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# Mapping of Olkaria Intrusives by Integration of Geologic and Geophysical Techniques

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**ABSTRACT**

Olkaria geothermal field under Kengen's concession area is divided into 7 fields for easier resource management. These are Olkaria East, Central, Southeast, Northeast, Southwest, Northwest and Domes fields. Olkaria West field is under Orpower 4. The area under study occupies parts of Olkaria East and Southeast fields. It is bounded by coordinates 196000E & 200500E and 9900000N & 9903000N covering an area of approximately 15km$^2$.

The surface is partially covered by rhyolitic lava flows (Oloolbutot lava flow) and pyroclastics, the former being the younger unit. Several wells have been drilled in this area and the subsurface geology studied from drill cuttings obtained. The main lithological units are pyroclastics, rhyolites, tuffs, basalts, trachytes, syenitic and granitic intrusions. These intrusions are of importance in this study.

Gravity survey has also been conducted and the gravity anomalies studied and compared with the subsurface rocks obtained during drilling for and correlation in their respective densities. It is evident that gravity is influenced by the rock's porosity, saturation, mineralogy etc. The different rock units encountered therefore have different densities which can be determined by gravity measurements. For example, the densities of deep-seated rocks like intrusives generally have higher densities than the near-surface and loosely-consolidated rocks. This is because the intrusive rocks like granites are usually compact and have less porosity as compared to pyroclastics and shallow tuffs.

This paper seeks to determine the extent of the intrusive rocks by correlating Bouguer anomalies form the gravity survey with the geological model formed from geology well logs.

## 1. INTRODUCTION

The area described in this paper covers an area of about 15km$^2$ and includes part of Olkaria East and Olkaria South East fields. The Olkaria South east field is still in the early stages of exploitation with about 20 geothermal wells drilled whereas East field is almost fully developed. Geological data used in this study was collected during drilling of the wells and modeled to give a geological model. Gravity data was collected, analyzed and the final Bouguer anomaly plotted on a contour map.

The two datasets were then compared and interpreted and forms the basis of this study.

## 2. GEOLOGICAL SETTING

(Omenda, 2000) divided the GOVC rock types into six major categories; the Proterozoic basement formation, pre-Mau volcanics, Mau tuffs, plateau trachytes, Olkaria basalt and upper Olkaria volcanics. The pre Mau volcanics, comprising of basalts and ignimbrites of unknown thickness is underlain by Mau tuffs. The latter are absent to the east of Olkaria Hill due to the high dipping angle fault passing through the Olkaria Hill. The surface geology in Olkaria geothermal field is dominated by rhyolitic lava flows and pyroclastics. The youngest lava flow in Olkaria is the Oloolbutot lava flow which erupted 180 ±50 yrs BP.

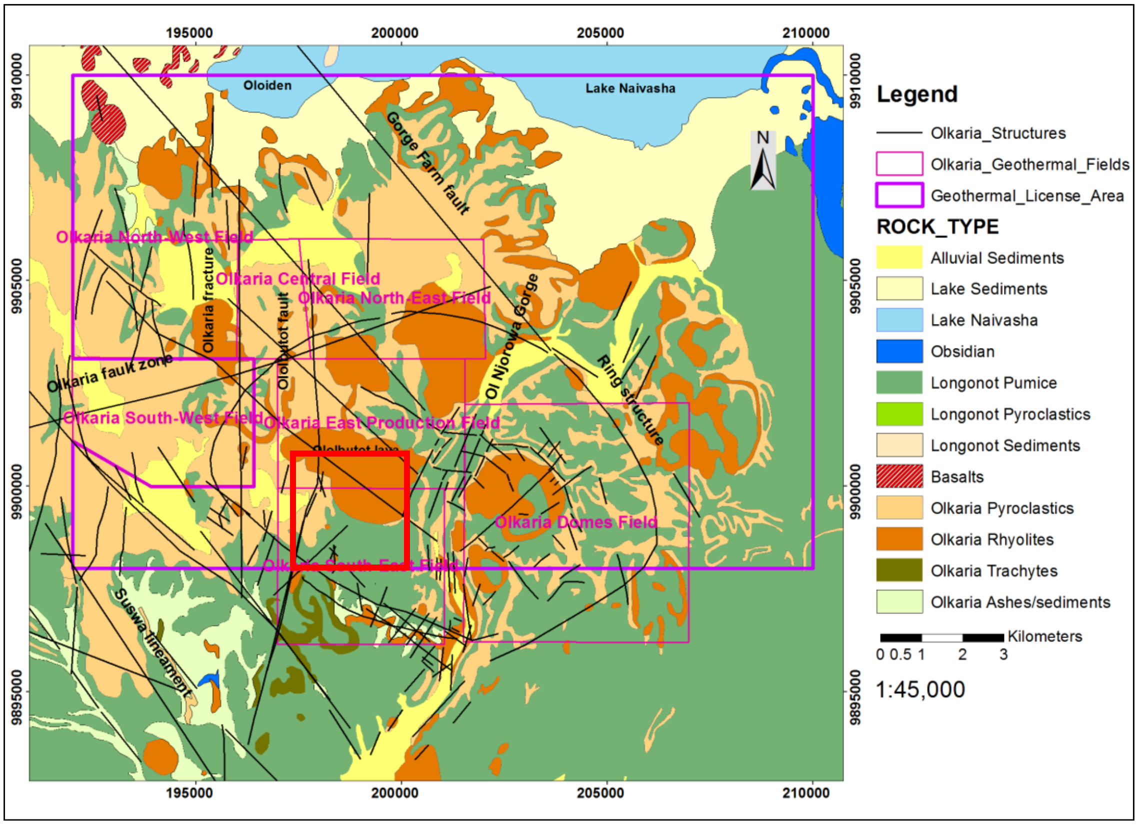


**Figure 1: Map showing the surface geology and the structures in the Greater Olkaria geothermal area. (Study area in red). (Munyiri, 2016)**

## 3. METHODOLOGY

### 3.1. The gravity method

#### 3.1.1. Basic theory

The basis of this method lies squarely on Newton's 2nd Law of motion and his Universal Law of gravitation. The former states that the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object. i.e.

$$a = F_{net}/m$$

If the acceleration, a, is in the vertical direction, then it is due to gravity, g. Therefore,

$$g = F_{net}/m$$

This can be rewritten as;

$$F_{net} = m \times g$$

Where;
g is the acceleration due to gravity,
Fnet is the net force and
m is the mass of the object.

Newton's Universal Law of gravitation states that particles/objects that possess mass exert a gravitational force of attraction on each other. This force of attraction is directly proportional to the product of the masses and inversely proportional to the square of the distance between their centres. That is;

$$F1 = F2 = G \cdot M \times m/r^2$$

Where;
F is the force,
G is the gravitational constant,
m is the mass of the object,
M is the mass of the earth and
r is the distance between the two masses.

The two laws can be combined and rewritten as;

$$F = G \cdot M \times m/r^2 = m \times g$$

Therefore;

$$g = G \times M/r^2$$

The above equation illustrates that the acceleration due to gravity is directly proportional to the earth's mass and inversely proportional to the square of the radius of the earth.

The Bouguer gravity anomaly is the end-product of gravity data correction. The Bouguer anomaly correlates with the lateral variations in density of the crustal rocks (Rivas, 2009). This means that a high density feature in a low density medium should give a positive Bouguer anomaly and vice versa (Rivas, 2009). Take an example of a granitic intrusion emplaced in a trachytic formation. The granitic intrusion is denser than the trachyte. For this reason, we expect to observe positive or higher Bouguer anomalies in areas where the intrusion in present. This explanation is illustrated below.

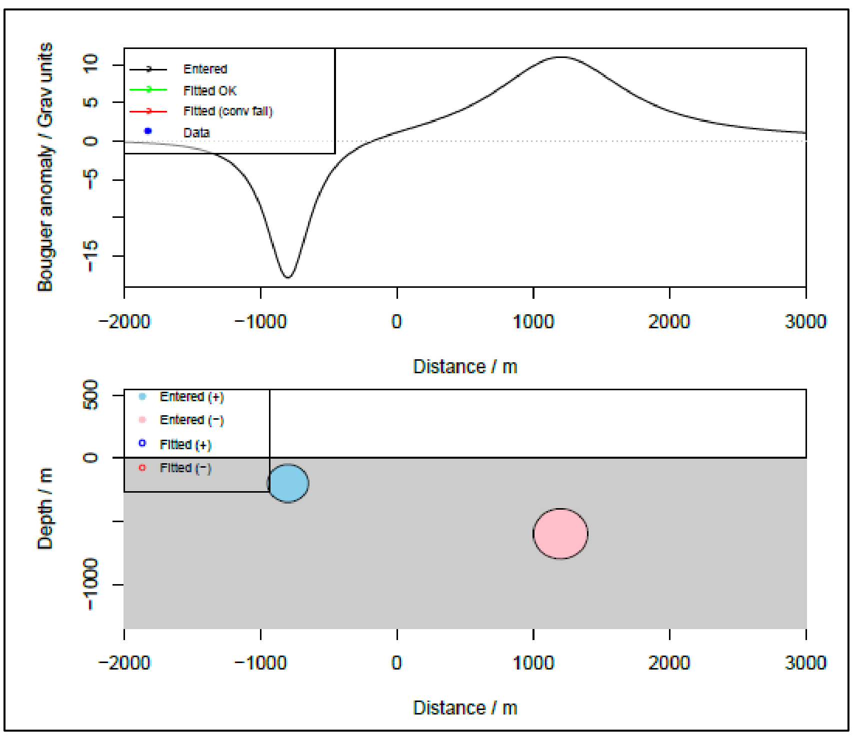


**Figure 2: The lower panel shows a cross-section through the ground. The circles represent denser (right) and less dense (left) regions. The upper panel shows the gravity that might be measured at the surface (Pumphrey, 2014).**

### 3.2. 3D Geological modelling

Rock samples were collected from every well during drilling and subjected to a number of tests to describe their properties. The first test was observation under a binocular microscope. This was done to identify the physical properties of the rock i.e. colour, texture, mineralogy, alteration intensity etc. Thin sections of the rock cuttings were also analyzed on a petrographic microscope to confirm the rock type and identify the alteration minerals that could not be identified under a binocular microscope. The geological data, i.e. the rock types were modeled using a software (RockWorks 16) to produce geological models as shown in figure 4. Figure 3 below shows the wells studied and their respective trajectories.

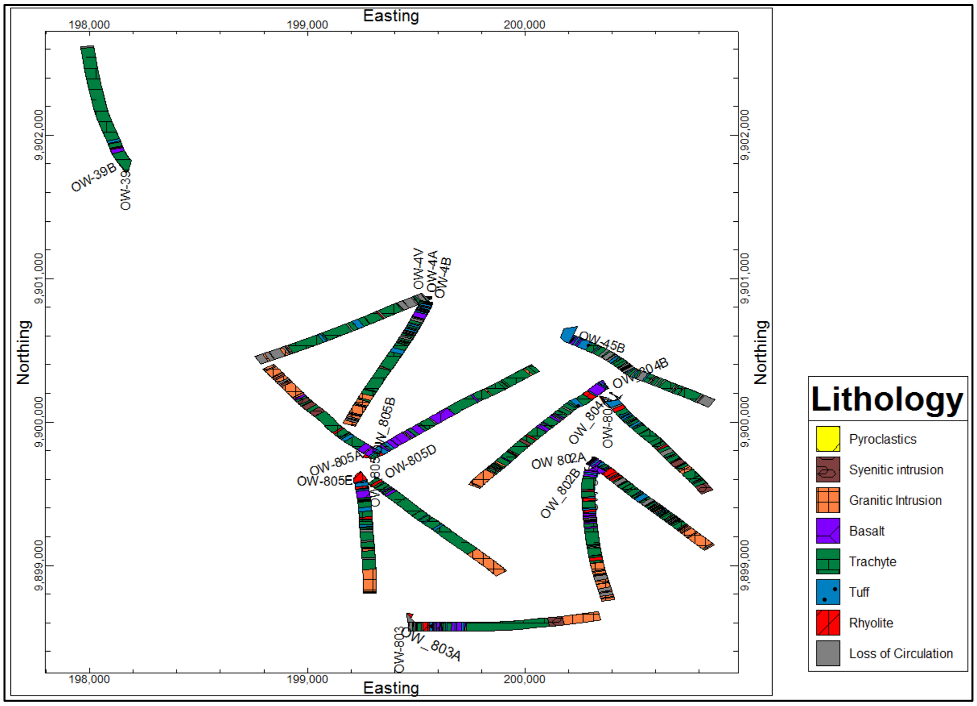


**Figure 3: Map showing the location of the wells and their respective trajectories**

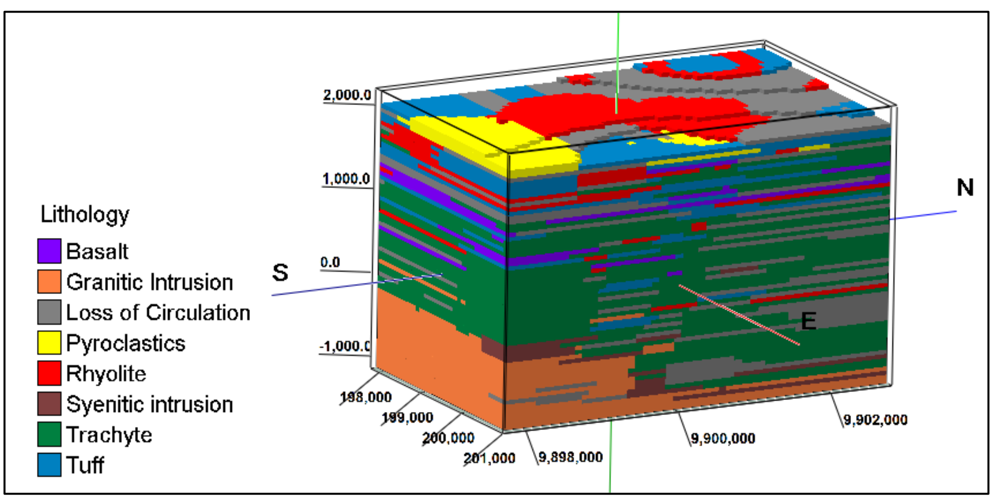


**Figure 4: 3D solid geological model of study area.**

## 4. DATA ANALYSIS AND RESULTS

### 4.1. Geology

The 3D geological model was built by modelling the rock types encountered during drilling of geothermal wells. The general stratigraphic sequence observed from shallowest formation to the deepest is

Pyroclastics
Rhyolite
Tuff
Basalt
Trachyte
Intrusions

The common intrusions encountered are granitic and syenitic intrusions. In areas covered by the Oloolbutot lava flow, the rhyolite lavas are younger than the pyroclastics and therefore are encountered before the pyroclastics. A second layer of rhyolite lava is found beneath the pyroclastics. Tuffs occur intercalated with basalts and trachytes but the trachytes form the bulk of the reservoir rocks. The intrusions occur as dykes and sills. However, no detailed study has been done to ascertain the extent of the intrusion but preliminary studies indicate a granitic intrusion of batholithic dimensions. These rock layers are represented in the simplified stratigraphic column below.

| | |
|---|---|
| | Pyroclastics |
| | Rhyolite |
| | Tuff |
| | Basalt |
| | Trachyte |
| | Syenitic Intrusion |
| | Granitic Intrusion |

**Table 1: Simplified stratigraphic column**

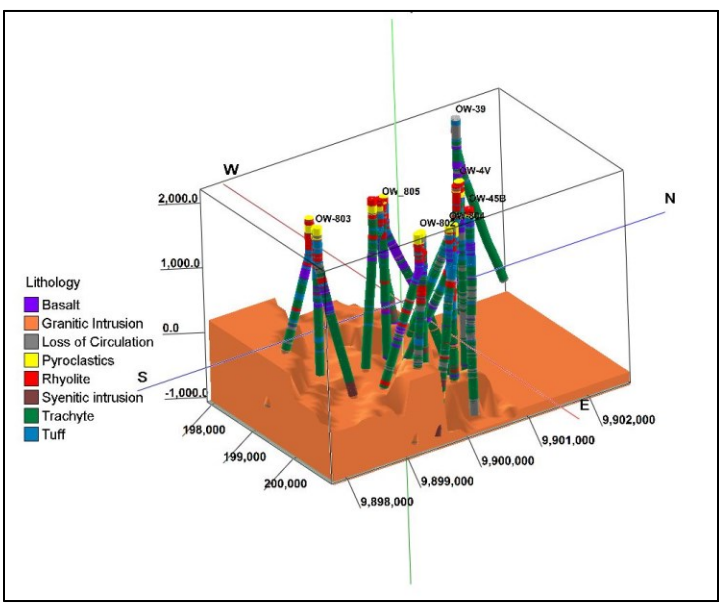


**Figure 5: Geological model showing the granitic intrusion and 3D striplogs of the geothermal wells.**

Figure 5 shows a modeled granitic intrusion together with well striplogs and their respective trajectories. The geometry of the intrusion is such that it appears at a much shallower depth towards the southern end at wells 803 and 805 and deeper towards the north at well 39.

Figure 6 is a geological cross section of the study area cutting through wells in well pads 803, 805, 4 and 39.

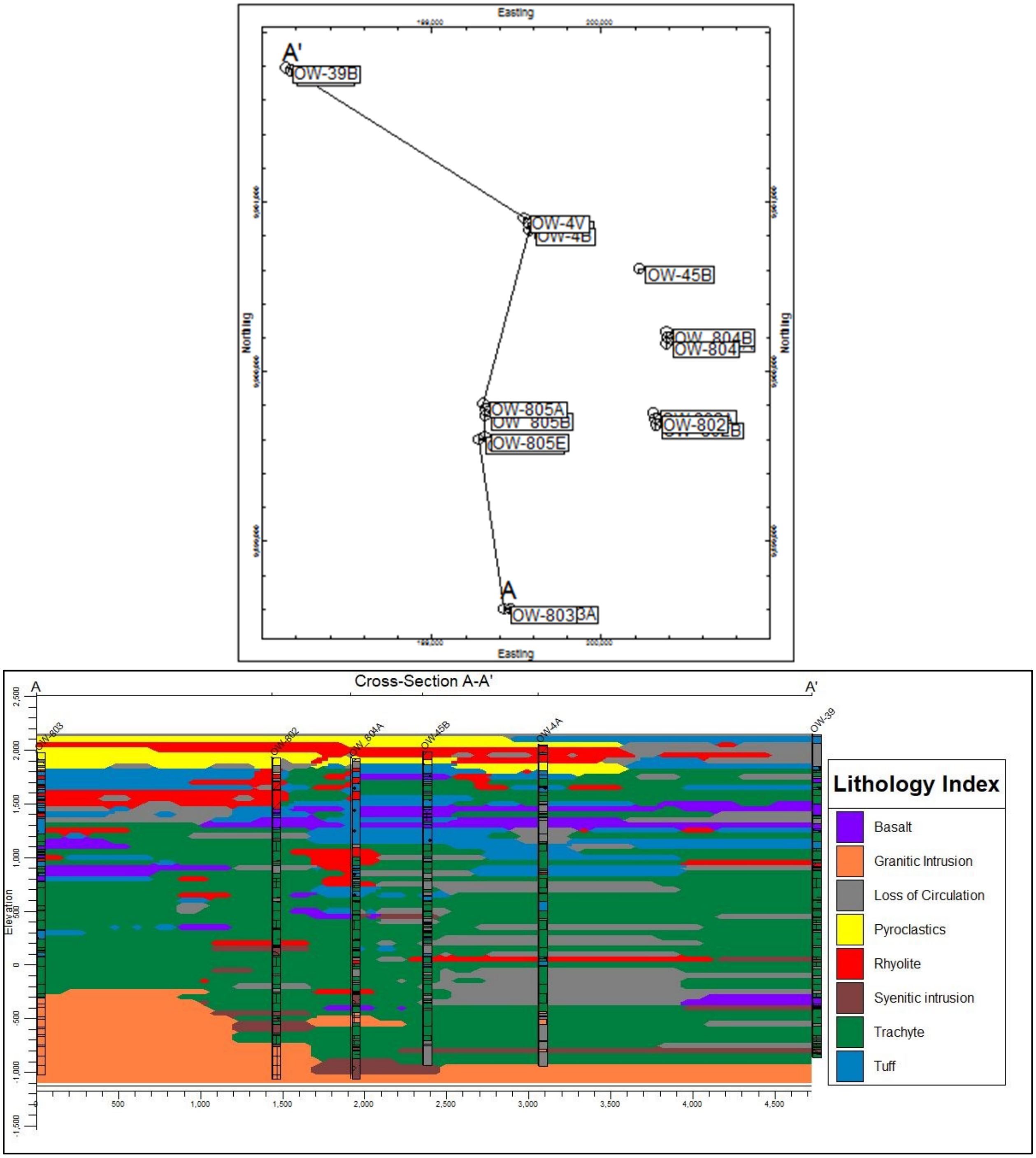


**Figure 6: Cross section A-A' through wells 39-4-805-803.**

The cross section above shows the granitic intrusion covering a larger portion towards the South at well 803 and reduces towards the north at wells 4 and 39.

### 4.2. Gravity

A total of 118 gravity points were used for this particular study. The figure below shows the location of the data points.

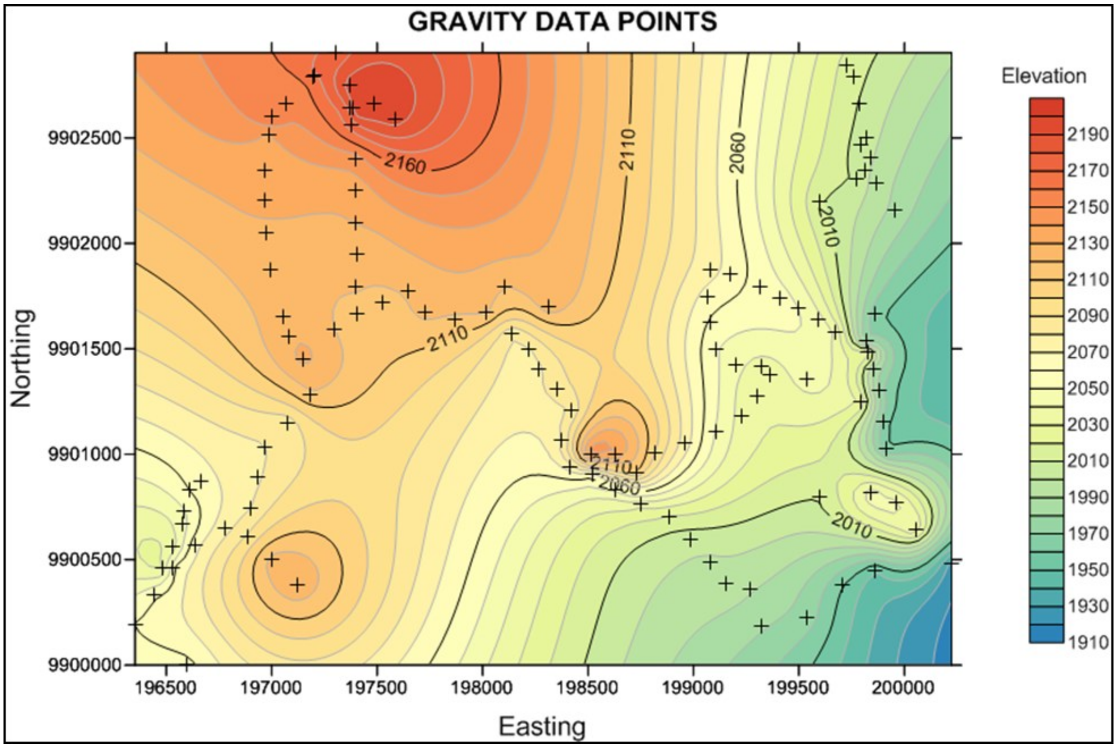


**Figure 7: Map showing the gravity data points.**

Generally, the area shows a largely negative Bouguer anomaly. The negative lows reach a minimum of -1883mGal while the gravity highs reach a maximum of -1733mGal. The highs are concentrated on the Western part of the study area. This area is centered over the locations where the granitic intrusion was shallowest.

Local density highs are associated with granitic intrusions and are clearly evident in areas where drilled wells encountered these intrusive rocks.

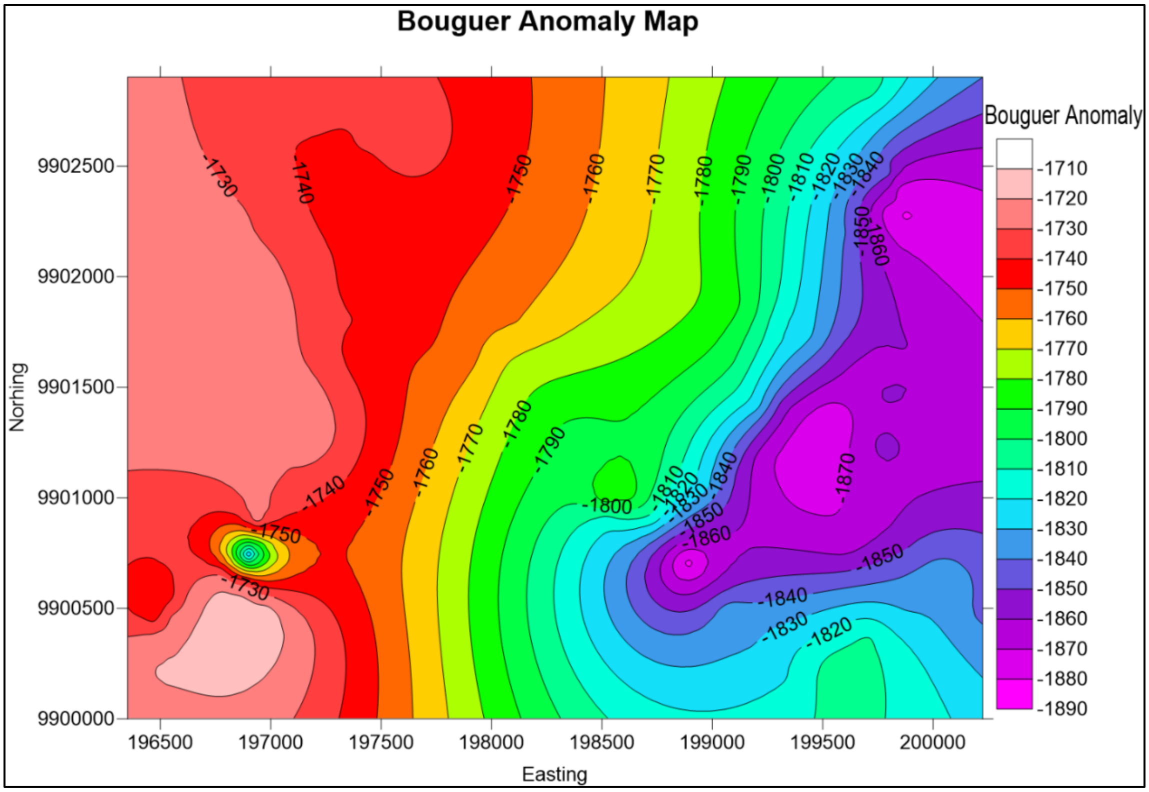


**Figure 8: Bouguer anomaly map**

A region of relatively high density is noted towards the western side of the map. This area covers areas occupied by some wells in the East Field and wells in the South East field.

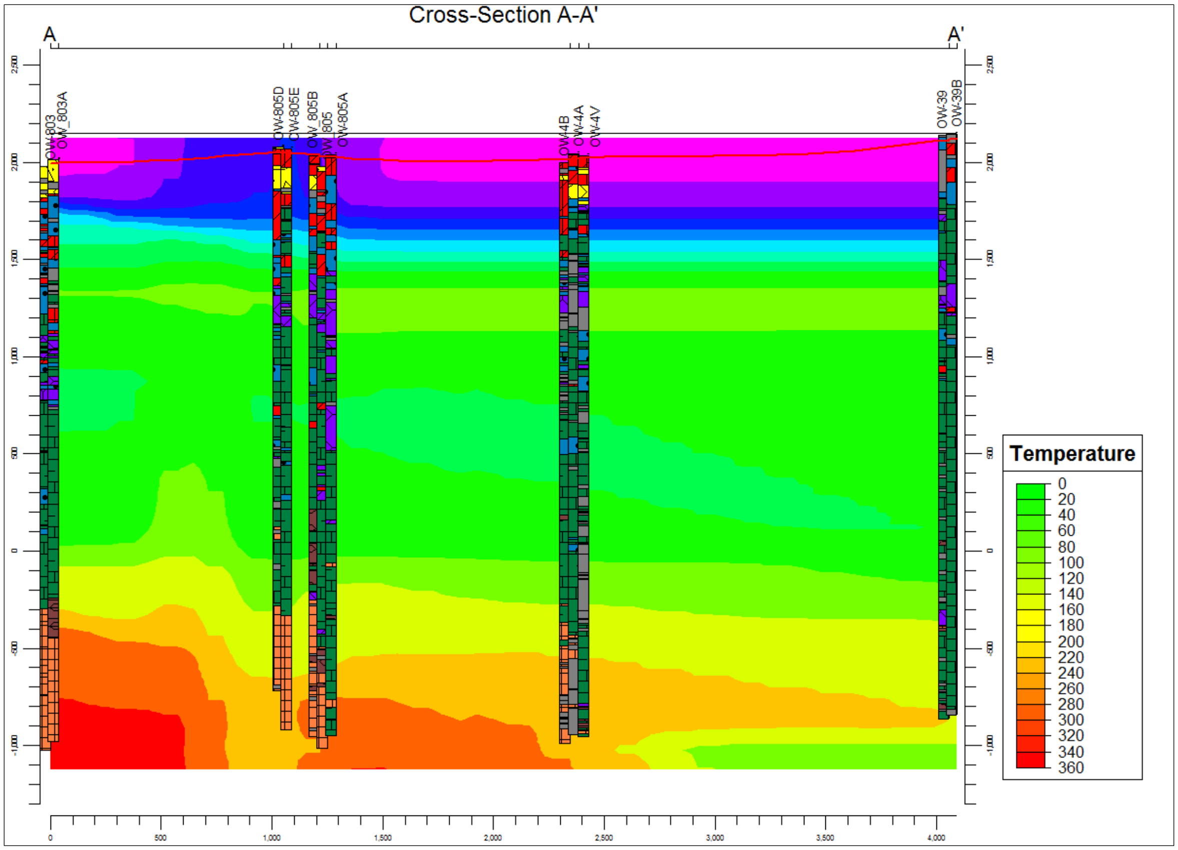


**Figure 9: Temperature cross section appended with well geology.**

The figure above shows elevated temperatures where the granitic and syenitic intrusion occurs. This demonstrates the importance of studying these intrusions and delineating their extent.

## 5. DISCUSSIONS AND CONCLUSIONS

From this study it is evident that the geology based model is consistent with geophysical data. The Bouguer anomaly is generally centered over the areas where the granitic and syenitic intrusions were shallowest. Gravity variations are as a result of the different lithological units which have different densities. The intrusions are compact, massive and denser than the other lava rocks which are relatively more porous. These porous rocks include the Tuffs and trachytes. The lava rocks also occur as thin intercalations.

It is recommended that more gravity surveys be conducted to the western side of the study area to determine the extent of this feature. 3D gravity modeling should also be undertaken in order to get the precise geometry of the intrusion to guide in future siting of geothermal wells. It has been proven that these intrusions provide heat to the geothermal reservoir and therefore defining its geometry goes a long way in making informed decisions in siting and drilling of geothermal wells.

The rock samples should also be analyzed for their bulk chemistry and the results displayed graphically for rock classification. The total alkalis ($Na_2O+K_2O$) is plotted against the silica ($SiO_2$) content on the TAS diagram to identify the rock type.

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