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Identifying Permeability controls by use of Gravity Method in Menengai Geothermal Field, Kenya

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ABSTRACT

Surface studies done in Menengai field have indicated a huge geothermal potential and has led to the drilling of several wells. However, some of these wells have not produced as earlier projected and there are questions as to whether this field has enough permeability. The purpose of this study was to employ gravity method to understand density variations in the Menengai field by developing structural models and establishing whether there is enough permeability. Raw data received from Kengen and GDC was reduced to simple Bouguer. The data was subjected to all reduction procedures and gravity models developed using surfer, a program by golden software. These models were then subjected to specific filters that helped in identification of structures responsible for permeability. These filters are: Band pass filter; applied to remove certain wavelengths, horizontal derivative filter; applied to image zones of sharp contrasts. Density inversion from results of simple Bouguer anomaly readings were generated by 3D inversion Grablox1.6 program that calculated synthetic gravity anomaly of a 3D block model. Comparison of gravity and resistivity models shows a good correlation of the magmatic intrusion and the TVA's. From this analysis, permeability controls for Menengai geothermal field were identified as follows: caldera rim faults that contribute mostly to deep vertical recharge, NNE-SSW faults along Solai graben, NNW-SSE faults along Molo axis, the southern fault extending towards Lake Nakuru and the uplifting dome in the central part of the caldera which enhance further fracturing within the caldera. This has led to a conclusion that there is enough permeability in Menengai geothermal field. The research and its findings therefore have shown that gravity should be used as a key technique rather than a preliminary tool in geothermal exploration.
Keywords : Menengai, Geothermal, Permeability

I. INTRODUCTION

The Menengai geothermal field is a high temperature field with a huge potential. The field is located within a region of intra-continental crustal triple rift junction where the Kavirondo Rift joins the main Kenyan Rift. The main rift is bounded by N-S running major rift scarps that depict different tectonic style on the two sides. The Menengai geothermal field covers the Menengai volcano, the Ol'Rongai volcanoes, Ol-Banita plains and parts of the Solai graben to the northeast.

This study will pay more attention on the Menengai Volcano. This part of the rift represent a breakaway section of major lithospheric detachments as evidenced by sharp scarps in the eastern side and gentle sloping one on the western side, Bosworth, Lambiase et al. (1986). The central ring structures of Menengai and Ol-Banita calderas represent collapses associated with emptying of shallow magma chambers underlying them. Menengai-Ol-Banita area is located within a region that is considered to overly a mantle plume, Burke and Dewey (1973). The surface is comprised of several eruptive volcanoes with caldera collapses and concentration of tectonic grid faulting (block and fissure faults) in its northern reaches which are characteristic of extension faulting associated with spreading (rifting) at crustal boundaries. Huge amounts of pyroclastics cover the slopes of Menengai and areas around Ol-Banita. These vary from ash fall, pumice rich ash deposits, welded pyroclastic flows (Ignimbrites) and some proximal lithic tuff outcrops adjacent to Menengai explosive caldera. The source of the pyroclastic eruptives is obviously the explosive eruption accompanying formation of Menengai caldera, Simiyu (2009).

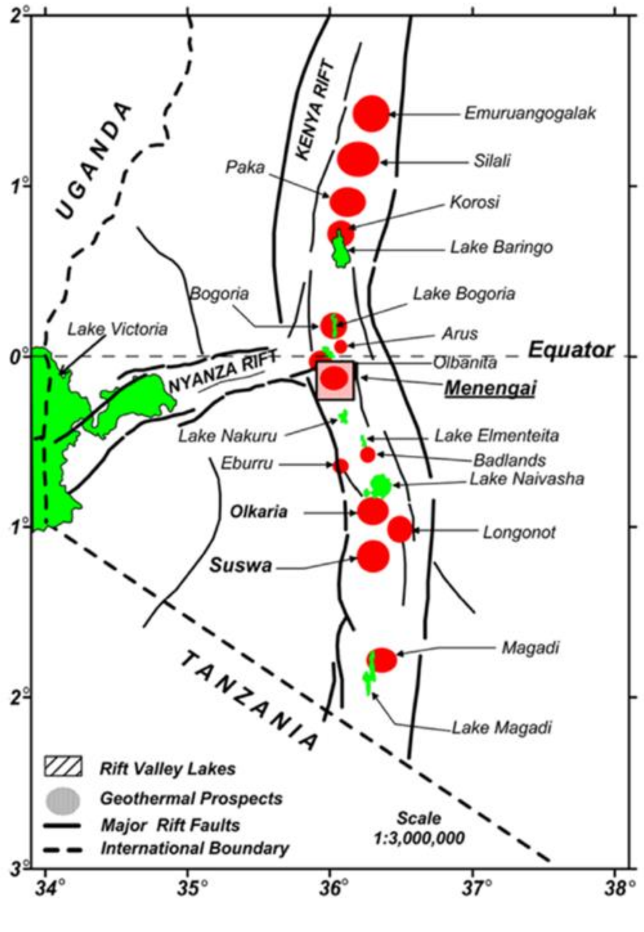

Figure 1: Map of Kenya showing location of Menengai, Simiyu (2009).

Geophysical exploration methods play a key role since they are the only means of locating deep seated structures that are responsible for controlling the geothermal system i.e. heat sources and possible conduits for geothermal fluids, the latter being the missing link in many areas and hence a let-down in geothermal development. Gravity technique is very powerful in this regard but much attention has always been directed towards resistivity and seismic methods and even when used most workers tend to concentrate mainly on identifying heat sources. Figure 1 is a map of Kenya showing the location of Menengai along the Kenya rift valley.

II. LITERATURE REVIEW

Geothermal is the thermal energy contained in the rock and fluid (that fills the fractures and pores within the rock) in the earth's crust. It is believed that the ultimate source of geothermal energy is radioactive decay occurring deep within the earth, Smith (1983).This chapter looks into detail the current geothermal trends in Kenya i.e. a short history from 1950's to date and the MWe realised so far. The chapter covers a short overview of permeability since this forms the basis of this study. Also discussed herein are the different geothermal exploration techniques namely: geophysics, geochemistry and geophysics. Theory and application of gravity method used as a tool for identification of permeable areas is also discussed in this chapter. Review of previous works done is covered in detail and deductions made revealing gaps that needed further study.

Geothermal resources in Kenya have been under development since 1950's and the current installed capacity stands at 676.8 MWe against an estimated potential of 10,000 MWe. Much of this comes from Olkaria geothermal field with an installed capacity of 674.4 MWe. A pilot plant in Eburru geothermal field produces 2.4 MWe. Development of geothermal resources in Kenya has been fast tracked with 335 MWe commissioned in 2014-2016 from conventional power plants and well head units. Production drilling at the Olkaria geothermal project for the additional 560 MWe power plants to be developed under PPP arrangement between Kengen and private sector is on-going. Geothermal Development Company (GDC) is currently undertaking production drilling at the Menengai geothermal field for 105 MWe power developments to be commissioned in 2018. Detailed exploration has been undertaken in Suswa, Longonot, Baringo, Korosi, Paka and Silali geothermal prospects and exploration drilling is expected to commence in year 2017 in Baringo – Silali geothermal area, Omenda and Mangi (2016).

2.1 Different Exploration Techniques

Geothermal energy exploration involves different disciplines namely; geophysics, geochemistry and geology. Under geophysics, there are different methods which include: magnetics, gravity, seismology and electromagnetism.

2.1.1 Geophysics

Geophysics is the study of physical parameters of the earth e.g. magnetism, density, seismicity and resistivity of rocks.

In geothermal exploration, magnetic and gravity surveys are employed mainly for mapping of geological structures. The most important applications are finding the depth and the location of concealed intrusives, locating dykes and faults, finding the depth to the basement. In particular, magnetic method is useful in evaluating paleo-magnetism and locating hydrothermally-altered areas while gravity on the other hand is employed to detect geological formations and lateral density variations. Different types of rocks in the subsurface have different densities, hence different gravitational forces.

Seismic measurements can be either active or passive. Passive seismic involve injecting waves into the ground and recording the energy that reflects back at different times and locations on the surface using geophone receivers. Processed seismic data can give information about subsurface geology, including rock types and fault structures. It can also be correlated with gravity to define more accurate velocity models which provide more accurate depth estimates, hence, useful while developing conceptual models and eventually locating drilling sites. A passive seismic method makes use of naturally induced micro-earthquake activities and can be used to delineate permeable fractures acting as a flow path for geothermal fluids, delineate the brittle-ductile zone, and also to monitor useful indicators in natural or induced reservoir phase changes during exploitation of a geothermal field, Simiyu and Keller (1998).

Electromagnetic techniques have proven to be very useful geophysical tools in geothermal investigations. This is due to the fact that the spatial distribution of conductivity in geothermal regions is not only determined by the host rock distribution, but is directly related to the distribution of the actual exploration target, hot water Berktold (1983). Two main methods are employed here namely Transient electromagnetic (TEM) and Magnetotellurics (MT).

2.1.2 Geochemistry

Geochemistry is the science that uses the tools and principles of chemistry to explain the mechanisms behind major geological systems such as the Earth's crust and its oceans. Geochemical techniques are an important and a useful addition to the hydrological, geological and geophysical techniques employed in geothermal energy development. Geochemical techniques are applied from the exploration stage to the plant operation stage of geothermal energy development.

Chemistries of the thermal fluids collected at the surface are used as indicators of fluid behaviour in the subsurface. Geochemical study of thermal fluids provides information on the origin, temperature, flow pattern and other characteristics of the subsurface fluids. Chemical reaction within thermal fluids is controlled by equilibration of chemical components in the fluids according to changes in temperature, boiling, variation in host rocks and other changes in physical conditions.

2.1.3 Geology

The role of geology in geothermal exploration is mainly for search of heat source and permeability. Geological mapping of the surface geology is used as proxy to the nature and condition of the heat source. In Menengai the age of the syn-caldera pyroclastics has been noted by many researchers, e.g. Leat (1983) published an age of 29,000±300 years for the older eruptives and 12,850 years for the younger ones. Geotermica Italiana Srl (1987) published an age of 14,900±900 years based on carbon dating of paleo-soils. An age of 1,400 years for the post-caldera lavas is published by Jones and Lippard (1979). Similar lava flows of equivalent freshness (lacking disturbances) like the Olkaria's Ololbutot lavas are dated around 180±50 years Clarke, et al., (1990). This young age of the rocks in volcanoes is an important indicator of an active magma system hence heat source.

Geological structures are in important for fluid paths and are good targets for well drilling. In Menengai surface data indicate that most important structures are N-S and NW-SE. These are related to regional tectonics. Result from current drilled wells proof this fact. For example well MW-01A encounters a NW-SE resulting in a very productive well. Geological structures are mapped using remote sensing and by traverses in the field.

Findings from these three disciplines; geophysics, geochemistry and geology are incorporated together to develop conceptual models for successful geothermal resources development. The key to the successful exploration, development (incl. drilling) and utilization of any type of geothermal system is a clear definition and understanding of the nature and characteristics of the system in question. This is best achieved through the development of a conceptual model of the system, which is a descriptive or qualitative model incorporating, and unifying, the essential physical features of the system.

III. DISCUSSIONS AND COCLUSIONS

The Bouguer anomaly map that was developed (Figure 2), shows an almost complete circular gravity low within the caldera associated with permeability and notable high gravity high in the central part of the caldera. The high amplitude gravity gradients in this map could indicate contact zones that separate this high gravity anomaly and the faulted zones. The dense body in the central part of the caldera coincide with the dome area. It is deduced that this anomaly represents a magmatic intrusion.

To perform terrain surface analysis, Band pass filtered maps were developed to filter low and high wavelengths and this slightly improved interpretation. A band pass filter of 50-3000 m was applied to the Bouguer data but little change occurred (Figure 3). Attempts to further interpret the data led to application of 100-3000m and 200- 3000 m filters (Figures 4 and 5) but this too didn't bring better resolution images. To overcome this huddle, regional effects had to be removed and a residual gravity anomaly map was constructed. The regional effects had magnified short wavelength anomalies to deep anomalies leading to wrong interpretations and therefore had to be removed (Figure 6). The resulting residual anomaly map filtered these effects leading to reduction in size of the highly positive anomalous body notable in the north North West orientation (Figure 7).

The importance of residual map is to remove the effects of Regional geology from the Bouguer anomaly map. The low gravity anomalies are associated to the axis of the caldera and Solai TVA to the NNE while the high anomalies are associated with dense magmatic bodies.

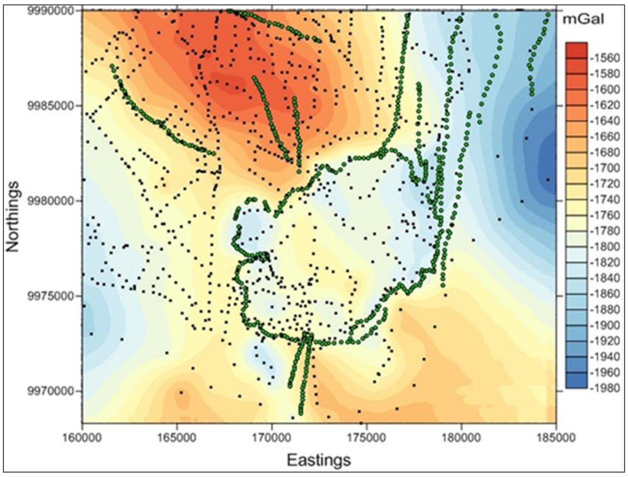

Figure 2. Gravity Bouguer anomaly map of Menengai Geothermal field. Black dots denote gravity sampling points.

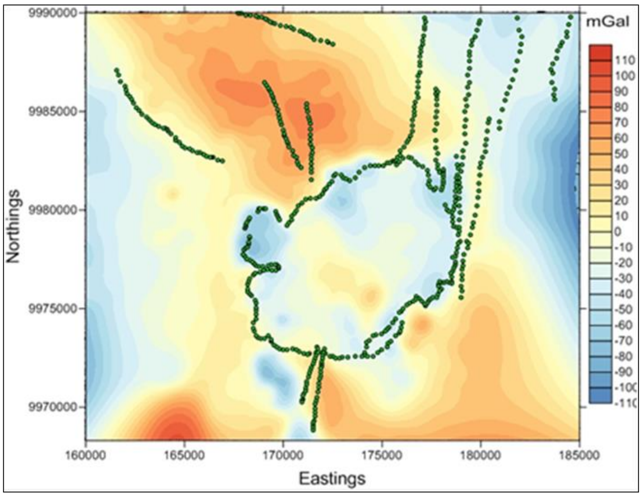

Figure 3. Band pass filtered Bouguer anomaly map of Menengai Geothermal field at 50 – 3000 metres.

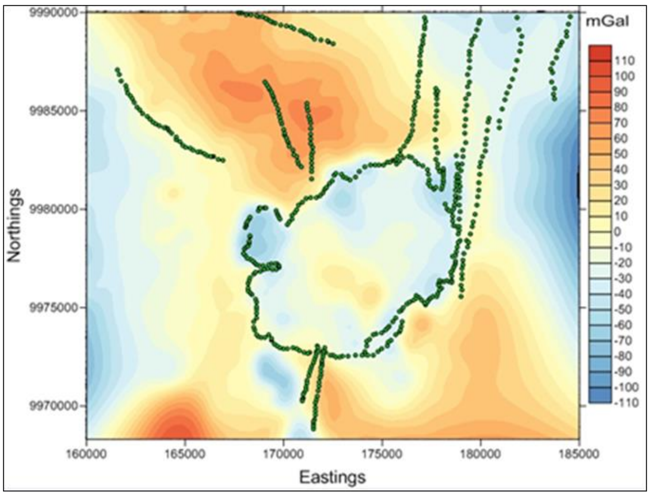

Figure 4. Band pass filtered Bouguer anomaly map of Menengai Geothermal field at 100 – 3000 metres.

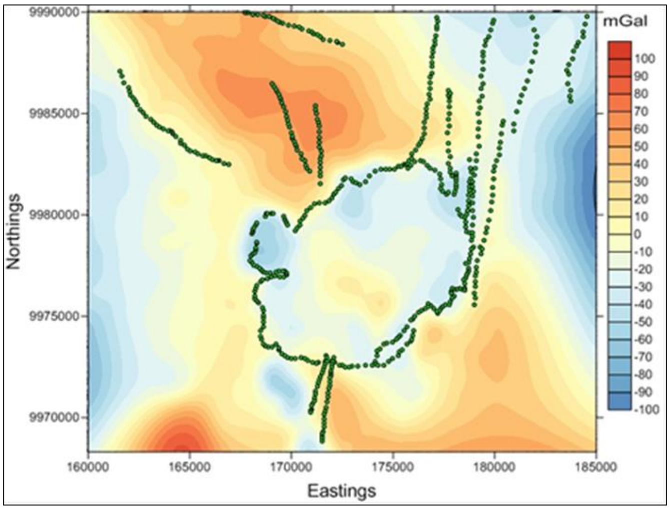

Figure 5. Band pass filtered Bouguer anomaly map of Menengai Geothermal field at 200 – 3000 metres.

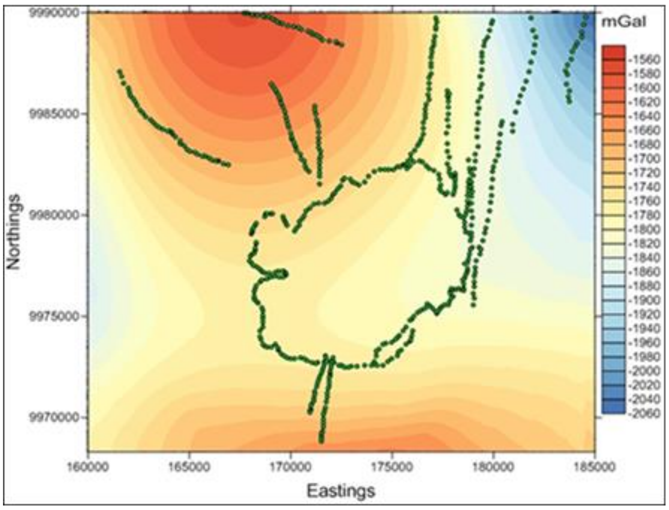

Figure 6. Regional anomaly map of Menengai Geothermal field.

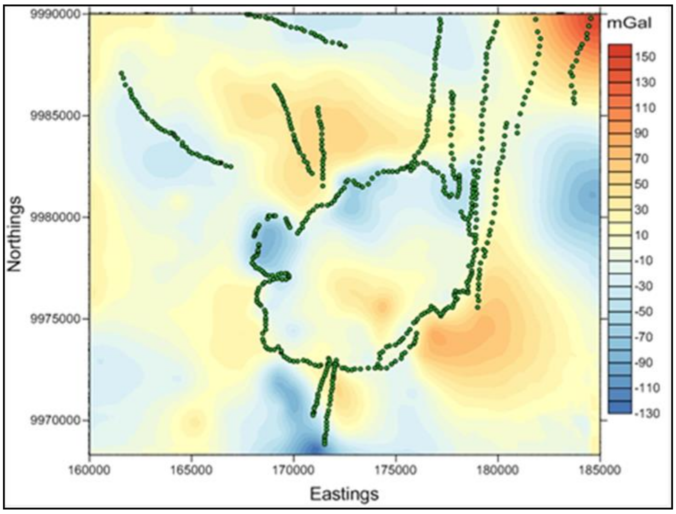

Figure 7. Residual anomaly map of Menengai Geothermal field.

To improve clarity and establish whether there is enough permeability, more terrain surface analysis were carried out. 200- 3000 m Band pass filtered anomaly map was subjected to horizontal first derivative filter. This filter allows for better delineation of contact zones by focussing mainly on the points of sharp gradients, thus delineating fractured zones (Figure 8). The same was done for the residual map and a map developed (Figure 9). These two figures show anomalous areas that are interpreted as local geologic features. The high amplitude gravity gradient which represents the major fault areas forms the basis of this research. These features are the highly fractured areas which are paths controlling fluid flow in and out of the caldera. The axis of the caldera is one clear area where geology is in complete agreement with these findings. The Molo TVA is another clear faulted area while the Solai TVA could not be captured by this filter.

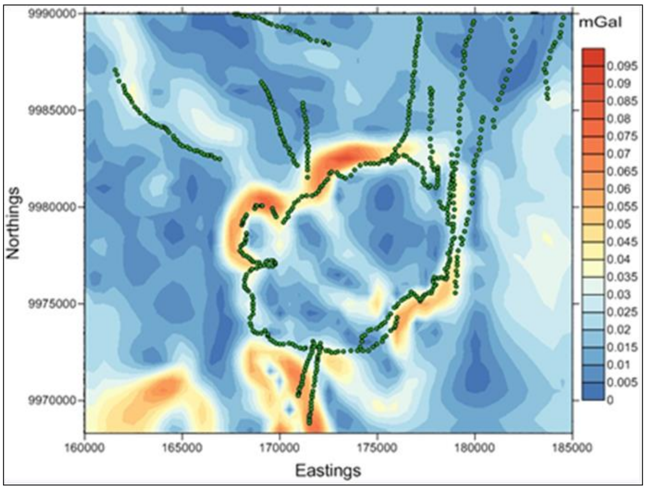

Figure 8. Horizontal derivative filtered 200-3000 Band Pass anomaly map of Menengai Geothermal field.

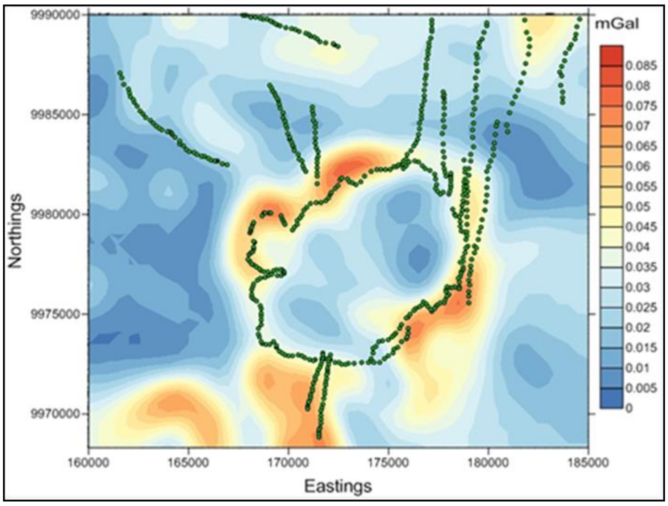

Figure 9. Horizontal derivative filtered Residual anomaly map of Menengai Geothermal field.

Figure 10 summarises the results of gravity survey in mapping subsurface density contrast to locate structures (low density lineament) that channel geothermal fluids at depth in Menengai geothermal field. When density is set to zero (0) during filtering, it enhances the contrast between negative and positive density boundaries at iso-dense contour of zero. The low density lineaments are fracture areas while the high density ones are intrusions. From this analysis, four groups of faults are identified, which include caldera rim faults that contribute mostly to deep vertical recharge, NNE-SSW faults along Solai graben, NNW-SSE faults along Molo axis and Southern fault extending towards Lake Nakuru.

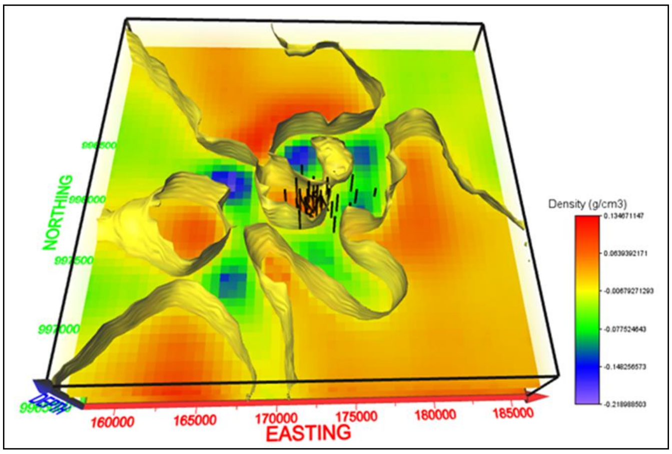

Figure 10. 3D iso-dense values at zero (0) to enhance structural boundaries.

This study has identified four main permeability controls for Menengai have been identified, these are: The axis of the caldera, Molo TVA, Solai TVA, Southern fault extending towards Lake Nakuru and the magmatic intrusion in the central part of the caldera. The caldera axis faults, Southern fault and the TVA's are conduits that facilitate fluid flow and therefore convective heat transfer while the magmatic intrusion was identified a permeability control due to tensional and compressional forces that would result from intruding magma. These forces are expected to have an impact on the host rocks creating new fractures. The fractures are seen to the depth of 3 km and this information is corroborated by the drilled wells where the production zone has been confirmed to be at a depth of 1.5 km to 3 km. From these interpretations of the Bouguer and filtered maps, it was therefore concluded that Menengai has enough permeability based on the well-developed fracture networks. The indication of good permeability and the presence of a possible heat source is therefore a good encouragement for continued geothermal resources exploitation in Menengai.

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