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Magnetotelluric and gravity surveys in Ambado-PK20 geothermal prospect, Djibouti

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ABSTRACT

Ambado-PK20 geothermal prospect is one of the nearest geothermal system to Djibouti town (situated about 20 km away). This area is located on the groundwater table which supplies water to the city of Djibouti. Several studies have been carried out of this site in the past especially on hydrogeological investigations. This site has two major advantages over other geothermal sites in the Republic of Djibouti. The first one is because of proximity to the national electrical grid and the second its location on the plain of Djibouti city which constitutes the main aquifer. However the site does not present any hydrothermal manifestations at surface which are generally useful in characterizing areas of geothermal potential. Only some water wells located in this area show a thermal anomaly of about 61.4 °C. The main objective of work on this project was to locate eventual possible geothermal reservoir for geothermal energy production. To realize this, several geosciences studies, including geology, geochemistry and geophysics were carried out. Magnetotelluric (MT) and gravity were carried to delineate the boundaries of the geothermal system. 34 MT/TDEM soundings were acquired using the metronix equipment with period range between 0.001s and 800s. At the same time, to complement MT data, 66 Gravity measurements were collected with a Scintrex CG5 gravimeter. Combining MT and gravity data tends to reduce the usual intrinsic ambiguity on the conceptual model. A geoelectric structure model obtained by the 1-D MT surveys shows a resistive layer at the surface overlying a conductive layer and a deep resistive layer. Residual anomaly shows a central low gravity extending towards the south and delineated by a heavy body in the northern part of system.Based on interpretation of results from both 1D inversion MT and Bouguer map anomaly, we found that the conductive layer is defined by a low value of gravity. This correlation can be associated to the cap rock of the system that is an impermeable layer affected by hydrothermal alteration which is responsible in reducing the resistivity and the mass of the rock.

1. INTRODUCTION

The republic of Djibouti is located in the Horn of africa on the estern part of Africa continent.By geological point of view, the country is situated in the Afar depression wich is the result of a triple junction of tree rifts: Continental East African Rift, the golf Aden and red sea oceanic rifts (Jalludin, 2010). Such a particular geodynamical situation gives the area a remarkable position for the development of the geothermal energy. Effectively, the underground heat sources are expressed on the surface by numerous hot springs and fumaroles aremainly distributed on the Western part of the country and along the Gulf of Tadjourah ridge (Figure 1). In spite of the significant geothermal studies and the deep drilling explorations conducted over the years since 1970 geothermal energy in Djibouti is yet to be fully developed.

This paper summarizes the updated exploration work carried out over the PK-20 Ambado geothermal prospect (Figure 5). This site is part of geothermal prospects listed in the Republic of Djibouti (Figure 2). As part of a geophysical study of the PK20-Ambado area started in December 2016, two geophysical methods of MT (Magnetotelluric) and gravity were used.

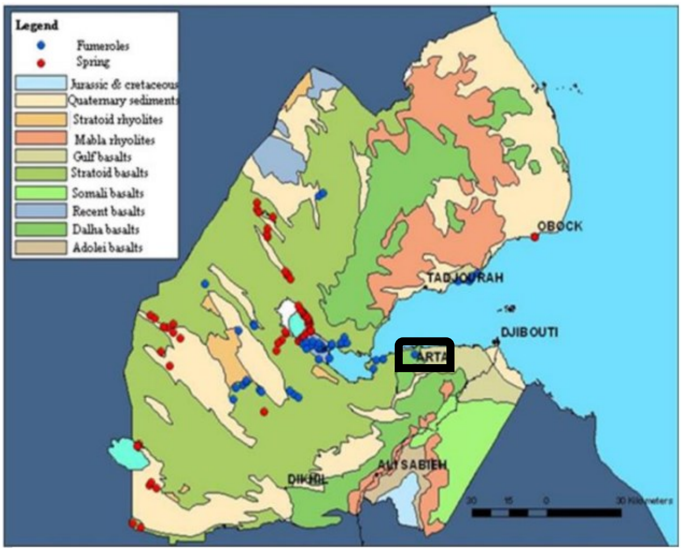
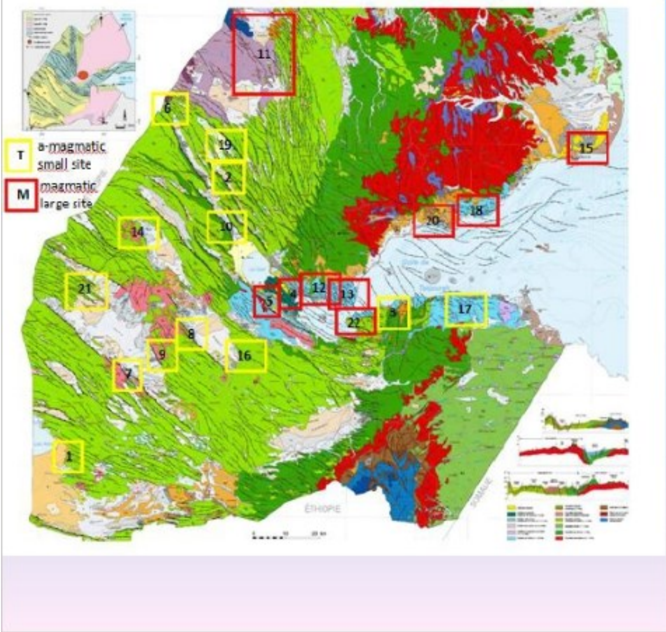


Figure 1: Geology map of the Republic of Djibouti (black square indicates the study area).



Geothermal sites	
1. Lake Abhe	12. Nord Ghoubbet (Afaî-Bolli Daar)
2. Sakalol	13. NE Ghoubet (Assa Foo)
3. Arta	14. Modayto (N Gaggade)
4. Asal Fialé	15. Obock
5. Asal gale-le-koma	16. Okililaeou (SE Gaggade)
6. Balho	17. PK 20-Ambado
7. Daggadé (W hanlé)	18. Roueli
8. Dimbir-Didir (W Gaggade)	19. Sakalol
9. Garabayyis (E Hanlé)	20. Tadjoura
10. Karapti-san	21. Agna-Galafi (NW Hanlé)
11. Manda Inakir	22. Sud Est Ghoubbet

Figure 2: Geothermal sites in Republic of Djibouti.

2. GEOPHYSICAL SURVEYS OF THE PK20-AMBADO GEOTHERMAL PROSPECT

2.1 MT method survey

The Magnetotelluric(MT) is a passive geophysical method that measures the variation of the natural electromagnetic field in orthogonal directions from the surface of the Earth to obtain an image on the variation of the resistivity under the ground. The method is based on the measurement of the currents induced in the ground by the temporal variations of the terrestrial magnetic field. The time-varying magnetic field and the associated electric field generated in the subsurface are measured simultaneously. Magnetic and electrical fields are measured on the Earth's surface in two orthogonal directions (Figure 3), Tikhonov (1950), and Kato and Kikuchi (1950), have pointed out that the electrical characteristics of the deep strata of the earth's crust could be determined from a combined analysis of geomagnetic and telluric field variations.

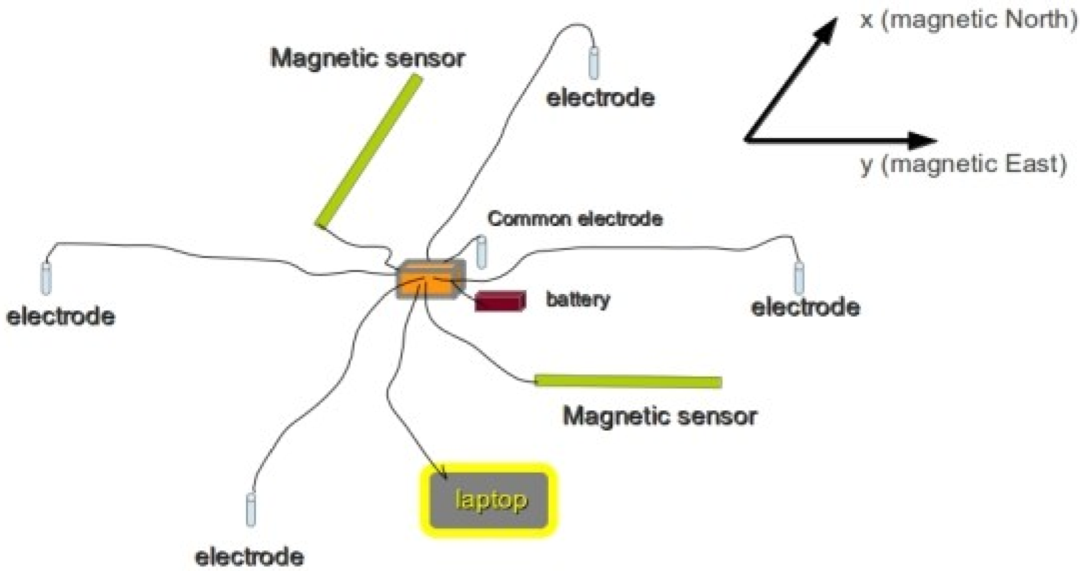


Figure 3: MT sounding configuration during the acquisition of field data.

<u>2.1.1 Acquisitions and processing the MT</u>

The Magnetotelluric method was used in the geophysical exploration efforts over the PK20-Ambado prospect in 2017. The MT data acquisition was done using metronix systems equipment. The system instrumentation included data logger, induction coils, non-polarizing electrodes, global positioning system (GPS), 12V battery, flash memory for data logging and telluric cables and magnetic. The other equipment used was the Metronix, which consisted of an ADU-06 type data logger, MFS-07e type magnetometers for measuring magnetic field induction and EFP-06 type electrodes for measuring the electrical component of the electromagnetic field.

A total 34 MT soundings are acquired by the two types of equipment during this campaign.

The processing step is crucial in the data treatment before inversion or interpretation and inference of geological structures. The quality of the underground resistivity model obtained will strongly depend on how these data are processed. Incorrect processing would systematically introduce an erronous result, that is, a geoelectric model far removed from the geological reality of the subsurface. To process data,the ProcMT software was used. The procMT software used in this reprocessing is an updated version provided by Metronix on september 19,2017.

2.1.2 Results and Discussions

After the processing of the MT data, some data from the surveys were very noisy because of electric lines of high voltage while others were of very good quality. This method indicates a heterogeneous medium, with the near surface 100m tending towards a resistant medium (Figure 4). Between 200 and 600m deep, the prospect is occupied by a conductive material especially in the central parts of the propspect. From 1000m down to a depth of 4000m, a resistant medium is indicated. The geo-electric model obtained by the method, the subsurface of the PK20-Ambado geothermal prospect suggests an area composed of a mixture of both resistant and conducting structures. TDEM method is also used during this compagny to do static shift correction.

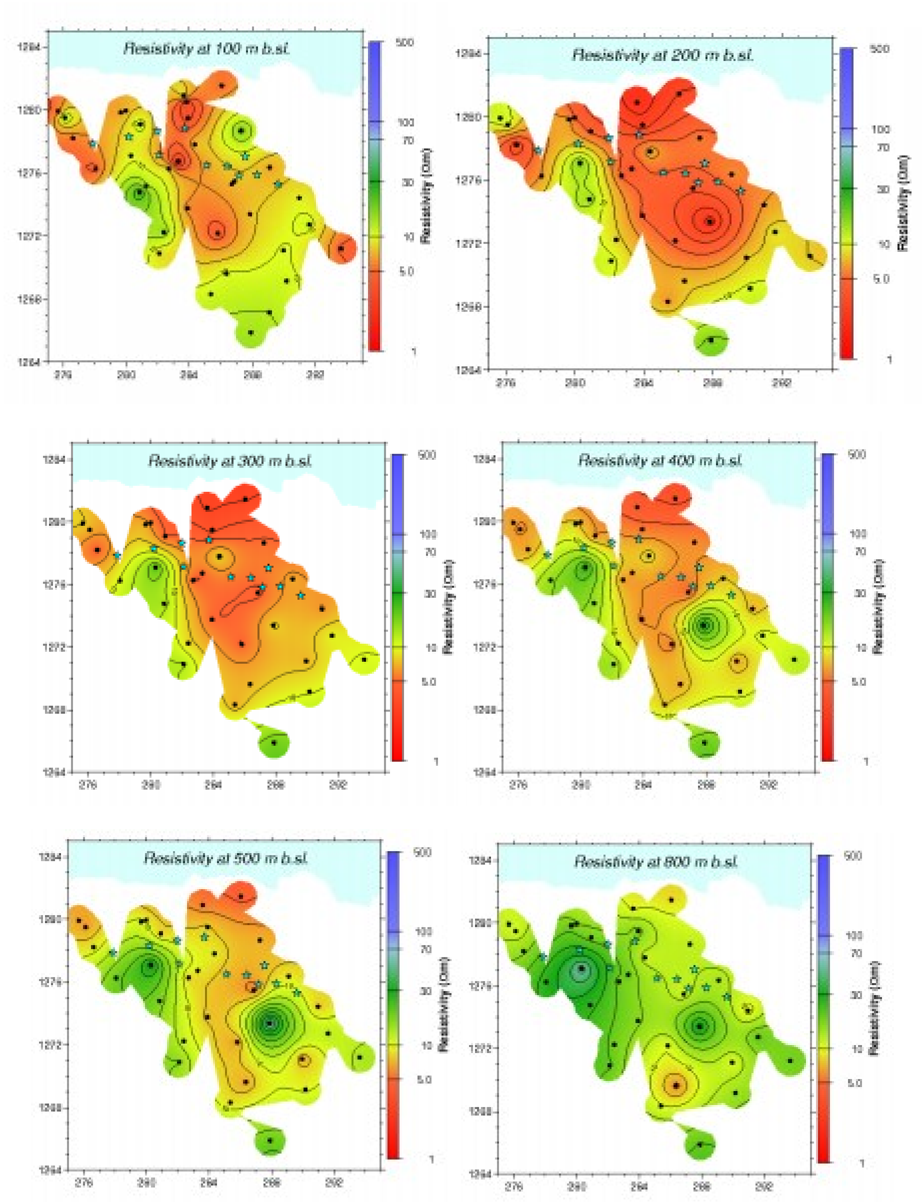


Figure 4: Distribution of the resistivity of the subsurface at different depths (100 m bsl, 200 m bsl, 300 m bsl, 400 m bsl, 500 m bsl and 800 mbsl) .The black dots are the MT surveys and the stars blue correspond to boreholes with a thermal anomaly.

In this case, the 1D resistivity models of some MT stations were interpolated as a vertical profile. This vertical section below highlights a subsoil constituted by a resistant structure in its near surface area. This resistant surface unit seems to be continuous in this direction (NW-SE) and thinner in the South-East where its thickness does not exceed a few tens of meters (Figure 5). On the other hand, in the northwestern part, the thickness of the latter can reach a hundred meters or more. Below this resistant formation, appears a conductive unit (~ 10 Ohm.m) which seems to contain a very conductive anomaly (<5 Ohm.m) in its central part. The thickness of this conductive formation varies between 700 and 900m since it seems to be thin at the ends of the profile and thicker in the central part. This conductive horizon rests on a resistant unit (~ 30 Om.m) with some very strong anomaly in its deep part (beyond 1000m depth). On the second profile (Figure 6)oriented SW-NE, we observe roughly the same geological units as the previous profile. However, in this direction, these units do not have the same geometry as the structures observed on the first profile. For example, the resistant surface horizon of this profile appears to be discontinuous at the center of the system.

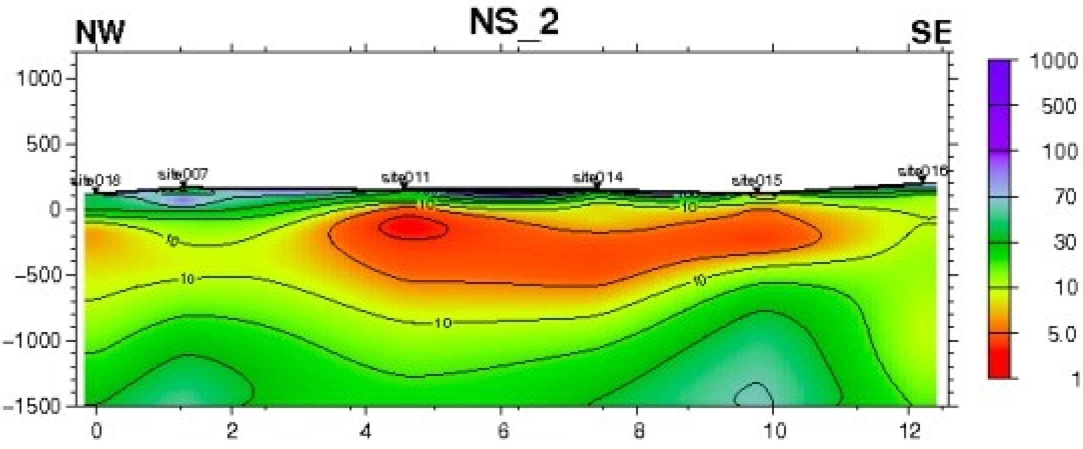


Figure 5: Vertical variation in resistivity along an NW-SE oriented profile.

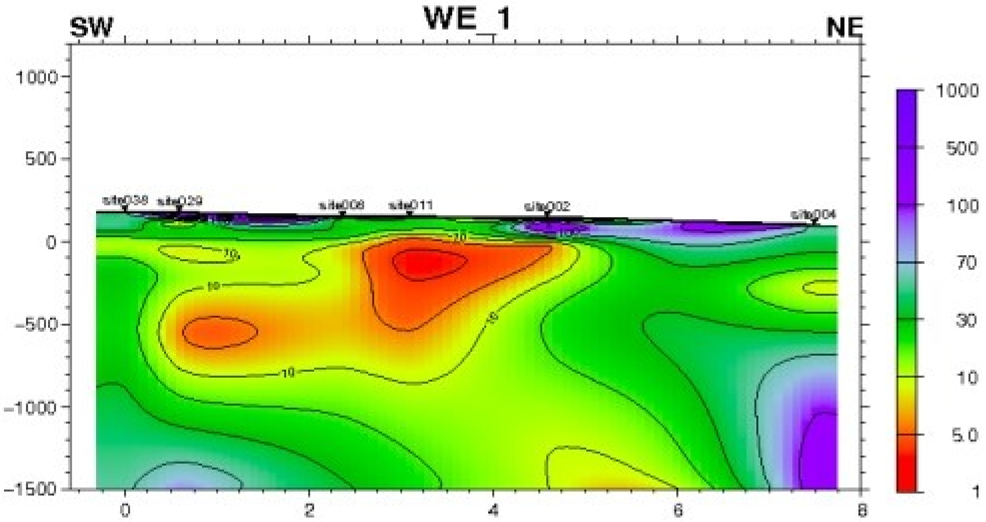


Figure 6: Vertical variation in resistivity along an SW-NE oriented profile.

2.2 Gravity method survey

Gravimetry is a geophysical method that makes it possible to study the spatial variations of the gravity field. It is applied to subsurface studies to calculate variations in the density of terrains and to image at different scales the internal structure of the Earth. The objective of this study was to get the subsurface imagery in terms of density variations of the study area.The gravity method is a fast and efficient tool for mapping geological structures and describing their directions. Linear gravity anomalies from anomaly maps are interpreted as having faults, contacts, and other tectonic and geological features. There are different methods for detecting gravity edge anomalies. The maxima of horizontal derivatives correspond to the limits of the source and are used to detect the boundaries of geological bodies (Bakely, 1995). After data processing, the gravimetric data analysis is performed by separating the regional anomalies from the residual anomaly by the polynomial filtering method. The horizontal gradient method was applied to detected geological structures such as fractures / faults in our study area.

The distribution of the general morphology of the PK20-Ambado zone was studied by the use of 3D images and predefined topographic sections as well as collected GPS data.. The topography of our study area varies from 0 to 700 m in altitude; the maximum altitude is found in the area around Arta with an altitude of 700 m. Towards the west, the difference in elevation is greater at the foot of the Arta bulge vault which varies from 500-700 m above sea level because the basalt of the Gulf abuts on the stratospheric series of reliefs or the characteristic of this bulge (Bernard, 1979). In the Ambado area, there is the graben called the Ambado Graben which collapses to the North. Structural observations made were from pre-existing structural maps. The observed deformations are important on the basalt of the Gulf in general, more precisely on the southern flank of the Gulf of Tadjourah and the zone of Ambado.

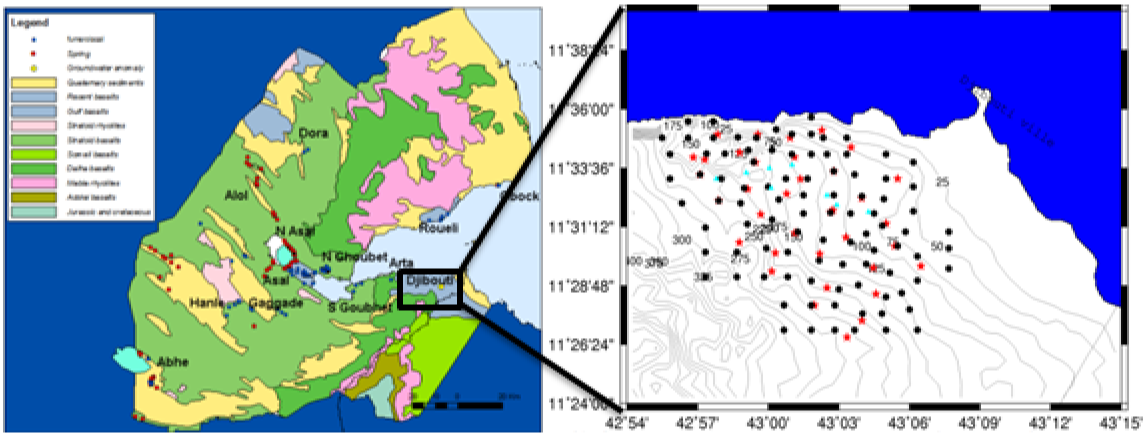


Figure 7: Map of Djibouti (left), localization of study area (right). The black dots show gravity measurement locations;, MT station locations are indicated in red stars while water wells are the green triangle.

In this investigation, the gravity data were collected using CG-5 (automated Gravity meter, Figure 6) made by Scintrex company, this device allows the recording of thousands of gravimetric data for a given station. These data were then filtered using Fourier transforms to eliminate undesirable (non-geological) effects such as ground vibrations. During the acquisition, in order to obtain optimal data quality, the device was programmed in an acquisition mode with 3 sets of 30 seconds for each measurement point and 5 sets of 60 seconds for the measurement of the station base. A tide correction was automatically calculated by the gravimeter processor.

Figure 8 : A : Scintrex CG5 Gravimeter, B : Field photo during an Gravity survey.

2.2.1 Results and Discussions

After applying these different corrections on the observations (Bernard G. and M. Chouteau,2008), we constructed a Bouguer map which would correspond to purely geological variations of the subsurface. The Bouguer anomaly map obtained by the treatment, from a value grid interpolated by PK20-Ambado, shows values between -350 and -310 mGals (Figure 7). The map has some anomalies of different wavelengths. The anomalies of the low amplitudes express a low density and the anomalies of strong amplitudes, a high density. High amplitude anomalies are localized in the Ambado zone. In the center of the map, there is an anomaly of low amplitude and a strong gradient. The small amplitudes are observed in the western and eastern parts of the map. The northern part is characterized by medium to strong amplitudes. The residual anomaly map (Figure 8) was obtained by subtracting this regional from the Bouguer anomaly. This map shows a series of closed, isolated, more distinct and more numerous anomalies than Bouguer anomaly map. The most obvious of these anomalies are described and interpreted qualitatively by relying on the geological knowledge of the region. The residual anomaly map of the study area (Figure 8) shows values ranging from -10 to10 mGals. Areas of positive anomaly and areas of negative anomalies are distinguished, as well as a zone with a high gradient observed also on the Bouguer map. Negative anomalies are related to local sub-basins or grabens. The positive anomalies, for their part, are due to a rise in the crystalline basement or horsts, so the anomaly in our case is anomaly is negative, which makes us suggest that the middle has a mass deficit or slight probably due to faults or fractures.

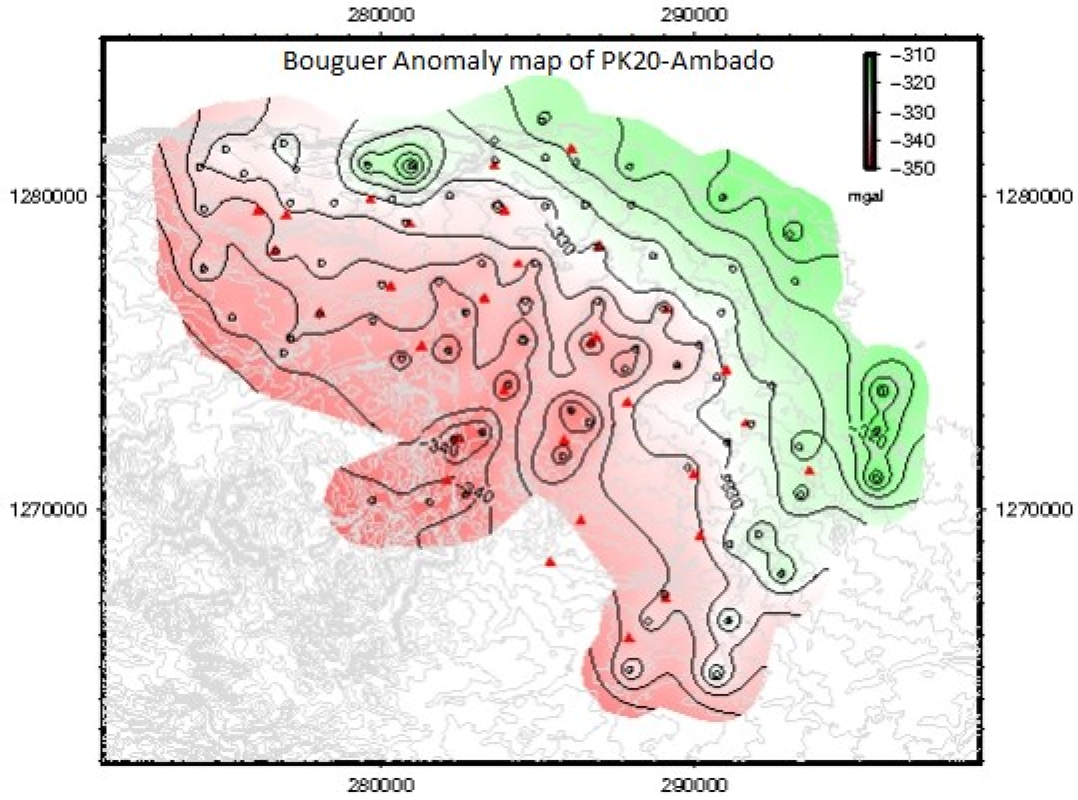


Figure 9: Bouguer anomaly map of the study area. Red dots represent MT surveys.

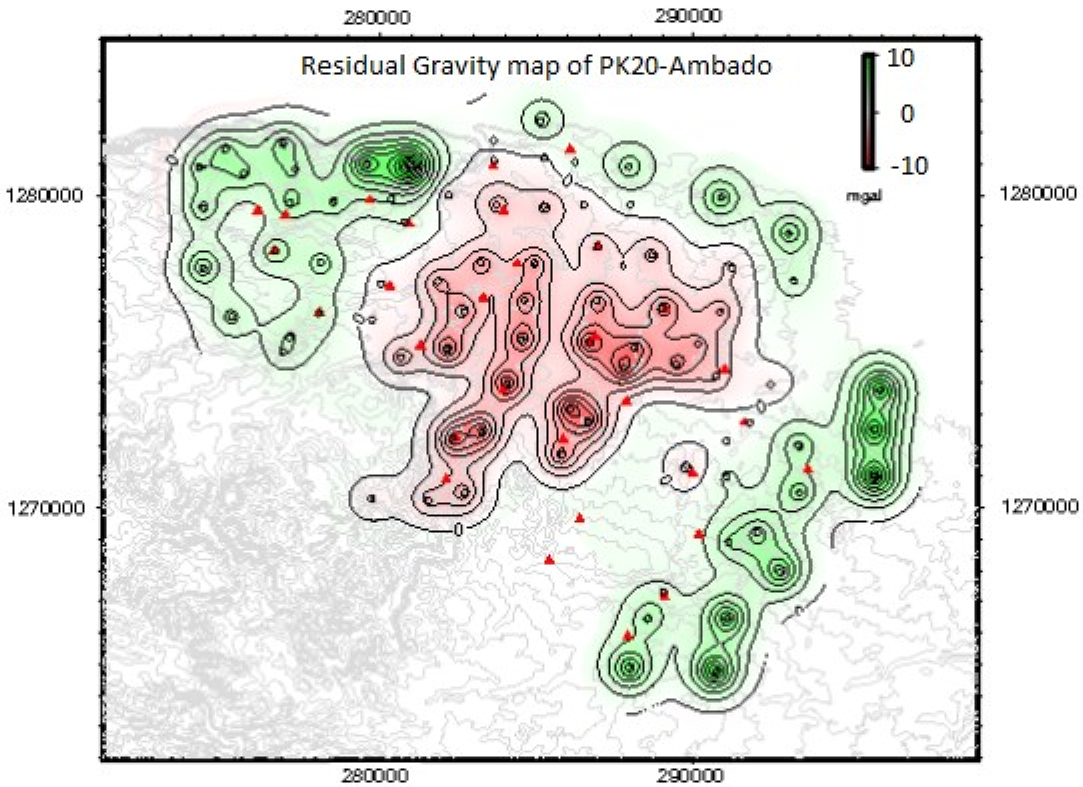


Figure 10: Residual anomaly map of the study area. Red dots represent MT surveys.

3. CONCLUSION

PK20-Ambado field is the one of the 13 prospects geothermal site. ODDEG conducted a pre-feasibility study to identify a geothermal reservoir. With regard to the source of heat at the origin of the temperature anomalies it is possible to glimpse two possibilities or even three. First, under the conductive anomaly of 100mbsl at 500 mbsl, the electromagnetic study shows a resistive assembly where the resistivity varies from 10 ohm.m to more than 100 ohm.m, and does not seem to identify any anomaly that can be attributed to a heat source at depth. If the heat source is indeed underlying the pk20 zone, it would be in diffuse form. The second possibility is linked to the arrival of convective thermal water flows along the main faults linking the reservoir system and the Tadjourah ridge region. The third possibility is linked to the Hayabley volcano with its probable source deep that would feed the superficial reservoir of PK20 by convection via NWSE faults. In hypotheses 2 and 3, the hydrothermal circulations are mainly through the NW-SE faults. The pre-feasibility study carried out in the pk20 zone showed a temperature between 120 and 165 ° C in depth between 500 and 600 m. To validate these results, three reconnaissance holes were proposed.

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