not significant. The same conclusion can be drawn also from a comparison between these dipoles and the results from dipole 6-5 of line 2, which corresponds to even lower grade.

The d(2.0)-factor responded positively over the mineralized ground giving significantly higher values over the different mineralizations compared with the barren rocks. The eastern mineralization has values ranging from 130 to 400 msecs and the main mineralization 230 to 330 msecs. The deeply seated mineralization of line 1 gave values as low as 60 msecs. The mineralization at stake 14 of line 1 has a value of 180. The barren rocks range in their values from zero to 30. From the above figures it is evident that over the mineralization, even when in depth, this parameter gives significantly higher values. A comparison between the values obtained from the different grades indicates that no distinction can be made between them on the basis of this factor.

The d(1.5)-factor also responded positively over the mineralized ground. The eastern mineralization has values ranging from 400 to 1400 msecs, the main mineralization values varying from 600 to 700 msecs with as low

/ as 200

as 200 msecs in the deeply seated mineralization of line 1, and the mineralization at stake 14 of line 1 has a value of 500. The barren rocks have generally much lower values ranging from 10 msecs to 110. From the above figures it is evident that this factor attains much higher values over the mineralization than over the barren rocks. Comparing the results from the different mineralizations, it is observed that their ranges of values are such that no distinction between them can be achieved. From the results of line 2 (Fig.161(b)) it appears that the high grade mineralization exposed about dipole 10-11 of this line,has lower values than the exposed eastern mineralization which has a lower grade. This is true, but this mineralization has also given lower values on the other lines suggesting that this factor cannot be of any assistance in distinguishing between the grades of mineralization occurring in this area.

3. Conclusions.

From the results presented above and the discussion which followed, it can be concluded that from the different factors which describe the characteristics of the $\log_e t$ plotted decays, some of them attain much different values over the mineralization compared with their values over barren rocks. The ranges of values for each of these factors over the different mineralizations of the area and the barren rocks which enclose them, are summarized in Table 75. From this table it can be concluded that the factors R1, R2, V_d,d(2.0) and d(1.5) attain higher values over the mineralization than over the enclosing barren rocks. The same table indicates that the ranges of these values in the three different mineralizations do not differ considerably, suggesting that a distinction between them on the basis of these factors is not possible. It should be remembered that the main mineralization has sulphur values ranging from about 10% to 40%. The eastern mineralization has lower values averaging about 7% sulphur, and the mineralization at stake 14 of line 1 has an average of 8.7% sulphur. No definite

/ conclusions

conclusions can be drawn on the remaining two factors, R1/R2 and t_d. The only conclusion which can be drawn from the results in this area is that these two parameters do not appear to vary significantly over the mineralized and unmineralized rocks.

D. The Bertin and Loeb's (Modified) Functions

These functions are the ratios $A1 = A/\rho/2\pi$ and $A2 = B/\rho/2\pi$ where A and B are defined in the equation of the decay curve $y(t) = Ae^{-\alpha t} + Be^{-\beta t} + P$. These were computed for the n = 2 dipole separations where the whole transient decays were recorded. These results are presented and discussed below.

1. Presentation of Results.

The results for all Vrechia lines are tabulated in Tables 76 to 78 and illustrated in Figs 163 to 165. Both the A1 and A2-factors attain higher values over the mineralized than over the barren rocks. Their ratio appears to attain lower values over the mineralizations and higher over the barren rocks.

2. Discussion.

From the results presented above, it is evident that these factors respond in most cases differently over the mineralization than over the barren rocks.

The A1-factor over the eastern mineralization has values ranging from 0.3 to 0.43. Over the main mineralization its values range from 0.25 to 0.46 in the exposed and near surface mineralization, and decrease only to 0.24 in the deeply seated mineralization of line 1. The mineralization at stake 14 of line 1 has a value of 0.21. The barren rocks such as those of dipoles 12-13 of all lines have values below 0.1 (0.05 to 0.08). From the above results it is evident that this function attains much higher

/ values

values over the mineralized than over the barren rocks. A comparison between the different mineralizations indicates that their values do not differ significantly from each other, suggesting that a distinction between them on the basis of these results is not possible. This is also proved by a comparison between the values of this function on dipole 10-11 of lines 2 and 3 which correspond to different grades. Their values are 0.39 and 0.36 respectively.

The A2-factor has values ranging from 0.17 to 0.34 over the eastern mineralization and 0.24 to 0.31 over the main mineralization, decreasing to 0.2 over the deep parts of this on line 1. The mineralization at stake 14 of line 1 has a lower value of 0.14, and the barren rocks (dipole 12-13) have values ranging from 0.03 to 0.06. From the above figures it is evident that this function discriminates very clearly between mineralized and barren rocks, attaining very low values in the second. A comparison between the different mineralizations indicates that they cannot be distinguished from the values of this function as they do not vary significantly from one to the other. Comparing the values of the 10-11 dipole of line 2 which corresponds to exposed mineralization of high grade, with the 10-11 dipole of line 3 which corresponds to much lower grade mineralization, it is observed that the first has a value of 0.3 and the second 0.24. This difference is attributed to the fact that the line 3 mineralization is not exposed, since a higher value of 0.34 was computed for the low grade eastern mineralization of line 2.

The A1/A2 ratio has shown in general rather irregular results which suggest that no definite conclusion can be drawn on the behaviour of this parameter. The values obtained in the different mineralizations and barren rocks over the three lines are as follows. The eastern mineralization has values ranging from 1.21 to 1.93, the main mineralization has values in

/ the range

the range 1.06 to 1.48, and the barren rocks have values in the range 1.03 to 1.44. From these figures it is evident that this parameter could give similar results over mineralized and unmineralized rocks.

3. Conclusions.

From the results presented above and the discussion which followed, it can be concluded that the Bertin and Loeb's (Modified) Functions are capable to discriminate between mineralization and barren rocks. Their ratio, however, does not give any discriminate values. The ranges of values for each function over the different mineralizations and barren rocks in the area, are summarized in Table 79. From this table it can be concluded that both A1 and A2 functions attain higher values over the mineralization than over the barren rocks. The ranges of these values show that there can be no discrimination on the basis of these functions for the different grades encountered in this area.

E. The Resistivity Results

The resistivity values were estimated for all readings taken in the area from the field results of the I.P. survey. These are expressed in $\rho/2\pi$ ohm-meters and are presented and discussed below.

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig.166(a). The first dipole and to some extent the second, show relatively high values followed by lower values in the receiving dipoles 5-6 to 7-8 with exception the n = 1 reading of the 7-8 dipole. The following dipoles which correspond to the main mineralization along this line, 9-8 to 10-11, and beyond stake 11, show equally low values in the small dipole separations n = 1 and 2, and

/ much

much higher values in the n = 3 and 4 separations. These high values correspond to the deeply seated mineralization in this part of the line. The following dipole shows much higher values than those recorded in the previous part of the line, followed by a relative decrease in the western end of this line corresponding to the mineralization occurring at stake 14.

Compared with the N.T.I. results of the same line (Fig. 154), it is observed that the high values ranging from just below 10.0 x 2π ohm-meters to over 11.0 x 2π ohm-meters recorded at the beginning of the line, correspond to the high N.T.I. results which both correspond to the eastern mineralization. It is interesting to note that the 5-6 receiver dipole gave high N.T.I. values and low resistivity values. The following dipoles (6-7 and 7-8) have low N.T.I. values together with the low resistivity results. The N.T.I. anomaly recorded in the 8 to 11 receiver dipoles coincides with the high resistivity values in the large dipole separations of this dipole, and in addition of dipole 11-12 which on the N.T.I. results it has lower values. The following dipole, 12-13, which is characterised by very high resistivity values exceeding the 20.0 x 2π ohm-meters, has given very low N.T.I. values. Further, at the end of the line there is an increase of the N.T.I. values together with a decrease of the resistivity values. In general comparing the two patterns, there appears to be a similarity between them although their relationship is antipathetic.

b. Line 2.

The resistivity results of this line are illustrated in Fig. 166(b). The first two receiving dipoles have relatively low values followed by higher values in the 6-7 receiving dipole. The resistivity decreases again in the 7-8 dipole, except for its n = 4 reading, to increase significantly in the following dipole (9-8) particularly in the large dipole separations. The dipoles 9-10 and 10-11 which correspond to the main mineralization are

/ characterised

characterised by very low readings in the n = 1 separation and higher readings in the rest. The remaining resistivity results up to the end of the line are much higher particularly in the 12-13 receiver dipole.

Compared with the N.T.I. results of the same line (Fig. 155), it is observed that the first two dipoles have high N.T.I. values corresponding to the eastern mineralization. The 6-7 dipole which has high resistivities gave very low N.T.I. responses. This applies also for the 8-9 dipole, whereas the 7-8 dipole gave slightly higher N.T.I. responses and lower resistivity values. The 9-10 and 10-11 dipoles which correspond to the main mineralization along this line occurring at a very shallow depth, show an increase in the N.T.I. values with a respective decrease in the resistivity values. The rest readings up to the end of the line have low I.P. responses with high resistivity responses. In general there appears to be a general similarity of the two patterns, the I.P. and resistivity, although their relationship is antipathetic.

c. Line 3.

The resistivity results of this line are illustrated in Fig. 166(c). The first receiving dipole shows relatively low readings followed by higher readings in the following two dipoles, 5-6 and 6-7. Further west up to and including the 10-11 dipole, the resistivity results are uniform with low values in the small dipole separations increasing in the large separations. In the last readings in the western end of the line the resistivity values are generally very high.

Compared with the I.P. results over the same line (Fig. 156), it is observed that the low resistivity values of the first dipole (4-5) correspond to high N.T.I. responses. In the following two dipoles 5-6 and 6-7, the increase in resistivity corresponds to a decrease in the N.T.I. values. In the following dipoles up to and including dipole 10-11, the resistivity values are rather uniform, whereas on the I.P. results there is a significant difference between the values of the 7-8 and 8-9, and 9-10 and 10-11 dipoles. Further west up to the end of the line the very high resistivity values correspond to very low N.T.I. values.

2. Discussion.

From the results presented above it is evident that the resistivity attains different values over the different rock types (including mineralized rocks) in the Vrechia area. In the following lines there will be a discussion on these results and in particular the significance of the different amplitudes recorded over the mineralizations and barren rocks.

The eastern mineralization which is believed after the drilling results to have sulphur values not exceeding the 8%, is characterised by a wide range of resistivity values. On line 1 this mineralization extends from stake 6 eastwards up to stake 3. The values obtained over this mineralization vary and decrease from the first dipole to the third. The range of values is from 11.30 to 5.44 x 2π ohm-meters. It is interesting to note that the lowest values were recorded in the 5-6 receiving dipole which stradles a fault separating the barren from the mineralized rocks. On line 2 this mineralization which occurs on the first two dipoles of the line, has values ranging from 5.44 to 10.11 x 2π ohm-meters. Dipole 5-6 also crosses the main fault separating the mineralization from the barren rocks, but without any significant drop in the resistivity values. On line 3 the resistivity values over the eastern mineralization vary from about 6.0 to 12.0 x 2π ohm-meters.

The main mineralization on line 1 where it occurs in depth under unmineralized volcanics, is indicated by high resistivity values on the large

/ receiver

receiver separations. Considering only the n = 3 and 4 separations, these values range from 10.18 to 14.79 x 2π ohm-meters. The same mineralized body on line 2 where is very close to the surface and of much higher grade than line 1, is characterised by values ranging from 4.4 to 12.98 x 2π ohm-meters. On line 3 the main mineralization occurring at a small depth corresponding to the receiver dipoles 9-10 and 10-11, is characterised by values ranging from 7.23 to 19.47 x 2π ohm-meters. The mineralization at stake 14 of line 1 has a value of 14.9 x 2π ohm-meters.

The barren rocks in the Vrechia area appear to be characterised by both high and low resistivity values. Considering for example the rocks overlying the main mineralization on line 1 which are considered to correspond to the resistivity results of the first dipole separation, it is observed that these are as low as 4.88 x 2π ohm-meters. On the same line the resistivity results of the 6-7 and 7-8 receiver dipoles range from 5.81 to 17.8 x 2π ohm-meters. Resistivity values falling in this range were also recorded on all lines in the area immediately west of the main mineralization. The recorded values are usually over 20.0 x 2π ohm-meters reaching a maximum of 27.1 x 2π ohm-meters.

From the above figures it is evident that there is a considerable overlap in the ranges of resistivity values attained by the different mineralizations and the barren rocks.

From the values on the different mineralized bodies, it is observed that low resistivities could be attained by both the high grade ore of the main mineralization and the low grade of the eastern mineralization. Similarly the two mineralizations could give equally high resistivities but in this case their grades do not differ considerably. The barren rocks also show a wide range of values. In the area over the main mineralization and in the space separating it from the eastern, the resistivity values are

/ relatively

relatively low and not differring much from those of the mineralized bodies. To the west of the main mineralization, however, the rock resistivities increase exceeding the values of the mineralized rocks.

From the comparison of the resistivity results with the I.P. results, it appears that in general the two patterns are rather similar to each other and in most cases the high N.T.I. values correspond to low resistivity values and vice versa.

3. Conclusions.

The results presented and discussed above suggest that the resistivities of both the mineralization and the barren rocks could vary considerably. As a consequence of the wide ranges of the resistivity values, it appears that a discrimination between mineralized and unmineralized rocks could not rely entirely on the resistivities of the rocks involved. From the comparison of the resistivity results with the I.P. results, it can be concluded that in general it appears that in the Vrechia area the mineralized rocks are characterised by lower resistivities than the unmineralized rocks.

F. <u>Conclusions</u>.

The geophysical studies presented above include both the investigation of I.P. parameters recorded during routine geophysical surveys and parameters which examine the variations of the shape of the transient decay curve. The routine surveys include also the resistivity values. From the results presented above it is concluded that the N.T.I., which is the routine I.P. parameter, is generally capable in discriminating between mineralized and unmineralized rocks. Comparing the responses obtained over the two mineralizations in the area, it is concluded that the main mineralization which is generally characterised by a higher grade than the eastern mineralization,

/ gave

gave higher N.T.I. responses. Regarding the factors which express the shape of the decay curve, it can be concluded that the A, B and P. factors attain higher values over the mineralization compared with values over the barren rocks. In addition, there is evidence that the B-factor attains lower values over the higher grade (main mineralization) than over the eastern one which has lower sulphur values. Some of the factors which characterise the $\log_e t$ plotted decay curves were proved to be capable to discriminate between mineralized and unmineralized rocks. These are the rates of decay curve, the potential value at which the two components separate, and the factors measuring the deviation of the one component from the other. Significantly different values over the mineralization as compared with those over unmineralized ground are also attained by the Bertin and Loeb's (Modified) functions which introduce the resistivity of the rocks. The present study included also an investigation of the resistivity values recorded along the geophysical lines. From these results it can be concluded that the resistivity values vary widely in both the mineralized and unmineralized rocks and it cannot give any definite assistance by itself in discriminating these two different types.

IV. GENERAL CONCLUSIONS

The Vrechia area which was the subject of the present Chapter is an example of sulphide mineralization occurring very low in the Lower Pillow Lavas, close to their boundary with the underlying Basal Group. The mineralization found in this area, although in some cases almost massive is of the replacement type formed in the lower levels of a fracture system which acted as a passage way of the mineralizing fluids. Certainly this type of environment is associated with lower grade mineralization of the disseminated type which could either occur as a halo or within the high grade, or even as a separate, but genetically related body of mineralization.

Under these geological conditions it is expected that the geophysical exploration will be capable, not only in locating the mineralized environment in general, but to discriminate between very closely spaced bodies of mineralization which are separated by relatively narrow areas of unmineralized rocks. In addition it is expected that some form of discrimination between grades of mineralization will be possible on the basis of these results. Indeed, the I.P. exploration carried out over the Vrechia area had these tasks. From the results presented and discussed in the previous sections, it can be concluded that the I.P. survey both in its routine application as well as with the assistance of the different parameters which describe the variation of the shape of the decay curve, is capable in descriminating between mineralized and unmineralized ground, particularly in the cases where two mineralized bodies are closely spaced. In particular the N.T.I. presented in the conventional pseudosectional plotting which gives directly the dipole from which each reading was recorded, can assist in locating with reasonable precision the location of the mineralized body together with indications of its relative depth under unmineralized rocks.

/ Regarding

Regarding the indications of the relative grade of the different bodies of mineralization occurring in the Vrechia area, the presently described investigation has proved that it is almost impossible to discriminate between the main mineralization in the area with grades up to 40% sulphur and the nearby eastern mineralization which has an average sulphur content not exceeding the 8%. The only parameter thatgives some indication that it attains different values over these two mineralizations is the true chargeability - the B-factor.

Together with the I.P. survey, there was an investigation of the resistivity results obtained along the same geophysical lines. This proved that the resistivity values of the two different rock types - mineralized and unmineralized could vary widely within ranges which overlap considerably with the consequence that the two types could not be discriminated between them with much certainty. In comparison with the I.P. results in general, this study demonstrated the superiority of the I.P. over the resistivity method.

CHAPTER EIGHT

ON THE GEOPHYSICAL RESULTS OF THE PETRA AREA

I. INTRODUCTION

The Petra area falls in the Kalavassos Mining Lease. Its exact location is shown in Fig. 1. A small tabularly to tubularly shaped sulphide body existed in the area and was exploited for its cupriferous pyrite by the ancients and later (1953-1962) by H.M.C. A recent study of this orebody based primarily on drilling and mining records, indicated that a dislocated part of it was likely to exist south of the exploited mineralization. For this purpose, the area was covered by an I.P. survey which revealed weak anomalies souteast of the known deposit. On the basis of these results the area was drilled with a number of vertical and inclined holes which proved the existence of mineralization.

The importance of this mineralization is that it is an example of an orebody occurring at the intersection of two major fault zones, one of them serving as feeder of the mineralizing fluids. This type of occurrence is common in the Cyprus deposits. For this, the new Petra mineralization, referred to below as the Petra mineralization, has been the subject of research. A total of five parallel lines were surveyed over this mineralization, striking at right angles to the direction of the fault zones. The purpose of the present Chapter is to investigate the I.P. method over this type of environment.

The Chapter begins with a description of the geology of the area followed by a description of the I.P. and Resistivity results together with a discussion on their interpretation. It closes with some conclusions on the applicability of these methods in this type of environment.

II. THE GEOLOGY OF THE PETRA AREA

The geological map of the area is shown in Fig. 167 together with the location of the geophysical lines. The southern part of the area is covered by sedimentary rocks of the Perapedhi and Lefkara formations. These are uncoformable over the volcanics with a shallow dip to the east. The volcanic rocks comprise Lower and Upper Pillow Lavas. The first are exposed in the west dipping almost vertically to the northeast. The Upper Pillow Lavas occupy most of the area and have a slightly shallower dip (60-65^{o}) again to the northeast. Lithologically the Lowers consist of andesitic flows and dykes, whereas the Uppers can be divided into a lower unit of limburgites and an upper unit of olivine basalts.

The main structural features of the area are the Mavridhia Fault and the Petra Faults. The first has a shallow dip, about 25^{o}, to the south trending almost east-west. This fault forms the boundary between the Upper and Lower Pillow Lavas, see Fig. 167. In places the fault is found by drilling to be propylitised with a sulphur content of up to 5%. On the surface it is seen in places to be gossanised. The second major structure, the Petra Fault, has a 50^{o} strike, dipping by 70^{o} to the east. This is the main fault zone which is responsible for the localization of the Petra mineralization. To the north this zone is exposed as evidenced by the elongated gossan. The partly exploited Petra orebody is located under this oxidised cap with a maximum width of 35 meters and a strike length of up to 300 meters. This orebody is believed to have been formed at the intersection of the Mavridhia and Petra Faults (Adamides 1976). It has a flattened pipe-like shape bounded on either side by clear-cut faults. The present horizontal attitude of the orebody is the result of the tilting of the lavas. Correcting for this tilting the orebody appears to have had an almost

/ vertical

vertical attitude during its formation. Thus, the top of the orebody is the present northeastern end of it, whereas the bottom is now in the southwest. In this direction the orebody was affected by a northwesterly trending fault and displaced to the southeast.

The southeastern extent of the mineralization discovered during the presently described I.P. survey, appears from both the drilling and the geophysical anomalies to have a southwest-northeast trend. Fig. 168 shows the geological sections along lines 2, 3 and 4. The South Petra mineralization is considered as being a tabularly shaped body with a vertical attitude. It is bound on both sides by Lower Pillow Lavas. Mineralogically it consists of low grade pyritic mineralization with very low copper values.

III. THE GEOPHYSICAL RESULTS

The area over the South Petra mineralization was covered by five parallel lines trending at 315°, i.e. at right angles to the direction of the Petra Fault. The line spacing was 50 meters. Readings on these lines were taken with the pole-dipole configuration at a spacing of 50 meters and with electrode separation n = 1 to 4. The period of the energising pulse was 8 secs at an on/off ratio of 1.0. The I.P. decay was recorded at four positions on the time axis: 55, 130, 280 and 580 msecs. from the time of interruption of the energizing current.

Below there is an analytical description of the N.T.I. and resistivity results obtained over this zone of mineralization, followed by a discussion on their applicability in this type of geological environment.

A. <u>The Normalised Time Integral</u>

1. Presentation of Results.

a. Line 1.

The results of this line are shown in Fig. 169. From the first integral value, Msec 1, there is evidence of an increase in the readings in the area corresponding to the receiving dipole 6-7. At the beginning of the line there is an increase in the responses particularly in the large dipole separations. The values decrease further along the line and increase in the 6-7 receiving dipole. Further, in the western half of the line the responses are generally low.

The second integral, Msec 2, demonstrates more clearly the same picture. There is a region of high values at the beginning of the line corresponding to the first three receiving dipoles 0-1, 1-2 and 2-3. After

/these

these dipoles, there is a decrease followed by a sharp increase in the 6-7 dipole. In the next dipoles the values drop again and remain so up to the end of the line.

A similar picture is shown by the third integral, Msec 3, with a region of high responses at the beginning of the line and on the 6-7 dipole, and a decrease in the rest of the line. It is interesting to note that the anomaly in the 6-7 dipole is not sharp as in the previous integral values, but extends also in the small dipole separation readings of the 5-6 receiving dipole.

The fourth integral, Msec 4, shows the same picture but in a more complicated form as demonstrated by the contours of the different values. The eastern half of the line shows generally high responses with the highest at the beginning, dipoles 0-1, 1-2 and 2-3, and also 6-7. The western half has generally low values.

b. Line 2.

The results of this line are illustrated in Fig. 170. The first integral shows two regions of high values. The first is at the beginning of the line concentrated in the large dipole separations (n = 3 and n = 4) of the dipoles from stake 0 to stake 3. The second anomaly corresponds to the receiving dipole 6-7. These two anomalous areas are separated by a region of lows in the small electrode separations. Further along the line the responses decrease gradually after the 7-8 dipole.

The second integral value, Msec 2, shows again the two anomalous areas at the beginning and middle of the line. The first anomaly appears to have higher responses in the 0-1 and 2-3 receiving dipoles. The second anomaly in the middle has its highest values in the 6-7 receiving dipole, and lower values in the adjacent dipoles. The two anomalies are separated by a

/ region

region of lower values which, however, are higher than those in the western end of the line.

The third integral value, Msec 3, shows again the same general picture, i.e. the two anomalies at the beginning and middle of the line, separated by an area of lower values. In the western part of the line the responses drop rather sharply to the lowest values.

The fourth integral, Msec 4, demonstrates the same picture. The first anomaly has higher responses in the 0-1 and 2-3 receiving dipoles. The second anomaly is centered about the 6-7 receiving dipole and is separated by the first by a region of low values. To the west the values drop rapidly to the lowest recorded along the line.

c. Line 3.

The results of this line are shown in Fig. 171. The first integral values, Msec 1, suggests three areas of high values. The first is at the beginning of the line recorded by the large electrode separation of the receiving dipoles from stakes 1 to 5. The second anomaly was recorded mainly by the 5-6 receiving dipole. After an interval due to the low readings of the 7-8 dipole in the n = 1 and 2 separations, there is an area of high values up to stake 11 dropping sharply to much lower values which remain so up to the end of the line.

In the second integral value, Msec 2, this picture is more clearly defined. The first anomaly is concentrated mainly in the 1-2 receiving dipole. The second anomaly was recorded mainly by the 5-6 and also the 6-7 receiving dipoles. The third area of high values corresponds to the dipoles 8-9 (n = 1-3), 9-10 (n = 1-2) and 10 to 12 (n = 1). The three anomalous areas are separated by lower values.

/ The

The third integral value, Msec 3, demonstrates the same picture more clearly. The three anomalous areas as described above are very clearly shown on the pseudosectional pattern.

The fourth integral value, Msec 4, recorded again the same picture as described in the previous integrals. The three areas of higher values are well defined on the pseudosectional plotting.

d. Line 4.

The results of this line are illustrated in Fig. 172. From the first integral, Msec 1, there is an indication of three anomalous areas as in the previous line. These are located at the beginning of the line at the receiving dipole 1-2, the middle of the line centered about dipole 6-7, and the third in the 9-10 and 10-11 dipoles.

The second integral values, Msec 2, give a better definition of the three anomalous areas. The first was recorded on the 1-2 and 2-3 receiving dipoles on their high electrode separations. The highest values are those of the first dipole (1-2). The second anomaly was recorded on the 6-7 dipole with slightly lower values in the adjacent dipoles. The third anomaly is separated from the second by the readings of the 8-9 receiving dipole. This anomaly is concentrated only in the small electrode separations of the dipoles from 9 to 11. It is worth noting that there is a more clear separation between the first and second anomaly than between the second and third. In the western end of the line the values are low.

The third integral, Msec 3, gives even a better definition of the three anomalies located in the same receiving dipoles as described above. An even better definition of the anomalies is demonstrated by the fourth integral. This shows a well defined anomaly at the beginning of the line concentrated in the large electrode separations particularly of the 1-2

/ dipole

dipole. The second anomaly, which is clearly separated from the first, is centered about the receiving dipole 6-7. The third anomaly extends in the region of stakes 10 to 12 and is concentrated only in the small electrode separations.

e. Line 5.

The results of this line are illustrated in Fig. 173. The first integral, Msec 1, suggests again as in the previous line three anomalous areas. The first at the beginning of the line in the large dipole separations, the second centered about the readings of the receiving dipole 7-8, and the third in the region of stakes 11 and 12.

This picture becomes more obvious in the second normalised integral, Msec 2. High values were recorded on the n = 3 and 4 separations of the dipoles 1-2, 2-3 and 3-4. Further along the line there is an area of low values up to the readings of dipole 6-7 which are followed by the second anomaly of the receiving dipole 7-8. In the following dipoles the readings decrease except for those corresponding to the small electrode separations of the dipoles 10-11, 11-12 and 12-13.

The third integral value, Msec 3, demonstrates the same picture as the other two integrals. The only difference is that the first anomaly seems to be affected by the transmitting pole position 7 and slightly 6. The second anomaly is again controlled mainly by the 7-8 receiving dipole. The third anomaly is observed again in the small dipole separations of the dipoles from stake 10 to 13.

The fourth integral value has a pattern similar to that of the third with the first anomaly again being controlled also by the transmitting pole 7.

/ 2. Discussion

2. Discussion.

From the results presented above, it is evident that in the area surveyed there are three different smaller areas with values higher than the background values. The first is at the beginning of the lines recorded by the first receiving dipoles particularly on lines 1 and 3, the second is at about the middle of all lines and the third is in the western half of lines 3, 4 and 5.

The first anomaly cannot be attributed to any known cause and will not be discussed further since it has not yet been drilled or investigated in any other way. For this the discussion will concentrate on the second and third anomalies. The second in particular was drilled thoroughly with vertical and inclined holes.

The second anomaly was detected along all five geophysical lines. In the first two lines the anomalous readings were mainly at the 6-7 receiving dipole. On line 3 almost equally anomalous readings were recorded on both the 5-6 and 6-7 receiver dipoles. On line 4 the anomaly was recorded by the 6-7 receiver dipole, but high values were also recorded on the 7-8 receiver dipole. On line 5 the anomalous readings were recorded only on the 7-8 receiver dipole.

It is worth examining the amplitude of the responses which were described above as anomalous. Examining all the N.T.I. results recorded in different time limits, it can be observed that the highest (anomalous) amplitude, does not usually exceed twice the value of the lowest N.T.I. recorded on the same line. In general the ratio of the anomalous responses to the non-anomalous can be considered as averaging about 2.0. This observation is important since it demonstrates clearly that mineralization of the type located at Petra and under similar geological conditions, must not be expected to be indicated by significantly high readings.

/ In connection

In connection with the above, it is also important to examine which of the four N.T.I. values recorded over Petra indicates more clearly the presence of mineralization. From the description of the geophysical results, the anomalies were in all cases evident from the first integral Msec 1. However, as a result of the increase of the values in the higher integrals, the pseudosectional plotting can be contoured in greater detail by introducing more contour values. It appears therefore that the higher integrals, and particularly the Msec 4, demonstrate more convincingly the anomaly, but this is not due to a higher ratio of the anomalous to non-anomalous readings, but due to the general increase of the integral values. In conclusion any of the four integrals recorded above can demonstrate the anomaly.

Another important feature of the Petra results which must be discussed, is the general shape of the anomaly as it appears on the pseudosectional plotting. This can be compared with the shape of the mineralization which is known from the drilling data, particularly for lines 2 and 3. From the geological sections of lines 2, 3 and 4 presented in Fig. 168, it can be concluded that the mineralized zone is located almost directly under stake 7 of line 2, and under stake 6 on lines 3 and 4. In addition the shape of the mineralization as expected from the geology of the area and also proved by the drilling results is sheet-like, standing almost vertical, trending approximately 50° NE, and having a maximum thickness of about 45 meters.

The anomaly of line 2 is centered about the readings of the receiver dipole 6-7. Lower values of about the same amplitude were recorded on the adjacent receiving dipoles. From the pseudosectional plottings (Fig. 170), it is evident that the anomaly becomes apparent from the 8-9 receiving dipole in the west, whereas in the east slightly higher values were recorded on the 4-5 receiving dipole. Further east, the anomaly is obscured from the anomalous readings at the beginning of the line. It is important to note that the anomaly was only recorded when the receiver was over the mineralization. For this, the anomaly is controlled by the 6-7 receiver dipole attaining therefore, as a result of the conventional plotting, a dip of 45° to the west. It is important to note that the "boomerang" shape is not apparent at all on the pseudosections of this line. If this was present, the first leg of the "boomerang" would be the 6-7 receiver dipole anomaly and the second would be on the 6 and 7 transmitting pole readings. Compared with the geological section (Fig. 168(a)), the mineralization is not directly under the 6-7 receiver dipole, but it appears to extend from the area of stake 6 more towards stake 5 to the east than towards stake 7 to the west. In other words the exact position of the mineralization cannot be pinpointed from the geophysical data. It is interesting to note that the depth at which the mineralization was encountered in the area of this line was only 40 meters.

The anomaly of line 3 is centered around stake 6. Anomalous values were recorded by the adjacent dipoles 6-7 and 5-6. Because of the proximity to the other anomalies, particularly the western one, it is difficult to establish the furthest dipole on either side from which the anomaly becomes apparent. In general, however, the anomaly on this line is controlled by the two receiving dipoles (5-6 and 6-7) and has an apparent dip of 45° to the west resulting of course from the pseudosectional plotting. The typical "boomerang" shape is not apparent on the section (Fig. 171). However, there is a small inflexion of the 250 contour value on the Msec 1 section caused by the n = 1 value of the transmitting pole 6. But this does not appear to show convincingly the double leg anomaly shape even in a highly asymmetric form. Compared with the geological section (Fig. 168(b)), the mineralization under this line is almost directly under stake 6 but it extends to the east towards stake 5. Drilling evidence suggests that there is no lateral extension to the west, at least in higher levels of the anomaly.

/ Returning

Returning to the N.T.I. results for this line, it is observed that the values recorded on the 5-6 receiving dipole are slightly higher than those of the 6-7 dipole. This could indicate a closer proximity of the 5-6 dipole to the mineralization than the 6-7 dipole. It was on this assumption that boreholes Δ410 and Δ413 were sunk on the locations shown in Fig. 168(b). Indeed they proved that the assumption was correct, but it was known beforehand that the target would be narrow (less than 50 meters). Therefore, in an area without any previous knowledge of the size of the conductor, its precise location, particularly if it is much narrower than the dipole spacing, is difficult to determine. The depth to the top of the mineralization under this line is estimated to vary between 60 and 65 meters.

The anomaly of line 4 (Fig. 172) is centered on the receiver dipole 6-7. High values on n = 2 and 3 were also recorded on the 7-8 receiving dipole. As with the previous line (3), it is difficult to ascertain which is the furthest dipole which begun to show values above background, because of the other anomalous areas. The shape of the anomaly is again simple, controlled by the receiver dipole readings and attaining therefore a 45^o dip to the west due to the conventional plotting which is employed. This line (4) shows very convincingly that it is a single leg anomaly, i.e. without high values on the transmitting pole readings when located over the mineralization. The geological section along this line (Fig. 168(c)), demonstrates that the mineralization is directly under stake 6. From the geometry of the mineralization shown in other lines, it can be assumed that it has a certain width extending therefore for some distance west of stake 6 (towards stake 7) and not much beyond the intersection of the inclined borehole Δ385. Irrespective of the above assumptions, the mineralization is around stake 6. Compared with the geophysical results (Fig. 172), it is observed that the anomaly is centered on dipole 6-7. Again this proves that the geophysical results are capable of showing the location

/ of the

of the mineralization, but with only a fair degree of accuracy. It is unfortunate that there are no drilling results between the 7-8 receiving dipole which could explain the high values on the n = 2 and n = 3 readings of this dipole. However, from the geology of Petra mineralization, there is no reason to believe that this will have a greater width in this area extending thus well under the 7-8 dipole area. The depth to the top of the mineralization under this line is about 90 meters.

Finally, it is worth noting that the amplitudes of the anomalous readings do not appear to depend greatly on the depth of the mineralization. The maximum amplitudes recorded on line 4 where the mineralization is at a depth of 90 meters, was almost equal to the corresponding values on line 2 where the mineralization is only at a depth of 40 meters.

The third anomalous area was recorded only on lines 3, 4 and 5. This anomaly was not drilled after the presently described I.P. survey. However, from past drilling it is known that the Mavridhia Fault is in places strongly propylitised with sulphur values up to 5%. Indeed, boreholes Δ3, Δ5, Δ8, Δ163 and Δ234, have all proved the existence of sulphide containing propylite up to 20 meters in thickness (Δ3), at the boundary between the U.P.L. and the L.P.L., i.e. the Mavridhia Fault. (The depths at which this mineralization was encountered in these boreholes is noted on Figs 167 and 168).

The third anomaly on line 3 appears in the east from the receiving dipole 8-9 where it was recorded on both n = 1 and n = 2. Similarly, amplitudes above 300 on the Msec 4 integral (Fig. 171) were recorded on the adjacent dipole 9-10. In the next two dipoles (10-11, 11-12) equally high values were recorded on the n = 1 dipole separation only. Further along the line the N.T.I. amplitudes decrease.

The same anomaly on line 4 extends from the receiving dipole 9-10 in the east, recorded on both n = 1 and 2. This also applies for the 10-11

/ receiving

receiving dipole. But on the 11-12, amplitudes above 300 (see Fig.172) on the Msec 4 integral were only recorded on the n = 1 separation. Further west beyond stake 12 the amplitudes decrease.

On line 5 the anomaly starts from dipole 10-11 in the east with amplitudes above 300 in the Msec 4 integral up to n = 2. In the next receiving dipole an equally valued amplitude was only recorded in the n = 1 separation. Further west beyond stake 12 the amplitudes decrease.

In general, the N.T.I. amplitudes of these anomalies are low just over two times the value of the background. Compared with the second anomaly it is observed that the responses of the third anomaly are generally lower.

As it was stated above, this anomalous area is attributed to the presence of sulphide mineralization along the plane of the Mavridhia Fault which exists at depth in the area. As it is shown on Figs 167 and 168, this fault has a shallow dip to the south, and in the area surveyed geophysically it underlains lines 3, 4 and 5. The anomaly of line 3 (Fig. 171) extends from dipole 8-9 to 11-12. This appears to be in agreement with the geology. The mineralized fault becomes very shallow without much evidence of mineralization along its outcrop in the area of stakes 12 to 15, except for a very thin layer of gossan. Borehole Δ8 has intersected at a depth of 57 meters 11 meters of mineralization. The shape of the anomaly appears to be in agreement with the geology in the fact that the mineralization occurs in depth to the east, and becomes shallow to the west. The anomaly of line 4 extends mainly from dipole 9-10 up to 11-12 and from the drilling data it is known that the Mavridhia Fault is mineralized from borehole Δ234 to borehole Δ5. No signs of mineralization were observed in borehole Δ16. The anomaly of line 5 indicates that the mineralization is limited in its lateral extend in this area and is primarily in the region of stakes 10 to 12. Boreholes Δ218 and Δ271 have found no mineralization when intersected

/ the fault

the fault, suggesting a thinning out of the propylitic concentration in this area.

3. Conclusions.

From the preceding discussion it can be concluded that the two mineralized bodies in this area responded positively in the I.P. survey. The Petra mineralization, second (central) anomaly, which is a sheet-like body about 50 meters thick, standing almost vertical, gave anomalous I.P. results which demonstrated convincingly its existence. In general the amplitudes of the anomalous values are low not exceeding by three times the background amplitudes. The shape of the anomalies on the pseudosectional convention of plotting appear to be single-leged, dipping to the west as a result of this convention. The anomalies are centered about the receiver dipole readings and they are located over those dipoles which are over or closer to the mineralization. It is important to note that only the receiver readings taken across the dipoles which straddle or are the closest to the mineralization, show anomalous results. This leads to the important aspect of the location of the mineralized body with respect to the geophysical grid. From the preceding discussion it can be concluded that the cause of the anomalous responses must be looked for under the area of the receiving dipole which gave the highest values, and it must not be excluded from extending for some distance into adjacent dipoles. In the case that two adjacent dipoles give approximately the same values, then the cause for the anomaly must be looked for in the area of the common pole. Another conclusion which can be drawn, is that at least for the geological conditions in the area in question there is no significant decrease of the amplitude of the responses with the increase in depth of the mineralization, at least in the range of depths this occurs at Petra.

The mineralization which is found locally along the plane of the

/Mavridhia

Mavridhia Fault, was also demonstrated convincingly on the I.P. results. The anomalous responses are generally low and exceeding by three times the background amplitudes. The anomaly is broad and concentrated on the small dipole separations, verifying the fact that the mineralization itself is broad and not extending in depth.

B. <u>The Resistivity Results</u>

1. Presentation of Results.

a. Line 1.

The resistivity results of this line are illustrated on Fig. 174(a). The resistivity ($\rho/2\pi$) values are generally low except at the center of the line, centered around stake 7. The background values are below 2.0 x 2π, whereas in the anomalous area they have a maximum of 11.6 x 2π ohm-meters. It is interesting to note that this anomaly seems to be concentric about a point near stake 7 and does not appear to be controlled in any way by a receiver dipole or a transmitter pole as in the N.T.I. anomalies described above. There is also an increase in the resistivity values at the end of the line.

b. Line 2.

The resistivity results of this line are illustrated on Fig. 174(b). Low values almost generally below 2.0 x 2π ohm-meters were recorded on both ends of the line with a resistivity high occupying its central part centered about dipole 8-7. The anomaly appears to be roughly concentric with most of the high values concentrated on the small dipole separations, except for one case on the n = 4 dipole separation. There does not appear to be any dependance of the resistivity anomaly on the receiving dipoles or the transmitting poles.

c. Line 3.

The resistivity results of this line are illustrated on Fig. 174(c). The main feature of this line is a broad area of high values centered about the n = 1 separation near stake 9 and extending up to stake 6 to the east, and stake 12 to the west. As with the previous lines, the anomalous readings are concentrated in the n = 1 dipole separation decreasing towards the higher values. To the east the resistivity values drop below 2.0 x 2π ohm-meters but increase slightly above this value on the 1-2 receiver dipole readings. West of the main anomaly the resistivity values remain above 2.0 x 2π ohm-meters up to the last receiver dipole reading where they drop just below 2.0 x 2π ohm-meters. As with the previous lines, the central anomaly is not controlled by the receiver dipole readings as with the N.T.I. results.

d. Line 4.

The resistivity results of this line are illustrated on Fig. 175(a). The pseudosection can be divided into two parts. The eastern part with values generally below 2.0 x 2π ohm-meters and the western part with higher values. The highest values appear again on the n = 1 dipole separations and decrease in the higher separations.

e. Line 5.

The resistivity results for this line are illustrated on Fig. 175(b). The pseudosectional plot can again be divided into two parts: an eastern one with generally low values, below 2.0 x 2π, and a western one with generally higher values, above 2.0 x 2π ohm-meters. As before, the anomaly has its highest values on the small dipole separations. From the contours it appears that the highest values were recorded on the 11-12 receiver dipole. In addition, it is observed from the 3.0 contour that the 7-8 receiver dipole

/ also

also gave higher values than expected from the 11-12 centered anomalous pattern.

2. Discussion.

From the results presented above it can be directly stated that the resistivity values failed to show the presence of the Petra mineralization in this area. For this it is considered pertinent to compare the resistivity with the I.P. results and also the drilling data.

On line 1 the resistivity anomaly is narrow and can be said to coincide with the N.T.I. results of this line (Fig. 169),except from the fact that the high N.T.I. does not concentrate only on the small dipole separations. Compared with the geology-drilling results, it is observed that the resistivity high coincides with the mineralization along this line. From all the boreholes close to this line (1), see Fig. 167, only boreholes Δ74 and Δ418 encountered mineralization.

Line 2 also shows a relatively limited resistivity anomaly which does not appear to coincide well with the N.T.I. results (Fig. 170). The difference between the two patterns is that the N.T.I. anomalous values are centered about the dipole 6-7 and extend up to n = 4,whereas on resistivity the anomalous values are the highest on the 7-8 and remain mostly on the small dipole separation. Compared with the geology it is observed that the Petra mineralization in this area is considered to be centered about stake 6. In this case the resistivity high does not coincide with the mineralization.

The N.T.I. pattern of line 3 (Fig. 171) shows for the first time the second I.P. anomaly,indicated by high values in the small dipole separation centered about stake 10. On the resistivity results of the same line the resistivity anomaly is broader than in the previous lines and with lower values. It appears, therefore, that the resistivity anomaly recorded on

/ this

this line is caused by the same effect which produces the N.T.I. anomalous values in the region of stake 10 (Fig. 171). The N.T.I. anomaly and the mineralization itself are located near stake 6. However, in the resistivity results there is no significant change around this stake.

Comparing the resistivity and the N.T.I. results of line 4, it is evident that the resistivity high can be correlated with the high N.T.I. values recorded in the region of stake 11 (see Fig. 172). In the region of the N.T.I. anomaly caused by the mineralization (stakes 6-7) there appears a small inflection in the 3.0 x 2π contour value which turns to include the 7-8 receiver dipole readings. This could indicate an increase in the resistivity values in this area probably caused by the Petra mineralization, which in this area is at a depth of 90 meters.

Lastly a comparison of the results of line 5, shows again a correlation between the resistivity high and the N.T.I. values in the 11-12 dipole region (Fig. 173). The only indication of the N.T.I. anomaly on the 7-8 receiver dipole, is the broad inflexion of the 3.0 x 2π contour value which indicates higher values than expected in the 7-8 receiver dipole.

From the geology of the area it is known that there are two different mineralizations in this area. The first is the Petra mineralization and the second is the mineralization along the plane of the Mavridhia Fault. The only case where there was described a definite coincidence between the I.P. and resistivity results was in line 1 where the Mavridhia Fault does not overlie the Petra mineralization. Line 2 begins to show a broader resistivity anomaly compared with the I.P. anomaly which does not extend beyond the 8-9 receiver dipole. This anomaly is attributed to the Mavridhia Fault mineralization which, however, does not extend beyond stake 9 as confirmed by borehole Δ232. The resistivity high in the n = 4 dipole separation of the 6-7 receiver dipole could probably be attributed to the Petra mineralization

/ which

which in this area occurs in depth under this dipole. On line 3 the resistivity anomaly becomes broad and appears to mask any significant responses from the Petra mineralization. As it was indicated by boreholes in this area, the Mavridhia Fault is mineralized with up to 5 meters of 2% sulphur over the Petra mineralization (boreholes Δ413 etc. Fig. 168(b)). Borehole Δ383 found no mineralization along this plane, but further west the fault plane is well mineralized as it was described above. On line 4 the resistivity anomaly is mainly in the western half of the line caused by the extensive mineralization along the Mavridhia Fault plane in this area. Borehole Δ414 also intersected 3 meters of mineralization with 5% sulphur along the fault plane but this appears to be limited at least to the east from the negative results of borehole Δ385, see Fig. 168(c). As it was stated earlier the small inflexion in the 3.0 x 2π contour corresponding to the 7-8 receiver dipole results along this line could correspond to the Petra mineralization. On line 5 the resistivity anomaly in the western half of the line appears to have a smaller extent than in the previous lines (3 and 4) and this is in agreement with the I.P. results. Boreholes Δ203 and Δ218 did not intersect any mineralization along the Mavridhia Fault plane. This suggests that the increase in the resistivity values in the readings of the 7-8 receiving dipole can be attributed to the Petra mineralization, whereas the high resistivity values in the vicinity of the 11-12 dipole are due to the Mavridhia Fault mineralization.

3. Conclusions.

From the preceding discussion it can be concluded that both the mineralizations in this area, the Petra and the Mavridhia Fault mineralizations are characterised by high resistivity values. The Petra mineralization was clearly indicated by the resistivity results only on line 1 and possibly 5. In the rest of the lines it was masked by the overlying Mavridhia

/ Fault

Fault mineralization. On lines 2 and possibly 4 this masking was partial but on line 3 the Petra mineralization was totally masked out by the extensive, low dipping and relatively thin layer of mineralization.

C. Conclusions

The geophysical survey presented and discussed above represents an example of a routine I.P. and Resistivity survey carried out for sulphide mineralization. The targets in this area were two different bodies of mineralization with genetic relationship but disposed in different ways. The first being vertical and relatively thick, whereas the second dips gently at a shallower depth, but much thinner. The grade of the two mineralizations on the average was about the same. An important feature of this geological setting was the fact that the second mineralization was in places overlain by the first. The I.P. survey demonstrated the existence of these two mineralizations and succeeded to show distinctive and convincing I.P. anomalies which proved not only the existence of the two mineralizations in depth, but also their shapes and their geometrical dispositions. The I.P. anomalies demonstrated with relative accuracy the position of the vertical mineralization and also suggested its extent in depth. With regard to the shallow seated and low dipping second mineralization, the I.P. survey was equally successful. The Resistivity survey over this geological setting also demonstrated the mineralization, in fact as resistive and not conductive, in both cases. However, it failed to discriminate between the two bodies as it responded even to a small thickness of the second mineralization which overlies the first (vertical) mineralization.

/ IV. GENERAL

IV. GENERAL CONCLUSIONS

One of the most important environments which favour ore deposition is the intersection of two major fault structures,one of them representing the feeder of the mineralizing fluids. Typical examples of this type of deposits are found in the Kalavassos Mining area where the role of the feeder was played by the Mavridhia Fault, the most prominent tectonic feature in the area. This supplied the necessary solutions which formed pyritic deposits,in some cases of significant size and grade,in four different environments all related with N.E. trending structural features. These are the Mavri Sykia - Landaria zone, the Mavridhia zone, the Mousoulos Orebody (Fig. 1),and the Petra zone described in this Chapter. From this it is understood that the Petra type environment is of paramount importance in mineral exploration in Cyprus. In fact the purpose of this Chapter was to investigate the applicability of the I.P. method under these conditions, i.e. whether the method and particularly as applied in routine exploration (without recording the transient curves) is capable of locating concentrations of mineralization displayed in different attitudes along a particular mineralized fault plane (feeder fault). Indeed,the results presented in this Chapter proved that the I.P. survey succeeded in discriminating between the Mavridhia Fault mineralization which represents the feeder fault, and the Petra mineralization which occurred at some point along the strike of the Mavridhia Fault. From the shapes of the I.P. anomalies it was possible not only to recognise the existence of mineralization with a different attitude, but also to locate the concentration with relative accuracy and to recognise variations in the concentrations of mineralization along the feeder fault itself. It is important to note that the grades of mineralization involved in both cases were not high, and what was called above "mineralization" was sometimes propylitised (altered) lava with pyritic

/ impregnations

impregnations averaging 1% sulphur. Together with the I.P. survey the research project included an investigation of the Resistivity method over this environment. The results presented and discussed above demonstrated that this method is certainly capable to locate this type of mineralization, but it cannot discriminate between the two different dispositions when even a small thickness of low grade mineralization in the feeder fault overlies the differently disposed concentration. This effect demonstrated the superiority of the I.P. method over the Resistivity method in mineral exploration in this type of geological environment.

CHAPTER NINE

ON THE GEOPHYSICAL RESULTS OF THE KAMPIA AREA

I. INTRODUCTION

The Kambia area presents a typical example of a mineralized zone occurring in the Lower Pillow Lava terrain. Its location is shown in Fig. 1. This zone, which in the region of the I.P. test is narrow, has been responsible for the formation of the nearby Kambia Orebody. This is a two-million tons orebody which was partly exploited in 1952-1958 by opencast methods. The purpose of the presently described research project was to investigate the I.P. responses over this type of occurrence which as mentioned in earlier Chapters, is important in mineral exploration in Cyprus.

The Chapter begins with a description of the geology of the area with some attention to the nearby Kambia Pit which demonstrates a typical horst-type emplacement. This is followed by the presentation of the geophysical results recorded over the area which include the M.T.I. and the resistivity values. There is a discussion on the results of each parameter as compared with the geological information on the area based on the drilling results over the geophysical targets.

II. THE GEOLOGY OF THE KAMBIA AREA

The geology of the Kambia area is illustrated in Fig. 176. This shows the Kambia Orebody in the southeast being in line with an elongated gossan which occurs to the northwest of the orebody. The background consists of Lower Pillow Lavas with andesitic lava flows and intrusions. To the north of the mineralized zone there is a limited development of picrite basalts of the Upper Pillow Lava Series.

Two different grades of mineralization may be distinguished in the Kambia Orebody. The first type includes the weakly mineralized stockwork type mineralization consisting of highly brecciated rocks impregnated with pyrite, together with sulphide and silica veining between the breccias. The second is the strongly mineralized type which itself may be divided into the medium grade mineralization, similar to the stockwork type but with more intensive brecciation, stronger impregnations and sulphide veining, and the massive pyritic ore.

The shape of the orebody has all the typical characteristics of a horst type structure as described in Chapter Two. Fig. 177 illustrates two sections across the orebody. Both show that the orebody is bounded by two major faults. These faults are very sharp and are clearly seen on the pit walls.

The southwestern boundary fault of the Kambia Orebody appears to extend to the northwest for a distance of about 100 meters beyond the pit. Further northwest, about 200 meters from this point (see Fig. 176), there is a strong and elongated gossan which is clearly defined between two parallel faults. In the area between this gossan and the extension of the southeastern fault there are two small patches of gossanised material appearing through the cultivated fields in that area. For this it was suspected that the

Kambia Orebody structure extends to the northwest, reappearing on the strong gossan 200 meters to the northwest and concealed in the space between them. As it will be demonstrated in the next section strong geophysical anomalies were recorded in the area northwest of the Kambia Orebody. On these anomalies a total of eight boreholes were sunk. The first two boreholes were drilled with the purpose of investigating the geophysical anomalies and in addition to investigate the hypothesis that the southeastern boundary fault was a post mineralization structure which cut and displaced laterally to the northeast the Kambia orebody. Both these boreholes, KB 32 and KB 33 (Fig. 176) were negative. Their logs are shown on Fig. 178. All the other boreholes were drilled solely on the basis of the geophysical results and all of them intersected mineralization. Their location and logs are shown on Figs 176 and 178 respectively.

From the drilling results it was proved that the Kambia mineralized zone indeed extends to the northwest covered only by a thin layer of soil of about two meters thick. The grade of this mineralization in sulphur varies from a few percent to values up to 30%. It is generally considered as averaging about 10%. The mineralization has also some copper and zinc values.

III. THE GEOPHYSICAL RESULTS

The geophysical survey consisted of nine parallel lines crossing at right angles the suspected mineralized zone. The layout of these lines is shown on the geological map of Fig. 176. The line spacing was 50 meters with an equal electrode spacing. The survey was carried out with the pole-dipole configuration and readings were taken at the n = 1-4 dipole separations. The period of the energizing current was 8 secs at an on/off ratio equal to unity. The I.P. transient was recorded at four points along the time axis, namely at 55, 130, 280 and 580 msecs. The geophysical parameters recorded and studied are the N.T.I. and resistivity. These results are presented and discussed below.

A. The Normalised Time Integral

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig. 179. This line was surveyed only up to stake 8 because of the existence of dumps from the opencast mining along its remaining part. From the first integral (Msec 1) it is evident that anomalous readings were recorded on the 4-5 dipole position. This anomalous pattern is more pronounced in the higher integrals. It is interesting to note that the readings corresponding to the transmitting pole position 5 are higher than the background values. Together with the receiving dipole anomaly it forms an asymmetrical "boomerang" shaped anomaly, much stronger on the receiver dipole readings. Another important feature on this anomaly is that the amplitude of the N.T.I. decreases with increasing dipole separation on both the receiver and transmitter anomalies.

/ b. Line

b. Line 2.

The results for this line are illustrated in Fig. 180. The presence of an anomalous pattern is evident from the first integral and is demonstrated more clearly in the higher integrals. The anomalous readings were taken on the receiving dipole 4-5 and less strongly on the 5-6. It is interesting to note that some increase in the integral values is evident on the readings taken with the transmitting pole at 5. This is more evident on the Msec 2 integral pseudosection. The resulting anomalous pattern is again one of a "boomerang" shape but with a much stronger value on the receiver dipole readings.

c. Line 3.

The results for this line are illustrated in Fig. 181. The presence of an anomalous pattern is evident again from the first pseudosectional plotting. The anomalous values were recorded primarily on the 4-5 receiver dipole. Slightly lower values but still higher than background were recorded on the 5-6 receiving dipole. This anomalous pattern is more pronounced in the higher integral values. Another feature of this pattern are the higher than background values recorded on all separations of the transmitting pole 5. This is evident on the last three normalised integral values. In general the anomaly is controlled by the 4-5 receiver dipole readings.

d. Line 4.

The results for this line are illustrated in Fig. 182. The presence of anomalous readings is evident from the pseudosectional pattern on the first integral. The anomaly was recorded by the receiver dipoles 4-5 and 3-4. In all the pseudosectional patterns it is also evident that the transmitting pole 4 gave rise to slightly higher values than background,

/ producing

producing therefore a "boomerang" shaped anomaly which, however, is much stronger on the side of the receiver dipoles.

e. Line 5.

The results for this line are illustrated in Fig. 183. The pseudo-sectional patterns of all integrals show very clearly an asymmetrical "boomerang" shaped anomaly. The strong leg of this anomaly corresponds to the receiver dipole 4-5 and to a lesser degree dipole 3-4, whereas the weak leg corresponds to the transmitting pole 4. It is worth noting that the readings which on the pseudosectional conventions of plotting occur directly under stake 4,have values which are much lower than the background values recorded in the rest part of the line. From the Msec 1 integral it appears that these low values are controlled by the receiver dipoles.

f. Line 6.

The results for this line are illustrated in Fig. 184. The pseudo-sectional patterns show in all integrals an asymmetrical "boomerang" shaped anomaly. The strong leg of this anomaly corresponds to the 4-5 and 3-4 receiver dipole and the other leg to the transmitting pole 4. Between these two legs the readings attain very low values. The magnitudes of these values seem to decrease in the higher integrals. This is particularly evident in the Msec 4 where it is also obvious that the low responses are controlled by the receiving dipoles.

g. Line 7.

The results for this line are illustrated in Fig. 185. The pseudo-sectional patterns of all integrals show that the 3-4 receiving dipole recorded anomalous values in all dipole separations. Another area with slightly higher values than background was recorded in the region of stakes 6 to 8. This anomaly is more apparent in the Msec 3 and Msec 4 plottings.

/ h. Line

h. Line 8.

The results for this line are illustrated in Fig. 186. A weak anomaly was recorded on the 2-3 receiver dipole. This becomes evident in the high integral values. A second area of slightly anomalous values, again more apparent on the Msec 3 and Msec 4, was recorded centered about the dipole 7-8.

i. Line 9.

The results for this line are illustrated in Fig. 187. A weak I.P. anomaly appears from the first integral values becoming clearer in the higher integrals. This is centered about the receiver dipole 2-3. Some high values were also recorded in the northeastern half of the line, the most prominent being on the 9-10 receiver dipole.

2. Discussion.

The results presented above demonstrated that the I.P. survey carried out in the area delimited well defined anomalies on all lines. Almost all these anomalies were subsequently drilled proving that indeed mineralization is located where it was suspected to exist. However, a number of important points regarding the location of the anomalies with respect to mineralization call for discussion.

The geological study of the area carried out before the geophysical survey proved that at least over lines 6 and 7 and possibly 5, there existed a mineralized body with very steep dip - perhaps vertical, and with a narrow width. This was indicated by the gossan in that area. The first indication which was presented by the geophysical survey was that this mineralization extends between the gossan and the Kambia orebody. Further it proved that it terminates on the surface in the area between lines 7 and 8

/ and is

and is displaced to the south. The termination was also suspected from the geology. The boreholes which were subsequently sunk, namely boreholes KB 34 to KB 39 (Figs 176 and 178) verified the above assumption based on the geophysical results. From the negative results of borehole KB 32 and KB 33 and the small thickness of mineralization encountered on borehole KB 36, as well as the shape of the exposed mineralization - the gossan, it was proved that the mineralized body had a narrow extent and an almost vertical dip. The average grade of this mineralization in sulphur was found to be about 10%. In some places it had grades of over 20% sulphur.

It is interesting to examine now the I.P. responses of this vertically standing and narrow body of mineralization with respect to its actual location both vertically and laterally. From the results presented above it is possible to distinguish three types of geophysical anomalies. The first type includes those anomalies in which anomalous values were recorded primarily on a single receiving dipole. Example of such anomalies are those of lines 7, 8 and 9 (Figs. 185, 186 and 187 respectively). The second type represents those anomalies which were recorded primarily on a single receiving dipole and one transmitting pole (one of the two of the dipole), exemplified by lines 1 and 3 (Figs 179 and 181 respectively). The third type includes those anomalies which were recorded on two adjacent receiving dipoles and one transmitting pole, always the common pole of the two dipoles. Examples of these anomalies are lines 2, 4, 5 and 6 (Figs 180, 182, 183 and 184 respectively). Certainly these different types of anomalies are not accidental but they are related with the position of the mineralized body with respect to the geophysical grid.

The first type of anomalies were recorded on lines 7, 8 and 9. Examining the extent of the mineralization on line 7 it is observed that this is located between stakes 3 and 4 none of them being located over the mineralization. The anomalies of lines 8 and 9 are similar but the mineralization

/ is not

is not exposed and not even looked for by drilling after its lateral displacement to the south. Somewhat similar to this first type of anomaly is the second type represented by lines 1 and 3. These anomalies were drilled on stakes 5 which on each line gave anomalous values on the transmitting poles. These were boreholes KB 35 and KB 36. From the drilling results which were in both cases positive, it was proved that these points were underlain by mineralization at shallow depth. Borehole KB 32 which was located between stakes 4 and 5 was negative indicating that the mineralization does not extend much along this dipole although it has shown anomalous values. Borehole KB 36 proved that the mineralization does not extend much beyond stake 5. From the above data, this type of anomaly is interpreted as being caused by a mineralized body which extends at most of its width between a certain dipole, that giving the anomalous values, and one of the poles being right over the mineralization. This is the pole which gave the anomalous readings when the ground was energised through it. Compared with the first type of anomaly it is observed that the first type of anomaly appears to correspond to mineralization located entirely within a dipole.

The third type of I.P. anomaly is that of lines 2, 4, 5 and 6 in which two adjacent dipoles gave almost equally anomalous responses. The anomaly of line 2 was not drilled. But those of lines 4, 5 and 6 were drilled, the boreholes being numbered KB 34, KB 37 and KB 38. This type of anomaly is interpreted as being caused by mineralization which extends partly on one dipole and partly in the other. The common stake when used as a transmitting pole gives anomalous values. It is expected that the dipole which encloses the greatest extent of mineralization is likely to record the highest I.P. responses. However, this was not proved so far on the presently described targets.

A question which can be raised regarding the anomalous values recorded

/by the

by the transmitting pole is whether these were recorded because the pole overlies the mineralization, or the mineralization itself is very close to the surface. There is no sufficient information to answer this question at least in the area described in this Chapter.

An important point which was proved by both the I.P. anomalies and the mineralization regarding the representation of results in pseudosectional plottings, is the fact that the anomalous results were mainly recorded when the receiver dipole was in some relationship with the mineralization. And on a pseudosectional plot this is demonstrated by the fact that the contoured patterns are always inclined and controlled by the receiving dipoles which are closer to the mineralization. An analogous phenomenon is observed for the transmitting pole anomalous readings.

Another important point which was observed on some lines and particularly line 6, is that when the receiver dipole was on the one side of the mineralization and the transmitting on the other, none of them being over it, the I.P. responses were very low indeed much lower than those of the barren rocks. On the pseudosectional plotting this phenomenon is demonstrated by the "boomerang" shaped anomalous pattern, the concave part of which has these low values.

3. Conclusions.

From the preceding discussion it can be concluded that the I.P. survey carried out over the area to the northwest of the Kambia Orebody, detected successfully the extension of the mineralized fracture zone associated with that body into that area and its connection with a nearby gossan. The I.P. anomalies were very well defined and sharp and were mainly recorded on the receiver dipoles. On drilling these anomalies it appeared that the mineralized body is narrow and almost vertically standing.

/ Three

Three different shapes of anomalies were recognized each one corresponding to a certain relationship of the mineralization with the location of the receiving and transmitting poles. From the results presented and discussed above it can be concluded that when a narrow body of mineralization occurs within a certain dipole, significantly high I.P. values are recorded only on that dipole. If the mineralization extends over one of the poles of the dipole, then high readings are recorded on the two dipoles involved according to the degree of extent of this mineralization, and also on the transmitting pole corresponding to the position over the mineralization. There is not sufficient information from this area that the transmitting pole can give high readings when the mineralization is not close to the surface.

Another conclusion which can be drawn from these results is the usefulness of the pseudosectional convention of plotting which demonstrates clearly from which receiving dipole or transmitting pole each reading was recorded.

B. The Resistivity Results

1. Presentation of Results.

a. Line 1.

The results for this line are illustrated in Fig. 188(a). This shows an increase in the resistivity values on the 5-6 receiver dipole with values of $\rho/2\pi$ up to 3.15 ohm-meters, whereas the barren rocks are generally about 1.25 ohm-meters. A comparison with the I.P. results (Fig. 179) shows that the two anomalies do not coincide, the I.P. anomaly was recorded with very strong values on the 4-5 receiver dipole together with a significant increase in the values of the transmitting pole 5.

/ b. Line 2.

b. Line 2.

The results for this line are illustrated on Fig. 188(b). This line shows no significant variations in the resistivity values. In general the background values are slightly higher than the previous line. These values increase in the northeastern half of the line, except for an area of lower values centered about the 7-8 receiver dipole. Compared with the I.P. results (Fig. 180) this resistivity section does not show any similarity with the I.P. pattern which has an area of anomalous values centered on the 4-5 and 5-6 receiver dipoles.

c. Line 3.

The results for this line are illustrated on Fig. 188(c). The resistivity values are generally low. The most significant feature of the pseudosection is the low region recorded on the 7-8 receiver dipole which is surrounded on both sides by values generally above the background resistivity values. Compared with the I.P. pattern (Fig. 181) there appears to be no reflection of the I.P. anomaly recorded on the 4-5 receiver dipole on the resistivity results.

d. Line 4.

The results for this line are illustrated on Fig. 189(a). The main feature of this pseudosection is a resistivity high area centered about the receiver dipole 3-4, and to a lesser extent 4-5. To the northeast of this area in the region of stake 8 there is a well defined resistivity low followed by another region of slightly higher resistivity values at the end of the line. A comparison with the I.P. results along the same line (Fig. 182) indicates that there is a certain correspondence between the I.P. anomaly centered on the receiver dipoles 3-4 and 4-5 and the resistivity high about the 3-4 receiver dipole.

/ e. Line

e. Line 5.

The results for this line are illustrated on Fig. 189(b). This line demonstrates a slight resistivity increase about the 3-4 and 4-5 receiver dipoles. Compared with the I.P. results it appears that the two anomalies do not coincide exactly. The I.P. anomaly was recorded mainly on the 4-5 receiver dipole. However, anomalous values were also recorded on the 3-4 dipole.

f. Line 6.

The results for this line are illustrated on Fig. 189(c). This shows a more complicated pattern than those of the previous lines. It appears that the receiver dipoles 3-4 and 5-6 recorded high resistivity values, whereas the 4-5 and 6-7 dipoles recorded low resistivity values. A comparison with Fig. 184 which shows the I.P. results over this line, indicates that the highest I.P. responses were recorded on the 4-5 dipole. Anomalous responses were also recorded on the 3-4 receiver dipole and also on the transmitting pole 4.

g. Line 7.

The results for this line are illustrated on Fig. 190(a). This line shows a relatively smooth pattern. The main features being a region of slightly lower values than elsewhere along the line, located about the receiver dipoles 3-4 and 4-5. Another feature is a slight increase in the resistivity values in the area of the section immediately west of this low which is mainly defined by a single reading. A comparison with the I.P. results of the same line (Fig. 185), which shows the I.P. anomaly centered on the 3-4 receiver dipole, suggests a poor correspondance of the I.P. high values with the resistivity low.

/ h. Line

h. Line 8.

The results for this line are illustrated on Fig. 190(b). The main feature on this pseudosection is an increase in the resistivity values centered about the receiver dipole 2-3. Another feature is a resistivity low area recorded on the 7-8 dipole. Compared with the I.P. results of this line (Fig. 186), it is observed that the resistivity high on the 2-3 dipole coincides with an I.P. anomaly recorded on the same dipole. Further, on the 7-8 receiver dipole, where there is a decrease in the resistivity values, there is a slight increase in the I.P. responses.

i. Line 9.

The results for this line are illustrated on Fig. 190(c). This pseudosection shows an increase in the 3-4 receiver dipole followed by a decrease in the next dipole (2-3). Further south under the region of stake 3 the resistivity values are very low. Compared with the I.P. results (Fig. 187) it is observed that there is a correspondence of the I.P. high values with the resistivity lows of the 2-3 receiver dipole. The resistivity low under stake 3 does not correspond to any significant variations on the I.P. results.

2. Discussion.

From the results presented above it appears that the resistivity values ($\rho/2\pi$) recorded in the area are generally low. Slight variations were observed in some parts of the lines which in some cases coincided with the mineralization known to exist in that area. These variations are either slight increases or decreases of the background values. Below there will be a short discussion on the significance of these variations in the resistivity values.

/ From

From the results over the different lines it appears that the resistivity values of the country rocks varies about a value of 1.5 x 2π ohm-meters. The maximum and minimum values recorded over the mineralization or in neighbouring dipoles were 3.54 and 1.09 x 2π ohm-meters. From these figures it is evident that the variations are indeed very low. However, very slight increases were observed on the resistivity values of some lines on dipoles which demonstrated high I.P. values and were proved to be related to mineralization, or adjacent to these. These resistivity highs are those recorded on the 5-6 dipole of line 1, the 3-4 and 5-6 dipoles of lines 4 and 5, and the 3-4 dipole of line 6. Higher resistivities were also recorded on the 2-3 and 1-2 receiver dipoles of line 8, and the 3-4 dipole of line 9. Line 7 gave a slightly lower value over the mineralization only on the n = 4 dipole separation. Lines 2 and 3 show no variations at all on their resistivity values taken over the mineralization.

From the above it is apparent that the resistivity values recorded over the mineralization could either be equal to those of the country (barren) rocks or slightly above or below them. Certainly they do not attain significantly different values. Theoretically pyrite, or a massive pyritic ore is characterised by low resistivities. However, in the present mineralization although the main mineral could be pyrite, the mineralization includes also other high resistivity minerals, such as silica originating from the same general phenomenon as pyrite, which could act as an insulation between the pyrite grains. For this the mineralization in this area does not appear to show any very low values as expected from the theoretical resistivity of pyrite, but sometimes even slightly higher resistivities. However, one thing which is certain from these results is that the resistivity method does not demonstrate convincingly the presence of mineralization.

/ 3. Conclusions.

3. Conclusions.

From the results and discussion presented above it can be concluded that the resistivity method failed to present convincingly strong evidence for the existence of any mineralization in the area. There are no significant differences of the resistivity values over the mineralized ground compared with those recorded over the barren rocks.

/ IV . GENERAL

IV. GENERAL CONCLUSIONS

The Kambia area together with its orebody represents an example of sulphide mineralization occurring along a fracture zone, certainly the passageway of the mineralizing fluids, which was locally concentrated forming the Kambia orebody. It is suspected that this concentration of mineralization was localised at an intersection of the Kambia zone with another structure striking with an almost north-south trend. The importance of this environment is evident. Economic concentration of sulphides could be found in both the mineralized zone itself and also at an intersection with another structure. In the area covered by the present survey the zone has a relatively large width and it can form itself an economic concentration of sulphides. From the above it is obvious that this type of geological setting could be the subject of an exploration project. Such a project would aim in locating mineralized zones in the Lower Pillow Lava terrain which could include economic concentrations either along their extent, or at other favourable locations related to the tectonic structure of the area as a whole.

The I.P. survey carried out over the Kambia area, together with the Resistivity survey, both being applied in a routine I.P. field programme, demonstrated their applicability in the search for such zones of mineralization. It must be admitted, however, that at most of its extent the presently surveyed area exhibited the mineralization at a very favourable condition, i.e. at very shallow depth. From the results presented and discussed in the previous sections of this Chapter, it can be concluded that the I.P. survey as applied in the field is capable in locating such zones, not only when nearly exposed but also when concealed under fresh volcanic rocks. From these results, which were investigated by consequent drilling, it was concluded that the actual location of this zone with respect to the geophysical

/ grid

grid can be decided with relative accuracy. In general it can be concluded that the I.P. method is capable to locate such narrow mineralized targets. On the other hand the resistivity method appears to offer very little in this respect. The results obtained over the mineralization were not conclusive, suggesting that this method could not be applied in mineral exploration for such targets as a primary method but only in association with a more reliable one such as the I.P. method.

/ CHAPTER

CHAPTER TEN

THE APPLICABILITY AND LIMITATIONS OF THE INDUCED POLARIZATION METHOD

I. INTRODUCTION

The purpose of the present Thesis is to investigate the applicability of the I.P. method over the Cyprus sulphide mineralized zones all of which occurred within the Lower Pillow Lava Series. The preceding Chapters described the geophysical results over a number of areas where this mineralization is found. In all cases it was desirable to examine the method over simple geological environments avoiding in this way other geological conditions which could produce other geophysical complications. The Mathiatis area was an example of high grade mineralization very close to the surface and partly exposed, together with a parallel blind lower grade disseminated mineralization. The Klirou mineralization was an exposed low grade mineralization, together with two other high grade blind zones, one at a depth of about 10 meters and the other at about 100 meters. The Kokkinovounaros mineralization was an exposed low-medium grade mineralized zone. At Vrechia the mineralization was in an exposed low grade body and a shallow slightly deeper body of high grade. The Petra area was an example of mineralization at the intersection of two major tectonic structures, one being the feeder of the mineralizing fluids, and the other being a fracture normal to it. At this locality the lavas were partly overlain by younger Cretaceous marls. The Kambia area was a typical example of a mineralized fault which in fact was the feeder for a nearby massive pyrite deposit and could be traced for a long distance to the northwest up to the Upper Pillow Lava outcrop which is beyond the area of interest. The Agrokipia B Orebody

/ which

which was surveyed geophysically during the orientation study, was an example of a deeply seated sulphide body.

On the basis of the results presented and discussed in the previous Chapters, it will be attempted in the present one to discuss the applicability and limitations of the I.P. method in sulphide exploration in Cyprus. The Chapter begins with a study of the I.P. method as an exploration tool applied for the location of mineralized zones. This is followed by a discussion on the I.P. decay curve and the behaviour of the different parameters which describe its shape, and their potentialities to give indications of the grades of mineralization. Finally there is a brief discussion on the applicability and limitations of the resistivity methods since this is a normal companion of the I.P. in field surveys.

II. THE APPLICABILITY OF I.P. IN MINERAL EXPLORATION

A. Introduction

In all areas described in the previous Chapters there was an extensive account of what was considered as routine I.P. exploration. This included mainly the recording, presentation and interpretation of simple parameters describing the I.P. phenomenon, in this case the N.T.I. In this section there will be a thorough discussion on the results obtained in the different areas. This begins with an investigation of the magnitude of the I.P. responses over the different lithologies - mineralized and unmineralized rocks. This is followed by an investigation of the effect of depth on the values of these responses. Further, there is a thorough discussion on the effect of the size of the polarising body on these responses and its relationship with the electrode spacing applied. This is followed by a discussion on the shapes of the anomalous patterns obtained on the pseudo-sectional convention of plotting. Finally there is an investigation of the effect of mineral grade on the magnitude of the I.P. responses.

Before entering into discussion it is pertinent to mention that all geophysical results were obtained under similar field conditions. The pole-dipole electrode configuration with an electrode spacing of 50 meters was used throughout the survey. The period of energising current was kept constant at 8 secs (2 on, 2 off) at an on/off ratio equal to unity. Further the N.T.I. was being recorded at the same time intervals in all cases, as described in Fig. 26.

B. The Magnitude of the I.P. Responses

In all areas where sulphide mineralization was known to exist, irrespective of its grade, this was well indicated by the I.P. results. In addition new mineralized bodies were discovered in some of the areas, the most notable being the northern mineralization of the Klirou area. The I.P. phenomenon was recorded and studied at four different N.T.I. values. From the analytical discussions presented in each Chapter, it generally appeared that the I.P. anomalies were obvious from the lowest integral value Msec 1. However, in many cases it was concluded that the shape of the anomaly was becoming more clearly defined with increasing integration times. And in many cases the highest integral Msec 4 was referred to in the discussions.

As a whole the values of this integral, Msec 4, were found to vary considerably throughout the presently described research. Evidently much of this variation is related to the geological conditions in which each mineralization is found, such as whether exposed or in depth, and to what degree it is covered by unmineralized rocks. In discussing therefore the magnitude of these responses, the geological environment will be taken into account. Considering first the exposed mineralized bodies which were surveyed - in all cases covered with a thin oxidised cap - these include the Klirou western mineralization, the Kokkinovounaros mineralization (lines 1, 3 and 4), the eastern mineralization at Vrechia, and lines 6 and 7 of the Kambia area. In the first area (Klirou), the Msec 4 values over the exposed mineralization (Figs 98 to 102) vary from a few hundred up to sixteen hundred. In the Kokkinovounaros area (lines 1, 3 and 4, Figs 122, 124 and 125) the Msec 4 values are much lower not exceeding the nine hundred. Slightly higher values but in general below the one thousand were recorded in the eastern mineralization in the Vrechia Area (Figs 154, 155 and 156). On the Kambia lines (6 and 7, Figs 184 and 185) the Msec 4 values are much lower just exceeding the seven hundred. As it will be discussed below this could be due to the fact that no electrodes were put into the mineralization, or even on its gossanised capping.

/ For a

For a better understanding of these figures it is pertinent to examine also N.T.I. responses of the barren rocks in the Msec 4 integral. The Klirou area barren rocks are generally characterised by maximum values which range from less than one hundred in the small dipole separations to less than two hundred and fifty in areas away from mineralization on the large dipole separations. In the Kokkinovounaros area, however, these values are generally higher being in all dipole separations almost equal and generally higher than two hundred, exceeding in some cases the three hundred. In the Vrechia area it is difficult to assign any values to the barren rocks since the lines were too short to have surveyed barren rocks far away from mineralized ground. However, the lowest recorded Msec 4 integral values are over three hundred. In the Kambia area the situation is rather similar to that of Kokkinovounaros. It must be noted that the two areas are close to each other. From the above, it is evident that the I.P. responses obtained over apparently similarly mineralized grounds could be different. Similarly, it appears that the responses obtained over barren rocks from different areas can also be characterised by different amplitudes. It is interesting to note here the similarity of the Msec 4 values of the Kokkinovounaros and Kambia area. In the latter, on those lines where electrodes were put on the thin cover of the mineralization,for example lines 4 and 5 (Figs 182 and 183), the Msec 4 values are equal to those of the Kokkinovounaros lines mentioned above. Further, it is interesting to note that the two areas were surveyed at different periods of the year, the Kokkinovounaros in June under hot and dry conditions and the Kambia in early winter (November and December) under wet conditions. Most important, however, is the fact that the two mineralizations are parts of the same mineralized zone and the barren rocks are similar as they fall in the same region. Another important thing to have in mind is the fact that there does not appear to be a general shift of the values of the mineralized and unmineralized ground in the same direction. (The possibility of instrumental effects must be totally excluded because

/ the instruments

the instruments are calibrated with constant signals).

From the above discussion it is apparent that the degree with which a mineralization will be indicated by a field survey could depend not only on obvious factors such as its depth and size, but also on the relative contrast of the values from the mineralized and unmineralized rocks. In the Klirou area where the background consists of volcanic rocks of the higher parts of the Lower Pillow Lavas, or the lower parts of the Upper Pillow Lavas (lithologically this was not yet clarified), the exposed mineralization is more clearly defined than in the Kokkinovounaros and Kambia areas. Although there are clearly differences between the I.P. amplitudes of the barren rocks, it is difficult to attempt to come to any conclusion regarding the values of the mineralized zones since their sizes are not comparable. In other words it is assumed that the polarization of the mineralization will be much stronger if this has a larger extent than in the case of a smaller mineralized body. This will be discussed in a further part of this section.

C. <u>The Effect of Depth on the I.P. Responses</u>

From the small ratio of the anomalous to background values recorded in the exposed mineralization of the Kambia and Kokkinovounaros areas, it is justified to question how such a mineralization, particularly a thin mineralized fault like the Kambia target will appear, if not exposed on the surface, being covered by unmineralized rocks. The importance of these structures must not be underestimated. Their responses under a very thin cover of one to two meters of soil and drift is demonstrated by the results of lines 3, 4 and 5 (Kambia area, Figs 181, 182 and 183). In the first the mineralization is indicated by only slightly lower values than those of line 6, and almost equal to those of line 7, where the electrodes were not placed over the mineralization or its oxidised capping. A more drastic decrease

/ in the

in the Msec 4 integral values appears on lines 8 and 9 of the Kambia area (Figs 186 and 187) where the mineralized zone is displaced and downthrown, covered only by barren rocks. Although there are not as yet any drilling results over these lines (8 and 9), undoubtly the mineralized fault extends under these lines as proved by subsequent geophysical results northwest of this area. Irrespective of the above, it is observed that there is a substantial decrease in the values of the Msec 4 integral, the anomaly being defined by values less than one and a half times those of the enclosing rocks. Would such an anomaly be ignored in a different survey, after it is known that in this particular case it is related with a two million tons sulphide body, the Kambia orebody, five hundred meters away? A similar decrease in the N.T.I. values is also observed on lines 6 and 7 of the Kokkinovounaros area (Figs 127 and 128).

The investigation of the effect of depth on the I.P. responses can be extended in other areas such as at Mathiatis western mineralization, the Klirou southern mineralization and the Vrechia main mineralization. In the first case, in the Mathiatis lines 1 and 2 (Figs 66 and 67) where the mineralization is at a depth of 9 and 20 meters respectively, it is observed that the responses are about equal, their maxima being just under five hundred in the Msec 4 integral. It is noted that the respective values of the host rocks are relatively low. A more correct indication is given by lines 4 and 5 (Figs 69 and 70) of the same area where it is observed that they are about one hundred and fifty in the Msec 4. On line 2 where the depth to the top of the mineralization increases by twice, the responses do not appear to decrease significantly at all. There is however, some change in the pattern but this is related to the position of the electrodes with respect to the mineralized body which is discussed later in this section. The Klirou southern mineralization was recorded by lines 1 and 2 (Figs 98 and 99). In the first it lies at a depth of about 15 meters, and in the second 8 meters

/ under

under fresh volcanics. It is observed that the responses are generally the same in both lines ranging from nine hundred to over one thousand on the n = 2-4 dipole separations. The first dipole separation reading is slightly higher in the first line than in the second, contrary to the differences in the thickness of the overlying fresh rocks.

Examining the responses on the Vrechia lines, first on lines 2 and 3 (Figs 155 and 156), it is observed that the amplitudes of the Msec 4 integrals do not differ significantly when the mineralization is at a depth ranging from less than a meter to as much as twenty meters. Comparing the readings of the receiver dipoles 9-10 and 10-11 of line 2, where in the first the mineralization ranges from ten to twenty meters in depth and in the second starts from less than half a meter under a soil cover (stake 11), it is observed that their values are almost equal. Similar amplitudes were recorded on the 9-10 dipole of line 3 (Fig. 156) with the mineralization ranging from about twelve to twenty meters, and slightly lower on the 10-11 dipole of the same line with the mineralization being at about a depth of eight to eighteen meters.

From the above discussion for parts of the Mathiatis, Klirou and Vrechia mineralizations, it appears that the mineralization could be indicated by different amplitudes in each area. With respect to the depth to the top of the mineralization, however, in a particular area there does not appear to be a significant variation in the N.T.I. amplitudes with increasing depth once the mineralization is covered by barren rocks, provided that this depth does not exceed by much a certain value. This value is certainly crucial and some idea of its magnitude is certainly desirable. This brings the discussion into the effects of an increasing depth to the top of the mineralization. Returning to the Vrechia main mineralization it is noted that in the area of line 1 it is found at a depth of thirtyfour to fortytwo

/ meters

meters under dipole 10-11 (Fig.153), and at a depth of fiftythree meters under dipole 9-10, although there is strong evidence of an uplifting of the mineralization in the region of stakes 9 to 8. Examining the amplitudes of the Msec 4 integrals for this line (Fig. 154), it is observed that they differ from those of lines 2 and 3 mentioned above being lower by as much as thirty percent. This could indicate perhaps that the I.P. responses begin to decrease drastically when the depth of the mineralization approaches and exceeds the length of the dipole, in the present case about fifty meters.

The Klirou northern mineralization is a stage further in the discussion on the effect of depth. Assuming that its amplitudes when very close to the surface are not much different from those of the southern mineralization (Figs 98 and 99), it is observed that on lines 4 and 5 (Figs 101 and 102) where it was intersected at a depth of about one hundred meters, the Msec 4 amplitudes are as low as thirty to forty percent of those of the southern mineralization. The Agrokipia B Orebody occurs at about the same depth under fresh volcanics. Although the magnitude of the Msec 4 integral in much shallower positions is not known, it is observed (Fig. 50) that the highest values are not much different than those of the Klirou northern mineralization. Those of the horst rocks, however, appear to be slightly lower than the respective ones at Klirou. In this way the anomaly is enhanced.

D. The Effect of the Size of the Body and the Electrode Spacing on the I.P. Responses

The preceding discussion concentrated on the variation of the values of the I.P. responses under conditions of exposed mineralization and investigated their decrease with increasing depth. As was mentioned during the above discussion, the amplitudes of these responses could also be affected by other conditions such as the size of the mineralized body, together perhaps with its grade. The location of the electrodes with

/ respect

respect to the mineralization is also important as mentioned in a number of occasions in the individual Chapters. It is understood that this is related with the size, particularly the width of the mineralization. This will be the subject of the discussion which follows below.

Considering first the responses from an exposed narrow mineralization, the best example is offered by the Kambia area. By narrow we certainly imply a relationship with the electrode spacing applied. In the case of the Kambia mineralization this does not exceed the electrode spacing of fifty meters. Its minimum width appears on the surface to be fifteen meters. In discussing the responses from this mineralization in Chapter Nine, three different types of anomalies were recognised corresponding to the position of the receiving and transmitting electrodes with respect to the zone. In the first type, low I.P. amplitudes are recorded in the case where the mineralization is much narrower than the electrode spacing and falls between two electrodes, as on line 7 (Fig. 185). In this the first electrode separation reading is very low comparable with the amplitudes of the surrounding rocks, the other responses (n = 2-4) not being significantly higher. On line 6 (Fig. 184), however, where one of the electrodes is located directly on the mineralization,the responses of the receiving dipoles increase with respect to the previous line. Similar responses are shown by lines 5, 4 and 3 (Figs 183, 182 and 181). This is the third type of anomaly recognized in Chapter Nine. An important feature of this anomaly is the fact that the transmitting pole also plays an important role in the detection of the mineralization. When the current is transmitted through a pole located into the mineralization, high I.P. amplitudes are recorded on the corresponding receiver readings. This is examplified by lines 4, 5 and 6 (Figs 182, 183 and 184). From the above anomalies and the corresponding mineralization which gave rise to them, it is observed that anomalous values are recorded on both the receiving dipoles which have a common pole on the mineralization.

/ However,

However, by examining the responses of lines 1 and 3 (Figs 179 and 181), it is observed that in these cases the mineralization, although narrow, is shown very strongly on one receiving dipole only. This dipole is that which includes most of the width of the mineralized zone. In addition higher responses are given by the corresponding transmitting pole.

From the above discussion it is evident that the relationship of the mineralization with the electrodes, even at conditions where the first is almost exposed, plays an important role in the amplitude and shape of an anomaly. An important conclusion from this discussion can be drawn by referring for example to the results of line 1 (Fig. 179) of the Kambia area. Borehole KB 35 located on stake 5 intersected mineralization at a depth of five meters and terminated within it at a depth of fifty meters (Fig. 178). However, anomalous responses were recorded by the 4-5 receiving dipole only and almost no anomaly was recorded on the adjacent 6-5 dipole. This is a very important observation as it assists tremendously in the precise location of the mineralization with respect to the electrode positions. On the other hand, however, it points out the possible limitations of an I.P. survey when applied under certain field conditions aiming at this type of mineral targets. This matter was alluded in the discussion which followed the different Chapters and it will be discussed extensively below. Evidently it falls in the main subject of the present discussion which is the effect of the size of the mineralization and its relationship with respect to the geophysical grid.

In the following lines the responses from other exposed and wider bodies of mineralization will be examined. In the Kokkinovounaros area lines 3, 4 and 5 (Figs 124, 125 and 126) cross at about right angles the mineralization which in the area has a width of 100 to 140 meters. On line 3 (Fig. 124) the highest values were recorded on the 8-9 receiving dipole

/ where

where both the electrodes are over the mineralized ground. Similarly, lower but anomalous values were recorded on the 7-8 dipole. On line 4 (Fig. 125) anomalous responses were recorded by the 7-8 and to a lesser extent by the 6-7 receiving dipoles. A similar picture is shown by the results of line 5 (Fig. 126) where the anomalous responses were recorded by the 6-7 and 5-6 receiving dipoles. It is noted that in all three lines these electrodes were located within the boundaries of the mineralization or the two parallel bounding faults which enclose the mineralization (Fig. 120). Once an electrode of a receiving dipole is located outside these two faults, the responses drop significantly and in some cases are definitely non-anomalous. This phenomenon is shown better in the eastern dipoles where there are no effects from the transmitting poles when placed in the mineralization. On line 3 (Fig. 124) the receiving dipole 9-10 shows only a slight increase from the background values. On line 4 (Fig. 125) the receiving dipole 8-9 recorded results which cannot be considered anomalous. Similarly the 7-8 dipole of line 5 (Fig. 126). From this discussion it is verified that anomalous responses are attained only when both the receiving poles of a certain dipole are in the mineralization.

Before continuing the discussion into the effects of overlying unmineralized rocks, there will be an examination of the responses from much wider exposed bodies of mineralization with reference to the Klirou western mineralization and the Vrechia eastern mineralization. In the first which extends from 250 to over 350 meters in width (Fig. 96), it is observed that although the eastern boundary is well defined by an almost vertical fault, anomalous responses were recorded on all dipoles which cross these boundaries, see lines 1, 2, 3 and 4, dipoles 12-13, on the first three lines and 13-14 on the last line (4) (Figs 98, 99, 100 and 101). In the Vrechia area the exposed eastern mineralization is known to have an extent to the east exceeding the 200 meters. On all lines it was intercected by the

/ receiver

receiver dipoles 6-5 (Fig. 152). From the results of these lines, 1, 2 and 3 (Figs 154, 155 and 156), it is observed that the I.P. responses are equally anomalous on the said dipoles as on the other dipoles situated within the mineralized zone. It is interesting to note, however, that on line 1 (Fig. 154) where stake 6 is a few meters to the west of the mineralization, the 5-6 dipole gives the highest responses, whereas the 6-7 dipole next to it shows a significant drop. From this discussion it appears that in the case of wide zones of mineralization the I.P. responses do not drop significantly to lower values once a pole of the receiver dipole is on barren ground, but it does when both poles are outside the mineralization. The significance of this as compared with that of the much narrower zones is evident and it will be discussed further below as it is very important in exploration. Usually an exploration programme does not get involved in exposed mineralizations. However, the findings of this discussion for these conditions can be useful in understanding the effects in the cases of buried mineralized bodies.

From the preceding discussion it appears that the narrow mineralizations, such as those of Kambia and Kokkinovounaros, are characterised by lower I.P. responses than those of the bigger bodies, such as the Klirou and Vrechia. Certainly this was expected to be so, but it appears to be an explanation of the fact that a receiving dipole crossing the boundary of such a body gives lower responses from dipoles within the body, the amount depending on its size. For the examination of these effects under a thin layer of overlying unmineralized rocks the Mathiatis area offers the first examples. Line 1 intersected the mineralization at a depth of 8 meters under fresh volcanics (Fig. 64), and stake 7 is observed to be almost in the middle of this mineralized block whose width in this area is about 45 meters. The I.P. survey over this line (1, Fig. 66) recorded anomalous values on both dipoles adjacent to stake 7, i.e. 6-7 and 7-8, with almost

/ equal

equal amplitudes. On line 2 this picture is shifted to 20 meters below the surface and the mineralization is mostly concentrated in the region of the 6-7 dipole (Fig. 64). Turning to the results of the survey over this line (Fig. 67), it is observed that only this dipole gave significantly anomalous responses equal to those of line 1. The 7-8 dipole gave much lower responses which, however, can still be considered anomalous. The geological section over line 3 of Mathiatis shown again in Fig. 64, demonstrates an increase in the depth of the mineralization to about 35-40 meters. But the I.P. survey failed to give any definite anomalous responses over this structure. Neither the 6-5 nor the 6-7 receiving dipoles gave any responses. This observation is easily explained from the effects discussed on the previous lines of Mathiatis (lines 1 and 2). And although the explanation is easy, the results seem to be disappointing.

The Kambia mineralization also offers some examples of this type of structure although the targets were not drilled and the depth and thickness of the mineralization is not known. These examples are offered by lines 8 and 9 (Fig. 176) which intersected the mineralized zone after it was displaced to the south and downthrown, covered by fresh volcanics. The only indication which exists for the depth to the top of this mineralization is the fact that there does not appear from the tectonics of the area to be any major structure with a considerable vertical displacement in the area, except the one shown on the map. Figs 186 and 187 show the I.P. results along these these lines (8 and 9). It is observed on both that the I.P. responses are generally very low not even exceeding by twice the values of the responses in the enclosing rocks. Line 8 shows these values on two receiving dipoles (1-2 and 2-3) and line 9 on only one dipole (2-3). The continuation of this mineralized fault to the northwest was proved by mapping and geophysics in the adjacent area. However, no drilling started as yet on these anomalies.

The Klirou southern mineralization is another example of a narrow and concealed conductor. The geological sections along lines 1 and 2 of the Klirou area (Fig. 97) demonstrate the relationship of the southern mineralization with the position of the electrodes. The highest amplitudes on line 1 were recorded on the 9-10 receiving dipole (Fig. 98) which as shown on the geological section includes the highest parts of the mineralization. The adjacent dipoles gave much lower, though still anomalous values. The results of line 2 (Fig. 99) illustrate again that the highest responses were recorded on the 9-10 receiver dipole and lower on the adjacent ones. (Perhaps it is appropriate to question: how would these anomalies be if boreholes HKL 7 on line 1 and HKL 17 on line 2 (Fig. 97) were negative?).

In this context it is pertinent to discuss also the responses over the Petra mineralization. Although these anomalies were examined thoroughly in the relevant Chapter (Eight), it will be interesting to investigate the amplitudes of these responses and their relationship with the receiving dipoles. However, this mineralization was not drilled sufficiently to obtain a satisfactory picture of its shape. This is known only relatively well along the geophysical lines 2, 3 and 4 (Fig. 167) and is illustrated on the geological sections of Fig. 168. The responses of line 2 (Fig. 170) show high readings from the beginning of the receiver dipole (i.e. n = 1). This could be either due to the shallow mineralization or the nearby Mavridhia Fault which in places is weakly mineralized. In the larger dipole separations which are considered as corresponding to the main mineralized body beginning to appear from the depth of 40 meters, the responses due to the mineralization are generally low exceeding by only a small percentage those of the surrounding dipoles. A rather similar situation is observed on line 3 (Fig. 171) where the I.P. responses are low in the n = 1 separation and increase, though very slightly, in the larger ones. From the geological section it is observed that the main mineralization in this area is estimated

/ to begin

to begin from about 60 to 65 meters. Line 4 shows higher values than the previous lines although the minimum depth of the mineralization in borehole Δ414 is 70 meters. This implies that the highest part of the mineralization is justified to be looked for by drilling a few meters to the west of borehole Δ414. On all three lines mentioned above it is observed that the receiving dipoles adjacent to those which include the mineralization have generally low values. Another important observation is the fact that the responses due to the mineralization are generally low enough to make somebody ignore these anomalies. But still they correspond to a body which could very well be of economic significance.

This brings the discussion to wider and deeper seated mineralized zones. The Vrechia main mineralization along line 1 is the first example. A geological section of this line is shown in Fig. 153, illustrating that the mineralization occurs at a depth of 34 to 42 meters in the region of dipole 10-11 and at a depth of 53 meters in borehole CH 12 in the dipole 9-10. From the responses of lines 2 and 3 where the mineralization is very shallow, it is evident that there is a significant drop in the responses (Figs 153, 155 and 156). However, the anomaly is very well defined. Although the mineralization does not appear to terminate on borehole CH 2 near stake 11, it is observed that the 11-12 dipole gave non-anomalous responses. This illustrates that the I.P. responses are not anomalous unless both the receiving electrodes are over the mineralization, as discussed in other cases above.

The Klirou northern mineralization is the next example of a deeply seated mineralization with large lateral extent. This has a later extend of over 100 meters as shown in the geological section of Fig. 97. The I.P.

/ results

results over this line are shown in Fig. 101. From the drilling evidence there is little doubt that the I.P. responses are due to the deeply seated mineralization at an average depth of about 100 meters under fresh volcanics. These responses are observed in Fig. 101 to extend to the west from the region immediately east of the anomalous readings due to the exposed mineralization. These, however, could be attributed to the nearby exposed western mineralization, and the northern mineralization apparently begins from the receiving dipole 7-8 and extends to the east up to the region of the receiving dipole 3-4, or even beyond increasing also in depth in the same direction. From this discussion it is evident that the Klirou mineralization is indicated by relatively low amplitude responses because of the depth at which it lies. But certainly these responses are higher than what they would be for an equally placed mineralization but with smaller lateral extent. This leads to the question: Would that mineralization been detected if it had half the lateral extent?

The last mineralization to examine in this discussion is the Agrokipia B Orebody surveyed during the orientation study. A geological section along the surveyed line is shown in Fig. 48 and the I.P. results in Fig. 50. From these two figures it is observed that the top of the Agrokipia Orebody occurs at a depth of 125 meters below the surface and the I.P. responses which were measured over it have generally low amplitudes. An important observation which can be made on these results is the fact that the anomalous readings are not controlled by the receiving or transmitting electrodes, but on the pseudosectional plotting they coincide well with the actual location of the mineralization.

E. The Shapes of the Anomalous Patterns on the Pseudosectional Convention of Plotting

Throughout the field surveys presented and discussed in the present Thesis there was used only one electrode configuration, the pole-dipole with a

/ constant

constant electrode spacing of 50 meters. The purpose of this was simply to study and understand the behaviour of the Cypriot targets first under one particular condition before getting involved into more variables. For this purpose it is considered pertinent to discuss the shapes of the anomalous patterns as they appear on the conventional pseudosectional plotting, recorded by this particular configuration over the different modes of occurrence of the mineralization.

Beginning with the exposed mineralized bodies, it was observed and mentioned in many occasions that the highest values were recorded on the receiver dipoles which were said to "control" the shape of the anomaly on the pseudosectional contours giving the impression of 45° dipping anomalous patterns. Examples of these anomalies are lines 1-7 of the Kambia area (Figs 179 to 183), lines 3 to 6 of Kokkinovounaros area (Figs 124 to 127), all lines over the western mineralization at Klirou (lines 1-5, Figs 98 to 102), and all lines of the Vrechia area over the exposed eastern mineralization (lines 1-3, Figs 154 to 156). In the cases of the narrow mineralized bodies such as the one at Kambia, the anomaly is very sharply defined in one or two receiving dipoles. In the case of the much wider mineralized zones this definition is not so sharp. This was mentioned before as being due to the higher responses due to the increased size of the mineralized body.

With regard to the transmitting electrodes it was observed that these also show some effects on the I.P. responses but only when located over exposed or gossan covered mineralization, as seen for example in some of the Kambia and Kokkinovounaros lines. In these cases, the effect of the transmitting pole results in the formation of "boomerang-shaped" patterns which in the pole-dipole configuration are generally asymmetrical being stronger on the receiver dipole readings. An interesting feagure of these anomalies

/ is the

is the recording of very low responses in the concave parts of these patterns as for example of the Kambia lines 5 and 6 (Figs 183 and 184). From these two examples it is observed that these low values appear to be related to the receiver readings. It must be remembered that when these readings are taken the mineralization is located between the receiving dipole and the transmitting pole and implies that the polarization of the rocks is reduced to a minimum.

Extending our investigation in the shallow seated but nevertheless concealed mineralizations, as for example the Mathiatis western mineralization on lines 1 and 2 (Figs 66 and 67) and the Klirou Southern mineralization on lines 1 and 2 (Figs 98 and 99), it is observed that the anomalous readings are recorded only on the receiving dipoles with no effects on the readings corresponding to the transmitting poles. This control of the anomaly by the receiver readings is also observed in the rather deeper seated mineralization of line 1 at Vrechia (Fig. 154). And as in the previous cases, the anomalous patterns attain a 45^{o} inclination due to the conventional plotting. Evidently, when drilling such an anomaly the best location is within the dipole(s) which gave the high receiver readings.

Over the much deeper mineralized bodies of the Klirou northern mineralization, and the Agrokipia B Orebody (Figs 101 and 50 respectively), it appears that the anomalous responses are not controlled by the receiving dipoles. At least this is not shown by the contoured values. And by examining the actual location of the mineralization as indicated by the geological sections along those lines (Figs 97 and 48 respectively) it is observed that it appears to be a certain correspondence of the pseudosectional plot with the geology. It is noted that this is more apparent in the deeper seated Agrokipia B Orebody than the Klirou mineralization. In the latter it appears to be some controlling effect by the 7-8 dipole (Fig. 101).

/ It should

It should be remembered that on this side the mineralization is shallower, see Fig. 97.

The realization of the above phenomena regarding the shape of the anomalous patterns as they appear on the pseudosectional convention, is very important in the interpretation of the anomalies and the location of the exploratory boreholes. Further, the fact that the anomalous pattern is controlled or not by the receiving dipole(s) is an indication of depth. It is clear from the above discussion that the more the pattern depends on the receiver dipole readings, the closer the mineralization is to the surface.

The above discussion pointed out one more important observation. This is the usefulness of the pseudosectional plotting. Once it is realised that it is nothing but a pseudo(false) section, it is very useful in that it demonstrates the position of the electrodes with which a certain reading was obtained. If this is replaced by normal graphs where will each reading be assigned? The discussion presented above suggests that the point of assignment depends on the depth of the mineralization. If it is shallow this is in the mid-point of the receiving dipole. But if it is deep, then the position of the transmitting pole must be taken into consideration as well.

F. The Effect of Mineral Grade on the I.P. Responses

An important problem a geophysicist faces when attempting to interpret an I.P. anomaly is whether it could be the result of a high or low grade mineralization. This brings the discussion into the subject of predicting the grade of the mineralization from the I.P. responses. With a particular response the only variation it could have is in its magnitude. Therefore, if there are any effects on the N.T.I. by the change of the mineral grade,

/ these

these must be looked for in the variations of its values. However, after all the discussion which investigated the different phenomena which could effect significantly the values of the N.T.I., it could be considered as too demanding to attempt to relate such variations with changes in the sulphide content.

In the discussion which followed the presentation of the N.T.I. results in each Chapter, there was made in some cases a reference to possible effects of the grade on the I.P. responses. At Mathiatis for example, the higher amplitudes of the eastern mineralization compared with the western one were tentatively attributed to their differences in mineral grade. However, apparently they also differ substantially in their size and this appears to be a more reasonable explanation.

In the Klirou western mineralization it was recognised that both the poor and rich disseminations in this area show high I.P. responses but those of the rich disseminations appear to be of higher amplitude. The last area where some attempt to differentiate between grades was made, was at Vrechia where it was concluded that the richer main mineralization gave higher responses than the poorer eastern mineralization. From the above short discussion it can be stated that there does not appear to be any variation of the N.T.I. values which can be assigned even with a very small degree of certainty to the relative sulphide content. Even if there is proof to be a variation on the N.T.I. responses due to a difference in mineral content, this will be of very little help in the field since these values are vulnerable to many other phenomena.

III. THE SHAPE OF THE TRANSIENT DECAY AS AN INDICATOR OF THE MINERAL GRADE

A. Introduction

As it was pointed out by previous workers, for example Grant (1971) and Quick (1973), the shape of the I.P. decay could disclose information about the nature of the polarizing medium e.g. whether the polarization is membrane or electrode. One of the main objects of the present research was the investigation of this shape to take this thinking a stage further with an attempt to establish, if there exist, criteria which would enable the distinction between disseminated and massive mineralization. This will clearly improve the value of the method in the assessment of the deposits of Cyprus. The Mathiatis, Klirou, Kokkinovounaros and Vrechia areas were selected because there was a considerable amount of drilling information either from past or subsequent drilling, regarding the grade of the mineralization, which would enable the investigation to be carried out.

For the purpose of studying and thus comparing the transient shapes three different groups of parameters were computed and investigated. Those were first the parameters which express the decay as a series of exponential functions of the form Ae^{-at}, originally suggested by Hutchins (1971). The second group is related to the first and represents the quotients of the above functions at zero time divided by the corresponding resistivity value. This second group was a modification by the present author of two functions suggested by Bertin and Loeb (1974). The third group included a number of parameters suggested by the present author which express the shape of the I.P. decay when plotted on a $\log_e$ time axis. These last parameters were devised after the observation that the I.P. decay when plotted on a $\log_e$ time axis appears to consist of two different components. And the said parameters express the characteristics of each of these components and their inter-relation.

B. <u>The Decay Factors</u>

These factors were defined in an earlier Chapter of this Thesis as describing the transient decay in terms of exponential components. In the present research the number of exponential components was taken to be only two, since the sampling period did not extend beyond 0.78 secs in all cases. However, it was rarely observed that two components did not suffice because of high electromagnetic components. To facilitate comparisons, all the observations were made with the same current energising period and the decay curve sampled at the same times. It was found that the magnitude of the energising current had no effect on the shape of the curve by investigations carried out initially on the possible variations of the receiver readings with increasing current. This was in agreement with similar observations made by other researchers (Scott and West, 1969). The Agrokipia B experiments showed that variations were only observed with changes of the charging period and the on/off ratio. It should also be noted that throughout the field work the energizing current was usually greater than 2.0 Amps, to obtain the necessary depth of penetration in this low resistivity environment.

From the results obtained in the different areas it was always found that the A, B and P-factors could indicate the presence of mineralization and in some cases, particularly the B-factor, could discriminate between the disseminated and the higher grade mineralization. In this section there will be a general discussion on the significance of these different factors as indicated by the results from the areas as a whole. The results obtained in the different areas are summarized in Table 80. This table groups together the areas with relatively high grade of sulphide mineralization, those with lower grade down to the disseminated values, and the barren rocks.

With regard to the A-factor, the first to be observed from Table 80

/ is that

is that there is no overlap between the values of the barren rocks and those of the mineralized ground. The barren rocks have values ranging from 0.5 to 2.0 whereas the mineralization in general is characterised by values ranging from 2.0 to 7.6. From these figures it is evident that the A-factor can generally be used as a parameter which could discriminate between mineralized and unmineralized ground. Comparing the values from the different grades of mineralization it is observed that the higher grade ranges from 2.0 to 4.3, whereas the low grade mineralization which includes the richly disseminated grades such as those of Klirou and Vrechia eastern mineralization, have values ranging from 2.3 to 7.6. From these figures it appears that the A-factor could attain generally higher values over the disseminated mineralization than over the higher grade mineralization. However, there is a significant overlap between these ranges. And it is observed that the high value in A (7.6) was recorded at Klirou where the mineralization is extensive compared with other areas.

The B-factor appears in general to show high values over the mineralization than over the barren rocks, although for example the barren rocks in the Vrechia area have shown higher B-values than the Mathiatis high grade mineralization. The ranges of values for these two broad groups are 0.3 to 1.4 for the barren rocks and 1.0 to 4.0 for the mineralized rocks. Comparing between the two groups of mineralization, it is observed that the higher grade has B-values ranging from 1.0 to 2.8 and the disseminated mineralization values falling in the range 1.5 to 4.0. This excludes the part of the Klirou mineralization with a grade of sulphur below 1%. From these figures it is evident that the B-factor generally attains higher values over the richly disseminated grades of mineralization and lower over the higher, but there is a certain overlap between the ranges.

The P-factor is generally higher over the mineralized ground than

/ over

over the barren rocks. In the latter it ranges from 0.02 to 0.45, whereas in the mineralization its value ranges from 0.3 to 1.22. There is again a small overlap in these ranges. Comparing the two main grades of mineralization, it is observed that the P-values do not differ substantially except for the Klirou rich disseminations where it attains its highest value.

The remaining factors, α and β, always showed inconclusive results over the different lines crossing mineralized rocks. In general the profiles of these two factors do show some variations and in particular in positions adjacent to the mineralization. However, no conclusive remarks could be drawn from the present research.

The factoration of the decay curve into these components was based on the assumption that the decay, as measured in the field, is the sum of a number of exponential functions. However, Phillips and Richards (1974) who considered these functions and studied them over a mineralized zone, expressed serious doubts on the validity of this assumption. They factored the curve into three components and based the above conclusion on the fact that the second and third components (at $t = 0$) almost parallel each other indicating that they were both arising from the same source, the polarization induced within the mineralization.

Another argument against this assumption which is based on the results of the present research, is the fact that the α and β-factors showed a very wide range of values in all cases over both the mineralized and unmineralized ground. It must be remembered that these factors are the reciprocals of the relaxation times of the components of the decay curves. From the computations of the exponential functions it was indeed found that the first component had a short relaxation time and the second a much larger one. But from the profiles of these functions along lines crossing the mineralization, it was never found that they exhibited any significant variation which would indicate

/ different

different relaxation times over the different gross lithologies, i.e. the barren and mineralized rocks. The only observation which applies in all areas is that the relaxation times along surveyed lines showed smooth profiles when over barren rocks and irregular profiles over those lines which include mineralization. This effect was also observed on Phillips and Richards' (1974) results over a mineralized zone. As it was pointed out, in some lines, as for example in the Mathiatis area, the α-factor appeared to attain high values on one side and low values on the other side of the mineralization, resembling an electromagnetic anomaly with the mineralization on the crossover. Evidently this phenomenon, or even simply the fact that there is a variation on the profiles crossing mineralization, calls for further research with particular attention on this matter.

Regardless of the above limitations of these factors and the doubts expressed on the representation of the decay curve in this form, the components at $t = 0$, i.e. factors A and B, can be useful in discriminating between mineralized and unmineralized ground. There were indications that they could offer some assistance in discriminating between massive and disseminated mineralization as expected from the theory of the method. From the field results no firm conclusions can be drawn as there are no ideal situations where there exists massive mineralization without any lower grades in association with it. Obviously such a situation, which is what occurs in nature, would mask in some degree phenomena with lower amplitudes. Therefore, before the application of these findings in the field, it would undoubtedly be essential to verify them in the laboratory. Throughout the study of these functions attention was also paid on the P-factor. This is simply a measure of the amplitude of the I.P. transient at a particular time, in this case 1.75 secs, related to the function of the instrument used. Being such a parameter, i.e. an expression of the I.P., it was always considered.

/ C. The

C. The Bertin and Loeb's (Modified) Functions

Bertin and Loeb (1974) studied the shape of the I.P. transient decay with the factoration into two exponential components of long I.P. discharges from 1 to 20 secs. They introduced the parameters A1 and A2 as equal to the values of the first and second exponential components at t = 0 divided by the corresponding primary voltage. It was assumed by the present author that they kept a constant energizing current and they introduced a correction for the primary voltage which would involve the geometry of the electrode configuration. To overcome this, and particularly in order to introduce into the investigation of the transient decay the effect of resistivity, the present author modified these functions by dividing by the respective $\rho/2\pi$ value and not the primary voltage.

Basically the functions considered in the present research differ much from the original ones of Bertin and Loeb (1974). These authors ignored the transient decay before the first second and consider it from 1 to 20 secs, whereas in the present work the last point on the decay curve was at 0.78 secs. This is the most important modification of these two functions and perhaps it was unfortunate they were termed as "Bertin and Loeb's (modified) functions" and not something else. However, from the few examples they presented, for example Fig. 4 of Bertin and Loeb (1974), they suggested that the mineralization was characterised by high values in both their two functions, and their ratio increased over mineralized ground. In their conclusions they attributed the first function, A1, to rapid discharges identified with metallic I.P. of conductive minerals, and the second function, A2, representing slower discharges as being due to the electrolytic I.P. of the country rock. Below there will be a discussion on the results obtained in the present research over the mineralized grounds of Mathiatis, Klirou, Kokkinovounaros and Vrechia, and attempt to establish whether these modified functions can

/ offer

offer any information regarding the relative metallic content of the mineralization. It is understood that these functions are strongly influenced by the resistivity values. Before examining the values of these parameters in general, there will be a discussion on the conclusions drawn from each individual area. Table 80 summarises the results from the different areas.

In the Mathiatis area where there are two zones of mineralization, the eastern with disseminated pyrite with a sulphur grade of less than 2%, and the western with higher grades, it was concluded that the functions in question attain substantially different values over the two targets. In the first (eastern) the values of all three parameters, including their ratio, were low not differring from those of the enclosing rocks. In the western mineralization, however, the three parameters attained significantly higher values. On the basis of this it was concluded that these parameters were indicative of the grade of mineralization. In the study of the resistivity results over these two bodies of mineralization, it was found that they attained very high values over the eastern mineralization. This immediately explains the low values of the functions in question.

In the Klirou area, these functions were again found to be able to discriminate between the different grades of mineralization encountered in the area. The highest values were again computed for the high grade southern mineralization on both the A1 and A2 functions, and lower in the disseminated mineralizations. Further, between the two mineralizations it appeared to be a difference with higher values in the richly disseminated than in the poorly disseminated mineralization. Some differences, apparently insignificant though, appeared on the values of the A1/A2 ratio. With regard to the resistivity values of these different mineralizations, they were not found to differ as much as in the Mathiatis area. However, the southern mineralization was characterised by the lowest values and the poorly disseminated by the

/ highest

higest values among the mineralized bodies. This was in agreement with the observations regarding the A1 and A2 functions mentioned above.

In the Kokkinovounaros area the situation was different in that these functions had difficulties even in distinguishing clearly between mineralized and unmineralized rocks. This was attributed to the fact that the mineralization was bounded by significantly large fault structures which affected the resistivity values in their viscinity.

In the Vrechia area the A1 and A2 functions were found to discriminate well between mineralized and barren rocks with much higher values over the first, but there could be no distinction between the high grade main mineralization and the lower grade eastern mineralization.

From the above discussion it is evident that in the individual areas the functions in question are usually capable in discriminating between mineralized and barren rocks. Regarding the grade of the mineralization, it appeared that in some cases like Mathiatis and Klirou, there were differences in the values of the different grades. These, however, were found to reflect variations in the resistivity values recorded over the different mineralizations.

D. The $\log_e t$ Plotted Decay Factors

The transient decay curves recorded throughout the present research were plotted on a $\log_e$time axis and linear potential axis, and a number of parameters were determined which described the shapes of the transients when plotted in this way. It was always found that this mode of plotting demonstrated a two component curve which consisted of an early and rapid decaying linear component, and a slower decaying curved component. Figs 191(a,b) give examples of such plottings from the Mathiatis, Klirou, Kokkinovounaros and Vrechia areas. Fig. 30 defines the various parameters which describe

/this

this shape and which were investigated during the present research. These parameters were studied in the Mathiatis, Klirou, Kokkinovounaros and Vrechia areas, and attention was paid not only in their usefulness in distinguishing between barren and mineralized rocks, but in discriminating between disseminated and higher grade mineralization. In the Mathiatis area it was concluded that in most of these parameters there were significant differences between their values over the barren and mineralized rocks. With regard to the two different mineralizations it was found that the disseminated (eastern) had generally higher values, and particularly in those parameters which described the deviation of the second component from the first. In the Klirou area it was found again that some distinction could be made between the different grades of mineralization on the basis of these values. There were significant differences between the two grades of the western mineralization, the richer one being characterised in general by higher values. The southern mineralization was found to have intermediate values. Significant differences between the values from these three mineralizations were noted on the parameters measuring the deviation of the second component from the first. In the Kokkinovounaros area it was again demonstrated that these parameters could discriminate very clearly between mineralized and barren rocks. Similarly, in the Vrechia area these parameters had higher values over the mineralized compared with those over the barren rocks. It was attempted to discriminate between the different mineralizations occurring in this area on the basis of these factors. However, it was concluded that no definite conclusions could be drawn, and this was attributed to the fact that the grades of the two mineralizations were not much different from each other.

After this summary of the results from each area and the realization that at least some of these parameters could offer some assistance in discriminating between grades, each parameter is discussed individually below. The

/ results

results obtained from all the areas are summarized in Table 81.

The R1-factor over the barren rocks ranges from 1.2 to 2.0, whereas in the mineralized ground it is generally higher ranging from 1.5 to 5.3. In general this factor appears to distinguish clearly between mineralization and barren rocks. Regarding the different grades of mineralization, although in some areas it was found to show different values in differring grades (Mathiatis and Klirou), this cannot be generalized.

The R2-factor over the barren rocks ranges from 0.1 to 1.6, whereas the mineralized rocks attain values ranging from 1.0 to 4.1, indicating therefore a possible distinction between these two lithologies on the basis of this factor. With regard to the grades of mineralization again although there are some differences in individual areas (Mathiatis and Klirou) this cannot be generalized for all areas.

The R1/R2 ratio does not appear to discriminate clearly between barren and mineralized rocks. In the first, it can be considered as having generally high values ranging from 1.2 to 3.2,whereas in the second (mineralization) is lower falling within the range of 1.1 to 2.0. However, there is a considerable overlap in these two ranges not allowing for any generalization.

The V_d parameter seems to present different ranges of values over the two general lithologies. In the barren rocks this is 0.7 to 2.4 and in the mineralized rocks it has values from 1.9 to 7.5. In general although there is some overlap, it appears to be a difference between the two ranges. With regard to the grade of the mineralization, it appears that in general there are no significant differences. It is noted, however, that the lowest values were computed in the higher grades and the highest in the richly disseminated mineralizations.

/ The remaining

The remaining parameters are those which give a measure of the deviation of the second component from the first. These were computed at a number of values according to the amplitudes of the transient curves in an attempt to avoid long extrapolations. It is noted that the parameter t_d which is defined as the time corresponding to the V_d value, was omitted since in all cases it was found to show inconclusive results. Taking each deviation parameter separately, it is noted that in general it has low values in the barren rocks and high over the mineralization. In the d(0.5) parameter, excluding the Kokkinovounaros results which are very high in both cases, it is noted that the ranges of values are 30 to 630 and 800 to 6000 respectively. The Kokkinovounaros results also show differences between them. With regard to the grade of mineralization it is observed that the high grade mineralizations, such as the Mathiatis western and Klirou southern, are characterised by lower values than the disseminated mineralizations in these two areas with the exception of the poorly disseminated (<1%S) mineralization at Klirou.

The d(1.0) parameter, even with the inclusion of the Kokkinovounaros results, shows distinctly different values on the barren and mineralized rocks being respectively 0 to 300 and 130 to 2300. With regard to the grade of mineralization it is observed that the richly disseminated mineralizations such as those of Mathiatis eastern and Klirou 1-5%S mineralization, and even possibly the Kokkinovounaros mineralization, are generally characterised by higher deviation values than the higher grade Mathiatis western and Klirou southern mineralizations.

Some indication of different ranges of values in these two general grades are also shown by the d(1.5) parameter which was computed only for Mathiatis line 2 and the Vrechia area because of the high amplitude of the decay curves. Considering each area individually the higher grade has the

/ lowest

lowest values. This is clear in the Mathiatis area but in the Vrechia mineralizations there is some overlap, which could be attributed to the fact that the two grades in that area do not differ as much as they do in the Mathiatis area. The same effect for the Vrechia area is also observed in the d(2.0) values.

From the above discussion it is evident that the parameters in question attain different values over the barren and mineralized rocks. However, their values over the different grades, although in some cases they do show some differences, cannot be considered to be diagnostic except for those parameters which describe the amount of deviation of the second component from the first at given potential values. These deviation parameters demonstrate that in the low grade mineralization the second component of the transient decays slowly. It could also be argued that this is due to the higher amplitude of the decay curve in general over this mineralization. However, this did not become apparent in the other parameters which measure the amplitude itself. Irrespective of which explanation is the correct one, the deviation parameters could be considered as offering some assistance on the crude differentiation of the mineral grades. What is certain about them, is that their behaviour must be investigated in detail by laboratory studies after the indications as to their usefulness which were concluded from the present field research.

/ IV. THE

IV. THE RESISTIVITY METHOD AS A COMPANION OF THE I.P. FIELD SURVEYS

An I.P. field survey is normally accompanied by a Resistivity survey which is carried out simultaneously with the same apparatus and electrodes. For this, in all areas studied in the present Thesis some attention was also paid on their resistivity results. In general it appears that this method cannot contribute substantially to a general survey for sulphide mineralization under the conditions described in the different areas. However, it can disclose useful information which can assist in the successful interpretation of an I.P. survey.

The Mathiatis area illustrated both the advantages and disadvantages of the Resistivity method. It was found that the low grade eastern mineralization had very high resistivity values, whereas the western mineralization could not be distinguished from the country rocks. Another important finding in the Mathiatis area was that high resistivities were recorded very clearly in areas where the effects of mineralization are considered to be marginal, probably in the form of silicification and not pyritization, which are therefore undetectable with the I.P. method.

In the Klirou area the different mineralizations were found to have generally higher resistivities than the enclosing rocks. An important observation was that the resistivity values were found to increase with decreasing sulphide content. This is in agreement with observations made on synthetic rock samples (Scott and West, 1969, Mandel, et alia 1957, and McEuen, et alia 1959) and also on natural samples (Parkhomenko, 1967).

High resistivity values were also found to characterise the mineralization in the Kokkinovounaros area compared with those of the country rocks. Another observation made at Kokkinovounaros was that high resistivity values

/ could

could possibly be attained by structural features which were related to the overall mineralizing activity.

The Vrechia area showed a more confusing picture in that there could be no discrimination between the mineralized and unmineralized rocks in the area. On the basis of the resistivity values in both cases their results ranged widely. This perhaps could be explained from the fact that the Vrechia mineralization is found stratigraphically very low in the Lower Pillow Lavas, close to the Basal Group, where the rocks are expected to be widely affected by the mineralizing effects. This is supported by the widespread iron staining found in the area together with evidence of silicification.

In the Petra area the mineralization was also found to be shown by high resistivity values compared with the country rocks. Where the vertically standing Petra mineralization was not overlain by the Mavridhia Fault mineralization, the first was demonstrated sufficiently by the resistivity results. Otherwise it was masked by the high values of the Mavridhia Fault mineralization.

In the Kambia area the resistivity method seemed to be almost totally incapable of discriminating between mineralization and barren rocks, although their relationship in the area is very well defined by the structural control of the mineralization.

The deeply seated Agrokipia B Orebody was also found to be almost undetectable with the resistivity method. The readings which correspond to high I.P. values, most certainly due to the mineralization, showed only a very slight increase in the resistivity values.

From the preceding discussion it is evident that the resistivity method by itself can offer little in the search for sulphide mineralization in Cyprus. However, if it is combined with the I.P. it could be of some

/ assistance

assistance in the interpretation of field results. High resistivity values associated with high I.P. responses could be indicative of low grade mineralization. Also high resistivity values which could be associated with I.P. anomalies elsewhere in the area, could indicate extensions of the structural lineament which accommodated the sulphides and other associated minerals (silicification). It may similarly be concluded that if an I.P. anomaly is not accompanied by any high resistivity values compared with those of enclosing rocks, then the mineralization causing the I.P. anomaly would be of a higher grade. This was demonstrated in almost all areas where the I.P. anomalies responded to high grade mineralization,namely at Mathiatis western mineralization, Klirou southern and northern mineralizations, the Kokkinovounaros, the Vrechia and the Kambia mineralization, and the Agrokipia B Orebody.

/ V. CONCLUSIONS

V. CONCLUSIONS

From the preceding discussion a number of important conclusions can be drawn which express both the applicability and the limitations of the I.P. method over the sulphide mineralization in the modes it occurs in Cyprus.

The first conclusion is that indeed the I.P. method can give significantly high responses particularly when the mineralization is exposed (always covered by an oxidised layer). In this case the responses are generally higher, the bigger the size of the mineralized body. A significant drop in these responses appears when the mineralization is covered by even a small thickness of unmineralized rocks. It appeared from the previous discussion that up to a certain depth which was found emperically not to exceed the electrode spacing, this decrease in the I.P. responses remains constant. Below this depth, however, it appears that the responses suffer from a further decrease in their magnitudes. This is an important observation and it requires further investigation.

The indication of the existence of mineralization particularly when this is deeply seated, is certainly related with the magnitude of the responses of the enclosing rocks. From the preceding discussion it can be concluded that these could differ from one area to the other or more correctly from a certain stratigraphic layer to the other within the volcanic succession.

From the discussion on the variation in the width of a mineralized zone with respect to the position and spacing of the electrodes along the geophysical lines, it can be generally concluded that their relationship is very important. For exposed narrow zones, anomalous values are recorded if both the electrodes of the receiving dipole are over the mineralization. Significant decrease in their magnitudes are observed when one of these two

/ electrodes

electrodes is in the barren rocks. In cases where the other one is not well within the mineralized zone, then the responses could be low enough not to be considered as anomalous. Under the same conditions (exposed mineralization), the transmitting electrode also affects the amplitude of the I.P. values when placed in the mineralization.

The above behaviour of the receiving dipole appears to apply also for concealed mineralizations. From the above discussion it can be concluded that a narrow mineralized zone can only be indicated when it is included within a receiving dipole, and to a lesser extent when it is very shallow and a large part of the dipole length overlies the mineralized body. However, for depths even smaller than the electrode separation, there does not appear to be any anomalous response when only one electrode is over the mineralization. This is evidently a serious limitation and it implies that a survey can very well fail to record any anomalies over relatively shallow seated and narrow bodies of mineralization, as for example over the Mathiatis line 3.

This limitation does not apply when the concealed mineralized zone is wide enough to be covered by a number of dipoles. The only limitation is that it will appear on the anomalies as having a smaller width. From this it can be concluded that the wider the mineralization, the more likely is to be detected by I.P. Two phenomena contribute positively in this case: the size of the mineralization which will give higher responses, and the extent which will enable its detection by as many dipoles as possible.

With regard to the pseudosectional convention of plotting, from the preceeding discussion it can be concluded that provided the geophysicist is aware that this is a "false section", this can be a very useful way of displaying the results as it immediately demonstrates the position of the different electrodes which gave a particular reading. Further, from the pattern of the contours, the exact location of the polarising body can be

/ indicated

indicated together with a suggestion of the depth at which it occurs.

With regard to an indication of the grade of the mineralization it may be concluded that there can be no assistance from the N.T.I. values. These represent amplitudes of a certain response at a certain time period. If there is any information inherited in the I.P. responses regarding the sulphide content, this must be looked for in a spectrum of such values, in this case the I.P. transient decay. This was investigated thoroughly by considering a number of parameters which express the I.P. decays as an exponential decay and as a two-component $\log_e$ time decay. From the study of these parameters it can be concluded that no definite distinction between disseminated and higher grade mineralization could be made based on these parameters. There is an indication that the second component of the $\log_e t$ I.P. decay, decays more slowly over the disseminated than over the higher grade mineralization. This is an interesting observation, but the present author feels that it should be verified in the laboratory and with smaller spacing work over areas of known grade, as for example opencast benches, before it is applied with more certainty in the field.

Although the question of grade distinction is very crucial and no firm conclusions were drawn from the I.P. transient shape itself, the present research indicated that a more reliable indicator of the sulphide content is the resistivity of the rocks. Indeed it was demonstrated with little doubt that if an I.P. anomaly is accompanied by high resistivity values, it is certainly caused by disseminated mineralization. On the other hand, if the resistivity is very low approaching that of the enclosing rocks, then the mineralization is more likely to be of higher grade.

/ CHAPTER ELEVEN

CHAPTER ELEVEN

SUMMARY AND CONCLUSIONS

I. SUMMARY

The purpose of the present Thesis was to investigate the applicability and limitations of the I.P. method in the search for sulphide deposits in Cyprus. After a general review of the I.P. method presented in Chapter Two, there was given a description of the sulphide mineralization with particular attention to its mode of occurrence. This occurs in mineralized fracture zones of variable width and longitudinal extent. High grade concentrations could be found at any place in these zones depending on local conditions. Most commonly this occurs in the higher parts, either in the form of an exhalative deposit which was formed in those cases where the zone reached the surface, or as a sulphide concentration at the end of a fracture zone where the mineralizing fluids could not travel any further. Evidently, these zones could be either exposed or blind within the volcanic succession.

The present research intended to investigate the I.P. method over this type of environment. The primary objectives were to establish that the different modes where the sulphide mineralization is found, could be detected with the I.P. method. Further it intended to establish the conditions of locating these different targets in the field, particularly those with small width but nevertheless of great importance in mineral exploration. Another important objective was the establishment of criteria for the interpretation of the I.P. anomalies, by the study of the field results over mineralized bodies of known geometry. The purpose of this was

/ essentially

essentially to enable the determination, on the basis of the field results, of the exact position of these narrow zones of mineralization, together with an indication of their depth. Finally, the present research investigated the responses over the different grades of mineralization with the intention of establishing criteria which would enable the distinction between disseminated (generally uneconomic) and higher grade mineralization.

To achieve all these objectives, the I.P. method together with its field companion the Resistivity method, were applied over a number of areas which included sulphide mineralization in the different and commonest modes of occurrence it is looked for in a mineral exploration project. The responses over exposed mineralization were examined in the Klirou, Kokkinovounaros and Vrechia areas, where mineralized zones of variable width are exposed on the surface. Concealed mineralization responses were obtained in a number of areas. The Kambia area presented an example of a mineralized fault zone occurring in most part almost near the surface. The Mathiatis (western), Klirou (southern) and Vrechia (main) mineralizations were examples of shallow seated mineral deposits. The Petra area was an example of a concealed deposit occurring at a deeper level. The Klirou (northern) and the Agrokipia B Orebody, enabled the study of the responses over large sulphide deposits at depths exceeding the one hundred meters.

II. CONCLUSIONS

The first conclusion which can be drawn from the present research is that the different modes of occurrence of the sulphide mineralization in the Cyprus volcanic series can be detected by the I.P. method. However, the I.P. method behaves differently over the various modes. The highest amplitudes are recorded of course in those cases where the mineralization is exposed. Considerable decrease in the I.P. responses takes place when the mineralization is concealed even under a small thickness of unmineralized rocks. The amplitudes of the I.P. responses depend also on the size of the mineralization being evidently higher the larger the size of the body. With regard to the barren rocks, it can be concluded that these responses are generally low, but they show some variations within the volcanic succession.

Some important conclusions can also be drawn on the limitations of the I.P. method in the search for narrow mineralized zones. Their detection is greatly influenced not only by their size and depth, but also by their relationship with the geophysical grid. Anomalous readings in this case can only be recorded when the target is located within a receiving dipole. If it is located over a single stake there is a great possibility, with increasing depth and decreasing size, that no anomalous responses would be recorded. From the above, it can be concluded that the method suffers from serious limitations in the search for narrow mineralized zones or lineaments and perhaps up to a certain extent in depth, this cannot be applied at all.

With regard to the applicability of the method over large and deeply seated deposits, it can be concluded that these can be shown relatively satisfactory in an I.P. survey. The factors which control the detection

/ of such

of such bodies are their size and depth in relation to the electrode spacing applied. It is understood that the larger the electrode spacing the deeper the penetration, but also the greater the possibility of missing a body of mineralization. For this it can be concluded that the increase in the depth of penetration must be attempted with increasing the number of electrode separations applied, than the electrode spacing itself.

With regard to the presentation of the I.P. results, it is concluded that the pseudosectional plotting can be useful in showing the exact location of the polarizing body. Shallow seated bodies of mineralization are located within the receiver dipole(s) which gave the anomalous responses, and not necessarily where the anomalous responses fall on the conventional plotting. In deeper mineralizations the conventional pseudosectional plotting is found to correspond very closely to the actual location of the polarizing body. From the above it can also be concluded that the shapes of the anomalous patterns on the pseudosectional plots are indicative of the location, depth and size of the mineralization.

The I.P. transient was recorded over a number of mineralized bodies with the intention of investigating the possibility of distinguishing between disseminated and higher grades on the basis of the transient shape. The transients were factored in the form of two exponentials plus a constant related to the receiving instrument. From the study of these exponential factors at t = 0, it is concluded that although they show higher values over the mineralization compared with those over the barren rocks, they do not attain different values over the disseminated and higher grade mineralization. An important observation made during the present research was that on a logarithmic time axis and linear potential axis, the I.P. transient appears to consist of two components, an early, fast decaying and linear one, and a later slower and curved component. From the comparison of the various

/ parameters

parameters which describe this shape, it was found that mineralized ground shows in general higher values compared with those of the barren rocks. Regarding the grade of the mineralization, from the various results it can be stated that the parameters which describe the deviation of the second component from the first, appear in general to attain higher values over the disseminated mineralization. The conclusion which can be drawn on this phenomenon is that it suggests a possible distinction of the mineral grade on the basis of the decay curve shape and calls for further investigation particularly under laboratory conditions.

Together with the I.P., the present research examined also the applicability of the Resistivity method. The conclusions which can be drawn regarding this method is that it can offer very little when applied by itself, since the resistivity values of the mineralization do not always differ from those of the country rocks. Low grade disseminated mineralization is always characterised by very high resistivity values, whereas higher grade mineralization has lower resistivities approaching those of the enclosing rocks. From the above it can be concluded that the Resistivity method can be very useful when applied together with the I.P. method. High I.P. responses with high resistivity values indicate low grade disseminated mineralization, whereas high I.P. responses accompanied with low resistivity values are indicative of higher grade mineralization.

III. FURTHER RESEARCH

From the results of the present research programme and the discussion which followed, it becomes evident that some aspects regarding the applicability of the I.P. method require further investigation. These can be divided broadly into two categories. The first includes those aspects which are concerned with the applicability of the method as an exploration tool in the search for mineralized bodies of the type found in Cyprus. The second category includes all those aspects which are concerned with the variation of the transient shape with respect to the mineral grade and generally the mineralogy and texture of the rocks. These are discussed in detail in the following paragraphs.

The present research concluded on the applicability of the I.P. method for the search for mineralized zones, but it also pointed out its limitations, particularly in the detection of deeply burried and narrow bodies. For this, it is of atmost importance to investigate further the applicability of the method under such conditions and especially the limitations in the detection of a narrow body resulting from the electrode spacing and the location of the grid with respect to it. Such research should include an investigation of the applicability of mixed profiling or the repeating of the geophysical lines with the same configuration but with a shift of the grid by a fraction (e.g. a half) of the electrode spacing. Such a procedure would achieve a more thorough survey along a particular line. For this purpose some form of modelling, both computer and laboratory, would be required. In addition this can be investigated in the field over targets of known geometry.

As pointed out earlier, there was an indication that the I.P. responses (N.T.I.) vary within the lava succession. This requires further

/ investigation

investigation in order to establish the different values which must be expected in a certain area in the Pillow Lava Series. Such an investigation could be carried out by taking readings using short electrode separations over the different parts of the succession.

Another subject which merits investigation is the possibility of variations of the I.P. responses with weather conditions. For this, it is essential to establish a standard line which can be surveyed periodically taking into consideration the temperature and rainfall. Such a line should certainly run over a concealed mineralization with sufficient information on its geometry and grade.

The pseudosectional convention of plotting was found to show some variations in its patterns which are indicative of the depth and geometry of the mineralized body. This should be investigated further as it could convey useful information particularly on the depth of the target. Mixed plotting could also be experimented with. Such investigations could be accomplished with the utilization of the computer and modelling results mentioned earlier in this section.

The present research concentrated mainly in the Lower Pillow Lava terrain and investigated the responses of shallow seated mineralization at a maximum depth of 125 meters. There is no doubt that mineralized bodies should exist at much deeper levels covered by post-mineralization volcanics and younger sediments. Their mode of occurrence would certainly not differ from those examined in the present research, but their detection would be subjected to various complications mainly due to their depth and the overlying rocks. For this, some other form of deep penetration geophysics must be investigated, in particular I.P. measurements in boreholes.

The I.P. decay shape was investigated both as an exponential and

/ as a

as a $\log_e$ time decay. In both cases it was found that the factors which describe these two shapes varied and in some of them these variations appeared to be related to the mineral grade. This observation calls for further research on this subject under laboratory conditions. Regarding the exponential decay it appeared in some areas that the electromagnetic and true chargeability components are related to the mineral grade. In addition, the relaxation time of the electromagnetic component demonstrated in some cases an interesting behaviour which calls for further investigation.

The present research demonstrated that the transient decay is not linear on a $\log_e$ time axis but it consists of two components. Further, a number of parameters which describe this shape were found to attain different values over disseminated and higher grade mineralization. Particular attention needs to be paid on the deviation parameters. In addition the values of all these parameters must be treated statistically, in order to define their significance, with the study of more examples. Finally, another subject which requires research is the investigation of the values of these parameters and also the resistivity, with regard to the mineralogy and texture of the rocks.

REFERENCES

Adamides, N., 1975. The Geology and Mineralization of the Petra Area. Unpupl. Report, Hellenic Mining Co. Ltd.

Adamides, N., 1976. Geological History of the Limni Concession, Cyprus, in the Light of the Plate Tectonics Hypothesis. Trans. I.M.M., Vol. 84, Sec. B, p.17.

Adamides, N., 1978. A report on the Geology of the Kalavassos Mining Lease. Unpupl. Report, Hellenic Mining Co. Ltd.

Anderson, L.A. and Keller, G.V., 1964. A Study in Induced Polarization. Geophysics, Vol. 29, p.848.

Badgley, P.C., 1965. Structural and Tectonic Principles. Harper and Row, London.

Bear, L.M., 1963. The Mineral Resources and The Mining Industry of Cyprus. Bulletin No.1, Geological Survey, Cyprus.

Bertin, J., 1968. Some Aspects of Induced Polarization (Time Domain). Geoph. Prospecting, Vol. 16, p.401.

Bertin, J. and Loeb, J., 1974. Traitement 'a la main' et sur ordinateur des transistoires en polarization provoquee. Geoph. Prospecting, Vol. 22, p.93.

Bleil, D.F., 1953. Induced Polarization: a Method of Geophysical Prospecting. Geophysics, Vol. 18, p.636.

Brant, A.A., 1959. Historical Summary of Overvoltage Developments by Newmont Exploration Ltd. in 1946-1955. Overvoltage Research and Geophysical Applications, J.R. Wait (editor), Pergamon Press, London, p.1.

Cantwell, T., 1960. Detection and Analysis of Low Frequency Magnetotelluric Signals. Ph.D. Thesis, M.I.T.

Christoforou, J., 1975. The Geology and Mineralization of the Kokkinoyia Orebody. M.Sc. Dissertation University of Cardiff.

Coggon, J.H., 1971. Electromagnetic and Electrical Modeling by the Finite Element Method. Geophysics, Vol. 36, p.137.

Coggon, J.H., 1973. A Comparison of I.P. Electrode Arrays. Geophysics, Vol. 38, p.737.

Collet, L.S., 1959. Laboratory Investigation of Overvoltage. Overvoltage Research and Geophysical Applications, J.R. Wait (editor), Pergamon Press, London, p.50.

Constantinou, G., 1972. The Geology and Genesis of the Sulphide Ores of Cyprus. Ph.D. Thesis, University of London.

Constantinou, G. and Govett, G.J.S., 1972. Genesis of Sulphide Deposits, Ochre and Umber of Cyprus. Trans. I.M.M., Sec. B, Vol. 81, p.33.

Crone, J.D., 1975. Pulse Electromagnetic - PEM Ground Method and Equipment as applied in Mineral Exploration. Paper presented at the AIME Annual Meeting, New York, 1975.

Dey, A. and Morrison, H.F., 1973. Electromagnetic Coupling in Frequency and Time-Domain Induced Polarization Surveys over a Multilayered Earth. Geophysics, Vol. 38, p.380.

Dey, A., Meyer, W.H., Morrison, H.F. and Dolan, W.M., 1975. Electric Field Response of Two-dimentional Inhomogeneites to Unipolar and Bipolar Electrode Configurations. Geophysics, Vol. 40, p.630.

Dieter, K., Paterson, N.R. and Grant, F.S., 1969. I.P. and Resistivity Type Curves for Three Dimensional Bodies. Geophysics, Vol. 34, p.615.

Dolan, W.M., and McLoughlin, G.H., 1967. Consideration Concerning Measurement Standards and Design of Pulsed I.P. Equipment. Symposium on Induced Electrical Polarization, University of California, Berkeley, Procedings p.2.

Ebell, H., 1965. Some Overvoltage Field Trials with a New Type of Equipment. Geoexploration, Vol. 3, p.105.

Gedde, R.W. and Howland - Rose, A.W., 1970. Adapting I.P. to W.A. Conditions: Southern Miner, Vol. I, p.14.

Grant, F.S., 1971. On the Need for Measuring the I.P. Decay Curves in Situ. Preprint for Geophysics, Huntec Ltd., Toronto.

Gullis, C.G. and Edge, A.B., 1922. Report on the Cupriferous Deposits of Cyprus. London, Crown Agents for Overseas Governments and Administrations.

Habberjam, G.M., 1972. The Point of Assignment of an Earth Resistance Measurement. Geoexploration, Vol. 10, No. 3, p.141.

Hallof, P.G., 1963. Induced Polarization Case Histories and Technical Papers. McPhars Geophysics Ltd., Ontario.

Hallof, P., 1967. Theoretical Induced Polarization and Resistivity Studies. Scale Model Cases. McPhar Geophysics Ltd. Ontario.

Hohman, G.W., 1973. Electromagnetic Coupling between Grounded Wires at the Surface of Two Layer Earth. Geophysics, Vol. 38, p.854.

Hutchins, R.W., 1971. A New Induced Polarization Instrument, Huntec, Ltd., Toronto.

Hutchinson, R.W., and Searle, D.L., 1970. Stratabound Pyrite Deposits in Cyprus and Relations to Other Sulphide Cres. Symposium on Stratabound Sulphide Ore Deposits. IMA-IAGOD Meetings, Tokyo.

Keevil, N.B., and Ward, S.H., 1962. Electrolyte Activity: its Effect on Induced Polarization. Geophysics, Vol. 27, p.677.

Keller, G.V., 1959. Analysis of Some Electrical Transient Measurements on Igneous, Sedimentary and Melamorphic Rocks. Overvoltage Research and Geophysical Applications, J.R. Wait (editor), Pergamon Press, London, p.92.

Komarov, V.A., 1967. The Importance of Induced Polarization Method for the Exploration of Ore Deposits. Mining and Groundwater Geophysics, p.138, Can. Geol. Survey. Ottawa.

Madden, T.R. and Cantwell, T., 1967. Induced Polarization, a Review. Mining Geophysics, Vol. 2, Society of Exploration Geophysicists, Tulsa.

Maliotis, G., 1969. An Induced Polarization Study of Cyprus Ore and Rock Samples. M.Sc. Dissertation, University of Leicester.

Maliotis, G., 1974. The Geology of the Mathiatis (North) Mine. Unpupl. Report, Hellenic Mining Co. Ltd.

Maliotis, G. and Christoforou, J., 1975. A Geological Report on the Kokkinoyia Orezone. Unpupl. Report, Hellenic Mining Co. Ltd.

Mandel, P., Berg, J.W. and Cook, K.L., 1957. Electric Properties of Synthetic Metalliferous Ores. Geophysics, Vol. 22, p.398.

Marshall, D.J., and Madden, T.R., 1959. Induced Polarization: a Study of its Causes. Geophysics, Vol. 24, p.790.

Mayper, V., 1959. The Normal Effect. Overvoltage Research and Geophysical Applications, J.R. Wait (editor), Pergamon Press, London, p.125.

McEuen, R.B., Berg, J.W. and Cook, K.L., 1959. Electrical Properties of Synthetic Metalliferous Ore. Geophysics, Vol. 24, p.510.

Millett, F.B., 1967. Electromagnetic Coupling of Colinear Dipoles on a Uniform Half-Space. Mining Geophysics, Vol. 2, p.401.

Moeskops, P.G. and Quick, D.H., 1971. Field and Laboratory Studies of the Induced Polarization of Serpentinized Ultramafic Rocks from the Western Australian Archean Nickel Belt. Trans. I.M.M., Sec. B, Vol. 80, p.85.

Moores, E.M. and Vine, F.J., 1971. The Troodos Massif, Cyprus and Other Ophiolites as Ocean Crust: Evaluation and Implications. Phil. Trans. Roy. Soc. London, A, Vol. 268, p.443.

Mousoulos, L., 1957. Contribution a l' etude de Gisements de Pyrite Cuivreuse de l' Ile de Chypre. Ann. Geol. des Pays Hell., Ser. I, T. VIII, Athens, p.269.

Mousoulos, L., 1971. Report No. 8, Unpupl. Report, Hellenic Mining Co. Ltd.

Nettleton, L.L., 1971. Elementary Gravity and Magnetics for Geologists and Seismologists. Monograph No.1, The Society of Exploration Geophysicists, Tulsa.

Parkhomenko, E.I., 1967, Electrical Properties of Rocks. Transl. by G.V. Keller, Plenum Press, New York.

/ Patella

Patella, D., 1972. An interpretation Theory for Induced Polarization Vertical Soundings (Time-Domain). Geophysical Prospecting, Vol. 20, p. 561.

Phillips, W.J., and Richards, W.E., 1972. The Variation of Transient Voltage Decay Curves Across a Mineralized Zone. Geology in the Service of Man, University of Wales Colloquium, Gregynog.

Phillips, W.J. and Richards, W.E., 1974. A comparison of Transient Voltage Decay Curves obtained with different Electrode Arrays and Configurations over a Mineralized Zone. Geoph. Prospecting, Vol. 22, p.22.

Phillips, W.J. and Richards, W.E., 1975. Study of the Induced Polarization Decay Characteristics of some Sulphide and Graphite Mineral Deposits and a Discussion of some of the Factors Contributing to Induced Polarization Effects in Rocks. Trans. I.M.M., Sec. B, Vol. 84, p.83.

Quick, D.H., 1973. The Interpretation of Induced Polarization Surveys. Ph.D. Thesis, University of Leicester.

Schlumberger, C., 1920, Edude sur la Prospection Electrique du Sous - Sol. Gauthier - Villars, Paris.

Scott, W.J. and West, C.F., 1969. Induced Polarization of Synthetic High Resistivity Rocks Containing Disseminated Sulphides. Geophysics, Vol. 34, p.87.

Searle, D.L., 1968. Summary of the Geology of the Cyprus Cupriferous Sulphide Deposits and Notes on their Mineralogy and Origin. Unpubl. Report, Cyprus Geological Survey.

Searle, D.L., 1972. Mode of Occurrence of the Cupriferous Pyrite Deposits of Cyprus. Trans. I.M.M., Sec. B, Vol. 81, p.189.

Searle, D.L. and Constantinou, G., 1967. Geology of the Kalavassos - Drapia - Asgata Area. Unpubl. Report, Cyprus Geological Survey.

Searle, D.L. and Constantinou, G., 1968. Description of the Field Geology of the Tamassos Mining Area. Unpubl. Report, Cyprus Geological Survey.

Searle, D.L. and Panayiotou, A., 1968. The Geology of the Sha - Mathiatis Area. Unpubl. Report, Cyprus Geological Survey.

Siegel, H.O., 1959. Mathematical Formulation and Type Curves for Induced Polarization. Geophysics, Vol. 24, p.547.

Siegel, H.O., 1970. Induced Polarization Method. Mining in Canada, October 1970, p.3.

Stern, S., 1935. Notes on Spontaneous Polarization Observations, Unpubl. Report, Hellenic Mining Co. Ltd.

Sumner, J.S., 1976. Principles of Induced Polarization for Geophysical Exploration. Elsevier, New York.

/ Sunde

Sunde, E.D., 1949. Earth Conduction Effects in Transmission Systems. Van Nostrand, New York.

Swift, C.M., 1973. The L/M Parameter of Time-Domain I.P. Measurements - a Computational Analysis. Geophysics, Vol. 38, p.61.

United Nations Development Programme - Geological Survey Department, Cyprus, 1970. Survey of Groundwater and Mineral Resources, Cyprus. United Nations, New York.

Roussel, J., 1962. Etude sur modeles reduits des phenomenes de polarization provoquee. Annales de Geophysique, tome 18, fascicule A, October - December 1962.

Wait, J.R. (editor), 1959. Overvoltage Research and Geophysical Applications. Pergamon Press, London.

Ward, S.H., and Frazer, D.C., 1967. Conduction of Electricity in Rocks. Mining Geophysics, Vol. 2, Society of Exploration Geophysicists, p.198, Tulsa.

Wynn, J.C., and Zonge, K.L., 1974. EM Coupling, its Intrinsic Value, its Removal, and the Cultural Coupling Problem. Paper presented at the 44th International SEG Meeting, Dallas, 1974.