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Interpretation of Aeromagnetic Data of Kam, Using Semi-Automated Techniques

Sunmonu L.A.[1] and Alagbe O.A.[2*]
[1]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, NIGERIA
[2]Department of Physical Sciences, Ondo State University of Science and Technology, Okitipupa, NIGERIA

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Abstract

The Benue basin is a major geological formation underlying a large part of Nigeria, and also a part of the broader Central African rift system. The Upper Benue basin being part of Benue basin is believed to be rift valley and is expected to be a major depositional basin, because rifting structures are often good sites for mineralization. The strategic economic importance and the availability of data from the study area arose the interest of many researchers including this present work to focus their attention on the area in search of geological features that are favourable to mineral deposition in the basin. In this work, the interpretation of the data extracted from the aeromagnetic map of Kam, an area in the upper Benue basin which covers from latitude $08^0$00' to $08^0$30' N and longitude $11^0$00' to $11^0$30' E was carried out using a semi- automated techniques involving the analytic signal technique to delineate linear geologic structures such as faults, contacts, joints and fractures within the study area in a bid to unravel the gross subsurface geology of the area which would in no doubt help in better understanding and characterization of the area investigated. The residual magnetic field data was subjected to a filtering technique, the analytic signal which was employed to study source parameters which include location, depth and susceptibility contrast of the identified magnetic anomalies in the basement rocks. The results obtained from both profiling curves and depth contour map showed that the study area is magnetically heterogeneous and the basement is segmented by faults. Based on the results obtained from both profiling curves and depth contour map, it was revealed that the study area is divided into three basinal structures; deep sources ranging between 5km and 8.5km and the area is recommended for further investigation especially for its geothermal energy potentials. The intermediate depths between 2km to 4.5km correspond generally to the top of intrusive masses occurring within the basement, a depth deep enough for possible hydrocarbon deposit. Shallow depths between 0.01km and 2.5km are attributed to shallow intrusive bodies or near-surface basement rocks probably isolated bodies of ironstones formation concealed within the sedimentary pile.

Keywords: Aeromagnetic map, analytic signal, Kam, magnetic mineral, Rift valley, upper Benue basin.

Introduction

The aeromagnetic geophysical method plays a distinguished role when compared with other geophysical methods in its rapid rate of coverage and low cost per unit area explored. The main purpose of magnetic survey is to detect rocks or minerals possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the earth's magnetic field[1].

Airborne geophysical surveying is the process of measuring the variation of different physical or geochemical parameters of the earth such as distribution of magnetic minerals, density, electric conductivity and radioactive element concentration[2]. Aeromagnetic survey maps the variation of the geomagnetic field, which occurs due to the changes in the percentage of magnetite in the rock and reflects the variations in the distribution and type of magnetic minerals below the earth surface and measure variations in basement susceptibility. Local variations occur where the basement complex is close to the surface and where concentration of ferromagnetic minerals exists.

This research work deals with the interpretation of aeromagnetic map of Kam in part of upper Benue basin, using a semi-automated technique involving analytic signal. The analytic signal is formed through a combination of the horizontal and vertical gradients of a magnetic component; these derivatives are based on the concept that the rates of change of magnetic field are sensitive to the rock susceptibilities near the ground surface than at depth. The objectives of this research work are to trace out the structural controls like faults and fractures, to delineate lithologic boundaries as revealed by magnetic disturbances caused by different rock types, to determine the depth to magnetic basement and to interprete the magnetic anomalies revealed by the aeromagnetic map. The study area has a great potential due to its abundant mineral resources[3].

The Study Area, its Extent and Geological Setting: This study covers an area located in the north-eastern part of Nigeria between latitude $08^0 00'$ to $08^0 30'$ *N* and longitude $11^0 00'$ to $11^0 30'$ *N*. It forms part of what is largely referred to as the Upper Benue basin which is considered to be a failed rift valley[4,5], and so it is expected that the region should be a major depositional basin and therefore a good site for mineralisation.

The essential geological features in the basin consist of sedimentary rocks ranging in age from upper cretaceous to Quarternary, overlying an ancient crystalline basement made up mainly of Precambrian granites and gneisis.

The cretaceous sediments and the underlying basement complex, as in most other parts of Nigeria, are invaded by numerous minor and major intrusions of intermediate to basic composition. The older intrusives are largely granites and granodiorites while the younger intrusives are mainly granitic and pegmatitic types, although diorites and some synetites also occur. There were also occurrences of igneous and volcanic activities within the region extending from cretaceous to recent times. Prominent among the Tertiary and Recent volcanics in the region are the basic lavas of Biu and Longuda.

The crystalline basement whose topography is believed to be irregular[6] is exposed in a number of locations in the region. Intruded into the basement are series of basic, intermediate and acid plutonic rocks referred to as the older Granites. Notable outcrops of the older Granites include small inliers of biotite granites which are found around Kaltungo, Gombe, Kokuwa, and in the Bauchi area. The uplifted basement rocks in the North-westen part of the area were also intruded by orogenic acid ring complexes, the Younger Granites[7]. The cretaceous sediments in the area are believed to be compressionally folded in a non-orogenic shield environment[8], and the folding took place mainly along ENE-WSW axes, particularly in Dadiya, Kaltungo, Lamurde, and Longuda areas. Numerous faults have also been reported in the region[9,10]. These faults show variable trends but the dominant direction lies between north-north-east and east-north-east.

Material and Methods

The primary data used for this analysis is the aeromagnetic map of Kam (sheet numbers 236), from part of the upper Benue basin, published by the Geological Survey of Nigeria Agency, Airborne geophysical series (1974) on a scale of 1:1000, 000.

The survey was carried out along a series of NE- SW lines with a spacing of 2km and an average flight of constant elevation terrain of 152m above ground level. Other flying parameters given on the map used is as follows; Nominal tie line spacing: 20km, Average magnetic inclination across survey area; from $I=7^0$ in the north to $I= 4^0$ to the south. The regional correction on the map was based on International Geomagnetic Reference Field (I.G.R.F).

The map was carefully hand digitized into a 2km by 2km square matrix cell, given rise to a 27 by 27 square matrix, so 729 data points were processed and the digitization was carried out along flight lines. An interval of 2km directly imposes a Nyquist frequency of 1/4 km^{-1}. This implies that magnetic anomalies that are less than 4km in width may not be resolved with this digitizing interval. However[5], consider this digitizing interval suitable for the portrayal and interpretation of magnetic anomalies arising from regional crustal structures. Ajakaiye D.E. et al.[7] also indicated that, crustal anomalies are much larger than 4km and therefore lie in a frequency range for which computational errors arising from aliasing do not occur with a 2km digitizing grid.

The data obtained from the digitized map were used in generating the total magnetic intensity map for (Kam) the study area using Surfer 8 computer software. The geomagnetic gradient was removed from the data using International Geomagnetic Reference Field, IGRF (epoch 1 January 1974, using IGRF 1975 model) and this was used in producing the resultant residual anomaly data for the study area. The residual anomaly data was later subjected to analytic signal, a filtering and enhancement technique using Synproc (Signal Processing) software, which was later used for the interpretation. The processing technique is basically an imaging technique. One advantage that would be derived from the technique is that, by looking at many different types of presentation, the features that are not visible in some images will be more visible in other images. Magnetic profiles of the area were also generated which shows various degrees of variation in the magnetic susceptibilities in the basement rock of the area. The interpretation of the profilings was done both qualitatively and quantitatively.

Processing Method: **Analytic Signal Method:** The analytic signal is formed through a combination of the horizontal and vertical gradients of a magnetic component. Analytic signal (AS) requires first-order horizontal and vertical derivatives of the magnetic field or of the first vertical integral of the magnetic field. The horizontal derivative of magnetic field is a measure of the difference in magnetic value at a point relative to its neighbouring point whereas the vertical derivative is a measure of change of magnetic field with depth or height. These derivatives are based on the concept that the rates of change of magnetic field are sensitive to rock susceptibilities near the ground surface than at depth[11].

The first vertical derivative is an enhancement technique that sharpens up anomalies over bodies and tends to reduce anomaly complexity, thereby allowing a clear imaging of the causative structures. The transformation can be noisy since it will amplify short wavelength noise i.e. clearly delineate areas of different data resolution in the magnetic grid. The application of analytic signals to magnetic interpretation was pioneered by Nabighian M.N.[12], for 2D case, primarily as a tool to estimate depth and position of sources. More recently the method has been expanded to 3D problems[13] as a mapping and depth-to-source technique and as a way to learn about the nature of the causative magnetization.

The analytic signal of potential field data in 2- D could be written as,

$$A(x) = \varphi_x + i\varphi_z \quad (1)$$

where the 2-D analytic signal amplitude (ASA) of potential field is

$$\left|A(x)\right| = \sqrt{\phi_x^2 + \phi_z^2} \quad (2)$$

Roest et al.[13] write the analytic signal in 3D as a vector encompassing the horizontal derivatives and their Hilbert transform and the 3D analytical amplitude of the potential field $\phi(x, y)$ measured on a horizontal plane as

$$\left|A(x, y)\right| = \sqrt{\varphi_x^2 + \varphi_y^2 + \varphi_z^2} \quad (3)$$

For the 3 D case, the analytic signal is written as

$$A(x, y, z) = \frac{\partial \Delta T}{\partial x} i + \frac{\partial \Delta T}{\partial y} j + i\frac{\partial \Delta T}{\partial z} k \quad (4)$$

The amplitudes of the analytic signal (AAS) of magnetic could then be defined as the square root of the sum of the vertical and two orthogonal horizontal derivatives of the magnetic field.

$$\left|A(x, z)\right| = \sqrt{\left(\frac{\partial \Delta T}{\partial x}\right)^2 + \left(\frac{\partial \Delta T}{\partial y}\right)^2 + \left(\frac{\partial \Delta T}{\partial z}\right)^2} \quad (5)$$

The real and imaginary parts of the Fourier transform of equation (4) are the horizontal and vertical derivatives for ΔT, respectively.

The amplitudes of the analytic signal is simply related to amplitudes of magnetization which could be easily derived from the three orthogonal gradients of the total magnetic field using expression in equation (5). An important property of a 2-D analytic signal is that its amplitude is the envelope of its underlying signal.

Analytic signal method generally produces good horizontal locations for contacts and sheet sources regardless of their geologic dip or the geomagnetic latitude, therefore very useful at low magnetic latitudes.

The analytic signal amplitude peaks over magnetic contacts, but if more than one source is present, then the shallow sources are well resolved but the deeper sources may not be well resolved.

The analytical signal method is more sensitive to noise and aliasing in the data and the Peaks of the analytic signal amplitude are generally less enlongated and more circular. Depth information is limited to minimum and maximum values[14].

Results and Discussion

The Total Magnetic Intensity Maps (TMI): The 2D TMI map is as shown in figure 1. The analysis of the map shows the general magnetic susceptibility of basement rocks and the inherent variation in the basin under study. The map is presented as colour map for easy interpretation. The coloured maps aided the visibility of a wide range of anomalies in the magnetic maps and the ranges of their intensities were also shown. Areas of strong positive anomalies likely indicate a higher concentration of magnetically susceptible minerals (principally magnetite). Similarly, areas with broad magnetic lows are likely areas of low magnetic concentration, and therefore lower susceptibility.

The magnetic anomaly of magnitude between 7800nT and 7900nT appears to be very dominant (Yellow colour). It is observed to be conspicuous in the west, northwest, southwest, south and northeastern parts of the study area. Closely followed by these in spread are those anomalies ranging between 7700nT and 7800nT in magnitude (green colour). These are only prominent at the central part of the study area with little traces of it the northeast, southwest and northwest. Found almost in small quantity are anomalies of very high magnetic intensity value between 7900nT and 8000nT (Deep blue colour) which are observed the north and southeastern parts of the study area. Also found in small quantity in the area are the anomalies between 7600nT and 7700nT (Neon red colour) noticed in the southeast and northeast of the area.

Summarily, the 2D TMI map of Kam revealed that the area is magnetically heterogeneous. Areas of very strong magnetic values (7800nT to 8000nT) may likely contain outcrops of crystalline igneous or metamorphic rocks, deep seated volcanic rocks or even crustal boundaries. The areas between7600nT to 7700nT are suspected to contain near surface magnetic minerals like sandstones, ironstones, near-surface river channels and other near-surface intrusives.

Dicussion of the Residual Map: Large scale structural elements caused very long wavelength anomalies referrered to as regional, Superimposed on these are smaller localized perturbations, the residual caused by smaller scale structures or bodies. Magnetic data observed in geophysical surveys are the sum of magnetic fields produced by all underground sources. The target for specific surveys are often small-scale structures buried at shallow depths, and magnetic responses from these targets are embedded in a regional field that arises from magnetic sources that are usually larger or deeper than the targets or are located farther away. Correct estimation and removal of the regional field from the initial field observations yields residual field produced by the target sources[12]. Residual map have been used extensively to bring into focus local features which tend to be obscured by the broad features of the field. Discussed below are the features observed from the extracted residual map from the total intensity map generated.

The 2D residual map of kam (figure 2) revealed that local magnetic field variation whose magnitude varies between 0nT to 20nT (green colour) and those ranges between -30nT to 0nT (neon red) are very dominant in the study area and appeared to be well distributed almost in equal proportion throughout the entire study area. Residual anomalies with magnetic intensity ranging between -55nT to -30nT (pink colour) are observed at two places at the east and southeastern parts of the study area even though in small proportion. Equally, anomalies between 20nT to 35nT (yellow) are also observed in small proportions at north, northeast, east, and southeastern parts.

The residual aeromagnetic anomalies appear to be sufficiently isolated from regional field. At some places on the residual map (figure 2) there are anomalies that are not present on the total magnetic map (figure 1). These anomalies are due to magnetic source of shallow origin. Local positive residual anomalies observed in parts of the study area are interpreted or suspected to be some outcrops of cretaceous rocks and perhaps concentrations of sand stones within the study area[15]. These could also be associated with volcanic and ophiolitic rocks. Negative anomalies are associated with greater thickness of cretaceous rocks contained within the fault-bounded edges and depicting isolated basinal structuring and these are well distributed across the study area. Major faults may be recognized as a series of closed lows on the contour maps. Volcanic rocks with reverse polarity could also produce distinctive, high – amplitude negative aeromagnetic anomalies. The distribution of magnetic highs and lows (i.e. positive and negative anomalies) are as shown by the peaks and the depressions in the surface map of the residual map of kam (figure 3).

Analytic Signal Contour Map: Analytic function is extremely interesting in the context of interpretation, in that it is completely independent of the direction of magnetization and direction of the earth's magnetic field. This means that all bodies with the same geometry have the same analytic signal. An important goal of data processing is to simplify the complex information provided in the original data and such simplification is to derive or generate a map on which the amplitude of displayed function would be directly and simply related to a physical property of the underlying rocks[16]. An example of such map is the analytic signal map. With analytic signal method, it is now possible to isolate weak anomalies resulting from the subdued magnetic sources occurring within sedimentary strata. The analytic signal contour map (figure 4) allows us to identify and map near-surface magnetic minerals somewhat more readily. The 2D analytic signal Map of Kam (figure 4) revealed near-surface anomalies whose magnitude ranges between 0nT and 80nT (neon red) being dominant in the area in terms of distribution. Those anomalies whose magnetization varies between 80nT and 140nT (green) are observed in the northwest, and north and southwest in scanty manner, but occupying a reasonable parts of the study area around northeast, southeast, and central parts. Another major observed anomalies ranging between 140nT and 220nT (yellow) are observed in the north, northeast and southeastern parts of the area. Observed at three different locations within the study area are anomalously high value magnetic anomalies that ranges between 220nT and 300nT (deep blue). The suspicion around these areas to be an outcrop is very high. Also in the south, and northern parts are observed low magnetic field variation – 40nT to 0nT (pink). These areas are suspected to be occupied by a deep-seated magnetic body, weak magnetic bodies or a magnetic body or large area of extent.

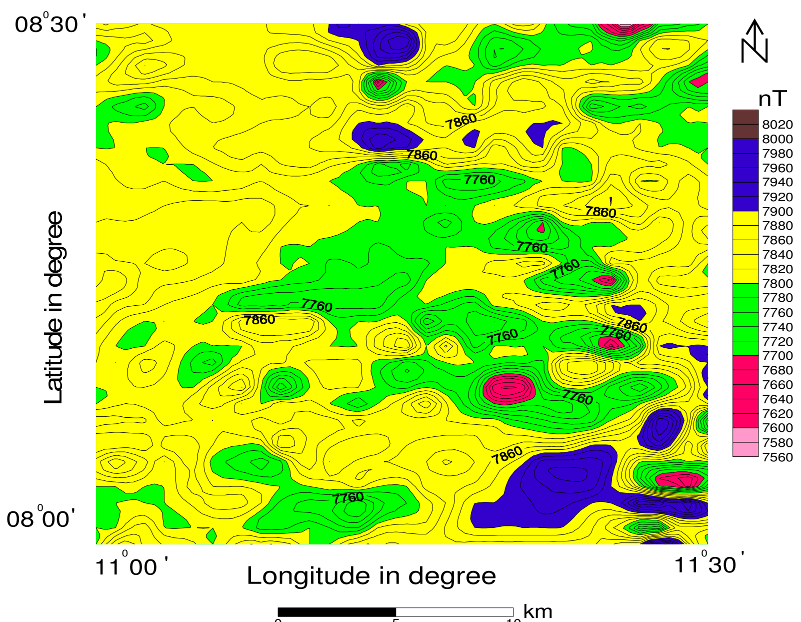


Figure-1
Total Magnetic Intensity map of Kam

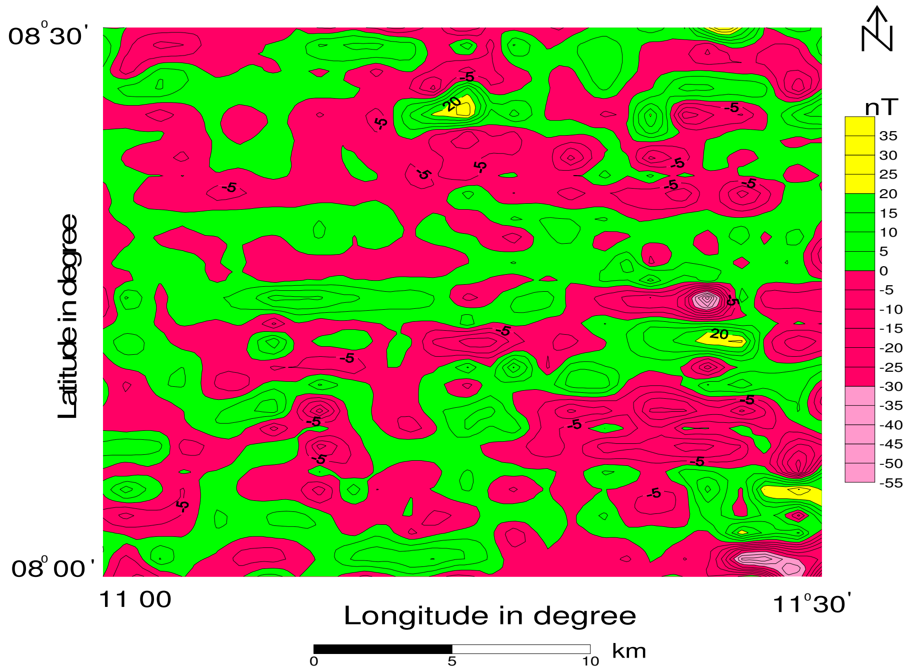


Figure-2
Residual map of Kam

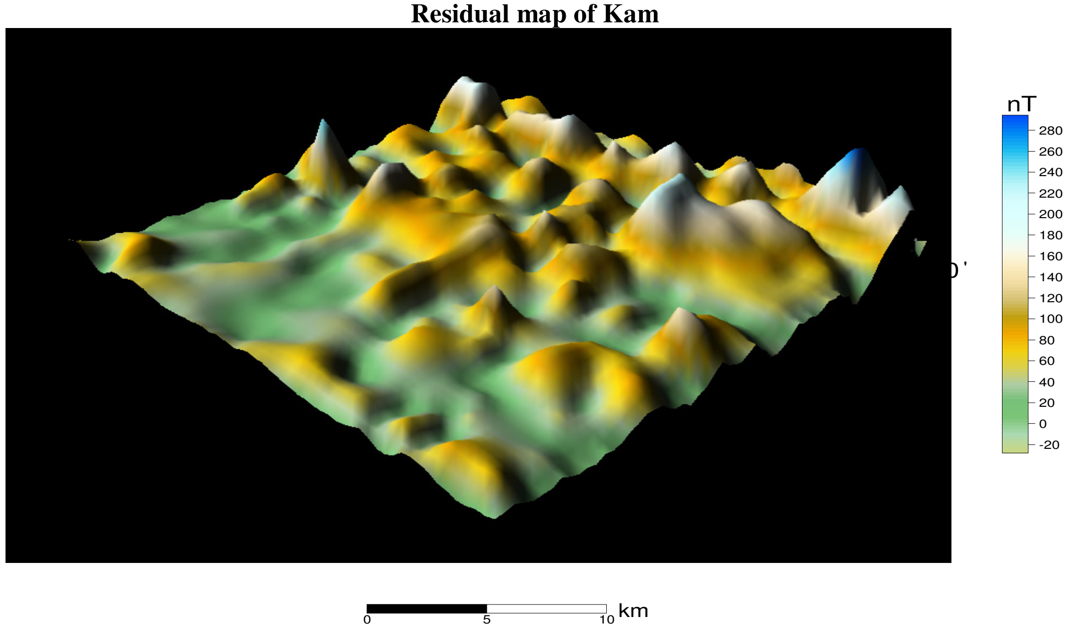


Figure-3
Surface plot of residual map of Kam

Generally, observed anomalies on the analytic signal maps are not entirely different from what was obtained from the residual map but the anomalies in the analytic signals are clearer and sharpened because many of the obscured anomalies are now brought to focus.

Now going by the geology of the study area which is part of Upper Benue and which affirmed the region to be a rifted zone coupled with the results of the analysis of data of the studied area in this research work, the region is actually fragmented by features such as outcrops, cracks, fractures, faults and joints all which serves as reservoir for the suspected minerals in the region.

From the investigation, some likely and common minerals in region are; lead, zinc, tin, columbite, limestone, gypsi-ferrous shales, sandstones, marble, tin ore, graphite, barite coal. Older and younger granites, quartzites and magmatites are common in outcrops in the area.

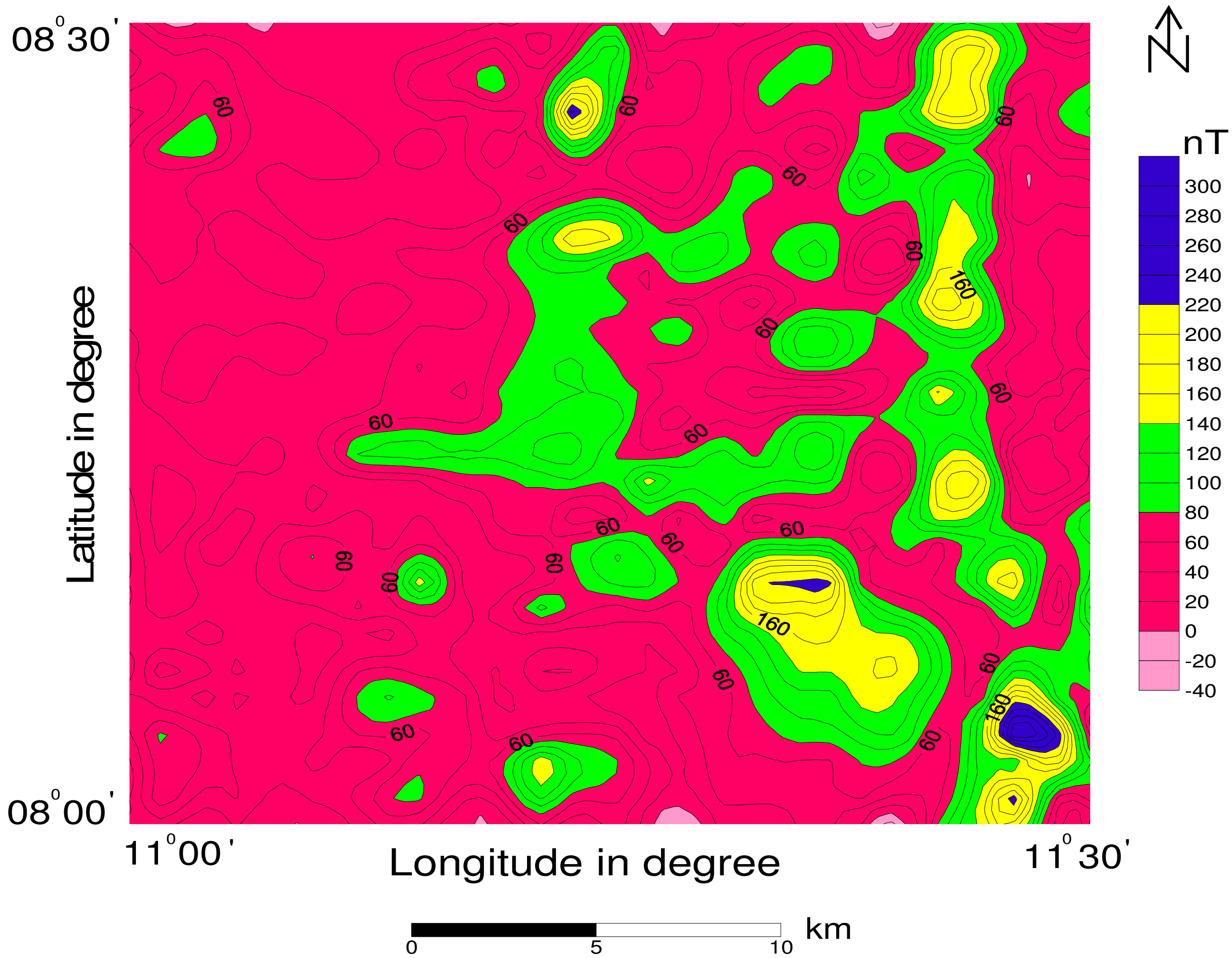


Figure-4
Analytic Signal map of Kam

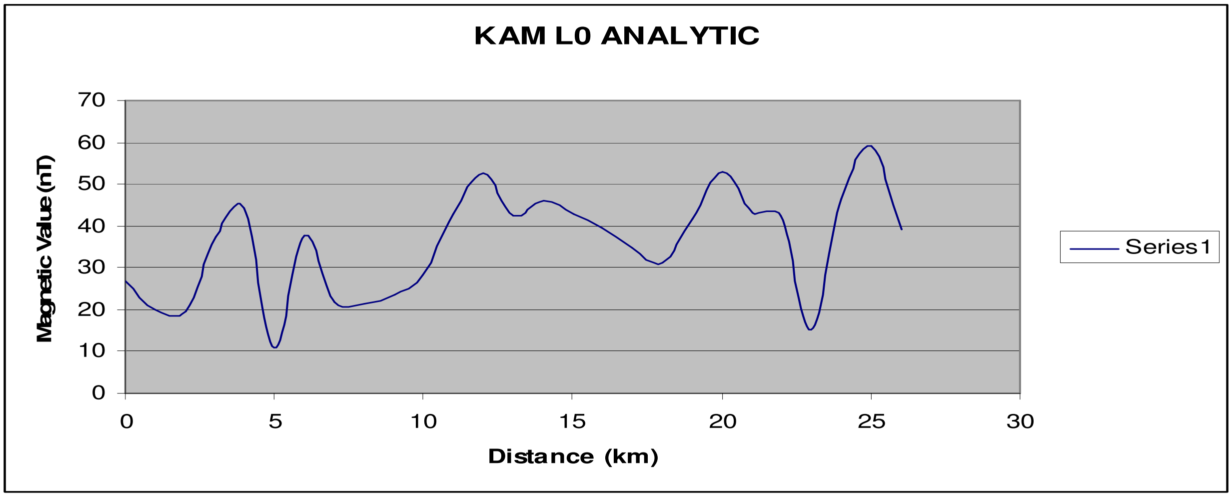
Analytic Signal Profilings: The analytic signal profiling shapes are used to determine the depth to the magnetic sources. The magnitude/ amplitude of the peak of the analytic signal signatures are believed to be proportional to the magnetization and that their maxima occur directly over faults and contacts. The 2-D profile analysis of the aeromagnetic data along the transverses suggests that the study area is composed of magnetic minerals in varying quantities along each profile as shown by the series of highs and lows. Major faults may also be recognized by pronounced lows on magnetic profiles.

Sharp peaks are indicators of outcrops while broad peaks indicate deep seated or magnetic minerals of very large areal extent. Depth estimates to tops of anomalous magnetic bodies are also generated from analytic signal method. To determine the depths to magnetic sources observed on 2D profiling curves, the anomaly width (model) at half the amplitude was used to derive the depths.

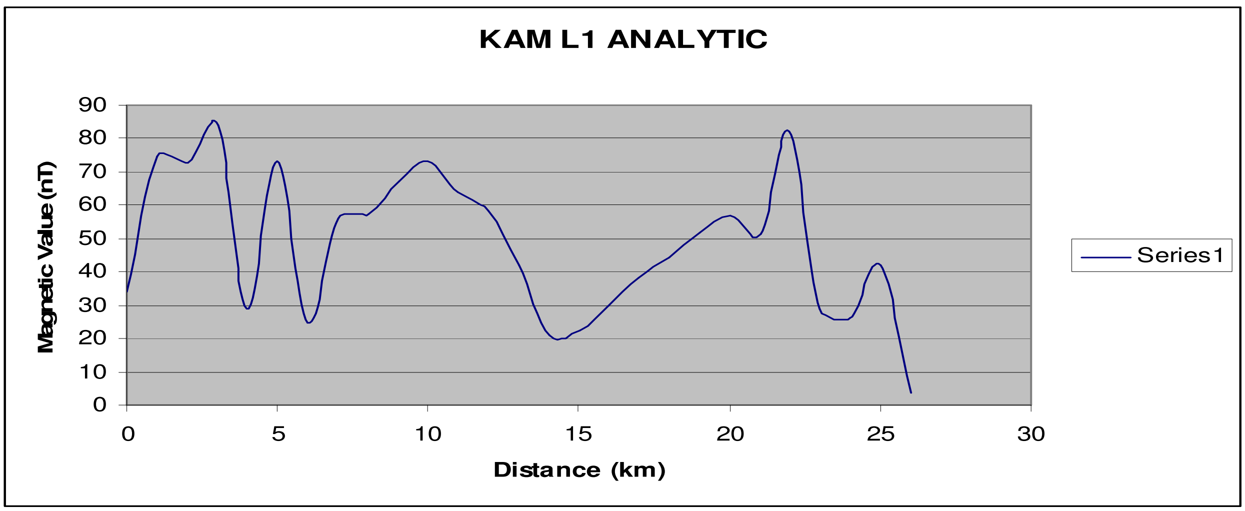
The amplitude of the peak of the profiles is proportional to the magnetization[17].

Qualitative Interpretation of the Profilings: The 2D profiling curves of Kam map (figures 5: Kam Profile L0-L26) has further revealed some interesting geological features in the area. Deep seated and or magnetic minerals of large areal extent are observed along profiles, L0, L1, L3, L10, L16, L18, L19, L20, L21, and L22. These could also be associated with deep faults, deep seated volcanic rock or igneous rock. It could also be a consequence of intensive weathering and erosion of the iron formation from plateaus, this may have yielded a local concentration of limonite or magnetite in the area.

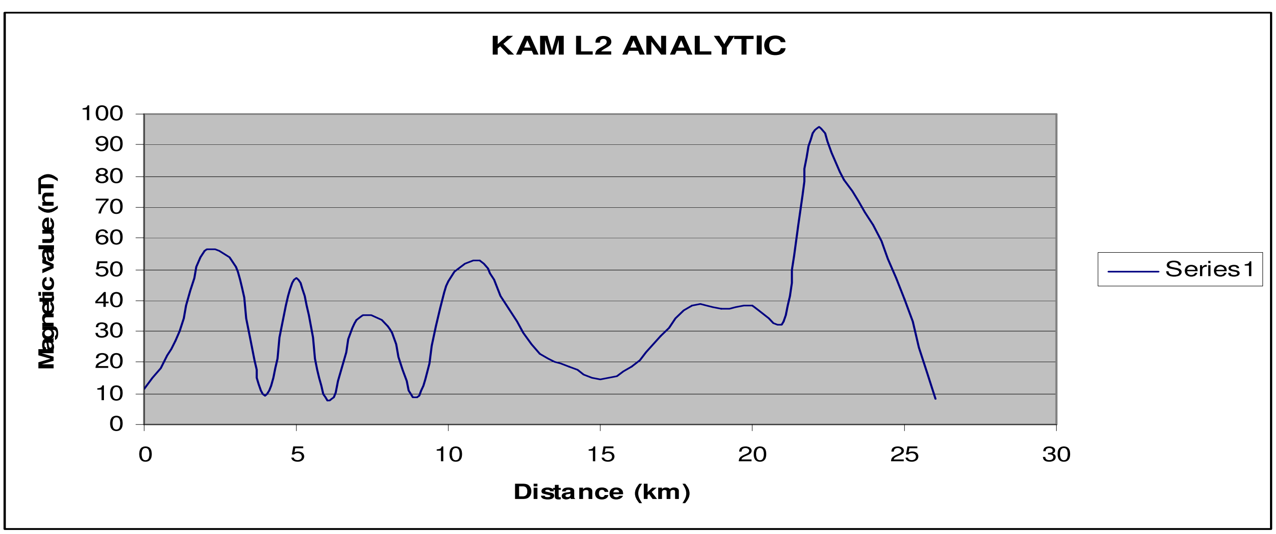
The very sharp anomaly peaks observed along profiles L2, L5, L6, L7, L8, L9, L12, L14, L17, L24, L25 could be attributed to the outcrops of crystalline igneous and/or metamorphic rock or even exposed volcanic rocks. The sharp inflections at about 27km on profiles L2 and profile L3 are indicative of rock contacts[18]. Other anomalies observed as revealed on the profilings are probably due to the presence of sandstones, ironstones, shales, graphites, limestones, intrusives and other near-surface magnetic minerals.



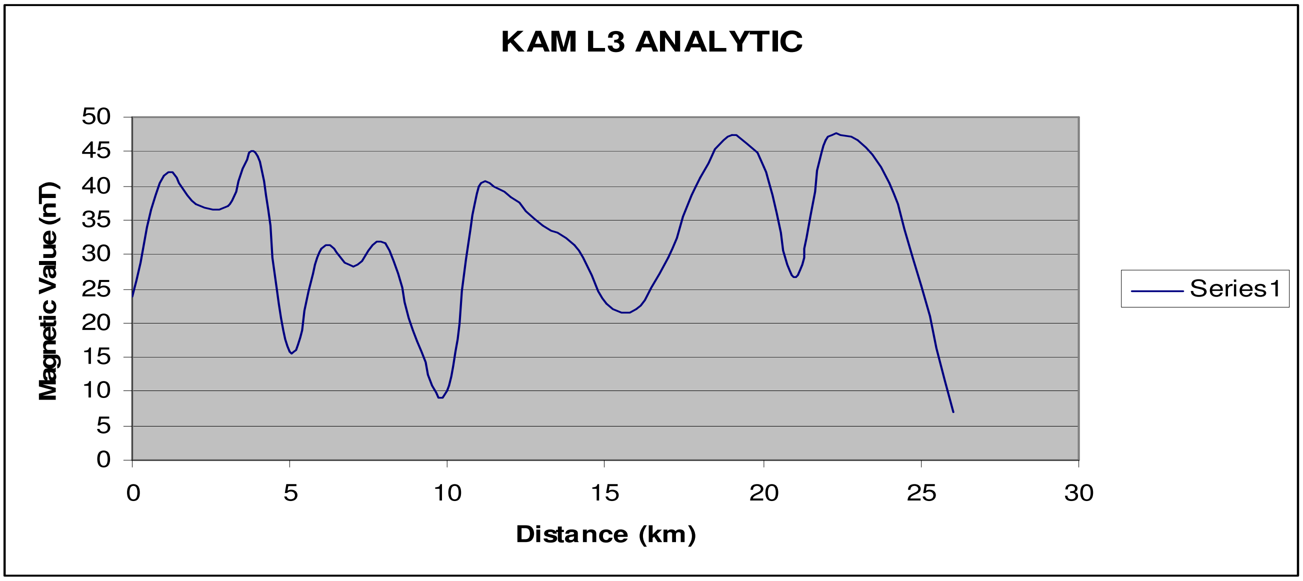
Kam Profile L0



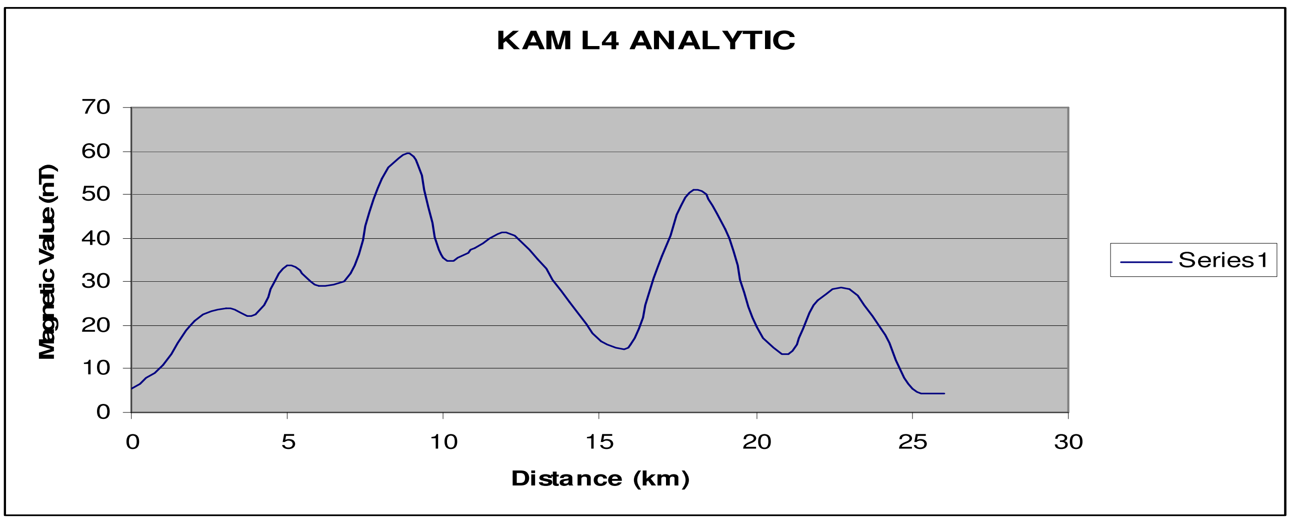
Kam Profile L1



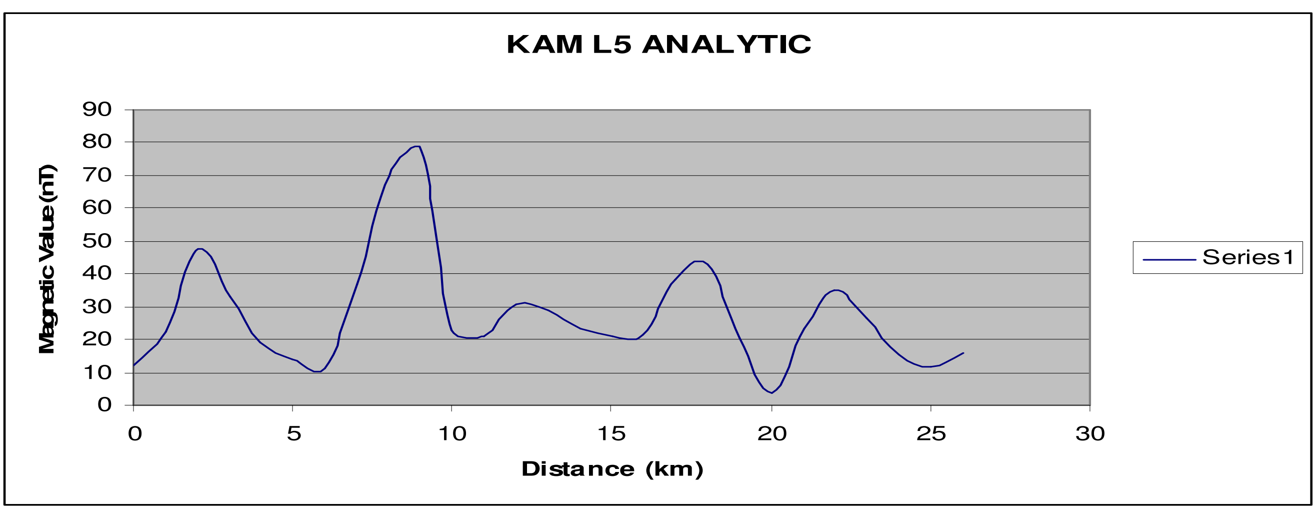
Kam Profile L2



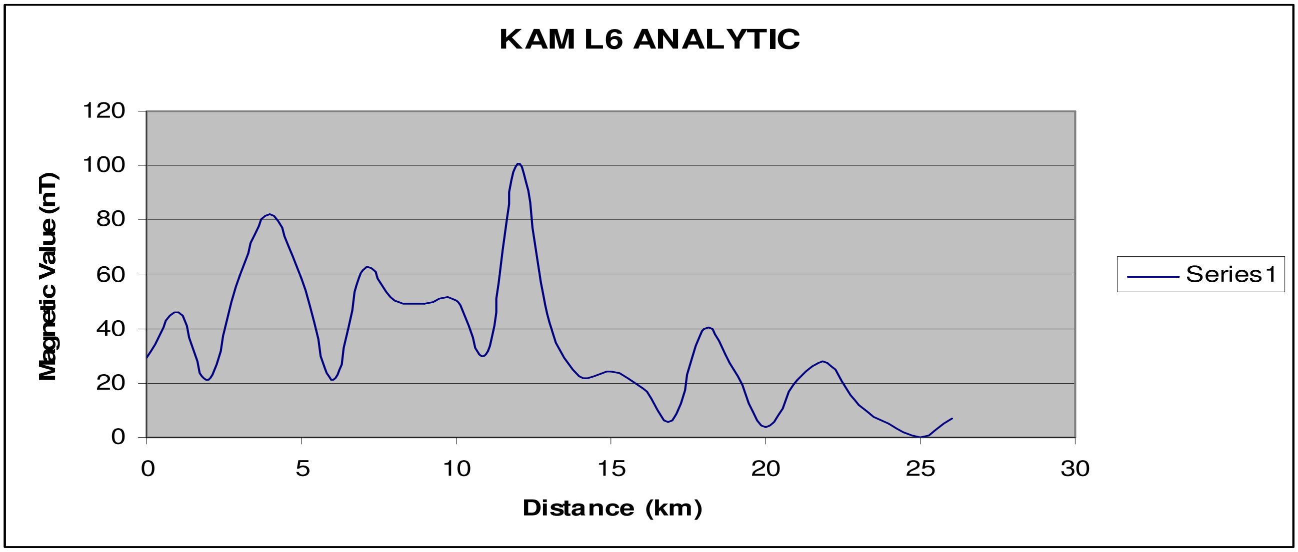
Kam Profile L3



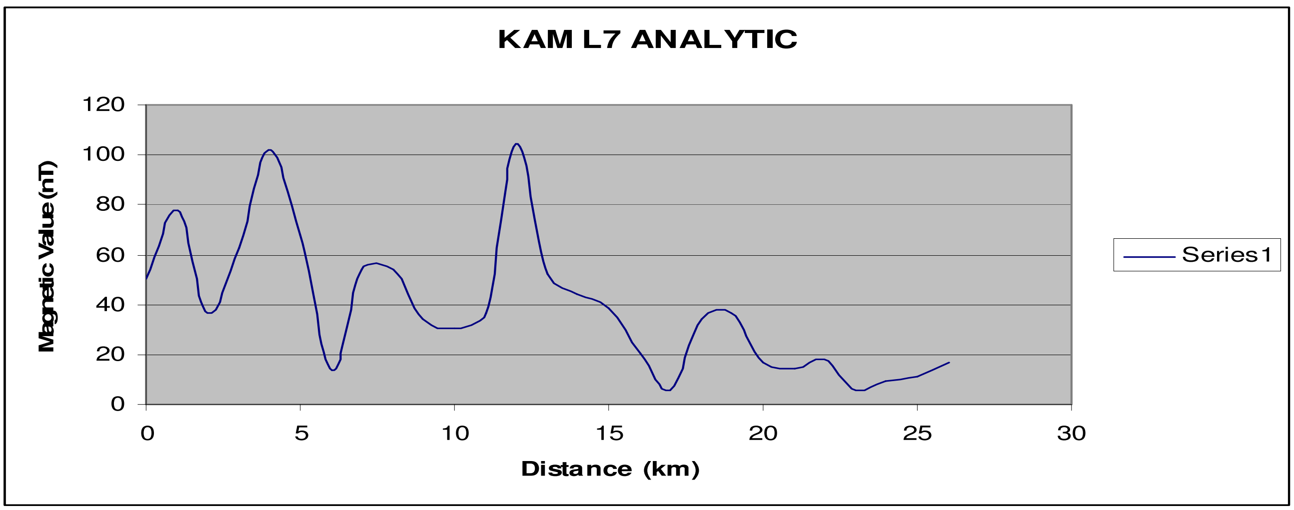
Kam Profile L4



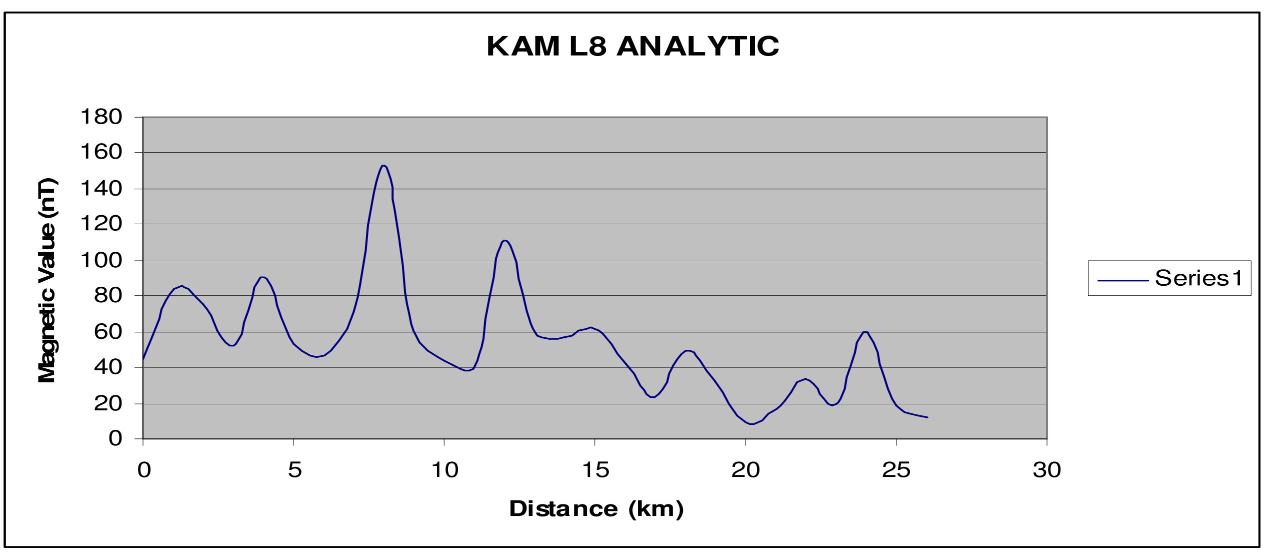
Kam Profile L5



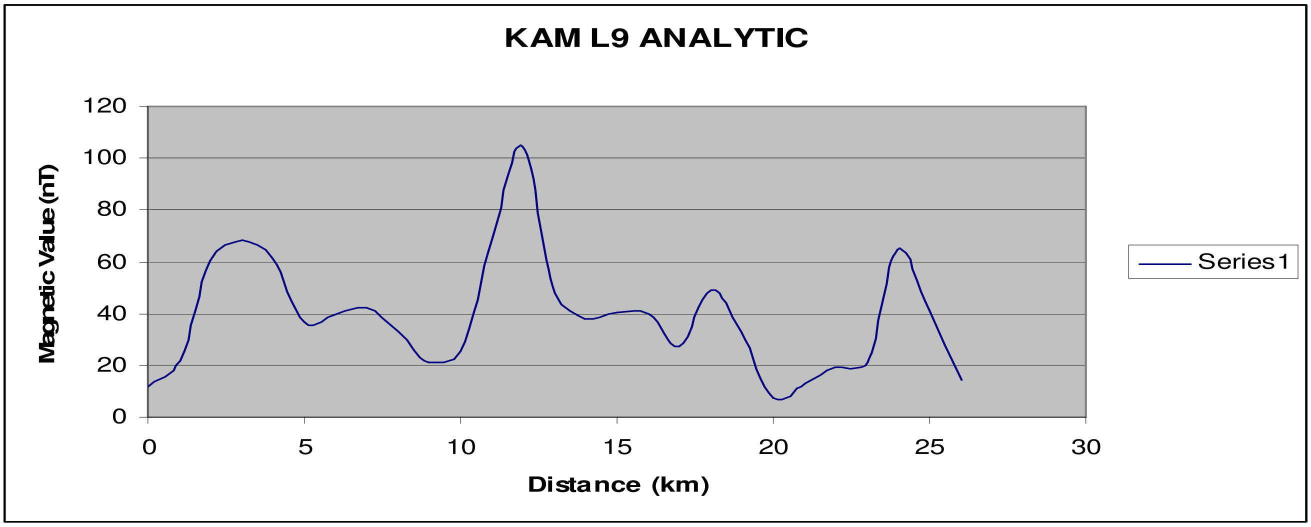
Kam Profile L6



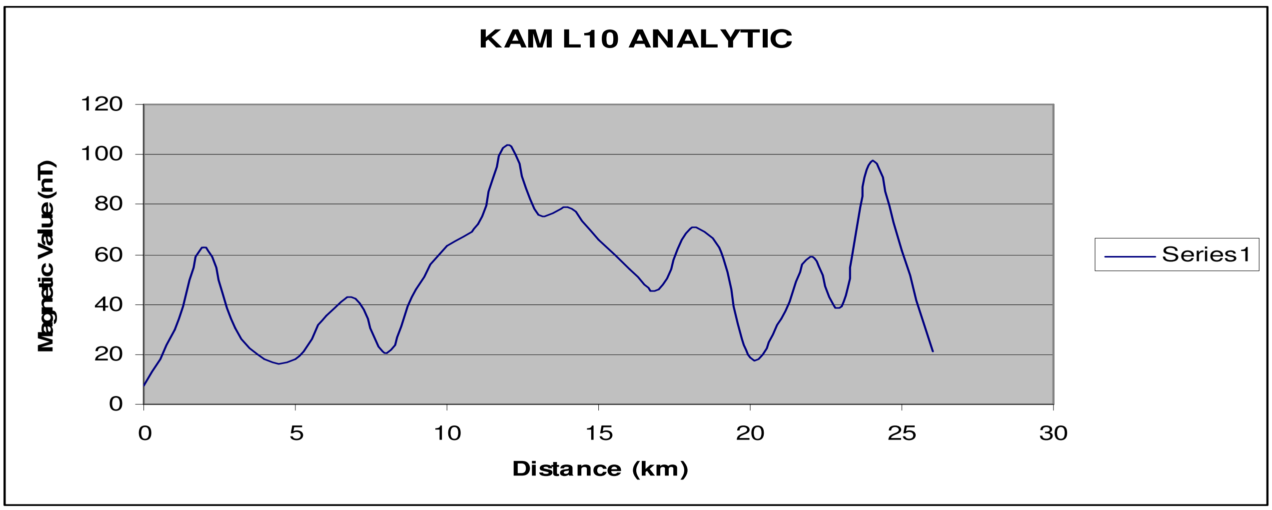
Kam Profile L7



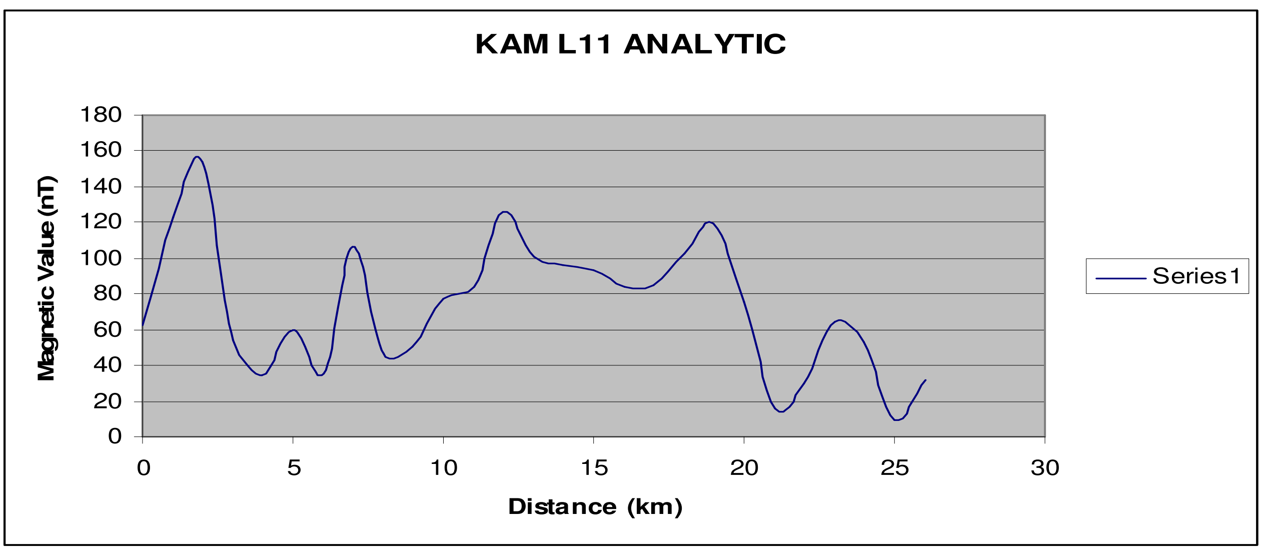
Kam Profile L8



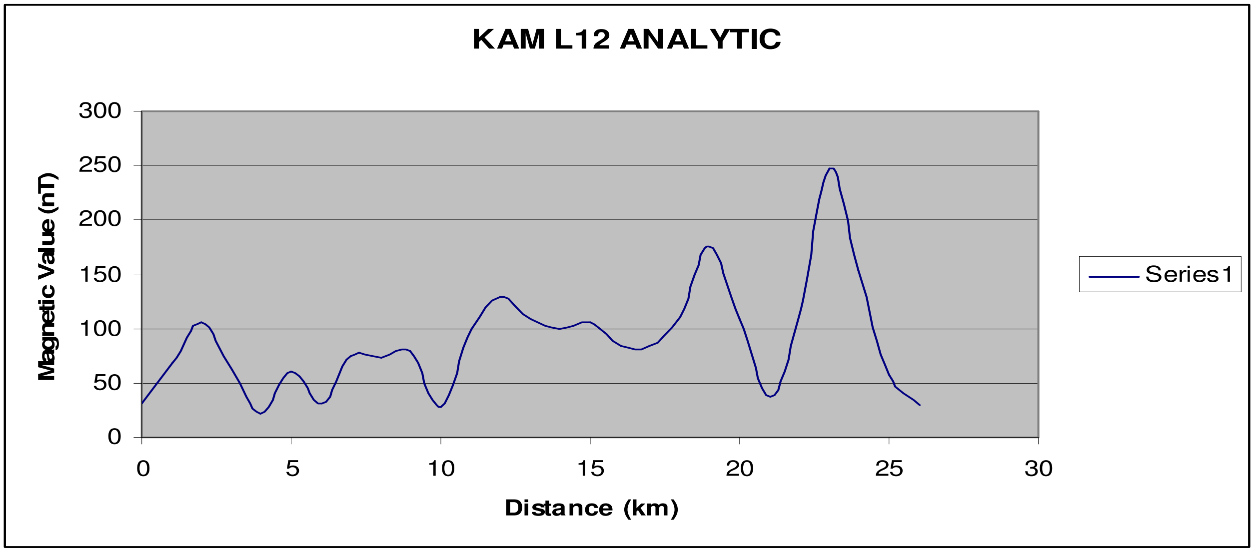
Kam Profile L9



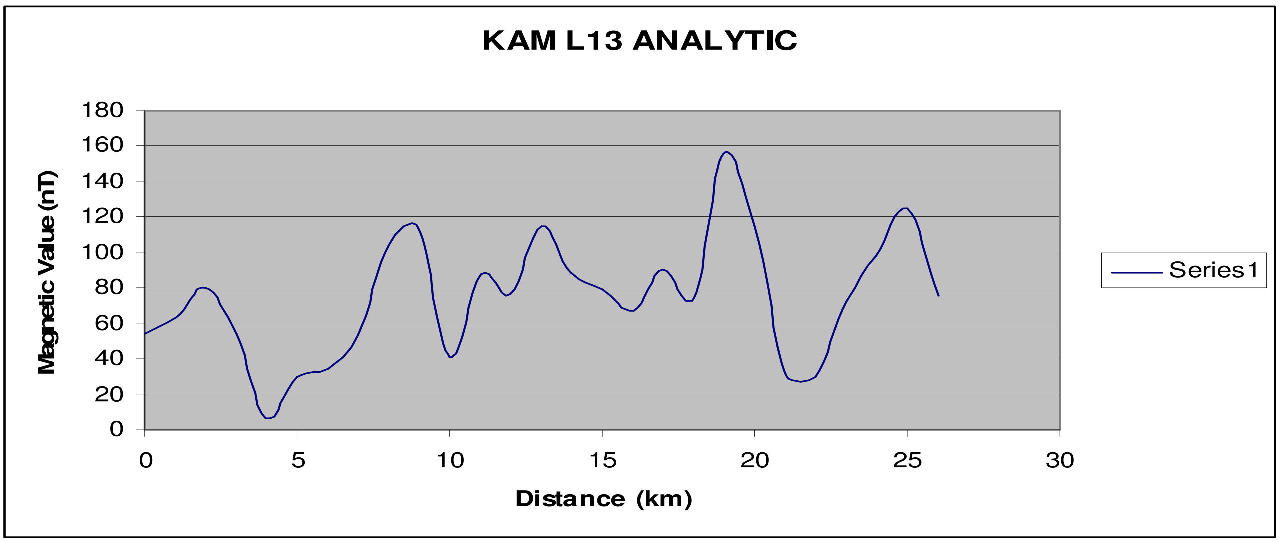
Kam Profile L10



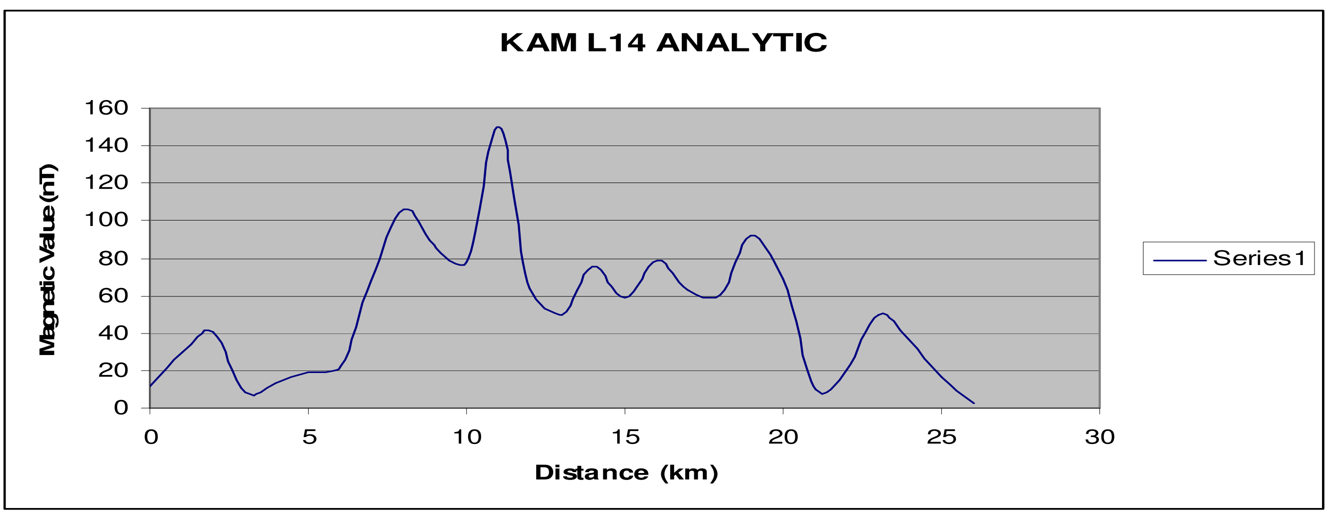
Kam Profile L11



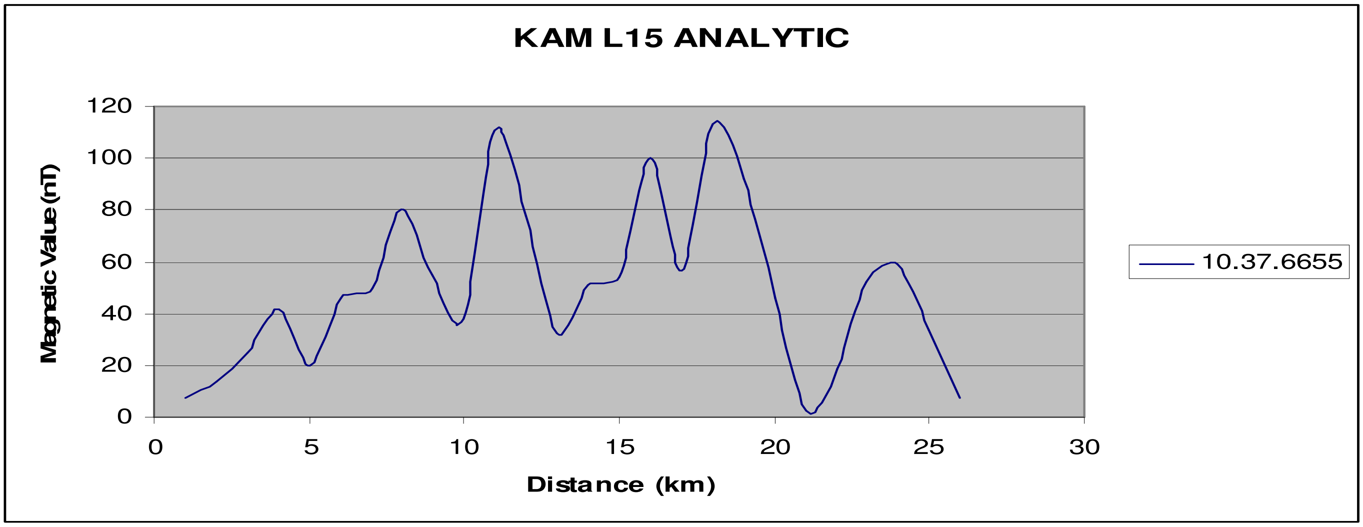
Kam Profile L12



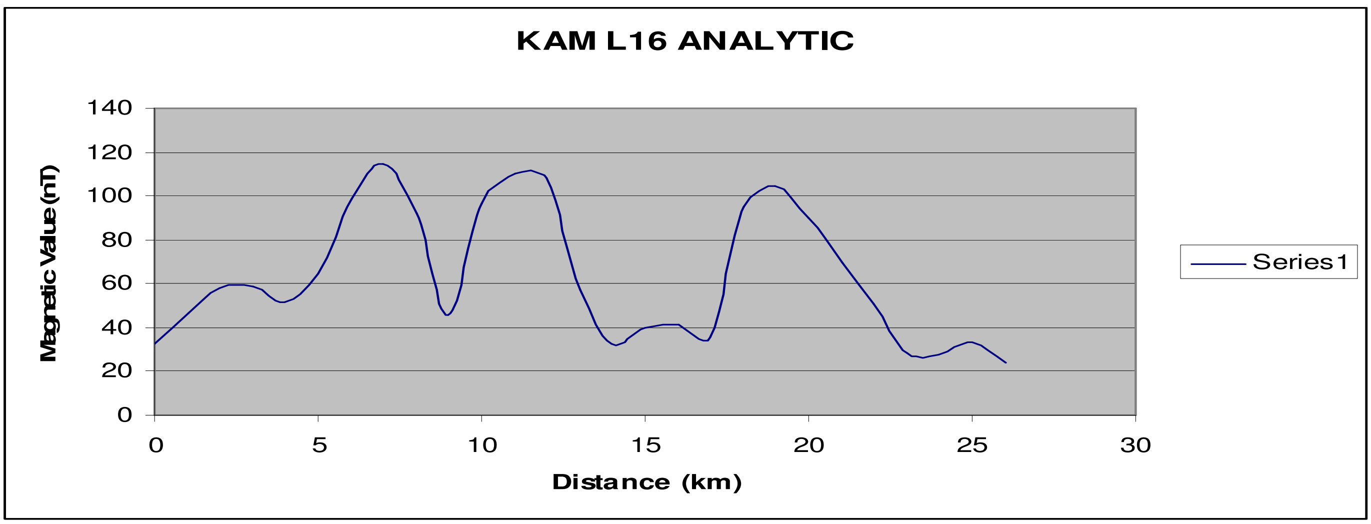
Kam Profile L13



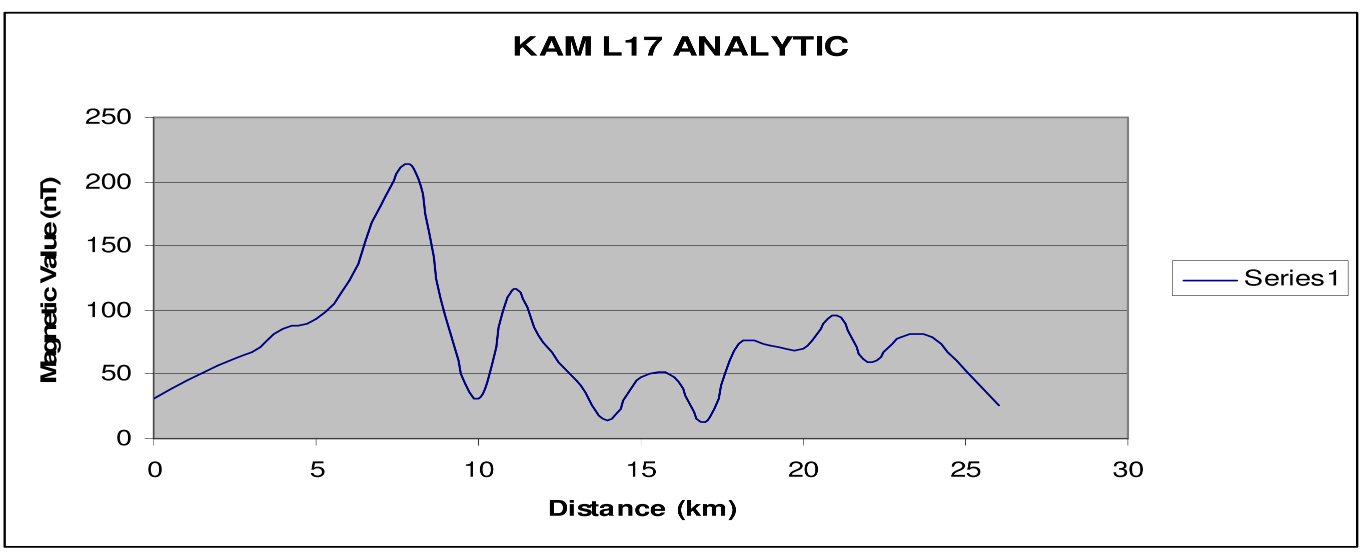
Kam Profile L14



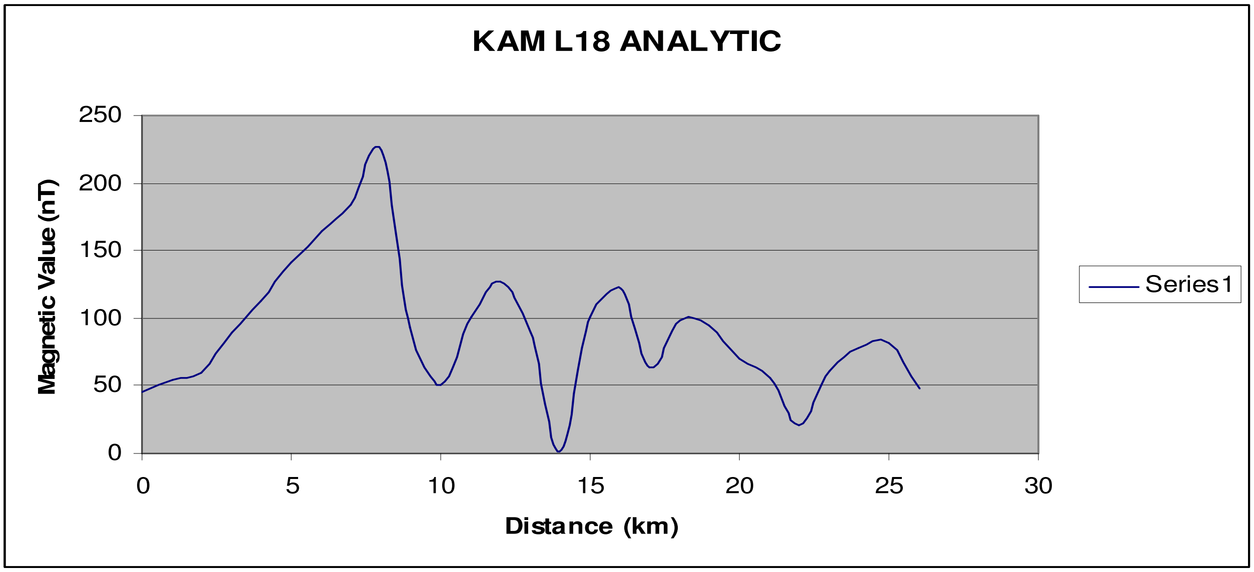
Kam Profile L15



Kam Profile L16



Kam Profile L17



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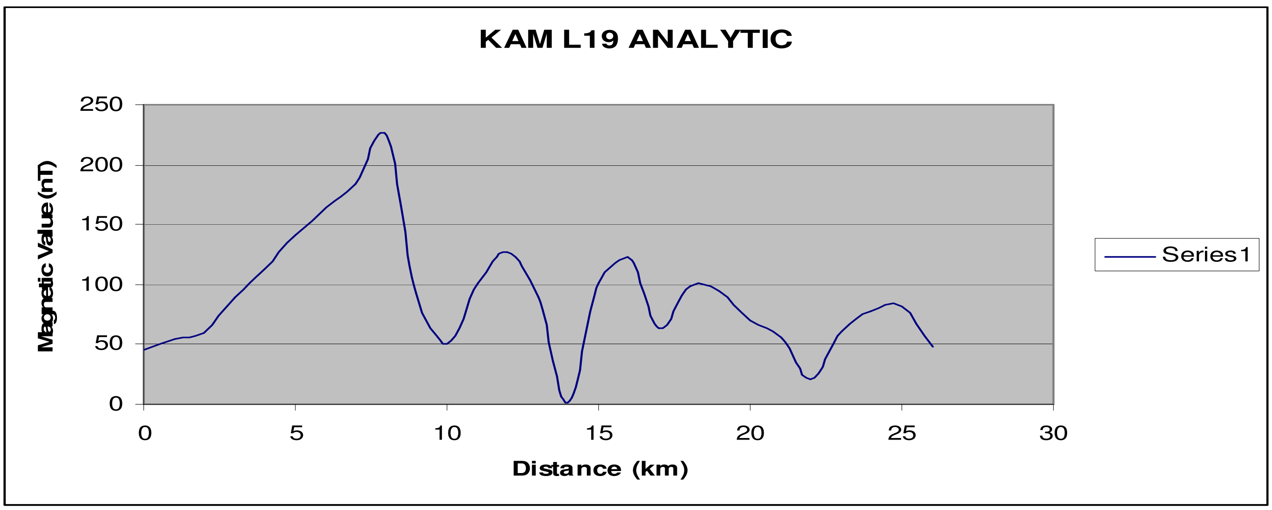

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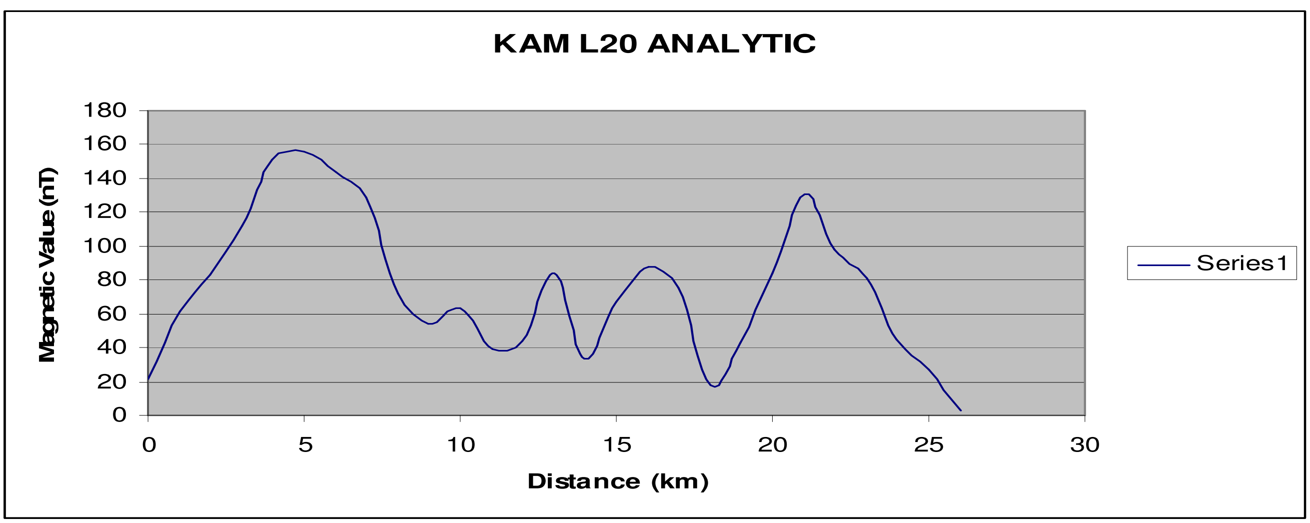
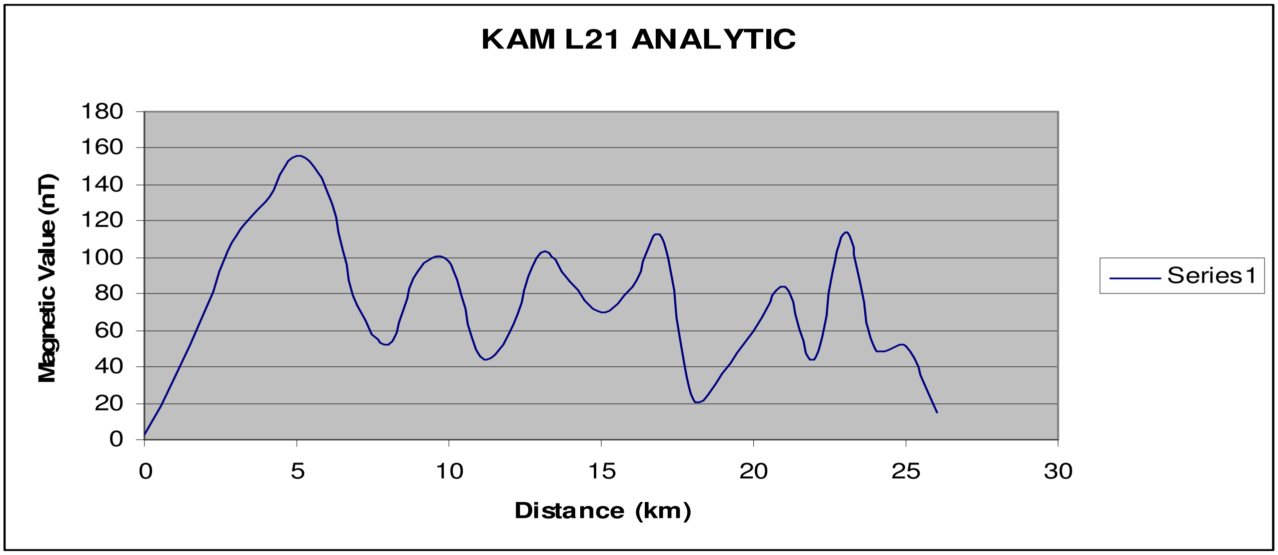
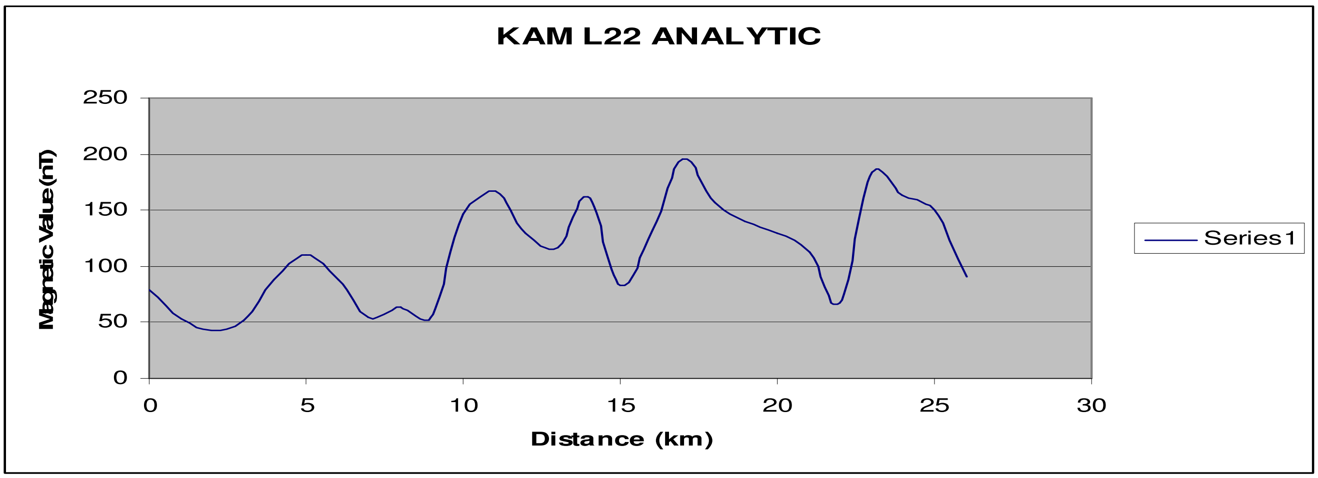


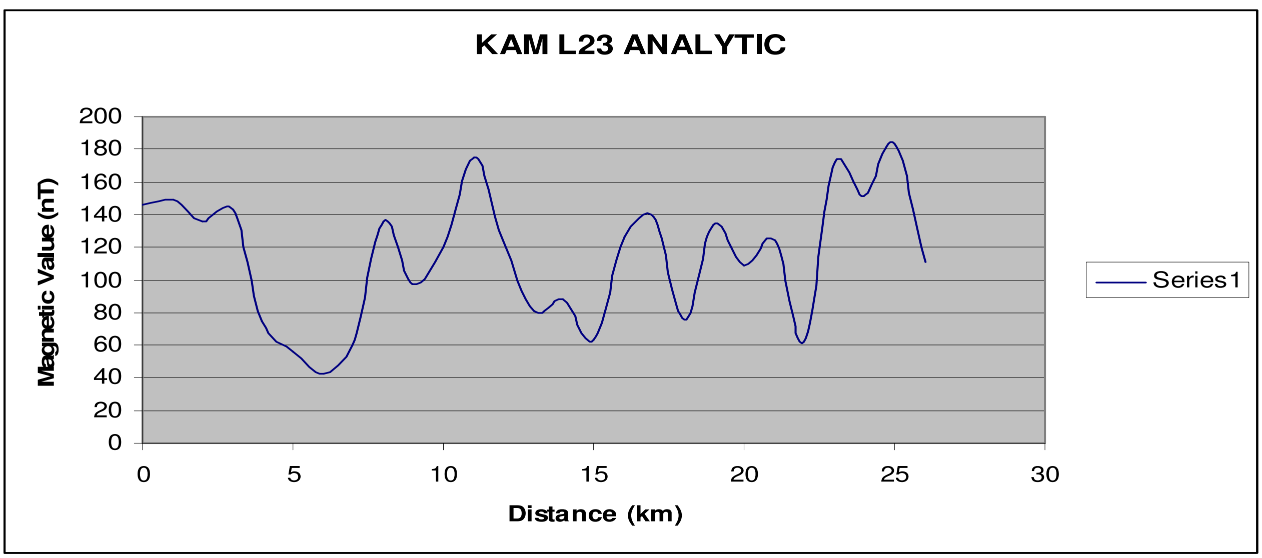
Kam Profile L20



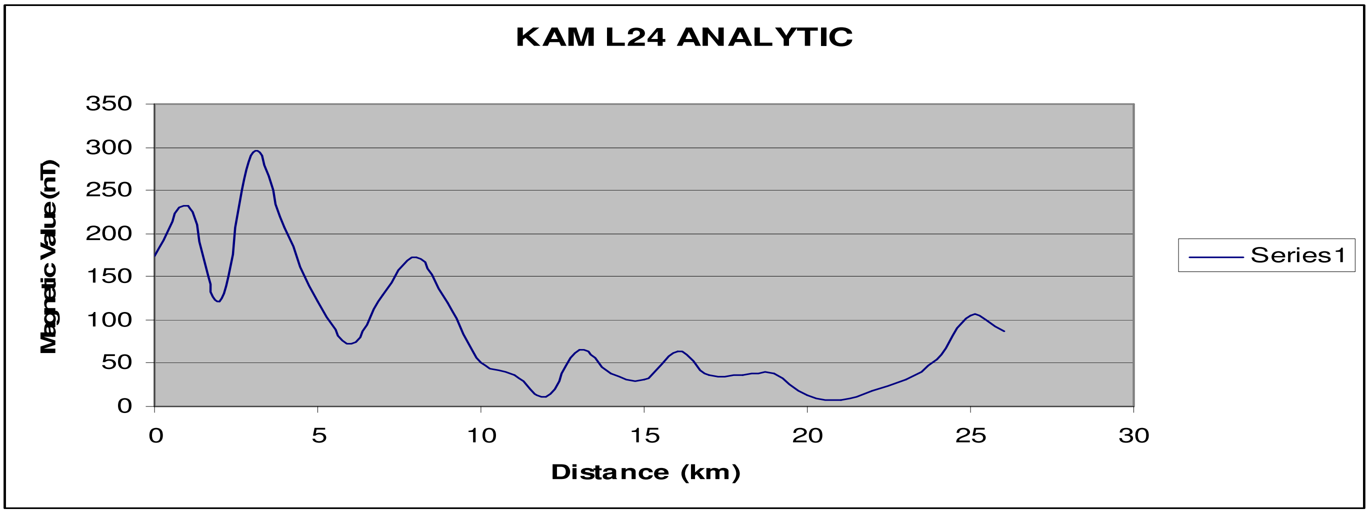
Kam Profile L21



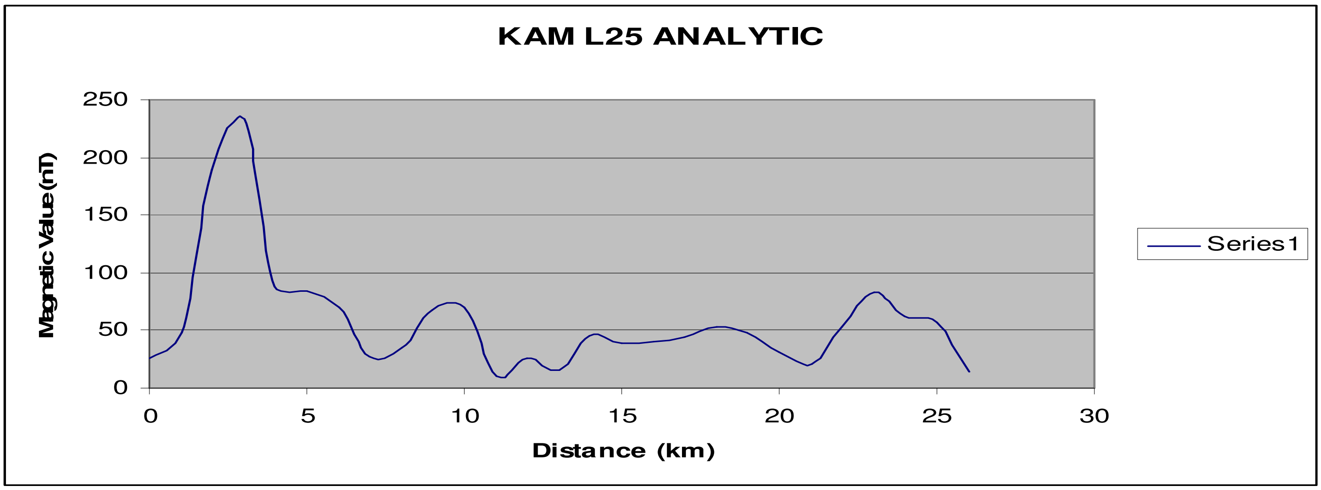
Kam Profile L22



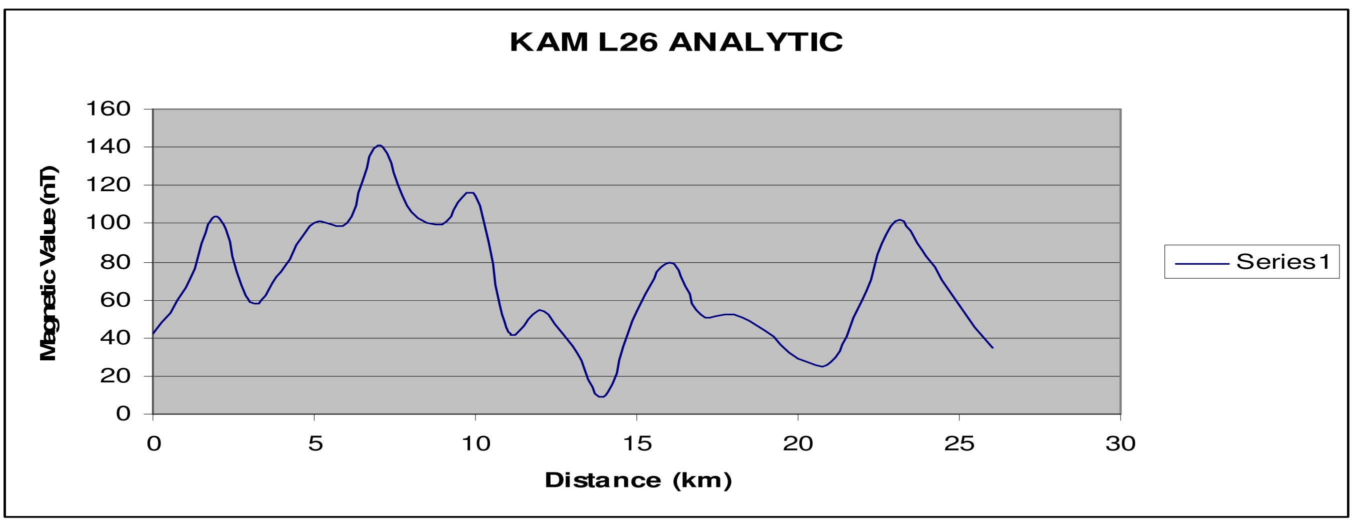
Kam Profile L23



Kam Profile L24



Kam Profile L25



Kam Profile L26

Figure-5
Kam Profile L0-L26

Depth Estimation from the Profilings (Quantitative Interpretation): The depths for each anomaly on each profile were calculated and averaged to obtain a representative depth estimate for the profile. These representative depth estimates was again averaged to obtain a representative depth estimate for the study area.

The depth to the magnetic source(s) along the profiles in the study area was found to range between 0.75km to 6.25km, with an average depth of 2.19km for the entire study area which are in agreement with the results of similar previous works in and around the study area[2,5, 15,17,19-21].

The summary of the distribution of the depths across the profile lines is as shown in table 1.

Depth Contour Map: The depth contour map (figure 6) showed that the depth is increasing towards the Western part of the map and decreases outwardly. Deep source magnetic anomalies observed at the Western part of the study area ranges between 5km to 6.5km Deep blue, dark brown colour (6.5km to 8.0km) and those from 8km and above (ice blue colour). These zones could probably be related to the presence of a deep fault or an intra-crustal discontinuity in the area. These regions are recommended for further investigation especially for its geothermal energy potentials.

The intermediate depths between 3.5km and 5km (yellow) correspond generally to the top of intrusive masses occurring within the basement. A depth of this magnitude should also be investigated for possible hydrocarbon deposit, and these zones are observed in three locations of the study area, the west, southeast, and east-central parts.

Depths between 2km to 3.5km (green) represent depths for the true basement surface. It appears to be the dominant depths in terms of spread in the study area, covering the entire northeast, southeast and east. These depths indicate clearly the magnitude of variations in depth of both the basement topograph and other intrusive in the area. These areas could also be investigated further for the major magnetic minerals like ironstone, sandstones, granite gneiss, magmatite, lead and so on. Additionally, the zone appears to be the store house for the concealed magnetic minerals.

Table-1
Depth Estimates From Analytic Signal Profiles On Map Sheet 236 (Kam), Using Half-Width Method

Profile Number	Anomaly Depth Estimates (km)								Average Depth
0	2	1.25	6.25	3.5	2	-	-	-	3
1	3.25	1	6.25	1	1	-	-	-	2.5
2	2.25	1	2	3	3.25	-	-	-	2.3
3	4	3	4	3	3	-	-	-	3.4
4	1.25	2.5	2	3	2.5	-	-	-	2.25
5	2.5	2.75	2	2.5	3	-	-	-	2.55
6	1.25	3	4	1.5	1.75	2.25	-	-	2.29
7	1	2.5	1.75	1.5	2	1	-	-	1.63
8	1.75	1.25	1.75	1.25	1.5	1	1.25	-	1.39
9	3.25	2	2.25	1.5	2	-	-	-	2.2
10	2	1.75	5.75	1.75	1	2	-	-	2.38
11	2.25	1	1	1.5	1.5	2	-	-	1.58
12	2.5	1.25	3	2.25	1.75	2.5	-	-	2.21
13	2.25	2.25	1	1.5	1	2	2.25	-	1.75
14	2	1.5	1.25	1	1.25	1.5	2.5	-	1.57
15	1.75	2	2	1.25	2.25	2.75	-	-	2
16	1.75	3	3.25	4	1.25	-	-	-	2.65
17	3.75	2	2	1.25	1.75	-	-	-	2.15
18	5.5	2.5	1.75	2	2.75	-	-	-	2.9
19	5.5	2.5	1.75	2	2.75	-	-	-	2.9
20	5.75	1	1	2.5	3.75	-	-	-	2.8
21	5.25	2	1.75	1.25	2	1.25	-	-	2.25
22	2.75	2.25	1	4.75	3	-	-	-	2.46
23	1	1	1.75	1.75	0.75	0.75	0.75	1	1.09
24	1	2	2.5	1	1	1	-	-	1.42
25	2	2	1	1.75	3.5	-	-	-	2.05
26	1.5	1.5	1	1	1.5	3	-	-	1.58

Average= 59.25/27 = 2.19 km

The shallow depths between 0km and 2km (neon red) are probably attributed to shallow intrusive bodies or some near-surface basement rocks. These could also be due to shallow buried river channels.

Lastly, a negative depth value of -1km to 0km (pink) is observed in the southwest and southeastern parts of the study area and this is most likely to be due to plume uprising during the volcanic activities in the region.

Conclusion

The analytic signal technique showed superior efficiency and accuracy in that, it has proved to be an excellent and versatile tool in its ability to reveal the magnetization levels of various concealed magnetic bodies, the source locations, their estimated depths and other complex geological structures. Another advantage of analytic signal technique is that it allows a rapid evaluation without any assumption as to the geometry or magnetization of the structures.

The results obtained from both profiling curves and depth contour map showed that the study area is magnetically heterogeneous and the basement is segmented by faults.

Based on the results obtained from both profiling curves and depth contour map, it was revealed that the study area is divided into three basinal structures; deep sources ranging between 5km and 8.5km and the area is recommended for further investigation especially for its geothermal energy potentials. The intermediate depths between 2km to 4.5km correspond generally to the top of intrusive masses occurring within the basement, a depth deep enough for possible hydrocarbon deposit. Shallow depths between 0.01km and 2.5km are attributed to shallow intrusive bodies or near-surface basement rocks probably isolated bodies of ironstones formation concealed within the sedimentary pile.

These deductions were arrived at after due consideration of both qualitative and quantitative methods of interpretation supported with geological information of the area.

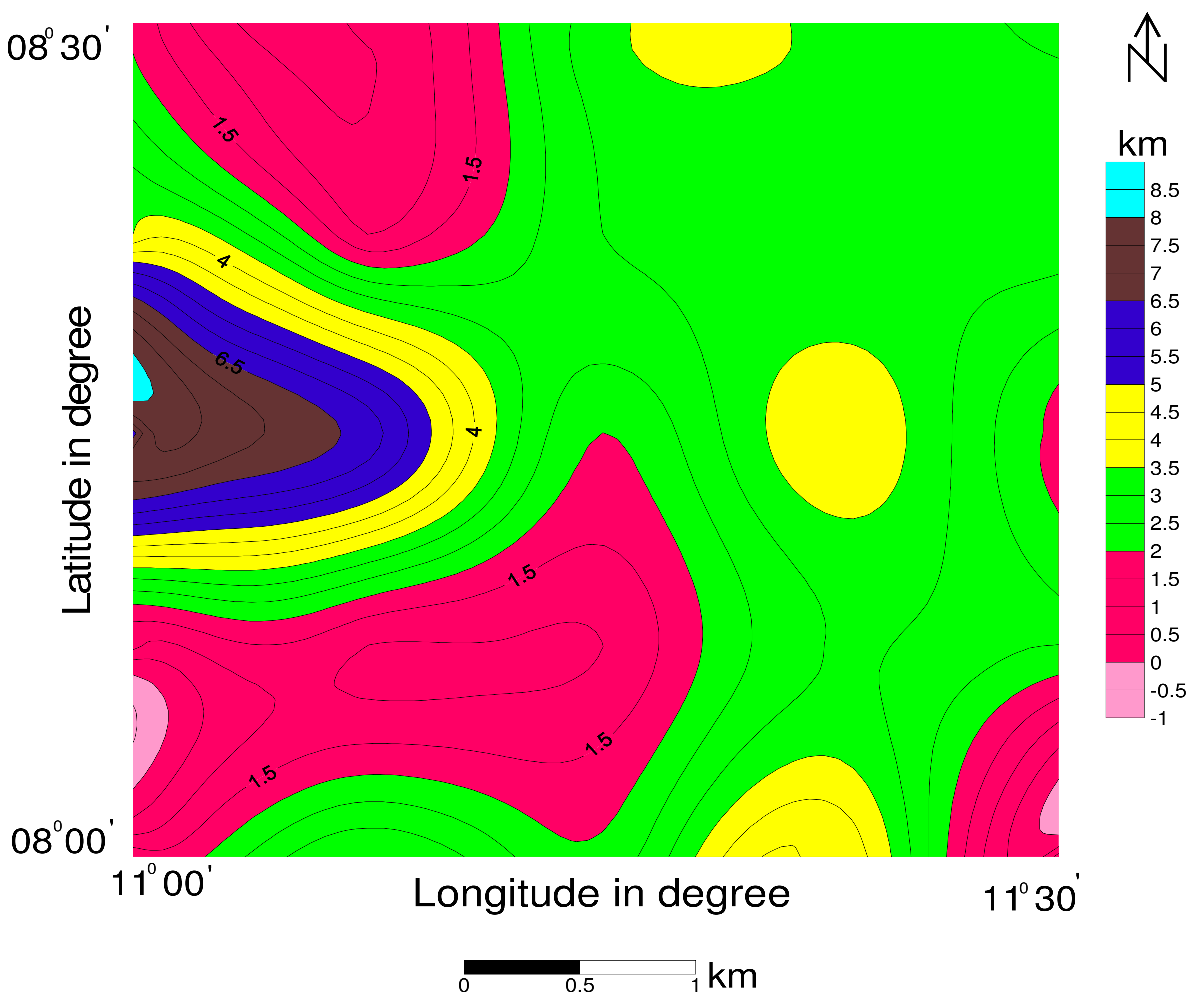


Figure-6
Contour map of the depth estimate of Kam

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