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Exploration of Geothermal Resources in Farafra Oasis, Western Desert, Egypt

Mohamed Abdel Zaher

National Research Institute of Astronomy and Geophysics, Helwan, Cairo 11421, Egypt

Moh_zaher@nriag.sci.eg

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ABSTRACT

The geothermal activity in Egypt is perceived in many areas, in terms of hot springs exposed at the surface or thermal deep wells. Harvesting the undiscovered geothermal resources could address local needs for energy. Farafra Oasis has been mentioned as the most interesting and promising geothermal resource for geothermal development in a protocol assigned between New and Renewable Energy Authority (Nrea) and Ganoub El Wadi Petroleum Holding Company (Ganope). An integrated regional geochemical and geophysical studies using remote sensing, seismicity, aeromagnetic and aerogravity data were done to evaluate the geothermal potential in the Farafra area. These provincial investigations show good correlations among high heat flow, shallow basement depths detected from gravity inversion and shallow Curie point depth obtained from magnetic data. Six zones of high geothermal probability are recognized in the Farafra oasis. These zones are southern Ain-Dalla, Bir-Sitta, eastern Qasr-Farafra, eastern Farafra, southern Farafra, and southern Abu Minqar. Geochemical analyses of thermal wells in farfara Oasis show that all the examined groundwater samples belong to good potable fresh water class for drinking and for irrigation purposes. Fluid geothermometer are not valid to be used.

1. INTRODUCTION

Geothermal resources in Egypt can be divided into two main systems; one is structurally and tectonic controlled that found in Red Sea-Gulf of Suez rift where a number of hot springs are located. The second is controlled by the depositional system of the different stratagraphic units in the Western Desert of Egypt, where many flowing hot springs are encountered. Generally, the geothermal activity in Egypt is recognized in different areas, in terms of small hot springs exposed at the surface or thermal deep wells. Many geothermal studies have been carried out in the eastern parts of Egypt, especially the Gulf of Suez and Red Sea regions. Abdel Zaher et al. (2018a) evaluated the geothermal potential in the Farafra oasis and its suitability for geothermal development in the Western Desert using different tools such as remote sensing, seismic events, and aeromagnetic and aerogravity data. Mohamed et al. (2015) developed a new predictive model to estimate geothermal gradients in the northern Western Desert based on bottom-hole temperature (BHT) and aerogravity data using an artificial neural network (ANN) approach. Abdel Zaher et al. (2018b) utilized aerogravity data to estimate the depths of basement rocks in the Siwa Oasis and used aeromagnetic data to estimate the Curie Point Depth (CPD), geothermal gradient and heat flow maps.

Farafra Oasis is located in the heart of the Western Desert of Egypt; approximately 500 km southwest of Cairo and 300 km west of the River Nile at Asyut, and midway between the Bahariya and Dakhla oases (Fig. 1). It is as a part of an arid area which characterized by the lack of rainfall in the whole year and groundwater is the main source of water for people in this remote area. Springs are the easiest and cheapest water supply for drinking and irrigation. In the last decade the water level in these springs showed a recognized lowering and some springs was completely depleted.

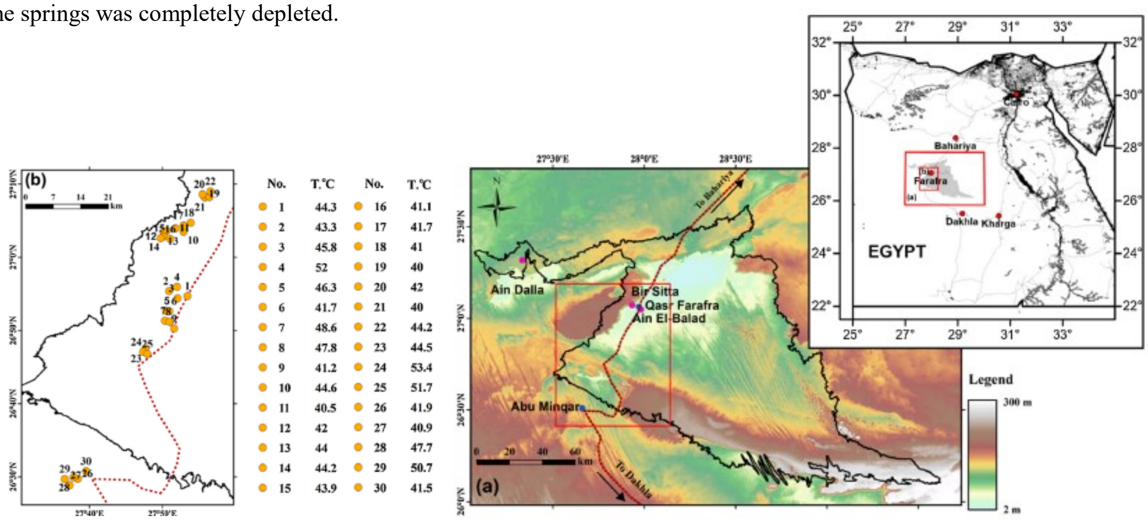

Figure 1: (a) Location and topographic map (DEM from a satellite dataset) of the Farafra Oasis. The map shows the outlines of the Farafra Oasis, with a surface area greater than 800 km2, and the locations of Ain Dalla and Bir Sitta. (b) Locations of thermal wells and their temperatures in °C, measured in December 2017.

The hot springs in the Farafra oasis include Ain El-Balad (28 °C) and Ain Dalla (35 °C). However, there are numerous thermal water from deep wells in Farfara oasis, many of which are artesian. The temperature of these thermal wells was measured and listed in Fig. 1 and ranges 40–50 °C. Integrated regional geology, remote sensing and geophysical (seismicity, airborne gravity and magnetic data) studies were done in addition to geochemical analyses were done on water samples collected from thermal wells in order to investigate the geothermal resources and obtain a full picture about the geothermal potential of the Farafra oasis. These regional studies help us to detect the locations of the most promising sites for detailed study to estimate the geothermal development and achieve the ideal utilization of geothermal resources in Farafra oasis.

2. CURIE POINT DEPTH (CPD), TEMPERATURE GRADIENT AND HEAT FLOW MAP OF FARAFRA OASIS

The aeromagnetic dataset used in this study is extracted from Getech's compilation study 'African Magnetic Mapping Project' (AMMP) which is in the form of unified 1 km grid of total magnetic intensity (TMI) (Getech, 1992; Green et al., 1992). The total magnetic intensity anomalies range from -90 nT to 150 nT (Fig. 2a). The white area at the northern part of the TMI map has no survey data. The magnetic values decrease southwestward due to existence of thick low-magnetized sedimentary cover. The main directions of magnetic anomalies are E-W, NW-SE and NE-SW. Positive magnetic anomalies are present in the southeastern and northwestern parts of the map and could be related to existence of shallower subsurface magnetic sources. Also, we can recognize positive anomaly at the area of Ain Dalla hot spring, northwest of the TMI map. The idea of using magnetic anomalies to estimate the geothermal gradient is based on calculating the depth to the bottom of the magnetic sources that caused these magnetic anomalies. This depth is equivalent to the Curie-point depth at which the substance loses its magnetic polarization.

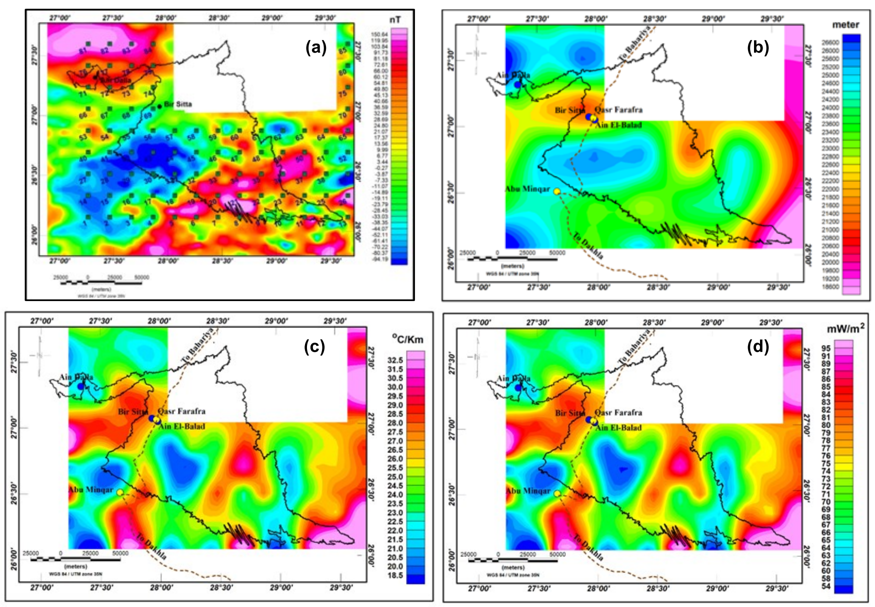

Figure 2: (a) Total magnetic intensity (TMI) map of the Farafra Oasis, green dots represent the locations of the centers of overlapping square subregions (windows) used for the power spectrum analyses, (b) Map of the CPDs of Farafra Oasis obtained using a minimum curvature gridding to the basal depths (Zb), (c) Temperature gradient map of Farafra Oasis obtained using a Curie temperature of 580°C and the derived curie depths from the aeromagnetic data, (d) Heat flow map of Farafra Oasis using an average thermal conductivity of λ =2.9 W/m°C. The solid polygons refer to the outlet of Farfara Oasis.

To estimate the CPD, the spectral analysis method has been applied to the aeromagnetic data and the basal depth of a magnetic source from aeromagnetic data is considered to be the CPD. Blakely (1995) introduced the power density spectra of the total-magnetic field anomaly. The slope of radially averaged power spectrum of the magnetic anomaly was used to determine the depths to the centroid (Z0) and to the top (Zt) of a magnetic layer and then the basal depth (Zb) can be calculated from Zb = 2Z0-Zt. To achieve accuracy in calculation, we extended the area of aeromagnetic map and use data outside of the study area and divided into overlapping square sub-regions (85 windows) with dimensions 76 x 81 km and a radially average power spectrum was calculated for each window. Figure 2b shows the CPDs for Farafra Oasis, carried out by applying a minimum curvature algorithm to the resultant of CPD (Zb).

Using a Curie point temperature of 580 °C and the derived curie depths, geothermal gradient map of Farafra Oasis was estimated as shown in Fig. 2c. Assuming no radioactive source, the geothermal gradient was used to compute the heat flow q (Fig. 2d) by: q=λ dT/dz, where λ is the coefficient of thermal conductivity (2.9 W/mK) that was measured by Morgan et al. (1983) for rocks forming the stratigraphic section in the northern part of the Western Desert of Egypt. The calculated geothermal gradients give values of between 18.39 °C/km to 36 °C/km and an average of around 26 °C/km, while the heat flow values range between 53 and 104 mW/m^2. The average heat flow in the study area is approximately 74 mW/m^2.

3- DEPTH TO BASEMENT ROCKS DERIVED FROM GRAVITY DATA

Airborne gravity data were utilized as a part of the present investigation for geothermal exploration at the Farafara Oasis. The aerogravity data were obtained from the AGP (African Gravity Project) data and arranged into 5-min grids (cell estimate ~ 0.08333 in degrees) (Getech, 1992). 3D inversion was applied on the gravity data in order to use a density model to fabricate such a geological status, to the point that would clear up the observed data. Gravity inversion and/or modeling are normally basic steps in gravity interpretation and include endeavoring to resolve the depth, density, and geometry of subsurface bodies. The model depends on a two layers; a sedimentary layer and a basement layer with average densities 2300 kg/m3 and 2760 kg/m3, respectively. The density of sedimentary rocks was supposed depending on the arbitrage between density ranges of different rocks reported in the literature. Geological information from deep well (Ammonite-1 well) was used for verifying the inversion results. The depth to the interface between upper and lower layers was extracted and contoured from the consequences of the 3D gravity inversion, which represents the depth to the Precambrian basement rock, in other words the aggregate thickness of the sedimentary rocks (Fig.4). Depths to the basement are generally greater than 2 km (b.s.l.) in most study area. The SW-NE trend of major basins (depth > 3 km) separates two basement uplifts (depth < 2 km) at the northwest and southeast of Farfara Oasis. These shallowest depths to the basement rock are encountered around the Bir-Sitta area, south and east of Ain-Dalla, and south of farafra outline. Structural lines (lineaments) on the basement surface were extracted and superimposed on the basement relief map, which represents the orientation of the discontinuities by straight lines (Fig. 15). The interpretation of linear features on the basement map by plotting rose diagram of basement lineaments (the orientation of the discontinuities represented by straight lines) shows that the lineaments mainly strike NE-SW and reveals the same change in lineament trends as seen in the surface geological map (4). This trend coincides with the trend of the Syrian Arc System, where the Farafra depression represents its southern extension.

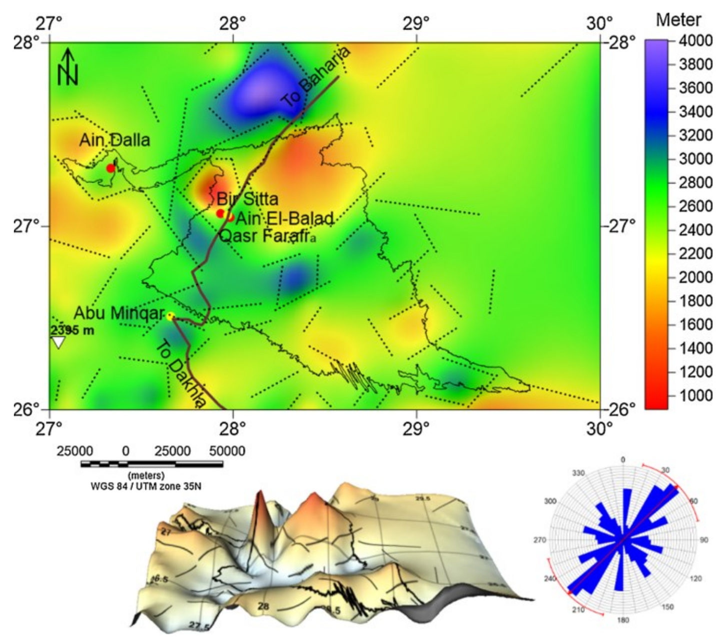

Figure 4: Basement relief map derived from the 3D density modeling. Depths are in meters above sea level. The inverted white triangle represents the Ammonite-1 well, and the number is the depth to the basement in the well. The lower figure shows a 3D view of the basement surface. Dotted lines indicate lineaments on the basement surface, and their numbers are illustrated in the rose diagram.

4. GEOCHEMICAL ANALYSES OF THERMAL WATERS

Forty-one groundwater samples were collected from the Nubian sandstone aquifer in Farafra Oasis, Western Desert, Egypt to analysis of major cations (sodium, potassium, calcium, and magnesium) and major anions (bicarbonate, carbonate, chloride, and sulphate) as well as trace elements. The locations of these samples are shown in Fig. 1b. Geochemical analyses of thermal wells in farfara Oasis show that all the examined groundwater samples belong to good potable fresh water class and can be categorized as good quality water for irrigation purpose. Additionally, according to pH, sodium, magnesium, calcium, chloride and sulphate concentrations, all the analyzed groundwater samples are suitable as drinking water. However, high concentration of iron (Fe) was detected and more than one removal option may be necessary. Fluid geothermometer are not valid to be used. Geothermometer calculation results of Na-K, (Fournier, 1979; Arnórsson, 1983; Nieva and Nieva, 1987; Giggenbach, 1988) and Na-K-Ca geothermometers have a relative overestimate of temperature. Otherwise, K-Mg geothermometer shows reservoir temperature ranging from 58oC to 121oC. Quartz geothermometers show that the reservoir temperatures are very low. The quartz geothermometer is best for reservoir conditions > 150°C. Quartz geothermometers in some hot springs have values less than 150°C, so that temperature is not valid. The trend of invalidity of some fluid geothermometers usually made many geochemists to become unsure to decide the right subsurface temperature. With three geothermometers based on graphical techniques as discussed above, invalidity of each geothermometer can minimize this effect. The important thing of these geothermometers is consider equilibrium of fluids.

5. SUMMARY AND CONCLUSION

There are certain correlations among the locations of higher heat flow and those of shallow basement depths derived from gravity inversion and shallow CPD obtained from magnetic data. Six sites with high geothermal potentials are well distinguished in the study area. These sites are located in southern Ain-Dalla, Bir-Sitta, eastern Qasr-Farafra, eastern Farafra, southern Farafra, and southern Abu Minqar. In contrast, the Ain Dalla spring area has low geothermal properties compared with the Ain El-Balad spring near Qasr Farafra. Comparing the results with structure geology and seismic activity can help in our geothermal investigation in the Farafra oasis. Figure 5 summarizes the results of the integration of different geophysical methods, geological structure and seismicity data.

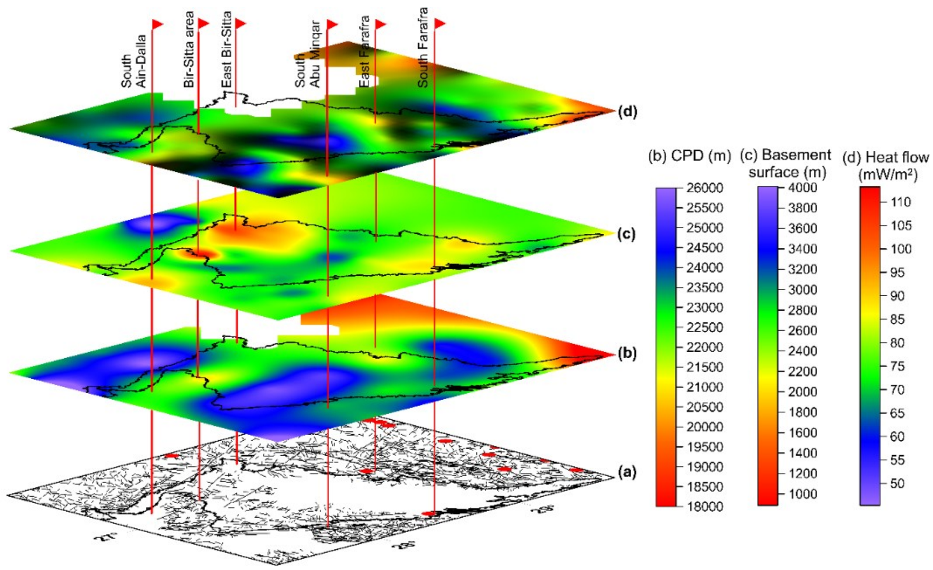

Figure 5: Figure 16. Locations of the most promising areas for geothermal exploration in the Farafra Oasis as a result of our regional studies. (a) Structural lines derived from the Geological map of Farafra Conoco Coral at a scale of 1:500,000© Egyptian General Petroleum Company (EGPC), 1987; red circles indicate the locations of earthquake epicenters. (b) CPD map derived from aeromagnetic data. (c) Depths to the basement surface obtained from gravity data. (d) Heat flow map of the Farafra Oasis.

The two sites with evidence of seismic activity, near the eastern border of the Farafra oasis and the other is located to the south, have high temperature gradients and heat flow values. This correlation can explain that the geothermal resources in these sites are structure control. Also, we can observe that most of the six geothermal areas are associated with faults on the basement rocks (derived from 3D gravity inversion). Finally, we can conclude that the geothermal resources in the Farafra oasis can be classified as low-temperature resources. So, it is important to noted that the contribution of geothermal energy from the Farafra oasis could not from adding megawatts to the electricity network but from reducing consumption by the direct use of geothermal resources, such as district heating, fish farming, agricultural applications and greenhouses. Next steps are to collect water samples from deep wells in the promising sites for geochemical analyses as well as land measurements using deep investigation geophysical methods (e.g., magnetotelluric) to assess their geothermal potential and to develop models for Enhanced Geothermal Systems (EGS) that accurately anticipate reservoir achievement.

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