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GEOTHERMAL GRADIENTS INSIDE WATER WELLS OF EAST OWEINAT AREA, SOUTH WESTERN DESERT OF EGYPT

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The regional geothermal pattern of Egypt has been previously defined from bottom hole temperature data inside oil wells in Northern Egypt and Gulf of Suez. For the same objective, geothermal gradient/heat flow determinations have also been conducted inside existing mineral exploration and water wells in Eastern Egypt and in Kharga Oasis in Western Desert as well as inside specially drilled regional gradient shallow boreholes in Eastern Egypt. To complement the regional geothermal picture in the southern part of Egypt, temperatures were measured inside seven water wells in a remote area in the south Western Desert at East Oweinat. The average calculated temperature gradient was found to amount to 12 mK/m, a value similar to that obtained from bottom hole temperature/depth relationship of deep artesian wells at Dakhla Oasis 300 km to the north, but much less than the normal gradient amounting to 20 mK/m in Northern Egypt. The data obtained emphasize the extension of the low heat flow province of the Mediterranean north of Egypt to its southern border with Sudan.

A distribuição regional de fluxo geotérmico no Egito foi previamente definida a partir de temperaturas de fundo de poço medidas em poços de petróleo no norte do Egito e no golfo de Suez. Com o mesmo objetivo, determinaçoẽs de gradientes térmicos e de fluxo de calor foram realizadas em poços para exploração mineral e de água no leste do Egito e no oasis de Kharga no deserto ocidental, assim como em poços rasos especialmente perfurados no leste do Egito. Para complementar a representação do fluxo térmico regional na parte sul do Egito, foram medidas temperaturas em sete poços de água em uma área remota no deserto do sudoeste em East Oweinat. O gradiente térmico médio encontrado é de 12 mk/m, valor similar ao obtido a partir de relaçoẽs de temperatura de fundo de poço/profundidade de poços artesianos profundos no oásis de Dakhla 300 quilômetros mais ao norte, mas muito inferior ao gradiente geotérmico normal de 20 mk/m encontrado no norte do Egito. Os dados obtidos enfatizam a extensão da província de baixo fluxo térmico do norte mediterrâneo do Egito para a sua fronteira sul com o Sudão.

(Traduzido pela Revista)

INTRODUCTION

Regional geothermal measurements in Egypt started since mid-seventies (e.g. Tewfic, 1975; Morgan et al., 1977). First attempts to define the geothermal pattern in Egypt were made by collecting Bottom Hole Temperature (BHT) data from oil wells in northern Western Desert of Egypt/Nile Delta region and Gulf of Suez region (Fig. 1). The mean geothermal gradients estimated from BHT data in 128 oil wells in northern Egypt and 38 oil wells in the Gulf of Suez (Figs. 2 and 3) by Morgan et al. (1977) were found to be 20.6 ± 5.0 mK/m (°C/km) respectively showing that the gradient in the Gulf is higher than in Northern Egypt by about 30%.

The mean heat flow for Northern Egypt was estimated to lie in the range of 42-47 mW/m² (Morgan et al., 1977) assuming a mean thermal conductivity of the rocks in this region of 2.0-2.3 W/m/K. This range is consistent with uniformly low heat flow values reported for the eastern Mediterranean region (30-45 mW/m²: Ryan et al., 1970; Erikson, 1970; Morgan, 1975). The low heat flow is interpreted as resulting from a stable mantle heat flow contribution with very low heat production in the upper crust.

Heat flow estimates have been later extended by more conventional geothermal gradient and heat flow measurements in 56 mineral exploration and water wells at 13 sites mostly concentrated in the Eastern Desert of Egypt (Morgan et al., 1980 and 1983) where temperatures were measured at 5 m intervals in the boreholes. Many of the estimated heat flow values for Eastern Egypt are relatively high in contrast with Western Egypt. Previous studies have been supplemented by geothermal gradient and heat flow investigations in 12 specially-drilled regional-gradient shallow boreholes (⩾ 100-150 m) in Eastern Egypt (Morgan et al., 1980, 1983, 1985). Morgan et al., 1985 found that heat flow well away from the Red Sea is probably in the range 3555 mW/m² and appears to increase relatively rapidly

3040 km of the Red Sea coast to 75-100 mW/m². The postulated thermal anomaly along the Red Sea margin with heat flow about 100 mW/m² appears to be related with the Red Sea opening and is primarily caused by high mantle heat flow causing lithospheric thinning centered beneath the Red Sea.

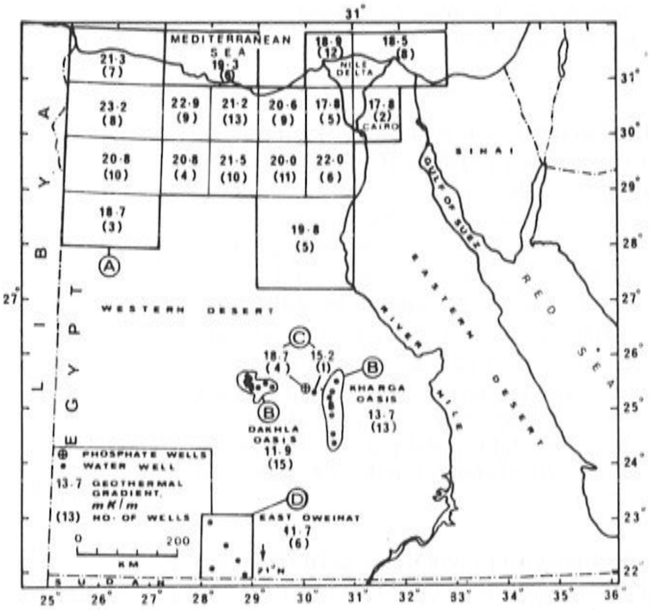

Figure 1 — Map of Egypt showing data of geothermal gradients in Western Egypt compiled from previous studies (A: Morgan et al., 1977; B: Swanberg et al., 1983; C: Morgan et al., 1980) and present study (D).

In the Western Desert, the surface water temperatures of artesian or continuously pumped water wells at Dakhla and Kharga Oases (Fig. 1) have been used to reflect the BHT and estimate the geothermal gradient in these regions (Swanberg et al., 1976 and 1983). Average gradients obtained at these oases by least squares linear regression analysis of measured surface temperatures of water wells amounted to 13.7 mK/m for 6 artesian and 7 continuously pumped wells (160-768 m deep) at Kharga Oasis and 11.9 mK/m for 15 artesian wells (280-1220 m deep) at Dakhla Oases.

In the present study, geothermal measurements have been conducted inside seven water wells drilled to basement to depths of 120-493 m in the south Western Desert of Egypt at East Oweinat in the vicinity of the Egyptian border with Sudan (Fig. 4). The temperatures data collected from the accessible logged depths (120280 m) were used to throw light on the geothermal pattern at the southernmost part of Western Egypt. The wells have been drilled by the General Petroleum Company in Egypt to evaluate the groundwater reservoir in the area. The aquifer which has been investigated in this area contains a low-salininty water which will be used to irrigate several thousands of feddans required for agricultural development in this remote area (El-Barkouky et al., 1979).

GEOLOGICAL SETTING

The area under investigation is almost flat with ground elevations at the wells ranging from 280 to 360 m

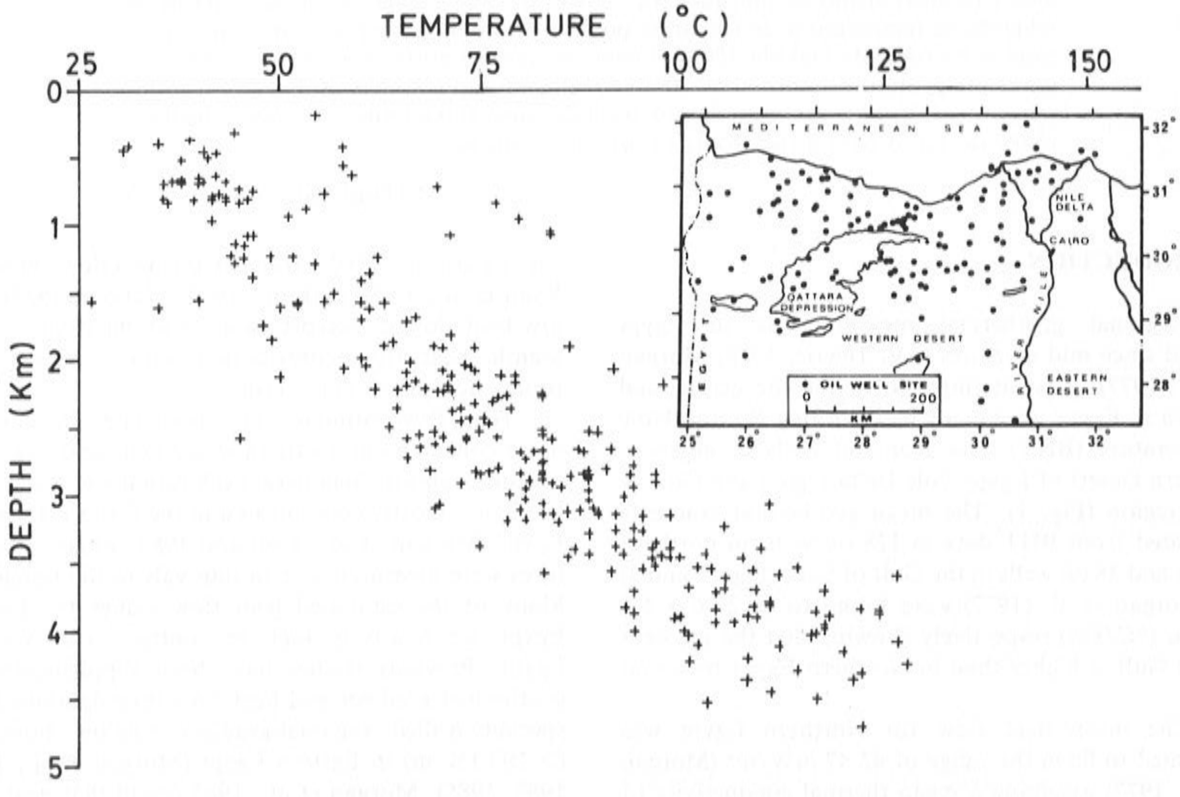

Figure 2 —Data of 289 BHT vs depth in Northern Egypt from 128 oil wells with their sites shown in the inset map (after Morgan et al., 1977).

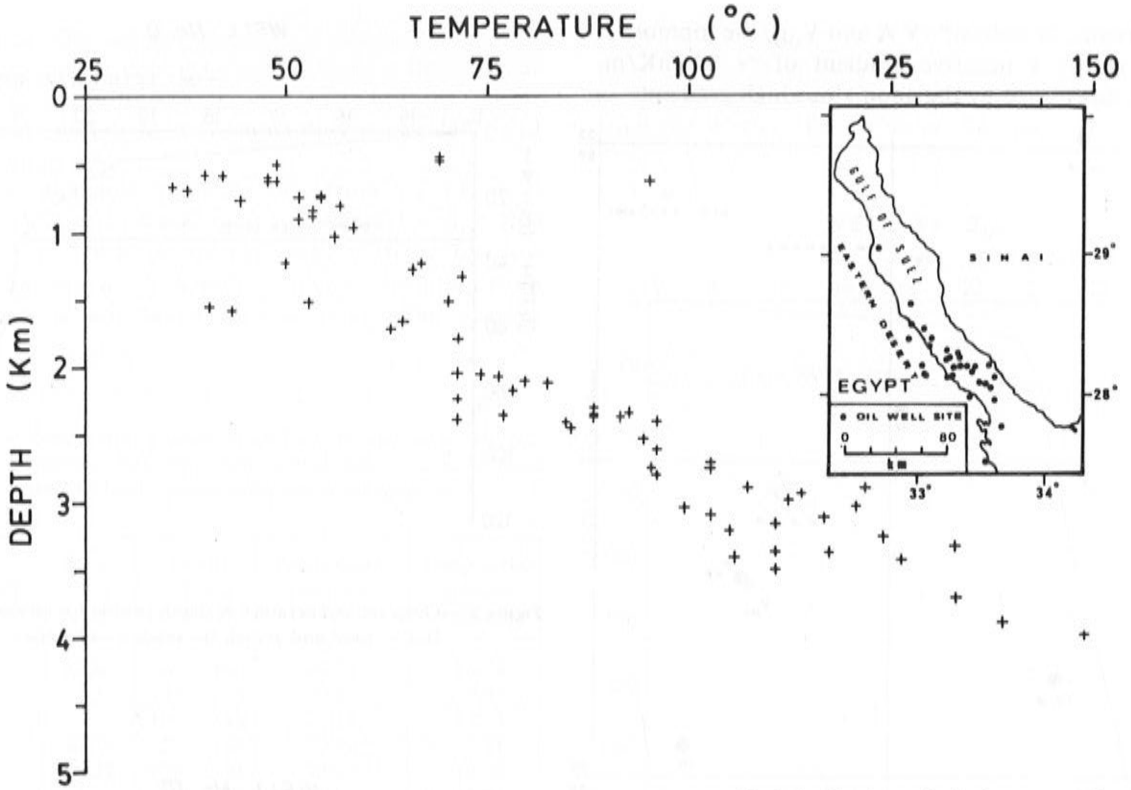

Figure 3 —Data of 76 BHT vs depth in the Gulf of Suez region from 38 oil wells with their sites shown in the inset map (after Morgan et al., 1977).

above sea level and covered by 2-3 m of Quaternary deposits of sands and gravels. The geological section as observed inside drilled wells consists of sands and sandstones in the upper horizon, and sandstones, siltstones, and clays at depth. The main formation underlying the Quaternary deposits is referred to as the **Nubian sandstone** (Cretaceous-Jurassic ?) and is lithologically porous sandstone (disregarding the siltstone and clays intercalations found at different horizons and localities). The thickness of this sandstone horizon ranges in the study area (Fig. 4) from 200 to 1000 m and exceeds 1700 m in the wider area bounded between 22° and 25° N & 27° and 31° E (El-Barkouky et al., 1979). The basement rocks outcrop about 15 km NE at Bir Tarfawi (Fig. 4), extend northeastward for about 45 km in an area of about 1500 km² (El-Barkouky et al., 1979), and appear at a depth of 257 m from the surface in well n? III (Fig. 4).

TEMPERATURE MEASUREMENTS

Temperatures were measured inside water wells using thermistor thermometer probe at 5 m intervals (except at wells nos. V_{pr} and V_{ob} (Fig. 4) where measurements were taken at 1 m interval from the surface to a depth of 14 and 11 m respectively). The precision of measurements is 0.01°C.

At each measuring depth, electrical resistance readings of the probe were recorded every 1/2 minute till 3 consecutive constant readings were obtained with a maximum period of 8 minutes from leaving the probe in position. In all the wells, at almost all horizons in the water column, the probe equilibrates very rapidly (< 1/2 min) with its surroundings and the recorded reading of the probe resistance (and accordingly the corresponding temperature) does not change completely in the first two minutes of leaving the probe in position. On the other hand, in the air column, the resistance of the probe was varying very rapidly indicating that the probe equilibrates relatively slowly with its surroundings. Accordingly, a series of resistance measurements vs time were made at each level and extrapolated to equilibrium conditions to obtain at infinite time the resistance, the corresponding temperature of which is estimated from calibration tables and represented on the temperature profile. Equilibrated temperature data were plotted vs depth for the logged wells n?s II, III, IV A, V_{pr}, V_{ob}, VI A, W. Selima-1 shown in Figs. 5-11 respectively.

GEOTHERMAL GRADIENT

It has been noticed that the temperature-depth profiles (Figs. 5-11) inside water wells are characterized in general by high temperature gradients for temperature measurements taken in the air column above the water table and relatively low gradients in the water column. The highest gradients in all wells (with the exception of wells n?s IV A and V_{ob}) are restricted to the uppermost 10 m horizon and amount to ~ 300-570 mK/m followed downward by segments on the temperature profile showing progressively decreasing gradients (~30-60 mK/m), i.e. 10 times lower in the underlying 25-

40 m-horizon. In wells n^{os} IV A and V$_{ob}$, the topmost 5 m-layer shows a negative gradient of ~ 90 mK/m followed downward by the anomalous high gradient.

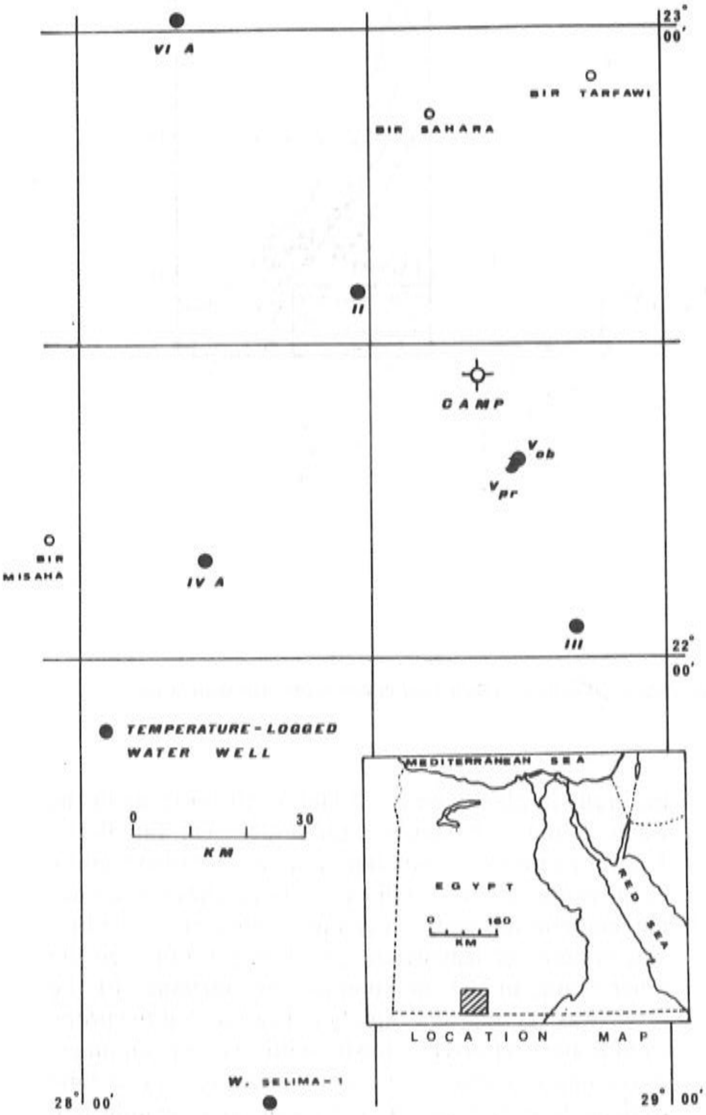

Figure 4 —Location map of temperature-logged water wells in East Oweinat.

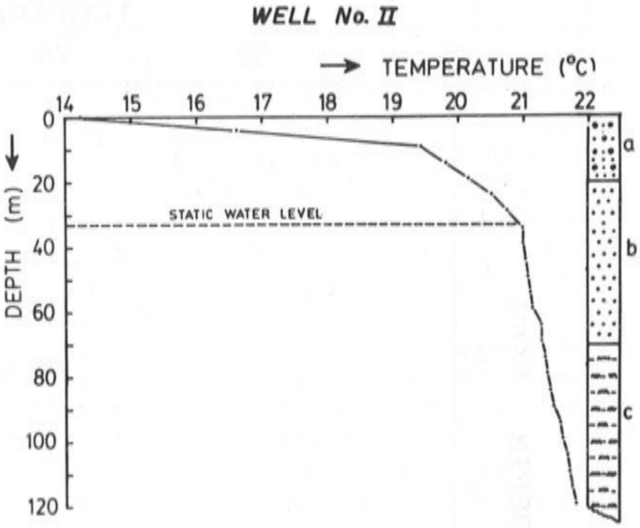

Figure 5 —Observed temperature vs depth profile for service well n° II.a — sand and gravel; b - sand; c - siltstone.

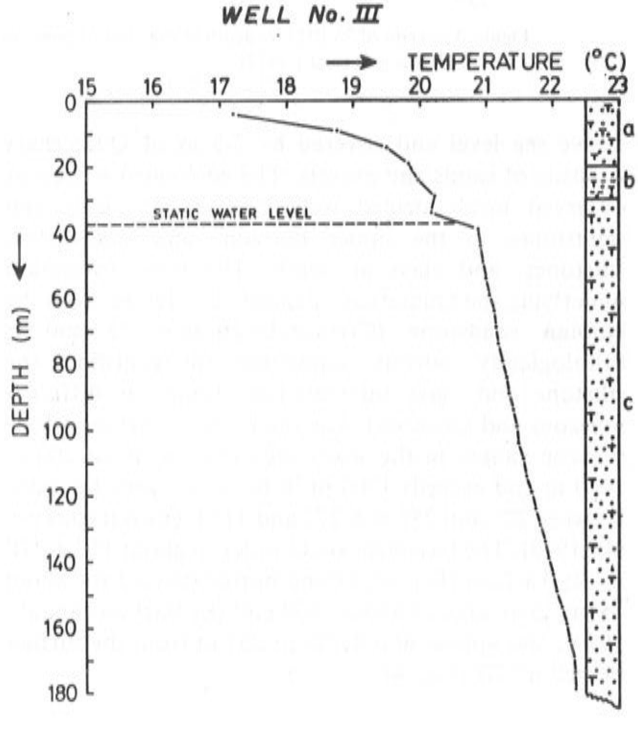

Figure 6 —Observed temperature vs depth profile for production well n° III.a - sandstone; b- kaolinite sandstone; c - sand and sandstone.

The temperature profile pattern above the water table seems to record the progression of a large annual temperature wave above the water table. To account for the depth of penetration of this annual wave, the data of the maximum and minimum monthly soil temperatures at different depths (0.02-3 m) for the year 1980 at the meteorological station at Kharga (25°27'N, 30°32'E) have been collected from E.M.A. (1980). This station is considered as the most reliable station and nearest to the study area. The top soil at which measurements were taken is loose granular sandy loam. The penetration depth of the annual temperature wave into the earth has been estimated by the author from the above data and found not to exceed 4.5m. According to Omara (1988), this depth with an estimated deviation of ± 5% can be considered, with a high degree of reliability, as representing almost the same depth at the study area being situated under almost the same climatic conditions as at Kharga. Hence, a complete damping of the annual wave is expected to be at a depth of 5m.

Subsequent measurements taken in the water column represent in most of the profiles an almost linear temperature-depth relationship and reflect the prevailing geothermal gradient of the region since the water acts as a good medium for transferring the temperature of the surrounding formations to the thermistor. Geothermal gradients inside each well have been estimated at depths below the static water level, at different depth intervals, by least squares linear regression analysis of the temperature-depth data, and are shown in table 1.

The calculated gradients vary from 5.2 mK/m at well n.º IV A to 14.4 mK/m at W. Selima-1 well, with a mean of 11.2 mK/m, or 11.7 mK/m if the too low gradient at well n.º IV A with the highest deviation from the mean is not taken into account. The average temperature intercept is 20.7°C which is lower than the mean ground temperature in most of Egypt amounting to 26°C as indicated from the temperature-depth data from the Western Desert oases (Swanberg et al., 1983).

Table 1 — Temperature gradient inside East Oweinat water wells estimated at different depth intervals below the static water level by least squares linear regression analysis.

Water well	Water level (m)	Depth interval (m)	Temperature intercept (°C)	Temperature gradient (mK/m)
II	33.3	39 – 140	20.55	10.78
III	37.3	39 – 109	20.47	9.93
		109 – 169	20.15	12.85
IV A	50	54 – 154	20.92	5.21
V_{pr}	26.37	24 – 94	20.79	10.09
		94 – 184	20.56	12.94
		184 – 219	21.03	10.40
V_{ob}	26.37	29 – 94	20.82	10.19
		94 – 249	20.47	13.59
VI A	48	54 – 94	20.94	11.67
		119 – 280	20.95	12.26
W. Selima-1	83.5	100 – 155	20.47	14.39

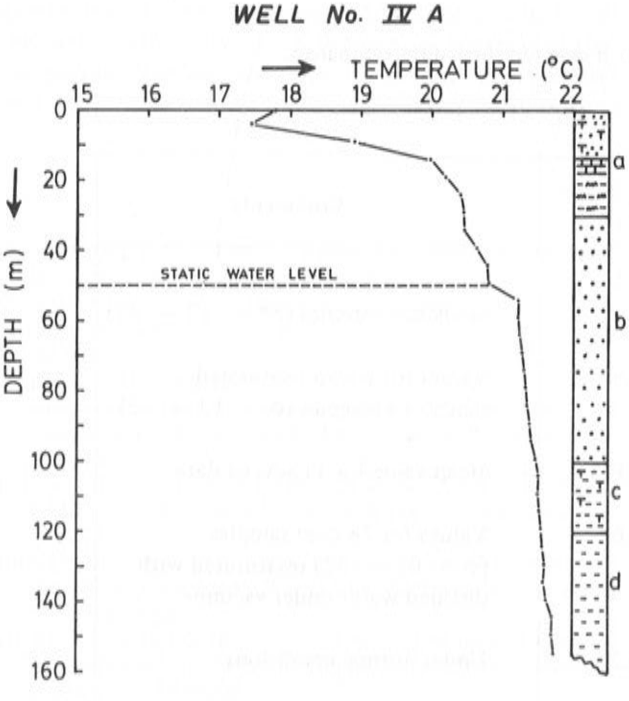

Figure 7 —Observed temperature vs depth profile for observation well n.º IV A. a - sandstone, limestone and siltsone; b - sand; c - kaolinitic sandstone; d - clay.

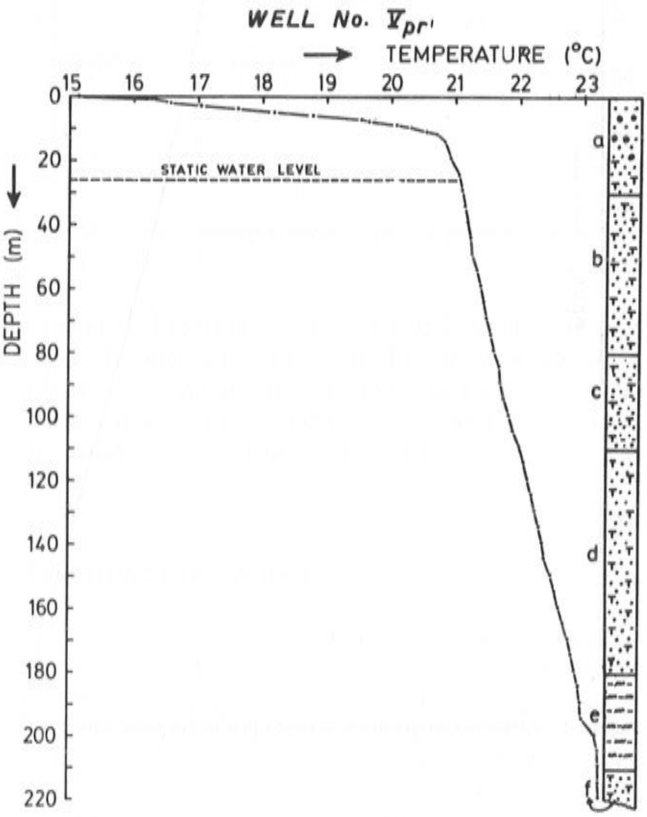

Figure 8 —Observed temperature vs depth profile for production well n.º V. a - sand, gravel and sandsone; b, d, f - sandstone; c - argillaceous sandstone; e - siltstone.

Compiling the previous and present data, a N-S geothermal gradient profile passing by longitude 28.5° E shows a southward decrease from the gradient value in the north (Fig. 12).

To account for the heat flow in the area, values of thermal conductivities of rock samples should be known. Actual conductivity measurements were not made at this stage. Variations of the conductivities of the sediments of the logged wells are expected to occur both vertically and laterally. Since the major constituent of the lithologic rock unit above the basement in the area is water-bearing porous sandstone as mentioned above, an estimated value of its conductivity will be derived from the literature. Published data about the conductivity of sandstone are given in table 2 showing a wide variation.

The effective conductivity of sandstone will be greatly reduced with increase in porosity (Hutt and Berg, 1968). Its conductivity in the study area is expected to be about 2 W/m/K or even lower. Accordingly, the heat flow may be as low as 30 mW/m² or lower.

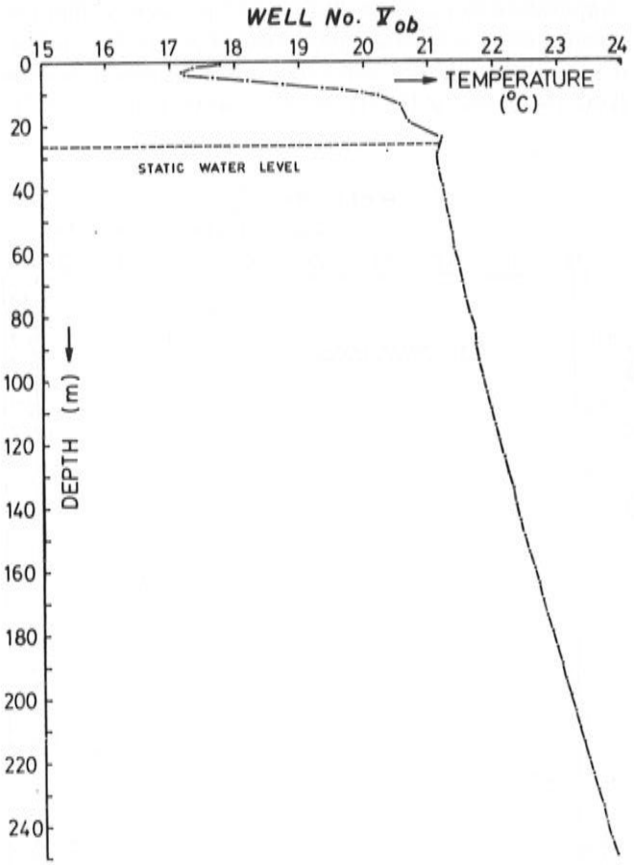

Figure 9 —Observed temperature vs depth profile for observation well n? V.

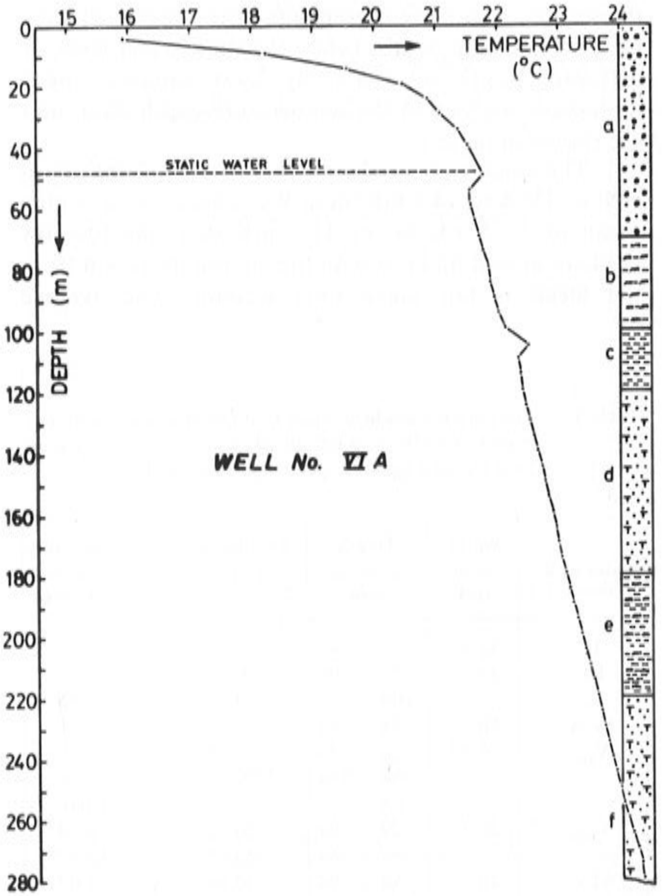

Figure 10 — Observed temperature vs depth profile for observation well n? VI A. a - sand and gravel; b - siltstone; c - clay; d, f - sandstone; e - siltstone.

Table 2 — Data of thermal conductivity (k) of sandstone from different sources.

Source	k (W/m/K)	Comments
Sugawara & Yoshizawa (1961)	1.5 – 1.5	Values for 5 water-saturated sandstone samples ($\phi^* = .12 - .32$)
Sugawara & Yoshizawa (1962)	1.0 – 1.6	Values for 6 water-saturated sandstone samples ($\phi = .12 - .42$)
Clark (1966)	3.093 ± . 393	Mean value for 11 sets of data
Hutt & Berg (1968)	1.8 – 6.6	Values for 28 core samples ($\phi = .02 - .32$) resaturated with distilled water under vacuum
Sharma (1976)	2.5 – 3.2	Under normal conditions
Buntebarth (1984)	3.2	Under normal conditions
* ϕ = porosity		

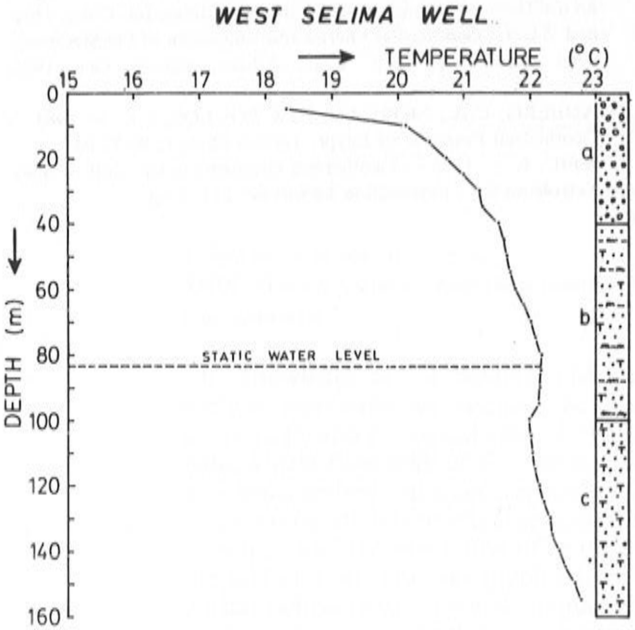

Figure 11 — Observed temperature vs depth profile for West Selima well. a - sand and gravel; b - siltstone and sandstone; c - sandstone.

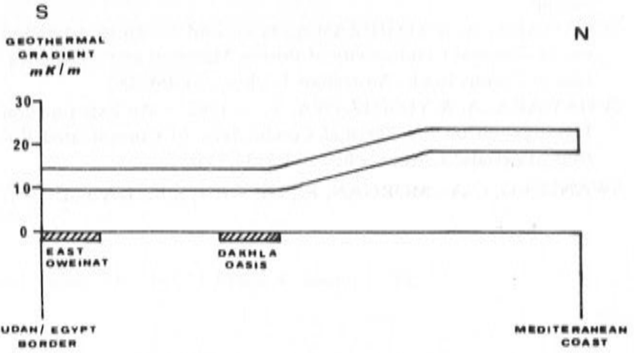

Figure 12 — N-S geothermal gradient profile passing by longitude 28.5° E.

CONCLUSION

The determined geothermal gradient at East Oweina is similar to that at Dakhla Oasis (Fig. 1) about 300 km to the north, and is approximately 12 mK/m. The data indicate that both sites are in the same geothermal regime. Since water is a poor conductor of thermal conductivity of 0.6 W/m/K, it is expected that the porous Nubian sandstone formation bearing water that feeds the oases of the Western Desert may possess an estimated thermal conductivity of 2 W/m/K or even lower. In such case, the heat flow may be about 30 mW/m² or lower and thus the low heat flow province in Western Egypt will extend to the southernmost part of the country to its border with Sudan.

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