USING LINEAR FILTERS TO PROCESS VLF-EM DATA – A CASE STUDY FROM THE WASA AKROPONG-GYAPA AREA

J. A. Arko, BSc, MSc
S. Torkornoo, BSc
Geological Engineering Department, U.S.T., Kumasi

ABSTRACT

The processing and subsequent interpretation of VLF-EM data are enhanced by the application of linear filters to the observed in-phase component of the vertical magnetic field coming from sub-surface conductors. An anomaly in the in-phase component exhibits a crossover response.

The filter process involves mathematically passing the shape of an expected anomaly signature along the various traverses. When this anomaly outline matches one in the measured data, a large positive number is obtained whose position along the traverse coincides with a conductive zone within the ground. Noise in the measured data, reverse crossovers and anomalies due to deep-seated conductors are all suppressed mathematically.

By adjusting the filter polarity, one can selectively filter the data for a measured anomaly response. All the filtered values are plotted on the traverses and the values are contoured to produce a map, which can be correlated with the geological map of the area to show the trend of subsurface conductors.

Linear filters of FRASER [1] and KAROUS-HJELT [2], have been applied consistently to the VLF-EM data collected in different directions along thirteen traverses between Wassa Akropong and Gyapa in the Western Region of Ghana. The results of the study show that some of the positions of the subsurface conductors located by the filtering process coincide with areas of known gold mineralization.

Keywords: *Frazer, filters, sub-surface conductors, anomaly profiles, crossover points, filter polarity, positive peaks.*

INTRODUCTION

The interpretation of VLF-EM data assumes specific shapes for the real and the imaginary profiles. An anomaly profile of the real component manifests itself as a non-symmetrical curve having a positive peak value ahead of and a negative peak value behind the conductor. The crossover point between the positive and the negative values coincide with the horizontal position of the sub-surface conductor causing the anomaly. The above method for locating conductor positions is possible only if the profiles are simple. In practice however, the real and imaginary profiles are very complicated due to the fact that the subsurface conducive bodies are not isolated from each other. In such cases, using linear filters can enhance the individual VLF profiles.

The linear filters proposed by FRASER [1] and KAROUS-HJELT [2] have been designed for processing the in-phase (real) component of VLF magnetic field due to subsurface conductive bodies.

One major problem affecting the accurate analysis and subsequent interpretation of VLF-EM data, is the inconsistent application of linear filters on the in-phase field data. This can cause false anomalies to be mistaken for true anomalies, leading to the mislocation of the sub-surface conductive bodies, which are the targets of exploration.

This paper discusses the processing and the analysis of a set of a VLF-EM data measured along thirteen traverses within the area between Wassa Akropong and Gyapa in the Western region (Figure 1). The baseline is parallel to the strike of the geological formations investigated while the survey lines cut across the north-east trending shear zones in the metavolcanics and metasediments of Birimian system, which are known to contain primary gold deposits.

Mr. J.A. Arko

Mr. S. Torkornoo

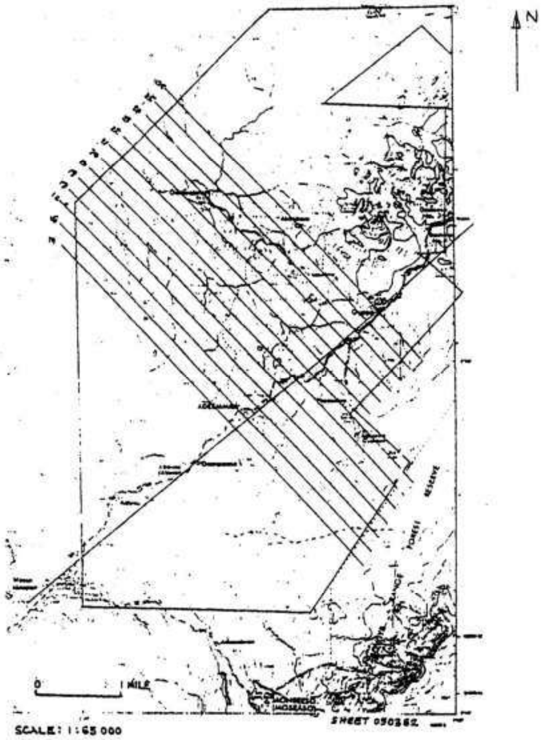


Figure1: Map Showing Baseline and Cross lines

BASIC VLF-EM PRINCIPLES

The essential principles of the VLF-EM method are that, at long distances from a VLF station, called the Transmitter, the radiated electromagnetic energy is carried into the ground as a plane wave, with its electrical and magnetic components perpendicular to each other.

The primary magnetic field is horizontal, parallel to the ground, and the electric field is oriented vertically. The primary magnetic field is oriented at right angles to the line connecting the observation point to the Transmitter.

In the presence of a subsurface conductor, the primary magnetic component Hx in Figure 2 induces eddy currents to flow in the conductor. A secondary magnetic field Hs is generated which is out of phase with and of smaller amplitude than the primary magnetic field. The interference between the primary and the secondary magnetic fields, produces a resultant magnetic field which is elliptically polarised (Figure 3). The orientation of this ellipse is arbitrary, but is greatly extended along the direction of the primary field. This is referred to as the polarisation ellipse.

In order to optimise the induction effect, the direction of the Transmitter is chosen to coincide with the strike of the conductive geological body. Although the preferred Transmitter in Ghana which is along strike is MOSCOW at 17.1KHz, the signal is too weak so that he Transmitter at Rugby England at 16.0KHz is used. While the direction of this station is 22½° North of the strike direction, this degree of non-alignment is acceptable in practice [3].

GEOLOGICAL SETTING

The geology of the study area has been described by TRASHILEV [4]. This area is underlain by alternating sequences of siltstones, sandy siltstones, silty sandstones interbedded with silt slates, slates and phyllites, and occasionally with tuffs or tuffaceous-arenaceous-argillaceous rocks.

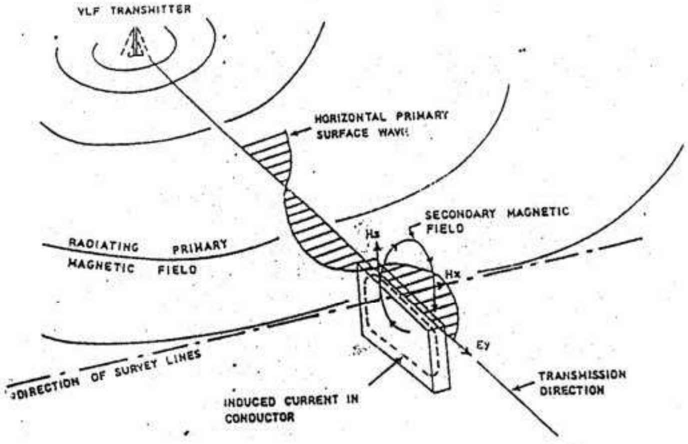


Figure 2: The Primary Field of a VLF Transmitter and the Secondary Field induced in a conductor. For maximum coupling the strike of the conductor should be towards the transmitter (After K. Witherly, [5])

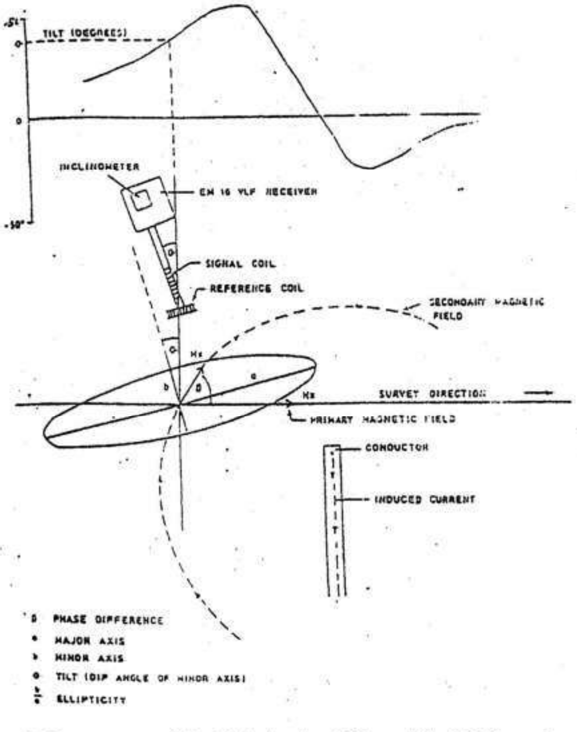


Figure 3: Parameters of the Polarisation Ellipse. The VLF receiver measures any two of the parameter θ, b, $^b/_a$. A tilt (θ) anomaly is shown at the top of the figure. (After K. Witherly, [5[)

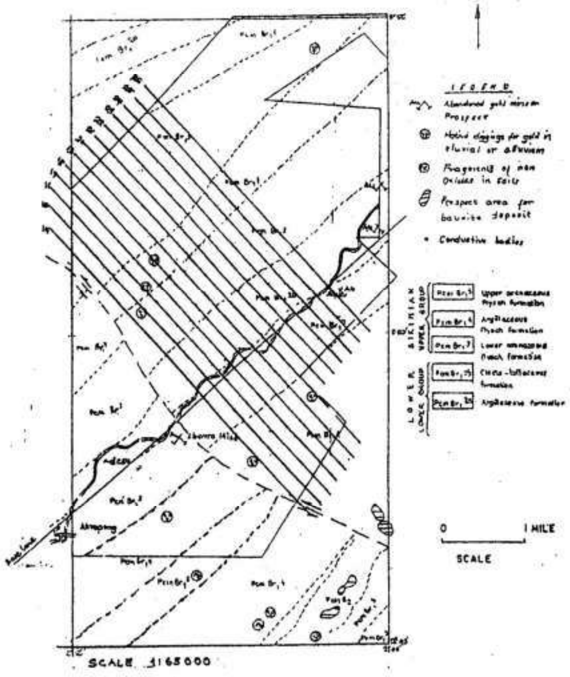


Figure 4: Showing Geology, Economic Minerals and Survey Lines

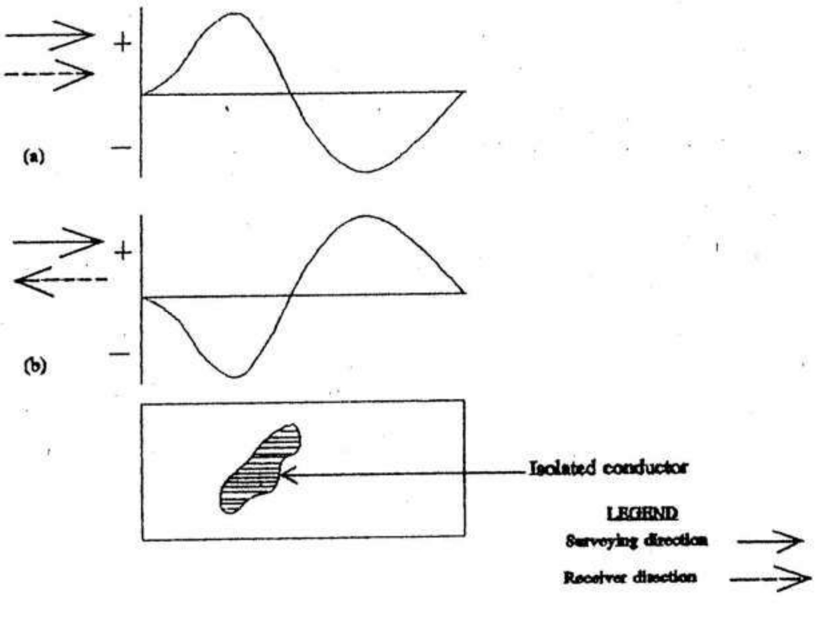


Figure 5: VLF Anomaly Profiles over an isolated sub-surface conductor

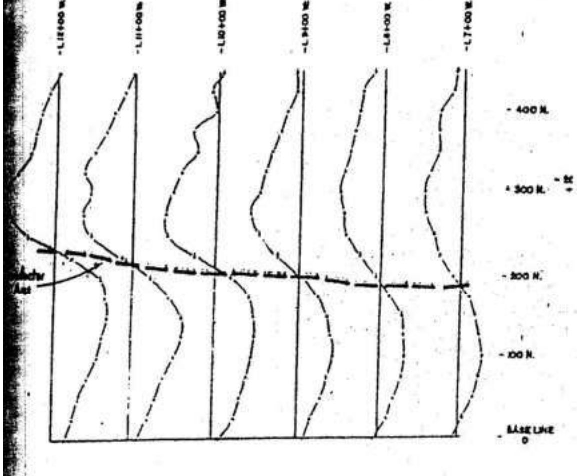


Figure 6: Stacked VLF Profiles

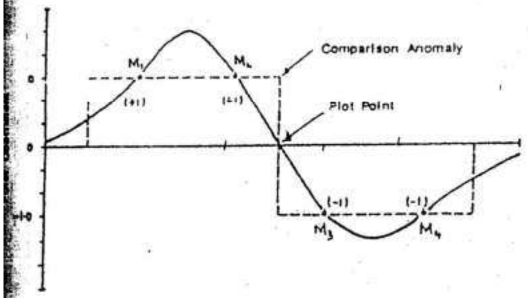


Figure 7 (a): Fraser Filter

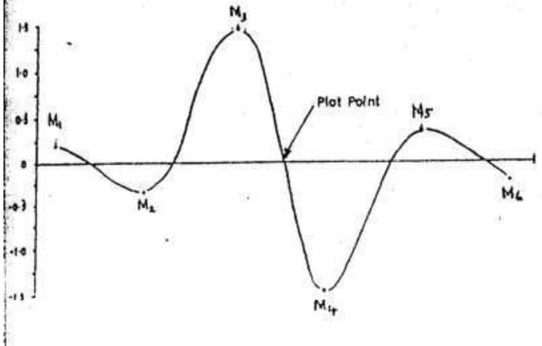


Figure 7 (b): Karous – Hjelt Filter

This series belongs to the uppermost parts of the Lower Birimian system (Figure 4).

The gold mineralisation in the Birimian rocks is believed to have been deposited by hydrothermal solutions containing gold, which were injected into fissures in the country rocks. Such fissures trend northeast-sorthwest and constitute the five major gold belts in Ghana [6]. The study area is located within the "Ashanti belt" where primary gold deposits have been mined in quartz reef in the past, and these deposits are known to occupy the north-east shear zones with strike parallel to the metavolcanics and the metasediments. Figure 4 also shows area alluvial digging, abandoned gold mines and prospects, which are believed to contain conductive sulphide mineralisation.

DATA COLLECTION

The VLF-Receiver (Geonics EM-16) was used to obtain data along all traverses in the field. The parameters of interest were (a) the orientation of the minor axis (tilt-angle) of the polarisation ellipse and (b) the ratio of the minor to the major axis of the ellipse (the ellipticity). These are equivalent to the in-phase (real) and the out-of-phase (quadrature) component of the secondary magnetic field respectively, expressed as percentages of the primary magnetic field, i.e. Hs/Hx %.

To determine the Transmitter direction, the receiver was held horizontally and swung sideways to obtain a minimum signal sound. At that position, the receiver was pointing towards the Transmitter station.

The receiver was turned 90° away from this direction and swung in the vertical plane, until another minimum signal sound was obtained. The quadrature dial was adjusted to obtain the best minimum sound and readings from the in-phase and the quadrature dials were noted as positive and negative percentages.

The survey lines were at 400m intervals with lengths long enough to cover the width of the study area. Observation points were established at 20m intervals. Crosslines 14 and 23 were surveyed from Northwest to the Southeast; while all other crosslines were surveyed from the baseline to either the Northwest or the Southeast ends.

Commercial VLF receivers are so designed that the anomaly indications in the real component are always similar to the one shown on (Figure 5a), that is, a positive peak appears ahead of the conductor and a negative peak appears behind it. This crossover anomaly depends on the specific direction the receiver operator faces when taking readings along a traverse. The anomaly profile would be 180° out of-phase if the operator faced the opposite direction when taking readings across the same conductor (Figure 5b).

To ensure that the various VLF profiles obtained along several traverses could be stacked together to determine the strike of any subsurface conductive bodies, the field readings were taken with the receiver operator always pointing Northwest, whether the traverse was being surveyed from Northwest to Southeast or from Southeast to Northwest. An example of stacked profiles is shown as Figure 6.

PROCESSING OF FIELD DATA

Since the subsurface geology is complicated, conductive bodies are not isolated and it becomes very difficult to locate the positions of individual bodies by simple visual inspection of the crossover anomalies. To overcome the problem posed by complicated geology, and overlapping effects from other anomalies, linear filters are used to enhance the measured data, to make it much easier to locate the positions of the individual conductors. The positions of the filtered peak values on the traverse then coincide with the subsurface conductor positions.

Filtering simply involves the process of mathematically passing the shape of a theoretical VLF anomaly response over an observed VLF profile. When the anomaly response matches a similar one in the observed profile, a filtered positive peak value is obtained.

The Fraser filter shown as Figure 7(a) uses four consecutive readings M_1, M_2, M_3 and M_4 along the traverse and, the filtered positive peak value is given by:

$$M_{2\text{-}3}= (M_1+M_2) - (M_3 + M_4)$$

The Karous-Hjelt filter shown, as Figure 7(b) is a six-point filter and the positive peak is given by:

$$M_{3\text{-}4} = K\,(0.102M_1-0.059M_2+0.561M_3-0.561M_4+0.059M_5-0.102M_6)$$

K is a constant that depends on the station interval.

The application of the linear filters must be done carefully if the direction of traversing is not constant. For examples, the anomaly profiles due to conductors along crossline 14 and 23 actually show a negative peak ahead of the conductors and a positive peak behind the conductors because the data were collected in a reverse manner.

These anomaly responses would be 180° out of phase with the known VLF anomaly shape. In order to obtain filtered positive peaks to coincide with the positions of the subsurface conductors, the polarity of the applied filter must also be 180° out-of-phase. That is, for the Fraser filter, the expression to use should be:

$$M_{2\text{-}3}= (M_1, + M_2)+(M_3 + M_4)$$

and for the Karous-Hjelt filter, the expression to use should be:

$$M_{3\text{-}4}= - K\,(0.102M_1-0.059\,M_2+0.561M_3 - 0.561M_4 + 0.059M_5 -0.102M_6)$$

The VLF-EM raw data along the first four crosslines are shown on Figure 8. The true crossover positions indicated by either a change from positive peak to negative peak or vice versa are shown. Figures 9 and 10 also show filtered profiles of the first four crosslines, using the Fraser and the Karous-Hjelt filters respectively.

The filtering process was repeated by moving the filter along the data file one station at a time. The co-ordinates of all selected positive filtered peak values were contoured to indicate the trend of subsurface conductors across the area of survey. These maps are shown in Figure 11(a) and 11(b).

the baseline to either the Northwest or the Southeast ends.

Commercial VLF receivers are so designed that the anomaly indications in the real component are always similar to the one shown on (Figure 5a), that is, a positive peak appears ahead of the conductor and a negative peak appears behind it. This crossover anomaly depends on the specific direction the receiver operator faces when taking readings along a traverse. The anomaly profile would be 180° out of-phase if the operator faced the opposite direction when taking readings across the same conductor (Figure 5b).

To ensure that the various VLF profiles obtained along several traverses could be stacked together to determine the strike of any subsurface conductive bodies, the field readings were taken with the receiver operator always pointing Northwest, whether the traverse was being surveyed from Northwest to Southeast or from Southeast to Northwest. An example of stacked profiles is shown as Figure 6.

PROCESSING OF FIELD DATA

Since the subsurface geology is complicated, conductive bodies are not isolated and it becomes very difficult to locate the positions of individual bodies by simple visual inspection of the crossover anomalies. To overcome the problem posed by complicated geology, and overlapping effects from other anomalies, linear filters are used to enhance the measured data, to make it much easier to locate the positions of the individual conductors. The positions of the filtered peak values on the traverse then coincide with the subsurface conductor positions.

Filtering simply involves the process of mathematically passing the shape of a theoretical VLF anomaly response over an observed VLF profile. When the anomaly response matches a similar one in the observed profile, a filtered positive peak value is obtained.

The Fraser filter shown as Figure 7(a) uses four consecutive readings M_1, M_2, M_3 and M_4 along the traverse and, the filtered positive peak value is given by:

$$M_{2\text{-}3} = (M_1+M_2) - (M_3+M_4)$$

The Karous-Hjelt filter shown, as Figure 7(b) is a six-point filter and the positive peak is given by:

$$M_{3\text{-}4} = K\,(0.102M_1 - 0.059M_2 + 0.561M_3 - 0.561M_4 + 0.059M_5 - 0.102M_6)$$

K is a constant that depends on the station interval.

The application of the linear filters must be done carefully if the direction of traversing is not constant. For examples, the anomaly profiles due to conductors along crossline 14 and 23 actually show a negative peak ahead of the conductors and a positive peak behind the conductors because the data were collected in a reverse manner.

These anomaly responses would be 180° out of phase with the known VLF anomaly shape. In order to obtain filtered positive peaks to coincide with the positions of the subsurface conductors, the polarity of the applied filter must also be 180° out-of-phase. That is, for the Fraser filter, the expression to use should be:

$$M_{2\text{-}3} = (M_1, + M_2) + (M_3 + M_4)$$

and for the Karous-Hjelt filter, the expression to use should be:

$$M_{3\text{-}4} = -\,K\,(0.102M_1 - 0.059\,M_2 + 0.561M_3 - 0.561M_4 + 0.059M_5 - 0.102M_6)$$

The VLF-EM raw data along the first four crosslines are shown on Figure 8. The true crossover positions indicated by either a change from positive peak to negative peak or vice versa are shown. Figures 9 and 10 also show filtered profiles of the first four crosslines, using the Fraser and the Karous-Hjelt filters respectively.

The filtering process was repeated by moving the filter along the data file one station at a time. The co-ordinates of all selected positive filtered peak values were contoured to indicate the trend of subsurface conductors across the area of survey. These maps are shown in Figure 11(a) and 11(b).

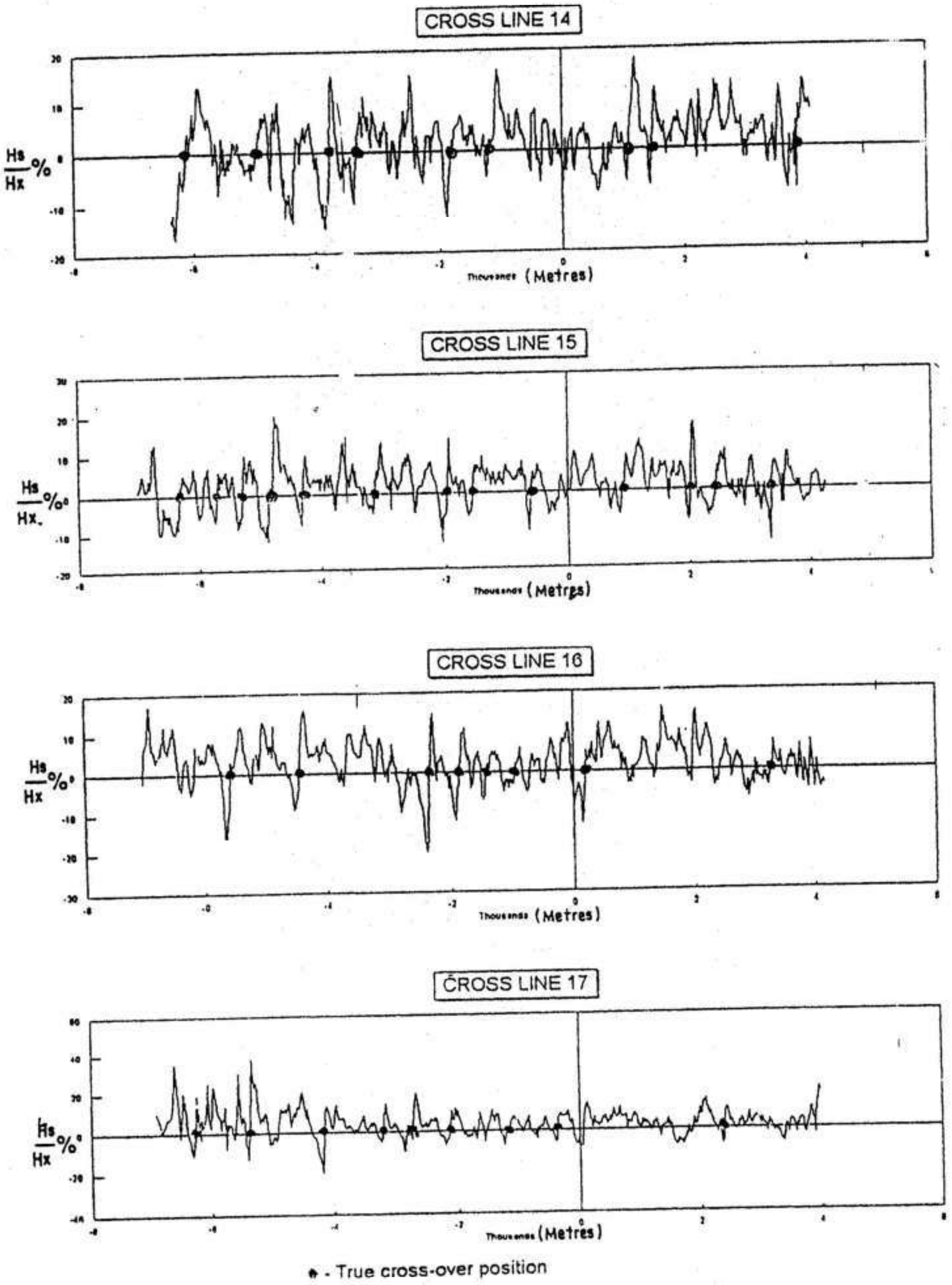


Figure 8: VLF-EM Originalin-Phase Data Profiles

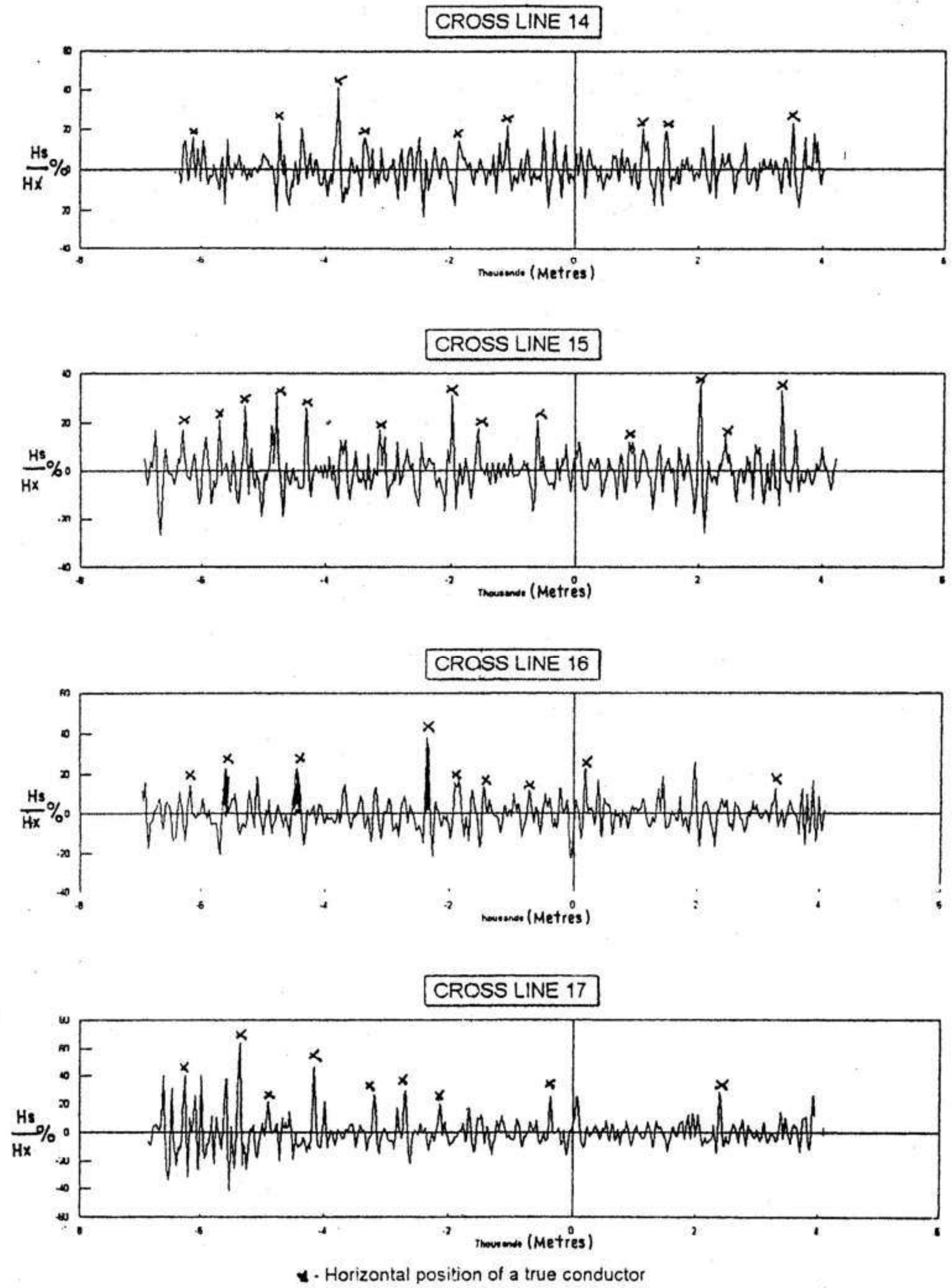
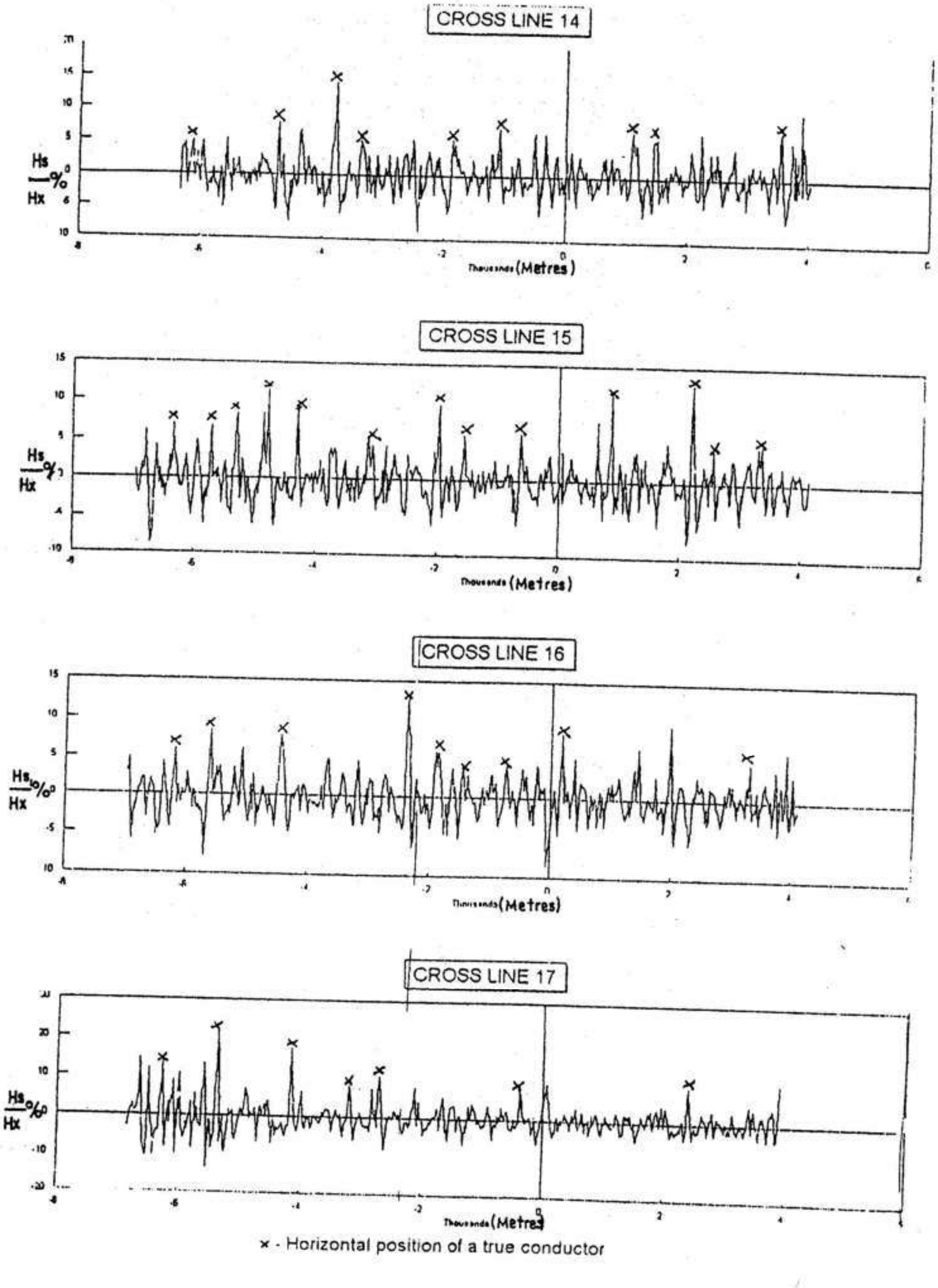


Figure 9: VLF-EM In-Phase Fraser Filterer Profiles


CROSS LINE 14

CROSS LINE 15

CROSS LINE 16

CROSS LINE 17

× - Horizontal position of a true conductor

Figure 10: VLF-EM In-Phase Karous and Hjelt Filterer Profiles

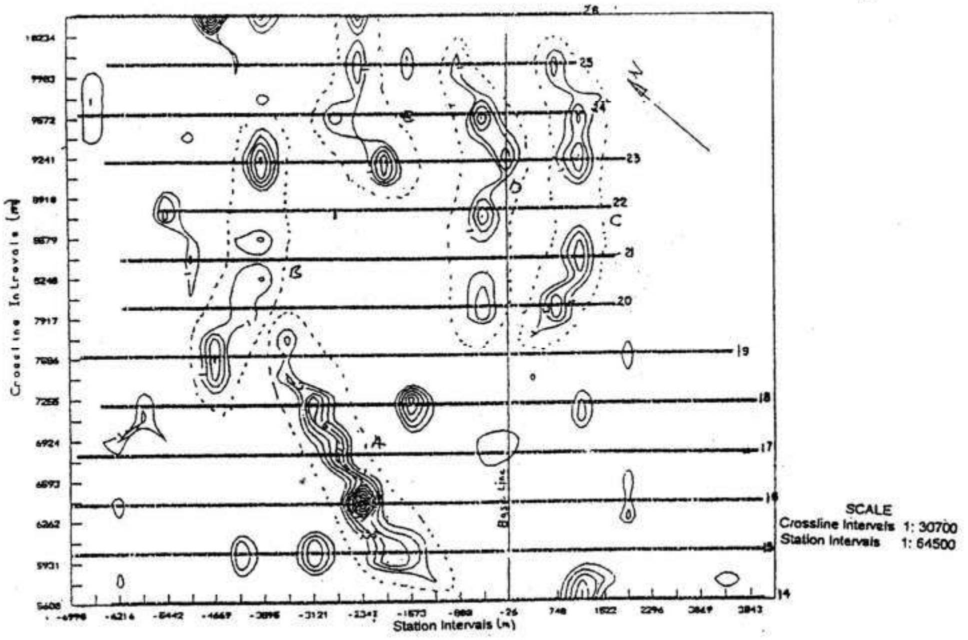


Figure11 (a): Fraser Anomaly Map

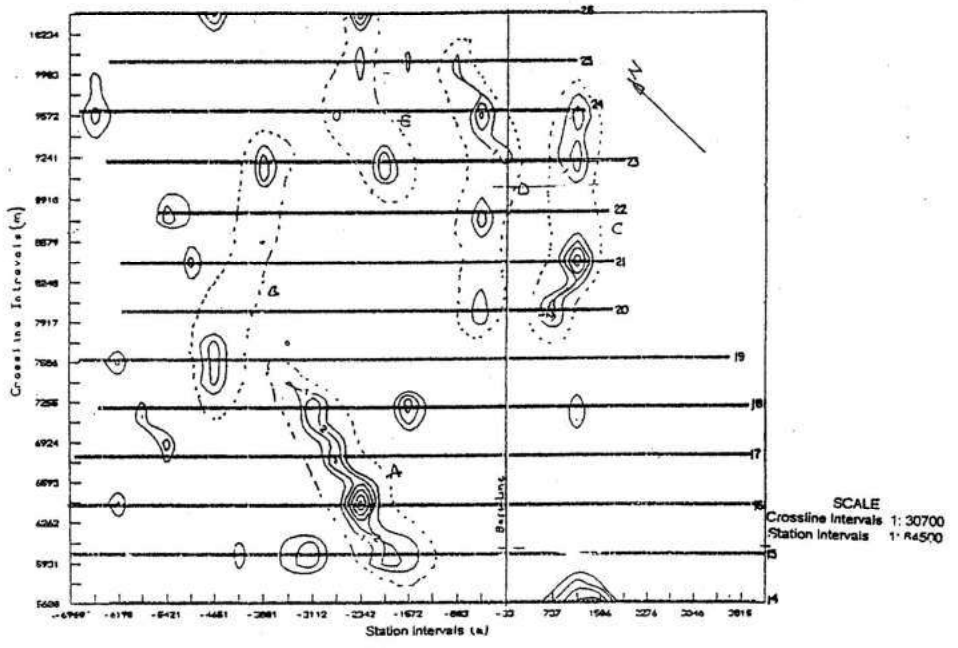


Figure11 (b): Karous and Hjelt Anomaly Map

INTERPRETATIONS

The VLF receiver detects conductive bodies in each geological formation. This is evident, if one carefully compares Figures 11(a, b) with Figure 4. It is also evident that some of the conductors coincide with the positions of abandoned gold mines, prospects, and alluvial diggings. Others are on the contact between the metavolcanics and metasediments of the Birimian system which is marked by mineralized graphitic argillites [7].

Figure 11a and b show five anomalous zones, namely, A, B, C, D and E, which represent the trend of conductive bodies. Zone A falls within the area of the three alluvial diggings, which trends northwards from crossline 15 to 19. Zone B also stretches from crossline 19 to 23 in a northeasterly direction. These two zones lie within the metasediments where gold is known to occur within the graphitic phyllites, sericite schists and greywackes [7,8]. They are different parts of a single zone, which stretches, from crossline 15 to 23.

Zone C stretches from crossline 20 to 25, and lies within the metasediments on the eastern side of the base line. Its position coincides with a string of abandoned gold mines from Abawso (Aboso) to Gyapa.

Zone D lies on the western side of the baseline and trends northeasterly from crossline 20 to 25. The zone coincides with the contact zone between the metasediments and the metavolcanics, which is known to be mineralised. Zones C and D are parts of a single zone, which stretches from crossline 20 to 25. Zone E stretches from crossline 22 to 26 and beyond in a northeasterly direction. It falls within areas underlain by mineralised metasediments.

CONCLUSIONS

The fruits of the consistent use of linear filters to process VLF-EM data have been shown by the results obtained. The five anomalous zones fall within area of gold mineralisation, which is the ultimate aim of the VLF surveying.

It is not always possible to conclude from geophysical data alone whether or not anomalous zones coincide with mineral deposits. It becomes necessary to integrate the geophysical results with the results of a systematic geochemical soil and trench sampling, and surface geological mapping. In any case, an exploration programme may be made more cost-effective if operations such as trenching and drilling, which provide the ultimate proof of the existence of a mineralised area, are concentrated in areas delineated by the VLF-EM anomalies.

ACKNOWLEDGEMENT

Permission to use the VLF-EM data for teaching and research by the consulting Geologist, of Terrex (Ghana) Limited, is gratefully acknowledged.

REFERENCES

1. Fraser, D.C. Contouring VLF-EM data, Geophysical prospecting, 31 pp. 977-991, 1969.
2. Karous, M. and Hjelt S.E. Linear filtering of VLF-EM dip angle measurements, Geophysical prospecting, 31 pp. 782-794, 1983.
3. GEONICS LTD. Operating Manual of VLF-EM 16 receiver, Geonics Ltd., 1983.
4. Trashilev, S.S. The Geology of Field Sheet 82, Wiawso and Field Sheet 46, Asankragwa N.E., 1972.
5. Witherly, K. A short guide to VLF-EM survey, pp. 48, 1989.
6. Dzigbodi-Adjimah, K. Geology and geo-chemical pattern of the Birimain gold deposits, Ghana, West Africa, Jour. Geochem. Expl. 47, pp. 307-313, 1993.
7. Hirst, T. Geology of the Konongo Gold belt and surrounding country, Gold Coast Geological Survey Bull. No. 14, 1942.
8. Junner, N. R. Gold in the Gold Coast, Geological Survey Memoir 4 pp. 76, 1935.