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Geophysical and Chemical Analysis of Iron ORE Deposits in Maua, Kenya

Benson C. Mwirigi*[1], John G. Githiri[2], Willis Ambusso[3]
*[1,3] Physics Department, Kenyatta University, Nairobi, Kenya
[2]Physics Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

ABSTRACT

Ground magnetic surveying was used to detect magnetic rocks within host formations in Kindani area of Maua. A fluxgate magnetometer was used to measure the vertical component of the Earth's magnetic field in some 98 stations, covering an area of about 25km^2. Diurnal and geomagnetic corrections were done on the data. A RMI contour map delineates varied anomalies spread out within the region. The anomalies mostly trend on NW-SE and SW-NE directions. Four cross sectional profiles were drawn across anomalous regions. The data obtained was used in 2D modeling using Euler software which gives estimated depths to magnetic structures at between 0 -1500m. Forward modeling using Mag2dc software shows bodies of susceptibility between -1.724 SI to 1.7624 SI. The depth to top of magnetic structures ranges from 0-136m, which indicates shallow structures. A chemical analysis of some rock samples indicates quantity of Fe_2O_3 at an average of 25%. This shows significant quantities of iron which confirms presence of iron ore in the area. This confirms presence of extended iron deposits within the region, in addition to the deposits discovered at neighbouring Kimachia.

Keywords: Iron ore, Ground Magnetics, Energy Dispersive Spectroscopy

I. INTRODUCTION

This paper presents results and analysis of ground magnetic data carried out over Maua area covering about 25km^2 in Meru County, Central Kenya. The studied area is bound by the Eastings 389000-394000 and Northings 19000-24000. The area is located about 7km South West of Maua town. The survey aimed at delineating areas of possible iron ore deposits after significantly magnetic rocks were found in the area. The residual magnetic intensity map (RMI) delineates regions covered by magnetic anomalies. Euler deconvolution gives the possible locations and depths of these anomalous bodies. Mag2dc software was used to model the possible body shapes of the anomalous bodies. Euler deconvolution results were used as initial parameters for 2D modeling. The study reveals new regions of iron ore deposits within the County.

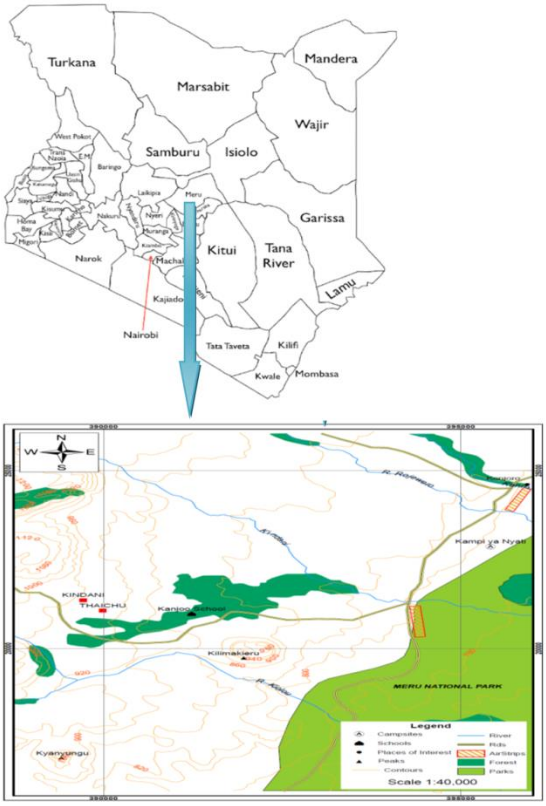

Figure 1 (a) : Physiological map of the study area

Geological Setting

The area under study is bound by the longitudes $38^0 00'$ E and $38^0 05'$ E and latitudes $0^0 05'$ and $0^0 15'$. This area falls to the North East of Mt. Kenya. The study area falls within the outskirts of Nyambene ranges. The Nyambene volcanic range is elongated in a north-east to south west direction from the foothills of Mt. Kenya and rises to an elevation of 7000 feet. Rocks in the Nyambene volcanic series are young Tertiary, Pleistocene and recent extrusive rocks and subordinate sediments. The Pleistocene-recent lava is mostly olivine basalts. The basement system metamorphic rocks comprise gneisses, plagioclase amphibolites, and crystalline limestone and quartize [14].

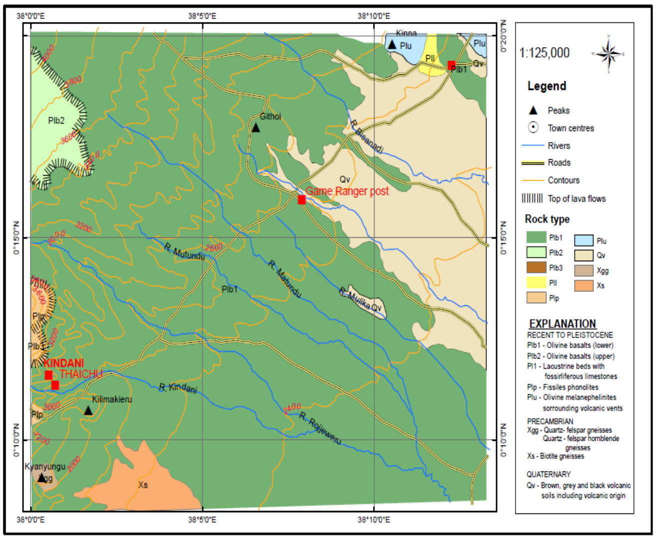

Figure 1 (b) : Geological map showing study area and adjacent regions (simplified from Rix, 1967)

II. METHODS AND MATERIAL

Ground magnetics surveying

Magnetic surveying aims at locating rocks or minerals with anomalous magnetizations which reveal themselves as anomalies in the intensity of the earth's magnetic field [2, 3]. The ground magnetics survey carried out in Maua region aimed to locate possible sources of iron ore in the region. Magnetic surveying involved 3 major steps:

i. Measuring the terrestrial magnetic field at some predetermined points.
ii. Correcting the magnetic data for known changes.
iii. Comparing the resultant value of the field with the expected value at each measurement station [10]

The expected of the field is the value given by the International Geomagnetic Reference Field (I.G.R.F). The difference between the observed values and the I.G.R.F values gave the magnetic anomaly which was then appropriately processed and interpreted

The vertical magnetic component was measured using a Flux gate magnetometer in 98 stations, about 500m apart and extending about $25km^2$. The station positions were determined using a GPS machine.

III. RESULTS AND DISCUSSION

A. Data analysis

There are several methods of presenting magnetic data [10, 12]. Presentation was done by drawing magnetic contour maps and using traverses to draw magnetic profiles. Depth estimates was done using Euler Deconvolution [13], using Euler 1.0 software.

B. Qualitative analysis of magnetic data of the area

The residual magnetic intensity (RMI) data obtained after doing diurnal and geomagnetic corrections was used to draw a contour map shown in figure 3 below.

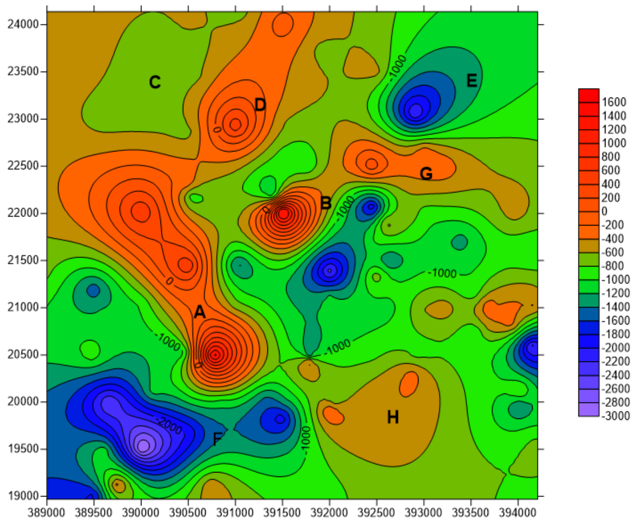

Figure 2 : A residual anomaly map of the area

Qualitative interpretation of a magnetic map begins with a visual inspection of the shape, trend of the major anomalies, and examination of the characteristic features of each individual anomaly. Such features may include the relative locations and amplitudes of the positive and negative parts of the anomaly and the aerial extent of the contours and sharpness of the anomaly, as distinguished by the spacing of the contours [11, 15].

The map above shows a color range of magnetic residual anomaly values, with red as the highest and blue-purple being the colors with the least values. The highest anomaly rises to about 1600 nT while the lowest values are at about -3000nT.

The anomalies in the region show 3 major orientations: SE-NW, SW-NE and the E-W orientations. The longest positive anomaly, marked A is elongated on a SE-NW direction. It has values that rise to about 1600 nT on the lower end and to about 200 nT on the upper end. The high amplitudes suggest near surface magnetized bodies. Such high values are usually characteristic of highly magnetized ores such as those containing high magnetite content. Anomaly B is a magnetic high circular anomaly appearing at the center of the study area. It also rises to a high of about 1600 nT.

Anomalies marked E and F are negative anomalies with anomaly F getting to a low of up to -3000nT. The anomalies marked E have a SW-NE orientation. The anomaly F has a SE-NW orientation which is a common trend with the other major anomaly in the neighborhood, anomaly A. Since these negative anomalies occur near the positive anomalies, they could be the negative poles on the same bodies since magnetism is a dipolar quantity. The anomalies D, G and H represent more subdued highs. These lower amplitude anomalies suggest deeper buried bodies which may be of volcanic origin. Area C and the lower parts of H are more magnetically quiet areas and suggest absence of highly magnetized bodies. These areas seem to have homogenous non-magnetic material.

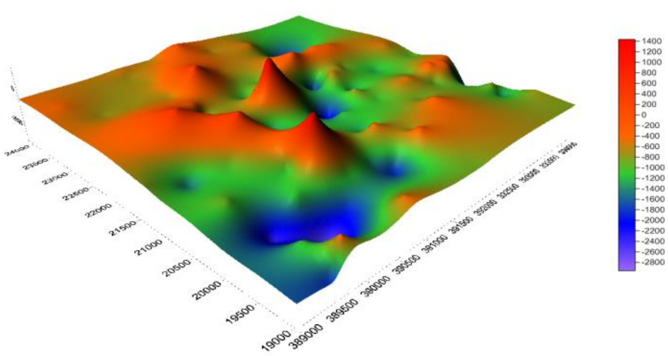

Figure 3: A 3-D Magnetic intensity surface map of the study area.

C. Quantitative Analysis

Quantitative analysis in this study involved interpretation of profile data and forward modeling. Four profiles AA', BB', CC' and DD' were chosen, cutting across major anomalies observed in the study area. Each profile was chosen to cut through both magnetic highs and adjacent lows because magnetism is a dipolar quantity. Anomalous objects are therefore expected to show both positive and negative poles in observed data. The figure below shows the profiles.

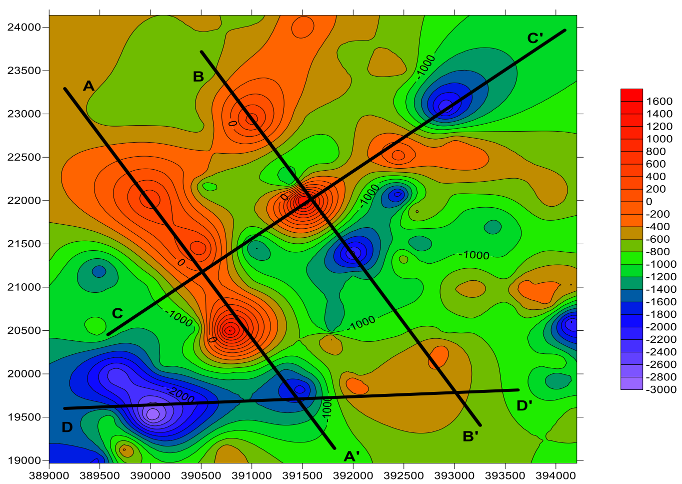

Figure 4: Profile cross-sections

D. Euler De-Convolution

Euler deconvolution is a technique which uses potential field derivatives to image subsurface depth of a magnetic or gravity source [8,5]. Euler deconvolution is expressed as

$$(x-x_0)\ \delta T/\delta x + (y-y_0)\ \delta T/\delta x + (z-z_0)\ \delta T/\delta z = N\ (B-T)$$

Applying the Euler's expression to profile or line oriented data (2D source), x-coordinate is a measure of the distance along the profile and y-coordinate is set to zero along the entire profile [1]. The equation is then written as

$$(x-x_0)\ \delta T/\delta x + (z-z_0)\ \delta T/\delta z = N\ (B-T)$$

Where (x_0, z_0) is the coordinate position of the top of the body whose total field T is detected at point (x,z) B is the value of the regional field and N is the structural index which is a measure of fall-off rate of the magnetic field. It depends on the geometry of the source [6, 1].

Euler De-Convolution Solutions and Discussions

Euler 1.0 software was used to map the depth to subsurface magnetic structures in the survey area. A window size of 11 was chosen, with a X-separation of 255.71 m and Y separation of 127.86m. A structural index of 1.0 was chosen as it best represents the structural geological formations of the area. The I.G.R.F values used for this area are shown below.

Table 1: The I.G.R.F values for Kindani Area

Component	Field Value
Declination	0.67 degrees
Inclination	-19.828 degrees
9Vertical Intensity (B_z)	11455 nT
Total Intensity	31770 nT

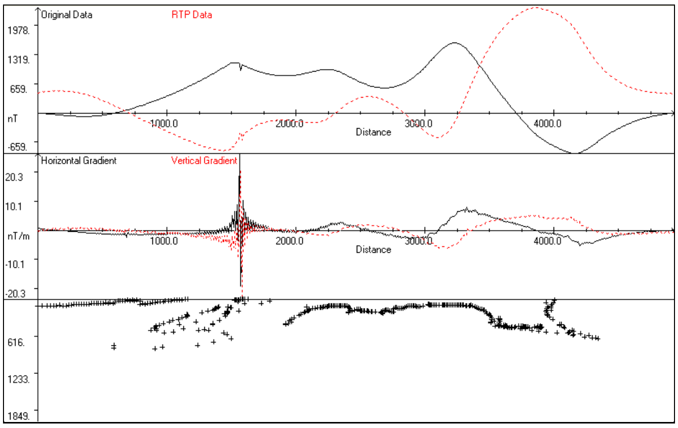

Figure 5(a) : Euler solutions along profile AA'

From the profile AA', Euler solutions suggest shallow magnetic structures at just below the surface to a maximum depth of less than a km below the surface. The RTP curve rises to its highest at a distance of 4 km along the profile and is lowest at 1.5 km. The high suggests a source of high magnetic susceptibility relative to host rocks while the low may suggest rocks of lower susceptibility.

From profile BB' solutions clusters occur near surface and between distances 0.75km to about 1.75km along the profile. They also occur at 2.25 km and between 4.6 - 5 km along the profile. There is an abrupt change in vertical and horizontal gradients at 2.25 km. This also corresponds to an abrupt change in the RTP data curve outline. This point also corresponds to one of the near surface Euler solution clusters. A discontinuity at a distance of 4.5km suggests presence of faulted structure.

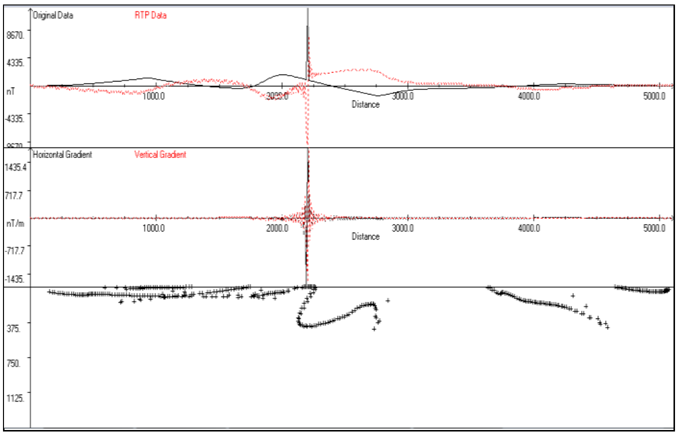

Figure 5 (b): Euler solutions along profile BB'

On profile CC', Euler cluster solutions occur less than 100m below the surface at 0.25km, 1 km and at 2.5 km along the profile. The deepest solution clusters occur at 0.53 km. These indicate presence of shallow magnetic structures which could be iron ore bodies. The solutions at 0.25km and 1km along the profile coincide with areas of abrupt changes in horizontal and vertical gradients. These may represent abrupt lateral change in magnetization relative to host rocks. Solutions at 4.25 km coincide with a point of inflection on the RTP curve which may indicate the top of a magnetic body. There is also a rapid fall of both vertical and horizontal magnetic gradients at 2.5km. This indicates a rapid change in magnetism relative to host rocks.

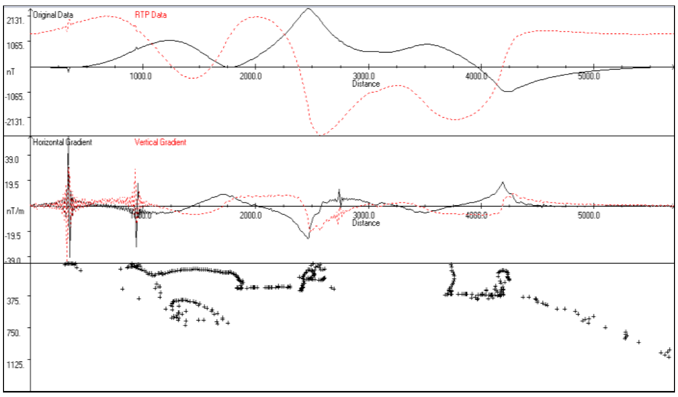

Figure 5 (c) : Euler solutions along profile CC'

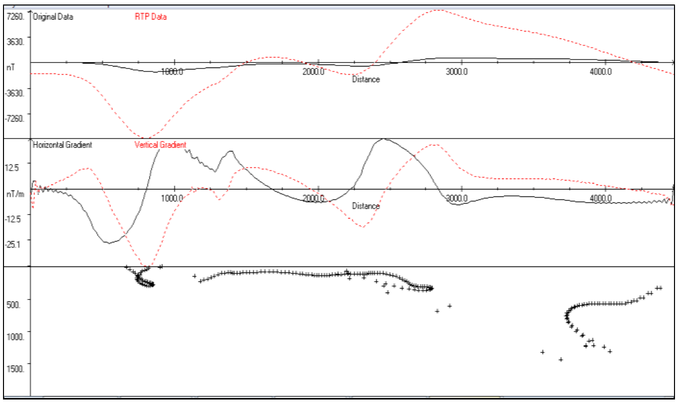

Figure 5 (d) : Euler solutions along profile DD'

The Euler deconvolution solutions for profile DD' indicates presence of magnetic sources at a shallow depth of about 200m below the surface. The deepest sources occur at a depth of 900m. These solutions occur at 0.8, 2.75km and at 3.75km. These indicate relatively shallowly buried magnetic bodies. The RTP curve dips deepest at 0.9km along the profile and rises highest at about 2.8 km which indicates low and high magnetic susceptibility bodies respectively.

E. Forward Modeling Results

Forward modeling was done using mag2dc software developed by Cooper, (2004). The results obtained from Euler deconvolution were used as start parameters in forward modeling. The software is based on Talwani algorithm and allows manipulation of parameters like magnetic susceptibility, shape, and depth until a best fit of calculated values to the observed values is iteratively obtained. The results of the modeling are shown below in figures 4.8 (a)-4.8 (d). The bodies are labeled i, ii, or iii respectively from left to right in all the four profiles.

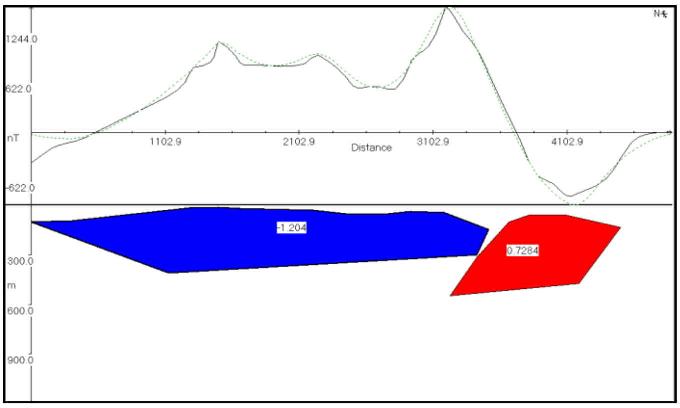

Figure 6 (a) 2-D Modeling results along profile AA'

The profile AA' is about 4.7 km in length and trends NW-SE of the RMI contour map. It cuts through an elongated positive magnetic anomaly that has a NW-SE trend and also cuts through a magnetic low on the southern part of the map. The models on the profile indicate two causative bodies with magnetic susceptibilities -1.204SI and 0.7284 SI respectively. Body (i) is at a shallow depth of about 13.3m while body (ii) is at a modeled depth of 58.7m. Body (i) is extensive covering a length of about 3.5 km while body (ii) has an approximate width of 1.3km. These bodies are speculated to be ferromagnetic subsurface bodies. The negative susceptibility of body (i) could be as a result of reverse magnetization.

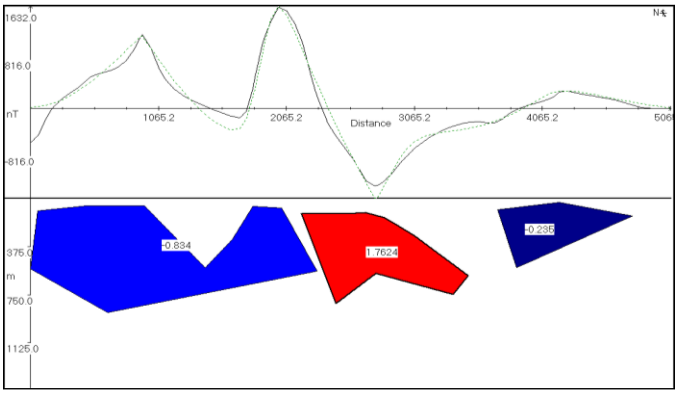

Figure 6 (b) 2-D Modeling results along profile BB'

Profile BB' runs NW-SE at a bearing of 1460 to the North. It cuts through several magnetic highs and lows in the Kindani study area. The profile runs about 5km in length. 3 magnetic bodies were modeled along the profile. Body (i) occurs at the start of the profile and has a body width of about 2245m. Its depth is estimated at 59m below the surface. Its modeled susceptibility is -0.834SI. Body (ii) is an intrusive speculated to be an ore body of depth 112m below the surface. Its body width is modeled as 1300 m and its susceptibility is 1.7624 SI. Body (iii) has a magnetic susceptibility of -0.235SI. Its modeled body width is 1070m at a relatively shallow depth of 58 m.

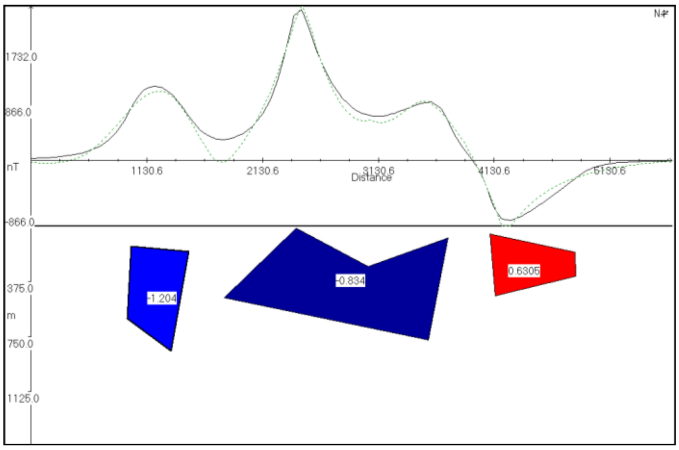

Figure 6 (c) 2-D Modeling results along profile CC'

Profile CC' has a SW-NE trend on the RMI map. It cuts through successive magnetic highs and a low near its tail end. The profile runs a length of about 5.5 km, on a bearing of about 0520. Three causative anomalous bodies are modeled along this profile. These are speculated to be iron ore bodies which are the sources of the highly magnetic surface rocks found in the area. The 3 bodies (i), (ii) and (iii) have magnetic susceptibilities -1.204, -0.834 and 0.6305 respectively. The three bodies are all relatively shallow at about 136m, 12m and 53 m respectively. Their body widths are modeled as 533 m, 1926 m and 743 m respectively in length. This indicates possible presence of extensive ferromagnetic ore bodies in the study area.

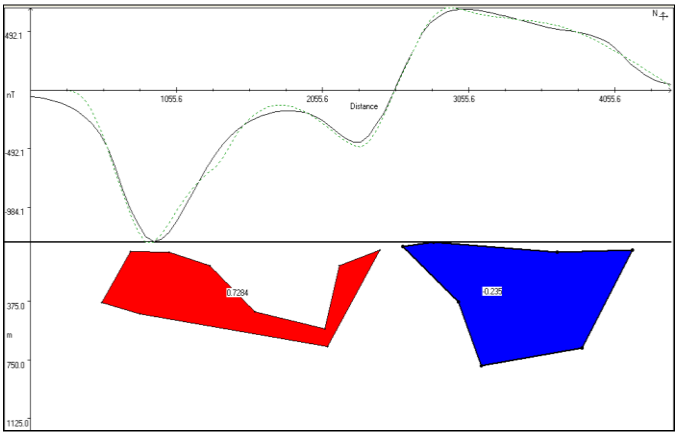

Figure 6 (d) 2-D Modeling results along profile DD'

Profile DD' cuts almost horizontally at the southern part of the map on a bearing of about 860. It stretches about 4.2 km in length and cuts across the magnetic anomalies on the southern part of the map. Two causative subsurface bodies are modeled on this profile. Both bodies are near surface intrusives at 57.7m and about 0.01 m respectively, below the surface. Body (i) stretches about 2.04 km in length while body (ii) has a body width of about 1.57 km. Body (i) has a high magnetic susceptibility of 0.7284SI while body (ii) has a negative susceptibility of -0.235 SI. Both bodies are postulated to be magnetized iron bearing ores. A summary of anomalous bodies' properties is shown in the table 2 below.

Profile	**Body**	**Depth To Top Of Body (M)**	**Body Width (M)**	**Modeled Susceptibility (Si)**
AA'	i	13	3499	-1.204
	ii	59	1274	0.7284
BB'	i	59	2244	-0.834
	ii	112	1300	1.7624
	iii	58	1070	-0.235
CC'	i	136	533	-1.204
	ii	12	1926	-0.834
	iii	53	743	0.6305
DD'	i	58	2037	0.7284
	ii	0.1	1573	-0.235

Table 2: Summary of the 2-D modeling results

F. Chemical analysis results

Four rock samples, from the Kindani survey area were presented for Chemical analysis. The analysis was done by Energy Dispersive Spectroscopy (EDS/EDX). The results are shown in table 3 below.

Element	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
Point picked/pit Easting/Northing	**389705 22873**	**390928 22805**	**390928 22805**	**389776 21617**
Silicon as SiO_2 % m/m	27.48	27.87	27.68	30.11
Iron as Fe_2O_3 % m/m	24.95	25.79	24.20	25.72
Aluminum as Al_2O_3 % m/m	22.74	25.35	23.83	22.21
Calcium as CaO % m/m	10.40	9.83	9.93	10.38
Potassium as K_2O % m/m	8.78	5.02	8.83	8.77
Phosphorous as P_2O_5 % m/m	2.91	3.31	2.83	-
Titanium as TiO_2 % m/m	2.03	2.13	1.96	2.09

Table 3: Chemical analysis results of the area samples

The rocks found in Maua area are mostly ferromagnesian basaltic rocks of igneous origin. Ferromagnesian silicates are minerals rich in iron and or/magnesium and typically low in silica. Olivine, pyroxene, biotite and amphibole are common ferromagnesian constituents.

The mineral olivine is the most common in the Maua rocks. Olivine , according to the Bowen's reaction series is one of the minerals that crystallizes first during cooling of basaltic magma [4]. This is then followed by crystallizing of calcium rich plagioclase ($CaAl_2Si_2O_8$). The chemical analysis table above support presence of these compounds in the area rocks.

The silica composition of rocks in area is low at about 28%. In turn the values of Iron, aluminum and calcium are high. Titanium, Phosphorous and Potassium are at about 2%, 3% and 8% respectively on average. Other minerals like sodium are at negligible quantities.

The high quantity of iron suggests presence of the different ores of iron such as magnetite (Fe_3O_4) and hematite (Fe_2O_3). The presence of the some titanium also suggests presence of compounds like Ilmenite ($FeTiO_3$) and ulvospinel (Fe_2TiO_4). Ilmenite usually is iron-black or gray with a brownish tint [7]. Ilmenite is usually found in both igneous rocks, such as those in the area and in metarmorphic rocks. It usually occurs within the pyroxenitic portions. Many igneous rocks contain grains of intergrown magnetite and ilmenite usually formed by the oxidation of ulvospinel.

These elements also suggest presence of other different compounds. The high quantity of aluminium suggests presence of the compound orthoclase ($KAlSi_3O_8$) and bauxite ($AlOH_3$). Bauxite usually occurs together with the iron oxides goethite and haematite, kaolinite and anatase (TiO_2). These lateritic bauxites were most likely formed by laterization of various silicate rocks such as granite, gneiss, basalt, syenite and shale, most of which are present in the Maua area. This suggests that there has been significant weathering of the rocks in Maua area.

IV. CONCLUSION

The contour map reveals an area with extensive anomalies covering the entire study area, while the 3-D surface map gives a 3-dimensional view of the magnetic variations within the study area. The major trend of the anomalies is NW-SE and SW-NE trends. Four cross-sectional profiles were chosen cutting across major anomalies in the study area. Euler deconvolution and 2-D forward modeling was used to analyze the data quantitatively. Chemical analysis was also done by Energy Dispersive Spectroscopy (EDS) on a few rock samples to quantify amount of Iron in the samples. Euler deconvolution results reveal mostly near surface bodies interpreted as possible iron ore deposits. The anomalous bodies are shallow, with the greatest depths of solutions noted at about 1500m on profile DD'. These bodies are the sources of the highly ferromagnetic surface rocks seen in the study area.

The high susceptibility values of up to 2.000SI modeled using Mag2dc software indicate high magnetization of rocks in this area. Magnetization values are usually determined by the amount of iron bearing minerals in a rock. The Chemical analysis results confirm considerable quantities of iron (as Fe_2O_3) with up to 25% by mass. There is a need to revise the geology of the area to include the new findings. It's also necessary to do more studies using other methods since geophysical surveys require multiple approaches to reduce ambiguity of data.

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