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SUBSURFACE GEOTHERMAL INVESTIGATION IN THE NILE DELTA, EGYPT.

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ABSTRACT

The Nile Delta area is geothermally studied to define the behaviour of geothermal gradient in different wells and to determine the distribution of heat in some interesting rock formations. The geothermal investigation of the hydrocarbon bearing Abu Madi and Qawasim Formations revealed new data regarding the subsurface structures and throw some light on the generation and acumulation of the hydrocarbons in the area.

INTRODUCTION

This study comprises a detailed geothermal investigation of the Neogene sedimentary section and to a limited extent the available Pre-Neogene of the middle and northern parts of the Nile Delta region with special emphasis on the hydrocarbon bearing Abu-Madi and Qawasim Formations. The whole area under study covers about 47500 km^2 and extends 190 kms North South and 250 kms East West from suez Canal in the East, to Maryout lake in the West (Fig. 1).

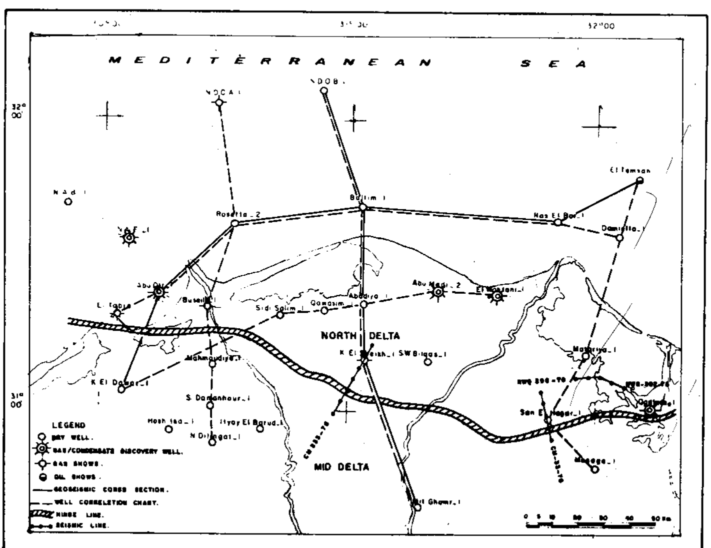

Figure 1 Location Map

It lies between Latitude 30° 33′ and 32° 16′ N and
Longitudes 29° 40′ and 32° 20′ E.
About half of the studied area is located offshore in the Mediterranean Sea.

Recent studies of geothermal gradient show that it can be claculatead to an accuracy of about 10% (Harper 1971; Evans and Coleman 1974). Combination of the geothermal gradients with rock thermal conductivities allows heat flow values to be estimated. Tawifk (1975) studied the geothermal gradients, using the temperature data from the oil wells driled in the Gulf of Suez region, to reveal some relation to the hydrocarbon accumulation. No previous attempts have been made using geothermal data for oil and gas exploration in the Nile Delta, except for certain preliminary studies carried out by Morgan, *et al.*, (1976) on the northern part of Egypt.

SOURCE OF DATA

Several hundred temperature measurements were carried out during routine electric logging runs in the well drilled for hydrocarbon findings in the Nile Delta area. Data available from thirty wells, extending through considerably variable depths, were used in this study. Generally, these measurements were made using mercury in glass maximum thermometer strapped to the logging cable just above the measuring sonde. When logging runs are made at different depths during drilling of well, temperature values can be mesured at more than one depth (Morgan, *et al.*, 1976). In this manner two main sources of error can affect the temperature measurements with respect to the geothermal gradient determination namely, the measurement error and the transient temperature disturbance. The first error can be generally checked by the use of two thermometers whereas the second source of error depends mainly on the sufficiency of data concerning, the thermal parameters of rocks, drilling fluids and drilling history to estimate the magnitude of temperature disequilibrium.

This error is generally less than 10% (Harper, 1971; Evans and Coleman, 1974) and its correlation cannot be reliably estimted at this stage. Consequently, in the present work, the possible systematic error in the calculated geothermal gradients is less than 10%. The geothermal gradient for any drilled well can be calculated as follows:

$$\text{Geothermal gradient} = \frac{\text{BHT}(^\circ\text{C})\text{-MAST } (^\circ\text{C}) \times 100}{\text{D (m)}}$$

where BHT is the bottom hole temperature, MAST is the mean annual surface in degrees centigrade and D is the respective bottom hole in metres. The gradient is expressed in degrees centigrade per meters (°C/100 m). The mean annual surface temperature varies in the area under study and ranges between 15.5 °C in the North to 26°C in the South.

The area under investigation is divided for gradient calculations into three zones with respect to the mean annual surface temperature. The northern offshore zone include the wells NDOA-1 and NDOB-1 which have MAST value of 15.5 °C and the southern offshore zone includes the wells El Temsah-1, NAB-1, NAF-1, Rosetta-2, Baltim-1, Raş El-Bar-1, Damietta-1, Abu Qir-1 and El-Tabia-1 with a MAST of 21.1°C while the land zone includes the rest of the wells which have a MAST value of 26.7° (Table 1).

TABLE 1
Geothermal characters in drilled wells.

Serial Number	Well name	Mean annual surface temp. MAST °C	Bottom hole temp. BHT°C	Bottom hole depth below sea level in meters	Geothermal gradient °C / 100m	Depth in meters below sea level		Geothermal temp °C on top of		Depth of 93°C or 200°C below sea level (meters)
						Abu Madi Formation	Qawasim Formation	Abu Madi Formation	Qawsaim Froamtion	
1	NDOA-1	15.5	62.3	2423.4	1.93	2417.0	2535.7	62.1	64.4	4015.5
2	NDOB-1	15.5	87.8	3797.2	1.90	2644.5	3014.0	65.7	72.7	4078.9
3	El Temsah-1	21.1	95.5	3584.4	2.07	2765.0	3019.0	78.3	83.6	3473.4
4	NAB-1	21.1	74.4	2858.0	1.86	2493.5	2548.0	67.5	68.5	2865.6
5	NAF-1	21.1	68.9	2402.5	1.99	2920.5	3047.7	79.2	81.7	3613.0
6	Rosetta-2	21.1	96.0	3265.6	2.99	2649.4	2659.4	81.7	82.0	3139.7
7	Baltim-1	21.1	86.0	3349.3	1.94	2895.4	3122.4	77.3	81.7	3706.2
8	Ras El Bar-1	21.1	101.7	4144.0	1.94	2683.0	—	73.2	—	3706.2
9	Damietta-1	21.1	71.1	2565.0	1.95	—	2396.6	—	67.8	3687.2
10	El-Tabia-1	21.1	75.5	2128.0	2.56	—	2022.5	—	72.9	2808.1
11	Abu Qir-1	21.1	88.9	3051.0	2.22	2334.0	2491.5	72.9	76.4	3238.7
12	Buseili-1	26.7	88.9	2686.0	2.32	2329.0	2430.0	80.7	38.1	2857.8
13	Sidi Salim-1	26.7	93.9	3442.9	1.95	2383.0	2669.5	73.2	78.8	3400.0
14	Qawasim-1	26.7	87.8	3030.5	2.02	2649.5	2791.5	80.2	83.1	3282.2
15	Abadiya-1	26.7	87.8	2766.3	2.21	2782.0	3045.0	88.2	94.0	3000.0
16	Abu Madi-2	26-7	120.0	4152-0	2.25	3117.0	3306.0	96.8	101.1	2946.7
17	El Wastani-1	26.7	96.0	3448.4	2.01	2746.6	2868.6	81.9	84.4	3298.5
18	Mahmoudiya-1	26.7	68.9	2396.3	1.76	1720.0	1821.0	57.0	58.7	3767.0
19	Kafr El Sheikh-1	26.7	95.5	3334.8	2.06	2726.8	3110.8	82.9	90.8	3218.4
20	S.W. Bilqas-1	26-7	112.0	4350.0	1.96	2743.6	3050.5	80.5	86.5	3382.7

Table 1 (Cont.)

Serial Number	Well name	Mean annual surface temp. MAST °C	Bottom hole temp. BHT°C	Bottom hole depth below sea level in meters	Geothermal gradient °C / 100m	Depth in meters below sea level		Geothermal temp °C on top of		Depth of 93°C or 200°C below sea level (meters)
						Abu Madi Formation	Qawasim Formation	Abu Madi Formation	Qawsaim Froamtion	
21	Matariya-1	26.7	83.9	3324.7	1.72	2239.0	2279.0	65.2	65.9	3854.7
22	Qantara-1	26.7	135.0	4186.7	2.59	1710.7	1833.7	71.0	74.2	2559.8
23	Kafr El Dawar-1	26.7	80.0	2650.3	2.01	1613.0	—	59.1	—	3298.5
24	Hosh Isa-1	26.7	73.3	1777,0	2.62	1064.0	—	54.9	—	2530.5
25	S. Damanhour-1	26.7	79.4	2505.3	2.10	1476.5	—	57.7	—	3157.1
26	N. Dilingat-1	26.7	70.5	2109.0	2.08	1296.6	—	53.7	—	3187.5
27	Itay El Baroud-1	26.7								
28	San El Hagar-1	26.7	116.1	3764.0	2.38	1863.0	1965.0	71.0	73.5	2785.7
29	Monaga-1	26.7	91.7	3496.4	1.86	—	0691.4	—	39.6	3564.5
30	Mit Ghamr-1	26.7	57.8	1201.0	2.59	0999.0	—	52.6	—	2559.8

$$\text{Geothermal gradient} = \frac{\text{BHT°C - MAST°C}}{\text{Depth (m)}}$$

$$\text{Geothermal temp. on top of formation} = \text{geoth. gradient} \times \text{form. depth} + \text{MAST°C}$$

$$\text{Depth of 93°C geoth. temperature} = \frac{\text{93°C} - \text{MAST°C}}{\text{geoth. gradient}}$$

INTERPRETATION OF THE GEOTHERMAL DATA

The geothermal data have been plotted on depth-temperature diagrams "geothermo-grams" (Figs. 2,3,4,5 and 6), geothermal gradient contour map (Fig. 7), isotemperature contour maps on tops of Abu Madi and Qawasim Formations (Figs. 8 and 1), and isotherm depth map for the temperature pf 93°C (Fig. 10). In addition to the previously mentiond constructed maps, a regional isogradient contour map related to the basement complex has been applied for separating the regional geothermal gradients trend (Fig. 11).

In most of the drilled wells in the Nile Delta, the temperature values as a function of depth, approach a straight line. This can be clearly shown in the wells NDOA-1, Baltim-1, Sidi Salim-1 and San El-Hagar-1 (Figs, 2, 3, 4 and 5), which means that the gradient is constant in terms of the depth. Some of the depth temperature curves are slightly convex towards the depth axis to the left, which mean that they become less steeper with depth. This indicates that the gradient related to the curve increases by depth as shown in the wells Ras El Bar-1 and Qantara-1 (Figs. 3 and 5). The deviation from the straight line is less than 20% of all measurements (Fig. 6). Extrapolation of the depth-temperature line back to the surface gives an intercept of temperature value of 21.1°C which is actually the known mean annual surface temperature of the studied area.

The geothermal gradient contour map was drawn to show the horizontal distribution of its value which was found to range between 2.62°C/100 meter at Hosh Isa-1 well and 1.72°C/100 meters at Matariya-1 well (Fig. 7). The average geothermal gradient in the Nile Delta area is 2.17°C/100 meters (Fig. 6). The Gradient anomalies within the area can be classified into thermal trends, with geothermal gradient values over 2.0°C/100 meters and thermal low trends, with values less than 2.0/100 meters (Fig. 7). The localities with relatively higher gradient values are alligned in two zones extending in a more or less E-W direction and separated by a parallel zone with relatively lower gradient values. The thermal high zones are almostly coinciding with the structural high features where hydrocarbon occurences are found especially in the northern high gradient zone where El Temsah, El Wastani, Abu Madi and Abu Qir discoveries are located.

The isotemperature maps on top of Abu Madi and Qawasim Formations (Figs. 8 and 9) can be easily matched with the structural contour maps of the two formations which actaully show great similarlity between each other (Figs. 13 and 14).

The most prominent feature of the isotemperature map on top of Qawasim Formation is a hot zone of temperature 100°C trending or less in a NE-SW direction. The hot belt attains its maximum value in the vicinity of Abu Madi-2 well. Corresponding to this belt another one reappears in the isotemperature map of the Abu Madi Formation with axial trend extend in NW-SE direction.

It is assumed that the minimum subsurface temperature needed for hydrocarbon generation from potential source rocks, in the Nile Delta area, is 93 degrees centigrade (Knewtson and Barakat, 1976). The depths at which 93°C occur in the area under study are shown on the isotherm depth map (Fig. 10).

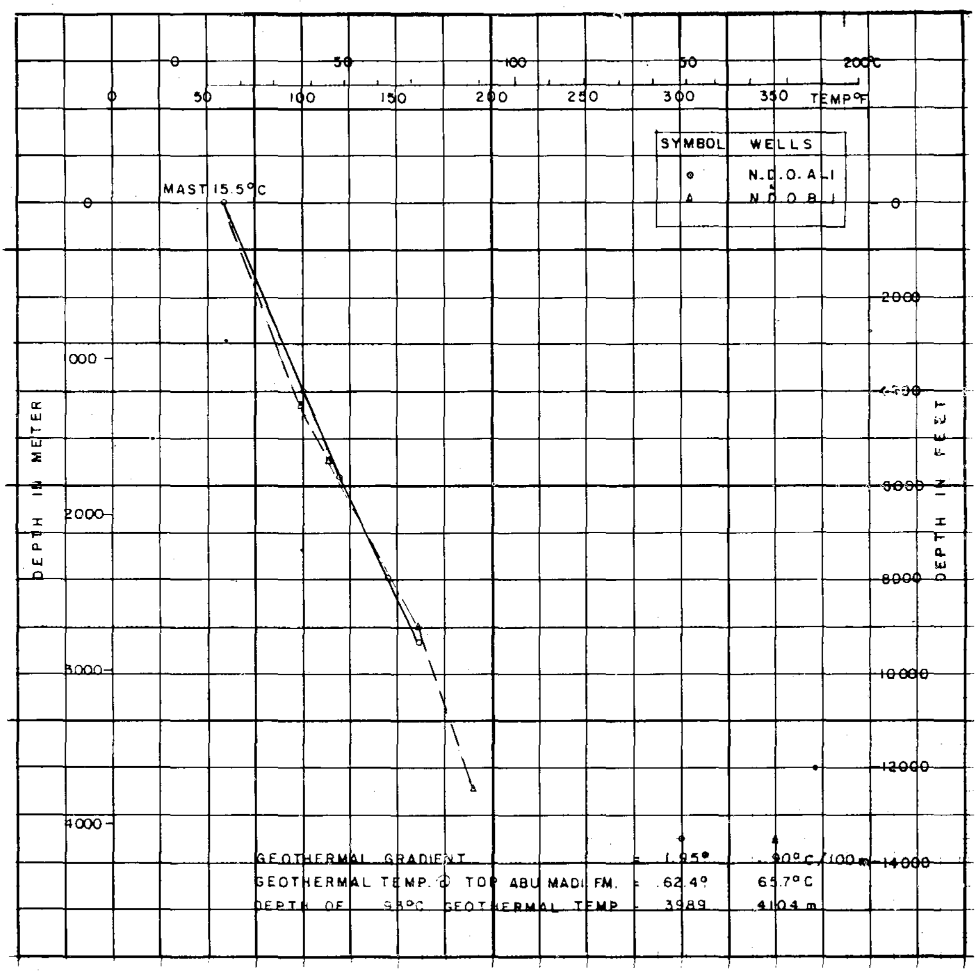

Figure 2 Geothermal gradients in the northern offshore wells.

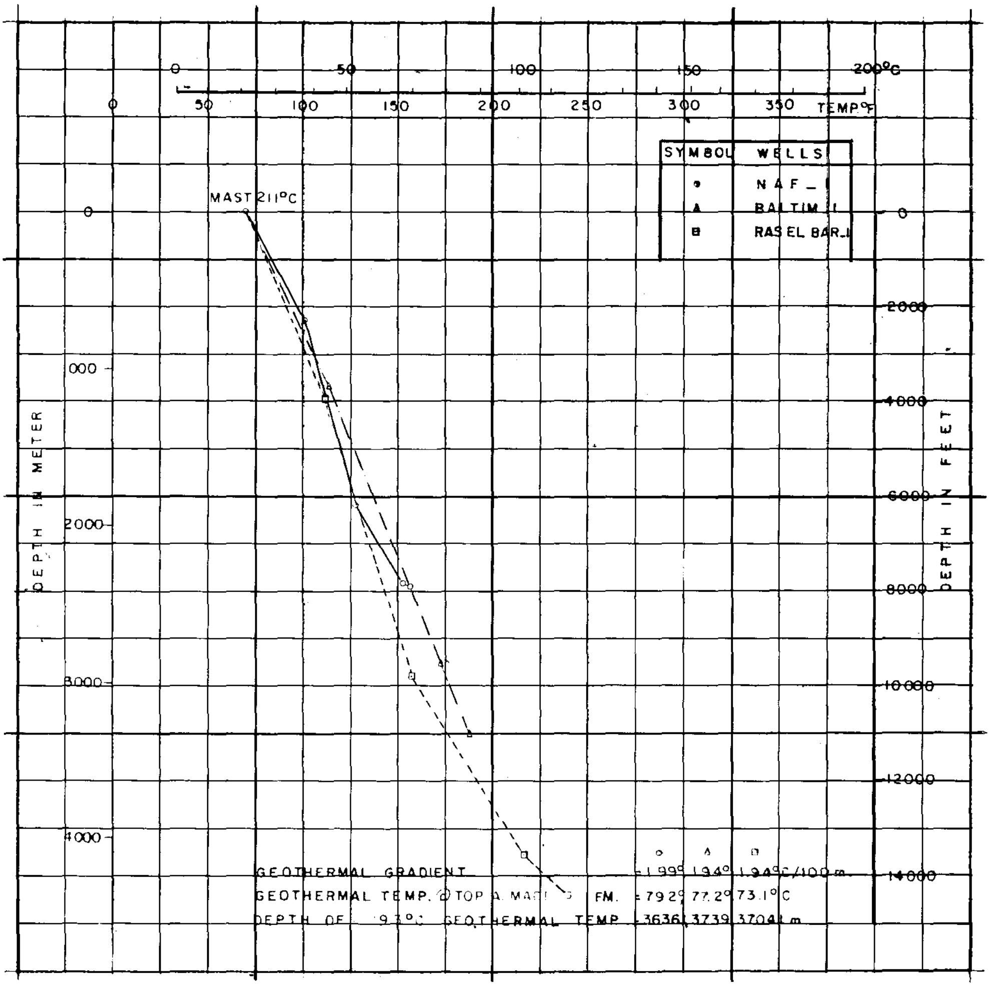

Figure 3 Geothermal gradients in the southern offshore wells.

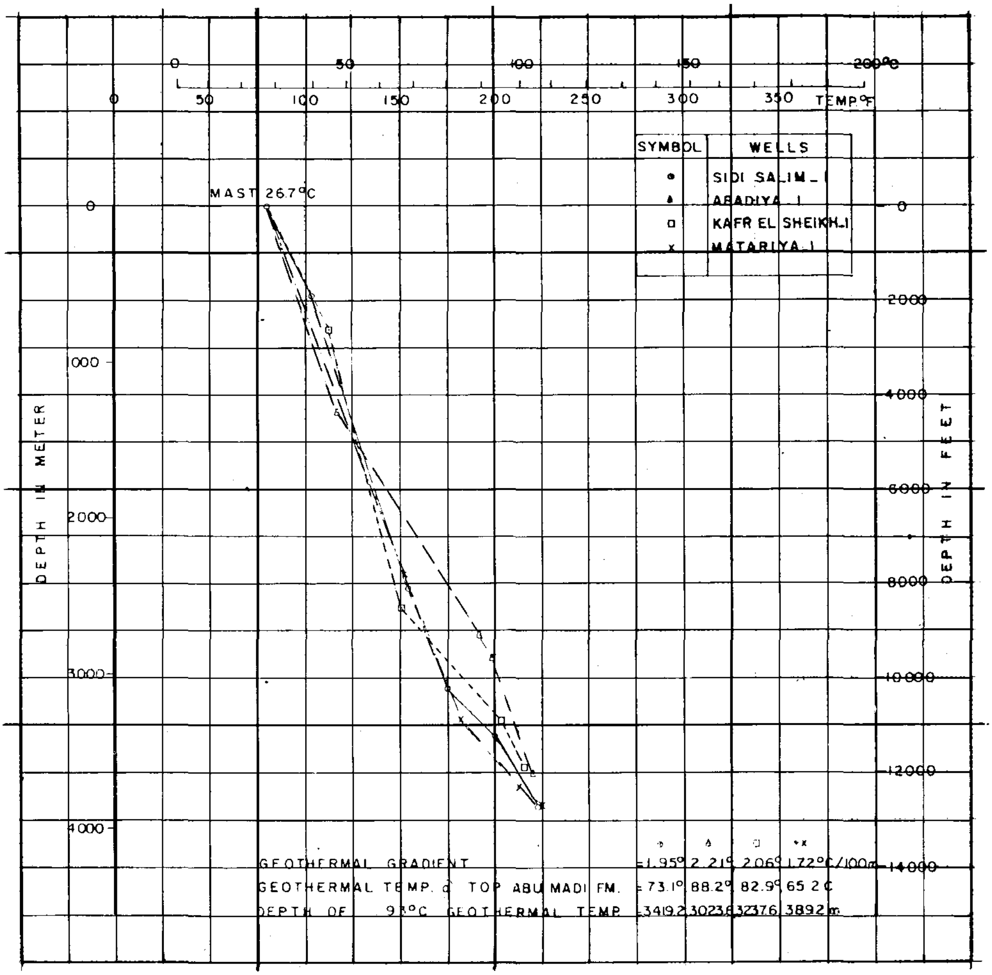

Figure 4 Geothermal gradients in the northern onshore wells.

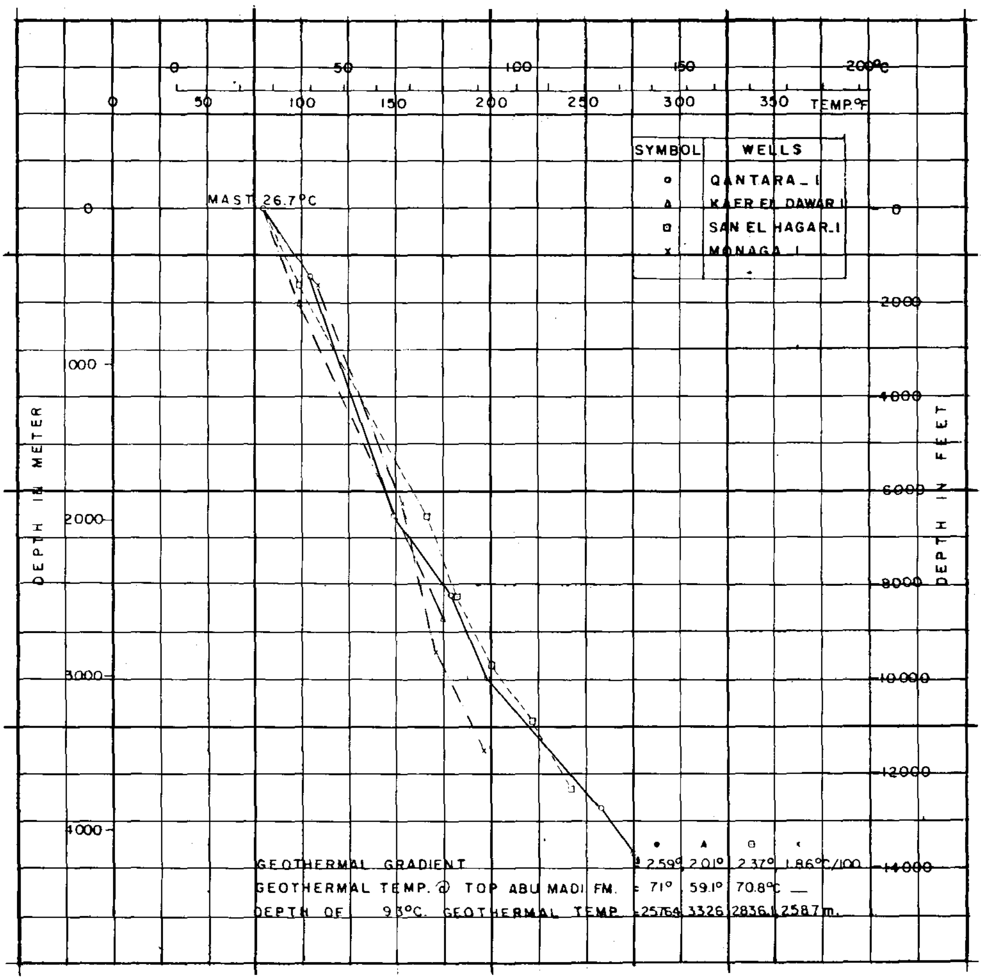

Figure 5 Geothermal gradients in the southern onshore wells.

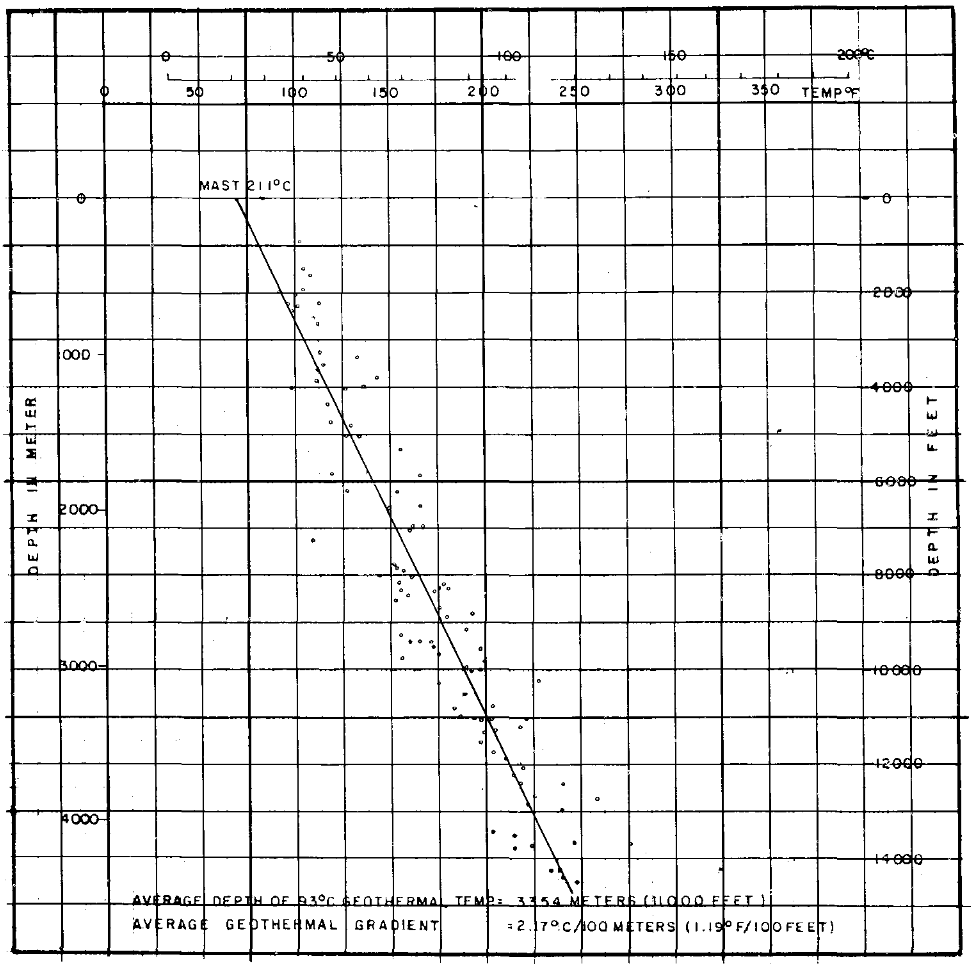

Figure 6 Average geothermal gradients in the Delta area.

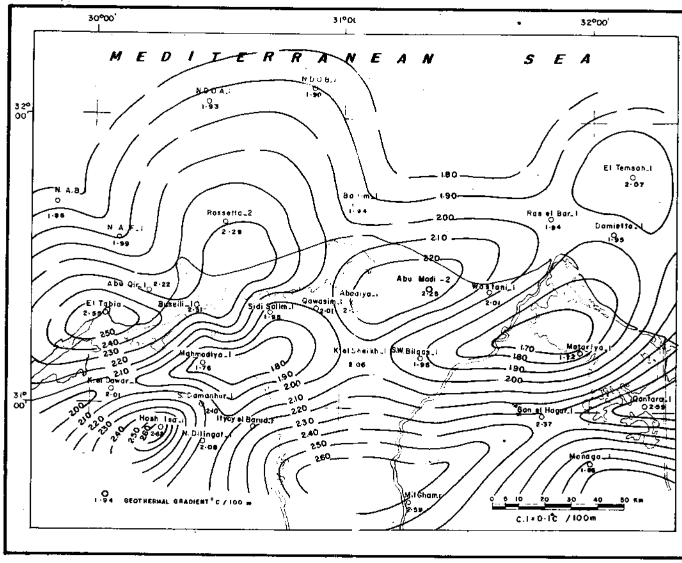

Figure 7 Geothermal gradients contour map.

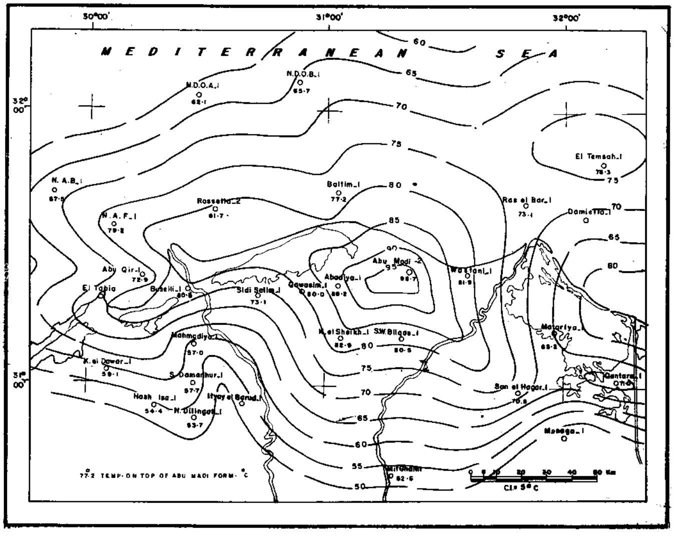

Figure 8 Isotemperature map on top of Abu Madi formation.

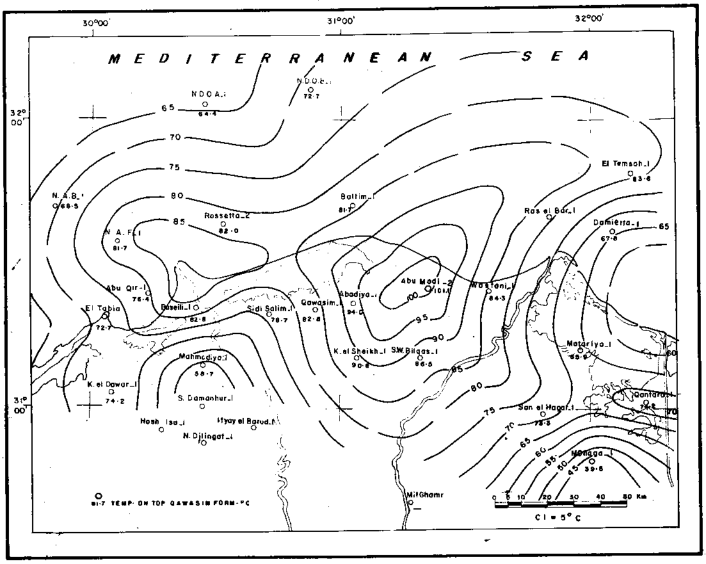

Figure 9 Isotemperature map on top of Qawasim formation.

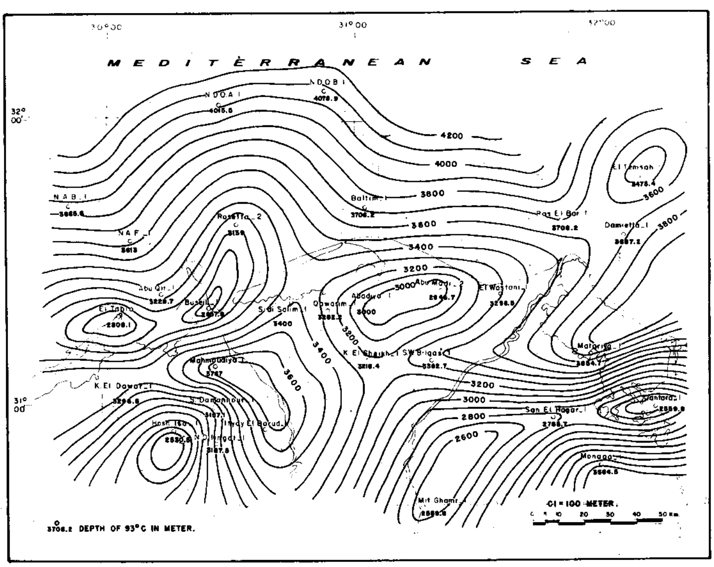

Figure 10 Isotherm depth map (93° or 200°F)

This isothermal surface is shallow in the South and gets deeper towards the North, where it reaches a depth of more than 4000 meters. The areas near Abu Madi-2 Buseili-1 and El-Tabia-1 maintain a shallower depth of about 3000 meters in contrast to the surrounding areas. Source rocks of younger age expected northwards in contrast to the older rocks in the South.

A comparison between the isogradient map (Fig. 7) with the facies map constructed for the Abu Madi Formation (Fig. 15) shows that the geothermal gradient is generally much higher in its sandy parts, whereas in the clayey parts of this formation the geothermal gradient is much lower. This is explained by the change in thermal conductivity of rocks drilled, and that the high gradient areas may represent a better clastic reservoir rock developmet.

The deep seated basement in the Nile Delta area (Fig. 11) is characterized by a pronounced geothermal gradient less than 2.0°C/100 meters at the middle and eastern parts and having an E-W trend, while in the wetsern part the basement gradient exceeds 2.0°C/100 meters, which means the presence of a warmer zone near Hosh Isa-1 and El-Tabia-1 wells and indicates the shallower existance of basement complex which may consist probably of high temperature granitic type rocks. The influence of the basement is clearly reflected on the behaviour the geothermal gradient in the area (Figs. 7 to 11) and most probably has affected the formation and accumulation of hydrocarbons in the thermal high zones.

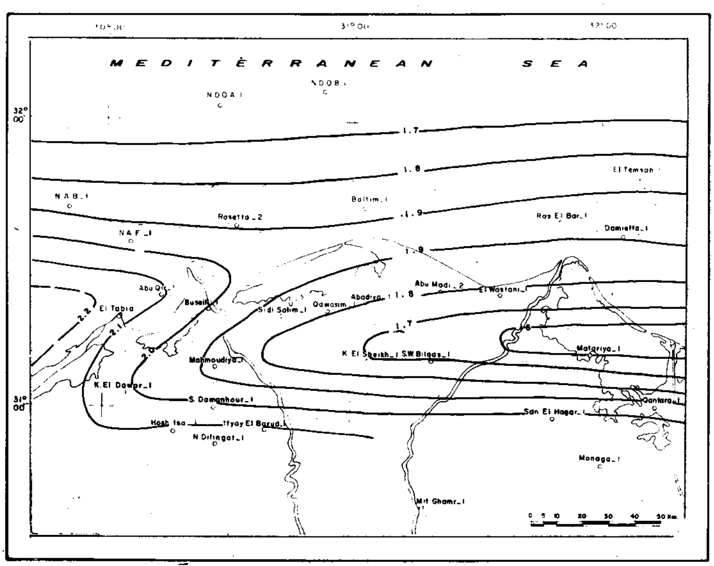

Figure 11 Regional geothermal gradient of the basement complex.

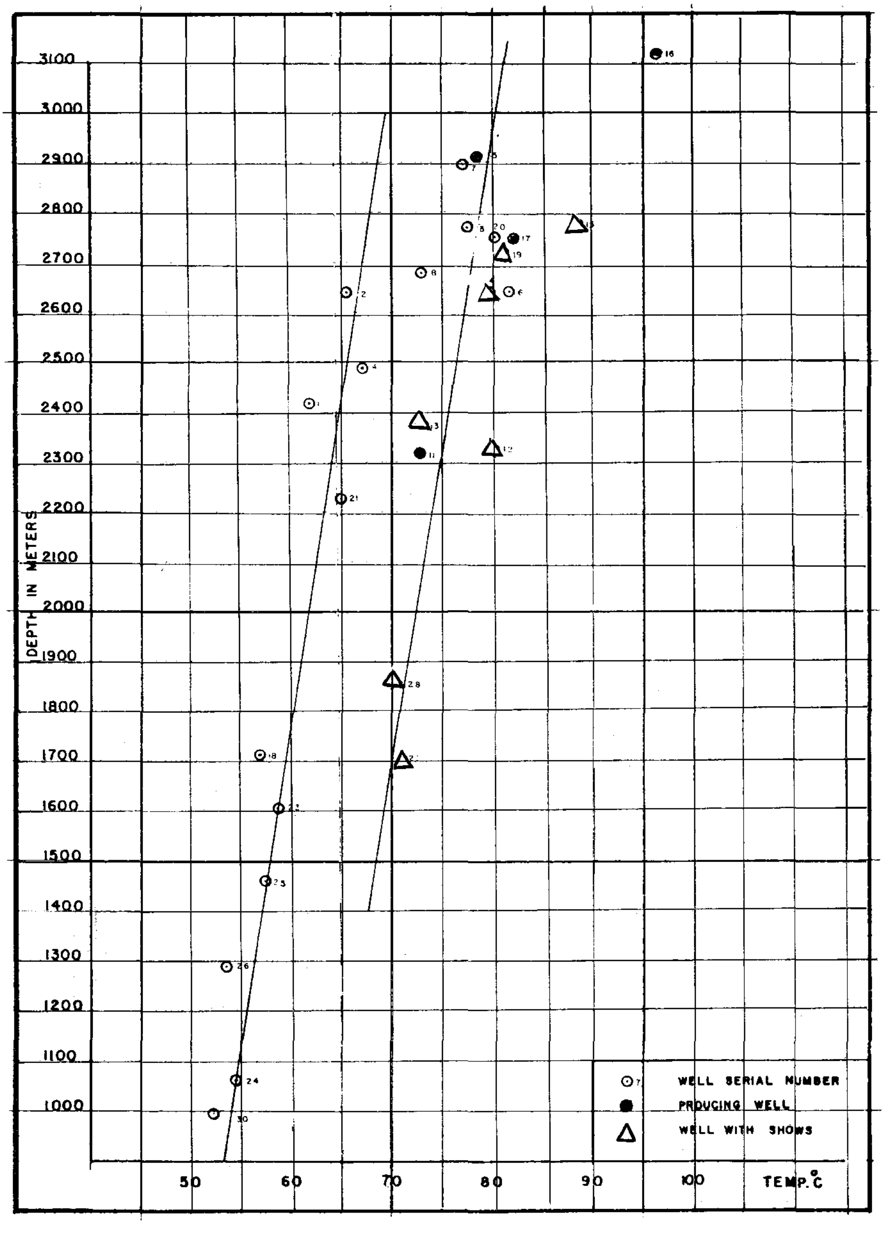

Figure 12 Relation between the temperature and depth for Abu Madi formation in Nile Delta wells.

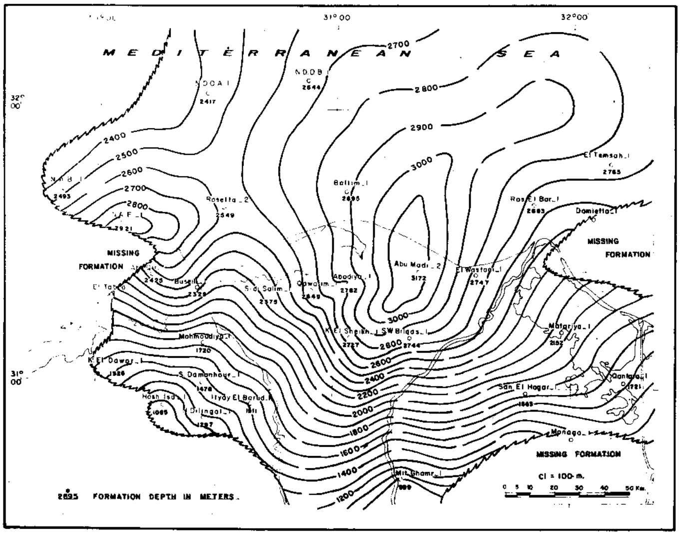

Figure 13 Tentative structure contour map on top Abu Madi formation.

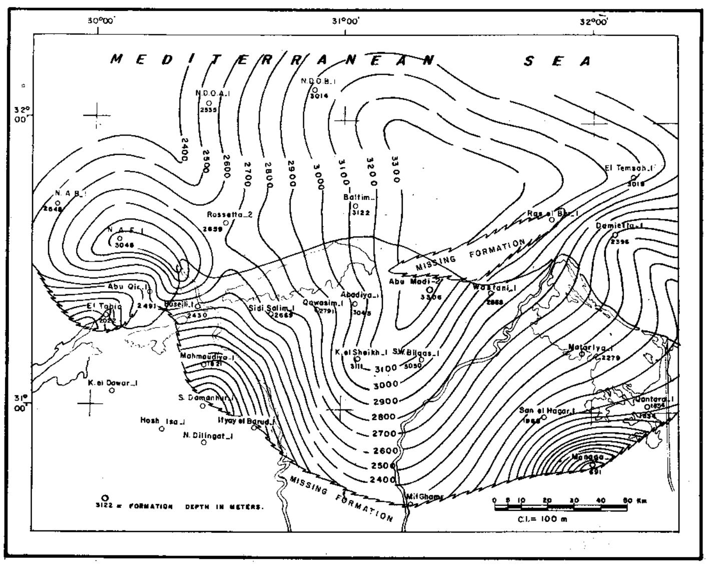

Figure 14 Tentative structure contour map on top Qawasim formation (Top Miocene unconformity).

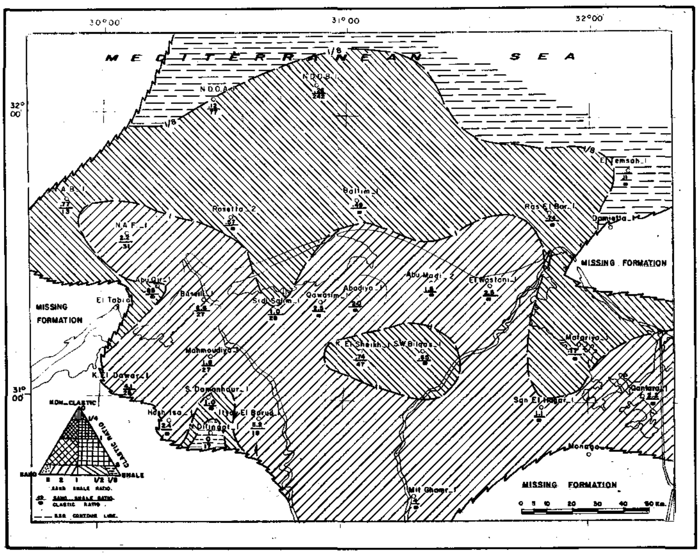

Figure 15 Lithofacies map — Abu Madi formation.

The temperature depth graph of Abu Madi Formation (Fig. 12) show two nearly parallel curves. This feature has not been explained before, and it indicates that the curve of higher temperature extends more or less through the locations of the hydrocarbon producing wells or the wells that have good hydrocarbon shows, whereas the curve of lower temperature passes through the dry wells. Good prediction of hydrocarbon occurence can be made in the vicinity of the wells that are located in the higher temperature zone. The dry wells that happened to be located in the higher temperature zone can be explained as having some hydrocarbon which have been already sourced but later on migrated away to a suitable reservoir. Examples of these locations are Qawasim-1, Abu Diya-1 and SW. Bilqas-1 wells.

SUMMARY AND CONCLUSIONS

1. The geothermal gradient anomalies in the area are classified into thermal high trends geothermal gradients over 2.0°C meter and thermal low trends with values less than 2.0°C/100 meter. Two higher gradient trends are extending in more or less East-West direction. The northern thermal high zone is almost coinciding with the structural high features where hydrocarbon occurrences are found. The influence of the basement is clearly reflected on the behaviour of the geothermal gradient in the area, most probably has affected the formation and accumulation of hydrocarbons in the high thermal zones.

2. The isotemperature maps on top Abu Madi and Qawasim Formaions are almost matching with the structural contour maps of the two formations.

3. The isothermal surface of 93°C (suitable temperature for generating hydrocarbons) is shallow in the soutern part of the area and gets deeper towards the North where it reaches a depth of more than 4000 meters.

4. The geothermal gradient is generally much higher in the sandy parts of Abu Madi Fm. rather than in he clayey parts, which is due to the change in thermal conductivity of rocks.

5. Temperature-depth graph of Abu Madi Fm. shows two nearly parallel lines. The higher temperature line extends more or less through the locations of the hydrocarbon producing wells or the wells that have good hydrocarbons shows while lower temperature line passes through the dry wells. Good prediction of hydrocarbon occurrence can be made in the vicinity of the wells located in the higher temperature zone.

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دراسات حرارية تحت سطحية بمنطقة دلتا نهر النيل ـ مصـــر

محمد محمد العوضي   محمود يسري زين الدين   محمود عبد اللطيف مرزوق

يتضمن هذا البحث دراسة تحت سطحية لتسجيلات درجات الحرارة في الأبار المختلفة التي تم حفرها بمنطقة دلتا النيل . وأستناداً إلى البيانات الجيولوجية لمعظم الابار الاستكشافية تم أستنباط معدلات التغير في الحرارة وتحديد منسوب وأعماق درجات الحرارة المناسبة لتوليد وتواجد الزيت والغاز في دلتا نهر النيل .