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M. HAMED METWALLI, C. PHILIP & A. M. A. WALI

Repeated folding and its significance in northern Western Desert petroleum province, Egypt

ABSTRACT: The detailed structural synthesis of the subsurface structure in the northern part of the Western Desert of Egypt has become of great interest. In petroleum potential the northern Western Desert of Egypt is the second most promising localities of Egypt after the Gulf of Suez province. A detailed study of the structural modeling of Abu El-Gharadig and El-Razzak oil and gas fields in the northern part of the Western Desert of Egypt has shown that their structures change in shape, size or amplitude and shift their position laterally as a result of repeated folding stages that affected the study area during the Cretaceous age. This study is of great value where folding at the surface or at shallow depth is therefore not always a reliable guide in searching for petroleum pools that are trapped in reservoir rocks at great depths, for it frequently does not parallel the deeper folding.

INTRODUCTION

Geologic data in the study area are still limited, but accelerated petroleum prospecting since the mid-sixties of this century has created an urgent need for detailed subsurface structural models.

This paper deals with the structural synthesis of El-Razzak and Abu El-Gharadig oil and gas fields, located in the central part of the northern Western Desert of Egypt. The study area is located between latitudes 29°30′—30°40′N; and longitudes 28°22′—28°38′E, covering about 180 km^2 in El-Razzak field area; and 240 km^2 in Abu El-Gharadig field area. These two fields lie within an area that comprises a group of oil, gas and gas-condensates fields (Fig. 1).

The Western Desert of Egypt covers an area of about 700,000 km^2, or more than two thirds of the whole area of Egypt; however, the explored area is about 250,000 km^2, mainly north of the latitude 28°. Oil exploration in this vast area of the Western Desert is recent compared with that in the Gulf of Suez area, where the first well was drilled in

1908, while active exploration in the Egyptian Western Desert started in the mid-fifties.

Acknowledgements. The authors are grateful to the *Egyptian General Petroleum Corporation (EGPC)* and *GUPCO* oil company, Cairo, for providing logs and exploration and production data used in this work and permission to publish this work.

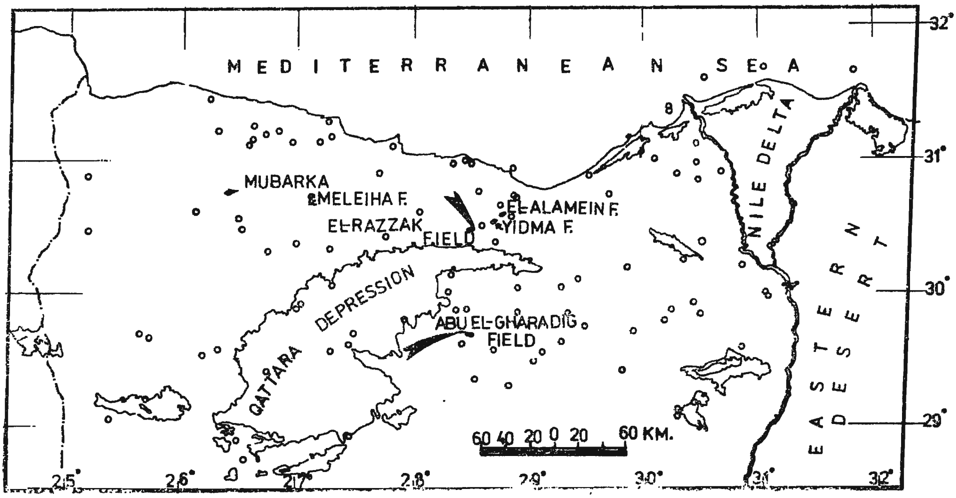

Fig. 1. Location map of the investigated area

HISTORY OF EXPLORATION

Active exploration of the investigated area began when Sahara Petroleum Company *(SAPETCO)* was granted exploration rights over the entire area of the northern part of the Western Desert.

Seismic Survey: Three periods of exploratory seismic work are distinguished, the first from 1933 through 1954, is characterized by limited activity. The second period lasted from 1954 to 1958, while the third started in 1964. During the years 1954—1958, *SAPETCO* covered the concession area by seismic survey. Activities were again resumed in 1964, when *Philips Petroleum Company (PPCO) Pan American Oil Company (AMOCO)* signed agreements with the *Egyptian General Petroleum Corporation (EGPC).*

Seismic activity in the concession of *PPCO* resulted in discovering the Alamein field in 1966, the first commercially productive oil field in the Northern Western Desert. Activities by *AMOCO* resulted in the discovery of Abu El-Gharadig oil and gas-gas condensate field in 1971 (22,000 *BOPD* at the end of 1972), while in the *Nile Petroleum Company (NIPCO)* concession area, El-Razzak oil field was discovered in 1972 (14,000 *BOPD* at the end of 1972). The two fields were discovered as a result of seismic activities of the Colombian and Western Geophysical companies applying the *CDP* analog technique (Ezzat, 1972). However, this technique failed to attenuate multiples which are a determinate to pre-Tertiary mapping. A digital "vibroses" crew was carried out by the second company which successfuly resolved the problem of poor reflections. Oil production in El-Razzak field is from the Aptian clastics, Aptian dolomite and Cenomanian clastics and carbonates; while in Abu El-Gharadig field it is from the Turonian carbonates and clastics, while gases are produced from the Cenomanian clastics.

Magnetic and Gravity Survey: Bouger and residual gravity coverage of about 18,500 km², as well as 140,000 km² of aeromagnetic survey were carried out in the Western Desert of Egypt.

GENERAL GEOLOGIC SETTING

The stratigraphic section in the northern Western Desert of Egypt ranges in age from the Cambro-Ordovician to the Recent.

The area includes a relatively thick marine and non-marine series of sedimentary rocks overlying the basement rocks, and it varies in thickness from one locality to another. Not much work has been done on the geology and structure of the basement rocks for the lack of accurate records on thickness variations of the total sedimentary sequence overlying the basement complex, particularly in the northern part of the Western Desert.

The Quaternary, Pliocene, and Miocene sediments are exposed on the surface and form the blanket over the subsurface section that has been penetrated by fourteen wells in El-Razzak area; and eighteen wells in Abu El-Gharading field area.

Uptill the present, there is no accepted classification for the subsurface stratigraphic units in the Western Desert. The main sequence penetrated is the Tertiary and the underlying Cretaceous lithostratigraphic units by the operating oil companies. Accordingly, stratigraphers based their classification on the succession penetrated by the drilled wells which reach around about 200 wells till the present. However, some detailed informations based on surface geology and drilled wells has already been reported (Shukri 1954, Kostandi 1959, Shata 1955, Amin 1961, Said 1962, El-Shazly & *al.* 1964, Norton 1967, 1971, Youssef 1968, Issawi 1972, El-Gezeery & al. 1972, Metwalli & Abd El-Hady 1973a, b, 1975a, b, El-Gezeery & O'Connor 1975).

The oil companies use the classification of Norton (1967) and El--Gezeery & O'Connor (1975) which are adopted in the present work as the subsurface structures are concerned as the main aim of the present paper.

Most of the wells drilled in the study area (Abu El-Gharading and El-Razzak fields) were ended in the Lower Cretaceous deposits, except Abu El-Gharadig well no. 1 *(AG-1)*, and El-Razzak wells nos. 1 and 13 *(RZK-1, RZK-13)* which penerated the upper Jurassic rocks.

The following is a generalized description of the sedimentary succession in the study area from top to base.

TERTIARY

(1) El-Jaohboub Formation (Recent — Middle Miocene): it covers the entire area of the northern Western Desert, the type locality is the high escarpment bordering El-Jaohboub Oasis (29°48'N; 24°31'E) in Libya (Desio 1928).

This formation is developed at the northern escarpment of Siwa Oasis 29°16'N; 25°31'E), where it attains a maximum thickness of about 255 ft. Said (1962a, b) equated the El-Jaohboub Formation to the Marmarica limestone which mainly formed the Middle Miocene section in the northern Western Desert of Egypt. This formation reaches about 305 ft thick in El-Razzak field, where the penetrated section in El-Razzak field is mainly of chalky limestone with some shale interbeds, indicating a shallow neritic to marginal marine depositional environment. While the formation pinches-out south-wards, where it is not recorded on the surface at Abu El-Gharadig field area.

(2) Moghra Formation (Lower Miocene — Oligocene): it underlies conformably El-Jaohboub Formation, and is composed of sandstone with interbeds of grey shale and limestone. It has been penetrated completely in El-Razzak field area, where it shows marked thinning-out south-wards and is represented only by surface clastics exposures with minor carbonate interbeds at Abu El-Gharadig field area.

(3) Daba Formation (Oligocene — Upper Eocene): it is penerated completely in the study area, and possess nearly the same thickness in the two fields areas. Its formational name was introduced by Norton (1967), who described a shale section (about 1450 ft thick), reflecting an open to shallow marine depositional environment in Daba well no. 1 (30°1'19"N; 28°29'42"E): it underlies conformably the Moghra Formation.

(4) Apollonia Formation (Middle to Lower Eocene): its type locality is Apollonia (Mersa Susa) in Libya (32°55'N; 22°05'E) with a maximum thickness of about 660 ft (Norton 1967). In the study area, it possesses a remarkable increase in thickness towards the south, from 300 ft mainly of limestone, occasionally glauconitic and argillaceous, to about 2000 ft in Abu El-Gharadig field, where it is represented by a limestone section with shale interbeds and sandstone streaks indicating by Norton (1967), an open marine environment.

MESOZOIC

The main sedimentary succession is penerated by fourteen wells in El-Razzak oil field area; and eighteen wells in Abu El-Gharadig field area, passed the Cretaceous and reached only the Upper Jurassic deposits. The Cretaceous successions are the main aim of the detailed structural analysis in the present paper, because oil exploration and production is restricted till now to these very successions in the study area.

UPPER CRETACEOUS

(1) Khoman Formation (Santonian — Maastrichtian): the type locality is the scarp to the west of Ain Khoman, south-west of Bahariya Oasis (27°55'N; 28°30'E), where it is 164 ft thick of chalk, moderately hard, fractured with calcite fillings,

richly fossiliferous reflecting an open marine environment with: *Globotruncana falsocalcarata, G. stuarti, Rugoglobigerina macrocephala,* and other foraminifers (Kerdany 1969).

This formation represents the major erosional phase that affected the structure of the study area. It is unconformably overlain by the Apollonia Formation and unconformably underlain by the Abu-Roash Formation.

(2) Abu-Roash Formation (Upper Cenomanian — Coniacian): its type locality is Abu-Roash surface section (29°54'N; 31°05'E), where it unconformably overlies the Bahariya Formation (Norton 1967; El-Gezeery O'Connor 1975).

This formation is made up of shallow to open marine limestone unit, formed of seven members (*A, B, C, D, E, F,* and *G;* Norton 1967). The members *A, B, D, F,* and *G* are formed of limestones, while *C* and *E* members are formed of sandstone which proved to be oil-bearing in Abu El-Gharadig field; their equivalents in El-Razzak field are mainly of open marine limestone.

(3) Bahariya Formation (Lower Cenomanian): its type locality is Gebel El--Dist, Bahariya Oasis, Western Desert (Stromer 1914, Said 1962); and Bahariya exploratory well no. 1 (28°25'21"N; 28°58'0"E), where it reaches a thickness of 1134 ft. It unconformably underlies the Abu-Roash Formation in Abu — El-Gharadig field, and conformably underlies Abu-Roash Formation in El-Razzak field area. It is composed mainly of inerbedded sandstone and shale sequence. The sandstones are the main, gas-gas condensate pay-zones in Abu El-Gharadig field, while it is one of the main oil-bearing formations in El-Razzak field.

LOWER CRETACEOUS

(1) Kharita Formation (Albian): it is composed mainly of sandstones and shales with rare carbonate interbeds. It underlies unconformably the Bahariya Formation in El-Razzak field area. The Kharita and the underlying Alamein Formation are not penetrated in Abu El-Gharadig field area, where they are thinning-out to the south. Its type locality is Kharita well no. 1 (30°33'48"N; 28°35'32"E).

(2) Alamein Formation (Aptian): it is of prime interest in oil exploration since it was the first commercially oil-bearing horizon discovered by *WEPCO* in Alamein oil field (Metwalli & Abd El-Hady 1973a, b, 1975a, b). The Alamein Formation is subdivided into two lithostratigraphic units with respect to the oil-bearing characteristics: *(a)* the upper unit commonly known as the Alamein Dolomite, consists minly of carbonate deposits; *(b)* the lower unit consists essentially of classtic components making up a thick alternating sequence of sandstone and shales.

The Aptian age of this formation is based of the presence of *Orbitolina discoidea* (*cf.* Metwalli & Abd El-Hady 1973a). This formation is oil-bearing in El--Razzak field, where oil is produced from the vuggy fissured dolomite horizon, which is not recorded in Abu-El-Gharadig field area.

(3) Alam El-Bueib Formation (Aptian — Barremian): its type locality is Alam El-Bueib exploratory well no. 1 (30°38'39"N; 29°08'37"E), where its thickness is 1200 ft. It is mainly composed of massive sandstone with infrequent shale interbeds.

(4) Betty Formation (Neocomian?): its type locality is Betty well no. 1 (29°40'08"N: 27°26'45"E), where it attains about 390 ft thick. It is composed mainly of sandstone and shale sequence. This formation is considered by Metwalli & Abd El-Hady (1973a), as a transitional unit between the lower-most Cretaceous and uppermost Jurassic rocks of about 1,655 ft of proposed early Lower Cretaceous? in Alamein oil field area. It is recorded in El-Razzak well no. 1 *(RZK-1),* about 460 ft thick.

JURASSIC

The penetrated Jurassic units in the study area are only the Masajid and the underlying Khattatba Formations.

(1) Masajid Formation (Kimmeridgian — Callovian): its type locality is Wadi Masajid, north of Bir Maghara, northern Sinai, Egypt (from 30°42′15″N, 33°22′45″E), to 30°43′50‴N, 33°12′00″E), where the maximum thickness is 1890 ft (Al-Far 1966). It underlies unconformably the Betty Formation. In El-Razzak oil field, it is represented by dolomite beds as it reached about 76 ft in well *RZK-13*. Barakat (1970) and Khaled (1975) assigned Callovian — Kimmeridigian age to this formation which was deposited in a shallow to open marine environment.

(2) Khattaba Formation (Bajocian — Callovian): its type locality is Khattatba well no. 1 (30°13′44″N; 30°50′E), where it attains about 2300 ft thick. In El-Razzak well no. 13 *(RZK-13)*, it reaches about 1174 ft thick, formed mainly of shales and siltstones with massive fine grained sandstone near the base. It underlies conformably the Masajid Formation and overlies the Eghei group of Norton (1976), which is not completely penerated in the study area.

TECTONIC SETTING AND STRUCTURAL MODELS OF ABU-GHARADIG AND EL-RAZZAK FIELD AREAS

This tectonic study is mainly concerned with the critical analysis of the available exploratory data from wells drilled in Abu El-Gharadig and El-Razzak fields. The tectonic setting of the northern Western Desert attracted the attention of many workers concerning its surface and subsurface structures (*cf.* Krenkel 1925, Picard 1939, Henson 1951, Shukri 1954, Yallouze & Knetch 1954).

Said (1962) detected three major groups of folding in the Western Desert: *(a)* the N—S fold trend that shows mostly in the subsurface, and which is of old age and affects markedly the Paleozoic sediments; *(b)* the north-eastern folds of presumably old age, which were especially active during the Cretaceous and lower Tertiary time (Syrian arc movement of Krenkel, 1925) and which show on the surface at Abu-Roash, Wadi El-Rayan, and Hadahid (Fayum area); in the subsurface, the trend is of spectacular appearance as seen from gravity survey (*e.g.* Alamein oil field); *(c)* the north-west folds, described by Shata (1953) who mentioned several of these surface structures between Moghra and Cairo, and to the north-east of Siwa Oasis.

Youssef (1968) reported that folds which are parallel to the prominant fault trends are around and along the Nile Valley; in and around the Gulf of Suez; in the Eastern Desert, specially along the Red Sea coast and the Cairo — Suez district; and across the Western Desert. He stated that some of the folds were formed during the deposition of the Upper Cretaceous sediments (*cf.* Shukri 1954, Youssef 1968). Most of these folds on close examination proved to be supratenous and many of the reported local unconformities are believed to be related to their effect.

Abdine & Deibis (1972) stated that faulting is evidenced in the Lower Cretaceous sediments in northern Western Desert and the strike faulting is predominantly parallel or perpendicular to the trend of folds of the Syrian arcs of Krenkel (1925) which are contemporaneous with Mesozoic folding through rejuvenation of the older Meridian faults.

Aadland & Hassan (1972), agreed with Abdine & Deibis (1972), concerning the fault trends and stated that Abu El-Gharadig field is located on a north to north--east deep-seated nose.

Metwalli & Abd El-Hady (1973a) in their tectonic analysis of the subsurface sedimentary succession in Alamein oil field area (28°40'—28°48'E, 30°32'—30°38'N), concluded that the field was drilled on a folded horst-block, lying within the axis of the structural Qattara — Alamein Ridge trending NE—SW. They draw the attention to the crestal shifting which might be taken into consideration in any drilling and exploration programming for petroleum in Alamein oil field area and similar structures.

Ezzat & Dia-El-Din (1974) stated that El-Razzak field is a structurally controlled oil trap that lies on the north--east plunging anticlinal nose of one of the series of the structural highs which forms the Qattara — Alamein Aptian ridge, and that Abu El-Gharadig field is a highly faulted anticlinal structure, as a result of differential movement of basement blocks.

Ezzat (1975) discussed the factors that affected seismic exploration in El--Razzak area which consequently affect the reliability of mapping subsurface structures and concluded that El-Razzak oil field is in structural alignment with that of the Qattara — Alamein ridge along which the three structures: El-Razzak, Yidma and Alamein structures proved to be oil-bearing fields.

Khaled (1976) in his subsurface study of El-Razzak oil field reached conclusions which are not far or even the same as Ezzat & El-Din (1974) and Ezzat (1975).

From this review of the previous works on the structures in the study area, it could be stated that the former workers dealt only with the type of structure without any detection or reference to change in shape, size or amplitude or detailed shifting of the structure except Metwalli & Abd El-Hady (1973a), who dealt and recognized the crestal shifting of the Alamein oil field structure.

STRUCTURAL MODEL OF ABU EL-GHARADIG OIL AND GAS-GAS CONDENSATE FIELD AREA

In the present work, the drilling data of eighteen vertical wells in Abu El-Gharadig field provided by *GUPCO*, are used critically for a detailed restudy and mapping of the structure of the field area.

As far as the authors are aware, Aadland & Hassan (1972) and Ezzat & Dia El-Din (1974) were the only authors who dealt with the general geologic and tectonic setting of Abu El-Gharadig field area. This field is given by Ezzat & Dia El-Din (1974) as a highly faulted anticlinal structure as a result of three main episodes of deformation that occurred in the late Lower Cenomanian and Late Turonian — pre-Maastrichtian periods, which affected the petroleum accumulation in Abu-Roash Formation, and the late Cretaceous — early Tertiary time which affected the Bahariya gas reservoir.

The detailed structural analysis of Abu El-Gharadig field area is of prime interest to understand the subsurface structures change in shape,

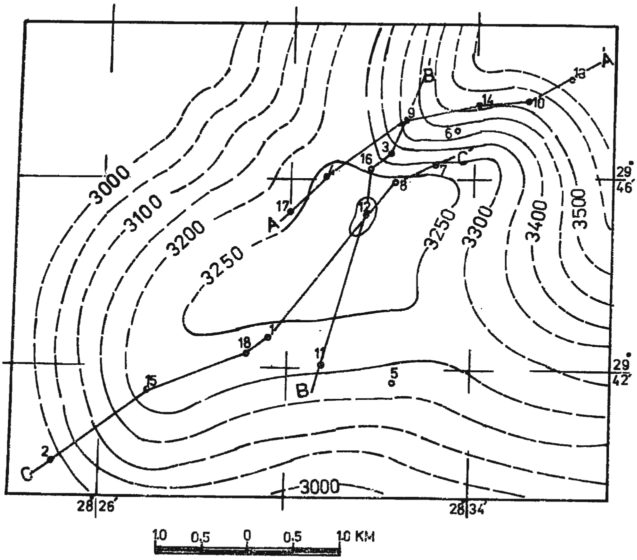

Fig. 2. Structural contour map on top of the Apollonia Fm., Abu El-Gharadig field; *A—A′*, *B—B′*, and *C—C′* indicate the lines of cross sections presented in Figs 6—8

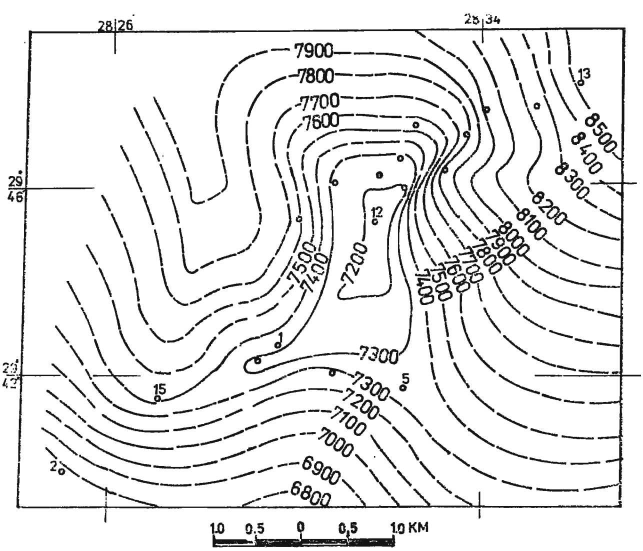

Fig. 3. Structural contour map on top of the Khoman *A* Mbr, Abu El-Gharadig field

size, or amplitude, or shift of their position laterally in-passing the vertical sedimentary successions down to the reservoir rock. The actual downward changes of the subsurface structures in the study area might play a very important role in the geologic life and capacity of rocks as petroleum reservoirs in the sedimentary succession in the northern Western Desert of Egypt.

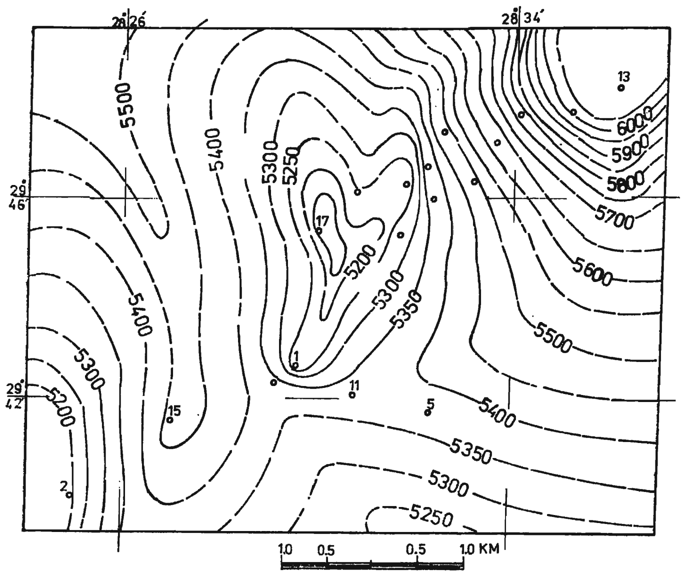

Fig. 4. Structural contour map on top of the Khoman *B* Mbr, Abu El-Gharadig field

The structural contour maps (Figs 2—5) and cross sections (Figs 6—8) show that Abu El-Gharadig field is an assymmetric plunging anticline trending NE—SW ("Syrian arc trend"). The structure is dissected by three traced faults prominant normal faults trending WNW—ESE. These faults (F_I, F_{II}, and F_{III}) divided the field into three main territorial portions: "*A*" portion, "*B*" central part, and "*C*" southern part.

The present authors consider the WNE-ESE trending faults as the main faulting trend in the area, and other hypothetical faults presumed and considered by former workers (Dia El-Din & Ezzat 1974) are rejected in the present work.

Abu El-Gharadig structural model shows that the fold closure of the various lithostratigraphic tops (Fig. 5) exhibits crestal shifting which is clearly seen in a NE-SW direction, *i.e.* the direction of the Syrian arc main folding movement that had been active during the Cretaceous and Lower Tertiary time. The various structural contours of the various tops of the different subcropping lithostratigraphic formations (Fig. 5) shows that the fold become increasingly more acute downward, that is they show more and more structural relief (Fig. 9) with increasing depth, and the formations become thinner at the crest of the fold than on the flanks and the thinning occur intermittently at some tops constructed, and a sudden increase in the intensity of folding is commonly observed below unconformity surfaces (see Figs 5 and 9).

Such gradual closure and growth of intensity of Abu El-Gharadig structure reflects a recurrent periods of folding during the Cretaceous

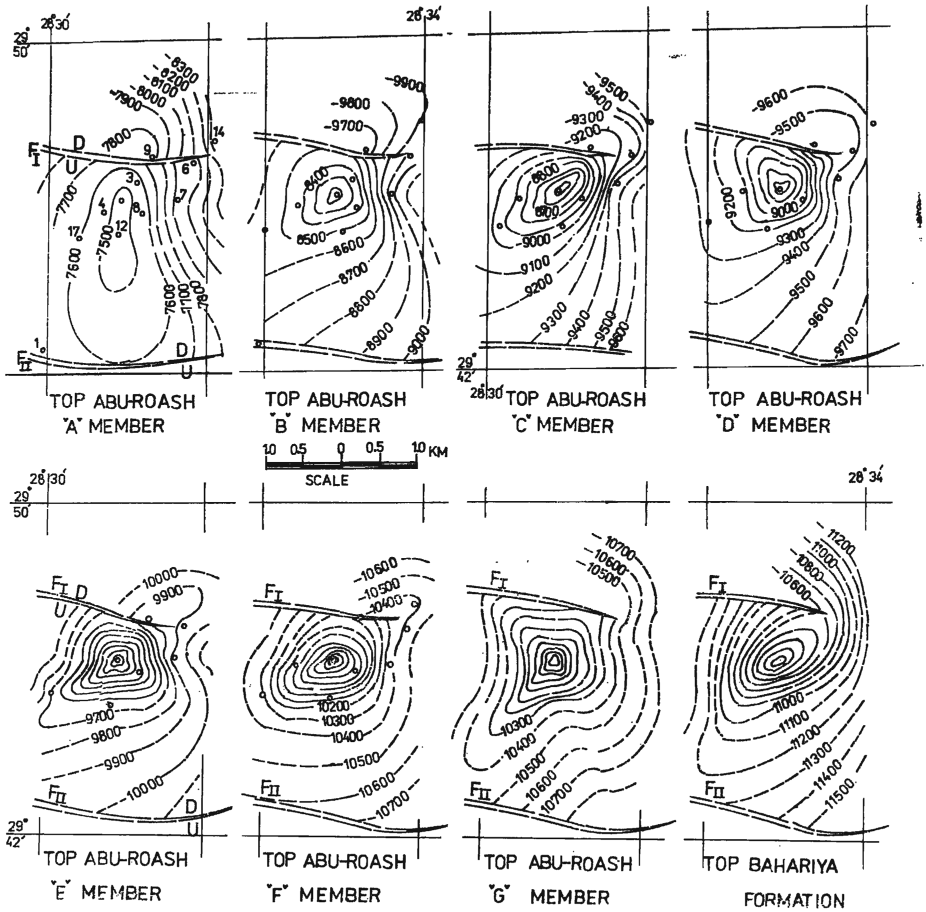

Fig. 5. Structural contours of the various tops of the subcropping formations (Abu--Roash and Bahariya) in Abu El-Gharadig field, showing crestal-shifting of the tops in a NE-SW direction, and gradual closure and growth of the structure by recurrent periods of folding which becomes more clear and acute downwards

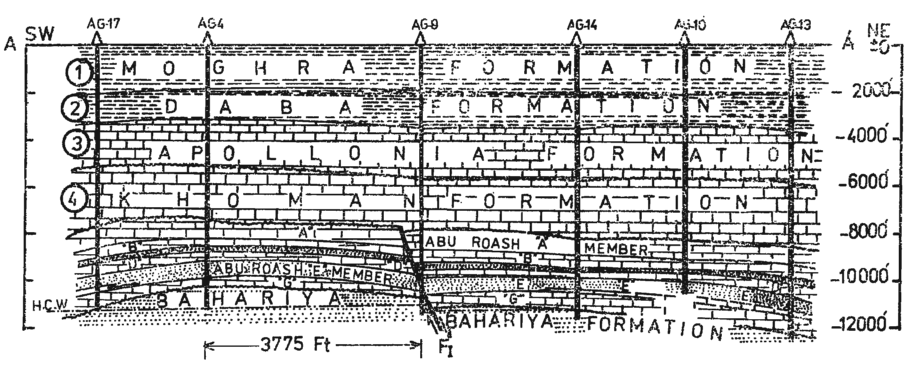

Fig. 6. Structural cross section across line *A—A'* in Fig. 2

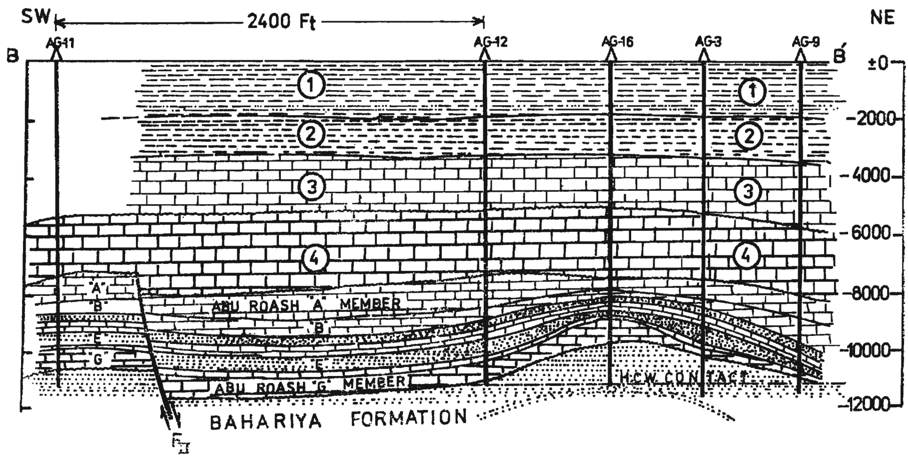

Fig. 7. Structural cross section across line *B—B'* in Fig. 2

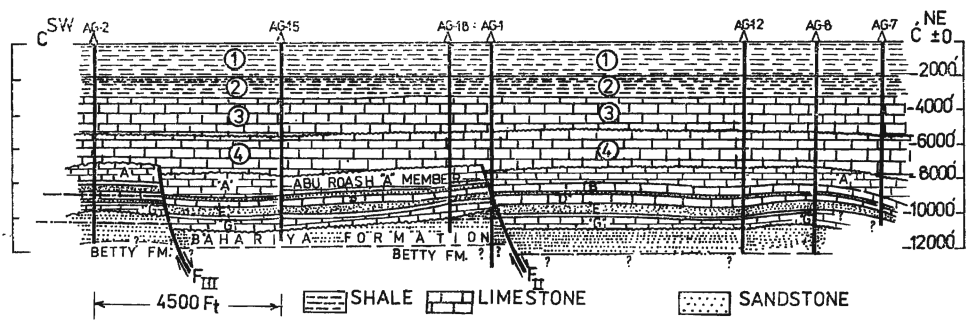

Fig. 8. Structural cross section across line C—C' in Fig. 2

which becomes more clear and acute downwards, i.e. the Abu El-Gharadig structure has grown repeatedly since the time, the reservoir rock was formed and the repeated folding of the strata is the main cause of the growing intensity of the fold with increasing depth from top of Abu-Roash "*A*" member, downwards to the top of Bahariya Formation. Accordingly, repeated folding of the strata is the main cause for the growing intensity of folding with increasing depth.

The Oklahoma City fold in Oklahoma (McGee & Clawson 1932), and the Hawkins fold in Texas (Wendlandt & *al.* 1946), are examples of folds that have grown repeatedly since the reservoir rock was formed.

The repeated folding of Abu El-Gharadig structure elucidated in the present work can be related to three main stages from base to top: *(1)* Post-Bahariya Formation (lower Cenomanian), *(2)* Minor post Abu-Roash "B" member, *(3)* Post Abu-Roash "A" member.

These three stages of repeated folding are directly restricted to the three unconformity surfaces encountered in the Cretaceous successions (see Figs 6—8).

The three faults (F_I, F_{II}, and F_{III}) are of the same age and belong to one deformational phase, which is believed to be pre-Khoman in age (pre-Maastrichtian). The stages of folding are earlier in age compared with faulting and are related to the Syrian arc compressional movement which was active during the Cretaceous and lower Tertiary times.

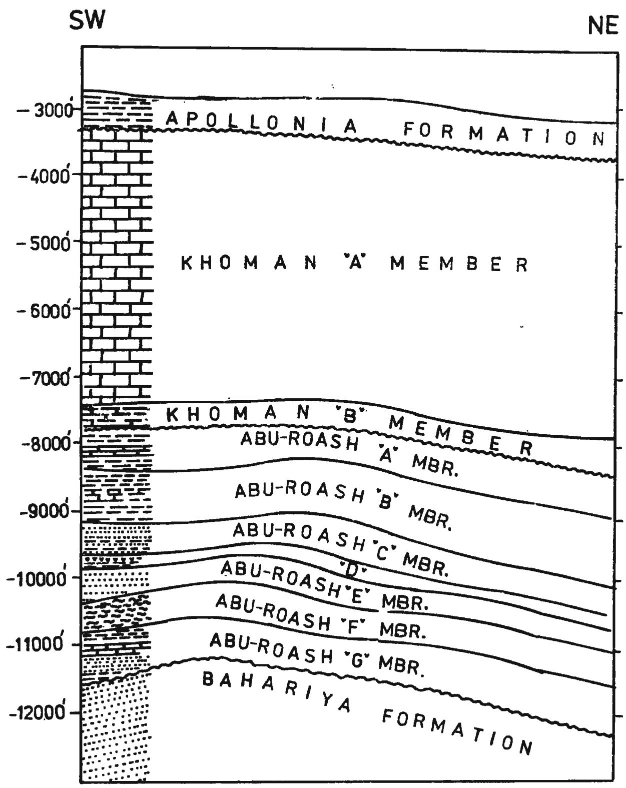

Fig. 9. Simplified subsurface section of the structural relief of the tops of the different formations in Abu El-Gharading field showing the crestal shifting in the NE—SW direction

STRUCTURE MODEL OF EL-RAZZAK OIL FIELD

El-Razzak oil field, the second structure in this work lies to the north of Abu El-Gharadig structure, more or less on the same longitude to the South-west of El-Alamein oil field (Fig. 1).

Ezzat & Dia El-Din (1974), Ezzat (1975), and Khaled (1976) are the only workers as far as the present authors are aware, who dealt with the tectonic setting of El-Razzak oil field. They considered El-Razzak structure as a north-east plunging anticlinal nose of one of a series of structural highs that form the Qattara — Alamein ridge.

The structural contour maps (Figs 10—12) and cross sections (Figs 13—14), show that El-Razzak oil field can be considered as a north-east plunging anticline which is dissected by two major normal faults (F_I and F_{II}) trending NE-SW. The analysis of the contour maps of the various tops of Abu-Roash, Bahariya, Kharita and Alamein Formations (Figs 11 and 15) are not going conformably with the structural synthesis of

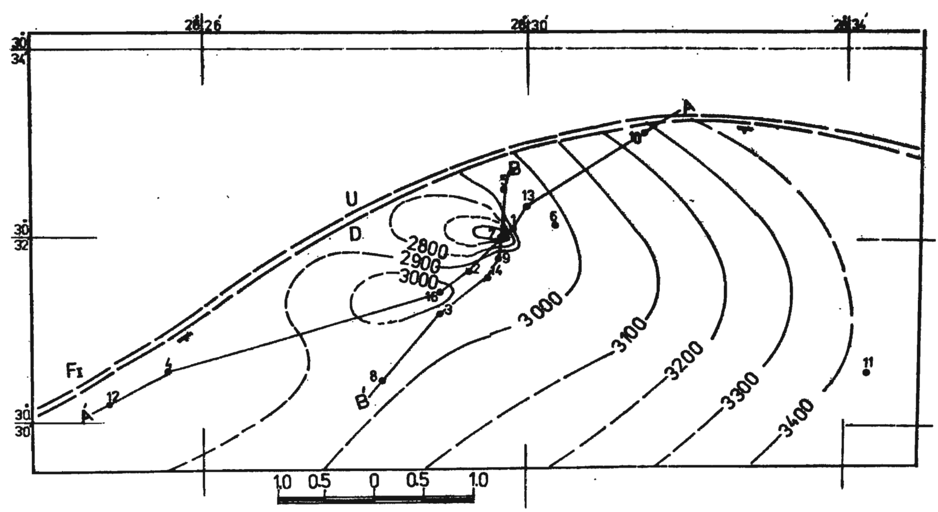

Fig. 10. Structural contour map on top of the Apollonia Fm. (El-Razzak oil field); *A—A′* and *B—B′* indicate the lines of cross sections presented in Figs 13—14

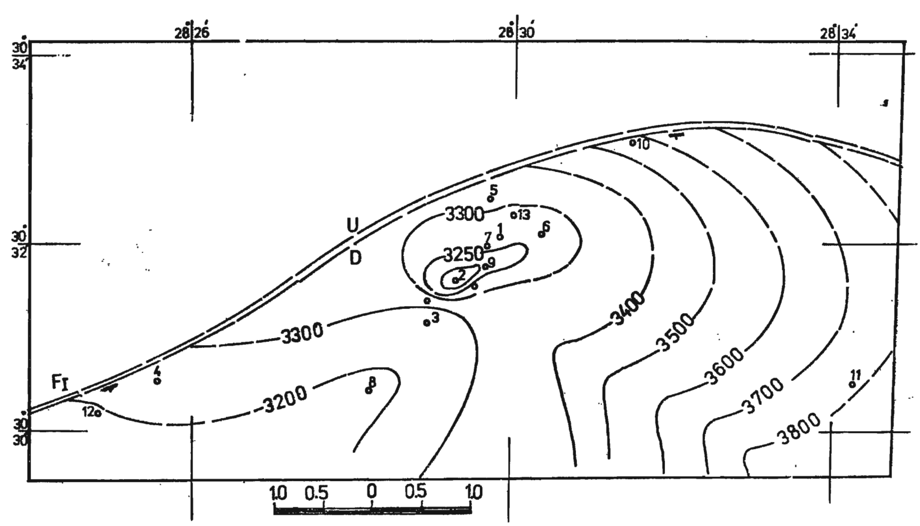

Fig. 11. Structural contour map on top of the Khoman Fm. (El-Razzak oil field)

Ezzat & Dia El-Din (1974) who considered El-Razzak structure as a "plunging nose". Also the three plunging noses together with the minor fault-pattern supposed and given by Khaled (1976), in his maps are not based on a pluzable geologic evidence and accordingly are eliminated in the present work.

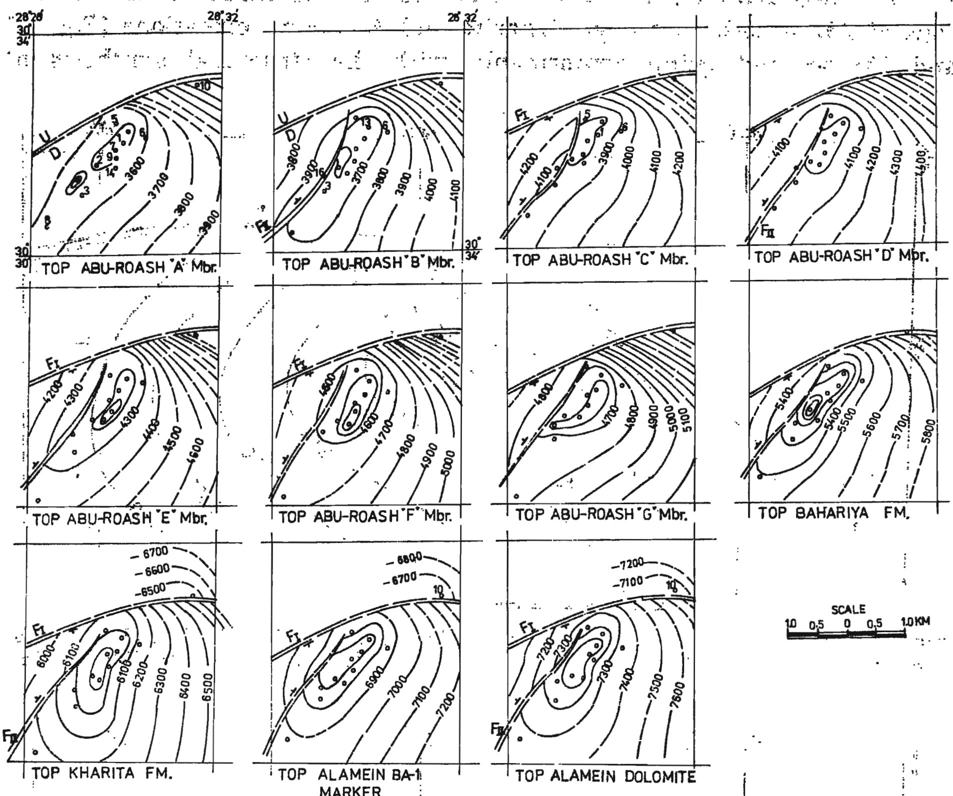

Fig. 12. Structural contour maps of the various tops of the different subcropping formations in El-Razzak oil field showing that crestal shifting is not clear, but apparently of slight magnitude

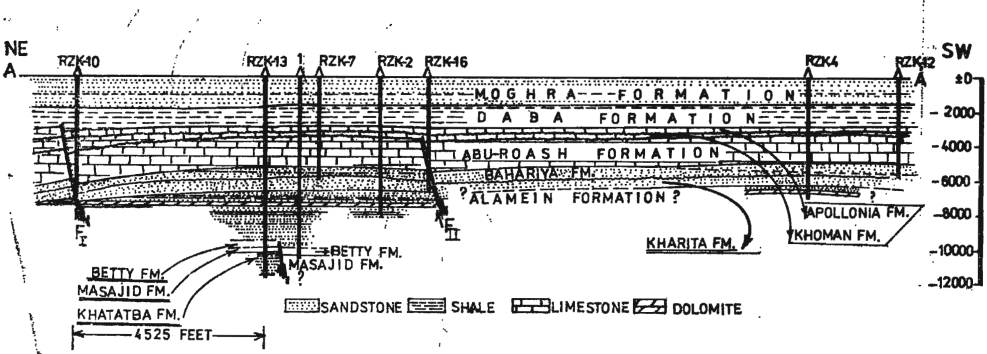

Fig. 13. Structural cross section across line $A—A'$ in Fig. 10

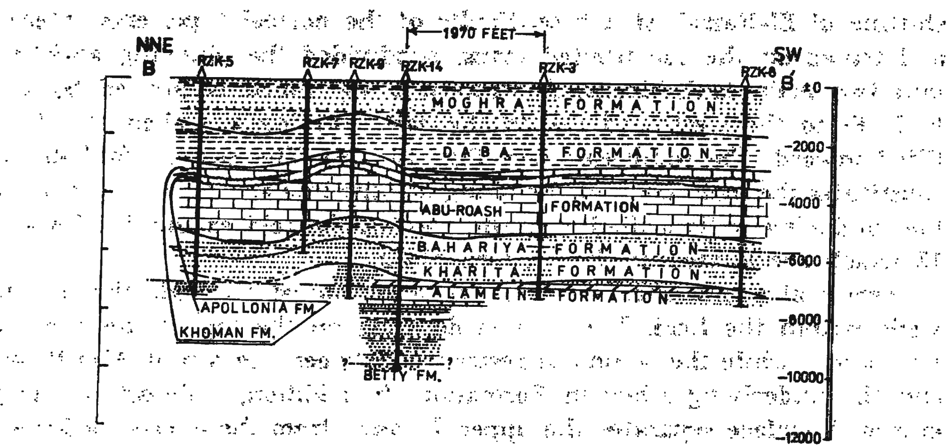

Fig. 14. Structural cross section across line B—B' in Fig. 10

It is of interest to state that the crestal shifting clearly seen in Abu El-Gharadig structure (Fig. 5), as a result of the asymmetric pattern of the fold is not clear in El-Razzak structure. The fold asymmetry of El--Razzak structure reflects only an apparent crestal shifting of a very slight magnitudes.

The structural contour maps of the various tops of the upper Cretaceous Formations in El-Razzak field, supported by the cross-sections, contradict the opinion of Khaled (1976) regarding his proposed crestal

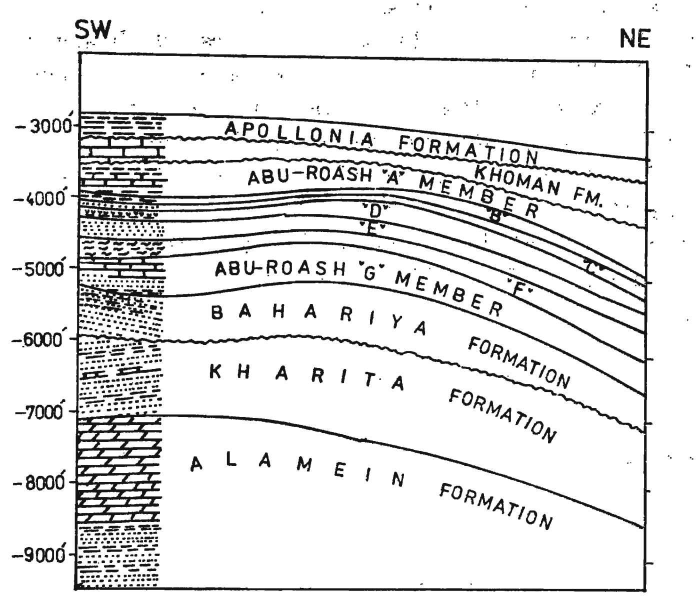

Fig. 15 Simplified subsurface section of the structural relief of the tops of the different formations in El-Razzak oil field in which the prominent crestal shifting of Abu El-Gharadig structure is not clear, but apparently of slight magnitude

shifting of El-Razzak structure. Faults of the normal type, encountered and traced on the constructed maps, subdivided the plunging anticline into two main fault-blocks. A western block which is limited by the fault F_I to the west, and F_{II}, to the east, forming a graben structure tilted towards the south-east (see Figs 13—14). The eastern fault-block constitutes the main body of the plunging anticline and comprises mainly the producing wells drilled over the crest of the fold except RZK-4 and 12 which are located at the western block.

Two major erosional surfaces are encountered through the drilled wells within the field. The first is detected on the top of the Kharita Formation, while the second is restricted between the top of Abu-Roash and the underlying Khoman Formation. In addition, a detectable deep erosional surface separates the upper Jurassic from the overlying lower--most Cretaceous section.

CONCLUSIONS

The phenomenon of repeated folding is clearly seen in Abu El-Gharadig structure, and can be seen in El-Razzak structure by comparing structure contour maps (Figs 5 and 12) on progressively deeper tops of the various formations, where the folds or the structure change in shape, size and amplitude and/or shift their position laterally down to the reservoir rock, which is clearly seen in Abu El-Gharadig structure and of slight magnitude in El-Razzak structure.

Abu El-Gharadig and El-Razzak structures which are faulted plunging anticlinal folds, are the result of the same compressional movement (Syrian arc movement) that prevailed on the territory of Egypt and other adjoining regions during the Upper Cretaceous — Lower Tertiary time, and the faults that dissected them are of the same phase (pre--Maastrichtian).

The poor quality of the geophysical measurements in the studied area and similar areas in the northern part of the Western Desert of Egypt are actually due to actual downward changes of structure due to repeated folding traced for the first time in this work, which should be a clue for further elaborate tectonic analysis of the burried tectonic models.

Faculty of Science, Department of Geology
of the Cairo University
Giza, A. R., Egypt
Present adresses:
Cultural and Scientific Office of A. R., Egypt
Al. Wyzwolenia 10, 00-570 Warszawa, Poland
(M. Hamed Metwalli)

Institute of Salts Ledges and Chemical Staples,
Academy of Mining and Metallurgy,
Al. Mickiewicza 30, 30-059 Kraków, Poland
(A. M. A. Wali)

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