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MODELLING OF THE BASEMENT SURFACE OF SIWA-QATTARA DEPRESSION AREA, NORTHERN WESTERN DESERT OF EGYPT

By

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ABSTRACT

Modelling study of the basement surface of Siwa-Qattara Depression area was done through the calculation of basement depth for 62 selected points using gravity interpretation methods.

The constructed basement relief map is justified and confirmed by data of many reference drilled wells in the study area. It is delineated by different systems of faults of different ages, origins and tectonisms.

A mathematical model was assumed as *5th* degree polynomial equation whose coefficients were calculated applying the least squares method. Computation was carried out by using I.B.M. of the National Institute of Oceanography and Fisheries, Alexandria. The *3rd* and *4th* degrees polynomials were also tried for the sake of justification. The best fitting of the constructed gravity basement depth map is found to be expressed by the *5th* degree polynomial.

The mathematical model of the basement surface of the study area as well as the computed deviations between the interpreted and the modelled depths are of great importance and significance in evaluating and selecting drilling locations for hydrocarbon exploration in this part of the Northern Western Desert of Egypt.

INTRODUCTION

The present work is a trial for quantizing the topographic surface of the basement complex of Siwa-Qattara Depression area of the Northern Western Desert of Egypt. The area of study is located between Latitudes 28° 14' 30" N and 30° 36' 30" N and longitudes 25° 00" 00" E and 28° 30' 00" E as shown in Fig. (1).

A mathematical trend expression of the basement surface would reflect the behaviour, attitude and complexity of its relief as well as its effect on the overlying sedimentary section. Furthermore it would throw light on the history and origin of formation of such surface. This additional knowledge is of great importance and significance in evaluating and selecting the drilling locations for natural resources in the area of study.

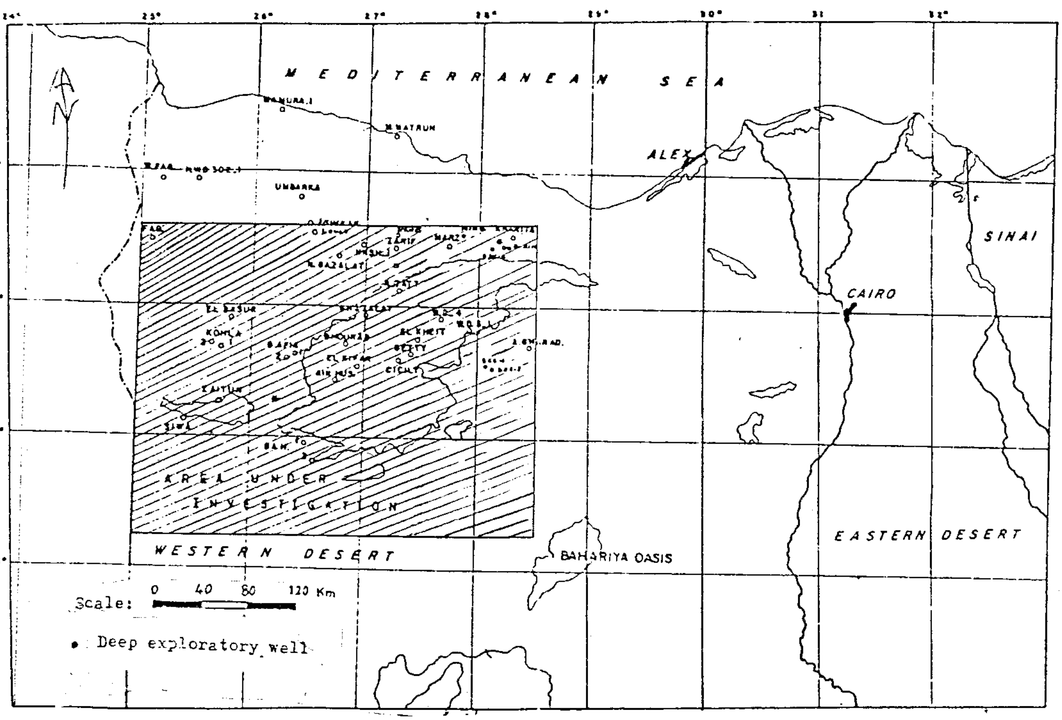
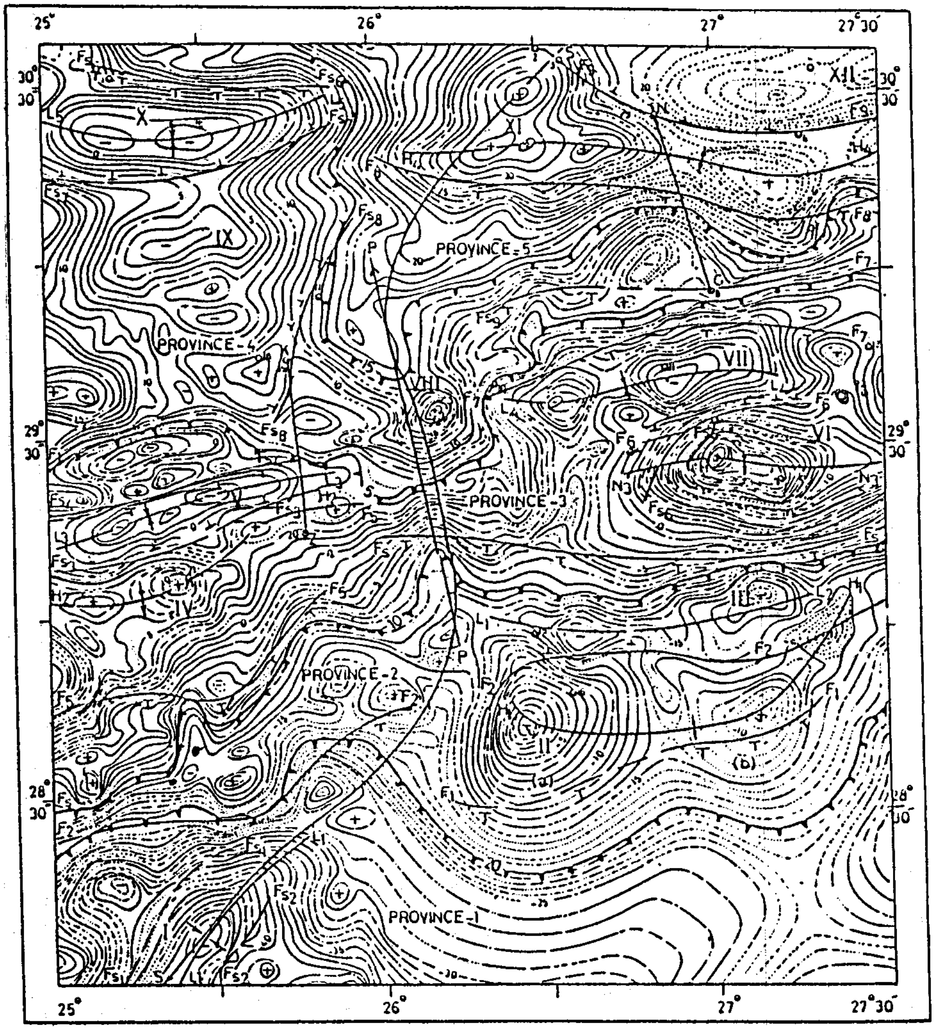


Fig. 1: Location Map of the Study Area.

The original data are represented by the Bouguer anomaly map (Fig. 2) which covers the major part of the study area and bore hole composite logs of 30 exploratory wells which have been kindly provided by the Egyptian General Petroleum Corporation in order to be used as a depth controlling parameter. For the same purpose two previously interpreted two-dimensional seismic/gravity models in the same area of study are also reintroduced here as shown in Figures (3) and (4).



(Interpreted by Awad & El Abd, 1989)

1-Faghur-1	2-Shushan-1	3-Louly-1
4-Hamed-1	5-N-Gazalat-1	6-Zarit-1
7-Ras-Qattara-1	8-Gazalat-1	9-Gibb-Afia-2
10-Gibb-Afia-1	11-Ghourab-1	12-El-Kreit
13-Kilar-1	14-Ein-Hassien-1	15-Bahrein-1
16-Bahrein-2	17-El-Basur-1	18-Kohla-2
19-Kohla-1	20-Ein-Zeitun	21-Siwa-1
22-Betty-1		

0 20 40 60 Km
SCALE

C.I. = 1 m gal
Province boundaries
Axis of anomaly belt (H&L)
F F Deep origin faults
Fs Fs Shallow origin faults

Fig. 2 : Bouguer Anomaly Map of the Study Area.

Regional Morphology, Surface and Subsurface Geology of the Area:

Briefly, the area of study is a part of the Western Desert that includes Siwa and Qattara depressions as shown in Fig. (1). Land surface slopes gradually from northwest of Bahariya towards Siwa and Qattara depressions far below mean Sea Level. Topography ranges between 0-200 m over the southern and north-western parts of the study area, while the lowest point (-134 m) is confined to Qattara Depression. Again the topographic range (200-500 m) characterizes the northern part.

The surface geologic map (Fig. 5), indicates that Pliocene, Miocene and Oligocene sediments are extensively covering the surface of the study area. Recent and Pleistocene sediments are confined to some localities to the south and northwest of Siwa as well as Qattara depressions. Marmarica Formation of white limestone forms the cap rock of Qattara wall. Its maximum thickness is about 93 m at Siwa, while it is gradually thinning towards east to reach 5 m thick at the eastern tip of Qattara Depression.

On the other hand, the Moghra Formation is considered to be the building stones of Qattara walls (murray, 1951 and Butzer, 1959). Its origin lies between pure marine fluviatile to fluvio-system that had been draining the north Aftican continent.

Subsurface geological setting indicates that the Tertiary sediments cover a very complicated geological structure made of a larg number of swells and basins. Moreover, the tectonic movements of intensive compressional and /or tensional forces seems to have played the most principal role in the complexity of the subsurface geology not only of the study area, but also for the whole Western Desert of Egypt.

Investigation of the data available from the drilled wells reveal the following characteristic remarks of the study area:

(a) Thick and variable sedimentary sections are present. For example sedimentary sections drilled in Shushan and WD5-1 wells (Fig. 2) indicate Lower Cretaceous of 3579 m (Aptian) and 4410 m (Albian) respectively with a tendency of thickening along the NE trend.

(B) A dissimilar stratigraphic section is encountered everywhere; consequently unconformities, wedging and truncations are highly expectable. This again may increase the complexity of the subsurface structures.

(c) Unconformities are existing between different stages and of all magnitudes, the most marked ones are those of Carboniferous/Jurassic, Cretaceous/Eocene and Post Jurassic/Pre-Middle Cretaceous ages.

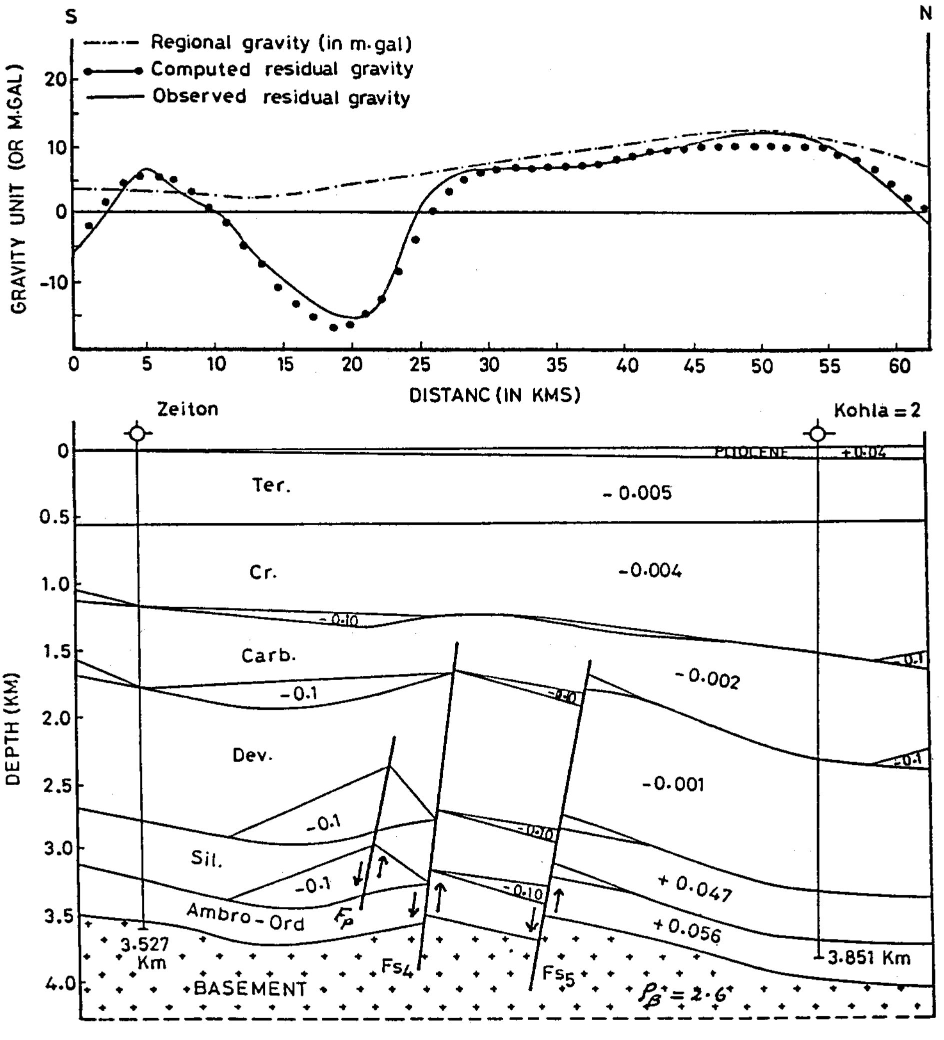


Fig. 3: Computed, Observed and Regional Gravity Anomalies along Zeiton - Kohla = 2 Profile and the Corresponding Assumed Structural Model (After Awad & El Abd, 1989)

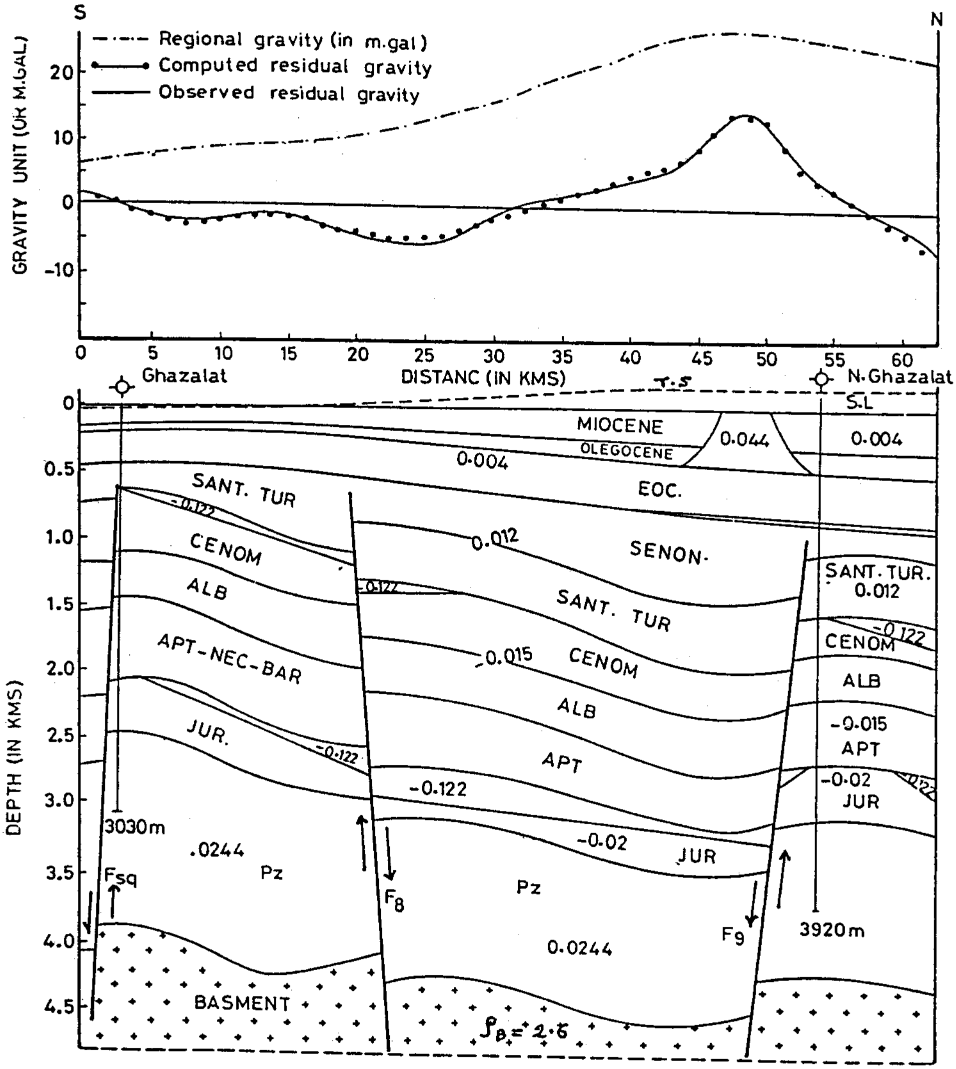


Fig. 4 : Computed, Observed and Regional Gravity Anomalies along Ghazalat-N. Ghazalat Profile and the Corresponding Assumed Structural Model. (After Awad & El Abd, 1989)

(d) Three different folding systems had affected the sub-surface geologic setting (Said, 1962):

(1) N-S folds that affected Paleozoic sediments.

(2) NE-SW folds had been activating during Cretaceous and Eocene times.

(3) NW-SE folds that were active during Oligocene age.

Some Remarks on the Tectonic History of Siwa-Qattara Depression Area

Many workers tried to investigate and study tectonism of the Northern Western Desert of Egypt, among them Ball, 1927; Murray, 1951; Rittman, 1954; Knetsch and Yallouze, 1955; Knetsch, 1958; Sigaev, 1959; Said, 1960; Said, 1962: Youssef, 1968; Bayoumi and El-Gamili, 1969; Kaiser and Vollen Weider, 1972; Bayoumi *et al.*, 1975; Awad, 1976, Kamel *et al.*, 1978; Meshref *et al.*, 1980; Keller and Russell, 1980; Boulos *et al*, 1980; Awad and El-Abd, 1989; and others.

Conclusively, the north western part of the Western Desert seems to have been subjected to intensive compressional as well as tensional movements which brought about a far more complex picture than observed in the stable shelf areas of Egypt, i.e., Arabo-African shield of basement rocks.

The following is a brief summary of the general views of some of these workers:

(1) Rittman, 1954 mentioned that Tertiary volcanic activities were closely related to the linear tectonics observed on the crust but having roots in the subcrust.

(2) Knetsch, 1959, stated that the compressive stresses affecting the area may be attributed to a deep-seated "Wedge-shaped" vector pointing northwestwards.

(3) Youssef, 1968, succeeded to fit the structural elements of Egypt into a pattern of compressive origin taking N10° W - S10° E. This compression is believed to have started since Pre-Cambrian age and is responsible for the production of the right and left lateral strike-slip faults of both Suez and Aqaba trends.

(4) Kaiser and Vollen Weider, 1972 based on seismic interpretation suggested that faulting of the Western Desert had started just before the formation of Upper Cretaceous carbonates and continued till Tertiary times due to acting tensional stresses. After early Tertiary times, due to acting tensional stresses. After early Tertiary times, the basement became stable and faulting was ceased. New submergence and deposition of younger beds were continued associated with folding during Aptian/Albian times. Plastic deformation was accelerated during Upper Cretaceous and attained its maximum at the end of Turonian

times. By the end of Eocene times, Oligocene compressional forces (NW-SE) had been affecting Cretaceous folding which led to the development of the "Syrian Arc System" in northeast direction accompanied by normal and reverse faulting parallel to folding axes. In turn, these structures resulted in varying the attitudes and thicknesses of the sedimentary cover associated with basaltic intrusions in some localities.

(5) Dealing with Siwa and Qattara depressions, Ball, 1927, considered their origin as due to weathering action, while Knetsch and Yallouze, 1955; Sabry, 1963; Rizkalla, 1975; and Meshref *et al.*, 1980 suggested their tectonic origin.

On the other hand, Bayoumi and Awad, 1975, suggested that Qattara depression was tectonically originated depending on gravimetric interpretation due to presence of a peculiar fitting between the gravity potential "shelf" and the topography of its western edge.

(6) In fact, drilling activity in the Western Desert of Egypt indicates that hydrocarbon generation is involved with sedimentary basins of different attitudes and having different trends e.g.,

(a) Siwa basin of Paleozoic age is represented as long and narrow feature. The rocks in this basin are of appreciable thickness belonging to Devonian-Carboniferous ages.

(b) Matruh basin of Jurassic age is extended southwards as far as Betty well. Lower Cretaceous is of considerable significant thickness.

(c) Miocene basin in the Western Desert trends northeast ward covering a remarkable area of the present study.

MATERIALS AND METHODS

(1) Basement Depth Configuration Map of the Study Area

A tentative basement relief map for the study area had been constructed and compiled in Fig. (6) based mainly on the interpretation of the earth's gravity field of the area. This map illustrates the morphological features of the basement surface as have been compiled and controlled from different sources:

(1) Drill hole data available in the area (not cited in order to overcome excess lengthening of the text).

(2) Depth control from previously interpreted seismic sections crossing the study area and displayed in Figures (3) and (4).

(3) Data from downward continuation of the gravity potential field of the area for

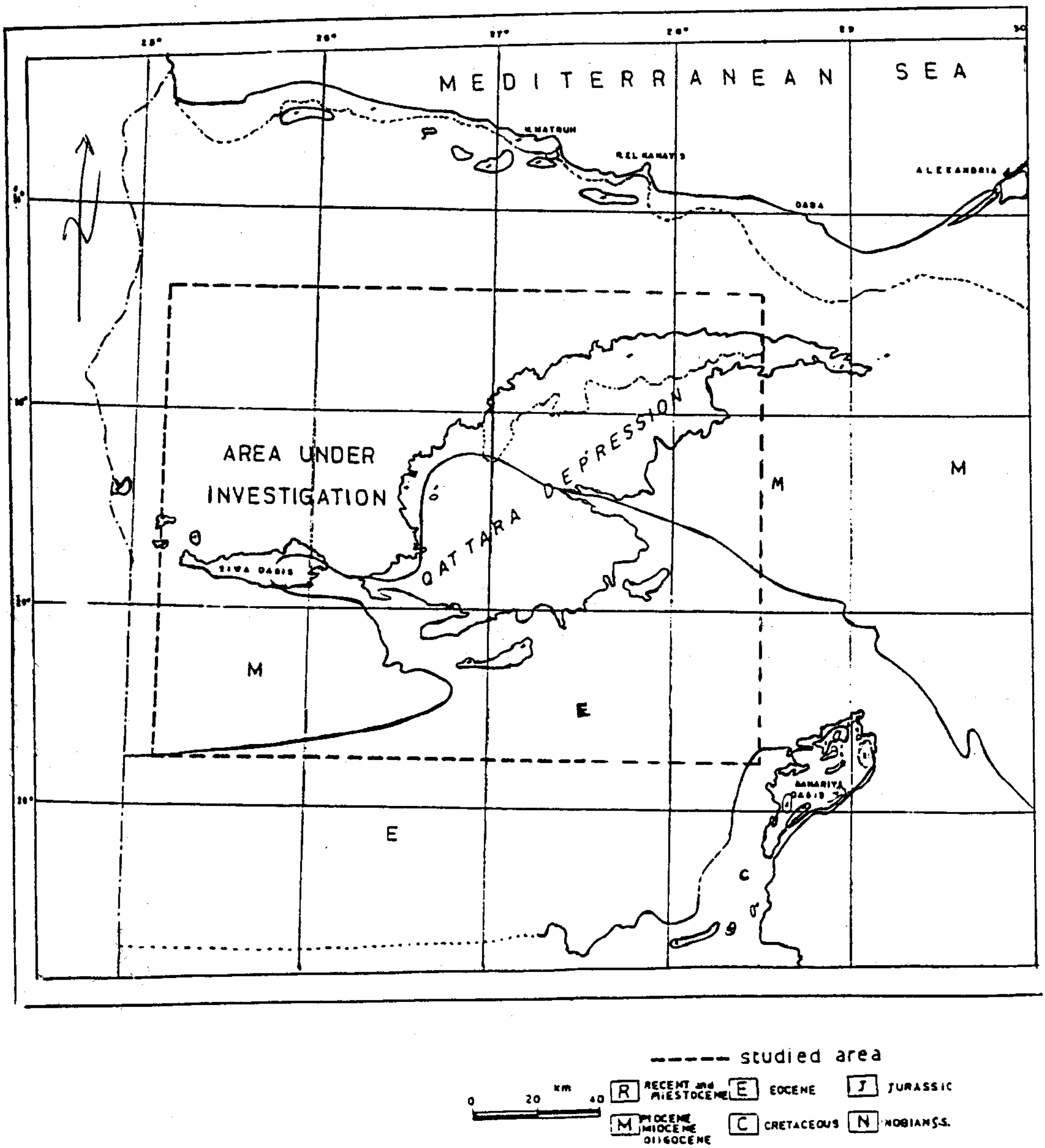


Fig. 5: Geological Map of the Study Area from Atlas of Egypt. From Said, R., 1962).

62 depth points using a technique suggested by Constanescu and Botezatu, 1961 and applying a tested convenient interval of 312.5 m.

(2) **Mathematical Modelling of the Basement Surface**

Basic Concepts

Least square method was used for fitting a mathematical model that approximate the basement depth points into three dimensional topographic polynomial surface. Applying two methods by Davis, 1973 and Abdel-Rahman, *et al*, 1985 for monorthogonal polynomial trend fitting, different mathematical models in the form of third, fourth and fifth order polynomial functions were tried and examined in order to better express the basement topographic relief in the area of study.

However, it is necessary to mention that the specific polynomial function of the trend chosen must minimizes the squared local depth fluctuations that superimpose wider range depth components. Also it has to be noticed that the sum of the squared deviations from the mean depth values define the variance of all depth data values. The more the model represents the depth data values, the less resulting fluctuations. In other words, as the order becomes higher, fluctuations of depths become sharper and smaller. On the other hand, higher orders emphasize noise and errors in real depth data which further distort the true fluctuations. For this reason more than one model were computed in order to achieve the best representative formula. This finally implies that any given depth observation is the outcome of the interacting geotectonic forces that formulated the geologic setting of the basement surface, superimposed by those small areas originated to deviate from regional pattern. As an example, within basins "regional structure" and folded structures may be developed from the local deviations as for instance gravity sliding, minor antithetic faulting, and failure of incompetent beds in areas of high dip,...etc.

INTERPRETATION OF THE PROCESSED DATA

The outlines of the present map (Fig. 6) reveals the following

(a) Crustal blocks appear to be separated by different systems of fracture zones trending mainly in an (E-NE) and (W-SW) directions. These directions are also clearly shown on the Bouguer map of Fig. (2), which leads to the belief that the observed gravity anomalies are mainly of structural origin rather than lithological variations within the basement.

(b) As examples of structural coordination between Fig. (6) and Fig. (2), the basin denoted by C_2 of Fig. (6) is matched with the low belt L_1 in Fig. (2). Again the high topography of the basement surface eastnortheast Siwa-1 well is

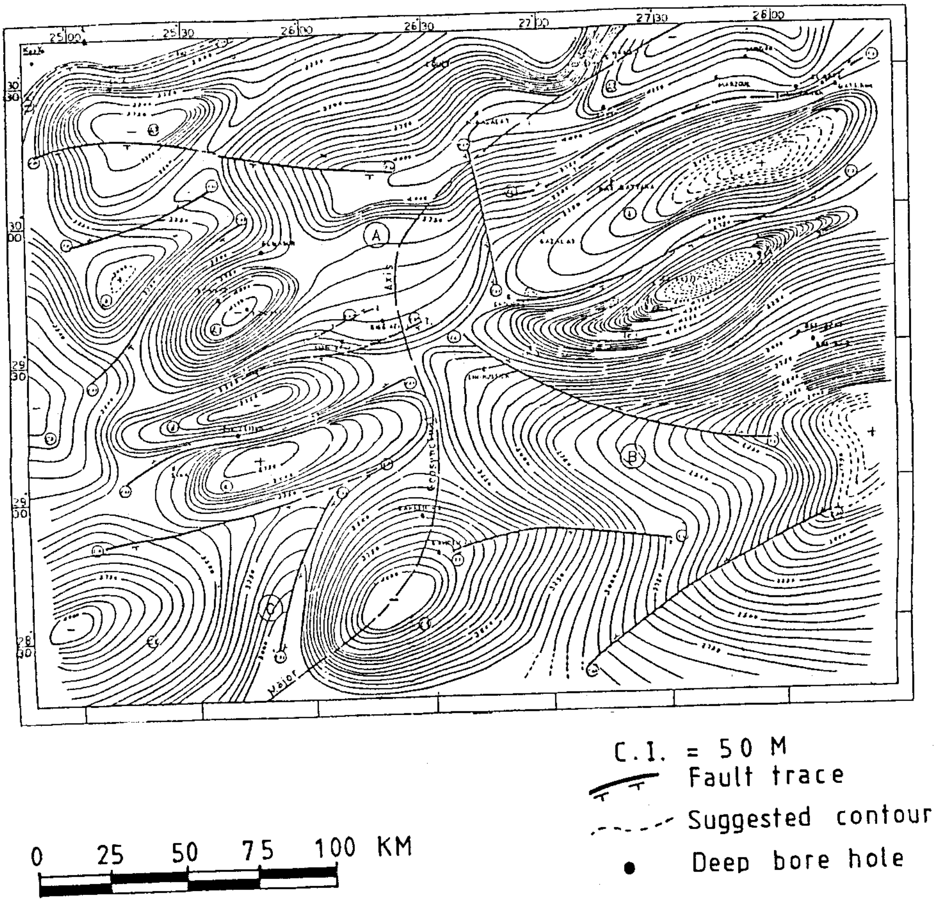


Fig. 6: Structural Contour Map of the Basement Complex in the area under Investigation

correlated with the high anomaly belt $H_2 - H_2$ on Fig. (2).

(c) The whole area of study is a part of a synclinal basin of an axis comparable with the S-shape axis indicated on both Fig. (2) and Fig. (6).

(d) The deepest part all over the map area is confined to El-Kheit Betty basin (more than 5000 meters depth) having NE-SW direction. On the other hand, the shallowest part is restricted within the southeastern corner (less than 2000 meters depth).

(e) The structural elements mostly recognized are:

1. **Kohla -Faghur-Marzouk Basin:**

It is denoted by "A" on the basement map Fig. (6), which approximately occupies a triangular area in the north-northwestern part of the map area. Its major axis extends along a NE-SW direction which is actually composed of A_1 (Kohla), A_2 (Marzouk) and A_3 (Faghur) basins of maximum depths 4050, 4450 and 3800 meters, respectively.

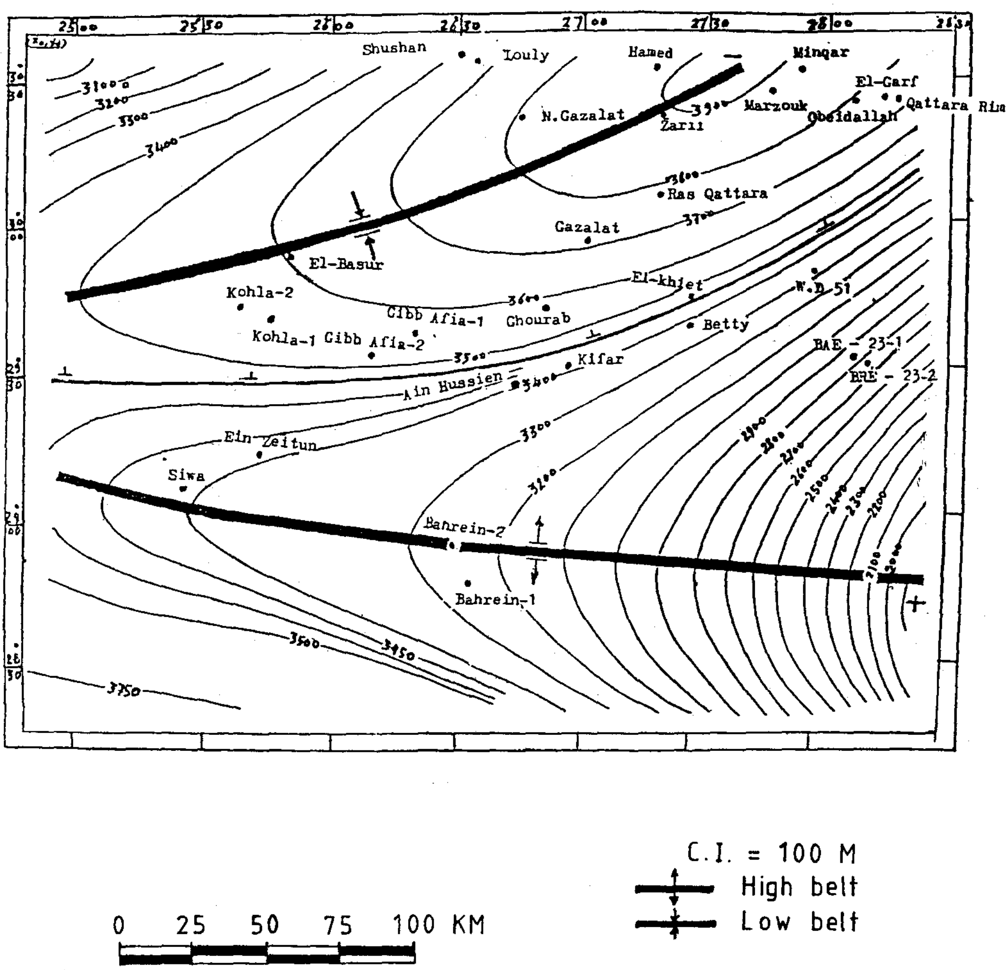


Fig. 7: Estimated Depth of Basement Complex Calculated from Third order Polynomial.

Kohla-Faghur-Marzouk basin appears to be affected by a set of faults Fs_6, F_9, Fs_9, Fs_4 and Fs_8 trending NE-SW and ENE-WSW directions together with the E-N fault Fs_3. It is noticed that Gibb-Afia Exploratory wells lie in the upthrown sides of Fs_4 and another suggested fault Fs_{10}.

However, the comparative study between the Bouguer map of Fig.(2) and the constructed basement map Fig. (6) concerning this particular basin arises some sort of contradiction, since it is manifested on the Bouguer map by some-how monoclinal gravity high. This contradiction can possibly be explained as attributed to either one or both the following factors:

i) High basicity of the basement complex comprising basin A.

ii) The presence of a very high density sedimentary column most probably composed of very hard limestones, and compacted shales,...., etc.

2. **Ain Hussein-Northwest Bahariya High**

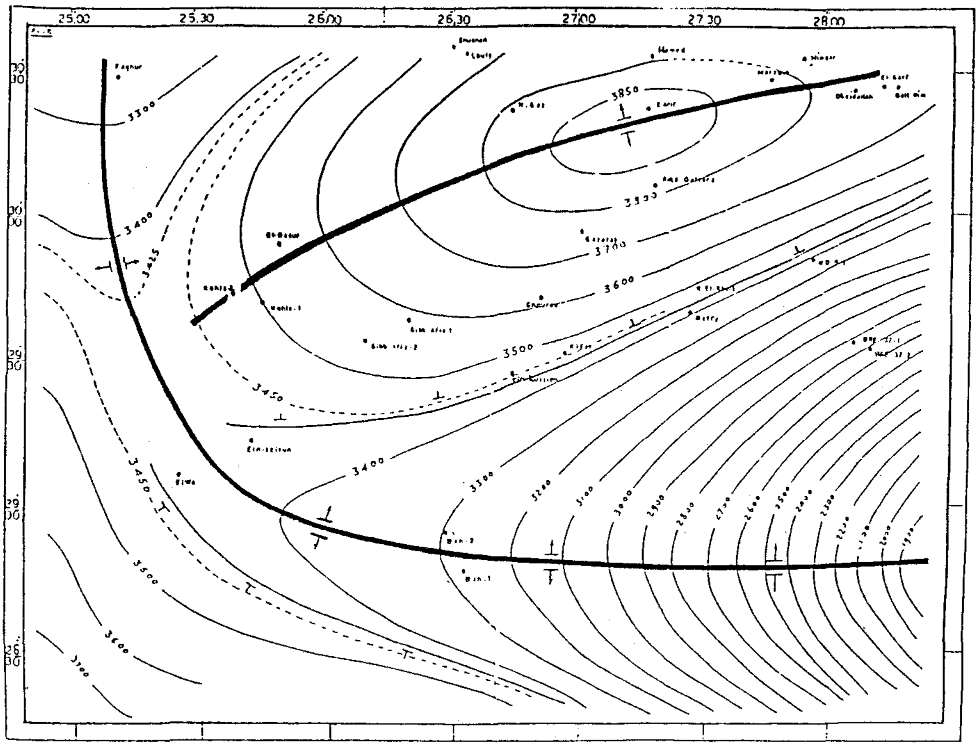
It lies in the southeastern corner, showing a maximum relief of more than 1000 meters (Fig. 6). The basement rocks of the present high is affected by three radiated fault zones F_6 (NW-SE), F_1 (E-W) and Fs_5 (NE-SW) which are intersected at the point of minimum depth of this high portion.

It is interest that the maximum vertical relief all over the map area can be observed in this particular zone reaching about 7.5 km which forms a topographic gradient rate amounting 1:4. This gradient is so big that a major fault zone of large displacement should be suggested between the two corresponding belts (B) and (C) (Fig. 6). More reasonably the assumed fault zone is suggested as consisting of three faults namely F_9, F_7 and F_6 which delineate such two belts (B and C) in the form of sharp horstal and grabenal features respectively rather than simple ones.

3. **Bahrein-Southwest Siwa Basin**

This basin occupies the southwestern corner of the study area and consists of three local basin C_1, C_2 and C_3 of more or less similar pattern together with a horst block "e" and a grabenal feature "d" made by (Fs_3 and F_4) and (Fs_3 and Fs_4) respectively. Moreover, Fs_3 separates the two belts in a manner that Siwa Exp. well is located in the high belt while the Ain-Zeitun is in the low one.

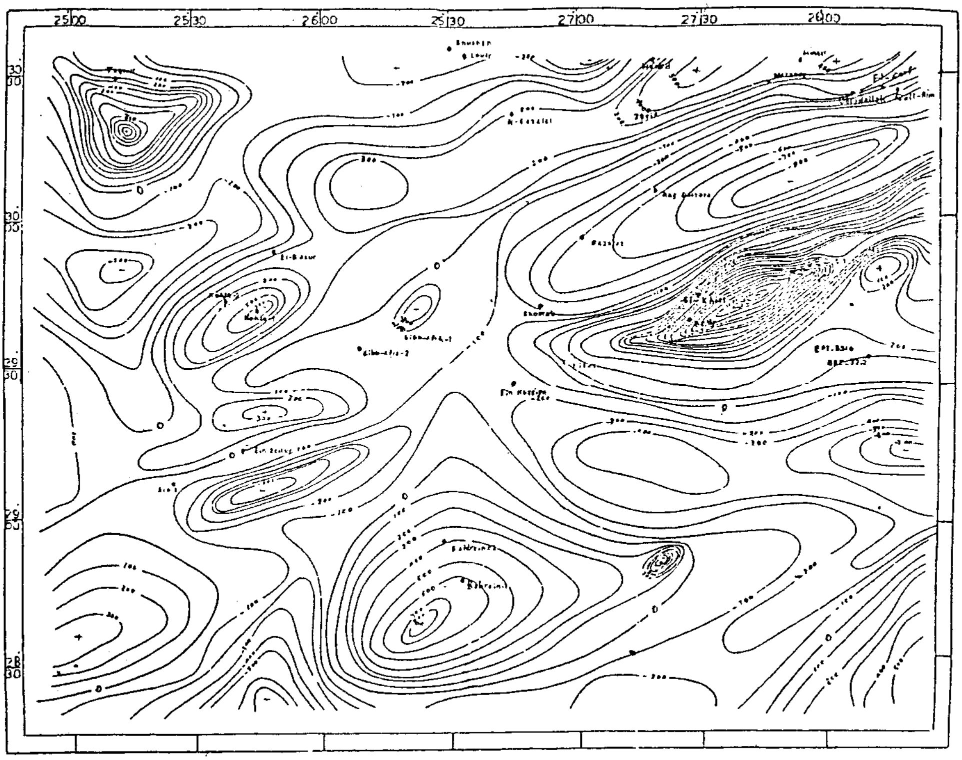
Conclusively, the above mentioned description had been visualized from the structural point of view. Such structural complication is considered as one of the main factors which promotes petroleum exploration and the accurate evaluation of the subsurface structural elements, in the area under investigation. This directed the writers to elaborate a mathematical regime to represent the basement relief in order



C.I. = 100 M

0 25 50 75 100 KM

Fig. 8: Estimated Depth of Basement Complex Calculated from Fourth order Polynomial.



C.I. = 100 M

0 25 50 75 100 KM

Fig. 9: Deviated Depth of Basement Complex Calculated from Third order Polynomial.

to facilitate quantitative study to clarify and delineate the most favourable sites for petroleum explorating wells.

Mathematical Models of the Regional Configuration of the Basement Surface

Applying the method discussed above on the depth data points, different polynomials could be obtained:

a) **A polynomial of third order**

$$^{Y}3\ rd = 2706.0366 + 24.9849\,x + 122.7699\,y + 0.8336\,x^2 - 2.1567\,xy - 6.1295\,y^2 - 0.0178\,x^3 - 0.0112\,x^2y + 0.0314\,xy^2 + 0.097\,y^3.$$

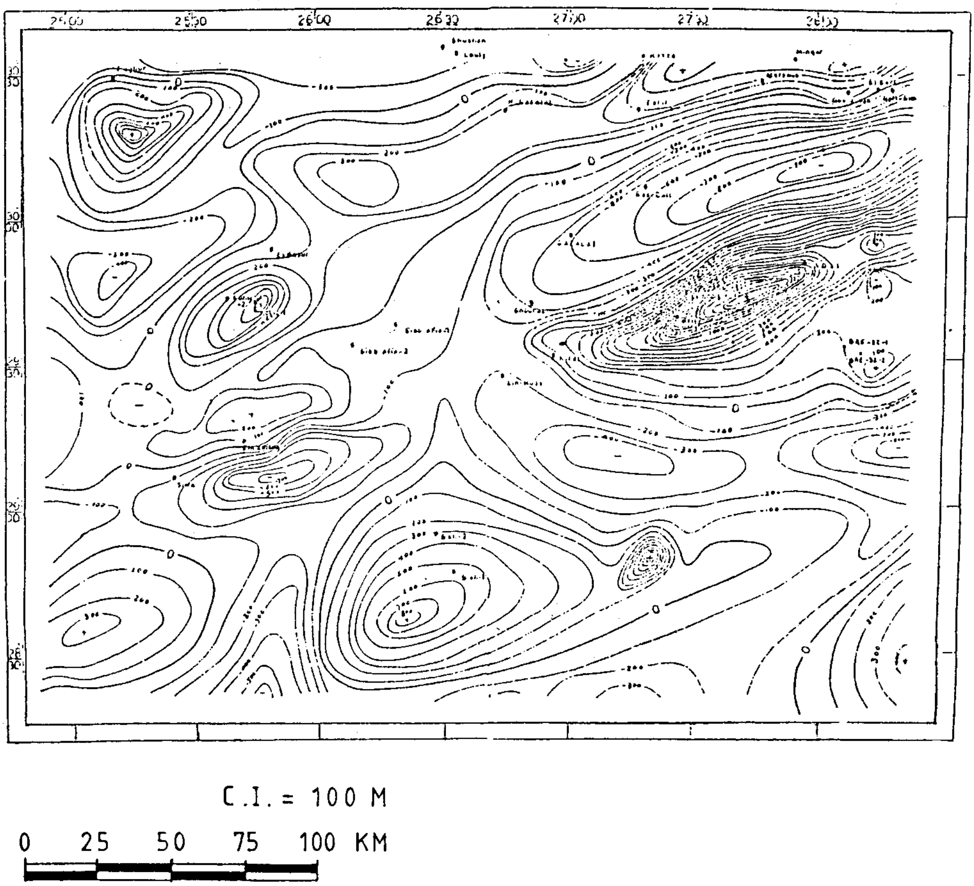


Fig. 10: Deviated Depth of Basement Calculated from Fourth order Polynomial.

which can be reduced to the following form

$^{Y}3\ rd = 2706.04 + 24.98\,x + 122.80\,y + 0.80\,x^2 - 2.20\,xy - 6.10y^2 \ldots.(1)$

b) **A polynomial of fourth order**

$^{Y}4\ th = 3228.0355 - 31.0706\,x + 22.2051\,y + 3.7603\,x^2 - 2.7167\,xy - 0.4842\,y^2 - 0.0987\,x^3 - 0.0401\,x^2y - 0.2099\,xy^2 + 0.0075\,y^3. + 0.0008\,x^4 + 0.00008\,x^2y^2 + 0.0033\,xy^3.$

Again this can be reduced to

$^{Y}4\ th = 3228.04 - 31.10\,x + 22.20\,y + 3.80\,x^2 + 2.72\,xy - 0.50\,y^2 - 0.10\,x^3 - 0.20\,xy^2 \ldots\ldots (2)$

Figures (7) and (8) represent the estimated contoured depth values of the basement surface over a regular grid of dimension 25 x 19 depth calculation points as represented by equations (1) and (2), respectively. Their outproduct fluctuation maps (Figs. 9 and 10 are observed as being still affected and biased to the original topography of the basement map (Fig. 6). This bias has led the writers to elaborate furthermore through a 5 *th* order polynomial, which takes the form:

$^{Y}5\ th = 2571.1456 + 140.5011\,x + 24.8634\,y - 5.6583\,x^2 - 22.1066\,xy + 23.8446\,y^2 + 0.1067\,x^3 + 0.6475\,x^2y + 1.4356\,xy^2 - 2.5644\,y^3 + 0.0007\,x^4 - 0.0179\,x^3y - 0.0050\,x^2y^2 - 0.0524\,xy^3 + 0.0923\,y^4 + 0.0020\,x^4y + 0.0001\,x^2y^3. + 0.0060\,xy^3 - 0.1100\,y^5 + \ldots\ldots (3)$

This is reduced to the following form

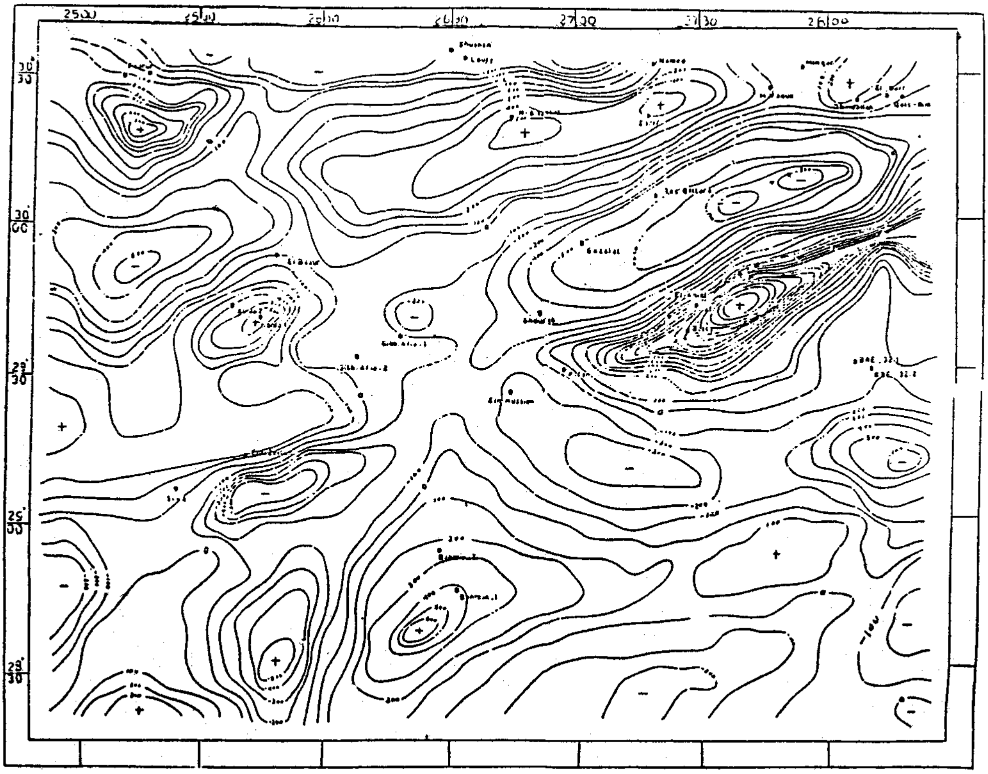
$^{Y}5\ th = 2571.1456 + 140.50\,x + 24.86\,y - 5.66\,x^2 - 22.11\,xy + 23.80\,y^2 + 0.11\,x^3 + 0.65\,x^2y + 1.40\,xy^2 - 2.60\,y^3 + 0.018\,x^3y - 0.52\,xy^3 + 0.09\,y^4 - 0.011\,y^5$ (4)

Figure (11), on the other hand, shows the deviation map of this fifth order polynomial. In fact, it strongly indicates the most preferable solution resulting a representative trend which is unbiased to the original basement topography (compare Fig. 11 with Fig. 6). The estimated fifth order polynomial basement surface is, therefore, shown in Fig. (12).

The following remarks may, moreover, support such preference:

1) The major structural elements (A, B and C) appearing on the original depth map are fairly recognized in the 5 *th* order polynomial map but through smoothed regional gradient slopes rather than their original correspondants, e.g., (Q_2), (B), (C_1), (C_2), (e) and (d).

2) Most of the fracture zones of the basement map (Fig. 6) are disclosed also in the 5 *th* order polynomial map with similar characteristics, e.g., Fs_3, s_6, F_7, and F_1.



C.I. = 100 M
0 25 50 75 100 KM

Fig. 11: Deviated Depth of Basement Complex Calculated from Fifth order Polynomial.

3) The total deviation, if homogeneously distributed all over the data values, is comparatively small (± 80 meters per each point of calculation).

4) The deviation map is of minimum bias to the original depth map (Fig. 6) although it still shows some minor features of its northern half.

5) The writers tried to classify the patterns of the 5 *th* order deviation map (Fig. 11) into three categories namely; negative, positive and around zero (minimum deviations) as illustrated in Fig. 13. However, it has to be of values smaller than the estimated ones. The third category is that of least deviation areas within a tolerance range of ± 100 meters comparatively less than the estimated ones. It is worth mentioning, however, that the last "zone" of deviation on the map of Fig.

(13) is the preferable and plausible site in selecting drilling locations for oil. The basement target for drilling purposes is lying within a tolerance range of ± 100 meters.

6) The last important remark that has to be taken into consideration is that all the calculations carried out in the basement surface mathematical representation procedures have been tied (based) to an origin (x_O, y_O) which is of coordinates 30° 40' 30" Latitude and 24° 43' 26" Longitude on the whole estimated maps.

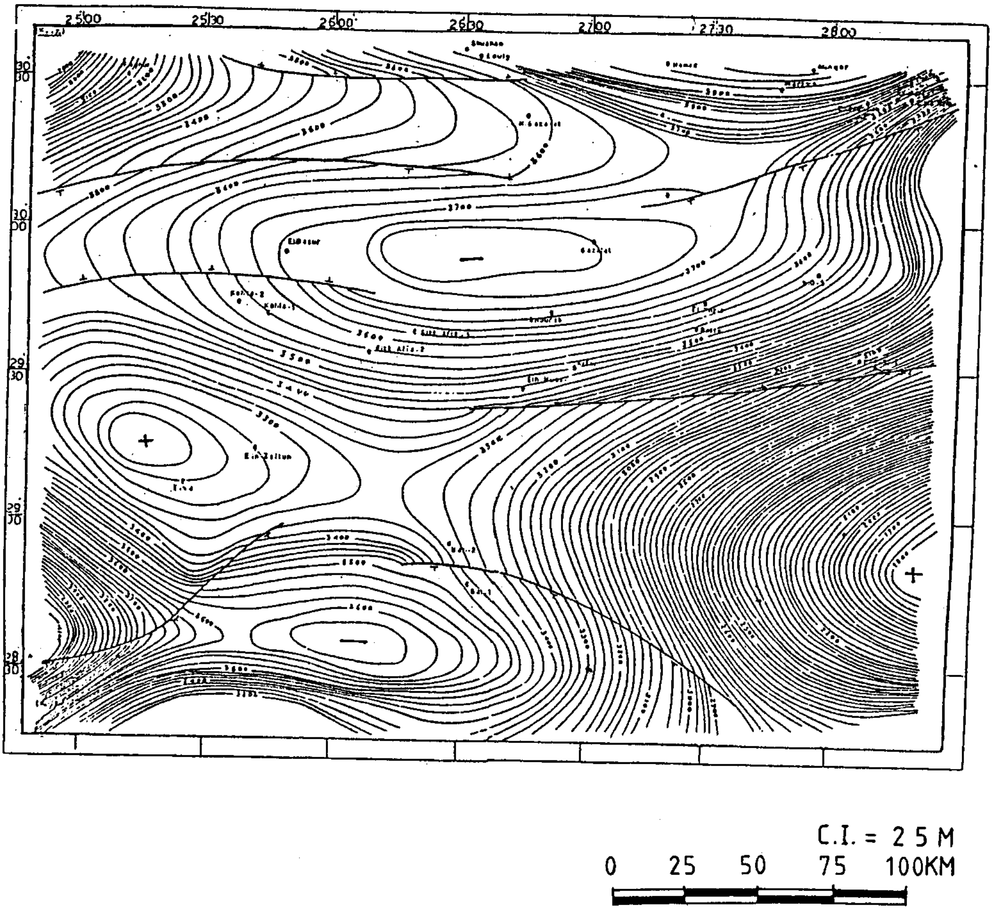


Fig. 12: Estimated Depth of Basement Complex Calculated from Fifth order Polynomial.

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التفسير الرياضي للسطح العلوي لصخور القاع بمنطقة سيوه منخفض القطارة بشمال الصحراء الغربية بمصر

رزق الله ابراهيم رزق الله و مراد باسيلي عوض

يتضمن هذا البحث حساب العمق إلى السطح العلوي لصخور القاعدة المعقدة لمنطقة سيوه ـ منخفض القطارة بالجزء الشمالي من صحراء مصر الغربية باستخدام خريطة الشذوذ التثاقلية للمنطقة .

وقد أمكن تمثيل هذا السطح العلوي لصخور القاع بواسطة الانموذج الرياضي متعدد الحدود ومن الدرجة الخامسة حيث تم تنفيذ الحسابات اللازمة والمعاملات الخاصة بهذا الانموذج الرياضي بواسطة الحاسب الآلي الموجود بالمعهد القومي لعلوم البحار والمصايد بالاسكندرية .

وقد ساعد هذا الانموذج الذي تم حسابه والانحرافات بينه وبين السطح العلوي لصخور القاع الذي يمثله والذي تم التوصل إليه من تفسير المدلولات التثاقلية من اختيار وتحديد الأماكن الأكثر أهمية من حيث احتمالاتها البترولية بمنطقة الدراسة .