CATRINA (2007), 2 (1): 23 - 32

Geothermal Studies at Gebel El-Maghara Area, North Sinai, Egypt

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ABSTRACT

Geothermal studies were carried out at Gebel El-Maghara area at Wadi El-Safa, Wadi El-Murra, Wadi El-Rakb, and Wadi El-Massajid, where continuous temperature logs were recorded within 40 coal and groundwater exploration wells with depths ranging between 60 and 383 m. The obtained geothermal parameters are; amplitude of surface temperature (A), mean surface temperature (MST), geothermal gradient (GG), thermal conductivity (K), heat flow (Q), diffusivity (μ), and the regression coefficient (R^2). Regression analysis technique was used to estimate the geothermal gradient and the regression coefficient, whereas, the thermal conductivity values of the penetrated rock units were used for estimating the heat flow and diffusivity. Results of the geothermal studies exhibited that, there are three types of geothermal gradients at Gebel El-Maghara area represented by low, normal, and high geothermal gradients with values ranging between 25 and 39 ºC/Km. The surface temperatures obtained for the study area range between 25 and 29 ºC and the heat flow values range between 54-89.7 mWm^{-2}. The formation temperatures of the top of the coal bearing horizon, upper coal seam, and the main coal seam encountered in the study area were calculated. Relatively high geothermal gradient occurs at Wadi El-Rakb according to the presence of thick coal deposits and the structure controlling the area.
Key words: Gebel El-Maghara, Geothermal gradients, Thermal conductivity, North Sinai.

INTRODUCTION

Geothermal energy is the heat, which contained in the subsurface rocks and can be brought to the surface in the form of steam or hot water and converting it to electrical energy. Although Egypt is not characterized by abundant Cenozoic igneous activity, its location in the north eastern corner of the African plate suggests that it may possess geothermal resources, especially along its eastern margin (Morgan *et al.,* 1977). Geothermal studies were carried out at Gebel El-Maghara area, which is known as one of the most important structural elements at north Sinai belonging to the Syrian Arc System. Gebel El-Maghara area is located at the northern part of Sinai Peninsula between longitudes 33˚ 10' and 33˚ 35' E and latitudes 30˚ 35' and 30˚ 50' N (Fig. 1), where continuous temperature logs were recorded within 26 coal exploratory wells drilled at Wadi El-Safa, Wadi El-Murra, and Wadi El-Rakb and 14 wells drilled at Wadi El-Massajid just for groundwater production, in order to use these water in coal industry. The topography, surface rock conditions, type of host rock, tectonic regime, heat source and fluid type are controlling the geophysical characteristics of any geothermal field. Thermal gradient/heat flow technique and groundwater temperature/chemistry technique can be used for geothermal exploration in a given area (Luetscher *et al.,* 2004). Thermal gradient/heat flow technique was used in the present study to estimate the different geothermal parameters encountered in the concerned area. The direct goal of the present study is to explore new geothermal energy sites and evaluate the geothermal parameters at Wadi El-Safa, Wadi El-Murra, Wadi El-Rakb and Wadi El-Massajid at Gebel El-Maghara area.

GEOLOGICAL AND STRUCTURE SETTINGS

Gebel El-Maghara is located in North Sinai, 70 km south of the Mediterranean Sea. Gebel El-Maghara is a double plunging asymmetric anticline bearing N25˚ E to N60˚ E dipping gently to the north and steeply to the southeast (Fig. 1). This important structure belongs to the Syrian Arc System, which comprises several sub-parallel chains of elongate asymmetric anticlines, due to Late Cretaceous basin inversion (Neev, 1975), (Fig. 2). Stratigraphically, Gebel El-Maghara is composed of thick (~2000 m thick) Jurassic sediments, which are subdivided into six formations (Al-Far, 1966) arranged in ascending order as: Mashabbah, Rajabiyah and Shushah formations (Early Jurassic), Bir Maghara and Safa formations (Middle Jurassic) and Masajid Formation (Late Jurassic).

The tectonic evolution of North Sinai was influenced by extensional stresses related to the opening and the evolution of the Tethyan Ocean, as well as the orientation and position of the Pre-Cambrian basement fabrics and structures. Several recent syntheses of the tectonic setting of North Egypt as a whole and, especially, North Sinai are available (Moustafa and Khalil, 1989; Ayyad *et al*., 1998; Guiraud *et al*., 2001). The sedimentary successions in North Sinai were deposited in half graben sedimentary basins during the Early Mesozoic and were later inverted and folded during Early Cretaceous as a result of the Laramide compressive movements (Ayyad *et al*., 1998).

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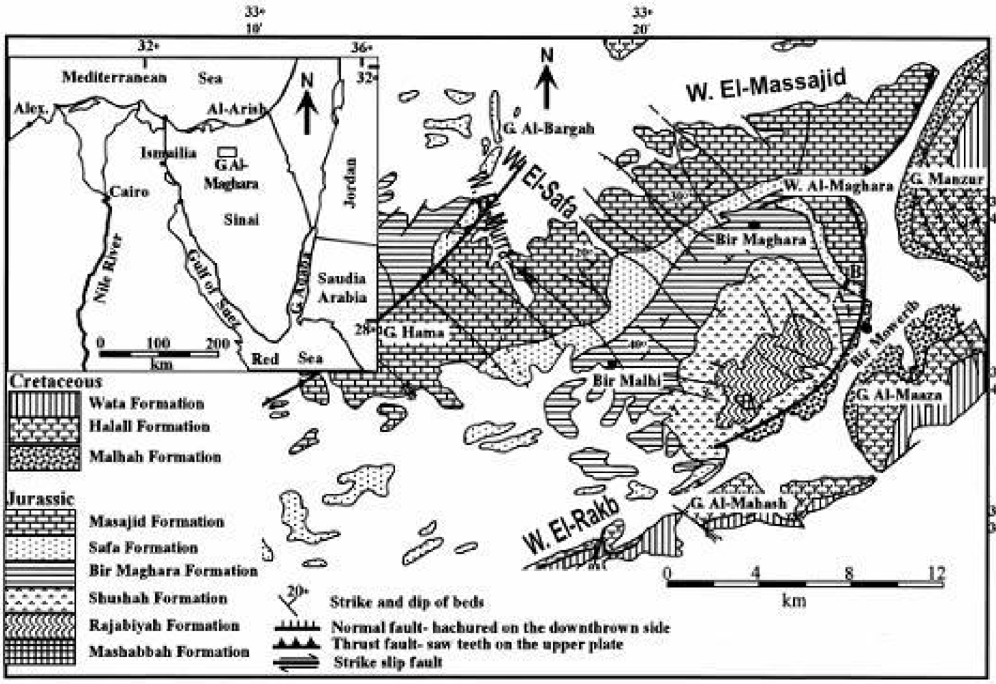

Figure (1): Location and simplified geologic map of Gebel El-Maghara, North Sinai, Egypt (modified after Egyptian Geologic Survey, 1993).

Structural studies across North Sinai indicated syn-depositional tectonism revealed by the abrupt thickening of Jurassic strata northward. For example, the Middle Jurassic succession attains thicknesses of 80 m at Gebel El-Minsherah (Issawi et al., 1999), 444 m at Gebel El-Maghara (Al-Far, 1966), and dramatically thickens northward to 780 m at Halal Well, 805 m at Giddi well and to 1800 m at Misri-1 Well (Ayyad et al., 1998).

The coal in Maghara Mine is found at Wadi El-Safa, Wadi El-Mura and Wadi El-Rakb, whereas Wadi El-Massajid has no coal and the drilled wells are for just groundwater resourse to use it in coal industry in the area. Saber (1986) estimated the workable coal seams in Maghara Mine at Wadi El-Safa, Wadi El-Mura and Wadi El-Rakb, and delineated that; (1) Coal seams at Wadi El-Safa are very similar to these located in Maghara coal mine with slight changes in depth. (2) Coal seams obtained from Wadi El-Mura are similar to those occur in Maghara coal mine but deeper. (3) Coal seams which were discovered at Wadi El-Rakb are different in thickness and deeper than aforementioned mines, where the upper coal seams at Wadi El-Rakb are thicker than the main coal seams. These changes resulted from the complex structure affecting Wadi El-Rakb area.

METHODOLOGY

Data used in the present study was obtained from two main projects carried out by the Egyptian Geological Survey and Mining Authority at El-Maghara area and the first author was the head of the scientific team of these projects. These two projects are concerned with coal exploration at Wadi El Safa, Wadi El Murra, Wadi El Rakb, and underground water exploration at Wadi El-Massajid.

Relation between temperature and depth

Generally this relation is given by straight line. Assume the temperature denoted by (Y) and the depth by (X), therefore the linear equation is;

$$Y = A + Bx$$

Where; A = Surface temperature and B = Geothermal gradient. In the present study computer program (SPSS) was used to evaluate A and B.

Thermal Conductivity

Thermal conductivity of the different rock units is very important for determining the heat flow, so the lithological sections of the study area are well known and the samples are obtained of the major rock units encountered in the study area for measuring the different thermal conductivity. A detailed lithologic section is available for each borehole drilled in the examined area as well. Abdine (1974) prepared a generalized stratigraphic column for the northern part of Egypt. This generalized stratigraphic column has been used to estimate the mean thermal conductivity of the rocks penetrated in the study area relevant to the northern Egypt geothermal gradient (Table 1) and some samples were checked at the laboratories of the Egyptian Geological Survey.

The generalized stratigraphic column is adapted from Abdine (1974). The average formation thicknesses (D) in m. Conductivities (K), are given in $Wm^{-1} K^{-1}$, and the bracketed numbers indicate the reference from which

Table (1): Generalized stratigraphic column at northern Egypt and assumed thermal conductivities (K).

AGE. Formation	D	Basic Rock Type	K
PLIOCENE (El Hammam Fm.)	58	Calcarenite and Sandy limestone	2.1 (1)
M. MIOCENE (Marmarica Fm.)	183	Limestone	2.2 (2)
L. MIOCENE (Moghra Fm.)	213	Sand and Gravel	2.1 (1)
OLIGOCENE and U. EOCENE (Ghoroud Fm.)	305	Shale	1.5 (3)
M and L. EOCENE (Guindi Fm)	122	Limestone	2.2 (2)
U. CRETACEOUS (Khoman Fm)	244	Chalk	1.8 (4)
U. CRETACEOUS (Abu Roash Fm.)	457	Limestone and Shale	2.0 (3)
U. and L. CRETACEOUS (Baharyia Fm)	488	Sandstone with Shale	2.6 (5)
L. CRETACEOUS (Kharita Fm)	219	Dolomite, Sandy dolomite, Limestone	3.8 (3)
L. CRETACEOUS (Alemein Fm.)	1219	Sandstone and Shale	2.6 (5)
U. JURASSIC (Alam El Bueib Fm)	305	Limestone and Shale	2.0 (3)
M. JURASSIC (Massajid Fm.)	610	Shale	1.8 (3)
L. JURASSIC (Khatatba Fm.)	207	Limestone	3.4 (6)
PERMIAN and CAMBRIAN (Yakout Fm.)	1829	Shale and Limestone	2.6 (5)
PRECAMBRIAN		Basement	2.9 (6)

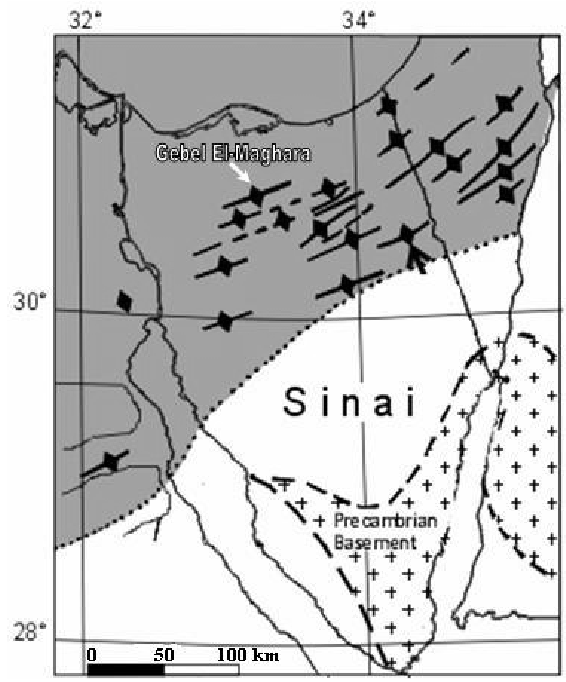

Figure (2): Syrian-arc-anticlines at north Sinai (modified after Neev, 1975).

the conductivity was determined; (1, 3, 4, and 6) estimated from Clark (1966) and (2 and 5) Coster (1947).

Heat Flow

Early observations in mines, which have later been confirmed by boreholes showed that temperature increases with depth, reaching over 6000°C in the inner part of the earth. Measured heat flows in the continental crust average 60 mWm^{-2} (Jessop, 1990). This heat flow value is leading to a geothermal gradient of about 30°C/km (Jessop, 1990). Preliminary heat flow values ranging from 42 to 175 mWm^{-2} have been estimated for Egypt from numerous geothermal gradient determinations (Morgan *et al.,* 1977). The heat flow value is based mainly on two factors, the geothermal gradient and the thermal conductivity of the penetrated rock units. David, *et al.* (1984) estimates the geothermal gradient and the heat flow by two methods;

1. *Thermal resistance method*

$$T_B = T_o + q_o \sum_{Z=0}^{B} \left(\frac{\Delta Z}{K}\right)$$

2. *Simple gradient method*

$$T_B = T_o + \left(\frac{\partial T}{\partial Z}\right) . B$$

$$q_o = K . \left(\frac{\partial T}{\partial Z}\right)$$

Where, T_o= Surface temperature, Z= Depth, K= Thermal conductivity, T_B= Bottom hole temperature, q_o= Surface heat flow.

Formation temperature

The temperature of a certain formation at depth (D) by using the geothermal gradient is given by Garvalk *et al.* (1977), as follows;

$$GG = 1000\ (Tf - Tm) / D\ °c/km$$

$$Tf = Tm + G.G\ (D/1000)\ °C$$

Where, GG=Geothermal gradient, T_m=Mean surface temperature, T_f=Formation temperature, D=Depth of formation.

The diffusivity

Bullard (1939) evaluate the empirical relation between the thermal conductivity (K) and the diffusivity (μ) as follow:

$$K = 1.3 \times 10^{-3} + 0.4\ \mu$$

Where, K=Thermal conductivity, μ=Diffusivity.

The mean surface temperature

The mean surface temperature (MST) which is used in this study is 26.7 ˚C. This value concords with the average surface temperature value of the Middle East, which is about 26.4 ˚C.

Well-logging devices used for measurements

Automatic well logging station type Aycks-1500 and Electronic thermometer type ATME-55 were used for measuring the continuous temperature logs inside 40 coal and groundwater exploratory boreholes drilled at Wadi El-Safa, Wadi El-Mura, Wadi El-Rakb and Wadi El-Massajid.

RESULTS

Wadi El-Safa

Wadi El-Safa is considered the most important valley at Gebel El-Maghara (Fig. 1), where a lot of coal mines are located. This wadi appears to be running along a fault plain, which takes the NW-SE direction parallel to the major structural trend of the area and located at the footstep faults occurring to the west of horst structure representing the shallowest area for the subsurface coal bearing horizon.

Geological and geophysical studies were carried out within 6 wells up to depth range between 90 and 220 m. The results of studies show that the area is characterized by shallow depths of the upper coal seam and main coal seam with large reserves that could be added to Maghara coal mine reserves (Saber, 1986), (Fig. 3).

Table (2): Formation temperature of the coal bearing horizon at Gebel El-Maghara area.

Well Name	Formation Temperature (°C)		
	C.B.Z	U.C.S	M.C.S
El Safa-1	27.5	28.1	28.3
El Safa-2	26.3	26.8	26.95
El Safa-3	26.3	26.9	27.1
El Safa-4	26.5	27	27.2
El Safa-5	28.3	28.97	29.2
El Safa-6	28.7	29.1	29.3
El Murra-8	33.6	34.4	34.7
El Murra-9	32.2	33.11	33.3
El Murra-10	32.45	33.1	33.22
El Murra-11	32.3	33.11	33.41
El Rakb-5	32.3	33.7	-
El Rakb-6	32.3	33.8	34.3
El Rakb-7	33.9	35.4	-
El Rakb-8	37.9	39.4	39.7
El Rakb-9	32.6	34.1	-
El Rakb-10	33.3	34.8	35.3
El Rakb-11	35.3	37.1	37.56
El Rakb-12	36.14	37.5	37.86
El Rakb-13	33.2	34.4	34.8
El Rakb-14	34.9	36.3	-
El Rakb-15	37.9	39.3	39.7
El Rakb-16	36.96	38.3	38.7
El Rakb-20	37.2	39.2	39.5

C.B.Z = Coal Bearing Horizon, **U.C.S** = Upper Coal Seam, **M.C.S** = Main Coal Seam

The subsurface section penetrated by B.H. El-Safa-1 is represented by El-Safa Formation of Middle Jurassic age and consists mainly from shale, marl, sandstone and less limestone. The mean thermal conductivity of these rock units is 2.4 $Wm^{-1} K^{-1}$. The temperature log carried out inside B.H. El-Safa-1 shows gentle slope and remarkable increase opposite to the coal bearing horizon (Fig. 4). The formation temperatures of the tops of coal bearing horizon, upper coal seam and main coal seam were found and the results are shown at (Table 2).

The relation between the depth (D) and the temperature (T) at Wadi El-Safa is represented by (Table 3) and (Fig. 5) and is given by the equation;

$$T = 25.5 + 0.025\ D$$

Regression analysis was carried out on data obtained from continues temperature logs. The mean surface temperature (MST), geothermal gradient (GG) and regression coefficient (R^2) of Wadi El-Safa are 25.5° C, 25° C/Km and 0.94 respectively (Table 4). The values of the heat flow (Q) and the diffusivity (μ) are 60 mWm^{-2} and 5.9, respectively (Table 4). The different geothermal parameters, which characterized Wadi El-Safa, are given in (Table 4). According to these results, Wadi El-Safa has low geothermal gradient.

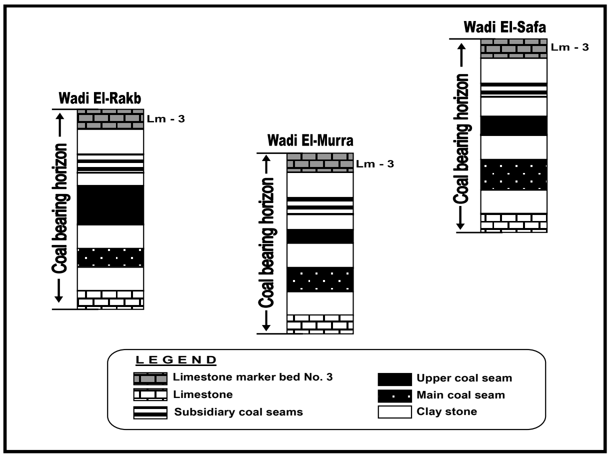

Figure (3): Correlation sketch of coal bearing horizon at Gebel El-Maghara area.

Table (3): Temperature-depth relations at Gebel El-Maghara area, north Sinai.

Wadi El-Safa	D (m)	10	20	60	70	110	120	160	170	210	230
	T (°C)	25.8	26	27	27.3	28.3	28.5	29.5	29.8	30.8	31.1
Wadi El-Murra	D (m)	10	20	60	70	110	120	160	170	210	310
	T (°C)	26.3	26.5	27.6	27.9	29	29.2	30.3	30.6	31.7	34.4
Wadi El-Rakb	D (m)	10	40	70	100	130	160	190	220	250	300
	T (°C)	29.8	31	32.1	33.3	34.5	35.6	36.8	38	39.2	41.1
Wadi El-Massajid	D (m)	10	40	70	100	130	160	190	220	250	300
	T (°C)	26.8	27.6	28.4	29.2	30	30.3	31.6	32.4	33.3	34.6

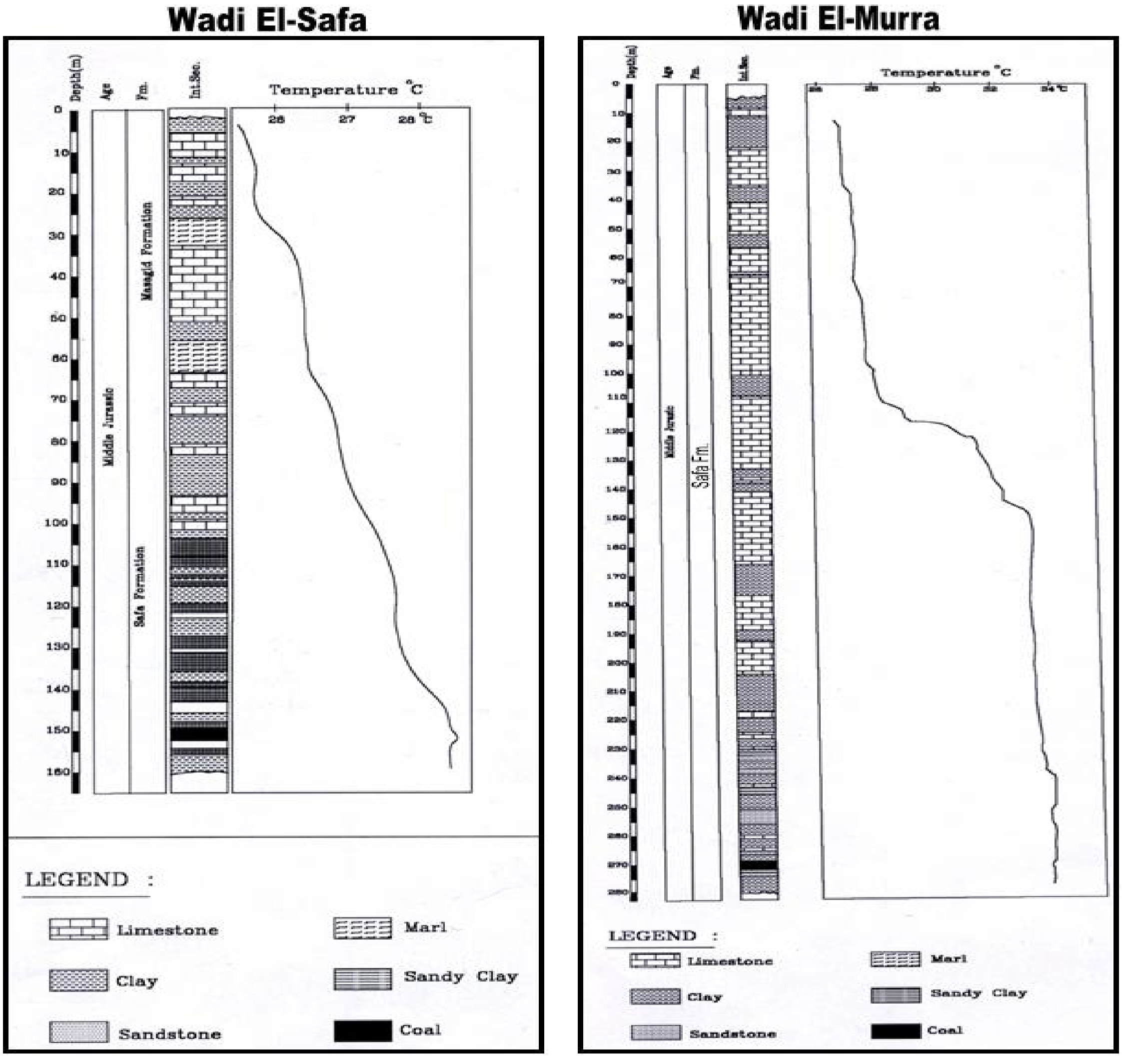

Figure (4): Temperature – Depth Curves at Wadi El-Safa B.H.No. 1 and Wadi El-Murra B.H.No. 9.

Wadi El-Murra

Wadi El-Murra is located to the west of Wadi El-Safa (Fig. 1). The major structure affected Wadi El-Murra is the same as Wadi El-Safa, where the affected fault takes the NW-SE trend. This trend is a part of the regional trend, which affected the northern limp of the double plunging anticline of the major structure of El-Maghara area. Geological studies show that the coal seams in the subsurface section of Wadi El-Murra are deeper than those of Wadi El-Safa due to the structure affected the area (Fig.3).

Table (4): Geothermal parameters for the study area.

Location	A	T_0	G	Q	R^2	K	μ
Wadi El- Safa	15	25.5	25	60	0.94	2.4	5.9
Wadi El-Murra	17	26	27	59.4	0.95	2.2	5.5
Wadi El-Rakb	16	29.4	39	89.7	0.91	2.3	5.7
Wadi El-Massajid	14	26.5	27	54	0.90	2.0	5

A = Amplitude of surface temperature ˚C., R^2 = Coefficient of determination, T_0 = Mean surface temperature ˚C, μ = Thermal diffusivity ($\times 10^{-3}$ Cm². Sec^{-1}), Q = Heat flow ($\times 10^{-6}$ Cal. Cm^{-2}. Sec^{-1}) G = Geothermal gradient ($\times 10^{-4}$ ˚C.Cm^{-1}), K = Thermal conductivity ($\times 10^{-3}$ Cal. ˚C^{-1} .Cm^{-1}. Sec^{-1}).

Geological and geophysical studies were carried out within 4 coal exploration wells up to depth range between 279 and 383 m. The results show that, the upper coal seam and the main coal seam encountered in Wadi El-Murra are similar to those occurring at Wadi El-Safa area, but deeper in depth due to the structure affected the area (Fig.3). The coal reserves at Wadi El-Murra are considered the second addition coal reserves for El-Maghara coal mine after those obtained from Wadi El-Safa.

The subsurface section penetrated by B.H. El-Murra-9 is represented by El-Safa Formation of Middle Jurassic age and consists mainly from limestone, shale and less sandstone. The mean thermal conductivity of these rock units is 2.2 Wm^{-1} K^{-1}, similar to the rock units of Wadi El-Safa. The temperature log carried out inside B.H. El-Murra-9 show low geothermal gradient up to depth 115 m followed by rapid increase in temperature at depth from 115 to 150 m, and then becomes constant until the bottom (Fig. 4). The formation temperatures of the tops of coal bearing

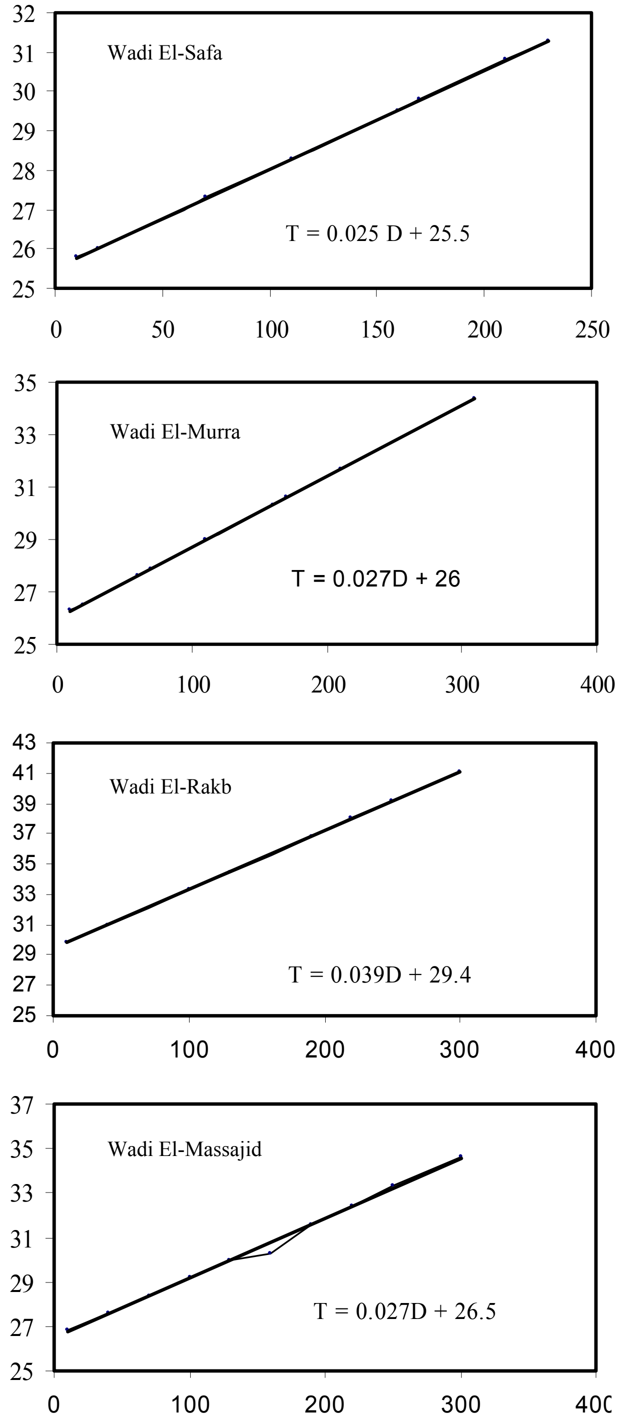

Figure (5): The relations between depth (m) and temperature (˚C) of the study area.

horizon, upper coal seam and main coal seam were estimated and the results are shown in (Table 2).

The relation between the depth (D) and the temperature (T) at Wadi El-Murra is represented in (Table 3) and (Fig. 5) and is given by the equation;

$$T = 26 + 0.027\,D$$

The mean surface temperature (MST), geothermal gradient (GG) and regression coefficient (R^2) of wadi El-Murra are 26° C, 27° C/km and 0.95 respectively (Table 4). The values of the heat flow (Q) and the diffusivity (μ) are 59.4 mWm^{-2} and 5.5, respectively (Table 4). The different geothermal parameters, which characterized Wadi El-Murra, are given in (Table 4). According to the results obtained, Wadi El-Murra have normal geothermal gradient.

Wadi El-Rakb

Wadi El-Rakb is located to the south of wadi El-Murra (Fig. 1). The major structure affected this wadi is represented by Ras Wagiba fault extending in NW-SE trend. Series of faults (step faults) are located to the west from this major fault. This system of faults is considered as a part of the regional system of El-Maghara area. The complex structure affected Wadi El-Rakb is owing to make the subsurface coal seam deeper to the north of Ras Wagiba fault than the southern area.

Geological and geophysical studies were carried out inside 16 coal exploration wells up to depth range between 260 and 330 m. The results show that, the upper coal seam and the main coal seam occurring in the subsurface section at Wadi El-Rakb are different from those Wadi El-Safa and Wadi El-Murra. The upper coal seam in Wadi El-Rakb is thicker than the main coal seams. Also the upper and the main coal seams at Wadi El-Rakb are located deeper than that found at Wadi El-Safa and Wadi El-Murra (Fig. 3). These two differences are due to the complex structure affected Wadi El-Rakb area. Wadi El-Rakb is considered the third addition reserves to El-Maghara coal mine reserves and may become the most economic one in the future.

The subsurface section penetrated by B.H. El-Rakb-8 is represented by El-Safa Formation of Middle Jurassic age and consists mainly from limestone, marl and less sandstone. The mean thermal conductivity of these rock units is 2.3 $Wm^{-1}\,K^{-1}$, similar to the rock units of Wadi El-Safa and Wadi El-Murra. The temperature log carried out inside B.H. El-Rakb-8 show high geothermal gradient, where is noticed a larger increase in temperature with depth (Fig. 6). The formation temperatures of the tops of coal bearing horizon, upper coal seam and main coal seam were estimated and the results are shown in (Table 2). The relation between the depth (D) and the temperature (T) at wadi El-Rakb is represented in (Table 3) and (Fig. 5) and is given by the equation;

$$T = 29.4 + 0.039\,D$$

The mean surface temperature (MST), geothermal gradient (GG) and regression coefficient (R2) of wadi El-Rakb are 29.4° C, 39° C/Km and 0.91 respectively.
The values of the heat flow (Q) and the diffusivity (μ) are 89.7 mWm-2 and 5.7, respectively. The different geothermal parameters, which characterized Wadi El-Rakb, are given in (Table 4). According to the obtained results Wadi El-Rakb has high geothermal gradient correlated with aforementioned wadis.

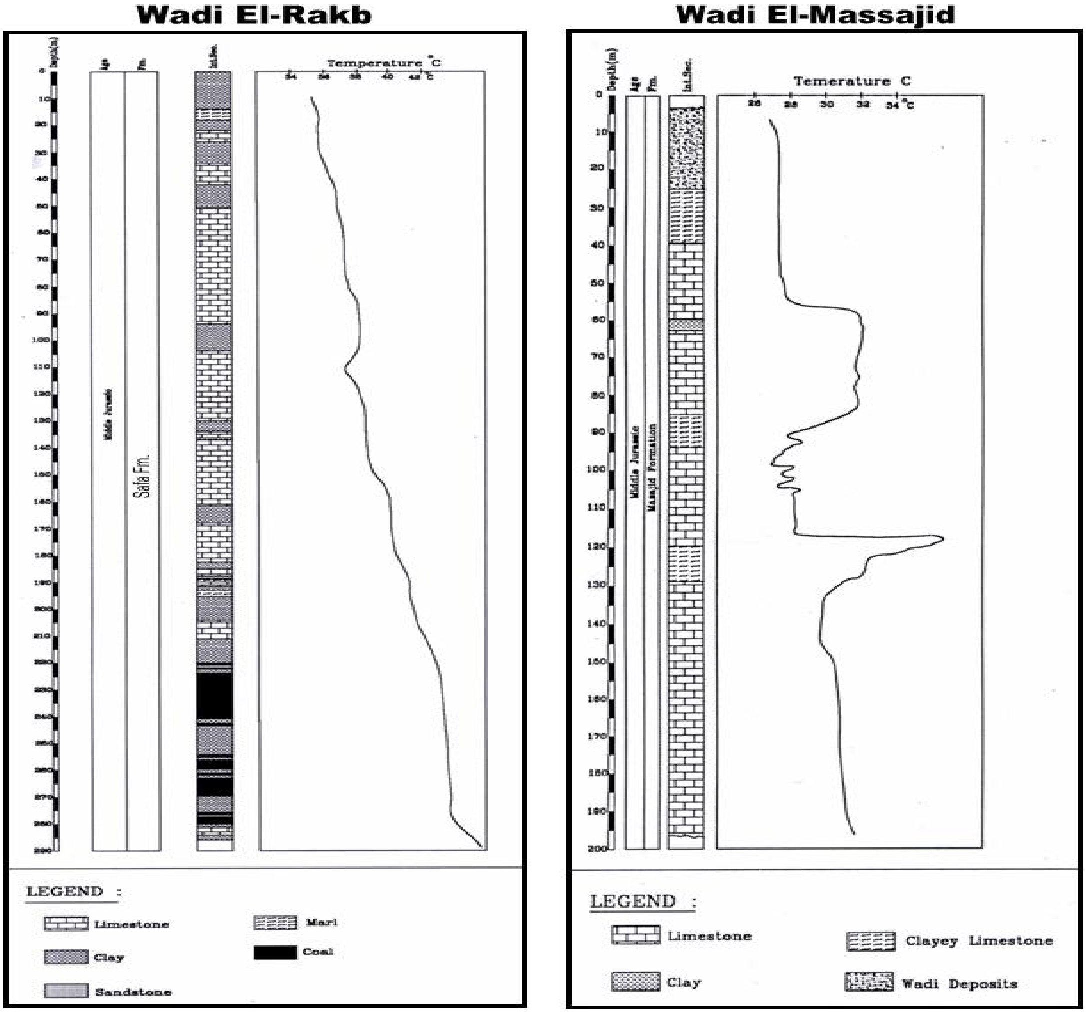

Figure (6): Temperature – Depth Curves at Wadi El-Rakb B.H.No.8 and Wadi El-Massajid B.H.No. 2

Wadi El-Massajid

Wadi El-Massajid is located to the northern flanks of the double plunging anticline of Gebel El-Maghara (Fig. 1). Wadi El-Massajid separates between the Middle Jurassic exposed of Gebel El-Maghara and the surrounding chalky limestone rocks of Lower Cretaceous age. The exposed rock unit at Wadi El-Massajid is Massajid Formation (marine facies), representing cycle number six and caped the Jurassic section at Gebel El-Maghara area.

Extensive geological and geophysical studies were carried out for water exploration, needed for the coal exploration and development of the area. 14 water exploratory wells were drilled up to depth range between 60 and 315 m. The results show that, the water bearing horizon is represented by fractured chalky limestone of Massajid Formation. The thickness of the water bearing zones varies from 118 and 120 m below earth surface and average salinity is 3500 ppm.

The subsurface section penetrated by B.H. El-Massajid-2 is represented by El-Massajid Formation of Upper Jurassic age and consists mainly from limestone and marl (marine facies). The mean thermal conductivity of the subsurface rock units penetrated by the water exploratory wells at Wadi El-Massajid is 2.0 $Wm^{-1} K^{-1}$, lower than those of Wadi El-Safa, Wadi El-Murra and Wadi El-Rakb. The temperature log carried out inside B.H. El-Massajid-2 shows an increase in temperature opposite two zones; the first at depth ranges from 55 to 90 m, whereas the second ranges from 120 to 130 m in depth. These intervals are corresponding to aquifer zones (Fig. 6).

The relation between the depth (D) and the temperature (T) at Wadi El-Massajid is represented in (Table 3) and (Fig. 5) and is given by the equation;

$$T = 26.5 + 0.027\ D$$

Regression analysis was carried out on data obtained from continues temperature logs. The mean surface temperature (MST), geothermal gradient (GG) and regression coefficient (R^2) of Wadi El-Massajid are 26.5°C, 27°C/km and 0.90, respectively. The values of the heat flow (Q) and the diffusivity (μ) are 54 mWm^{-2} and 5, respectively (Table 4). The different geothermal parameters, which characterized Wadi El-Massajid, are given in (Table 4). According to the results obtained, Wadi El- Massajid have normal geothermal gradient.

Relatively to the standard geothermal gradient, which is ~30˚C/Km (Jessop, 1990), Wadi El-Safa has low geothermal gradient 25˚C/Km, Wadi El-Murra and Wadi El-Massajid has normal geothermal gradient 27˚C/Km and Wadi El-Rakb has high geothermal gradient 39˚C/Km (Fig. 7 - A). The surface temperature and the heat flow at these different wadis were influenced by the values of the geothermal gradients (Fig. 7-B and C).

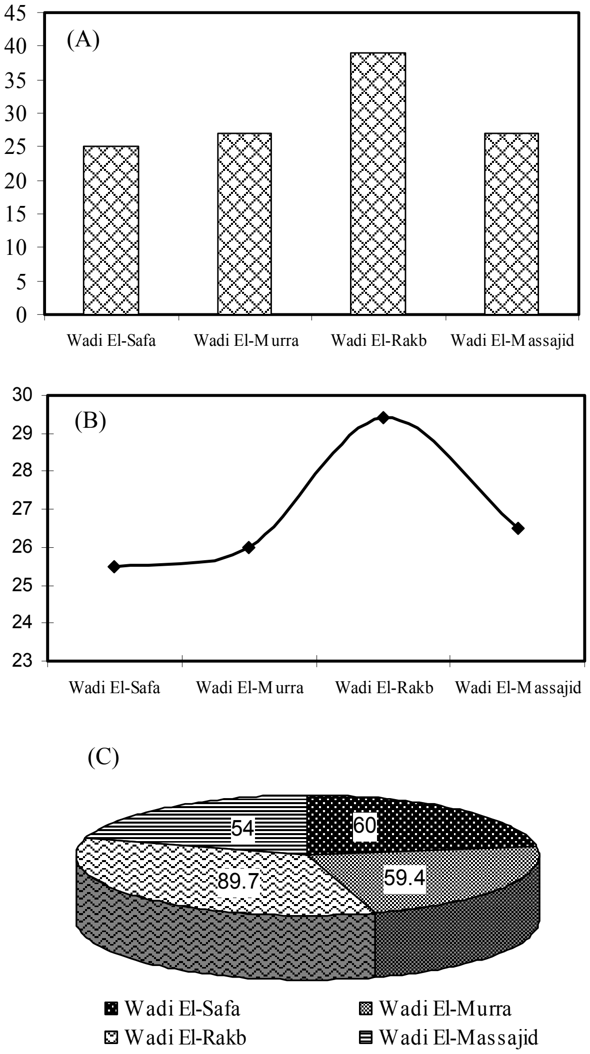

Figure (7): (A) Bar diagram of geothermal gradient, (B) Curve of surface temperature and (C) Pie-shape of Heat flow at Gebel El-Maghara area.

DISCUSSION

Geothermal energy is the heat, which contained in the subsurface rocks and brought to the surface in the form of steam or hot water and converting it to electrical energy. Geothermal studies were carried out at Gebel El-Maghara area at Wadi El-Safa, Wadi El-Murra, Wadi El-Rakb and Wadi El-Massajid for exploring new geothermal energy sites.

Continuous temperature logs were recorded inside 40 wells in Gebel El-Maghara area for groundwater and coal exploration. The different geothermal parameters; amplitude of surface temperature (A), mean surface temperature (MST), thermal conductivity (K), heat flow (Q), diffusivity (μ) and the regression coefficient (R^2) were estimated to evaluate the geothermal gradient in each wadi encountered in the area concern. The thermal conductivities of the subsurface penetrated rock units were estimated from Abdine (1974) and some samples were checked at the laboratories of the Egyptian Geological Survey.

Three types of geothermal gradient were given at Gebel El-Maghara area as follow; low geothermal gradient 25˚C/km is encountered in Wadi El-Safa, normal geothermal gradient 27˚C/km at both Wadi El-Murra and Wadi El-Massajid and high geothermal gradient 39˚C/km at Wadi El-Rakb. High geothermal gradient were recorded at Wadi El-Rakb due to the structure affected the area and the presence of thick coal deposits especially the upper coal seam, which is considered an exothermal body. Wadi El-Rakb is a promising area for new clean energy resource (geothermal energy), coal resource and water resource. These resources can be used for developing Gebel El-Maghara area.

ACKNOWLEDGMENTS

The authors would like to express their deep gratitude to the members of the coal project team work of Geological Survey of Egypt; Geoph. Hamed, S. Saber, Geoph. Mohamed, R. El Nouby and technitions Aly, A. El Said and Ramadan, T. Mohamed.

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Received October 18, 2006
Accepted March 26, 2007

CATRINA (2007), 2 (1): 23- 32

دراسات جيوحرارية في منطقة جبل المغارة، شمال سيناء، مصر

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الملخص العربـــى

تعتمد الدراسة علي القياسات الجيوحرارية التي تم تسجيلها في منطقة جبل المغارة في كل من وادى الصفا، وادى المره، وادي الركب ووادى المساجد عن طريق الرصد الحرارى المستمر داخل 40 بئراً إستكشافياً للفحم والمياه الجوفية فى منطقة جبل المغارة وقد تم حساب العوامل الجيوحرارية المختلفة مثل؛ مدى الحرارة السطحية (A)، متوسط الحرارة السطحية (MST)، التدرج الحرارى (GG)، التوصيلية الحرارية (K)، السريان الحرارى (Q)، الإنتشار الحرارى (K) ومعامل الإرتداد (R^2) للوحدات الصخرية تحت السطحية بالمنطقة.

وبإستخدام طريقة التحليل الإرتدادى تم حساب التدرج الحرارى ومعامل الإرتداد كما إستخدمت قيم معامل التوصيل الحرارى للوحدات الصخرية تحت السطحية المختلفة التي تم حفرها فى حساب قيم السريان الحرارى و الإنتشار الحرارى وقد أوضحت النتائج الجيوحرارية أن هناك ثلاث أنواع من التدرج الحراري فى منطقة الدراسة هم؛ تدرج حرارى ضعيف، تدرج حرارى متوسط و تدرج حرارى مرتفع بقيم تتراوح ما بين (25 – 39 ˚C/km) وتتراوح الحرارة السطحية مابين (25 - 29 ˚C) كما تتراوح قيم السريان الحرارى ما بين (54 – 89.7 mWm^{-2}). كما تم حساب درجات الحرارة للأسطح العلوية للنطاق الحاوى علي الفحم والطبقة العلوية للفحم والطبقة الرئيسية للفحم ومن خلال الدراسة تبين أن وادى الركب به أعلى تدرج حرارى وهو يعتبر مرتفعاً مقارنة بالنسبة العالمية وذلك بسب الحركات التكتونية التى أثرت على منطقة الدراسة ووضع رواسب الفحم داخل هذا الوادى.