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Investigation of the Extent of the Geothermal Resource South of MT. Longonot Volcano Using Gravity and Magnetics, Kenya

Jones Musyoki Mutua
Geothermal Energy Training and Research Institute,
Dedan Kimathi University of Technology, Kenya

Abstract:
Geothermal energy is increasingly becoming an important source of electricity generation in Kenya. The country has prominent Geodynamic features such as the Rift Valley which gives rise to high temperature magmatic heat sources and hydrothermal reservoirs which can be exploited to produce geothermal energy for power generation and direct heating. Identifying and delineating this resource can be done using combined appropriate Geological, Geochemical and Geophysical methods. The main objective of geothermal exploration is to obtain from surface studies adequate information about the promising features of a prospective geothermal system and therefore reducing uncertainties before embarking on costly and risky drilling. The main objective of this research was to investigate the extent of the geothermal resource to the South of Longonot Volcano using gravity and magnetic data that was availed by Kenya Electricity Generating Company. Surfer 11 software was used to process and analyse the data, presence of bodies with high density contrast and high susceptibility contrast were revealed. The research identified three potential wells in the study area.

Keywords: *Geothermal resource, gravity, magnetic, positive anomaly, negative anomaly*

1. Introduction

1.1. Background

Geothermal Energy is based on the extraction of heat from the earth and needs fluids to transport the energy from geothermal reservoir to the surface equipment for electricity production. Therefore, geo-scientific studies need to identify the location and characteristics of the heat source as well as of the reservoir characterized by fractures and pores within the hosting rock. The main objective of geothermal exploration is to obtain adequate information about the properties and features of a prospective geothermal system before embarking on drilling (Langat, 2007). According to Mariita (2009) and Omenda (2009), objectives of the surface field investigation of a geothermal prospect are to; determine the geothermal potential of the prospect by studying the structural volcano logical patterns, magmatic evolution, lithological outcrops, precise the characteristics of the cover, reservoir and heat source at depth using geological, geochemical and geophysical tools and develop a geothermal conceptual model of the area by integration of all available date on site. Geophysical exploration involves measurements on the physical properties of the earthanddetermines parameters that are sensitive to temperature and the fluid content of the rocks. Among these tools, gravity and magnetic methods are very effective for detecting structures and heat sources. Magnetic surveys are used specifically for mapping geological structures based on varying magnetization of rocks. It investigates the anomalies in the earth's magnetic field resulting from the magnetic properties of underlying rocks (magnetic susceptibility), (Otieno, 2008). Gravity survey is another structural method used in geothermal exploration to detect geological formations with different densities. Investigation based on relative variations in the earth's gravitational field arising from difference of density between subsurface rocks.

1.2. Location of Study Area

Longonot geothermal prospect is located at Latitude: 0° 54' 32.99' N, Longitude: 36° 27' 14.99' E in the Kenya Rift Valley, 60km Northwest of Nairobi and 10km East of the Olkaria Domes geothermal field**.** It borders Olkaria volcanic complex to the West, Lake Naivasha to the North, Suswa volcano to the South and Kijabe hill to the East. Longonot volcano occupies an area of about 350 km^2 and consists of a cone with a gentle slope to the south and attains a maximum height of 2776 masl.The area in and around Longonot is characterized by active manifestations that occur in the form of fumaroles, altered grounds, warm grounds, Sulphur deposition and silica deposition, and it is a Quaternary volcano (Mariita, 2006). The volcano comprises of a large trachyte caldera of about 11 km diameter and a resurgent activity on the caldera floor that formed a central volcano with a crater at the summit. The caldera floor is filled, largely, by trachytic ashes from the central volcano associated with the volcano (Omenda, 2013). A geochemical survey (Omenda 2013) revealed high radon and CO_2 gas discharges and indicated that the geothermal reservoir temperatures could exceed 300 ^{0}C. Figure 1 shows the Geological map of Longonot Geothermal area and figure 2 shows the upper part of Mt. Longonot caldera.

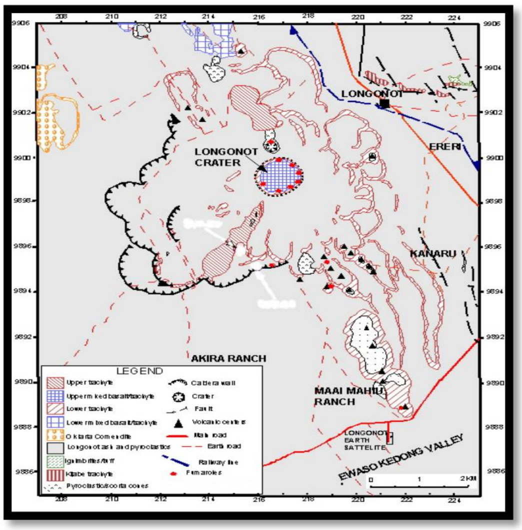

Figure 1: Geological Map of Longonot Geothermal Area (Omenda, 2013)

Figure 2 : Upper Part of Mt. Longonot Caldera
Source: Google Map

1.3. TheMain Objective

The main objective of the study was to determine the extent of geothermal resource to the south of Mt Longonot. This objective was achieved by investing the extent of the heat source and locating structures that could be permeable zones. The achievement led to proposing accurately suitable drilling sites.

1.4. Previous Studies

A gravity survey in Olkaria, Longonot and Suswa by GeotermicaItaliana (1989) suggested positive anomalies related to shallow bodies of dense lava flows and negative anomalies related to deeper sources. Another gravity survey report by Mariita in 2006 indicated that Longonot geothermal prospect has positive indicators of a geothermal resource and numerous manifestations occur within the summit crater and a few outside on volcanic centres to the south and on the southwestern caldera rim. The Kenya Electricity Generating Company (KenGen) carried out a detailed geo-scientific study at Longonot in 1998, which indicated a geothermal resource area of approximately 70 km^2 with an estimated power output of 128 MWe (KenGen,1998).

Results of DC resistivity survey at 1000masl (Onacha,1998) defined Longonot south as a zone of low resistivity and this was interpreted as a source of heat and the study identified a potentially active geothermal system in the southern part of Mt.Longono, figure 3

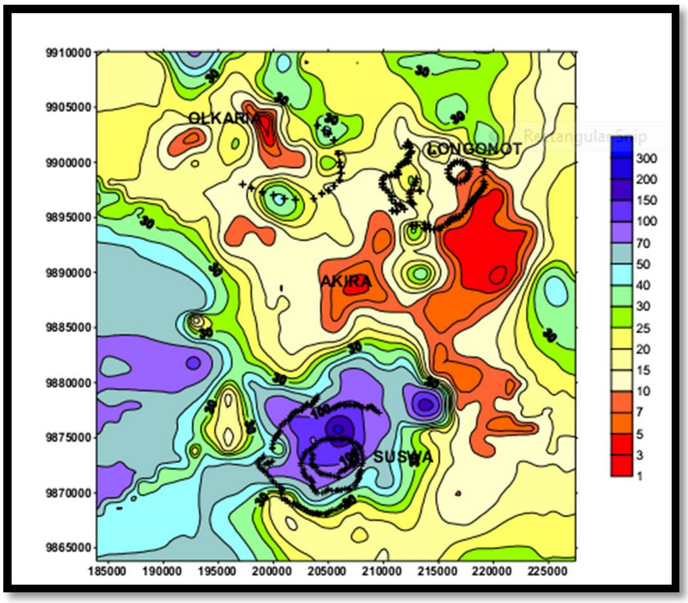

Figure 3: DC Resistivity at 1000masl (Onacha, 1998)

1.5. Geophysical Methods in Geothermal Exploration

Geophysical exploration (Georgsson, 2009) involves measurements on the physical properties of the earthanddetermines parameters that are sensitive to temperature and the fluid content of the rocks. Main geophysical methods are thermal methods (soil temperature, heat-flow), Electrical methods (resistivity, self-potential), Gravity methods (rock density), Magnetic methods (rock magnetization), Electro-magnetic and Magneto-telluric methods (measurement of naturally occurring magnetic and electric field Oscillations) and Seismic methods (sound velocity, seismicity, geological structure).

Geophysical techniques involve indirect investigation surveys which allow evaluating the distribution of some physical parameters that provide evidence of certain features of the underground. Some of these parameters are: temperature, density, magnetic susceptibility, resistivity, electrical conductivity.

1.5.1. Potential Fields

Gravity and magnetic methods are known as potential fields or structural methods as both detect structures (Wanjohi, 2014 and Langat, 2007). These two were used for this study.

1.5.2.Gravity Method

Gravity survey is a structural method used in geothermal exploration to detect geological formations with different densities. Investigation based on relative variations in the earth's gravitational field arising from difference of density between subsurface rocks, figure 4.

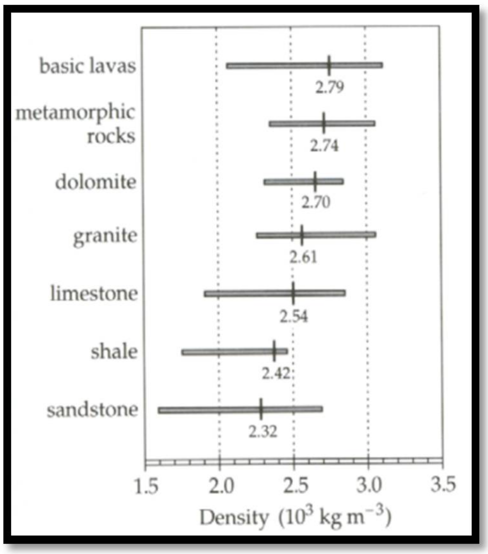

Figure 4: Density of Various Rocks (Marescot, 2016)

Heavier rocks may imply possibility of a heat source. Positive gravity anomalies imply higher density associated with plutonic intrusions and dykes, deposition of silicates from hydrothermal activities during green schist metamorphism as shown by figure 5.

Negative gravity anomalies imply lower densities caused by higher porosities or by highly fractured parts of a rock, alteration of minerals produced by circulation of hot water, figures 6, 7.

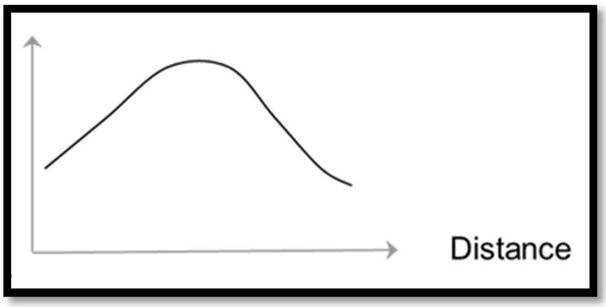

Figure 5

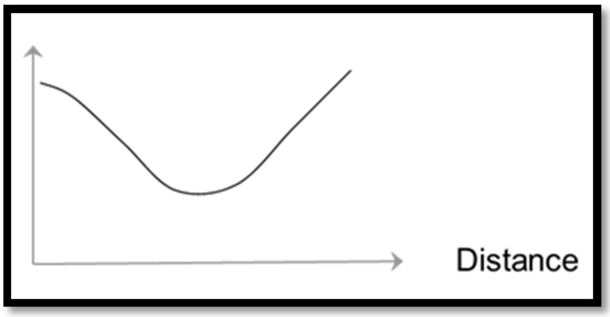

Figure 6

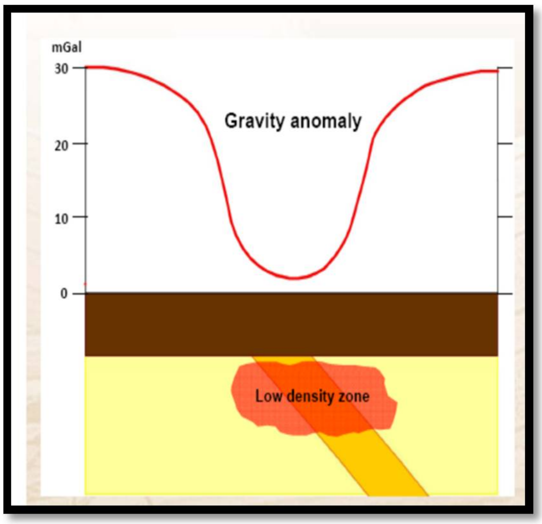

Figure 7: Gravity Surveys

1.5.3.Magnetic Method

Magnetic surveys are used specifically for mapping geological structures based on varying magnetization of rocks. It investigates the anomalies in the earth's magnetic field resulting from the magnetic properties of underlying rocks (magnetic susceptibility and remanence), (Otieno, 2008). The presence of dykes is revealed by high susceptibility, circulation of hydrothermal fluids causes alterations in the rock, which lead to a reduction in susceptibility.

This magnetic survey is important for mapping: demagnetized bodies, heat sources, dykes, buried faults, alteration zones and structures in general. Figure 8 shows a geophysicist with a magnetometer ready to take measurements.

Demagnetized bodies are associated with existence of hot rock mass in the crust.

Alteration of the rocks is associated with hydrothermal hot zones that lead to less susceptibility. High magnetic susceptibility is associated with igneous rocks and dykes, which have high concentrations of magnetite, figure 9.

Figure 8: AGeophysicist Ready for Magnetic Surveys (Www.En.Wikipidia.Org/Magneticsurvey)

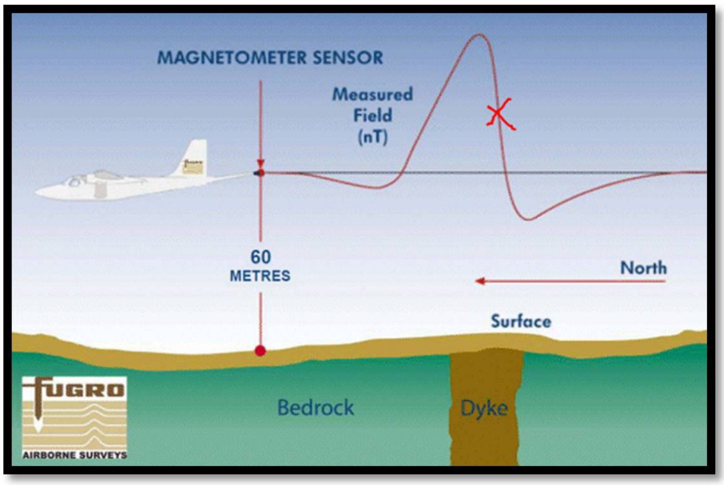

Figure 9: A Magnetic Reading Profile across a Dyke by Ground Magnetic Survey (Www.En.Wikipedia.Org/Magnetic Survey)

2. Methodology

2.1. Data Acquisition

The study investigated the extent of geothermal resource to the south of Longonot by analyzing the available data (gravity and magnetics) from KenGen. Three types of instruments have been used to collect gravity data. These were the Worden, La Coste Romberg and Scintrex CGgravimeter. The La Coste Romberg has been used the most. A magnetometer was the instrument used for measuring the intensity of the earth's magnetic field. Proton precision magnetometers or fluxgate magnetometers are normally used for the measurements. The Surfer 11 software was used to process and analyse the data.

2.2. Data Correction

Several corrections were applied to the field gravity readings to remove all known gravitational effects and errors not related to the subsurface density changes.

- Some of these corrections are:
- Free air gravity anomaly
- Bouguer anomaly
- Terrain correction

The correction for diurnal drift was done continuously on the magnetic data to monitor the temporal changes. This corrected magnetic data was then displayed as contour maps on which anomalies were identified, analysed and interpreted.

3. Results, Discussion and Interpretation

3.1. Introduction

The main goal of this research was to investigate the extent of heat source to the south of Longonot. Geophysical techniques involve indirect investigation surveys which allow evaluating the distribution of some physical parameters that provide evidence of certain features of the underground. Some of these parameters are: temperature, density, magnetic susceptibility, resistivity, electrical conductivity. Gravity and magnetic data were availed by KenGen and the results were compared with electrical resistivity survey. The results show a good correction between electrical resistivity, gravity and magnetic surveys.

3.2. Gravity Method

Gravity method assists in mapping gravity contrasts in the subsurface and helps in structural analysis, as well as identifying dense bodies that can be associated with magmatic bodies, which is of importance in geothermal exploration The Bouguer anomaly map at contour intervals of 5000 mgals was prepared for the study area, figure 10. The map shows negative gravity anomalies to the south of the crater which may correspond to thermally demagnetized volcanic rocks. This could be a zone of high porosity, fractured and rock alterations caused by water. Positive / high gravity could be associated with plutonic intrusions such as dykes. Red colour (Mwakirani, 2015). which was associated with gravity highs can be interpreted to be dense seismic events that reveal a magmatic body below the prospect and which may be a heat source for geothermal systems. Figures 11 shows the inferred fault line which could be acting as conduits for geothermal fluids and these zones are significant drilling targets for productive wells.

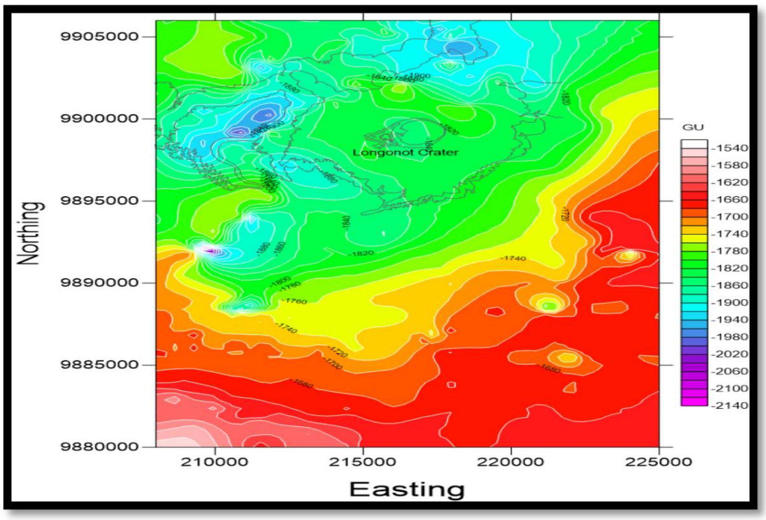

Figure 10: Bouguer Anomaly Map

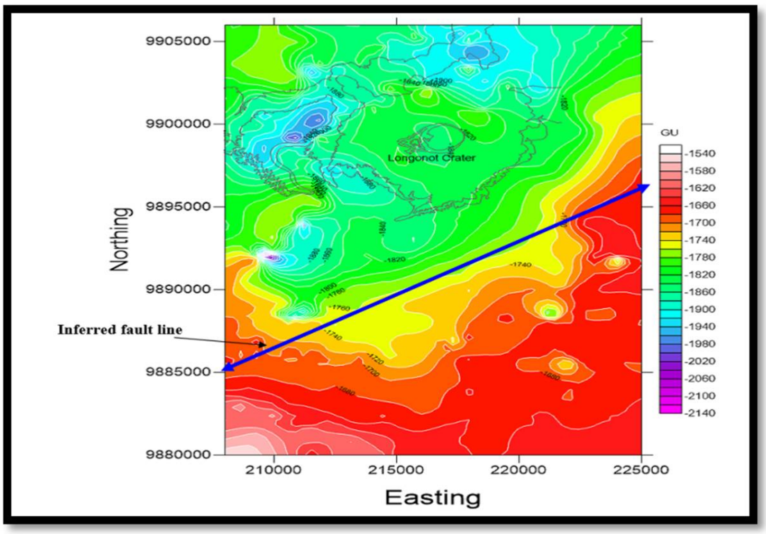

Figure 11: Showing the Inferred Line

3.3. Magnet Method

Magnetic surveys detect anomalies in the earth's surface resulting from the magnetic properties of the underlying rocks, (susceptibility). Demagnetised, (low susceptibility) rocks confirms presence of hydrothermal fluids. High susceptibility confirms presence of dykes and igneous rocks.The residual total magnetic field intensity map was prepared with contourIntervals of 5000nT, figure 12. The southern part of Longonot is characterized by both negative magnetic anomalies on the left of the inferred fault line and positive magnetic anomalies on the right of the inferred fault line as shown on figure 13. The negative anomalies may represent fractures or faults and possibility of demagnetisation due to fluid rock interactions and this confirms high porosity and high permeability. Onacha's (1998) electrical resistivity survey identified a potentially active geothermal system in the southern part of Mt. Longonot

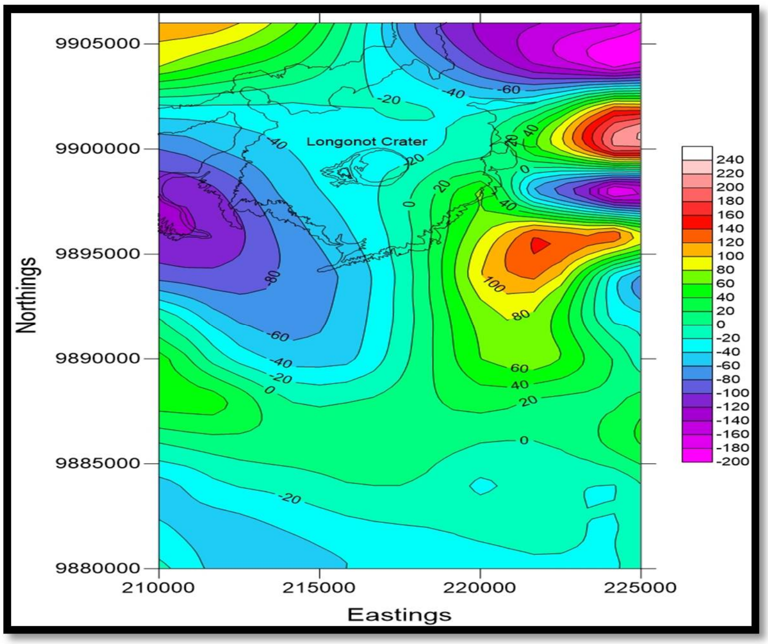

Figure 12: Magnetic Intensity Map of Longonot

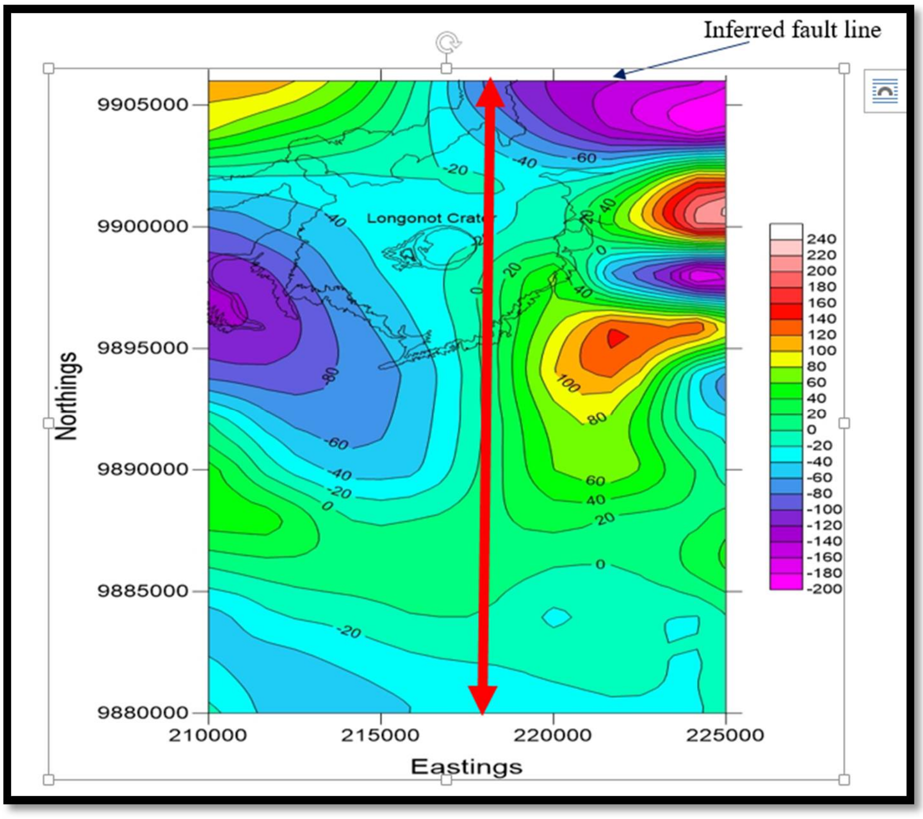

Figure 13: Inferred Fault Line on a Magnetic Intensity Map of Longonot

4. Conclusion

The application of both gravity and magnetic prospecting methods in southern part of Longonot has revealed presence of bodies with negative gravity anomalies to the south of the crater which may correspond to hydrothermally demagnetized volcanic rocks and negative magnetic anomalies on the left of the inferred fault line and positive magnetic anomalies on the right of the inferred fault line. A geothermal field suitable for exploitation should have the following;

- Heat source
- Reservoir
- Fluids
- Cap rock.
- Recharge system

This study has revealed the presence of potential geothermal fluids and permeable zones which are characterized by the inferred fault line. These permeable zones are significant drilling targets for productive wells. The magnetic survey indicated that the southern part of the Longonot was demagnetized indicating a zone of possible high temperature and higher degree of hydrothermal alteration. The negative gravity and magnetic anomalies are associated with high porosity, fractured rocks, faults, demagnetized rocks and this may be a zone of high permeability.

- The results indicate that the study area has porosity, faults, permeability and a heat source on the right of the inferred line
- A potential geothermal resource exists in Longonot south and three wells were sited, W1, W2 and W3 as shown on figure 14.

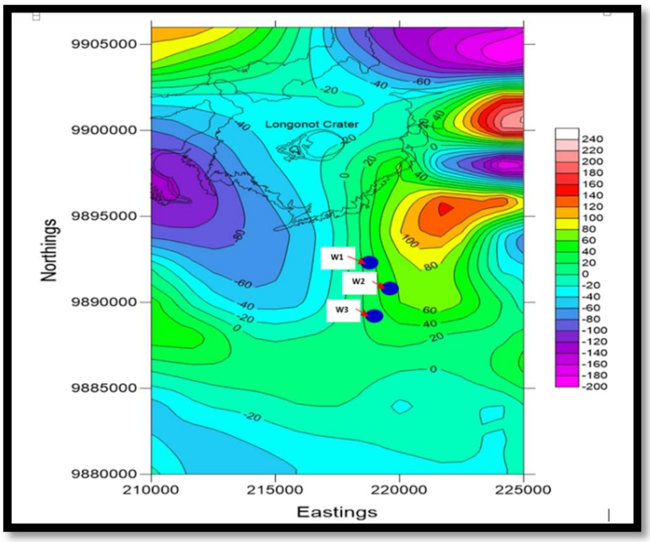

Figure 14: Sited Wells

5. Recommendations

As part of recommendation to this study, there is need to, therefore to carry out gravity and magnetic measurements to the north-east and immediate south-east of Mt. Longonot to infill the missing data.

6. Acknowledgment

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