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Geothermal Gradients in the North Western Desert, Egypt as Deduced from Bottom-Hole Temperature and Aerogravity Data

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ABSTRACT

The Western Desert of Egypt covers two thirds of the whole area of Egypt. Its northern part represents the second most promising areas of hydrocarbon potential after Gulf of Suez province. So, most of the explorations were focused only on hydrocarbon and water resources and limited work has been done on geothermal potential. Bottom-hole temperature (BHT) records of 149 deep oil wells (2000 – 4500 m) were used for evaluating the geothermal resources in the north Western Desert of Egypt. Correction was applied on the BHT data to obtain the true formation equilibrium temperatures that can provide useful constraints on the subsurface thermal regime. On the basis of these corrected data, temperature gradient was computed for the linear sections of the temperature-versus-depth at each well. Although the north Western Desert of Egypt has low regional temperature gradients (30 °C/km), some local geothermal fields with potential were located (40 – 50 °C/km). Heat flow at each well was also computed by combining sets of temperature gradient and thermal conductivity data. Aerogravity data was used for delineating the subsurface structures and tectonic framework of the north Western Desert. Geothermal gradient was integrated with corresponding gravity value at each well location using the Artificial Neural Network (ANN) method in order to predict the geothermal regime at localities where no boreholes exist. The result is a new geothermal gradient map of the north Western Desert developed from gravity and BHT logs data.

1. INTRODUCTION

The Western Desert of Egypt is considered a strategic water resource in Egypt as it is an important groundwater resource through the Nubian aquifer which is the main source of water for sustainable development. The north Western Desert also represents the second most important oil-producing area. Numerous studies have been carried out on the geology, hydrogeology and hydrocarbon potentiality of the Western Desert, while limited attempts have been done on its geothermal potential. The present study aims to throw more light on the geothermal resources and develop a new geothermal gradient map of the north Western Desert using different types of data. The study area is located between latitude 27° to 31°N and longitude 26° to 31°E (Figure1). The study area is characterized by a featureless plain cut by Qattara, Siwa, Farafera, Bahariya, Wadi Rayan, Birket Qarun and Wadi Natrun depressions. Temperature logs of more than 149 deep oil wells, with depths ranging from 2 to 4.5 km were collected and analyzed to delineate the temperature gradients and heat flow maps in the study area. Also, gravity data covering the whole north Western Desert, obtained from GETECH Group PlC, was correlated with temperature logs to investigate the subsurface temperature regime in the area and to predict the geothermal regime at localities where no boreholes exist using the Artificial Neural Network (ANN) technique.

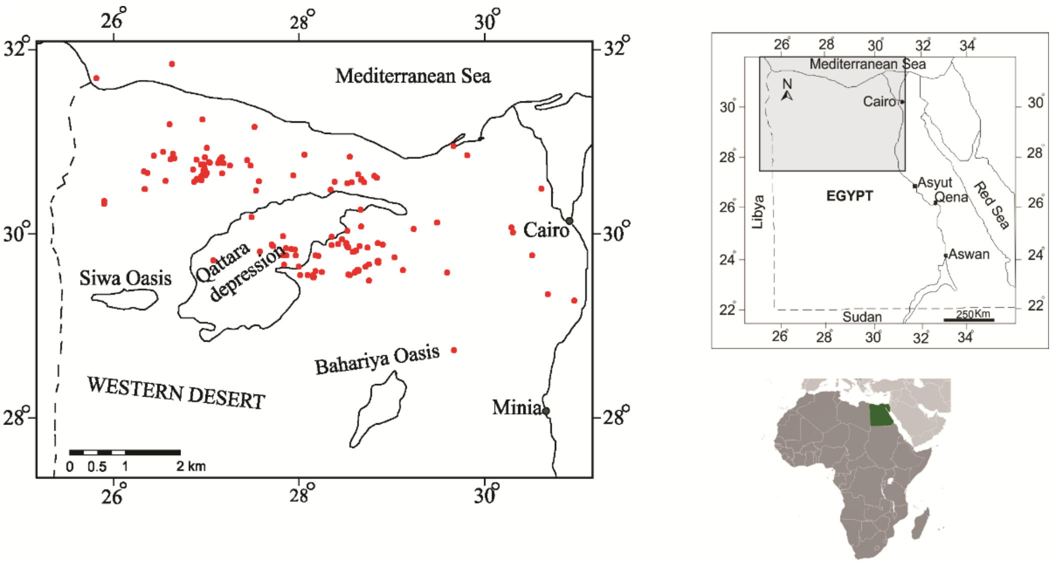


Figure 1: Location map of the north Western Desert; the red circles reveal the locations of oil wells used in the present study.

ANN has been applied to various gravity problems such as to determine depth and radius of subsurface cavities from microgravity data (Eslam et al., 2001). In addition, forced neural networks were used for forward modeling of gravity anomalies (Osman et al., 2006, 2007). Also, it is used to solve problems in modeling gravity data (e.g. Chakravarthi, 2010; Chakravarthi and Sundararajan, 2007; Rao et al., 1993). Abdel Zaher et al. (2009) used ANN to determine thickness of sedimentary cover in the south Western Desert from gravity data. Abedi et al. (2010) evaluated 2D residual gravity anomalies by using various inversion methods and ANN.

2. TEMPERATURE LOGS DATA

We have access to temperature data from 148 deep oil wells (2000 – 4500 m), based on measurements carried out by oil companies, including the Egyptian General Petroleum Company (EGPC), the Gulf of Suez Petroleum Company (GUPCO), and British Petroleum Company (BPC). Most of the wells are located in the north part of the study area. The temperature data are in the form of bottom-hole temperature (BHT), which is measured at the bottom of the well (highest temperature). Temperature logs are routinely measured during drilling or soon after circulation has ceased. Thus, these data are typically lower than the true temperature of the formation due to the cooling effect of the drill fluid circulation. So, the temperature logs were corrected on the basis of time from the end of mud circulation (TSC) using different methods. After determining the true Formation temperature, geothermal gradients were computed as rate at which the subsurface temperatures increase with depth assuming the mean annual surface temperature of 26.7^{o}C (Morgan et al., 1983) (Figure 2A). Heat flow values were determined by combining sets of temperature gradient and thermal conductivity data using the formula Q = K(dt/dz), where Q is heat flow, K is thermal conductivity, and t is the temperature at depth z. Preliminary heat flow values ranging from 40 to 100 mWm^{2} have been computed for the north Western Desert (Figure 3) with a reasonably good geographical distribution, and a limited number of thermal conductivity data determined by Morgan et al. (1983) (Figure 2B).

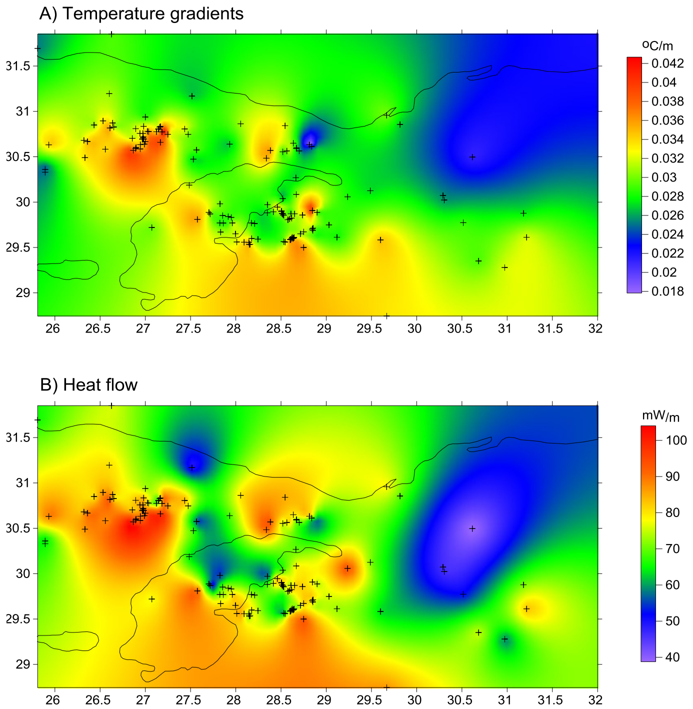


Figure 2: A) Temperature gradient; B) Heat flow maps of the north Western Desert; crosses relate to the location of oil wells.

3. GRAVITY DATA

Gravity data in the form of a Bouguer anomaly map, with contour interval of 5 mgal is considered as one of the principal sources of information on the internal structure of the earth's crust. The data were obtained from the GETECH Group PIC. It covers the land area of North Egypt in the form of a 1 km grid of TMI data at 1 km above topography for the area north of 27°N and west of 31°E. To enhance the structural features from the sedimentary and basement rocks that affect the study area, a separation of gravity data into regional and residual components was carried out. The separation process was done using the least-squares polynomial technique. Figure 3A shows the Bouguer anomaly map for the residual field (residual Bouguer anomaly gravity map).

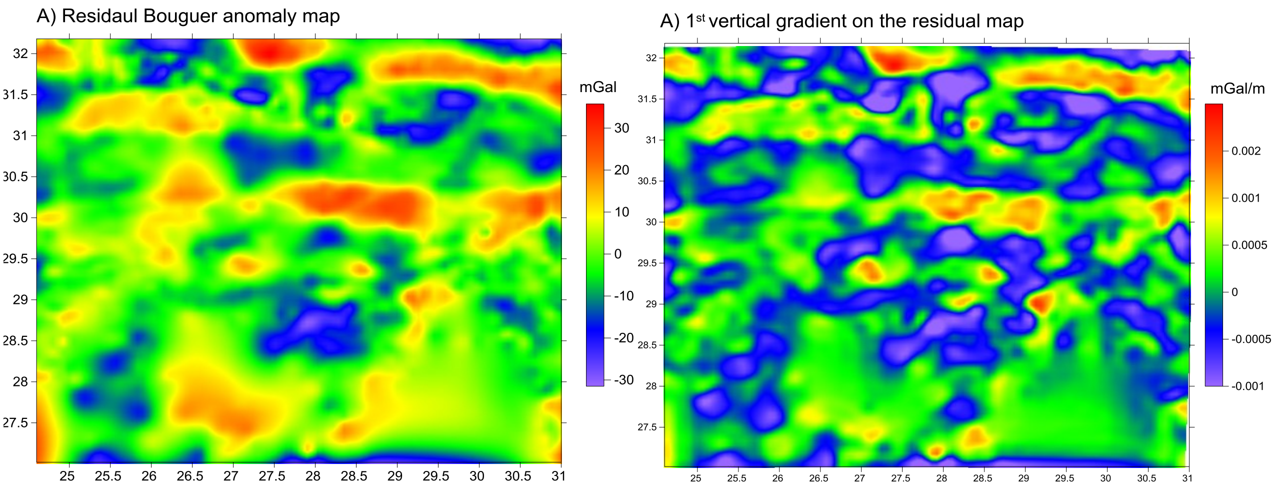
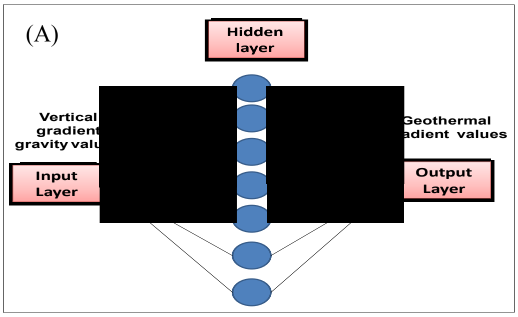


Figure 3: A) Bouguer anomaly map of the north Western Desert after separation of the regional field (residual anomaly); B) First-vertical gradient map for the residual data.

4. ARTIFICIAL NEURAL NETWORK (ANN)

The ANN uses training and learning process experience to build a system of neurons and weight links that allow it to make new decisions, classifications and predictions. Commonly, neural networks are adjusted, or trained, so that a particular input leads to a specific target output. In the present study, the Artificial Neural Network (ANN) method was used to build logical relationship between the geothermal gradient and the vertical gradient gravity values obtained from the first-vertical gradient gravity map. In all, 116 samples of data (temperature and gravity gradient) were used for training and testing the network; 93 samples for training and 23 samples for testing. The architecture of ANN is illustrated schematically in Figure 4A which consists of the input layer (gradient gravity values), and the output layer (geothermal gradient). After several attempts we found that using 7 neurons in the hidden layer gives the best fit between the observed and predicted data. For this, a back-propagation algorithm was used, a gradient descent system that tries to minimize the mean square error (MSE), for training the ANN. Figure 4B shows the error bars of all training samples (93 samples) using 10,000 Epochs for all training stages.



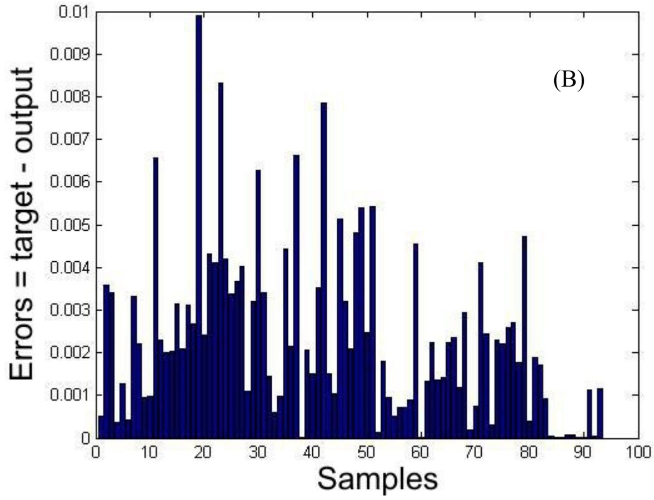


Figure 4: A) Architecture of the used ANN to correlate between gravity and temperature gradients; B) Error bars after 10,000 Epoch training of the data, i.e. the 93 samples.

The obtained correlation coefficient between the observed and predicted data was 0.7 in the training stage while it was 0.68 in the testing stage, which means that, although the geothermal gradient values cover a wide range, the network is able to follow the trend. Finally, we applied the well-trained ANN on the whole north Western Desert to obtain a developed geothermal gradient map based on gravity data (Figure 5).

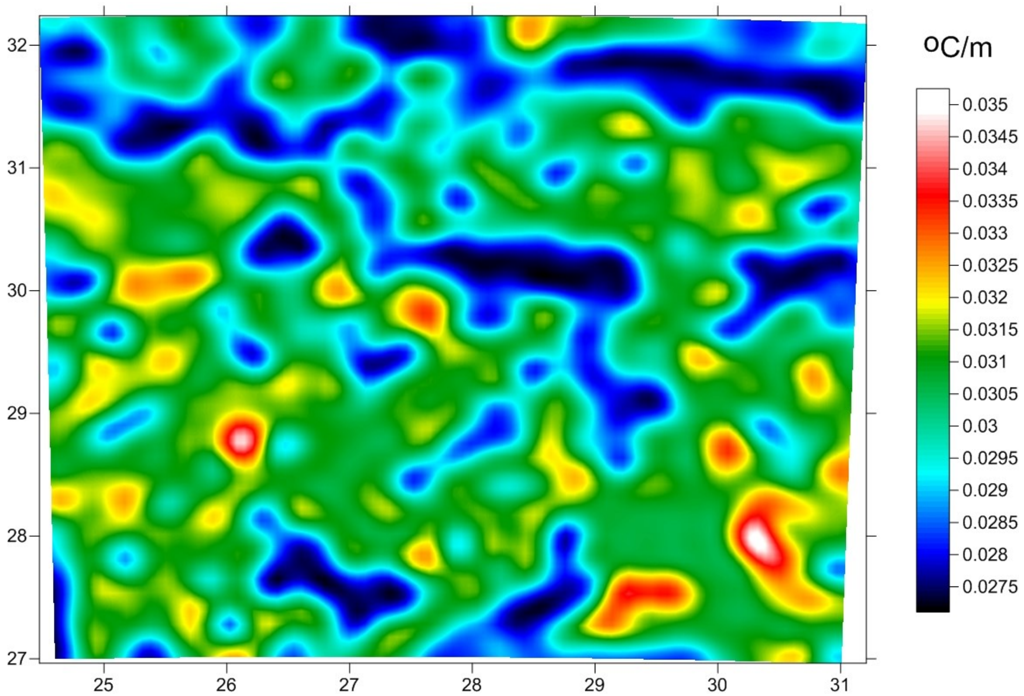


Figure 5: Gradient map based on low-pass filtering of the developed geothermal gradient map for all the north Western Desert using the gravity data.

The values of geothermal gradients ranged from 25 to 35C°/km. The highest gradient is located in some parts of latitude 29ºN, especially in the Bahariya Oasis. This increase might be due to existence of radioactive deposits in the Bahariya Oasis as well as iron ore deposits. On the other hand, the decreasing geothermal gradients northwards is due to the thickening of the sedimentary cover toward the Mediterranean Sea.

5. CONCLUSIONS

The artificial neural network (ANN) method gave a sound result, which is highly comparable or even better than conventional techniques. It proved to be a fast, accurate and objective method for correlating gravity with geothermal gradient and it performs best on new data. The new geothermal gradient map that was developed illustrates that the prominent geothermal gradient of the north Western Desert is low (25 – 35°C). The highest gradients, which are found in correlation with some depressions or oases may reflect a source of heat based on radioactive decay in the sedimentary rocks.

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