2D-Forward Modeling of Ground Magnetic Data of Homa-Hills Geothermal Prospect Area, Kenya

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Abstract: ***Two dimensional (2D) Euler de-convolution techniques was applied on the selected profiles of reduced ground magnetic data collected in Homa Hills area. Depth estimates of causative bodies were quantitatively analysed in the anomalous areas on the residual magnetic intensity map. These depth estimates were later used as start-up parameters for 2D-forward modelling using "mag2DC" software. Results of the analyses show that the magnetic anomalies in the region are caused by shallow-seated thermal intrusive structures of carbonatite origin. 2D-Euler solutions revealed subsurface faulting activities up to a depth of 250m and the presence of fluid-filled zones within the survey area which are marked by absence of magnetic sources. It is postulated from 2D-forward modelling that the heat sources are shallow intrusive bodies such as dykes, plugs and sills taping from a deeper magmatic body and that the thermal intrusive structures form along fracture zones.***

Keywords: Magnetics, Anomalies, Homa Hills, Thermal structure, Modeling

1. Introduction

This paper presents results of a quantitative analysis done on reduced magnetic data from the Homa Hills geothermal prospect located in Nyanza Rift. The field survey and partial analysis of data of the ground magnetic survey was presented by Otieno et. al (2011). The current analysis was intended to determine the subsurface structure of the field. The 2D-forward modelling of magnetic data was done to try and locate the nature of the heat sources and delineate the geothermal reservoir within the study area. The geothermal potential of Homa Hills has been studied previously using MT and TEM surveys which revealed heat source of deep dome-like magmatic intrusion with several sharp shallow dikes (Lagat, 2010). Magnetic survey has been conducted as a reconnaissance to the earlier studies. Homa Hills is located to the west of the central southern coast of the Winam Gulf and takes an incomplete rectangular form cut by a shore line at its southwest corner, occupying an area of approximately $70Km^2$. The area is located about 20Km west of Kendu Bay and 30Km north of Homa Bay townships. It is bounded by the coordinates: E661000 – 674000 and N9951000 – 9963000.

2. Geologic setting

The Homa Mountain is a cone sheet complex comprising a number of carbonatite cone sheets of large and small scales. Most of carbonatite-alkaline rocks, except those composing the carbonatite –ijolite complex in the south-eastern part of this area, is distributed in an oval area approximately 6km long in the NE-SW direction and 5km wide. The main carbonatite cone sheet of Homa Mountain, the largest of all, is located y to the southwest of the center of the oval area and composes the major structural element of the cone sheet complex. A series of intrusive activities of these cone sheets have resulted in domal uplifting of the Nyanzian Metavolcanics to an elevation 500m above the surrounding ground. The main cone sheet of the Homa Mountain, where its structures are well exhibited, is encircled by cliffs steeply standing out above the surrounding ground. These circular cliffs correspond to the contact between the carbonatite and the Nyanzian metavolcanics. The inside of the cone sheet, approx. 2.5km across in diameter, has a concentric structure in plan and is well observed in the field that the carbonatite sheets dip 40-60 towards the center of the cone. Modes of occurrences of various facies of the carbonatite suggest that the present level of erosion stays still in a relatively upper part of the carbonatite complex. The carbonatites adjacent to the ijolites in the Ndiru Hills and a group of carbonatites dykes in the south-eastern part of this area are presumed to be of relatively deeper facies judging from distribution of sovite. Figure 2 shows the geologic map of Homa Hills geothermal prospect with hot springs on the northern and southern parts of the area.

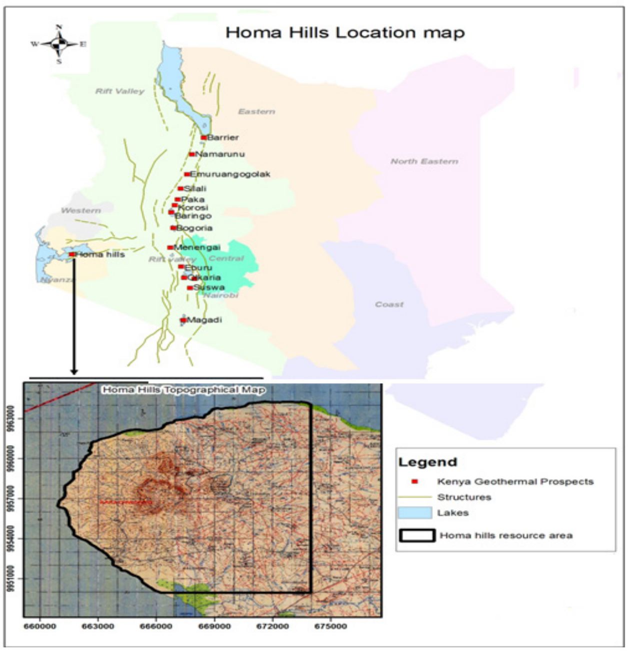

Figure 1: Location of Homa Hills geothermal Prospect

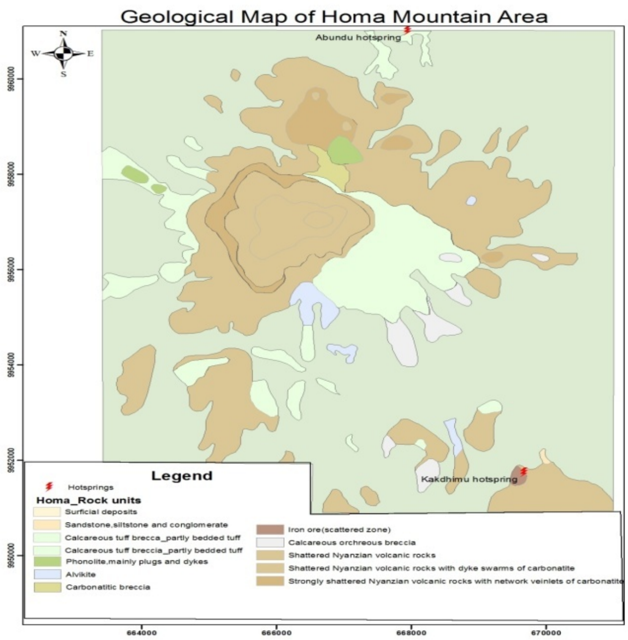

Figure 2: Geologic map of Homa Hills geothermal prospect

3. Ground Magnetic Data Analysis

3.1 Residual magnetic intensity map

Figure 3 shows the residual magnetic map of Homa Hills. This map was made after correcting for diurnal variations and removing geomagnetic corrections. Five short profiles cutting across in different directions as indicated on the map, were selected for farther enhancement and modeling.

3.2 Euler Deconvolution

Euler deconvolution is a data enhancement technique for estimating location and depth to magnetic anomaly source. It relates the magnetic field and its gradient components to the location of the anomaly source with the degree of homogeinity expressed as a structural index and it is a suitable method for delineating anomalies caused by isolated and multiple sources (El Dawi et al., 2004). Euler deconvolution is expressed in Equation 3.1 as:

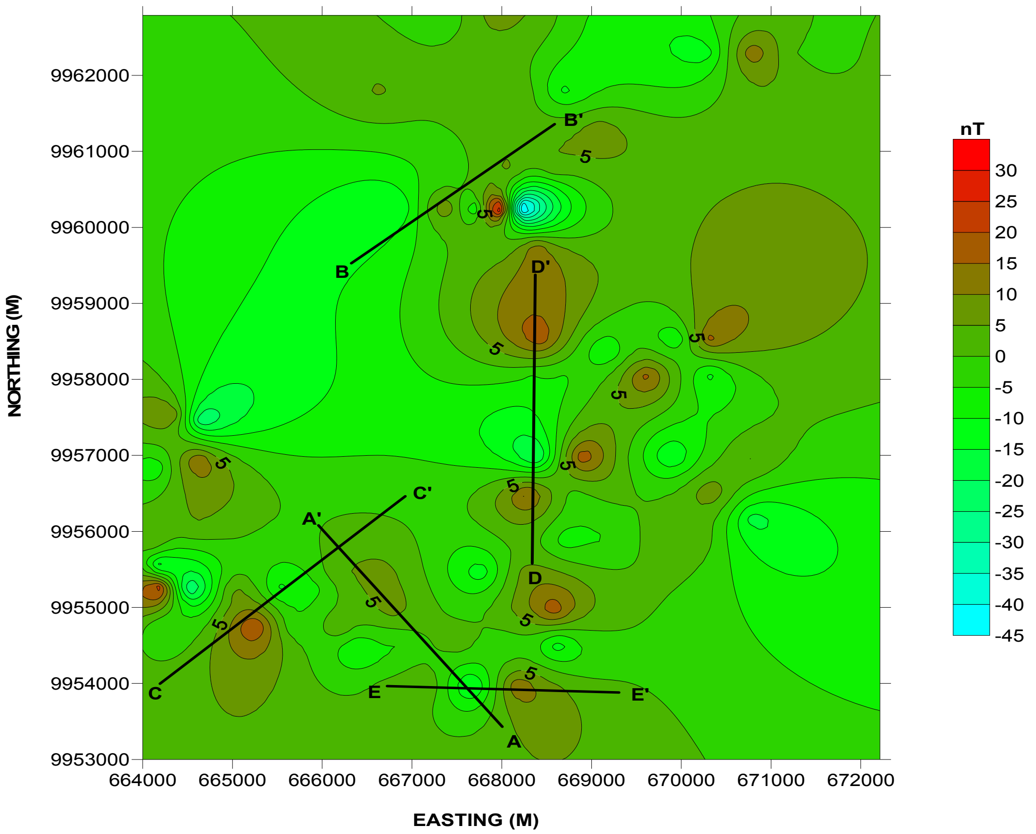

Figure 3: Residual magnetic map of Homa Hills

$$(x-x_o)\delta T/\delta x+(y-y_o)\delta T/\delta y+(z-z_o)\delta T/\delta z=n(B-T) \qquad 3.1$$

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. Equation 3.1 is then written in form of Equation 3.2 as:

$$(x-x_o)\delta T/\delta x+(z-z_o)\delta T/\delta z=n(B-T) \qquad 3.2$$

Where (x_o, z_o) is the position of a 2D magnetic source whose total field T is detected at (x, z). The total field has a regional value of B, and n is a measure of fall -off rate of the magnetic field. n is directly related to the source slope and is referred to as the structural index and depends on the geometry of the source (El Dawi et al., 2004). Estimating depth to magnetic anomaly using Euler deconvolution involves: i) Reduction to the pole and ii) Calculation of horizontal and vertical gradients of magnetic field data, calculated in frequency domain, iii) choosing window sizes and iv) structural index, e.g. contact and dyke.

The 2D-dimensional Euler deconvolution was generated by software developed by Cooper (2004) for constraining the subsurface geometry along the profile lines. The input parameters for the application include the geomagnetic field, survey locations, inclination and declination angles. The results of the International Geomagnetic Refference Field (IGRF) given in Table 1 were used as the inputs for the process. A window size of 11, 82.28m X-separation and 41.14m Y-separation were adopted. To better constrain the subsurface geology, 1.0 structural index (steep contact) which is an indication of faults contacts were plotted for all the five profiles; these are shown in Figures (4-8).

Table 1: IGRF components of Homa Hills

Component	*Field value*
Declination	0.9 degrees
Inclination	-22.3 degrees
Total Intensity	33420nT

3.2.1 Interpretation of Euler solutions

Figure 4 shows magnetic anomaly along profile AA'. Three distinct trends are evident which coincide with the location of dykes and faults within the study area. The profile begins with a relatively low magnetic anomaly points at station (666000-666509) which could be possibly a sedimentary layer. This signature is followed to the south by high signatures at station (666600-666700) and is postulated to be a faulted carbonatite dyke which is a common intrusive in the region. The third zone at station (667000.4-667609.4) shows no magnetic sources. The lack of magnetic sources coincides with faults, a possible evidence of the presence of the warm fluids.

Euler solutions for profiles BB' and CC' are shown in Figures 5 and 6 in which high magnetic signatures, station (66775.2-667975.2) are evident at a depth of about 350m below the surface for profile BB' and this is associated with an intrusive body probably a dyke. In profile CC' there is no concentration of Euler solutions at any point an indication of little tectonic activities along the profile. Figure 7 shows two distinct anomalies along profile DD'. There exist no magnetic sources (station 9955740.4-9956240.2) and (station 9956990.4-9958115.4) an indication of fluid filled zones. This postulates N-S trending fault in the study area. Figure 8 shows a high magnetic signature at shallower depth of about 205m (station 667694.8) an indication of magmatic intrusive body, and a very low magnetic signature (station 668194.8-668494.8) could be an indication of a fluid filled zone. These undulating signatures and the Euler deconvolution solutions clearly show shallower subsurface intrusions and faulting/contacts pattern within the geological units.

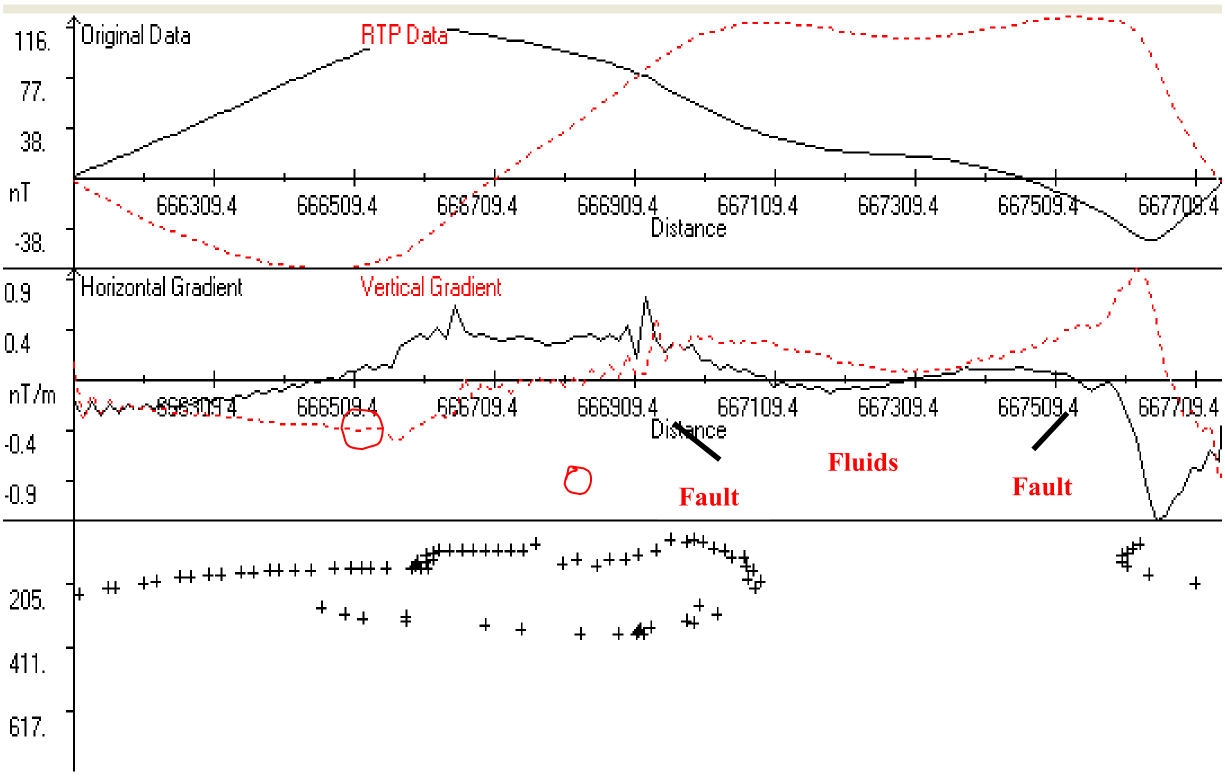

Figure 4: Processed ground magnetic data with 2D Euler solutions obtained along profile AA'. Plus (+) signs are Euler solutions for 1.0 structural index.

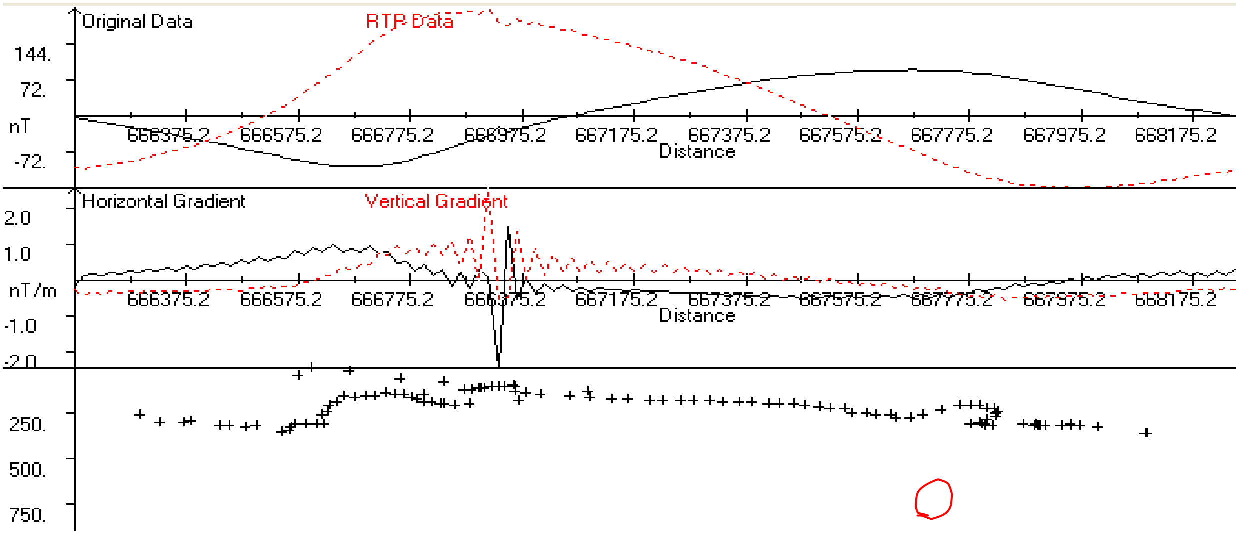

Figure 5: Processed ground magnetic data with 2D Euler solutions obtained along profile BB'. Plus (+) signs are Euler solutions for 1.0 structural index.

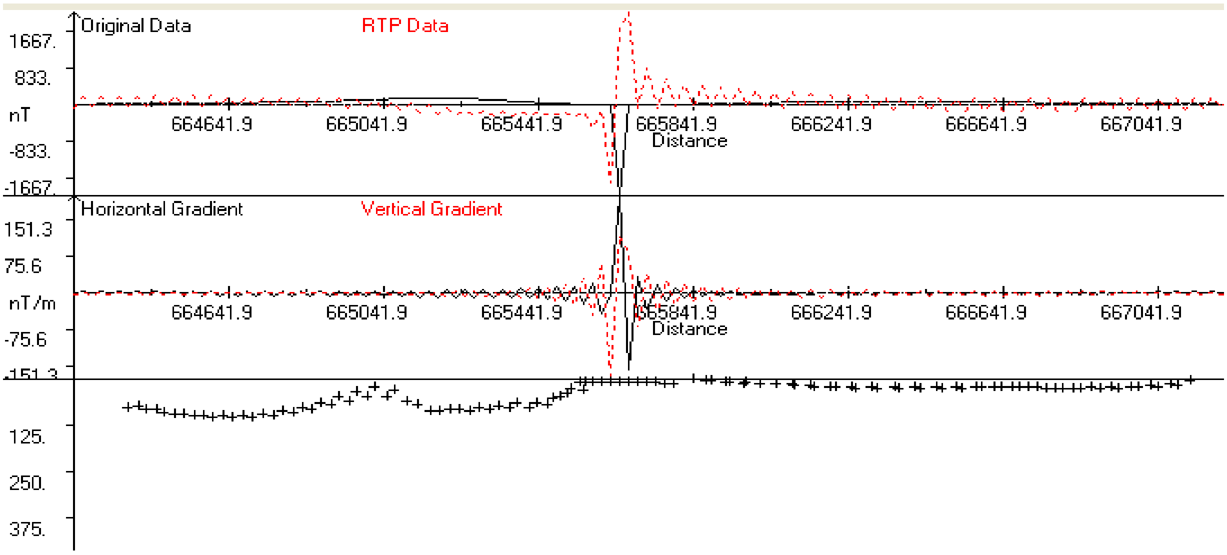

Figure 6: Processed ground magnetic data with 2D Euler solutions obtained along profile CC'. Plus (+) signs are Euler solutions for 1.0 structural index.

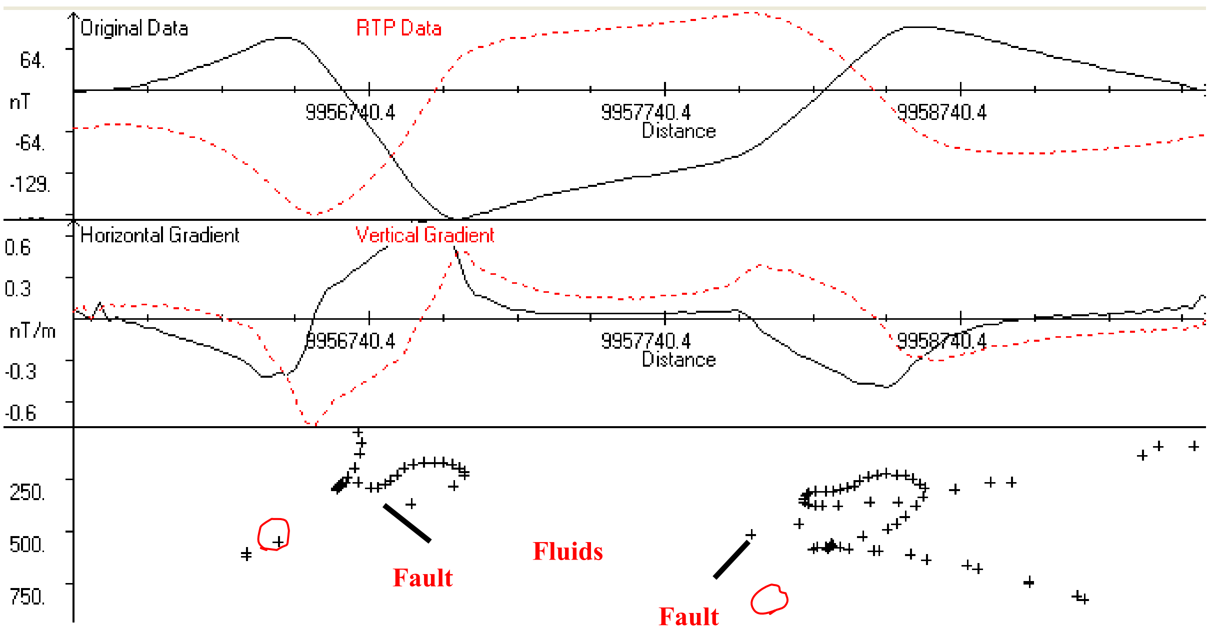

Figure 7: Processed ground magnetic data with 2D Euler solutions obtained along profile DD'. Plus (+) signs are Euler solutions for 1.0 structural index.

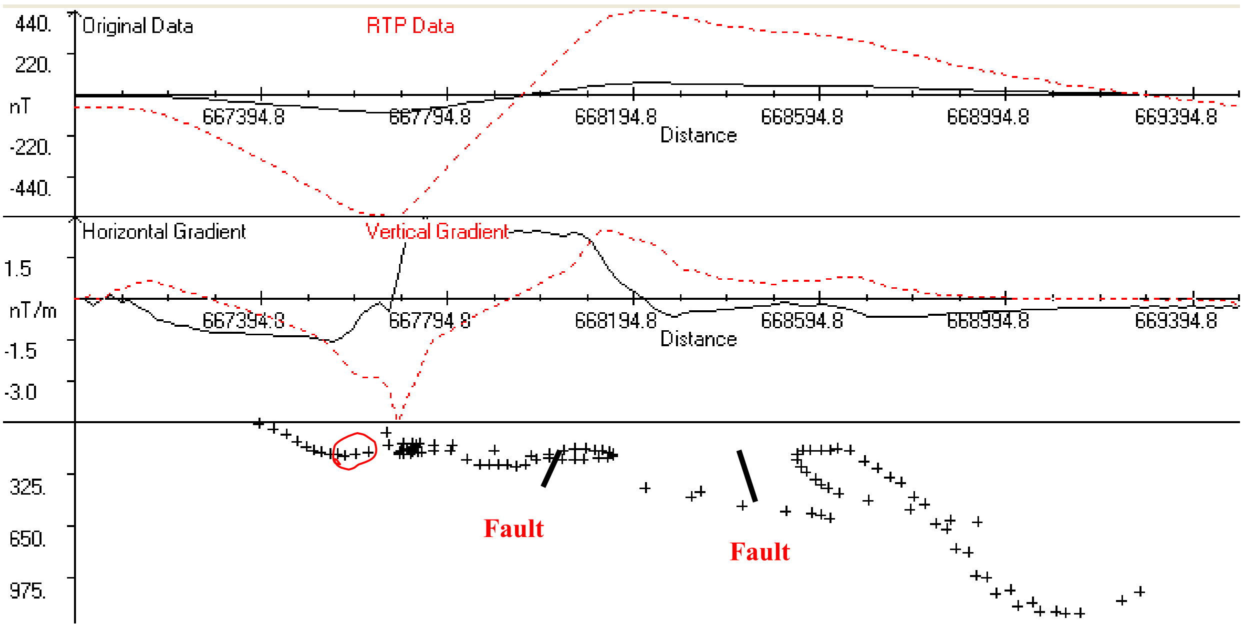

Figure 8: Processed ground magnetic data with 2D Euler solutions obtained along profile EE'. Plus (+) signs are Euler solutions for 1.0 structural index.

3.3 2D- Forward Modeling

Forward modelling was done using "mag2DC" computer program. "mag2DC" calculates the anomalous field caused by an assemblage of 2 – dimensional magnetic bodies defined by a polygonal outline. The description of the method of the program "mag2DC" can be found in the work of Talwani and Heirtzler (1964). The use of this program involves a trial and error procedure to obtain a good fit to the observed anomalies. Depth estimates of the possible causative bodies determined from euler deconvolution were used as start-up parameters in the "mag2DC" software. Figures 9 to 13 show the modeled bodies of the subsurface structures causing anomalies on the selected profiles.

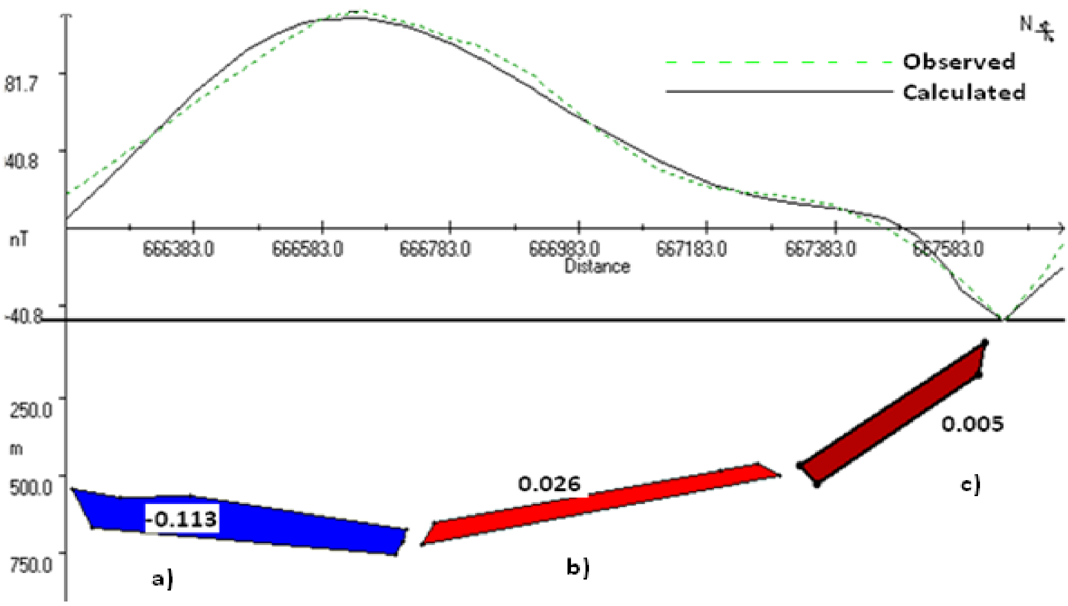

Figure 9: Models on profile AA'

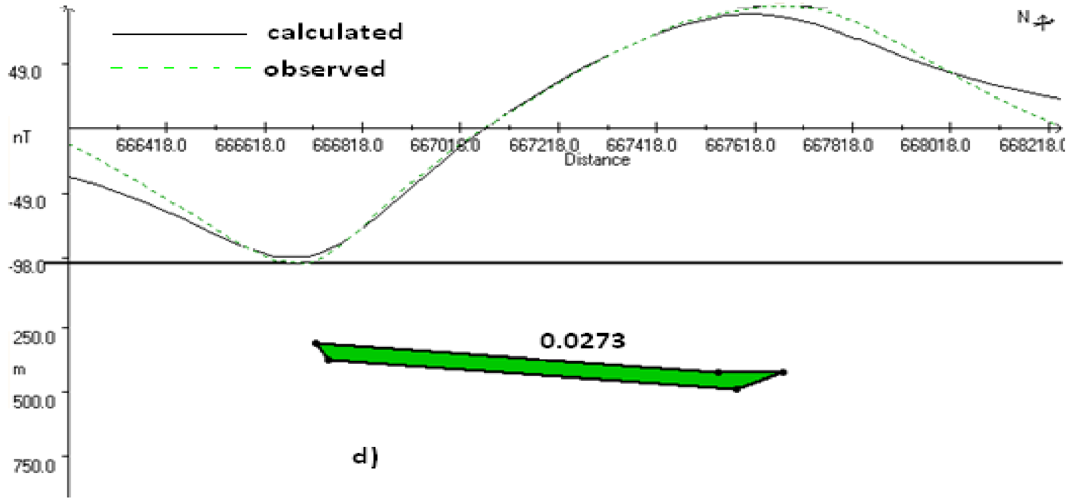

Figure 10: Model on profile BB’

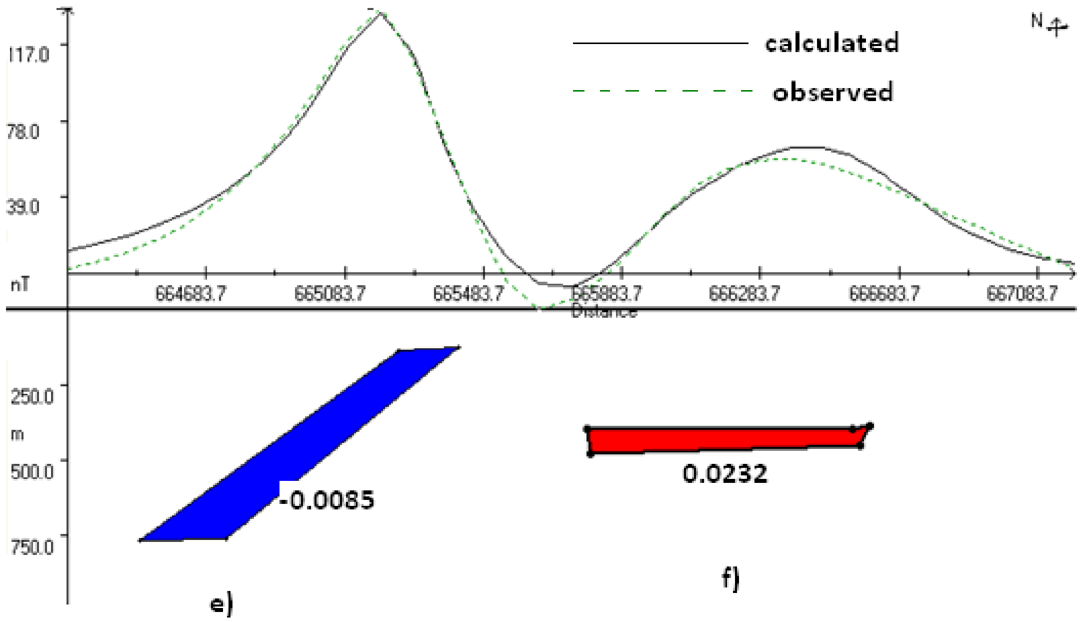

Figure 11: Models on profile CC’

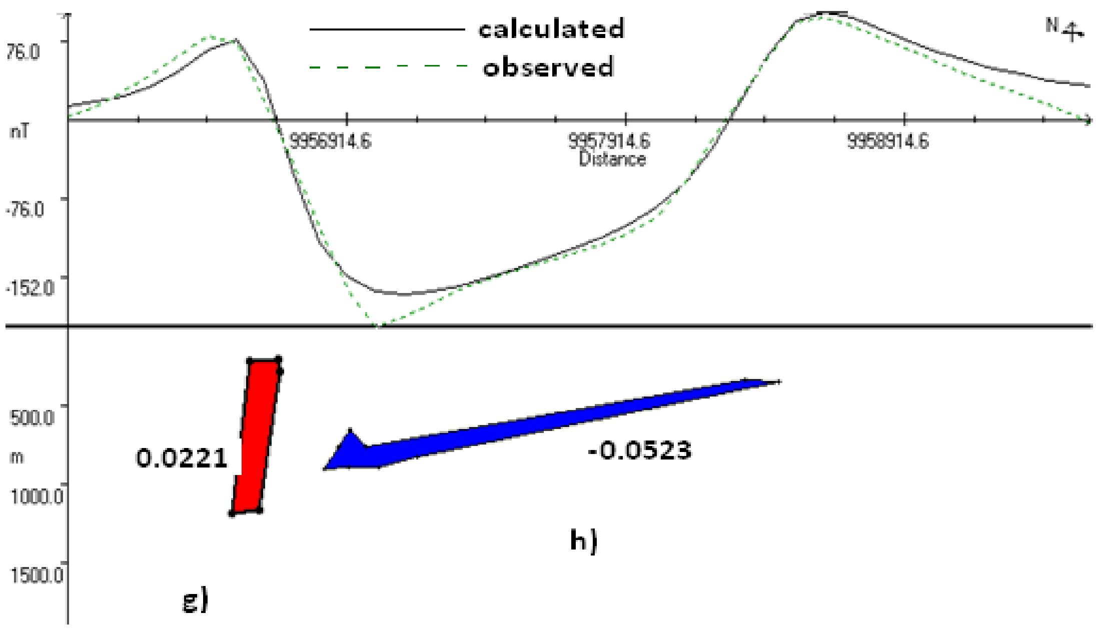

Figure 12: Models on profile DD’

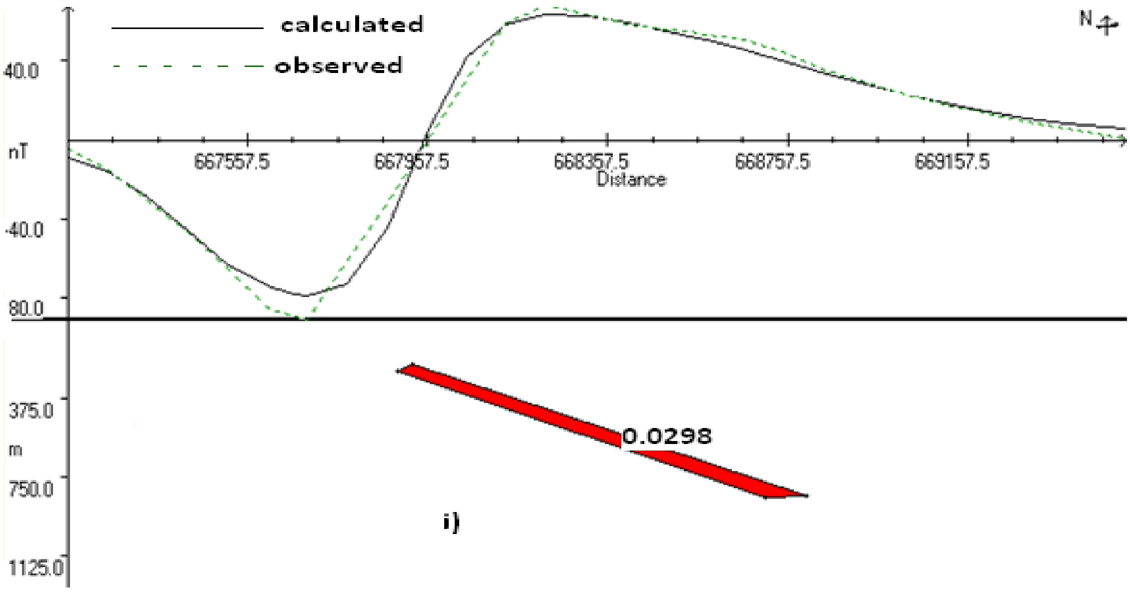

Figure 13: Model on profile EE'

Table 2: Modeled parameters of the causative bodies

Profile name	*Causative bodies*	*Modelled depth, a, (m)*	*Modelled susceptibility, k, (SI)*
AA'	a	346.19	-0.113
	b	271.47	0.026
	c	59.78	0.005
BB'	d	511.15	0.0273
CC'	e	125.41	-0.0085
	f	385.87	0.0232
DD'	g	208.18	0.0221
	h	333.33	-0.0523
EE'	i	210.94	0.0298

3.3.1 Models Interpretations

Models on profile AA' show three subsurface intrusive bodies which are postulated to be carbonatite sill and dyke forming along the fracture zones. The first body, (Fig. 9a) is a carbonatite sill forming at a depth of about 346m below the surface and has a magnetic susceptibility of -0.113 SI. Adjacent to it is the body in Fig. 9(b) which is a carbonatite dyke at a depth of about 271m from the surface to the top of the dyke and has a susceptibility of 0.026 SI. The third body, (Fig. 9c) is a diagonal dyke much closer to the surface at a depth of about 60m from the surface to the top of the dyke. It has a magnetic susceptibility of 0.005 SI. In between the bodies are perhaps indications of the faulted regions within the area. On the northern part of TMI map shown in Figure 3 is profile BB' trending NE-SW. A model on profile BB' shows an intrusive body with a high magnetic susceptibility of 0.0273 SI at a depth of about 311m from the surface to the top of the body. The intrusive body is near horizontal (Fig. 10) and is postulated to be a volcanic sill/vein along fractures. A high magnetic gradient evidenced on profile BB', farther points at a fault-lineament structure having the same orientation as that of the postulated sill on the profile. Profile CC' is on the South-western region of the TMI map of Homa Hills shown in Figure 3. The first body shown on Figure 11(e) is postulated to be a carbonatite dyke along a fracture due to its high magnetic anomaly as well as its magnetic susceptibility of about -0.0085 SI an indication of probably, a reversely magnetised intrusive body. The depth from the surface to the top of the plug is approximately 125m. The second body, Figure 11(f) is perhaps a volcanic sill along a fracture, due to its horizontal inclination. Its magnetic susceptibility is 0.0232 SI and it is at a depth of about 386m in the subsurface much deeper compared to the structure in figure 11(e). Both models on profile AA' and profile CC' tend to agree that at the point of their intersection, the subsurface structure is a sill approximately at equal depths, Figure 9(a) at a depth of 346m and Figure 11(f) at a depth of 385m.

Profile DD' trends in the direction N-S in the TMI map of Homa Hills shown in Figure 3. Models on profile DD' show two structures Fig. 12(g) and 12(h) of different parameters. The first body (Fig. 12g) is near vertical and is at a depth of about 208m from the surface to the top of the body, its magnetic susceptibility is modelled to be 0.0221 SI. This body is postulated to be a phonolitic plug along a fracture. The second body (Fig. 12h) is postulated to be a volcanic dyke. It is at a relatively deeper depth of about 333m below the surface and has a magnetic susceptibility of -0.0523 SI. The gap between the two structures coinciding with a negative magnetic anomaly is perhaps a faulted basement that is hydrothermally demagnetised since it acts as a conduit for geothermal fluid flow. The profile EE' is on the southern part of the Homa Hills TMI map shown in Figure 3. The structure beneath profile EE' has a magnetic anomaly of about 150nT. The model on profile EE' suggests a body at shallow depth of about 210m from the surface inclined in the NW-SE direction. This body is postulated to be a thermal structure, more specifically, a carbonatite dyke. This is particularly so because it agrees with the model of the body on profile AA' which intersects with profile EE' at the southern region and it also postulates a thermal structure at a shallower depth. The broad negative anomaly is due to demagnetisation of the rocks within the area as a result of higher subsurface temperatures above the Curie temperature ($T_c = 580^oC$).

4. Conclusion

The visual inspection and analyses of the total residual magnetic map, magnetic profiles and the models revealed that Homa Hills prospect is generally characterised by a broad and low magnetic signatures at the southern and northern parts surrounded by high magnetic belt from the NE and SE. Besides, it includes surficial or local anomalies of shallow seated origins, with orientations in the direction N-S, NW-SE and NNW-SSE. The average modeled depth for the near surface magnetic anomaly sources (postulated to be a carbonatite dyke) of the area is 205m, while that of the deep-seated anomaly sources is 511m. The results further support the delineation of faults/fractures trending N-W, NW-SE, NNW-SSE and NE-SW, and heat sources associated with shallow intrusive along structures.

The ground magnetic study of this area has helped in a number of ways to delineate lineaments and target zones with intrusives. Firstly, the major subsurface structures delineated (faults/fractures, sills and dykes) will aid the geothermal exploration work in the area. Secondly, the linear nature of the anomalies in this part suggests that the rocks may be bounded and offset by fault. The results further support the delineation of faults/fractures trending N-W, NW-SE, NNW-SSE and NE-SW, and heat sources associated with shallow intrusive along structures. Since geothermal exploration requires multi-disciplinary approach, other exploration methods such as detailed gravity survey done in the prospect area during the same period need to be analysed together with this piece of work in order to discern deeper tectonic lineaments in this prospect area.

5. Acknowledgement

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