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# MT and gravity surveys in Ambado-PK20 geothermal prospect, Djibouti

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## ABSTRACT

Magnetotelluric (MT) and gravity were carried in this prospect to delineate the boundaries of the geothermal system. 34 MT/TDEM soundings were acquired using metronix equipment with a periods 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 usually the intrinsic ambiguity on the conceptual model. A geoelectric structure model obtained by the 1-D inversion shows a resistive layer at the surface overlying a conductive layer and a deep resistive layer. Residual anomaly shows a central low gravity extended towards the south and delineated by a heavy body in the northern part of system.Based on interpretation of results from both 1-D inversion of MT data and Bouguer anomaly, we found that the conductive layer is found in the area defined by a low gravity value . 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

Ambado-PK20geothermal prospect is one of the nearest geothermal system to Djibouti town (situated about 20Km away). This area is located on the groundwater table which supplies water to the city of Djibouti. Several studies have been carried out on this site in the past especially on hydrogeological context 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 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 area of its 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 is to locate an eventual geothermal reservoir for geothermal energy production. For that several geosciences studies have been made (geology, geochemistry, geophysics….) in this area.

The Republic of Djibouti is one of the several African countries located on the East African rift system where geology is also resulting from the two other ridges of Red Sea and Gulf of Aden. Such a particular geodynamical situation gives to 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 are mainly 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 on several geothermal prospect zones, the geothermal energy in Djibouti is still to be developed.

This paper summarizes the updated exploration work carried out over the PK-20 Ambado geothermal prospect (Figure 2). This site is part of geothermal sites prospects listed in the country (Figure 3). As part of a geophysical study of the Pk20-Ambado area that started in December 2016, two geophysical methods including Magnetotellurique (MT) and gravimetric were used.

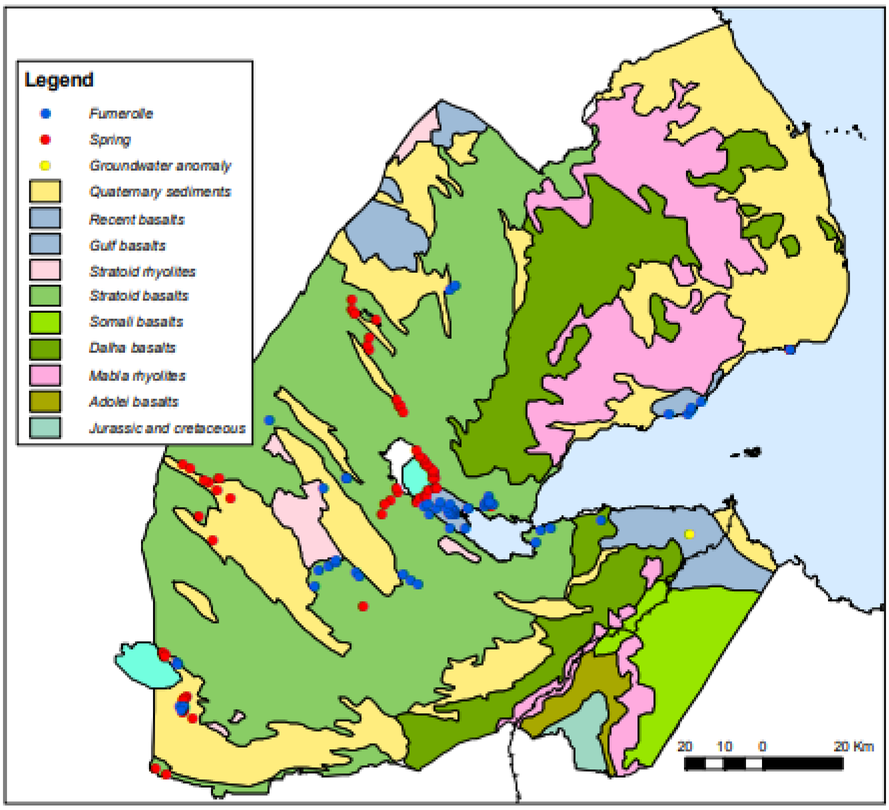
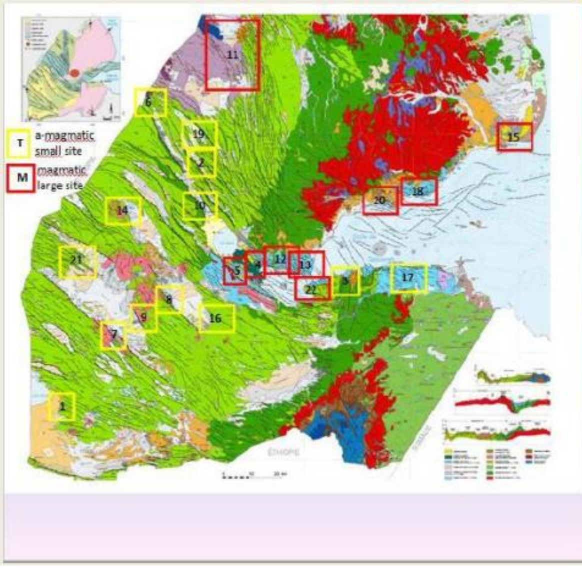



**Figure 1: Geology and hydrothermal activity of the Republic of Djibouti**




| 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**

Pk20-Ambado survey area is located approximatly 20 km west from the city of Djibouti (Figure 3). The topographic average varies from 0 to 400 m altitude, the maximum altitude is in the area of Arta with an altitude of 700 m. Going west, the difference in level 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 Robineau 1979).

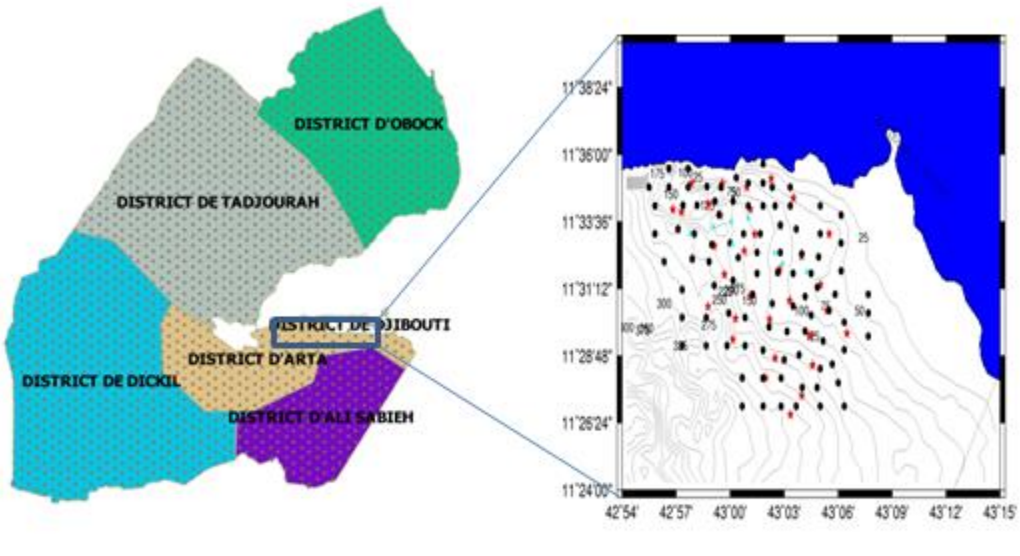



**Figure 3: Map of Djibouti, localization of study area (blue square) and Location map of gravimetric surveys (black dots), MT surveys (red stars) and wells of water (green triangle).**

## 2. Methodology.

### 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 MT 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 4). In fact, only some twelve years ago, Tikhonov (1950), and Kato and Kikuchi (1950) in Japan, 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.

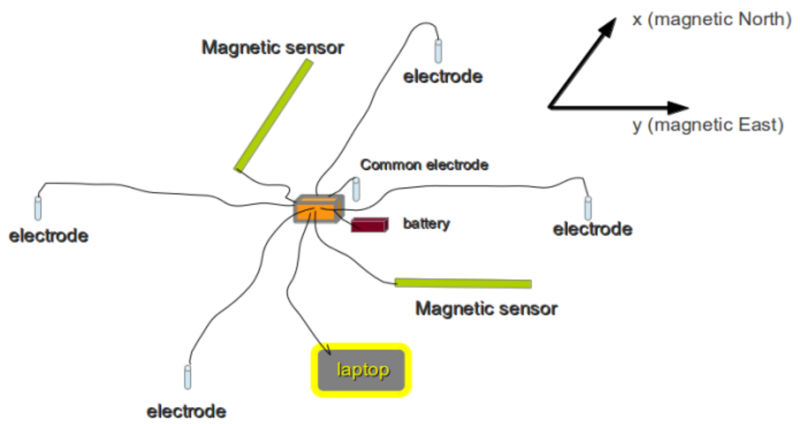



**Figure 4: Measuring setup for an MT sounding during the acquisition of field data.**

### 2.1.1 Acquisitions and processing the MT.

The Magnetotelluric method are used in the PK20-Ambado prospect in 2017. The MT data acquisition was done using metronix systems equipment. The instruments of the metronix system consist 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. In this prospect a total 34 MT soundings are acquired by two types ADU-07e of equipment (metronix ) during this campaign. The interval between two measuring stations is 500m and 1km in some stations.

The processing step is crucial for processing the data collected during the field study and will be evident for the next phase that corresponds to the procedure of inversion or interpretation of the data in terms of geological structures. The quality of the underground resistivity model obtained will strongly depend on how these data were processed. Mistreatment would systematically involve an erroneous result, that is, a geoelectric model far removed from the geological reality of the subsoil. To process data, use procMT software. The ProcMT software used in this reprocessing is an updated version provided by Metronix on septembre, 19, 2017.

### *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 result of 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). In this investigation, the gravity data were collected using CG-5 (automated Gravity meter) made by Scintrex company (Figure 5), 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 soil vibrations. During the acquisition, in order to obtain optimal data quality, they programmed the device 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. After applying these different corrections on the observations, we obtain a Bouguer map which would correspond to purely geological variations of the subsurface. After data processing, the gravimetric data analysis is performed by separating the regional anomalies from the residual anomaly by the polynomial filtering method. During this prospection, 65 Gravity measurements were collected with a step varying from 1km to 2km over the entire area.

The distribution of the general morphology of the PK20-Ambado zone is studied by the use of 3D images and predefined topographic sections as well as collected GPS data.


**Figure 5 : CG5 Gravimeter**

### 2.2.1 Results and Discussions

After the processing of the MT data, some data from the surveys are very noisy because of electric lines of high voltage while others have very good quality. This method MT puts in evidence a heterogeneous medium, with the near surface 100m the subsoil tends towards a resistant medium. MT data quality is largely correct for a 1D interpretation even if the data from some MT surveys are sometimes very noisy in the Dead Band and long periods. Between 200 and 600m deep, the prospect is occupied by a conductive anomaly especially in the center of the site. From 1000m up to a depth of 4000m, it appears a resistant medium with the appearance of some anomalies very resistant in depth. The geo-electric model obtained by the method, the subsoil of the PK20-Ambado geothermal site is constituted by structures of resistant / conducting / resistant.

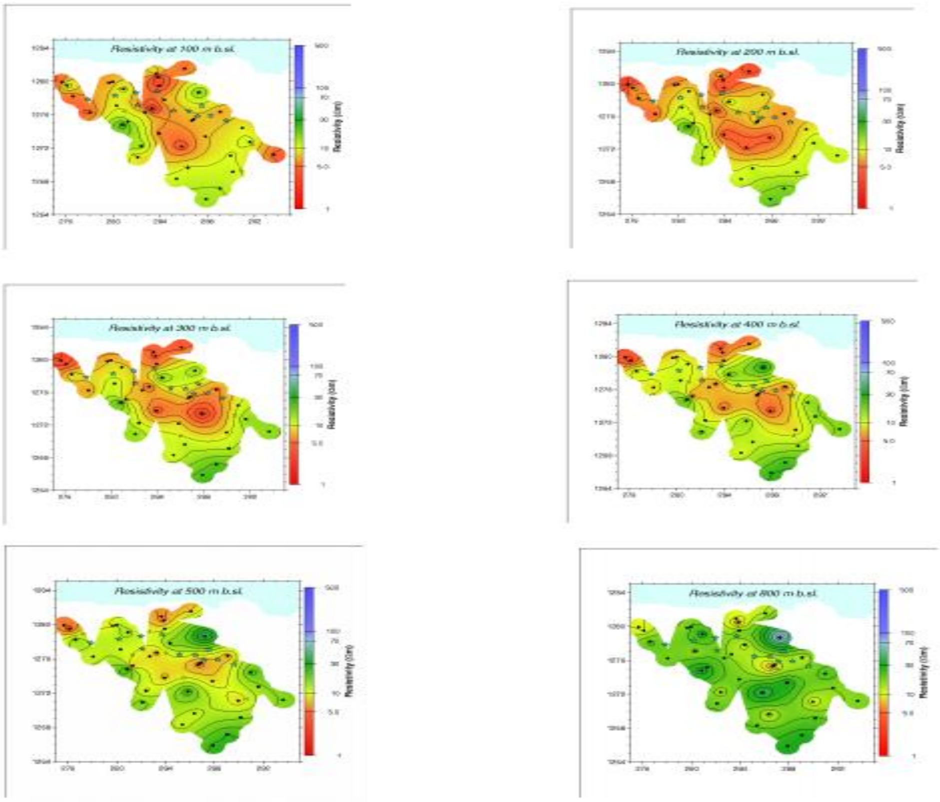


**Figure 6: Distribution of the resistivity of the subsoil at different depths (100 m bsl, 200 m bsl, 300 m bsl, 400 m bsl, 500 m bsl and 800 m bsl) .The black dots are the MT surveys and the blue stars represent boreholes with a thermal anomaly.**

The Bouguer anomaly map obtained shows values between -350 and -310 mGals (Figure 7). The map shows 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 (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 mGal. 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 say that the middle has a mass deficit or slight probably due to faults or fractures.This Bouguer anomaly indeed contains the regional anomaly and the residual anomaly, so the one that interests us is the residual anomaly (Figure 8).

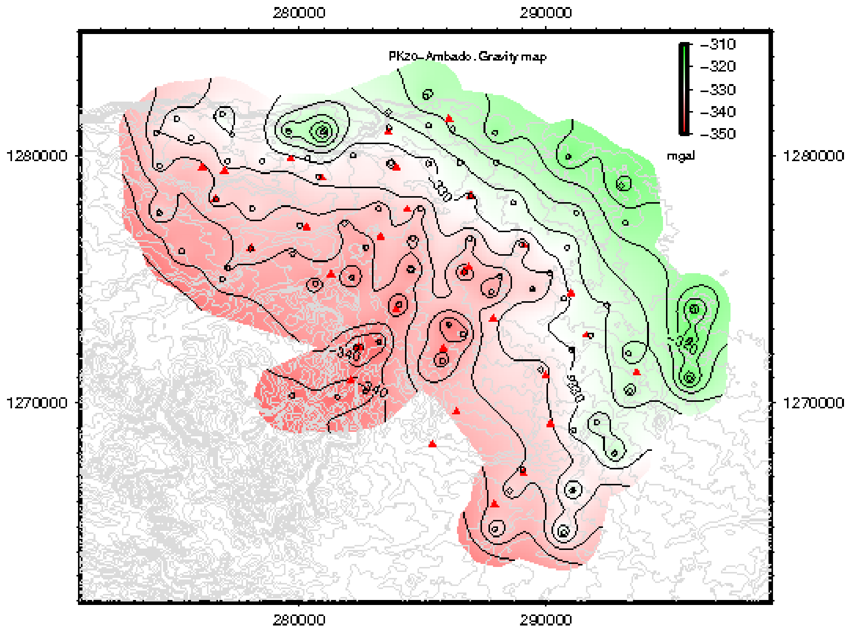



**Figure 7 : Bouguer anomaly map of the study area. Red dots represent MT surveys.**

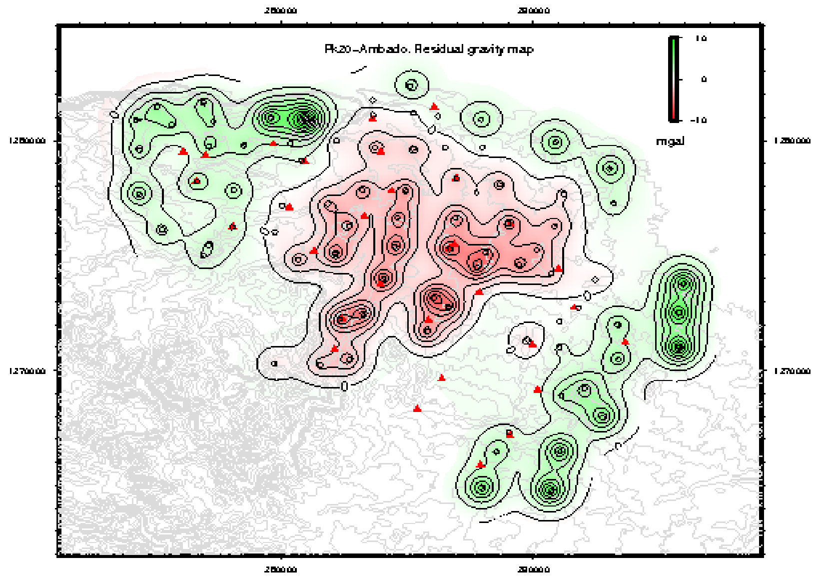



**Figure 8 : Residual anomaly map of the study area. Red dots represent MT surveys.**

## Conclusion

Two geophysical methods (MT and Gravimetry) used over the PK20-Ambado prospect has indicated the existence of a conductive anomaly located on the coastal zone and the south-southeast is best represented between 200 mbsl and 400 mbsl but would continue up to 500 mbsl. The gravimetric study shows a central strong negative gravity anomaly. The two anomalies (MT and gravimetry) overlap to the north and south of the prospect. The results show good correlation between the two anomalies and in conjunction with thermal anomalies found in the area makes the area a good target for drilling.

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