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Contact Locations Mapping of Magnetic Structures at Homa Hills Geothermal Prospect Area, Kenya

Onyango Shem[1], Bernard Adero[2]
[1]*(Ministry of Energy, Geo-Exploration Department, Kenya)*
[2]*(National Defense University, Kenya)*

Abstract:*The location of edges of magnetic structures can be delineated and mapped accordingly through a close and careful analysis of magnetic data. These structural edges are geological features such as faults with lateral changes in susceptibility and geological contacts otherwise known as boundaries where a magnetic body may discontinue or terminate with differing susceptibility. The present work, therefore, aims at delineating contact locations of magnetic structures beneath Homa Hills geothermal manifestations. Homa Hills is a site of volcano in tertiary and Pleistocene times in the West of Kendu occupying most of the Homa peninsula, protruding into the Winam Gulf forming the eastern flank of Homa Bay. The cone sheet complex of Homa Hills comprises of a number of carbonatite cone sheets of large and small scales. Relevant data reductions were done on the ground magnetic data acquired to reduce its complexity and to obtain the priori information that were used in the quantitative interpretation of the data. Pattern of recognition was based on the horizontal gradient obtained from the computation of the two first-order horizontal gradient with a reduction to equator approach. From careful inspection of the horizontal gradient map, best contact locations were isolated. The contact locations obtained were superimposed on a generalized derivative grid and a strong correlation is seen. The contact locations trend in the N-S, E-W, NW-SE and NE-SW direction and are structurally controlled.*

Keyword*: Contact Location, Generalized Derivative, Homa Hills, Horizontal Gradient, Reduction to the Equator*

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I. Introduction

In exploration for geothermal resources, magnetic measurements aim at locating hidden intrusive features such as dykes, faults and lava flows, to find areas of reduced magnetization due to thermal activity and as an aid to geological mapping where outcrops are scarce (Otieno, 2012). Contact location mapping play a big role in magnetic interpretation as it may be used in place of geological mapping in areas where there are no outcrops. Defining the extent of units with similar magnetic properties is analogous to the geological mapping approach of dividing the rock units of similar properties on the surface. Such mapping yields information on deformation regime, trends and styles (Pilkington & Keating, 2004).

Horizontal gradient method in recent years has been a great and an important utility in locating edges in potential field methods. Many Geoscientists have gained credit from their research works on the same. The horizontal gradient emphasizes source edge effects due to its high-resolution power thereby reducing the interference effects of the anomalies hence yielding an enhanced image of the boundaries (Bournas& Aziz, 2001). Crests of horizontal gradient yields information on the location of the edges of the sources in the horizontal dimensions with the main advantage that the magnetic field and the source parameters need not be assumed. The contact locations can be delineated from magnetic structures through determining the local maxima of the horizontal gradient of a magnetic field, calculated from the relevant order of derivatives. In particular, for contact location, derivatives work well for reduced-to-pole magnetic data since the magnetic anomaly source will be symmetric with magnetic source and the inclination of the geomagnetic field will not have any significance.

Cordell and Grauch (1985), devised a method for locating the horizontal extent of magnetic anomalies from the computation of maxima of horizontal gradient of pseudo gravity. They described their approach in three phase-procedures for locating edges of magnetic structures. The first step is applying pseudo gravity transform (Baronov, 1957), a linear filter applied in a Fourier domain. Pseudo gravity transform the observed anomaly over a magnetization distribution into a gravity anomaly that would otherwise be observed if density were constant. The second step is the computation of the horizontal gradient of the pseudo gravity. Since shallow bodies yield gravity anomalies whose horizontal gradient maxima peaks over their edges, the two stages, therefore gives a transformation of magnetic anomalies into peaks of maximum pseudo gravity gradient that may be centered over the edges of the causative magnetic structures. The final step is the horizontal gradient contour map that is visually inspected for the contact locations and significance of the linear maxima. The method was later applied to isostatic residual anomalies of the USA after automation by Blakely and Simpson (1986). In their study, Blakely and Simpson (1986), adopted the final step of the Cordell-Grauch procedure on a gridded horizontal gradient data for interpretation of horizontal gradient magnitudes on a magnetic data.

In low and middle latitude areas, the observed magnetic anomalies, show polarities that complicates its interpretation, contrary to gravity anomalies, in which anomalies are centered above the causative bodies (Bournas& Baker, 2001). Such skewness in the shape of the magnetic anomalies is caused by inclination of the induced magnetization vector. Baronov (1957) counter the skewness by introducing reduction to pole transformation that repositions the magnetic anomalies above the causative sources. Reduced-To-the Pole (RTP) is normally done at inclinations greater than 15° and inclinations less than 15° are reduced to the equator. Before mapping structural edges, the first step that is taken is removing the complexity of the anomalies by applying reduced-to-pole transformation so that RTP field has a close correlation with the basement surface generating the field. The noise and effects due to shallow sources are also minimized by upward continuation.

In this study, total horizontal gradient technique was applied to ground magnetic data acquired over Homa Hills Geothermal prospect area to locate the edges of magnetic structures as an aid for structural mapping. In a geothermal field, structural mapping is important in understanding fracture attributes, permeability development in fractured reservoirs and in analyzing the fault density with a goal of predicting areas of promising geothermal occurrences.

II. The Study Area

2.1 Location of the Study Area

Homa Hills is geographically located in Homa Bay county 50 km North of Kendu Bay and its part of the Nyanza rift. Homa Hills geothermal prospect area is bounded by Easting 661000 m to 674000 and Northing 9950000 m to 9865000 m, with an area approximately 155 km^2. Figure 1 shows the map of the study area.

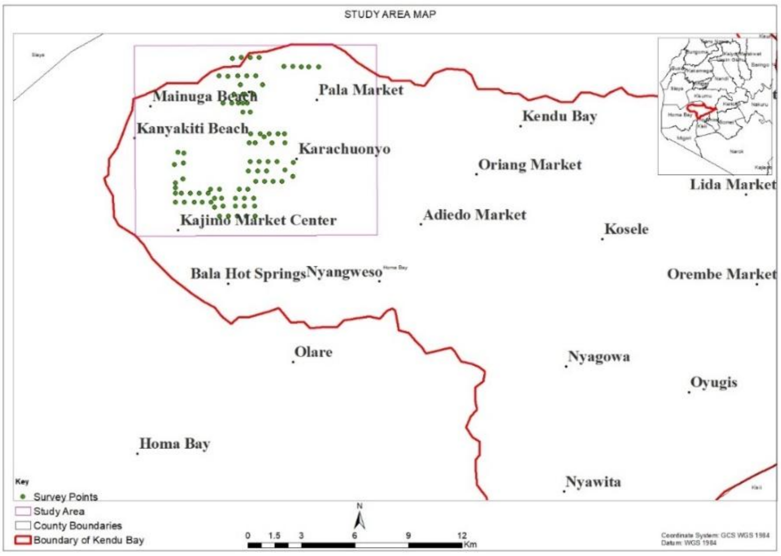

Figure 1: Map of Homa Hills Area

2.2 Geology of the Study Area

Homa mountain is a site of an active volcano in tertiary and Pleistocene times in the west of Kendu occupying most of the Homa peninsula, protruding into the Winam Gulf forming the eastern flank of Homa Bay. It is composed of three separate and massive peaks including Homa, Apoyo and Nyasanja with Homa as the largest peaking to about 5200 ft above the sea level

In between the peaks, there is a depression which does not represent an old volcanic crater or the circle circumscribing the peaks bear any relation to the ring structure of Pleistocene to recent. The cone sheet complex of the Homa Mountaincomprises a number of carbonatite cone sheets of large and small scales. Most of the carbonatite- alkaline rocks except for those composed of carbonatite- ijolite complex in the south-eastern part of this area, are disturbed in an oval area approximating about 6 km in length in the NE-SW direction and 5 km in width. The main carbonatite cone sheet of Homa Mountain is located slightly to the southwest of center of the oval area and composes the major structural element of the cone sheet complex.

The domal uplifting of NyanzianMetavolcanic to an elevation of 500 m above the surrounding ground resulted from a series of intrusive activities of these cone sheets, where its structures are well exhibited and is circled by cliffs steeply out above the surrounding ground. These cliffs correspond to the carbonatite and the Nyanzianmetavolcanics. Figure 2 shows the geological map of the area by Saggerson (1952).

The cone sheet has an internal diameter of about 2.5 km with a concentric structure which is well observed in the field having carbonatite sheets dipping at 40° to 60° towards the center of the cone. Modes in which the various carbonatite facies occur suggests the present level of erosion still stays in a relatively upper part of the carbonatite complex (Saggerson, 1952). In areas around Ndiru Hills, there is a group of carbonatite dykes in the south eastern part which are presumed to be of relatively deeper facies judging from the distribution of sovite.

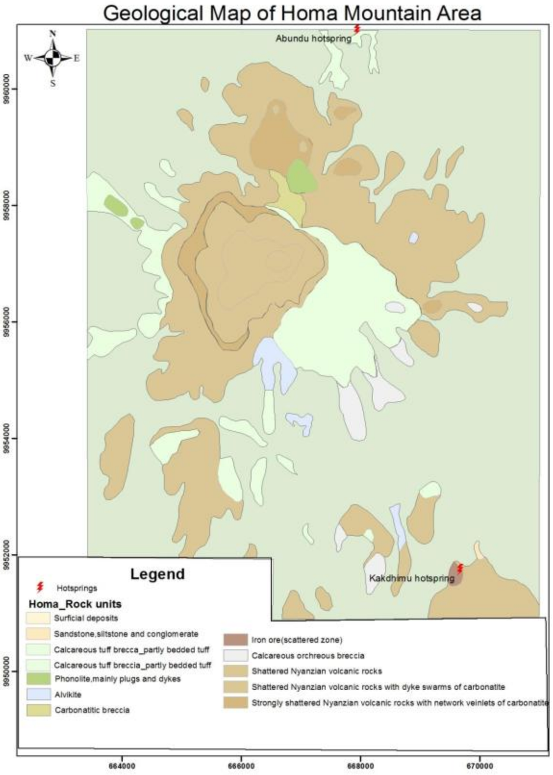

Figure 1: Geological Map of Homa Hills area (Saggerson, 1952)

III. Materials and Method

Ground magnetic data was acquired from Otieno (2012) during a study of geothermal potential Homa Hills area. The raw data was processed to prepare the data for further enhancement and interpretation. The following steps were followed; diurnal variation corrections and removal of the regional field (IGRF corrections)

Data enhancement always takes the form of transformation and/or filtering and generating a range of derivatives with the aim of reducing the complexity of the anomaly and therefore making interpretation easier. Data enhancement has an objective of isolating features an interpreter would wish to identify prior to quantitative and qualitative analysis. In this study, therefore, a number of methods and/ or filters will be applied on the residual magnetic data including: Reduction-to-pole (RTP), upward continuation, and horizontal gradient.

3.1Reduction to Pole Transformation

Reduction to the pole (RTP) is a mathematical approach proposed by Naudy and Baronov (1964) to simplify anomalies shape estimates. RTP is a field transformation technique and it transforms magnetic intensity anomalies into anomalies that would be measured if the field were vertical. This RTP filter makes the shape of the anomalies more closely related to the true location of the source structure therefore easier interpretation of the magnetic anomaly. In this work, however, reduction to the equator was adopted since it works well for smaller inclination less than 15 degrees.

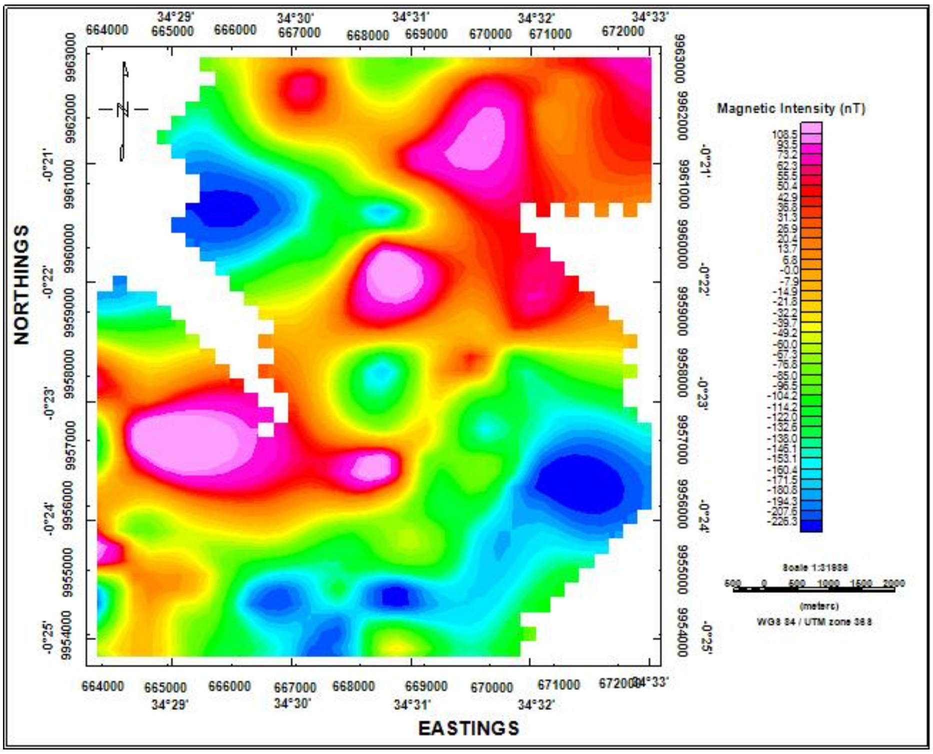

Figure 2: Reduction to the equator (RTE) grid map of Homa Hills generated with an input of an inclination of -21.97 degrees and declination of 0.9 degrees

3.2 Upward Continuation

In areas of near surface magnetic sources such as dykes and other intrusions, upward continuation is normally applied in the interpretation of magnetic fields (Keary et al., 2002). It weakens the high wave number anomalies associated with such features and relatively enhances the anomalies due to deeper- seated structures. Because of this, it is normally used to minimize or remove the effects of shallow sources and noise in grids.

Telford et al. (1990) provides an equation for upward continuation as follows:

$$F\,(x,y,-h)\,\frac{h}{2\pi} = \iint \frac{F\,(x,y,0)dxdy}{\{(x-x')^2+(y-y')^2+h^2\}^{\frac{1}{2}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where, the left side of the equation is the total field at point $F\,(x', y' - h)$ on which F (x, y,0) is known. The procedure for calculation takes the form of replacing them with values of weighted sums taken on a regular grid.

Henderson (1960), gives an empirical formula for a field at an elevation h above the surface in terms of values F(r), the average F (r_i) centered at the point (x, y, 0:

$$F\,(x,y,-h) = \sum \bar{F}(r_i) K\,(r_i - h) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where, $K\,(r_i - h)$ are weighting coefficients that gives upward continued field within 2%.

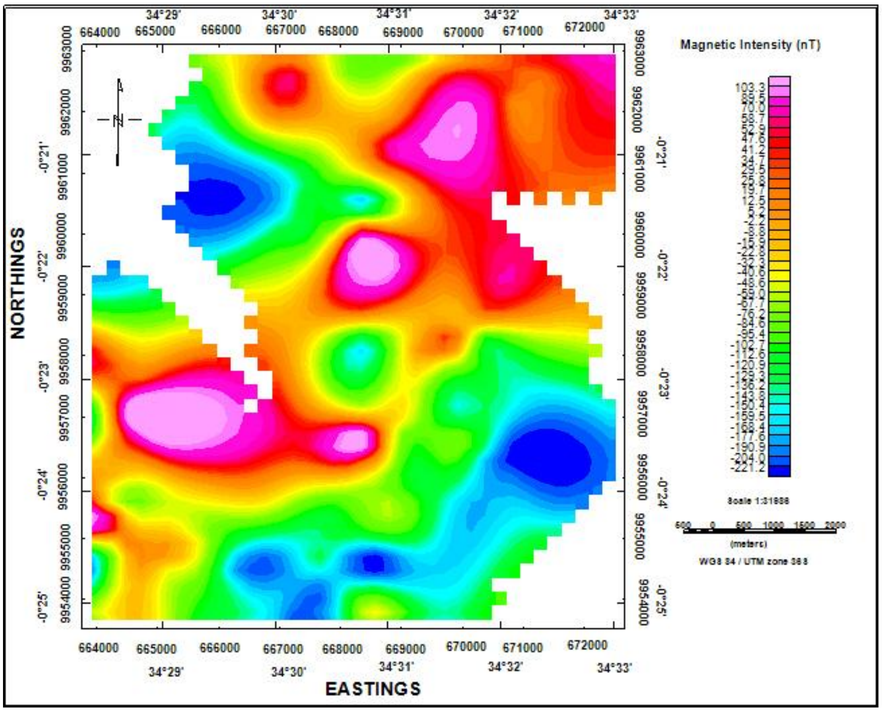

Figure 3: Upward Continuation map of the study area at 20 meters

3.3Horizontal Gradient Method

The horizontal gradient utilizes the magnitude of the horizontal gradient computed from the two first-order horizontal derivatives. Horizontal derivatives enhance high wave number horizontal variations in potential field data that are always caused by edges between different geological units, thereby presented as a useful method for detecting and delineating such features.

For profile data, the horizontal gradient uses the magnitude of the horizontal gradient as;

$$|H\ (h)| = \left|\frac{\partial M}{\partial h}\right| \text{..................................3}$$

And;

$$|H\ (x,y)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial x}\right)^2} \text{.................................. 4}$$

For gridded data where, M is either the reduced to pole magnetic field or the pseudo gravity transformation.

For a reduced to pole magnetic field, the equation above applies to a vertical contact of large depth extents. Thus, the horizontal gradient method can be a useful tool in locating the tops of isolated vertical contacts from the reduced to pole magnetic field (Phillips, 2000). Since the horizontal gradient requires the two first-order horizontal derivatives, it is very insensitive to noise, therefore it produces apparent contours that are linear and continuous. This is opposed to higher order horizontal derivatives and vertical derivative which are highly susceptible to noise in the data.

IV. Results and Discussions

4.1 Total Magnetic Intensity Map of Homa Hills

TMI map of Homa Hills was generated after the raw magnetic data was corrected for diurnal variations. In the region trending NE-SW direction there are high magnetic values recorded. The intrusions in the stated direction in form of dykes that can be shown by long narrow anomalies on the map is believed to be the reason behind high magnetic signature.

In the region NW and SW of the study area, a magnetic low of the tune of below 270 nT can be seen. The reason behind the low susceptibility could be due to the flow of crustal fluids along the faults and fractures in the N-S and NW-SW direction. When the fluids interact with the subsurface magnetic minerals, the minerals lose their magnetism in the process.

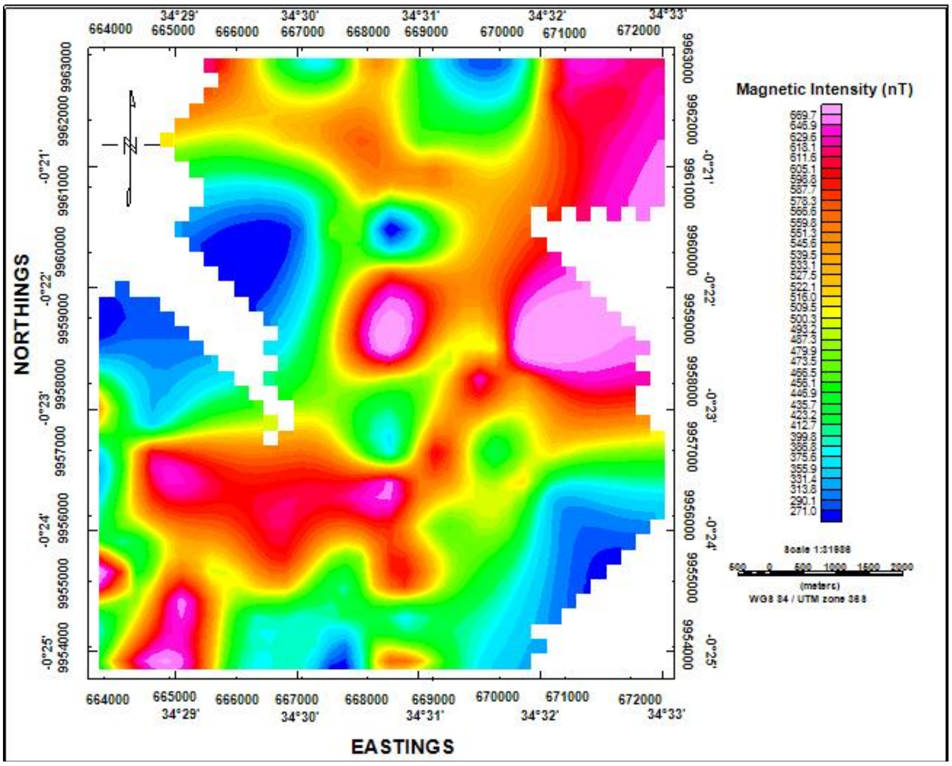

Figure 4: Total magnetic intensity map of Homa Hills

4.2 Residual Magnetic Map of Homa Hills

After the removal of the regional field, the residual map of Homa Hills was generated. The visual inspection of the residual map was based on the trend patterns and variation in magnetic intensities. The area is characterized by magnetic anomalies ranging from 125 nT to as low as -266 nT. The values were recorded because the removal of the regional field isolates the field and therefore all the contributions are chiefly due to anomalous body from local sources. In the region trending NE-SW direction, strong positive anomaly spreads widely. In the NW and SW region of the study area low magnetic signatures are recorded to as low as -266 nT. Low magnetic signature can perhaps be due to the demagnetization of the subsurface rocks through its interaction with the hydrothermal fluids.

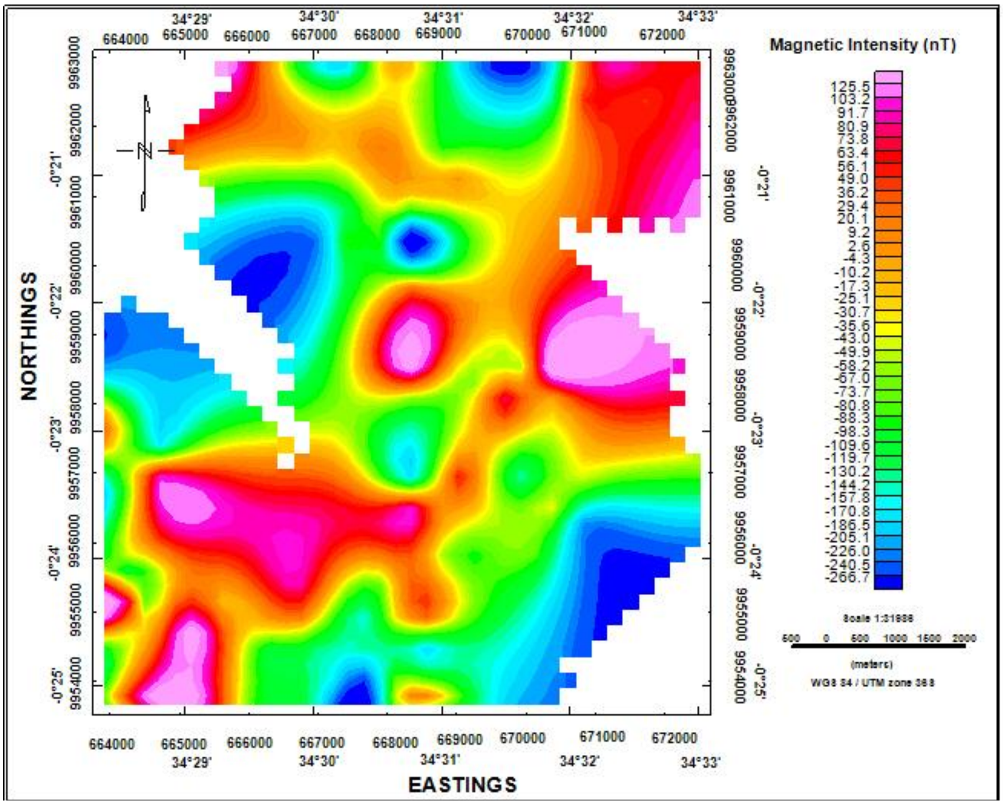

Figure 5: Residual map of Homa Hills showing reduced values of magnetic intensity. In the region trending SW-NW trending direction and a magnetic low in the SE and NW part of the study area.

4.3Generalized Derivatives Map of Homa Hills

Generalized derivative operator is a linear combination of the horizontal and vertical field derivatives, normalized by amplitude of the analytic signal (cooper & Cowan, 2011). Dividing the field derivatives in three dimensions by the amplitude of the analytic signal gives

$$\mathrm{GDO}=\frac{\left(\frac{\partial F}{\partial x}\sin\theta+\frac{\partial F}{\partial y}\cos\theta\right)\cos\varphi+\frac{\partial F}{\partial z}\sin\varphi}{\sqrt{\left(\frac{\partial F}{\partial x}\right)^2+\left(\frac{\partial F}{\partial y}\right)^2+\left(\frac{\partial F}{\partial z}\right)^2}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where, θ is the azimuth in the horizontal plane and φ is the elevation in the vertical plane.

GDO has the capability in that its directional sensitivity can be controlled. It also enhances edges of magnetic structures with all orientations within the data rather than those with known azimuth. Generalized derivative filter was implemented using Oasis Montaj program that enhanced signals along a specific direction and has also revealed small magnetic signatures that have been obscured by large amplitude anomalies.

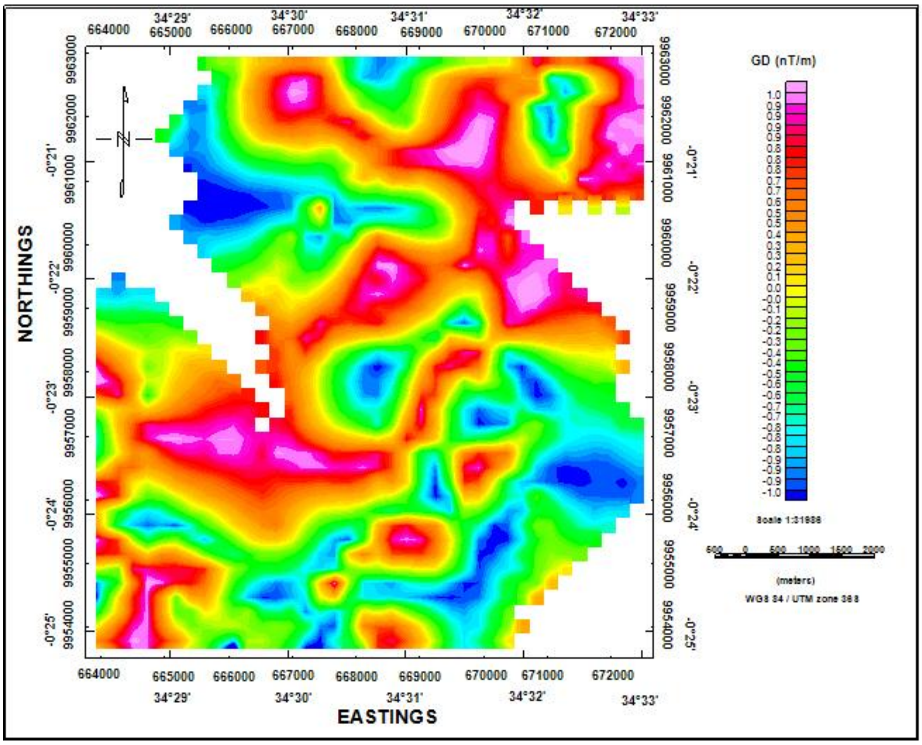

Figure 6: Generalized Derivative map of Homa Hills area

4.4 Horizontal Gradient Map of Homa Hills

Horizontal map was computed from the magnitude of the two first-order horizontal derivatives. With its ability to enhance high frequency horizontal variations in the magnetic data caused by edges between different geological units, the edges were delineated. On inspecting the horizontal gradient map, linear structures trending in the N-S, E-W, NW-SE and NE-SW direction. The structures shown by dashed lines are the contact locations of magnetic structures (faults, and edges between magnetic structures). Peaks of horizontal gradient are seen to be continuous.

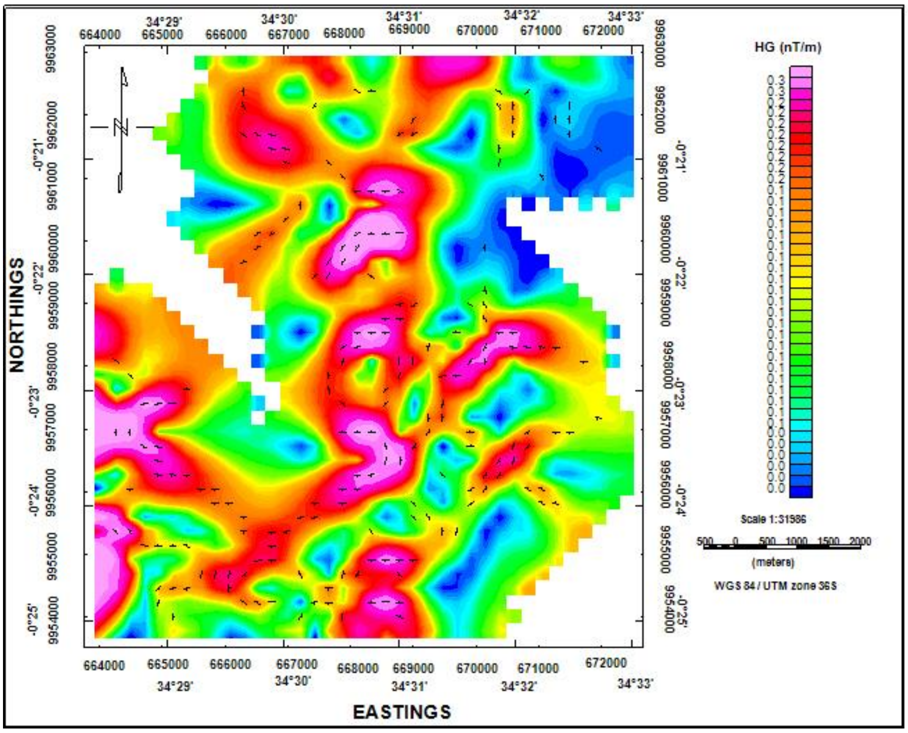

Figure 7: Horizontal Gradient map of Homa Hills showing the location of the contacts of magnetic structures. The edges are shown by dashed lines.

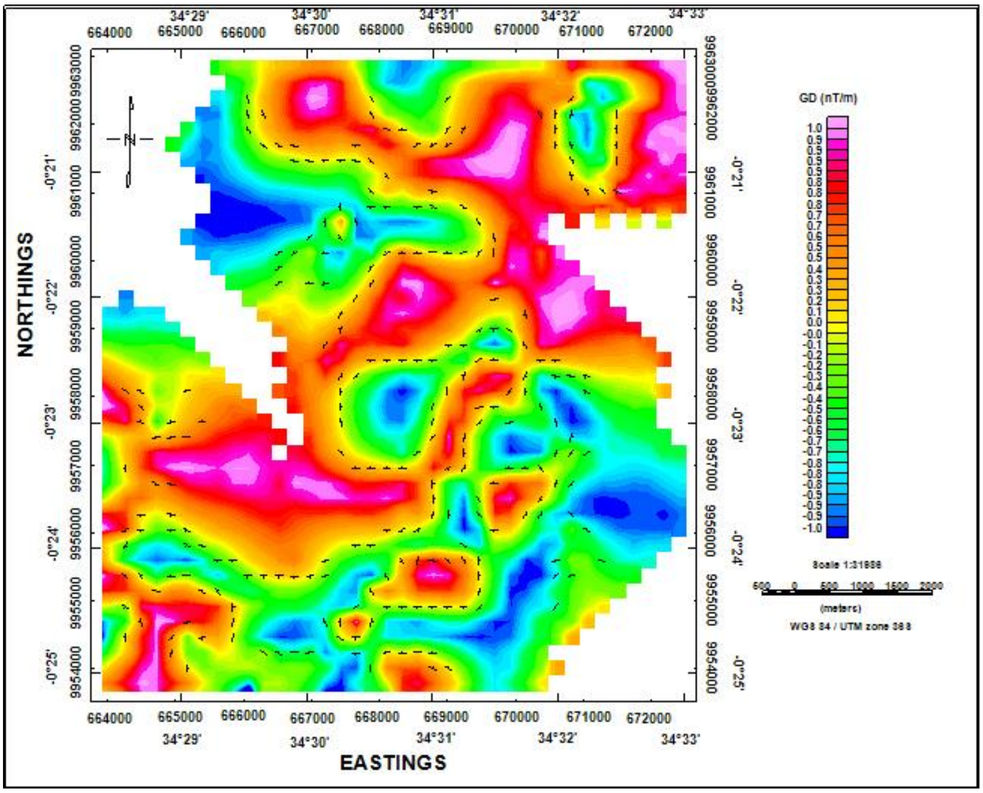

Figure 8: Contact locations shown in dashed lines superimposed on the Generalized Derivative grid

V. Conclusion

In this study, the horizontal gradient was applied to magnetic data obtained from ground magnetic survey to estimate the contact location of magnetic structures in the Homa Hills Geothermal prospect area of Homa Bay County, Kenya. To apply this technique, Geosoft software was used. The estimated contact locations were visualized on grids to show the continuity and strike of the edges. Generalized derivative filter enhanced signals along a specific direction and has also revealed small signatures in the magnetic data that were obscured by large amplitudes anomalies. Horizontal gradient map locates peaks of horizontal gradient with the edges trending in the N-S, E-W, NW-SE, and NE-SW direction and are seen to be continuous. Superimposing the contact locations on a generalized derivative grid reveals a strong correlation and it is sufficed to believe that the edges of the magnetic structures are structurally controlled.

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