

Precise Microgravity Monitoring In Olkaria Domes

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ABSTRACT

Microgravity Monitoring involves measurements of small gravity changes with time over cross network of stations with respect to the fixed base. The changes in time caused by production and reinjection was detected based on the base reference data. The changes is valuable tool for mapping the redistribution of subsurface mass that is associated with exploitation of geothermal reservoir with time; hence gravity changes enables the characterization of subsurface processes. The gravity and GIS survey teams, work together with the aim of obtaining relative elevation data for each measurement at the same time on the benchmarks for unambiguous interpretation of the results

Olkaria Domes field is a high temperature two-phase water dominated geothermal field located in a hilly topographical terrain to the south east of Olkaria East production field.

Microgravity monitoring was first initiated in Olkaria East production field in 1983 to monitor the effect of mass balance due to withdrawal and reinjection. The monitoring was done over the network of benchmark stations with respect to fixed base station. Utilization of production wells in Domes field started in 2014 when 140MWe Olkaria IV power plant was commissioned for operation with addition of an average of 48.7MWe from wellheads. Olkaria domes will also host Olkaria V power plant under construction with expected output capacity of 170MWe. The Olkaria Domes field has the highest production well OW921A in the entire Olkaria Geothermal field with the output capacity of 30MWe and temperature of about 330°C.

The microgravity monitoring done in May and December 2017 in the domes field indicated a good response in reinjection areas and decrease in the production areas especially around OW907.

1. Introduction

The Great Olkaria Geothermal Area (GOGA) is a high temperature two-phase water dominated geothermal field located about 130km North West of Nairobi. The topography is characterized by hilly terrain with an average elevation of about 2000m above sea level.

GOGA is divided into seven sectors; Olkaria East, North-East, Central, South-East, South-West, North-West and Olkaria Domes as shown in Figure 1.

Various geophysical surveys and monitoring campaigns including microgravity monitoring have been conducted in GOGA at various stages of its development. The geophysical survey and monitoring of Olkaria geothermal field was of assistance in understanding changes in the geothermal field. Where, microgravity monitoring was initiated in 1983 in Olkaria East field. This was carried out to monitor small gravity changes as a result of geothermal fluid withdrawal over time, across a network of stations with respect to a fixed base station.

During this early stage of development, microgravity monitoring, was used to evaluate the characterization of the subsurface mass balance effect with time, due to reinjection and production mass into and out of the geothermal reservoir, hence validation of mass balance associated with exploitation process. In subsequent years, maximum gravity changes showed a constant trend in time. The monitoring information correlated with production data from reservoir team and was used in the identification of zones for reinjection (Mariita, 2009)

Olkaria Domes production field is located in the southeast portion of the Olkaria East Production Field (Figure 1). Bounded by the ring structure in the eastern boundary and the Ol Njorowa Gorge in the western margin. Production from the Domes field started in the year 2014, with Olkaria IV Power Station, which is rated at 140MWe with a steam consumption rate of ≈ 600 tonnes/hour and Wellhead generating units producing an average of 48.7MWe as at May 2016. Currently, Olkaria V power plant is in the construction stage with the expected output capacity of 170MWe. The initial exploration wells were drilled in Olkaria Domes between 1998 and 1999 (Ouma, 2009).

The production field in Olkaria Domes emerged as one of the sectors for geothermal exploitation after a detailed geo-scientific study carried out between 1992 and 1997 which involved geology, geophysics, and geochemistry and heat flow measurements sections. From the initial data gathered, three-exploration wells OW901, OW902 and OW903 were sited and drilled between 1998 and 1999 (Ouma, 2009). All the three wells were successful and were able to discharge. This prompted advance geophysical techniques Magneto telluric (MT) and transient Electromagnetic (TEM) to be applied in Domes field for better imaging of the subsurface for further drilling which culminated in the drilling of three successful explorations wells as well and enabled the demarcation of the resource area boundary. Most of the wells drilled in Olkaria Domes have indicated success with some encountering high temperatures above 300°C (Ouma, 2009). It is noted that Olkaria domes remain one of the sector with highest production well OW921A in the geothermal fields in Africa as it stand with the temperature about 330°C and power output of above 30MWe.

Since commencement of exploitation in GOGA and addition of production wells, the reservoir data indicate a decline in pressure in some wells. The decline generally has been compensated by drilling and connecting make up wells in the field and reinjection of condensate and brine. Thereby stabilizing the system over the prolonged production periods beyond the expectations in the previous models.

The high production and reinjection of the fluids over a long period of time is a process with possible impacts to the geothermal system. This need to be observed for present and future management of the fields.

Therefore, microgravity monitoring of the relevantly new Domes production field will enable us to:

- i. Evaluate the effect of mass balance due to reinjection and extraction hence allows monitoring of the fluid movement during geothermal exploitation.
- ii. Investigate the subsidence, which may occur as a result of mass reinjection and extraction.
- iii. Identify areas where reinjection can be most effective to the production field.
- iv. Used for geometric and dynamic modeling of the reservoir

Good geothermal management practice in the world geothermal reservoirs like Waireki geothermal field in New Zealand, which has been in operation since 1958, has shown that the power plant can be sustained over a long period of time. The earlier studies outline the gravity changes in Waireki Geothermal field was due to net mass loss from the reservoir and vertical ground movement (Hunt, 2000).

2. Methodology

Precise microgravity monitoring involve taking repeated gravity measurements at specific established benchmarks points in the field. This is carried out at different times within a year with the aim to determine gravity changes between different survey cycles. The changes are expected be relatively minimal compared to regional gravity survey.

The survey methods used must result in high quality measurements of the data observed. The data reduction technique should incorporate gravity effects due to extraneous factors such as earth tides, changes and tares which is a sudden jump in gravimeter reading associated with vibration during transport (Hunt and Tosha, 1994).

2.1 Measurement

The microgravity measurements were done on sixty (60) observation benchmark stations (Figure 2) using CG-5 Autograv Scintrex Gravimeter, and the precise height leveling was concurrently acquired using the Trimble R8 instrument (Figure 3). The measurement followed a predefined network loop and networked to a reference station as illustrated in Figure 4.

The two-way measurement method was adopted to evaluate the instrumental drift and precision with an error of observation estimated to $\pm 10\mu\text{Gal}$ (Nishijima *et al.*, 2015). Two measurement reading time at each benchmark was 200 seconds, the first reading was 100 seconds and the repeat reading at the same benchmark was done with the same duration before moving to another station. This was enough time to help the meter attain stability to get more stable and accurate mean value. The gravimeter was well secured on transit from the office to the field in the meter box and from the vehicle to the monitoring benchmarks. At the monitoring station the meter was allowed to settle for about 3 to 5 minutes before operating for the readings. At least five benchmarks and a base station were revisited during a day's survey.

For all measurements, height of the meter were taken for height correction during data processing. Benchmark BM09 located about 8km North of Olkaria Domes production field was used as the reference station, while the benchmark OCD1 was used as the base station.

Measurements are related to a far reference station outside the production area of interest. Locating reference station too close to the production area causes serious ambiguities due to

the subsurface processes in the deep-seated mass/density may affect gravity measurements at both the reference and network baseline (Battaglia *et al.*, 2008).

Two measurements we carried out starting with a baseline survey in May 2017 and a repeated measurement in December 2017, following a biannual calendar.

3. Results

The results of the microgravity measurements are presented in Figure 5, Figure 6 and Figure 7 below, illustrating the initial baseline readings, repeated reading and the change model respectively. Where, the gravity changes in Domes production field show a good response in the field with very minimal changes observed.

There is notable increase in gravity towards the W, S, E, NE and NW side of the field, while to the North part of Domes, indicates low gravity value this is well illustrated in Figure 7 below. It was also observed that the gravity increase as much as +0.5 mGal in the reinjection areas and a decrease as low as -2.3mGal around OW907 in the production region.

4. Conclusion

There was a good response of the gravity measurements in the reinjection areas during this monitoring period. The reinjection areas are identified with wells OW901, OW902, OW911, OW906, and OW913. The response on the production area around OW907 and OW908 shows low gravity values an indication of mass deficit from the reservoir without adequate replenishing.

The gravity changes were consistent with pressure drawdown in the reservoir that has been reported in OW907 and OW908. It is evident from the result and observation that the rates of mass production to some extent is higher than the rate at which reinjection process replenishes the reservoir resulting to mass balance deficit. The negative gravity values as shown in the change model could be attributed to a mass deficit within the reservoir, on the other hand, a large positive gravity changes around the reinjection wells is due to an excess mass influx attributed to reinjection, steam displacement in the reservoir by infiltration of water from a shallow aquifer connected to geothermal reservoir and natural recharges areas.

Generally the Domes field experiences less mass deficit in the production field apart from area around OW907. Therefore, the main factor that can cause observed changes in the field are amount of fluid withdrawal, subsidence and shallow ground water variation. These observations might change in the succeeding monitoring when more wells will be in use for the operation of Olkaria V.

5. Recommendations

From the changes observed, more additional reinjection wells are needed in Olkaria Domes field in the regions with low gravity values, especially to the North of OW907 and East of OW914. This will help in addressing the effect of mass balance in the field. It recommended for deformation monitoring to be carried out for the entire geothermal field for settlement analysis due to ongoing drilling of wells, natural induce tectonic event in the Rift valley system, mass reinjection and extraction for proper management of the geothermal field.

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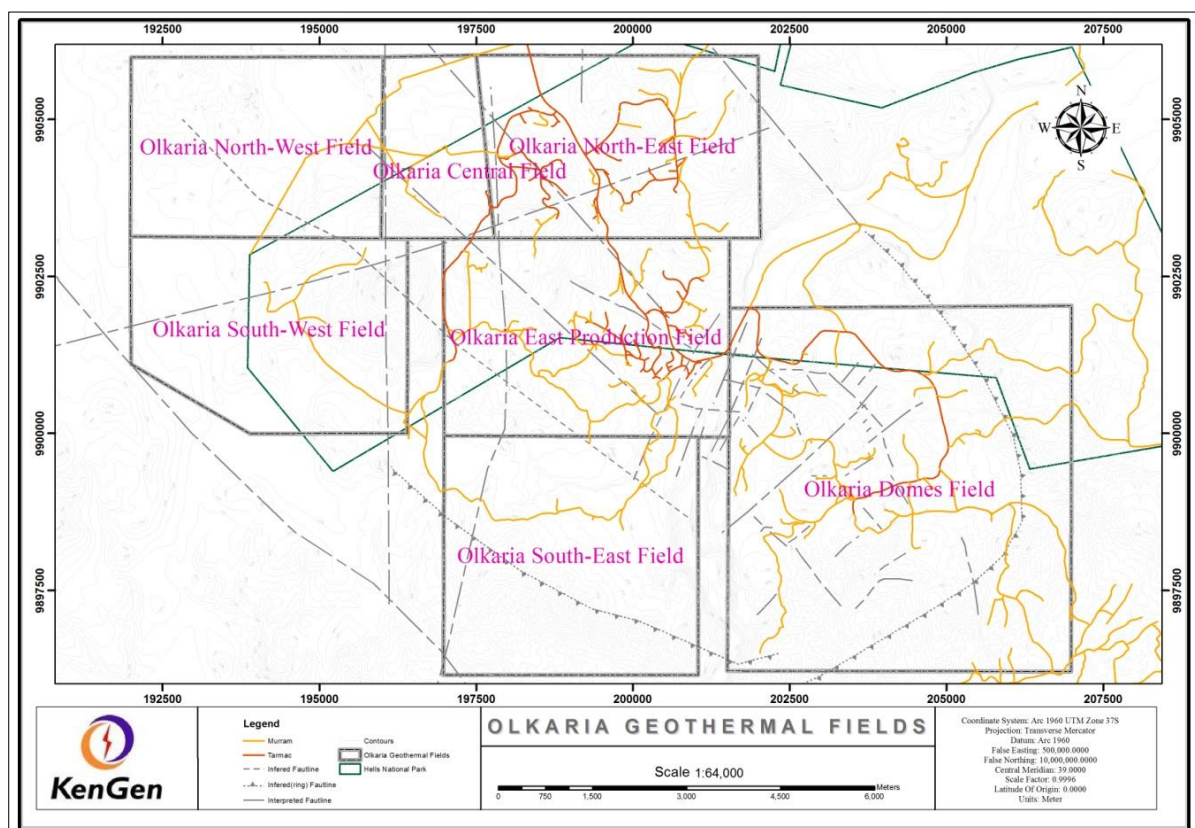


Figure 1: The Great Olkaria Geothermal Area Field Map

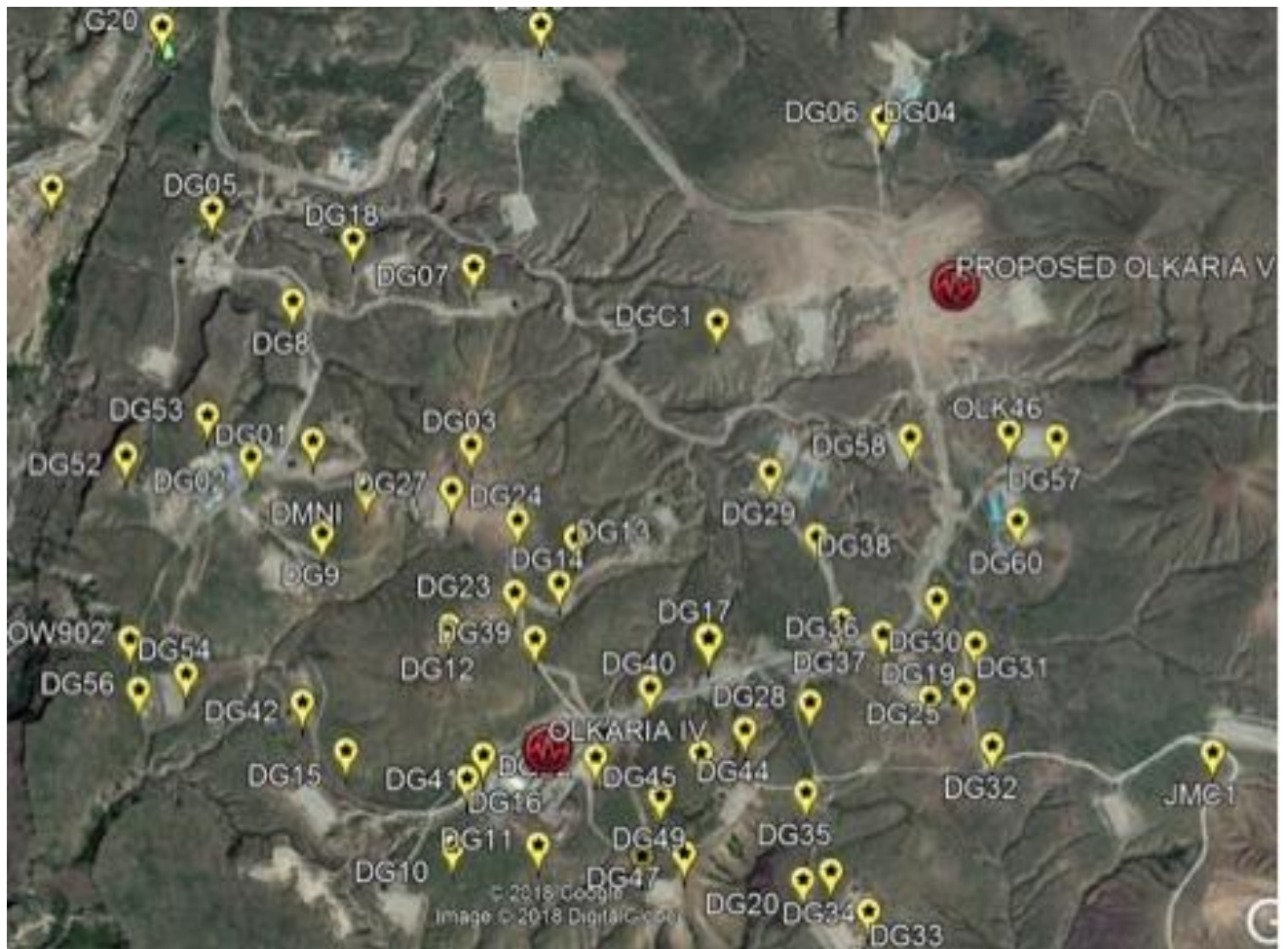


Figure 2: Gravity Benchmarks in Olkaria Domes



Figure 3: CG5-Gravimeter and Trimble R8 on the OCD1 Base Station

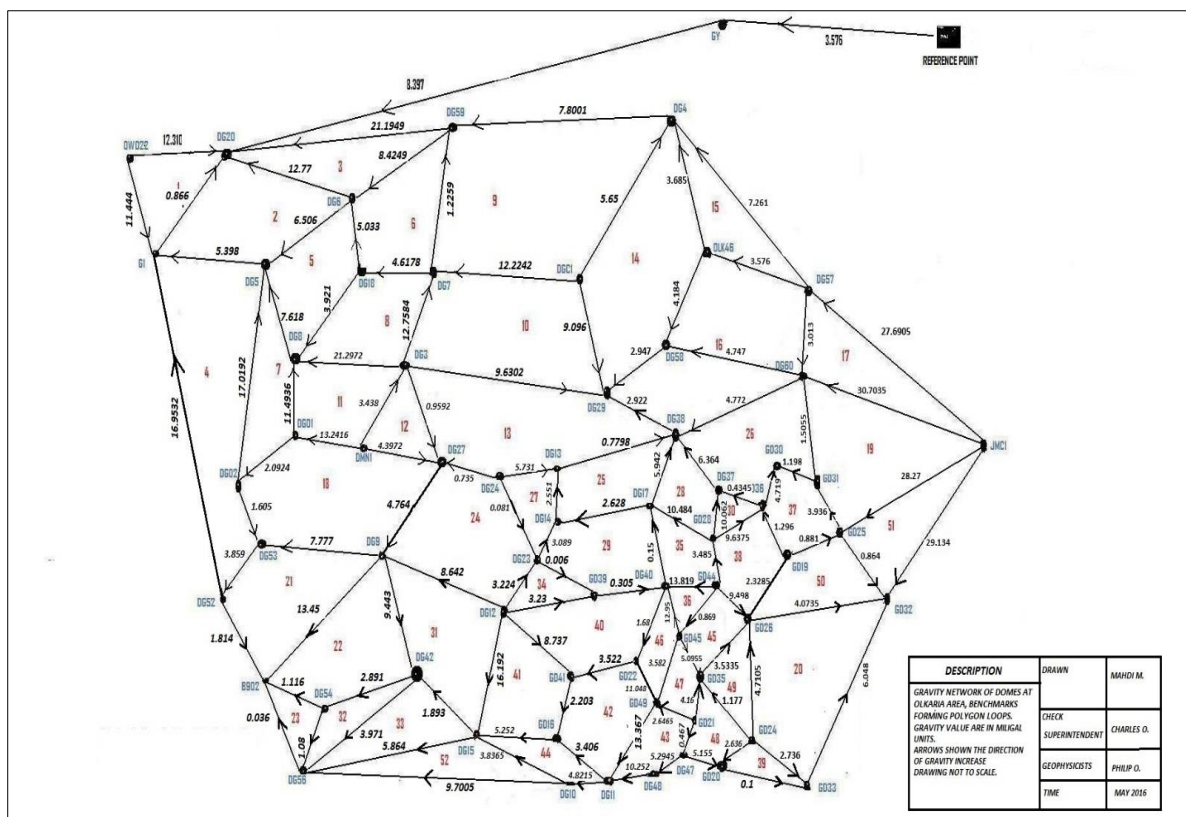


Figure 4: Domes Gravity Network to Reference station

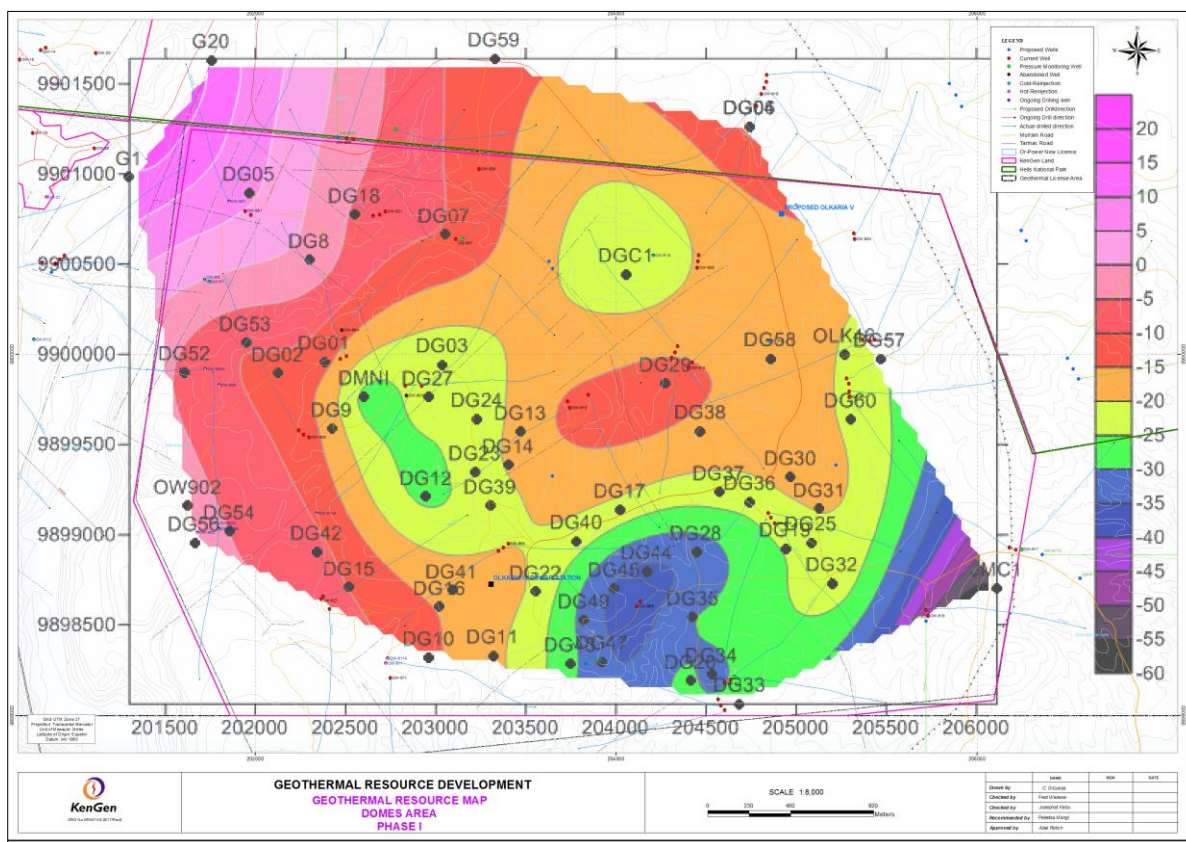


Figure 5: Initial Baseline Reading of May 2017

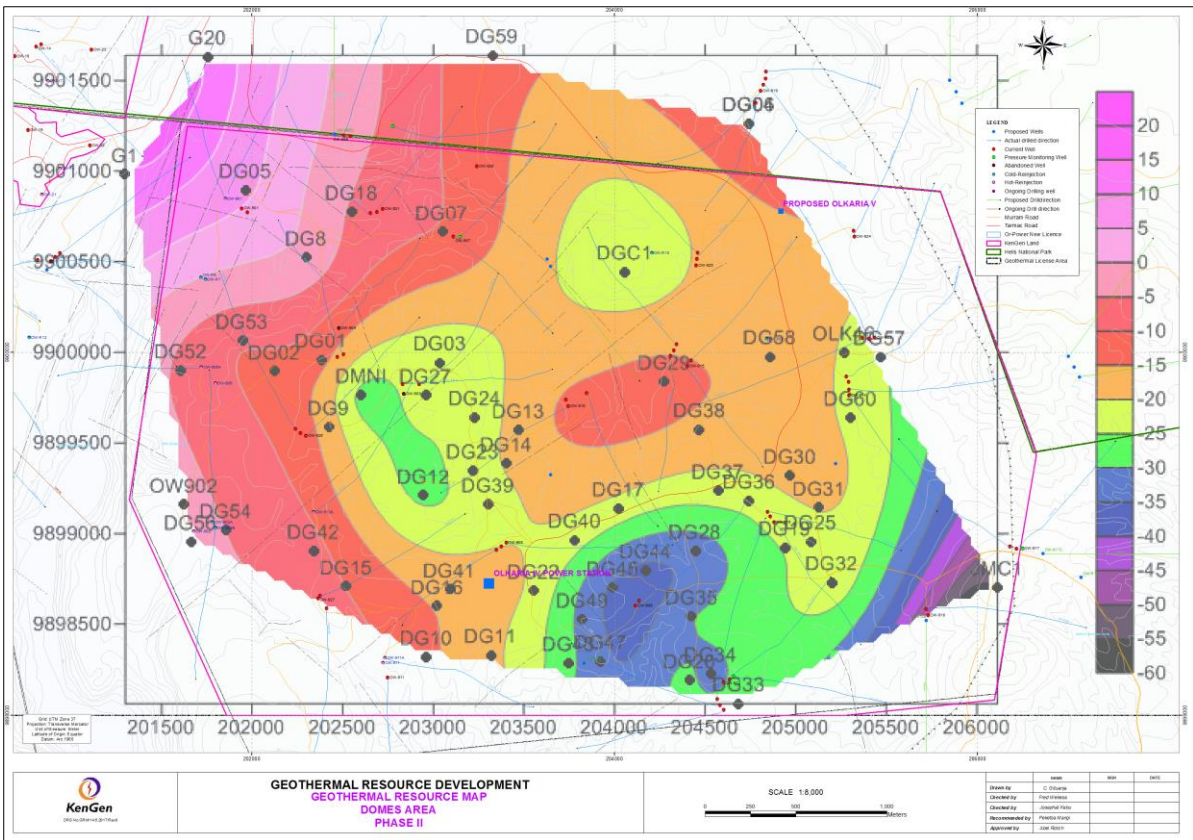


Figure 6: Repeated Reading in December 2017.

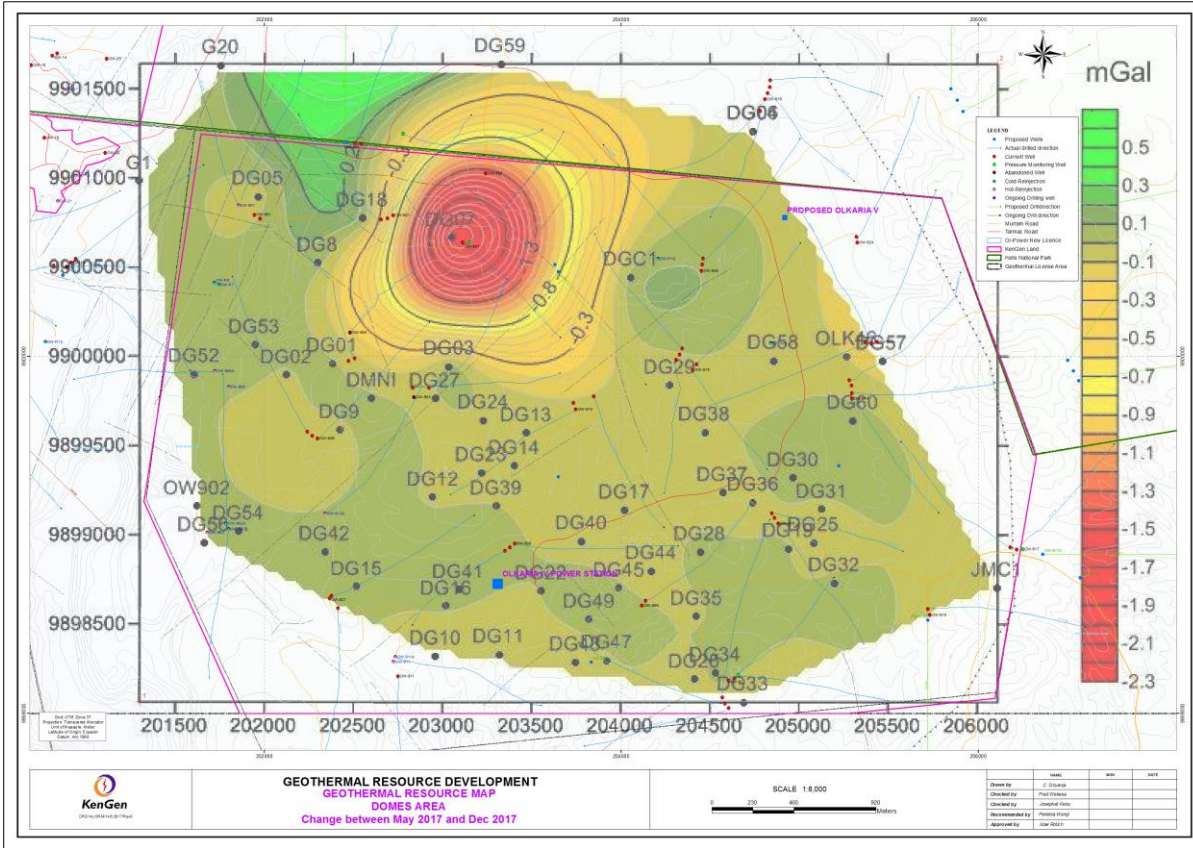


Figure 7: Micro-gravity Change Model between the Months of May and December 2017

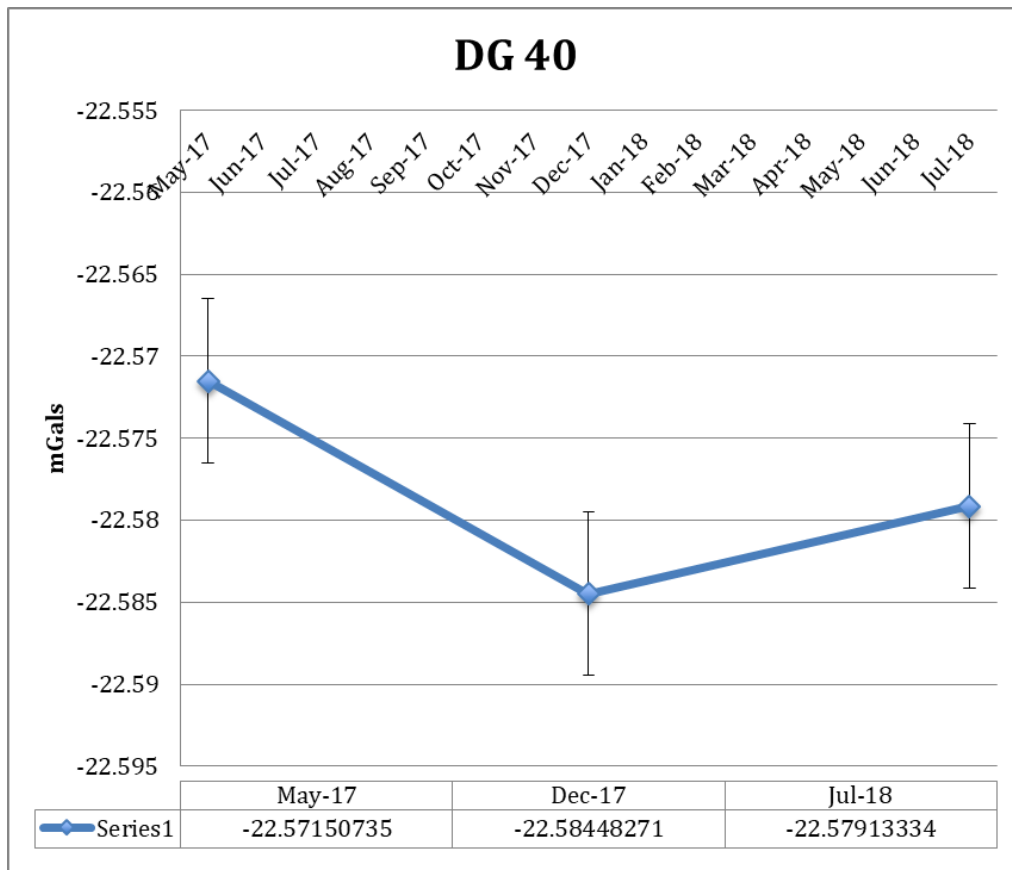


Figure 8: Gravity change over Benchmark DG40 with respect to reference station BM9

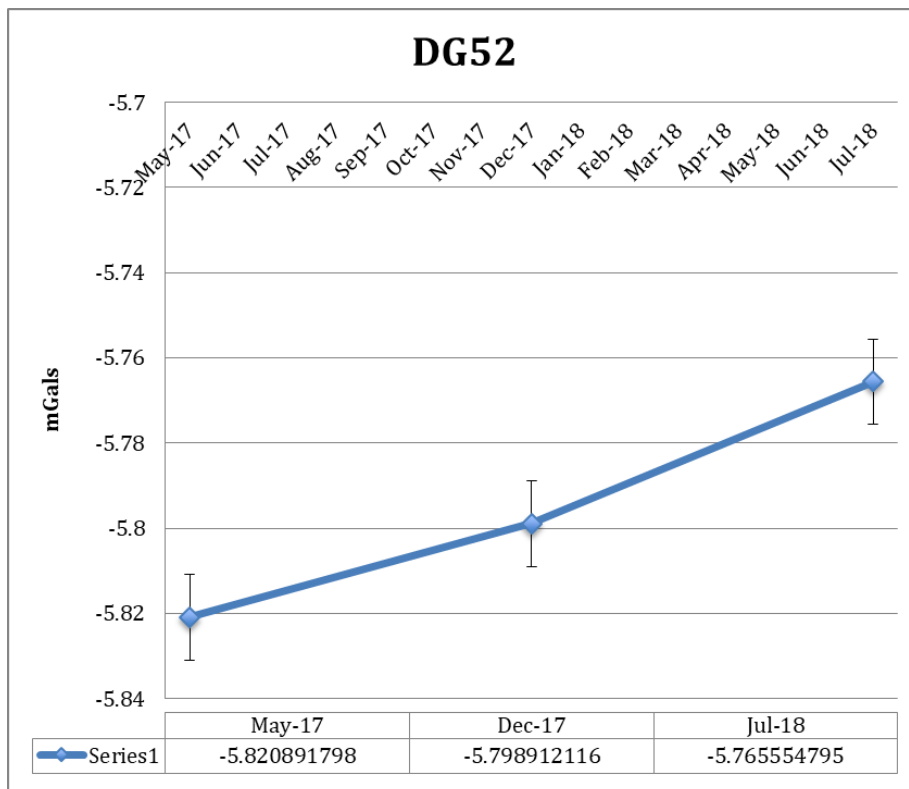


Figure 9: Gravity change over Benchmark DG 52 with respect to reference station BM9