GEOPHYSICAL TECHNIQUES USED IN VOLCANOGENIC MASSIVE SULPHIDES EXPLORATION IN THE ARCHEAN GREENSTONE BELT OF WESTERN KENYA

CASE STUDY YALA-(KAKAMEGA)

SGL 413: PROJECT IN GEOLOGY

MBAU GITONGA

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DECLARATION AND APPROVAL

Declaration by Candidate

I declare that this is my original work and has not been presented for examination elsewhere.

Name: Mbau Gitonga (I13/2354/2007)

Signature…………………………………………………………………….

Date……………………………………………………………………………

Approval by Advisor

Prof. J. O Barongo

Department of Geology

Signature……………………………………………………………………..

Date……………………………………………………………………………..

Approval by Supervisors

Name……………………………………………………………………………

Department of Geology

Signature……………………………………………………………………..

Date……………………………………………………………………………..

ABSTRACT

A prospect is restricted volume of ground that is considered to have the possibility of directly hosting an ore body. As earth scientist therefore we look for ways of imaging the subsurface to rule out the question of a prospect. This project addresses how to use electromagnetic technique in imaging or locating conductive volcanogenic massive sulphides (VMS) and how geology influences mineralization. The case study area Yala- Kakamega located in Busia County with coordinates 0.06° and 34.32° where a ground follow up of an input airborne electromagnetic survey was conducted (Barongo 1987). Observations from the interpreted data in this report showed that graphite and Pyrite bodies which constitute the main target ore bodies reach near ground surface. The ore body also occurs mostly in the andesites and rhyolites rocks (Kavirondian system) as well as they are nearly vertically dipping due to the folding structures of the area. This correlation is useful in geological mapping. The electromagnetic method therefore is a simple technique which does not require any expensive trenching and is very effective in delineating these ore bodies.

ACKNOWLEGDMENT

I express my deepest appreciation to my advisor Prof. J.O Barongo for the commitment he has shown in guiding me in my work. I also thank Dr. Daniel Olago and Dr. C. Gichaba, my course coordinators for their tremendous efforts in seeing me through this project. This work would not have been accomplished without their help. I am greatly indebted to the Ministry of Environment and Mineral Resources for their library materials. Finally, my dear parents, siblings and to all my classmates for their support.

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CHAPTER 1

1.1 Introduction

Volcanogenic massive sulfide ore deposits (VMS) are a type of metal sulfide ore deposit, mainly Copper (Cu)-Zinc (Zn)-lead (Pb) which are associated with and created by volcanic-associated hydrothermal events in submarine environments. They occur within environments dominated by volcanic or volcanic derived (e.g., volcano-sedimentary) rocks, and the deposits are coeval and coincident with the formation of associated volcanic rocks. As a class, they represent a significant source of the world's Cu, Zn, Pb, Gold(Au), and Silver(Ag) ores, with Cobalt (Co), tin (Sn), as by-products. Volcanogenic massive sulfide deposits are forming today on the seafloor around undersea volcanoes along many mid ocean ridges, and within back-arc basins and fore arc rifts. Mineral exploration companies are exploring for seafloor massive sulfide deposits; however, most exploration is concentrated in the search for land-based equivalents of these deposits, (Alan 2007).

Kenya has tremendous potential of hosting these land-based VMS deposits due to its favorable geological setting. However; since most of these ores are located in the subsurface except for a few gossans, geophysical methods such as gravity methods, magnetic methods and electromagnetic methods are simple techniques which do not require crude exploration drilling or trenching. Many local miners especially in Western Kenya make use of crude methods such as this and end up in many cases not locating ores which becomes frustrating and its time consuming.

A lot of exploration and mining of VMS is carried out in Western Kenya hence much of the information and interpretations are as a result of the case study at Yala- Kakamega which involved geophysical detection of mineral conductors in Tropical Terrains with Target Conductors partly embedded in the conductive overburden, (Barongo 1987). Ground geophysical methods were used in the greenstone belt of Western Kenya as follow up of an input airborne electromagnetism (EM) survey, in which in late 1977 a combined EM airborne survey was flown in the greenstone belt by Terra Survey Limited of Ottawa Canada on behalf of the Kenyan Government. The survey covers a total area of $4000Km^2$ in which geological, geochemical soil mapping and ground geophysical surveys were later carried out on selected anomaly sites.

1.2 Statement of the Problem

A prospect is a restricted volume of ground that is considered to have the possibility of directly hosting an ore body and Kenya being a prospecting country has discovered its potential of hosting VMS deposits. However most local miners make use of crude methods of mining such as trenching, drilling in prospecting for these ores and end up becoming frustrated. This report seeks to address the exploration question of how to pinpoint these restricted volumes of ground through simple geophysical techniques and trying to correlate mineralization to geology.

1.3 Objectives

- Describe the geology and structure of the greenstone Belt of Western Kenya.
- Describe the geophysical Electromagnetic method which directly locates VMS deposits.

1.4 Methodology

- Desktop studies of the geology of the cratonic belt of Western Kenya
- Electromagnetic survey which include;
    - Airborne Time domain EM
    - Vertical Loop EM
    - Horizontal loop EM

1.5 Justification

VMS mineralization is located in the contacts of basalts and/ or volcano sedimentary formations in the earth and are host to precious metals such as gold silver or industrial metals Cu-Zn-Pb cobalt, tin and many others. These deposits therefore are of economic importance to the country.

1.6 Aim

The aim therefore is to get to appreciate simple ways of locating these deposits and to emphasize their importance to local miners.

1.7 GEOGRAPHY OF YALA (KAKAMEGA)

Figure 1.1 Geographical location of the study area in a blue dot.

(http://www.mapcruzin.com/free-maps-kenya/kenya_sm_2008.gif)

Yala is located in the previous Nyanza Province of Western Kenya about 42Km North West of Kisumu and 100km South West of Kakamega but now lies in Busia County bordering Kakamega County to the west. Its coordinates are 0.06°N and 34.32°E however; the survey area divided into blocks covers coordinates 0.05N and 34.25E with an approximate area of 4000Km^2.

The area generally hilly with altitudes varying from about 1300m in the western portion of the area to over 2100m on top of Nandi scarp. Rainfall is adequate and well distributed with annual averages between 60 to 75 inches and temperatures of about 25 to 30. The area is thickly populated and heavily cultivated except in the forest reserves and Nandi reserves. The main crop grown is maize and sugarcane in considerable tonnages others include, yams and cassava.

Three major river systems in the area, the Nzoia, Yala and Kiboi systems of these, the Nzoia with its tributaries is by far the largest. In the Mumias granite area these streams flow in the general NE- SW direction but on reaching the Kavirondian system, they swing to the east- west line roughly following the strike of the rocks. The rivers and their tributaries show evidence of rejuvenation in the form of waterfalls, gently sloping divides often drop sharply to the newly incised modern stream valleys. This rejuvenation has been caused by general uplift along Nandi fault. (Huddlestone 1954)

1.8 Geology of Yala –Kakamega

1.8.1 Geological Setting

The Archean greenstone of Western Kenya is a part of the greater Nyanzian shield which forms a major structural unit. Its bounded by the Mozambiquian Belt on the eastern side while on the south and southeastern side it's bounded by Ubendian Belt. The greater part of the geology of Yala- Kakamega area is the Nyanzian shield. Three lithological systems have been recognized in this shield, these include; Dodoman, Nyanzian and Kavirondian, (Ngecu 1991). However in the area of study, only the Nyanzian system forms the lower succession in the Nyanzian shield. Its composed of steeply dipping basic, intermediate and acidic volcanic rocks which are usually accompanied by minor pyroclastic developments. The upper succession of Western Kenya, Archean greenstone belt is predominantly composed of sedimentary formations which make up the Kavirondian system (figure 1.3).

The Nyanzian rocks of Kakamega area are represented by rhyolites, rhyolitic tuffs, andesites, andesitic tuff and basalts. The Nyanzian volcanics mainly occur to the southeast and also in the central portion of the Kakamega District.

The Precambrian (Archean) sedimentary rocks of the Kavirondian group which occur in a slightly arcuate zone in the middle of Kakamega district area trending from the west of this area and curving slightly North Eastwards to the Nandi fault, overly unconformably the Nyanzian rock. The rocks of the Kavirondian system are represented mainly conglomerates, grits and mudstones which are believed to have originated from the Nyanzian rocks,(Ichang'i 1983).

The major and minor intrusives are represented by the Mumias and Maragoli Goldfields granites (Huddlestone 1954) admellites, syenites, syenodiorites, diorites epidiorites, quartz-porphyry, granite porphyry, lamprophyres as well as altered dolerites.

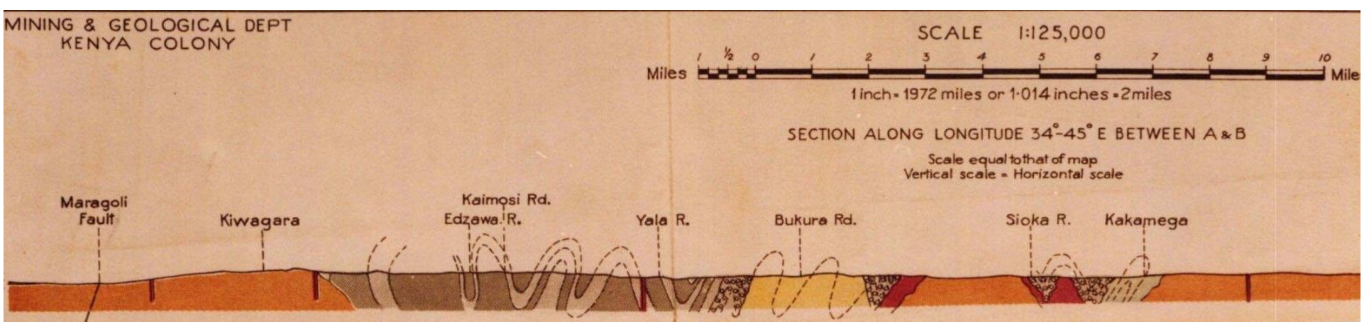
Tertiary phonolites which occur in the south- central portion of the Kakamega district while Pleistocene recent soil and lateritic iron oxides representing the youngest group in this area.

Mineralization in the greenstone belt consists of gold in association with silver both of which occurs mostly in small quartz veins or reefs, lead, zinc and copper in the form of sulphides(galena, sphalerite and chalcopyrite.) (Pulfrey 1952).

1.8.2 Structural Geology

The metamorphic effect encountered in the rocks are to a greater part as a result of thermal metamorphism due to Mumias granite and diorite intrusions (Pulfrey 1946). He was able to delineate two major metamorphic zones in the Nyanzian volcanic rocks in the Maragoli Region these are Hornblende zone and Hornblende Biotite zone.

Most of the area is underlain by sedimentary rocks of the Kavirondian system and these have approximately East – West strike lines over most of the area. The sedimentary rocks have been folded approximately along East-West fold axes and dips are on average high ranging from 50° to almost vertical generally (figure 1.2) towards the north and south (Ichang'I 1981).



mudstone
grit
(………….) conglomeratte
rhyolite
Granite intrusive
Basement rock

Figure 1.2 Geological Cross section of the region. (Huddlestone 1954)

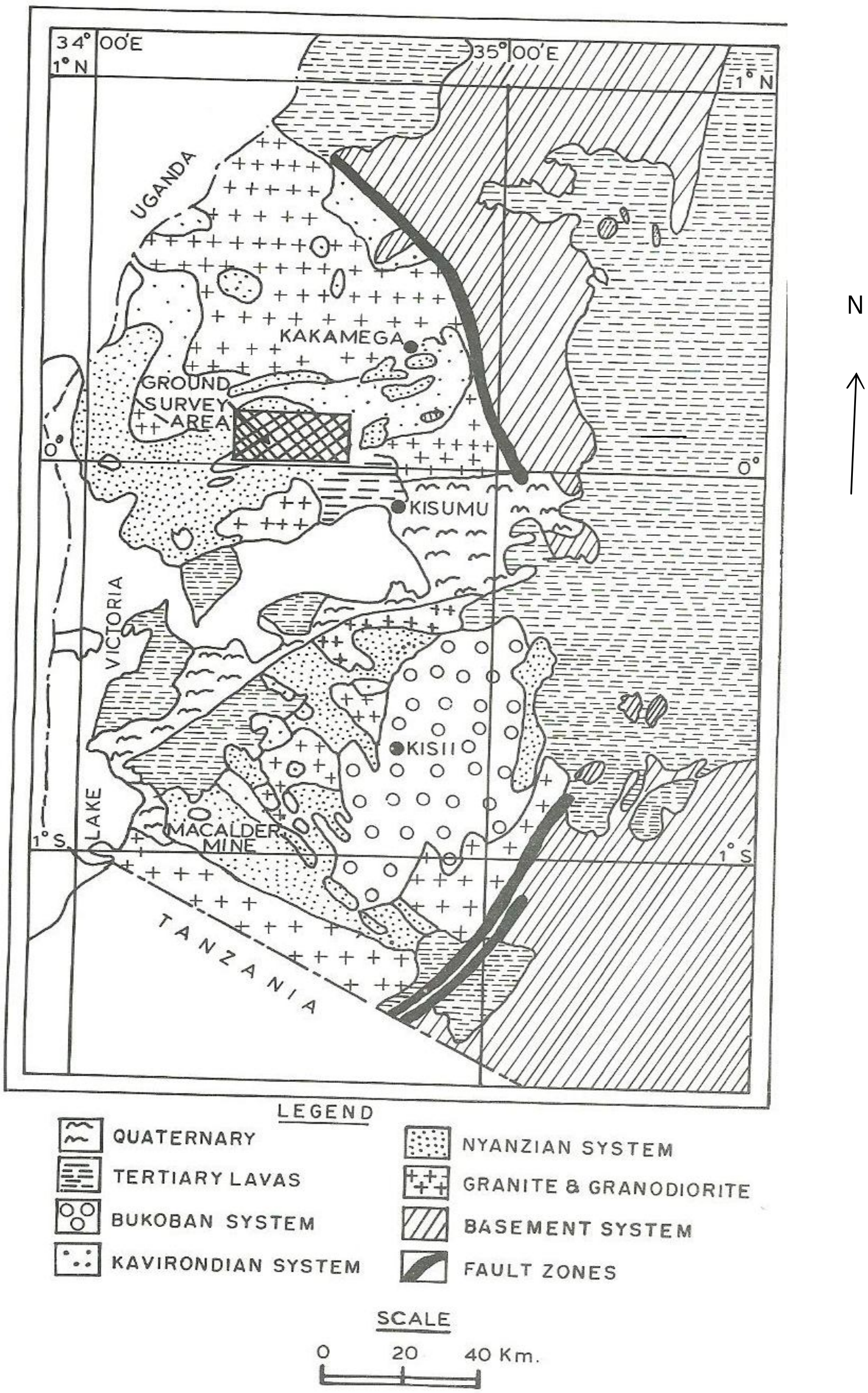


Figure 1.3 Geological map of Yala – Kakamega area. (Barongo 1987)

CHAPTER 2

2.1 BASIC PRINCIPLES

2.1.1 Electromagnetic Methods

Two types of electromagnetic survey were currently practised:

- Time – Domain Electromagnetic (TDEM) survey which is used for depth sounding and recently in some metal detector type instruments.
- Frequency – Domain Electromagnetic (FDEM) survey which is used predominantly for mapping lateral changes in conductivity.

Electromagnetic method generally uses coils and there is no need for probes to be in contact with the ground. This technique measures the conductivity of the ground and maps its variation within the earth's surface. From basic principle (Lowrie 2007), Coulomb's law shows that an electric charge is surrounded by an electric field, which exerts forces on other charges, causing them to move, if they are free to do so. Ampère's law shows that an electric charge (or current) moving in a conductor produces a magnetic field proportional to the speed of the charge. If the electric field increases, so that the charge is accelerated, its changing velocity produces a changing magnetic field, which in turn induces another electric field in the conductor (Faraday's law) and thereby influences the movement of the accelerated charge. The coupling of the electric and magnetic fields is called electromagnetism

Electromagnetic (EM) surveys are carried out at frequencies based on the principle of electromagnetic induction. An alternating magnetic field in a coil or cable induces electric currents in a conductor. The conductivity of rocks and soils is too poor to permit significant induction currents, but when a good conductor is present a system of eddy-currents is set up. In turn, the eddy currents produce secondary magnetic fields that are superposed on the primary field and can be measured at the ground surface.

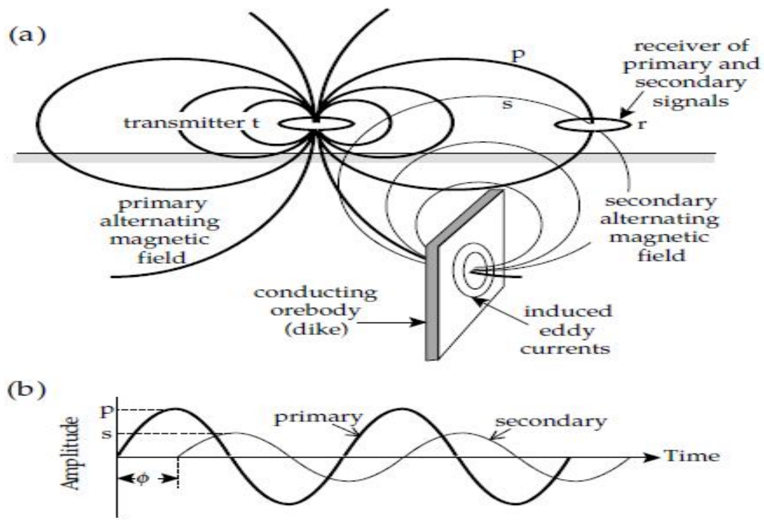


Fig 2.1 (a) Primary and secondary fields in the horizontal loop induction method. (b) Amplitudes and phases of the primary (p) and secondary (s) fields. (Lowrie 2007)

2.1.1.1 Frequency Domain E.M Method

To illustrate the concept involved, consider the simplified figure 2.1 above. Each of the three coils represent a particular agreement of an actual E.M system. The transmitter generates the primary field at a fixed frequency. The conducting loop represents an idealized geological conductor in the subsurface, with resistance (R) and self-inductance (L), while the receiver loop measures the resulting magnetic fields. Each loop is coupled to the others by mutual inductance. For a fixed frequency, let ($e_{p)}$ represents the induced voltage in the receiver caused by the direct coupling to the transmitter, while ($e_{s)}$ represents the induced voltage in the receiver caused by secondary field created by the ground loop.

The ratio of (e_s) to (e_p) voltages or ratio of H_S/H_P in the receiver is a measure of the response from the ground conductor necessarily normalized to offset any variance in the primary field strength as observed at the receiver.

In frequency domain surveys, alternating currents are passed through transmitter loop or wire at frequencies 200-4000HZ. There will, in general be a phase difference between the primary and secondary fields and anomalies are normally expressed in terms of amplitude of the secondary field (e_s) competent that are in **IN PHASE** and **QUADRATURE** (out of phase by 90°) with the primary. For any given body, the **amplitude (Response Function)** of the In Phase and Quadrature anomalies are determined by a **Response Parameter α** that varies with conductivity and frequency.

The most important is that the operating frequency is low enough at each of the intercoil spacing that during HLEM the electrical skin depth in the ground is always significantly greater than the intercoil spacing. Under this condition (known as operating at low induction numbers), virtually all response from the ground is in the quadrature phase component of the received signal. With these constraints, the secondary magnetic field can be represented as;

$$\frac{H_S}{H_P} = \frac{i\omega\mu_0\sigma s^2}{4}, \quad \text{therefore} \quad \sigma_a = (4/\omega\mu_0 s^2)(H_s/H_p)_q$$

where

H_S = secondary magnetic field at the receiver coil

H_P = primary magnetic field at the receiver coil

ω = $2\pi f$, f = frequency in Hz

μ_0 = permeability of free space in henry/m

σ = ground conductivity in S/m (mho/m)

s = intercoil spacing in m

I = $(-1)^{1/2}$, denoting that the secondary field is 90° out of phase with the primary field

2.1.1.2 Time Domain E.M System (TDEM)

In Time domain E.M system, the time variation of the current is a switch on, followed by a switch off i.e uses current pulses. When the current is off the receiver voltage is simply the secondary voltage (e_s) and primary (e_p) voltages.

The secondary voltage shows the characteristic exponential decay of an LR circuit, that is to say, the rate of decay depends on the resistance (R) and inductance (L) of the ground. In general good conductors have secondary field responses which decay slowly after switch off. These good conductors can be detected at great depth when the conductor is large and the intervening material is highly resistive. Poor conductors have responses that decay rapidly.

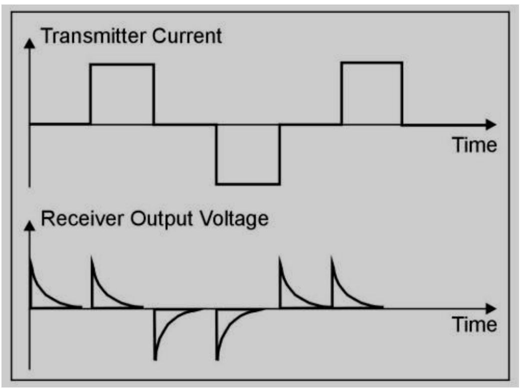


Figure 2.2 transmitter current pulse and current decay after current is switched off. (Lowrie 2007)

CHAPTER 3

3.0 METHODOLOGY

Geophysical exploration of VMS involves reconnaissance survey to search for areas where mineralization occurs. This is followed by detailed survey to pinpoint or delineate the VMS mineralization.

Reconnaissance Survey

- Time Domain Airbone EM.
- Vertical Loop EM. (VLEM)

Detailed Survey

- Horizontal Loop EM. (HLEM)

3.1 TIME DOMAIN AIRBORNE EM METHOD

Controlled source airborne EM survey systems were developed after the Second World War to explore for mineral deposits to respond primarily to conductivity of material in the earth (Richard 2010). Their primary success by International Nickel Company in early fifties was discovering highly conductive massive sulphide bodies located in resistive terrain in Canada.

3.1.1 Field Proceedures.

The receiver is towed behind and below the aircraft. These systems have a transmitting coil mounted around the aircraft giving a large dipole moment usually around $10^5 Am^2$. Typically they have a large transmitting- receiving coil separation (75-100m) and flying at an altitude of 100-150m above ground level at an approximate speed of 160 to 180km/hr. A flight path is determined by describing the flight line and line spacing for the aircraft navigation. Extraneous

EM noise produced by man-made and natural signals eg radio waves, electric power lines quite often pose severe problems. Therefore most EM signals should be fitted with 50 or 60 HZ to counteract this effect.

In late 1977, a combined electromagnetic/magnetic airborne geophysical survey was flown in the greenstone belt of Western Kenya by Terra survey limited of Ottawa, Canada on behalf of the

Kenyan Government. This was a reconnaissance survey to locate possible areas of anomalous or mineralization. A towed bird time domain input MKV system was used. The survey area was divided into five blocks covering a total area of about $4000km^2$. The flight line spacing in all blocks was 200m except for some extensions with a line spacing of 500m. a total of approximately 18600 line km were flown at an average terrain clearance of 1200m (Barongo 1987).

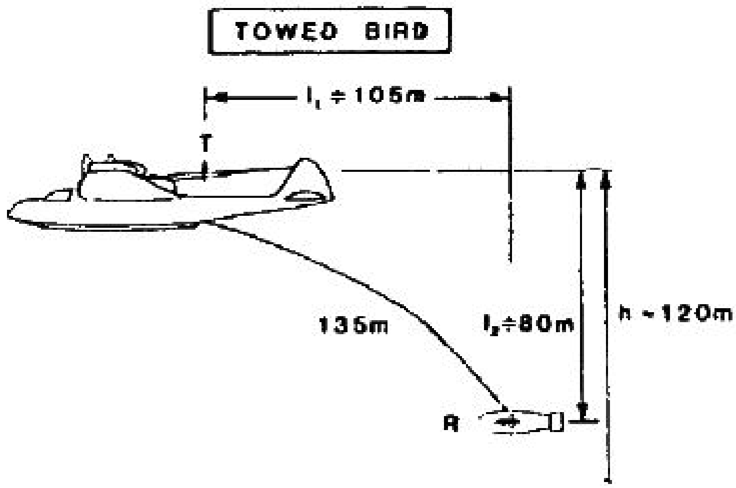


Figure 3.1 Airbone EM Survey plan. (Lowrie 2007)

From basic principle a current pulse is transmitted and the transient EM response is measured after the pulse is turned off.

The input AEM system samples the anomaly decay curve at 6 different time windows and records then on six channels. Therefore a complete input AEM anomaly would contain bars or signature of at most 6 different characters. The bars with dark shading represents an anomaly that shows on all six channels. Anomaly recorded on only one channel is represented by two parallel dashed lines.

The higher the number of channels a particular anomaly shows the higher the conductance or conductivity thickness product of the conductor the bar represents. A group of enclosed bars or signatures represents an input AEM anomaly which in turn delineates a conductive zone in the ground.

3.2 Ground Geophysical Surveys

Ground follow up was conducted in several phases (Barongo 1978) which consisted of geophysical surveys, geological mapping and geochemical soil sampling on selected anomaly.

A survey grid was cut on each anomaly site consisting of a base line and several traverse lines with a standard separation of 125m or less and observation or reading stations at 25m interval in the East –West direction.

3.2.1 VLEM

Instruments

- Crone VLEM
- Jalander Vertical Field fluxgate Magnetometer

Objective

To delineate rapidly and accurate the conductor's axis and hence its strike direction on the ground and check whether the conductor had any magnetic anomaly associated with it.

3.2.1 Field Proceedure

VLEM configuration used is the fixed transmitter technique in which the receiver and transimitter travel in tandem along parallel lines directly opposite each other. At a reading station, the transmitter loop, is placed vertically over the anomaly and oriented so that its planes concide with the receiver station. When the transmitter is turned on, the receiver operator, some distance away rotates the receiver coil round a horizontal axis that joins the two station until the receiver coil is in a position of minimum induction and the corresponding tilt angles are determined. This angles are normally measured at two operating frequencies 390 and 1175HZ

Once the tilt angles have been measured they are plotted in a profile along the line of their recording to determine the **crossover** that is any point on the grid where this value is zero or places where the dip angle measurement change sign through zero in a certain sense.

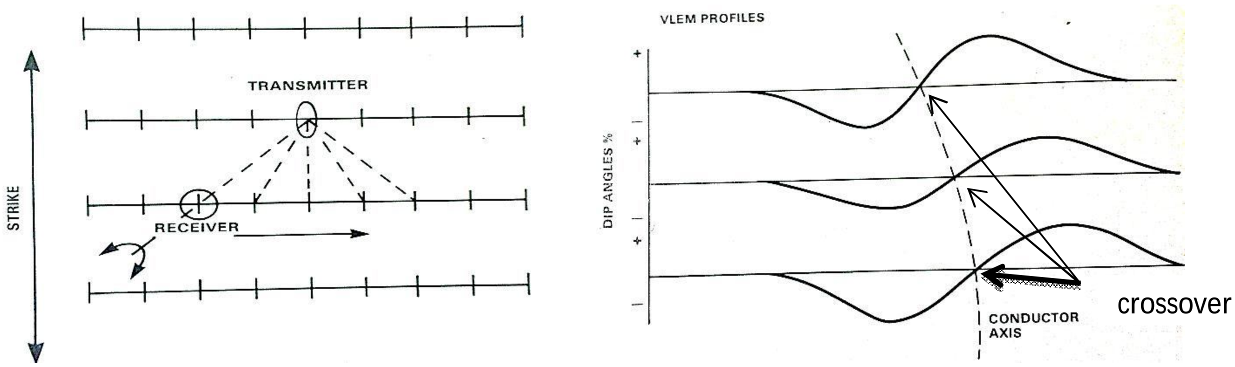


Figure 3.2 (a) Plan view of VLEM field procedure (b) strike direction of a conductor. (Melvyne 1989)

3.2.2 HLEM

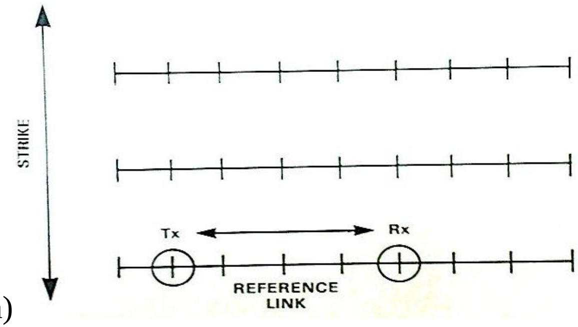
The horizontal loop EM system used consist of a consist of a transmitting coil and a receiver. The transmitter generates a frequency which is usually set between 200Hz and 4000Hz. This signal is detected by the receiving coil and a cable connecting the transmitter and receiver allows the signal to be completely cancelled when no geological conductor is present. If a conducting body is present the transmitted signal will generate eddy current in that body. These eddy currents in turn generate a secondary magnetic field which is detected and measured by the receiving coil. It is customary to measure the component in phase with the primary transmitted signal and that which lags it by 90° (quadrature)

Instruments

- Apex Max MinII HLEM System

3.2.2.1 Field procedure

The transmitter (Tx) and receiver (Rx) coils remain in coplanar configuration at constant seperations. When surveying the Tx and Rx coupled by the reference cable move as a unit long the traverse line (figure 3.3). Intervals reading are taken at one quarter the coil separation. When an anomalous response is encountered, readings are often closed up to one eighth the coil separation to provide greater density of data to aid in its definition.

(a) 

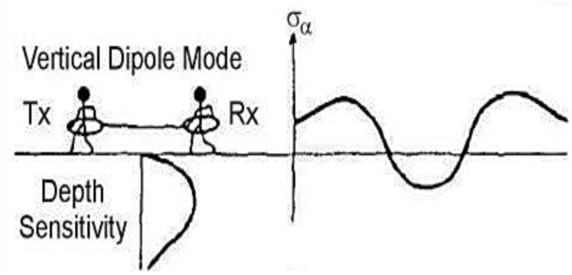
(b) 

Figure 3.3 (a) Plan view of HLEM field procedure (b) Tx-Rx configuration over a conductor.(Melvyn (1989)

The methods are illustrated by the horizontal loop electromagnetic method (HLEM) (figure 3.3b) ,popularly known also by the commercial names *Slingram* or *Ronka*. The receiver and transmitter are coupled by a fixed cable about 30 to 200 m in length, and kept at a constant separation while the pair is moved along a traverse of a suspected conductor. The cable supplies a direct signal that exactly cancels the primary signal at the receiver, leaving only the secondary field of the conductor. This is separated into inphase and quadrature components, which are expressed as percentages of the primary field and plotted against the position of the mid-point of the pair of coils. The in-phase and quadrature signals are zero far from the conductor and at the places where either the transmitter or receiver passes over the conductor. This enables the outline of a buried conductor to be charted. The signal rises to a positive peak on either side and falls to a negative peak over the middle of the conductor. The peak-to-peak responses of the in-phase and quadrature components depend on the quality of the conductor, which is expressed by a response parameter % H_s/H_p or % V_s/V_p. A suitable function is the dimensionless parameter $\boldsymbol{\alpha=\mu_0\sigma\omega sl}$, which contains the conductivity σ and width s of the conductor as well as the coil spacing l and frequency ω of the EM system.

HLEM surveying was done at anomaly p using the Apex Max MinII system with a transmitter receiver separation of 150m using frequencies of 222HZ, 444HZ, 888HZ, 1777HZ, and 3555HZ. Plotting of amplitudes of in-phase and out-of-phase profiles for all frequencies was done using Microsoft excel and surfer 8 softwares, after removal of the background effect.

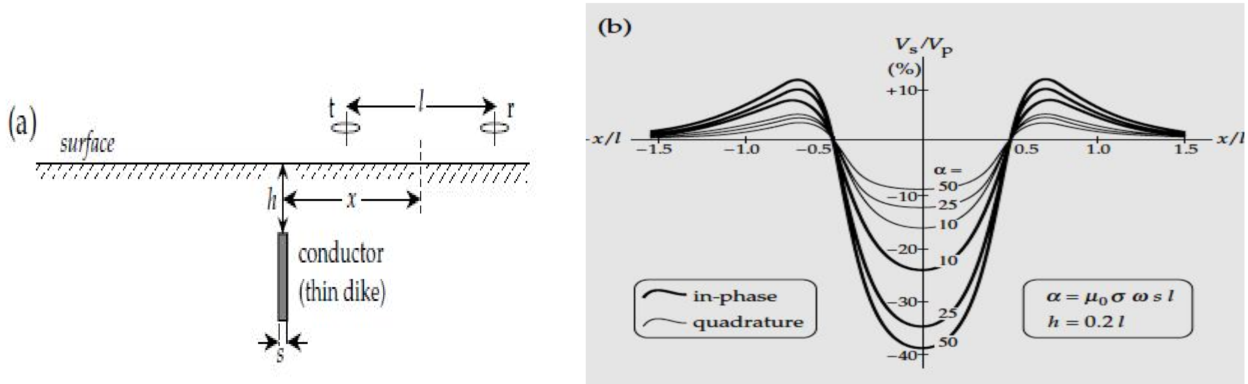


Figure 3.4 (a) Geometry of an HLEM profile across a thin vertical dike. (b) In-phase and quadrature profiles over a dike for some values of the dimensionless response parameter *a*. (Lowrie 2007)

CHAPTER 4

4.0 RESULTS and INTERPRETATION

4.1 Results

4.1.1 Reconnaissance AEM RESULTS

Two sets of input AEM anomaly maps figure 4.1 and figure 4.2 were prepared at a scale of 1:25000 and 1:50000. In these maps the airborne anomalies are represented by groups of enclosed EM signatures in the form of parallel or semi-parallel thin bars with or without a pointer in the middle. The extent of each bar or signature marks the extent of a conductor along a particular flight line. As the input AEM system samples the anomaly decay curves at six different time windows and records them on six channels, a complete input AEM anomaly map would contain bars or signatures of at most six different characters.

The bars with dark shading represent an anomaly that shows on all six channels of the input AEM record. The other bars have a decreasing intensity of shading related to the number of channels on which the anomaly is recorded. An anomaly recorded on only one channel is represented by two parallel dashed lines. The higher the number of channels a particular anomaly shows on, the higher the conductance or conductivity-thickness product σt (where σ is the conductivity and t is the thickness). A group of enclosed bars or signatures represents an input AEM anomaly which in turn delineates a conductive zone on the ground.

4.1.2 Interpretation

Applying the convectional criteria for selecting conductor anomalies due to massive sulphide bodies namely; conductance, magnetic association, and conductor isolation a priority rating of (1-3) is assigned to most probable bedrock for the purpose of ground follow up.

After ground follow up through geochemistry and ground geophysics and geology, the rating is modified based on high conductance, favourable geology and presence of mineral outcrops to select potential targets for further study.

Figure 4.2 shows the location of the four input AEM anomalies and the geology in which they occur. **Anomaly P** is wholly situated in the mafic geology of the Kavirondian system dominated by mudstones. **Anomaly Q** occurs on or near the boundary between the Nyanzian andesites and rhyolites and the Kavirondian conglomerates and grits. **Anomaly R** in the felsic and highly resistive rhyolitic geology of the Nyanzian system while **anomaly S**, which occurs on the boundary between the Nyanzian rhyolites and andesites.

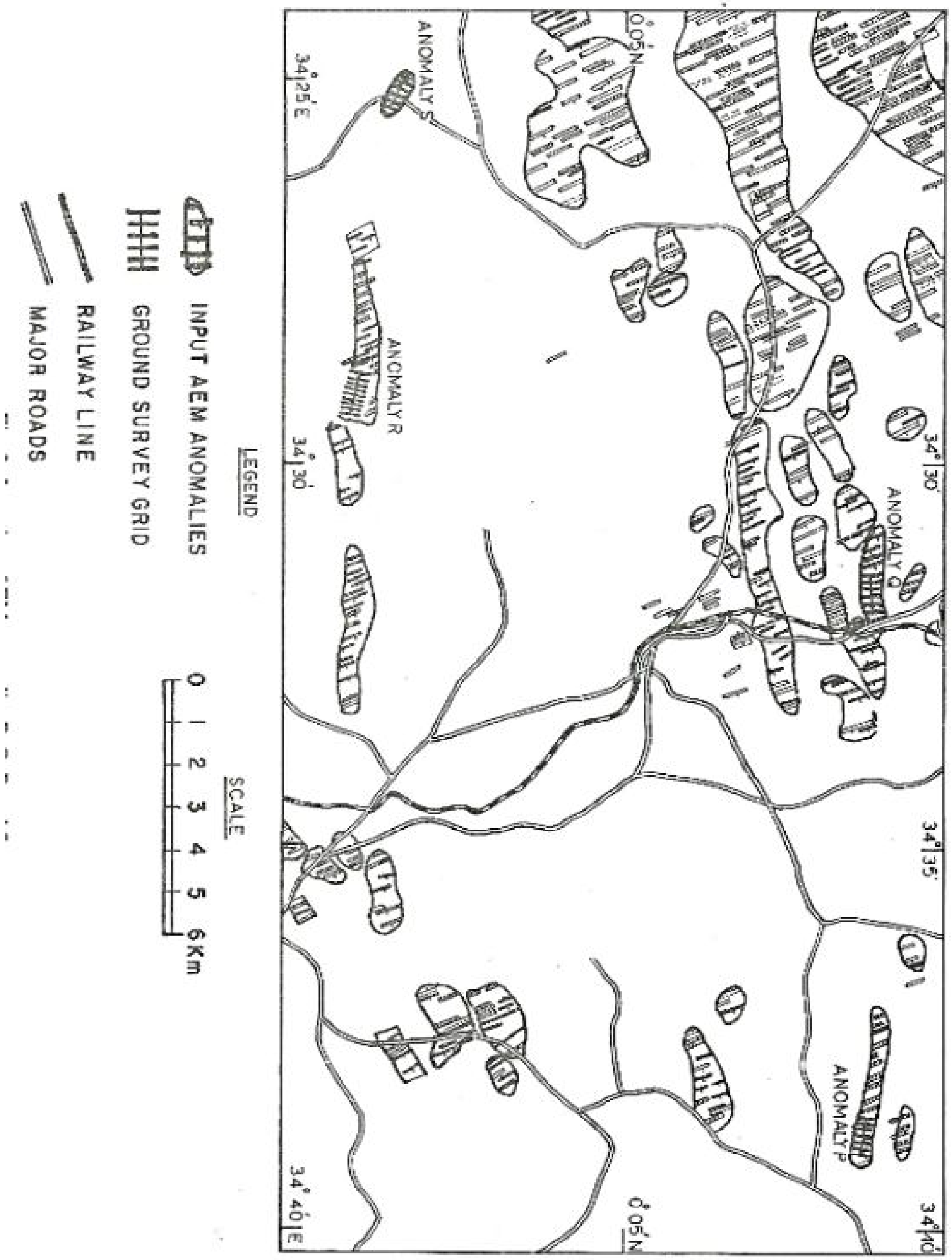


Figure 4.1 location of EM anomalies P,Q,R, and S. (Barongo 1987)

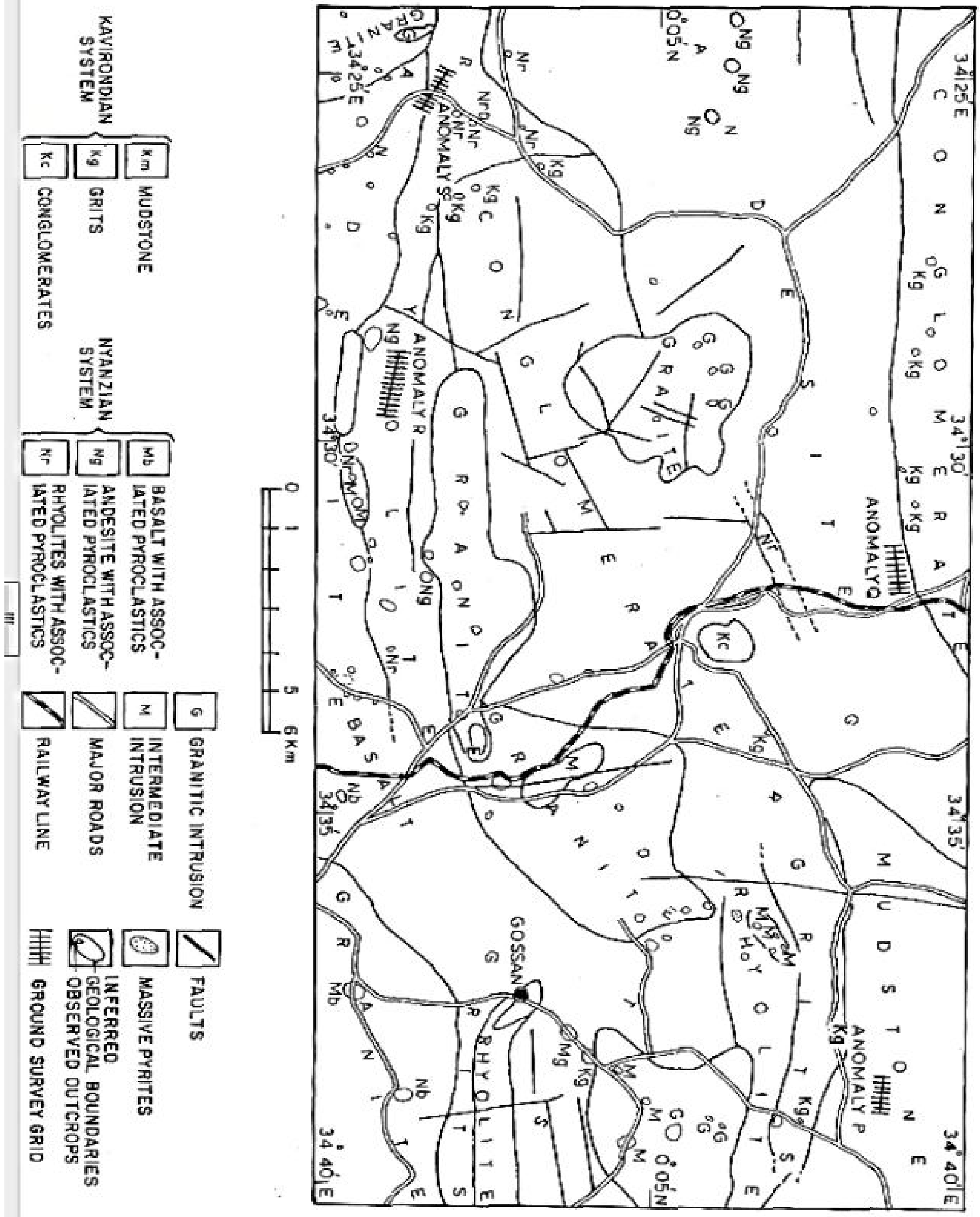


Figure 4.2 Geology of the area containing EM anomalies P,Q,R, and S (Barongo 1987)

An interesting correlation between the anomaly map and geology is observed. Figure 4.2 shows that about one third of the area to the northwest is covered by elongated anomalies that coincide well with the area covered by Nyanzian andesites while the regions covered by granitic intrusives show no anomalies. The regions covered by Kavirondian conglomerates, grit and mudstone show no anomalies.

4.1.3 Detailed Ground Survey Results

Ground geophysical survey which involved Vertical loop EM (VLEM) to delineate the strike of the conductor and Horizontal loop EM (HLEM) to determine the depth and thickness of the ore conductor. However, only anomaly P was taken into consideration in this report since they offer substantial information.

4.1.3.1 VLEM Results

The angles measured (appendixII) at null position that is the crossover points at zero or horizontal position and values plotted for both 390HZ and 1175HZ (figure4.3)

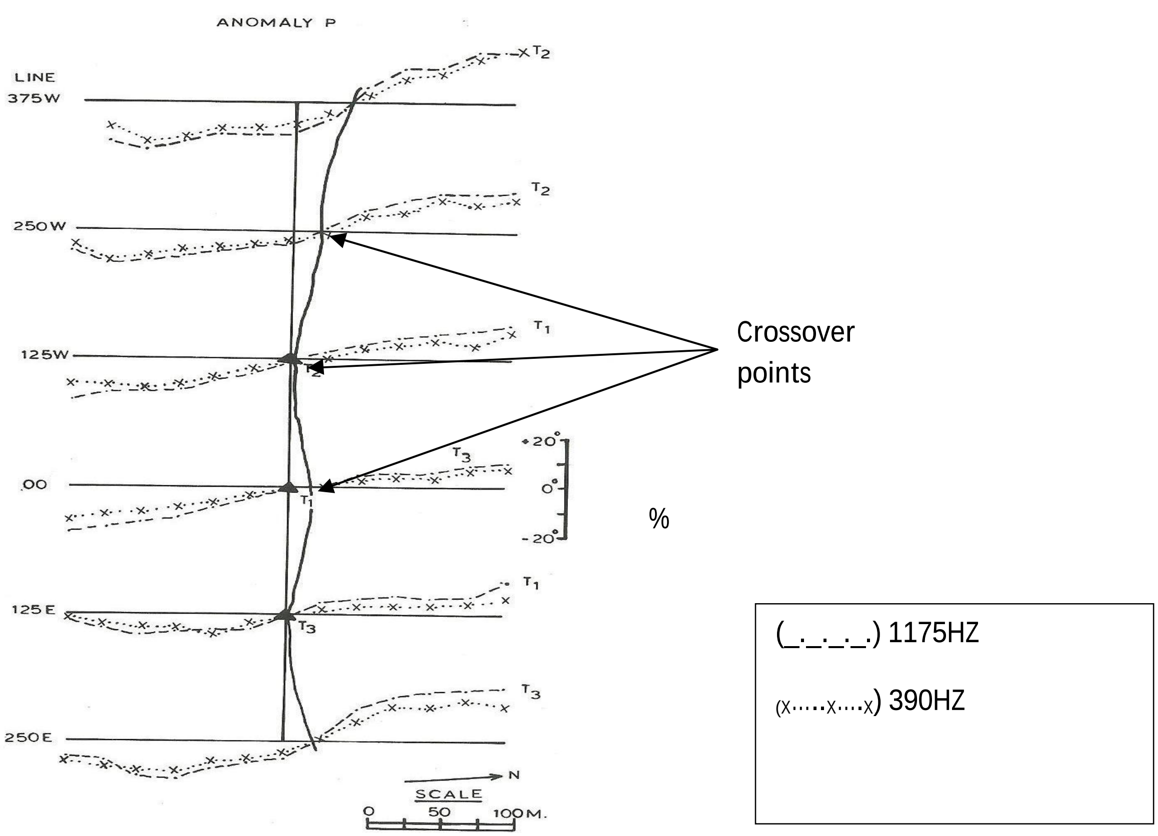


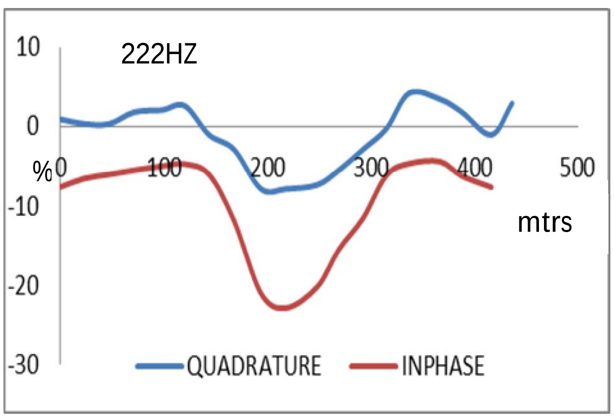
Figure 4.3 Crone fixed transmitter vertical loop EM profiles across anomaly p. (Barongo 1987)

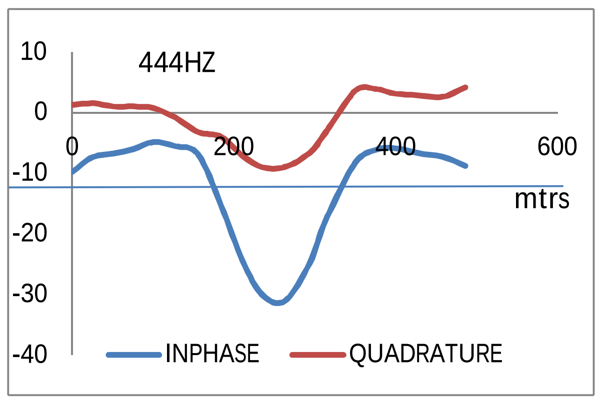
4.1.3.2 Interpretation

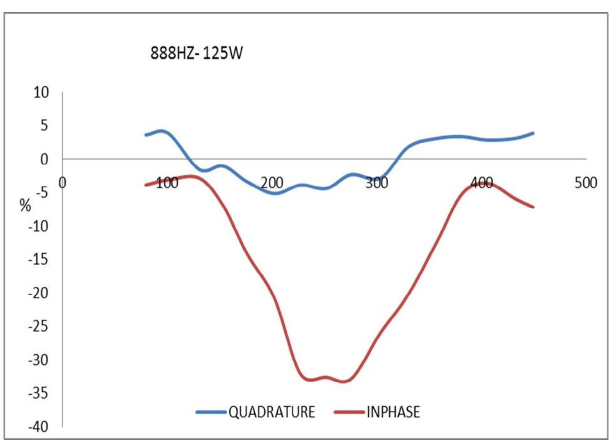
The trace of the conductor is found by joining the crossover points from one traverse line to the next (figure 4.3). The strike is found to be roughly to the east – west direction. There is a correlation between the geological structures and the strike- dip direction. From previous mineralization the VMS deposits occur as stratiform deposits that is horizontally parallel to the rock structures. However due to metamorphism as discussed in the geology its evident that the VMS have been folded together with other rocks and occur now as sheeted dykes. Anomaly Q occurs in the same latitude or horizon with anomaly P hence they have same strike.

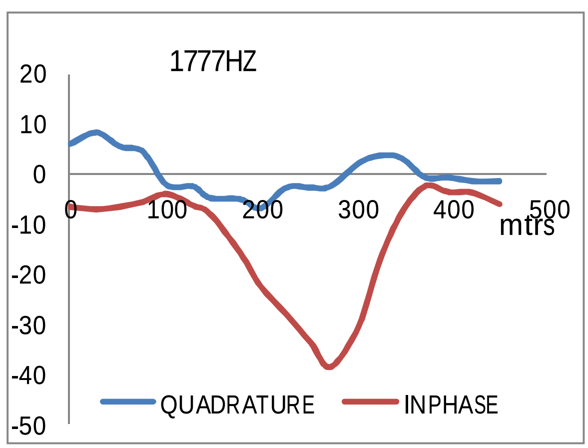
4.1.3.3 HLEM RESULTS

Ground survey done at a separation between the receiver and transmitter at 150m were conducted along anomaly P and Q. Traversing perpendicular to the strike the response curves of the in-phase and out of phase data computed by the instruments see (appendixI) were plotted for different frequencies using excel as a data compiler and sufer8 to plot these data **(H_S/H_P)% against distance in meters.**









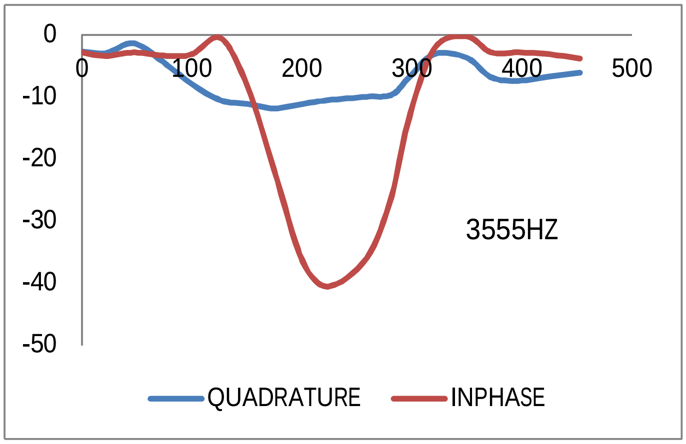
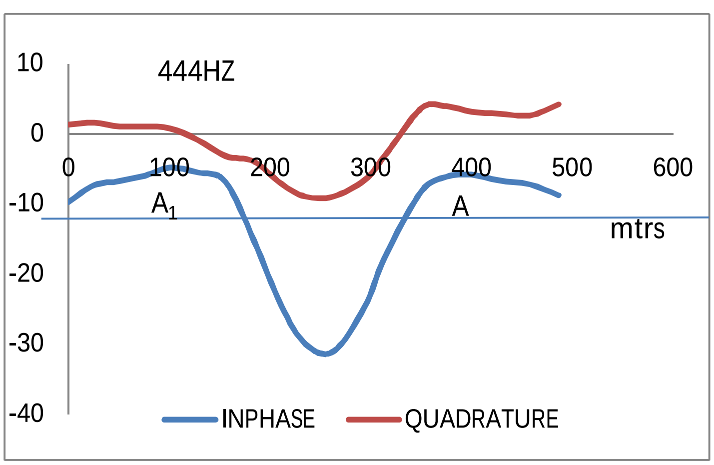


Figure 4.4 HLEM profiles for frequencies 222HZ, 444HZ, 888HZ, 1777HZ and 3555HZ.

4.1.3.4 Interpretation

The anomaly curves observed for the HLEM measurements show a significant response at the location of the buried ore conductor. At low frequencies of 222HZ and 444HZ, significant anomalies are observed especially on the in-phase component. At high frequencies however, there is a general gradual increase particularly on in-phase amplitude due to the skin depth effect discussed in chapter two.

The profiles also show a common symmetrical shape more on the in-phase component. This indicates that the ore body is vertical or has a 90° dip. This is supported from the calculation of dip based on the ratio of the areas under the two shoulders of the curve (A_1/A_2) in which it varies from one for a symmetrical, vertical case to zero for a horizontal sheet (John 1997).



Ratio ${A1}/{A2}$

${379.79}/{281.99}=1.35$

DIP =89.9°

Figure 4.5 Calculation of dip of ore body.

Free-air phasor diagrams of Nair Biwas and Mazumdar (1968) in appendixIII are used to calculate the values of depth to the top of the conductor (d) and its conductivity thickness product σt.

	222HZ	**444HZ**	**888HZ**	**1777HZ**	**3555HZ**
In-Phase	-15.79	-21.32	-27.43	-31.54	-37.14
Quardrature	-8.67	-8.90	-6.13	-6.90	-8.43
d (depth) m	45.0	39.0	37.5	35.0	22.5
σt (s)	53.2	37.5	34.0	35.0	12.3

Table 4.1 interpreted results from the HLEM profiles of anomalyP.

The table below shows the thickness of the ore body calculated as the difference between the two shoulder distances.

Frequency Hz	**222**	**444**	**888**	**1777**	**3555**
Thickness (m)	246.1	300	275	271	223
Average Thickness	**263.0m**				

Table 4.2 interpreted thickness from the HLEM profiles of anomaly P.

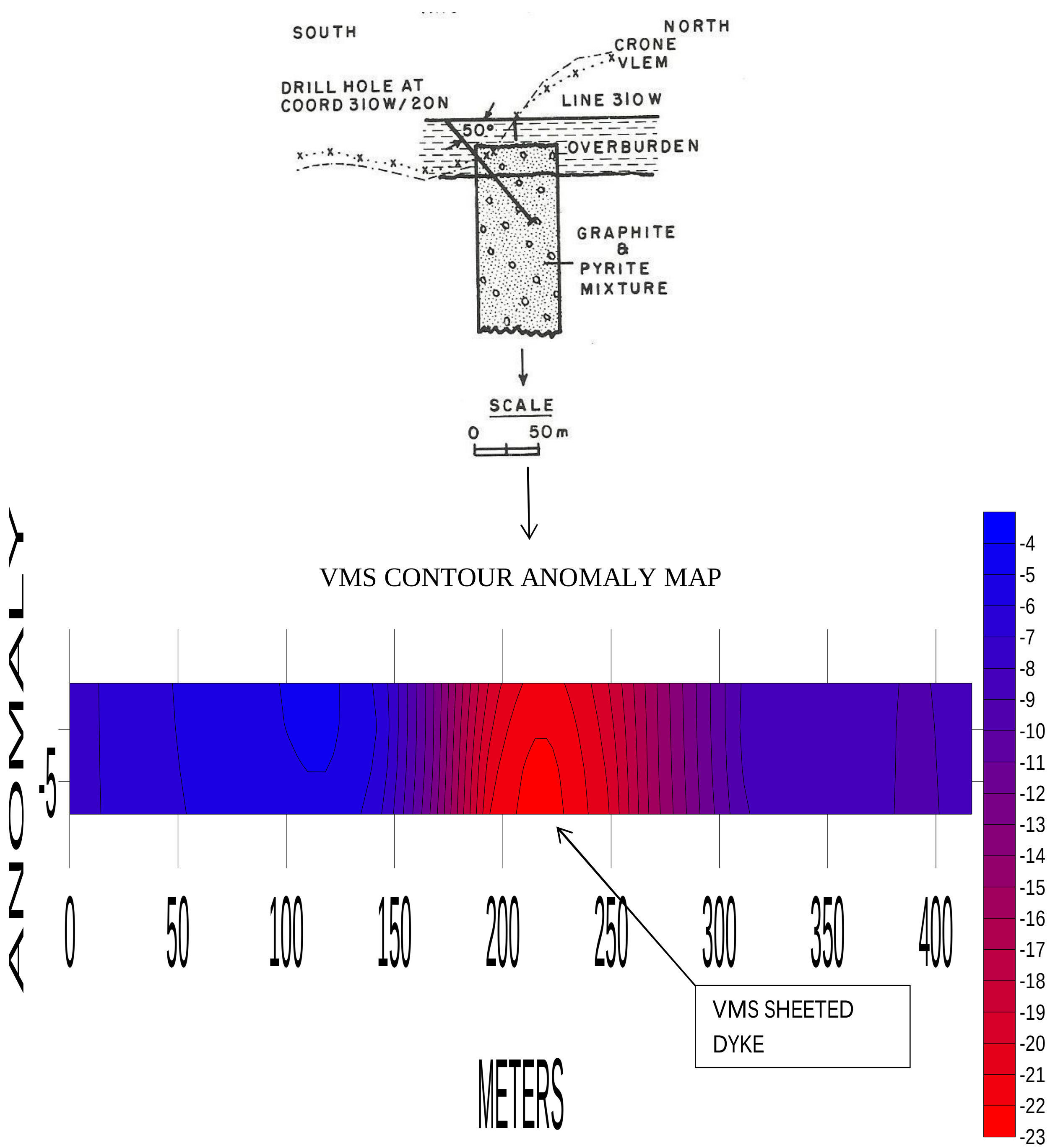


Figure 4.6 (a) A drill hole of anomaly s at 310w traverse line. (Barongo 1987) (b) An interpreted contour anomaly map.

A contour map showing the anomaly with red indicating anomalies while blue shows background or host rock plotted for all frequencies, plotted using surfer8 software.

CHAPTER 5

5.0 DISCUSSION CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

The electromagnetic method is effective in locating and detecting shallow VMS deposits. It is observed that the VMS deposits are found at shallow depth with an average value of 40 meters deep, and a thickness of about 263m. Upon drilling (figure 4.6a) shows mineralization to be composed of pyrite and graphite.

It is observed that the input airborne EM response is much more common in the areas underlain by andesites and rhyolites than any other rock type (figure 4.2). The area covered by granitic intrusives is completely bare of these anomalies. This correlation can be useful in geological mapping.

Mineralogy of VMS states that they occur as stratiform deposits. However from dip calculation and strike delineation, the VMS occur as a sheeted dyke. In context, metamorphism caused folding and dipping of host rocks to nearly vertical positions (Huddleston 1954) hence stratiform layers were oriented almost vertically to form sheeted dykes. This is evidenced by the presence of graphite which forms under extreme temperature and pressure.

It is observed that the effect of conductive overburden in galvanic contact with a target conductor (VMS) affects the EM response at high frequencies. Tropical environment has a conductive upper zone due to water and weathering products such as clays which interfere with the EM response as frequencies increases. The overall effect makes the target conductor appear shallow and less conductive at higher frequencies. (Mwanifembo 1997).

5.2 Conclusion

The geophysical techniques are very important tools in the imaging the subsurface. Its accuracy and simplicity makes electromagnetic technique very efficient and cheap. The geology and structures are important in locating these deposits. VMS deposits occur mainly in felsic extrusive igneous rocks such as rhyolites and andesites. These rock types are good location areas for VMS deposits. The structures are important in delineating their occurrence and give vital information on how to mine them.

5.3 Recommendation

- VMS deposits are source of base metals and gold and from the study , they occur at shallow depths. These deposits therefore can be excavated easily and cheaply.
- The greenstone belt extends for miles into Tanzania. These are areas of potential VMS deposits which should be surveyed using the EM technique and anomaly maps be sketched for further detailed geophysical studies.
- The VMS deposits are associated by submarine environments (Alan 2007). Kenya hosts the Mozambique Belt which is a collision zone, closing up an ocean (Prichard and Alabaster 1993). Therefore VMS deposits have a potential of being hosted in these areas.
- Geophysical techniques need to be embraced in each county if they are to locate and manage their own geological resources.

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APPENDIX I

DATA RESULTS FOR VLEM AND HLEM SURVEY (Barongo 1987)

VLEM DATA

375W	390HZ	1175HZ
0	-8.70364	-14.43536
24.3103	-14.4354	-17.83191
50.6896	-12.7371	-14.64767
75.0001	-9.76512	-12.10019
100.345	-9.5528	-12.31251
124.655	-8.27911	-11.67566
147.414	-4.24571	-6.580878
175.345	2.54739	5.519406
199.138	8.49133	12.73704
222.931	10.6142	12.94935
248.793	15.9214	19.10561
278.793	19.5301	19.31792

250W	390HZ	1175HZ
0	-4.45793	-6.45793
23.2759	-10.8265	-11.8265
49.6552	-8.70364	-10.8265
72.9311	-6.58079	-8.915956
97.7587	-5.73163	-7.642171
122.069	-4.45793	-6.156253
145.345	-3.39655	-5.09478
172.242	1.09823	1.061472
197.586	5.51941	7.642261
222.414	6.7931	11.03881
249.311	11.4634	14.43536
273.104	9.5528	13.79851
298.966	11.0388	14.85999

125W	390HZ	1175HZ
0	-8.91597	-15.28454
25.3447	-9.3405	-12.94937
50.1723	-11.0388	-12.31252
73.9655	-9.55281	-11.67567
98.276	-6.79311	-8.703654
124.138	-4.0334	-6.156261
150.517	-0.21231	-1.698322
173.793	-0.42454	2.33517
198.621	3.18424	4.670251
221.897	4.45794	7.64227
247.242	6.15626	8.915967
273.104	4.24572	10.18966
298.448	9.3405	12.10021

0	390HZ	1175HZ
0	-12.5247	-16.98275
24.8276	-10.402	-15.49674
50.1725	-9.76503	-13.5862
74.4828	-7.64226	-11.67566
98.276	-6.15625	-8.066796
122.586	-2.97193	-4.670246
173.793	-0.21222	-0.212223
199.138	1.91054	4.245711
221.38	2.7597	4.882558
248.276	2.54748	4.882558
271.552	5.09487	7.217726
297.414	5.94403	8.066796

250E	390HZ	1175HZ
0	-7.80488	-6.829196
26.7426	-9.26824	-13.41456
49.3253	-11.2194	-15.12192
74.8794	-11.7073	-10.73168
99.2447	-7.80488	-8.536562
124.204	-4.31704	-7.31704
147.976	0.46241	0.243922
172.935	0.73177	11.9512
199.084	6.82929	16.34145
222.26	12.439	18.29273
247.22	11.7074	18.78049
272.18	14.8781	19.75609
298.328	12.439	20.7561

125E	390H	1175HZ
0	-1.0613829	-1.0613829
23.27588351	-3.1842381	-4.8825582
50.68959034	-4.6702458	-7.6422611
72.41376283	-5.094781	-6.3685658
97.75866709	-7.854484	-5.5194058
123.1035714	-3.1842381	-5.5194058
147.9311659	7.583E-09	-0.2123124
172.2414507	1.6983201	4.67024581
195.0002426	2.9720153	5.51940584
220.3451469	2.7597029	6.58087825
245.1727414	2.5473905	5.51940584
271.0347372	3.3965506	6.15625347
295.8623318	5.3070934	11.6756593

HLEM DATA FOR 125W

222HZ	QUADRATURE	INPHASE
0	0.894567602	-7.631596283
22.75839	0.31585355	-6.579046501
46.89626	0.31585355	-6.052660601
71.03414	1.789468032	-5.526496714
97.93042	2.052549976	-5.000110814
119.9999	2.578935876	-4.73702887
143.4478	-1.052771606	-6.052660601
167.5857	-2.894789232	-11.84223945
193.7925	-7.894900239	-21.05277161
217.9304	-7.894900239	-22.89490024
248.2756	-7.368514339	-20.21064298
268.9651	-5.526496714	-15.52649672
292.4135	-2.894789232	-11.5789355
315.1719	-0.263303762	-6.157982183
337.2408	4.210421345	-4.684368083
366.8961	3.420953502	-4.421064127
387.5855	1.84201782	-6.210531971
416.5513	-1.052771606	-7.684368083

444HZ	INPHASE	QUADRATURE
0	-9.7346797	1.31585355
25.5174	-7.3135044	1.578935494
51.0342	-6.7345687	1.052771606
75.8621	-5.9451009	1.052771606
100.689	-4.818715	0.78946765
127.586	-5.4714868	-0.789468032
155.862	-6.8398903	-3.157871558
184.138	-15.260955	-3.947339401
211.034	-24.471487	-7.105210765
235.172	-29.997762	-8.947450403
262.758	-31.050533	-8.947450403
293.793	-24.734569	-6.578824871
313.793	-17.629358	-3.157871558
350.345	-8.155744	3.684257076
375.172	-6.1029722	3.94733902
400	-5.8398903	3.157871176
426.896	-6.6293581	2.894789232
457.931	-7.2082938	2.631707288

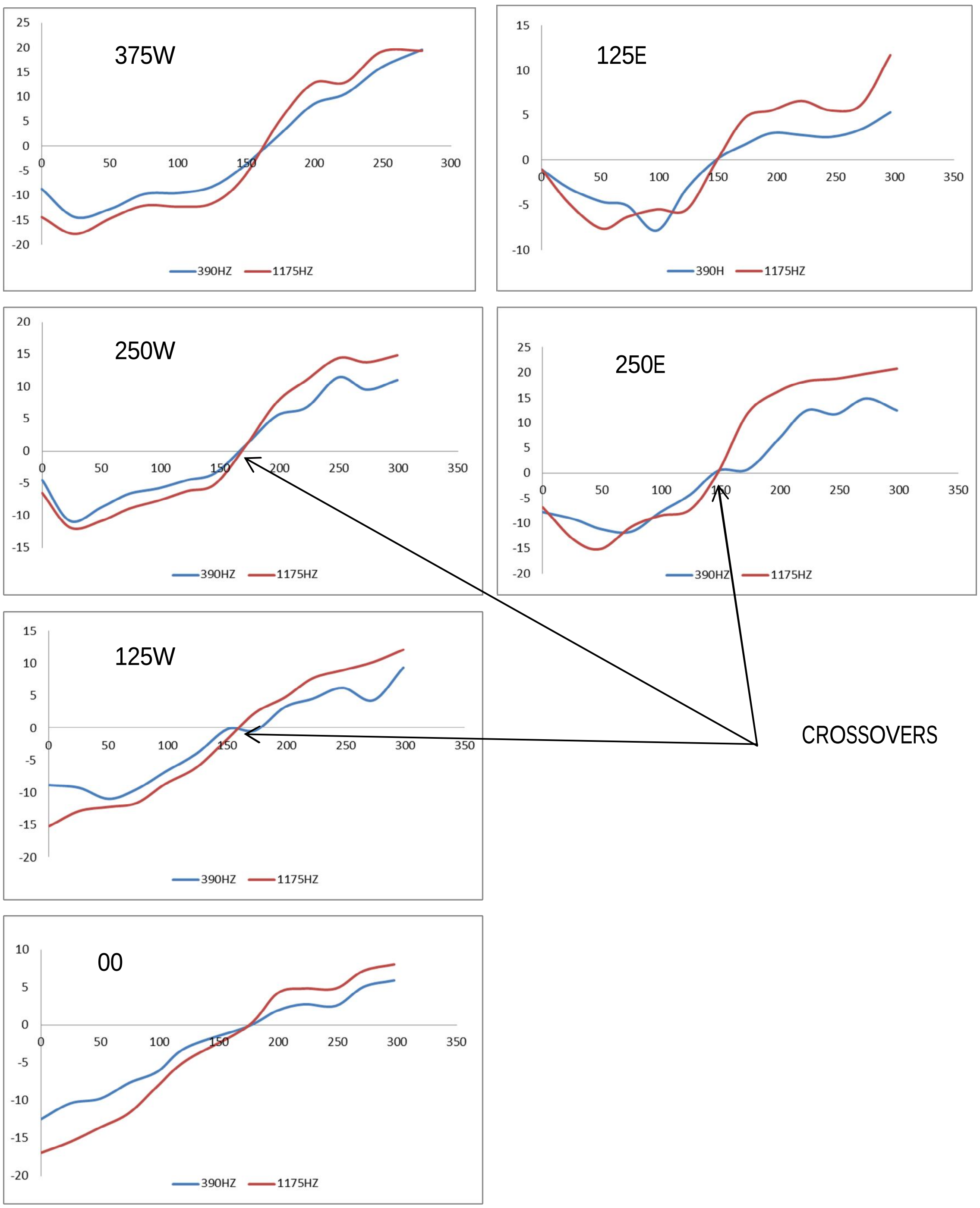
888HZ	QUADRATUR	INPHASE
0	6.153995912	-6.66666667
28.2758	7.17955374	-5.12822177
51.7242	5.897444215	-4.35899932
79.3105	3.589776867	-3.84611224
100.689	3.846112245	-3.0768898
130.345	-1.5384449	-2.82055442
153.104	-1.02555783	-6.92300204
175.862	-3.33322518	-14.1025558
202.069	-5.12822177	-20.7692225
226.896	-3.84611224	-32.0512238
251.724	-4.35899932	-32.5641109
275.173	-2.30766735	-32.8204463
303.448	-2.82055442	-25.8974442
329.655	1.794996593	-20.2563354
357.242	3.076889799	-12.3075592
381.379	3.33344149	-5.12822177
405.517	2.820554422	-3.58977687
431.724	3.076889799	-5.89744422

1777HZ	QUADRATURE	INPHASE
0	5.897444404	-6.66666648
27.5863	8.205111752	-7.17933724
52.4137	5.384773649	-6.66666648
76.5516	4.358999502	-5.64089234
101.379	-2.307667165	-4.10244744
128.965	-2.564002542	-6.41011479
146.207	-4.87166989	-7.94855968
178.621	-5.128221581	-15.8973359
200	-6.923001861	-22.5640025
226.896	-2.82033792	-28.2051114
252.414	-2.82033792	-33.8460039
273.103	-2.564002542	-38.7178903
302.758	2.051332154	-30.5127787
324.827	3.589777056	-17.4357808
347.586	3.077106301	-7.94855968
372.414	-0.769222262	-2.51288726
396.552	-0.769222262	-3.692441
422.069	-1.538444714	-3.84632875
450.345	-1.538444714	-6.15377941

3555HZ	QUADRATURE	INPHASE
0	-2.714251301	-2.857005101
21.3795	-2.999879502	-3.42850254
47.5863	-1.4286231	-2.857005101
77.2416	-4.857125619	-3.42850254
100	-7.999758942	-3.142874339
126.207	-10.5713769	-0.571256382
151.035	-11.14275382	-8.571256381
174.483	-11.8570051	-21.71401022
200.69	-11.14275382	-36.57101534
223.448	-10.57149746	-40.57101534
258.621	-10.00012054	-35.9995179
281.379	-9.714371819	-25.99963842
295.862	-7.142753861	-14.28550766
320	-3.142994899	-2.285748699
349.655	-3.714251259	-0.285628181
371.724	-6.856884582	-2.857005101
396.552	-7.428382021	-2.857005101
424.828	-6.714130741	-3.142753821

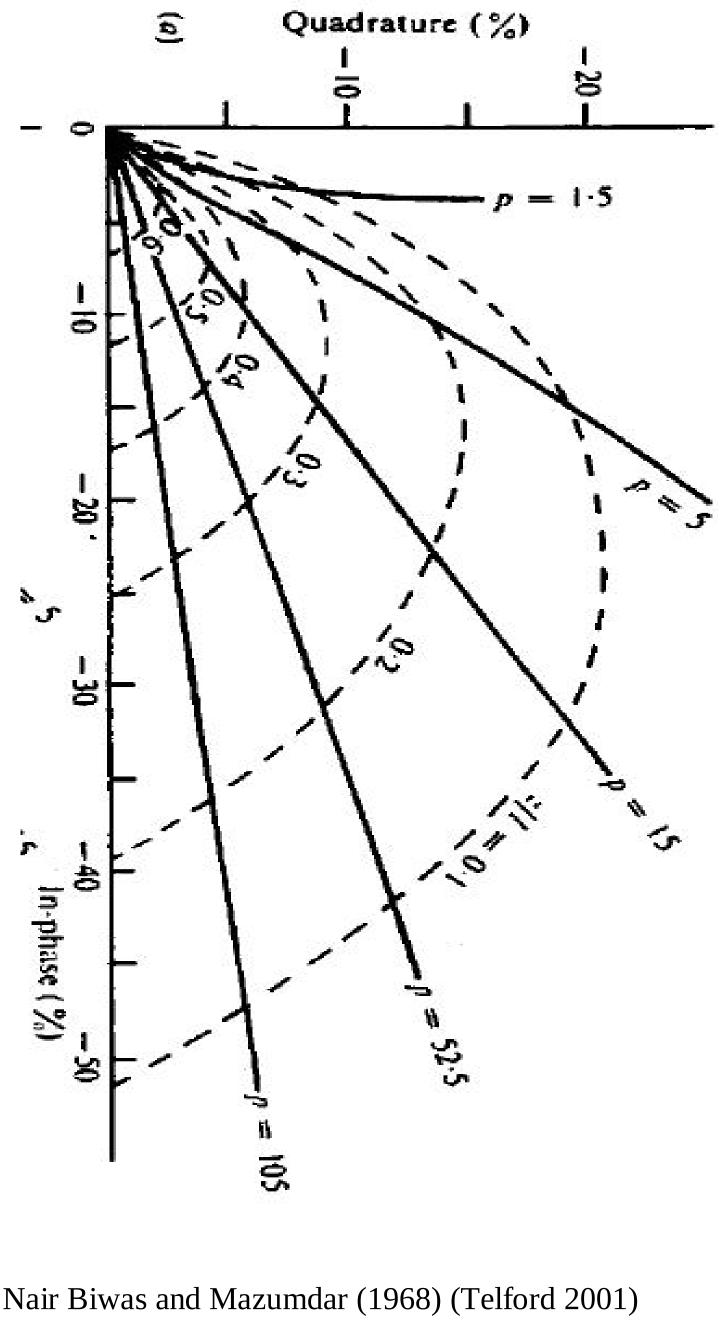
APPENDIX II

VLEM GRAPHICAL RESULTS



APPENDIX III

FREE-AIR PHASOR DIAGRAMS



Free-air phasor diagrams of Nair Biwas and Mazumdar (1968) (Telford 2001)