Geophysical Exploration of Iron Ore Deposit in Kimachia Area in Meru County in Kenya, Using Gravity and Magnetic Techniques

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Abstract: ***A combined geological and geophysical survey undertaken in Kimachia area of Meru County in central Kenya has established the existence of small scale iron ore deposit that seems to be part of a more extensive iron rich zone. The study has identified magnetite as the main ore in the geological formations. Kimachia iron can be classified as a sandstone deposit. The origin of the ore has not been established but, is obviously none magmatic. It is however possible that the ore deposits, like most iron ore deposits in the world, is formed from early Archean eon to late Precambrian. The study further established that the ore grade varies from medium to high quality. Alluvial iron rich sand deposits in the valley area were the first to be identified by use of simple magnets. Gravity surveys revealed a zone of high gravity anomaly aligned in the same direction as hills on the elevated topography. Further, magnetic methods conducted along the same stations used in the gravity survey revealed several zones with high magnetic anomalies coincident with the gravity anomalies characteristic of ferromagnetic rocks some of which have been magnetized over the hilly areas. Pitting in two selected zones within the gravity and magnetic anomalies confirmed the existence of the ore bearing rocks within a few feet of the surface.***

Keywords*:* Anomaly, Gravity, Magnetics.

1. Introduction

This paper presents results of a pilot study to establish the source of magnetite commonly found in alluvial sands in valleys and the lowlands in Kimachia area of Tigania in Meru County. The study that used geological and geophysical methods led to the discovery of a new localized iron ore deposit in the hilly parts of the area as the source of the magnetite. The study indicates that these deposits are part of a potentially extensive resource. The ore occurs in two forms; fine grained deposits that are mixed with the alluvial sand in the low lying areas and valleys, and rocky deposits found on the surrounding hills consisting of fist size rocks or larger similar to the well-known iron stones of Australia. The geophysical surveys show that the ore bearing minerals could be more extensive and deep. Pitting in selected parts of the area show that the ore occurs at a relatively shallow depth and even at the surface in some parts of the field.

Chemical analysis of various samples show that the fine grained deposits in the valleys contain over 90% magnetite while rocks on the hills contains medium to high grade iron ore with 40-90% magnetite. The Isiolo-Meru area of Kenya has been a target for mineral exploration since 1940's [1]. Of particular interest have been the granitic intrusions and relatively young Mbokoro Inlier that were seen to be part of basement rocks whose mineral bearing potential is well documented. However none of the early and subsequent surveys succeeded in locating any minerals. This failure to locate any useful minerals has been attributed to the thick soil cover from a series of volcanic activity during the formation of Mount Kenya and more recent lava flows associated with formation of the Nyambeni domes [2]. Whereas this is possibly true the discovery reported here implies that either the thick soil cover has been eroded in some parts or the iron ore are due to later iron rich intrusions.

2. Geology

The only detailed geological study of the Meru area was conducted by P. Mason in 1942 and 1952 and reported in 1956. The primary objective of the survey was to map granitic intrusions seen in several parts of the field that were considered possible source of valuable minerals. Based on this report, the Tigania area where Kimachia iron deposits occur is at the intersection of Nyambeni Range and the Lowlands. The two physiographic zones are part of the four geologic zones identified by Mason. The other two zones are the North-Eastern foot hills of Mount Kenya and the North-Western basement highland.

2.1 Kimachia-Mbeu Area

Figure 1 shows the location of Kimachia area. The prospect area is 20 km to the north of Meru city in central Kenya. It is a small geological complex of about 5 $km^{2,}$ in area that is in some respects a microcosm of the broad geology of the Nyambeni area. The main features of the area are the denudated land consisting of hills and valleys. The lithology of the area is quite eroded after uplifting and outcrops and sequence of faulting [3]. Kimachia area has many hills the lower part of which are characterized with areas with thick soil and sand cover. It is in these valleys that blast soil sediment which is high iron rich has accumulated.

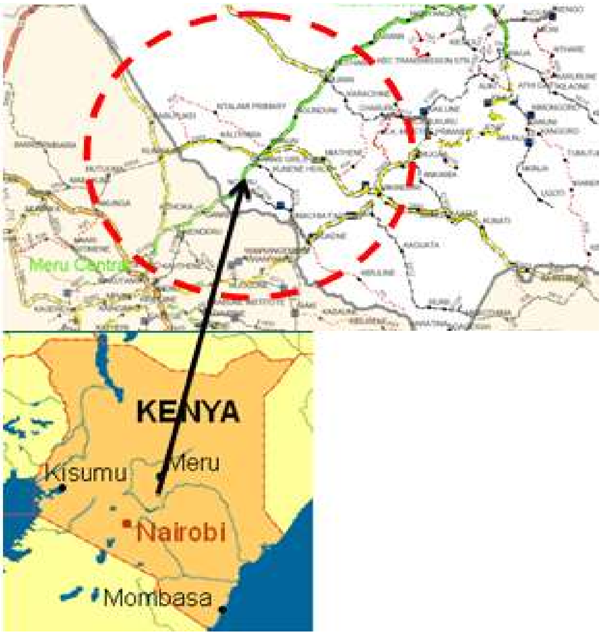

Figure 1: Location of Kimachia iron ore deposit-Meru County

In general mineral exploration can only be undertaken in areas where the existence of such minerals is suspected or some potential indicated by some form of manifestation. The Kimachia area has abundant sandy iron and sandstone in the lower lands and the valleys. These sands are harvested and used for civil construction in Meru city and nearby areas. This study was prompted by the desire to establish the source of the iron found in the sands of this region. A simple geological field survey of the hills established that magnetite occurs in two main forms: the first is where both iron and sandstone are imbedded in granitic rocks, and the second in similar environments where iron is imbedded in what is almost pure sandstone. The two forms are widespread on the surface and at shallow depths which indicates that these rock types are a potential source for large volumes of iron.

2.2 Assay Analysis

Surface and pit samples from various parts of the field were subjected to complete assay analysis. The samples included fine grains of magnetite separated from regular sand found in the valley by use of a hand magnate, and rock samples from a well in an isolated area to the south of the hills where the pits were dug. These results are shown in table 1.

Table 1: Assay Analysis

Sample Source	*Fe_2O_3 (%)*	*SiO_2 (%)*
Sandy Soils	92	ND
Granitic Rocks	86	6.6
Silica imbedded	22.5	45
Well Sample	11.8	57

3. Field Measurements

A total of 83 stations spread over an area covering about 5 km^2 were used for both gravity and magnetic surveys. However some of the points readings from the lowlands were left out in this analysis. Whenever possible the data was collected in regular spacing of about 20-50 meters. However because of the steep terrain some points were spaced wider or closer than this.

3.1 Gravity Surveys

Gravity measurements were done using a Sodin gravimeter. Instrument drift corrections were applied to the data before applying the standard data reductions [4]. Figure 2 shows a sample data of one of the drift corrections. The drift curve was done using a least square adjustment. The other standard corrections namely latitude, air and Bouger plate corrections were also applied to the data.

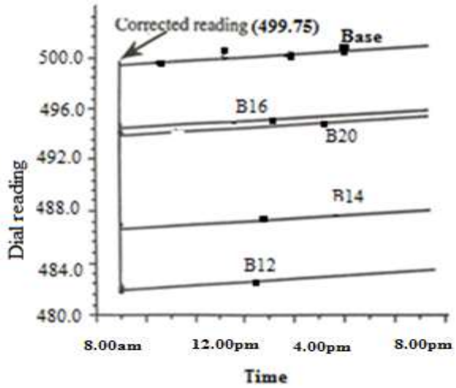

Figure 2: Drift curve for the work done on 11/05/2011 using the base station

The latitude correction was made using the standard equation,

$$\Delta g = 0.8140 sin2\theta \text{mgal/km} \quad (1)$$

Free air and Bouger plate corrections were made using the single equation, $= -0.19672 h\text{mg}$ (2)

Where$h$ is height in meters. A density of $\rho = 2.67\ g/cm^3$ was used in all calculations.

3.1.1 Qualitative Interpretation

Figure 3 below shows the contour map of the reduced gravity after applying the drift corrections. The Bouguer anomaly map reveals that the area with positive anomalies is in the northern part of the field running in the east-west direction. This is coincident with the high ground where the hills are and the rocky samples were collected.

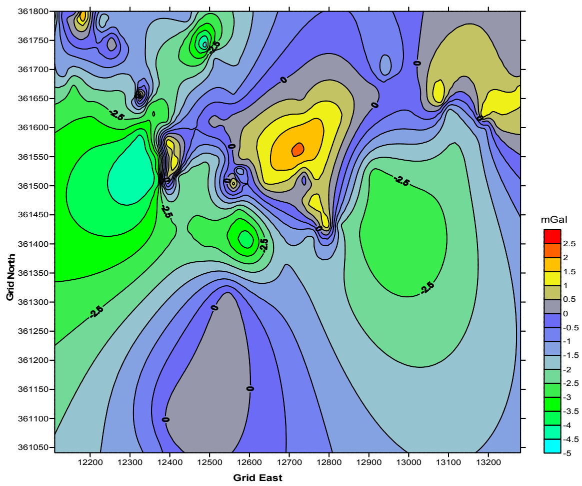

Figure 3: Bouguer gravity of Kimachia area

A regional profile of the data in 3-D rendition is shown in figure 4.

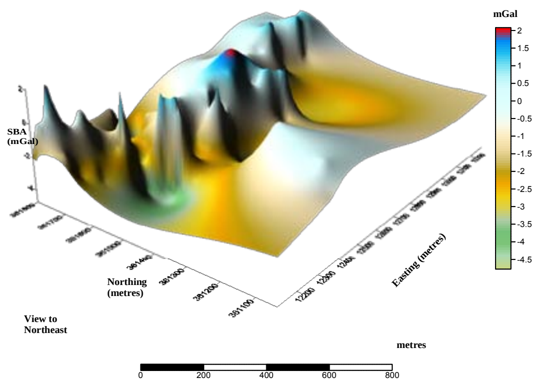

Figure 4: 3-D form of the gravity anomaly

Figure 5 shows the topography of the area of study. It is clear from the alignment of the gravity anomaly along the hilly topography that the hills are the most probable source of iron. The lowlands and the valleys to the south are in the gravity low.

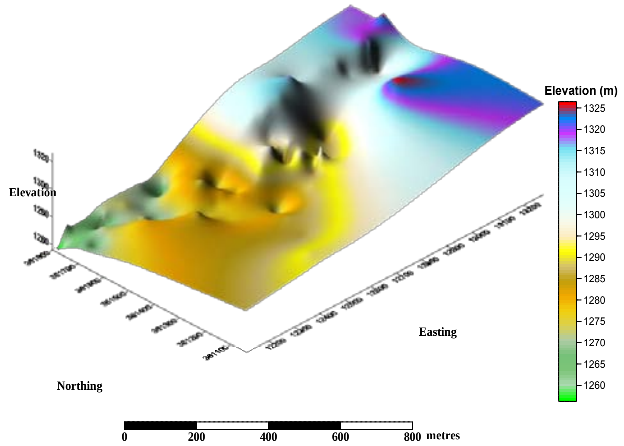

Figure 5: 3-D form of the topography of Kimachia area

3.2 Magnetic Survey

A magnetic investigation was done as a reconnaissance to the gravity survey. The survey used the same stations as those for gravity survey. A proton precession magnetometer was used to measure the total magnetic field. The data was corrected for diurnal variation. [5].International Geomagnetic Reference Field (IGRF) was removed using a mathematical application based on the IGRF model 2000-2015. The reduced data was used to plot the contours shown in Figure 6 while the 3-D view of the same data is plotted in Figure 7.

3.2.1 Qualitative Interpretation of Magnetic contour map

In general all magnetic readings were higher than the expected average value of 3200 nano Tesla based on International Geomagnetic Reference Field (IGRF). The contour map shows a large high magnetic signature trending in the north-south direction in the middle of the field along the 13200 Easting.

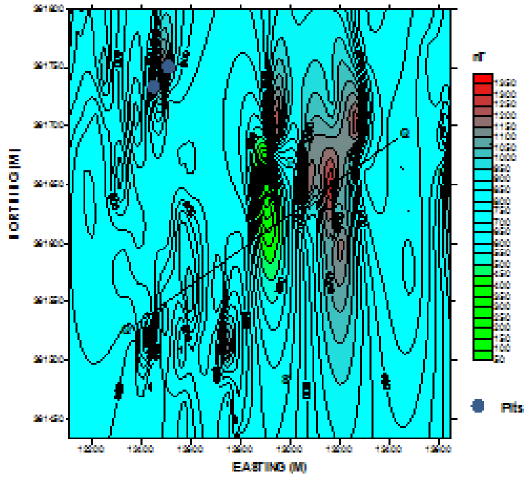

Figure 6: Reduced Magnetic Intensity map of Kimachia area

Two smaller positive anomalies are visible along 12800 and 12400 Eastings. The large magnetic anomaly is adjacent to a magnetic low or negative. The magnetic highs and adjacent lows and their orientation indicates that there are several variously magnetized bodies in this zone.

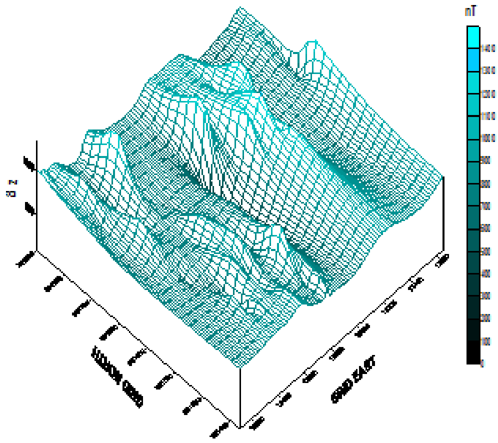

Figure 7: 3-D view of the Magnetic Intensity of Kimachia area

The magnetization is confirmed by the 3-D diagram. Whereas it is clear the magnetic field is in the north-south direction the bumps and valleys in the middle part of the field that coincide with high and low magnetic anomalies in hilly area identified in the contour map clearly confirms the earlier conclusions made from the gravity data. In general the trend in magnetization is the same as that for gravity but is slightly displaced to the south. The zone of gravity high lies on the hills while the magnetic anomaly begins from the edge of hills extending closer to the low lands. The contour trending (NW-E) show significant magnetic relief and reflect the presence of both shallow and deep magnetic sources. Figure 8 below shows a traverse along the profile QQ’ in figure 6. This profile cuts through the central part of the field.

This profile is characteristic of several alternately magnetized bodies or single body with parts that are alternately magnetized. The general trend is an indication of the degree of the magnetization of the rocks. The values of magnetic intensity depend on the amount of ferromagnetic, size and shape of material, the degree of magnetization and orientation relative to the ground surface.

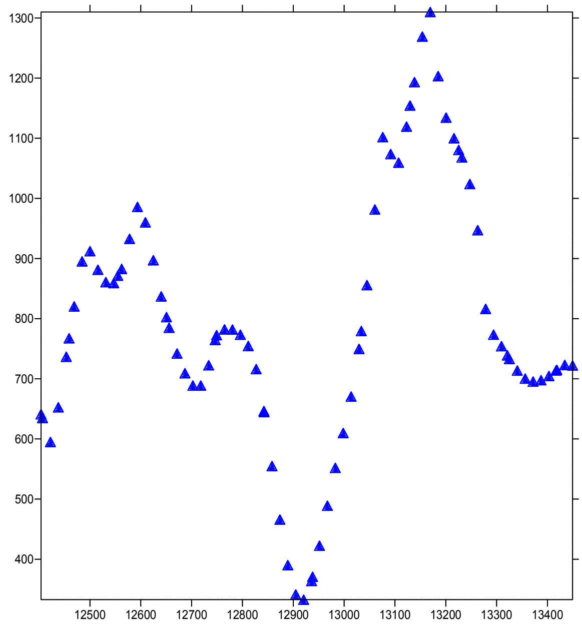

Figure 8: Magnetic Plot along the profile QQ'

4. Pitting

The two small magnetic anomalies at 12400 Easting and 316750 northings that were also within the gravity high were selected for pit investigations. Magnetite rich stones of different sizes were encountered within two feet of the surface. The iron rich zones extended up to the investigated depth of one and half meters. The rocks, some of which were larger than an average fist, were mixed and separated by normal soil and seem to have been part of a single piece of rock with the fragmentation being an outcome of weathering. Assay analysis showed that the rocks contained up to 80% magnetite with silica making up most of the rest of the rock. Similar pit investigations were also conducted within the lowlands where sand harvesting was taking place. A zone richer in magnetite than the upper sands was found within a foot of the surface. The separated magnetite particles had more than 90% magnetite.

5. Discussion

The pilot investigation reported in this paper has not only established that the hilly areas of Kimachia are the source of magnetite found in the alluvial sands in the lowlands but has also revealed that the iron ore is possibly part of a larger and more extensive resource below the hills within the area. This was confirmed by the pit investigations where high quality magnetite was found at accessible depths form the surface. The presence of low but significant levels of magnetite in rocks from a well that is not within the area with either the magnetic and gravity anomaly indicates that iron may be present in a wider area and in deeper part of the area.

In general both geophysical methods did not seem to pick the magnetite found in the alluvial deposits in the lowlands. This is possibly because the sediments at shallow depths, unconsolidated and low density, and cannot be picked by the gravity survey. Furthermore lose fine sediments however magnetized will probably have no major effect on the earth's magnetic field and cannot equally be detected by the magnetic survey. Thus there is need to use other methods such as electromagnetics that can detect small isolated electrical conductors.

There is need to re-assess and update the geology of the Meru area and the greater Mount Kenya region as a whole. Based on the current knowledge of geology of the region no valuable minerals were expected in the study area. The dominant geological activity in Kimachia being associated with the volcanic eruptions that led to the formation of Mount Kenya and the Nyambeni domes during the Oligocene and Miocene periods respectively having concealed most of the ancient. These events are relatively recent and could only lead to magmatic ore deposits. Magmatic deposits seen elsewhere are associated with relatively thin and well spread lava flows. Those in Kimachia do not seem to be of this form.

From the immediate evidence it is apparent the deposit is not a classic bedded iron formation (BIF) either. Kimachia iron deposits do not seem to have the thin lateral spread associated with lava flows similar to those seen in Chilean deposits. However, they are dark and mixed with almost pure silica indicating some form of fractionation of a felsic magma. The weathered and limited lateral extent does however point to dyke like intrusive that may be derived from a deeper lying intrusive.

This study has not been able to establish any lithologies that can be associated with the magnetite ore. Furthermore none of the earlier geological studies found evidence of significant hydrothermal activity that can be associated with mineral deposits of this kind. It may seem therefore that Kimachia iron would be of the same form as other resources of similar kind. It will be important to establish if the Kimachia iron is localized deposit or part of an iron or mineral rich belt.

6. Conclusion

The gravity and magnetic anomalies seen in the field are due tothe iron ore. The ore generally has a higher density than local rocks and is variously magnetized. It may seem that the gravity survey will be a more reliable indicator of the iron resource compared to the magnetic method. The later was apparently not able to reveal the continuous nature of the iron in the hilly areas due to its dependence on angle (azimuth) and degree of magnetization. These two properties may offset the anomaly beyond the immediate area within the iron rich area. Kimachia region indicate predominant magnetic anomaly trend NW-E, N-SW and NNW-SSE. Thus this region is relatively of high magnetic intensity. The visibility of sandy iron is widespread and indicates that there is potential for large scale alluvial accumulations found in valleys below the iron bearing hills. Further geological and geophysical studies will need to be under taken to establish if the Kimachia iron is part of an iron rich region or localized resource.

7. Acknowledgement

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