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# Scenario of Sedimentation in Relation to Tectonics along Bardawil Lake, Coastal Margin of Northern Sinai, Egypt

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ABSTRACT. Recent information gained by drilling allows the subsurface geology of north Sinai to be established. The subsurface depositional successions have been studied in three deep wells; Malha–1, El-Mazar–1 and Bardawil–1 drilled around lake Bardawil by the International Egyptian Oil Company.

The total thickness of the section varies from 2198 m at Malha–1 to 2492 m at El-Mazar–1 penetrating the Jurassic rocks. While at Bardawil–1 the thick succession reaches about 4490 m but penetrates only into Cretaceous rocks.

The subsurface lithostratigraphy has been studied to elucidate thickness variations, facies changes, depositional environments and paleogeography.

In general, there are slight changes in thickness for the Mesozoic sediments but much greater differences the Tertiary deposits. The thickness are least south Malha–1, with approximately 200 m and greater in the north west (Bardawil–1) with more than 2000 m of sediments indicating rapid filling of an actively subsiding basin in which the sediments had been dropped down-basin toward the Mediterranean sea by faulting. Rapid lateral and vertical changes in facies in response to tectonics have also been demonstrated. The relationship between sedimentation and possible tectonics in this particular area is further interpreted.

## Introduction

From latitude 30° northward, alternating faulted domes, anticlines and synclines known as the Syrian Arc form a contrasting topography of low alluvial plains and high hill masses (Fig. 1).

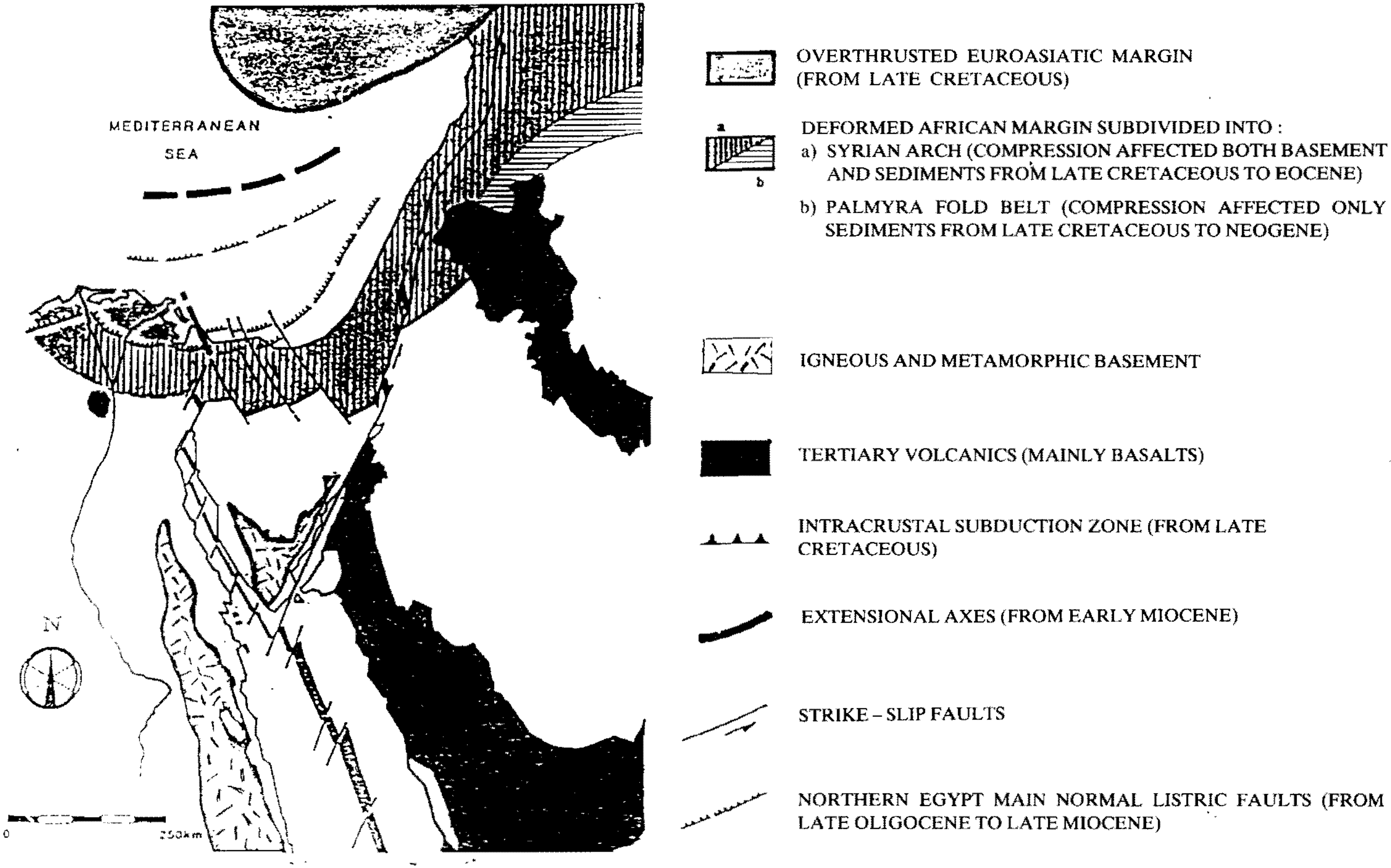


FIG. 1. Sketch of structural framework of the Eastern Mediterranean Sea (Massimo and Sergio 1986).

The northern Sinai comprises three structural units; the Mediterranean foreshore area, the north Sinai strongly folded area and the north Sinai fractured area (Shata 1956). The first is a belt of low relief and comprises the coastal area with a complex of parallel coastal dunes and offshore bars, enclosing in the centre the vast Sabkhet El-Bardawil.

In nothern Sinai, the principal site of the present paper, many workers dealt with surface stratigraphy exposed in Gebel Maghara and Risan Aneiza (Farag 1947), Gebel Halal and Gebel Yelleg anticlines, Gebel Giddi and Gebel Libni (Said 1962).

However, little is known about the subsurface geology in northern Sinai. Carry (1976) and Livermore and Smith (1985) assumed that during the Late Cretaceous-Eocene, the eastern Mediterranean Sea had a compressional character as a result of subduction of the African-Arabian Plate beneath the Euro-Asiatic over thrusted margin. This produced faulting in the study area and thrusting of the Syrian Arc towards the south. During the Oligocene-Miocene, the weakness and hinge lines (Fig. 2 ) which related to the previous deformational phases, were reactivated and normal fault systems were generated having a WSW-ENE orientation.

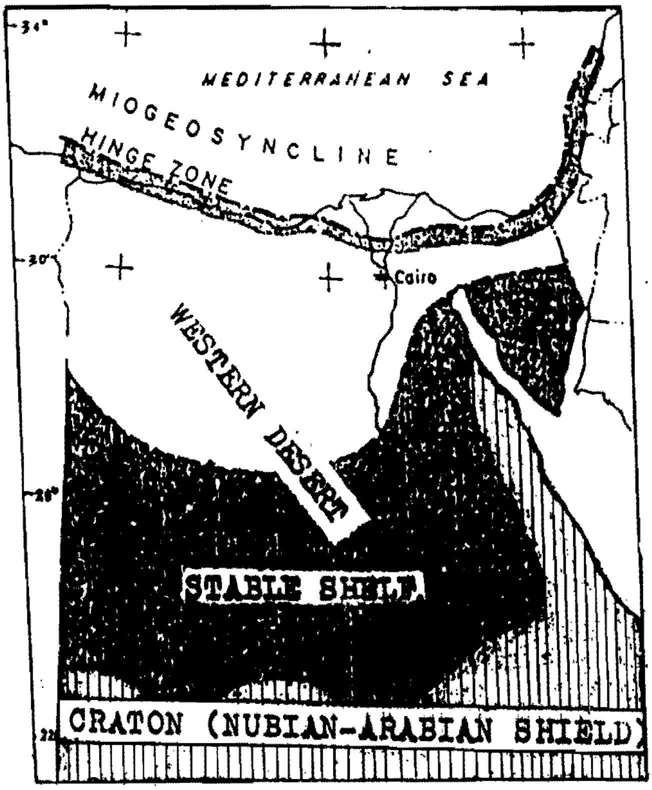


FIG. 2. Sketch of the structural aspects of the Nubian-Arabian Shield margin in Northern Egypt (From Schlumberger 1984).

The sedimentological-seismostratigraphic study of NE-Egypt permitted the identification of six genetic deposition sequences. These were grouped in turn into two supercycles connected with the two major tectonic episodes *i.e.* the late Oligocene and Serravallian phases (Massimo and Sergio 1986).

Middle Miocene sedimentation is characterized by an extensive open marine stage in which both inner and outer neritic environments are recognised. During the Late Miocene sedimentation took place in lagoonal to shallow marine environments (El-Beialy and Gheith 1992).

## Material and Techniques

The selected wells, drilled by IEOC in 1986 in the area of Lake Bardawil, were given the names Malha–1, El-Mazar–1 and Bardawil–1 (Fig. 3). Representative samples raised from these wells have been kindly provided by IEOC.

Malha–1 well is located to the south of Lake Bardawil (Lat. 30°59′, Long. 33°20′) and has penetrated a total thickness of 2198 m of rocks ranging in age from Jurassic to Quaternary.

El-Mazar–1 well is located on the shore of the lake (Lat. 31°05′, Long. 33°19′), the drilling penetrated 2492 m of Jurassic to Quaternary rocks.

El-Bardawil–1 well was drilled in the lake itself (Lat. 31°08′, Long. 33°07′) and has penetrated a total thickness of 4490 m of rocks from Cretaceous to Quaternary in age.

In order to designate the associations of the subsurface sediments penetrated in the three wells, 156 ditch samples were chosen representing the different time rock units. These were analysed for carbonate, sand and mud contents using 10% HCl (Folk 1968). The data obtained have been presented graphically in triangular compositional diagrams according to Füchtbauer and Müller (1970); Fig. 5. Furthermore, the stratigraphic compositional variation with depth is illustrated graphically in Fig. 6.

## Subsurface Lithostratigraphy of North Sinai

Very little information is currently available on the subsurface geology of northern Sinai. However, recently knowledge has been gained by drilling and through surface geophysical investigation.

The following is a lithostratigraphic description of the subsurface successions penetrated in the three studied wells; Malha–1, El-Mazar–1 and El-Bardawil–1 starting from base to top. The classification adopted herein is taken from the composite lithologic log prepared by IEOC in 1986. This is further illustrated by the constructed correlation chart prepared by the authors and shown in Fig. 4.

### *Jurassic*

Jurassic deposits are encountered only in the Malha–1 and El-Mazar–1 wells. It is

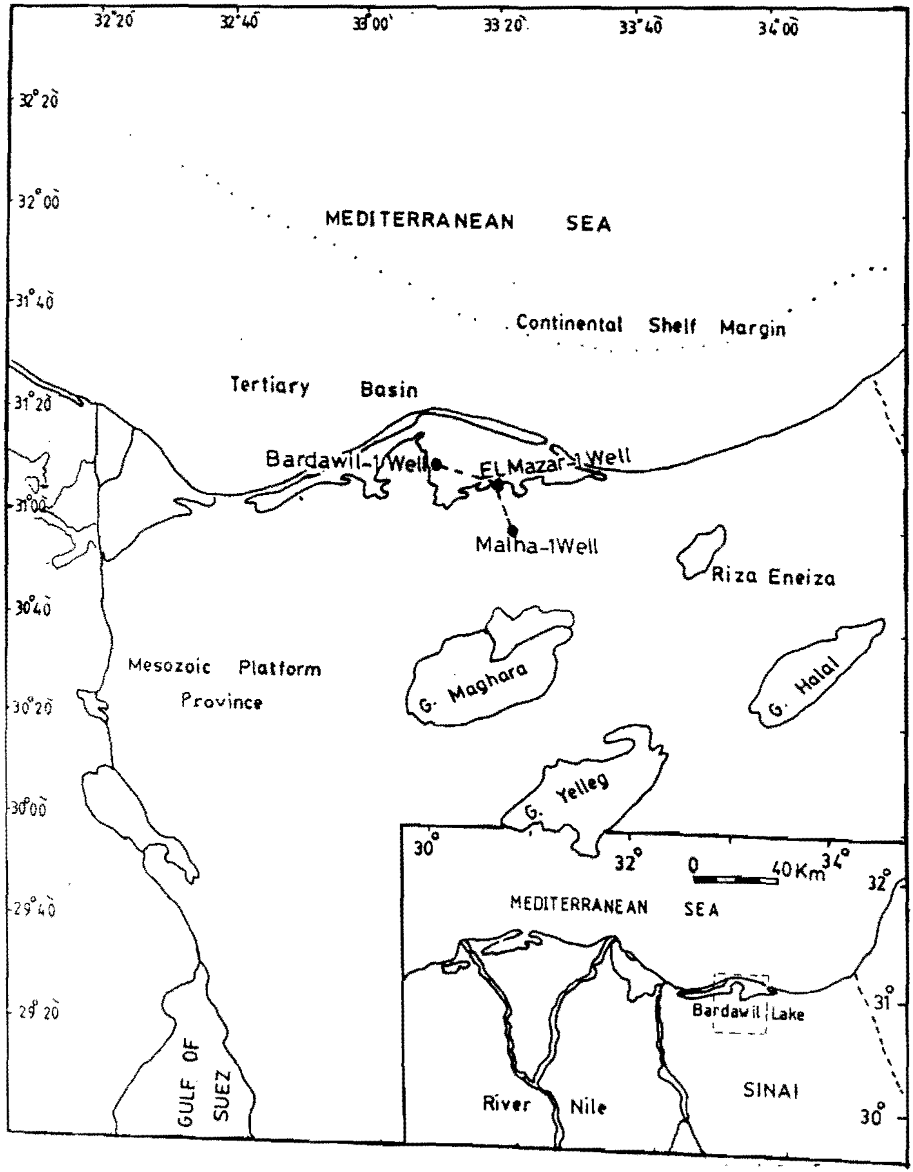


FIG. 3. Location map of North Sinai Wells (• studied wells) (Scale 1:500:000).

not penetrated in the Bardawil–1 well. The Jurassic sequence of the Malha–1 well is well developed and has a total thickness of about 1120 m. It includes three series :

i – Early Jurassic (2198 – 1947 m) :

This is mainly of dark grey shale interbedded by thin layers of limestone and sandstone.

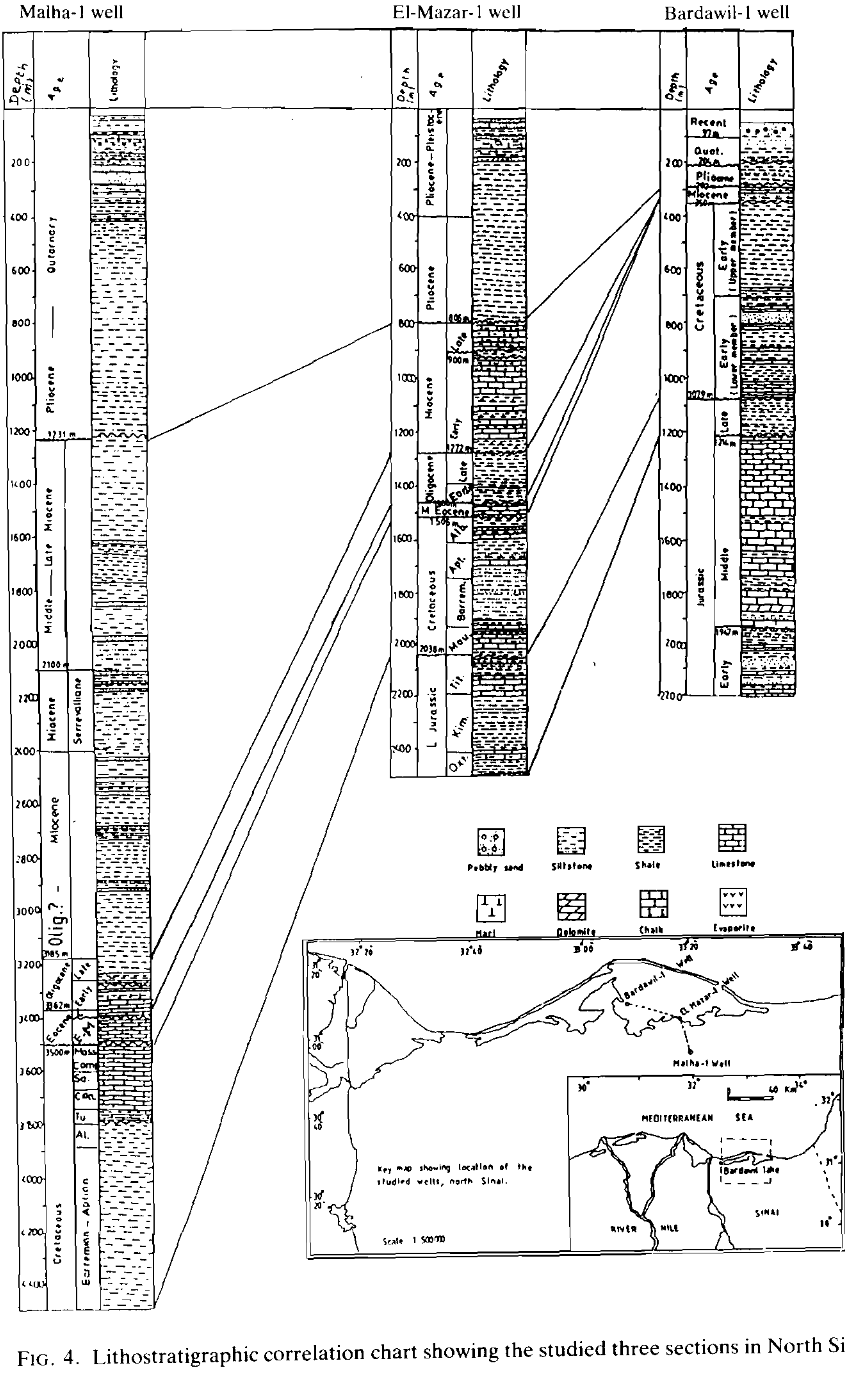


FIG. 4. Lithostratigraphic correlation chart showing the studied three sections in North Sinai.

ii – Middle Jurassic (1947 – 1214 m) :
This sequence is composed predominantly of limestone intercalated with thin streaks of shale and sandstone at bottom and top.

iii – Late Jurassic (1214 – 1079 m) :
It consists mainly of shale, silty and non-calcareous deposits pointing to shallow open marine environment.

From Malha–1 well, eighteen samples were analysed from the Jurassic sequence. In general, the samples have an arenaceous composition especially in the middle part. However, a wide range in lithology characterizes the Jurassic sequence of Malha–1. It varies between calcareous sandy mud, calcareous mud and muddy limestone (Fig. 5A). Apparently, early Jurassic sediments consists of alternating sandstone and mudstone, pointing to a shallow shelf environment of deposition. It is suggested that a high stand of sea level might have occurred in Middle to Late Jurassic times at the site of Malha–1.

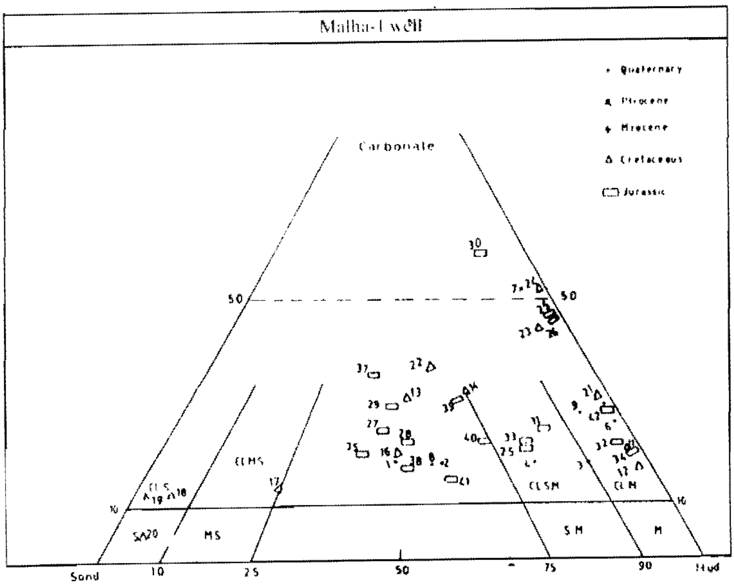


FIG. 5a. Carbonate-sand-mud compositional diagram for the subsurface sediments of Malha–1 well, North Sinai.

The Jurassic sequence of El-Mazar–1 well is represented by the late unit includes the series :

i – Oxfordian (2492 – 2412 m) :
This consists mainly of shale, greyish to greenish silty, pyritic and interbedded by limestone with thin occasional streaks of siltstone and sandstone.

ii – Kimmeridgian (2412 – 2190 m) :
This series is composed mainly of greyish shales.

iii – Tithonian (2190 – 2038 m) :
The Tithonian sequence consists mainly of shales interbedded by dolomitic limestone.

Eight samples were analysed from the Jurassic sequence of the El-Mazar–1 well. The samples in the top part have calcareous sandy mud and calcareous mud, (Fig. 5B). In the lower part of the core the samples were enriched in both carbonate and mud, while there was a remarkable decrease of sand content with depth is noticed (Fig. 6B). It is suggested that sea-level lowering occurred in the late Jurassic at El-Mazar–1.

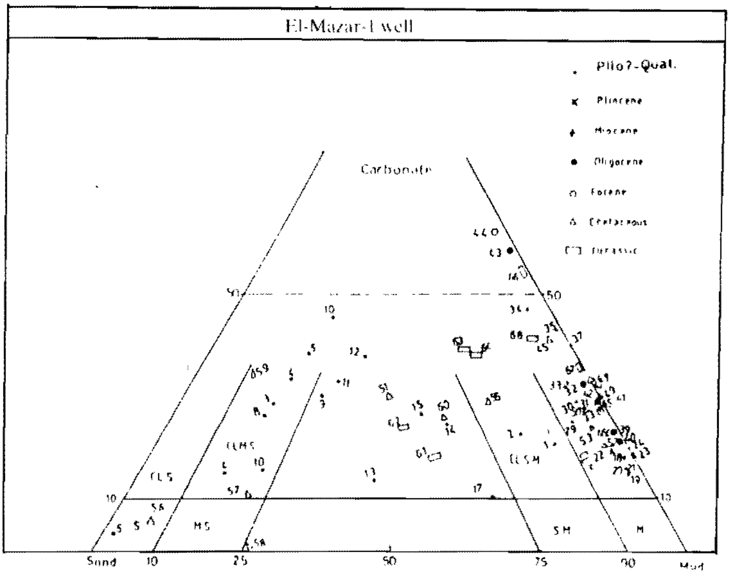


FIG. 5b. Carbonate-sand-mud compositional diagram for the subsurface sediments of El-Mazar–1 well, North Sinai.

### *Cretaceous*

The Cretaceous unconformably overlies the Jurassic sequence of Malha–1 well and El-Mazar–1 well. The early Cretaceous of Malha–1 consists of two members :

i – Lower member (1079 – 710 m) :
It consists mainly shale interbedded with thin layers of limestone, with marly beds and also sandstone at the top.

ii – Upper member (710 – 350 m) :
This is composed mainly of shale.

From Malha–1 well fourteen samples were analysed from the Cretaceous sequence. Generally, the samples at top are characterized by a high content of mud, minor carbonate and sand content (Fig. 5A & 6A). The lithology becomes totally different in the middle part, being composed mainly of sand. At base it is calcareous mud of marl. This compositional variation points to a regression of sea in early Cretaceous, then a marine transgression was re-established depositing carbonate and marl.

Meanwhile, the Cretaceous of El-Mazar–1 well is represented only by the lower rock unit, which includes the following series according to the stratigraphic classification adopted by IEOC (1986).

i – Hauterivian (2038 – 1930 m) :
This part of the sequence is composed of sandstone interbedded by shale and argillaceous limestone.

ii – Barremian (1930 – 1740 m) : .
This series consists mainly of sandstone alternating with shale and siltstone.

iii – Aptian (1740 – 1604 m) :
The lithology is mainly sandstone with argillaceous limestone at bottom and shale with siltstone at the top.

iv – Albian (1604 – 1505 m) :
Conformably overlying the Aptian beds and consists mainly of sandstone. It is generally calcareous with shale at the top.

Sixteen samples were analysed from the El-Mazar–1 well. They generally have variable composition; calcareous mud, calcareous sandy mud, calcareous muddy sand and sand (Fig. 5B). Sand increase with depth while carbonate decreases. This is probably related to the changing environment of deposition with time, being shallow marine at the base becoming progressively deeper marine towards the top.

The part of the Cretaceous sequence penetrated by the Bardawil–1 well is thicker than its equivalent in either of the other two wells. Its thickness reaches about 990 m and includes the following series :

i – Barremian-Aptian (4490 – 3884 m) :
The deposits consist mainly of shale and siltstone.

ii – Albian (3884 – 3779 m) :
The rocks are composed of shale interbedded with sandstone and streaks of limestone and marl at top.

The upper Cretaceous sequence includes the following series; Turonian, Coniacian, Santonian, Maastrichtian and Campanian within the interval from 3379 m to 3500 m. These series unconformably overlie the lower Cretaceous sequence and consist of limestone and chalks.

The nine samples analysed from the Bardawil–1 well have a variable lithological composition. They consist of limestone at top and calcareous sandy mud to calcareous mud in the middle and bottom parts (Fig. 5C). Generally, carbonate seems to decrease downwards (Fig. 6C).

***Eocene***

Poorly developed Eocene rocks are penetrated in the El-Mazar–1 and Bardawil–1

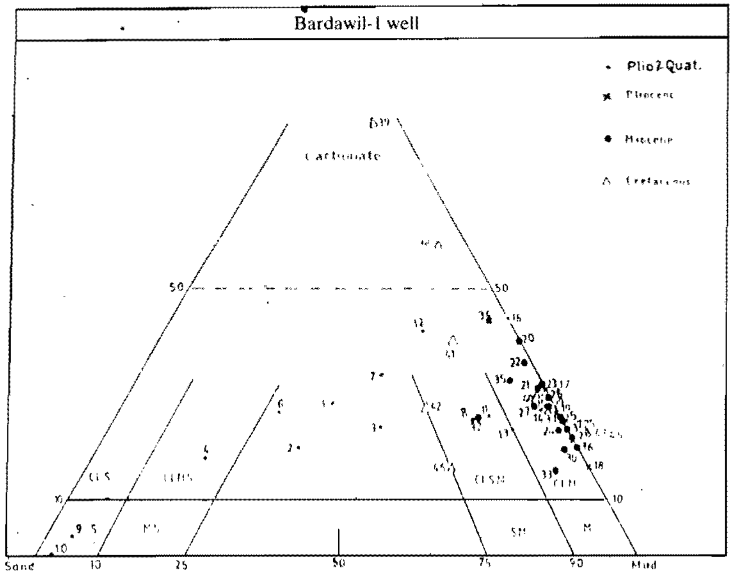


FIG. 5c. Carbonate-sand-mud compositional diagram for the subsurface sediments of Bardawil–1 well, North Sinai.

wells. They are absent in the Malha–1 well. However, the Eocene sequence penetrated is relatively very thin, with a total thickness of about 45 m of Middle Eocene in the El-Mazar–1 well and 138 m of Early, Middle to Late Eocene in the Bardawil–1 well. Eocene sediments unconformably overlie the Cretaceous and generally consist of limestone slightly chalky to argillaceous.

The single sample analysed from the El-Mazar–1 well is mainly of muddy limestone.

### *Oligocene*

Oligocene sediments are encountered only in El-Mazar–1 and Bardawil–1 wells. They pinch out in Malha–1 as the Eocene sediments. It is composed mainly of shale with limestone interbeds in the El-Mazar–1 well (188 m thick). But it consists of shale with sandstone interbeds and thin streaks of limestone in the Bardawil–1 well, with a total thickness of about 177 m.

The five samples analysed from the El-Mazar–1 well have a calcareous mud composition. The samples are possibly of shallow marine deposition.

### *Miocene*

Herein, the Miocene sediments show strong thickness and facies variations. In the Malha–1 well where it is about 58 m in thickness, Miocene unconformably overlies the Cretaceous and is composed mainly of clay with streaks of sandstones and limestones. Samples analysed from the Miocene sequence of the Malha–1 well have a composition of muddy sand at the top and calcareous mud at the bottom (Fig. 5A & 6A). The composition of the samples analysed points to lagoonal environment changing to shallow marine northwards.

The Miocene in the El-Mazar–1 well shows distinct thickness and facies variations. It has a total thickness of 466 m. The Early Miocene is 342 m thick, composed mainly of limestone, shale and marl, whereas the Late Miocene is about 130 m thick composed mainly of shale, limestone and dolomite. Fifteen samples have been analysed from the El-Mazar–1 well. Most have a calcareous mud composition similar to that of Bardawil–1 (Fig. 5B & 6B).

Moreover, the very thick Miocene of Bardawil–1 reaches a total thickness of about 1954 m, although it is not yet differentiated from the Oligocene at base. Generally, it consists of shale which becomes sand at the top. Eighteen samples analysed from Bardawil–1, generally have a calcareous mud composition. No systematic variation in composition with depth is observed (Fig. 6C). However, few sand streaks were encountered in the Early and Middle Miocene.

***Pliocene-Quaternary***

The Pliocene-Quaternary formations show strong thickness variation as in the Miocene, with increasing thickness towards the north. The Pliocene of the Malha–1 well is very thin, only 88 m thick and is composed mainly of clay grading to argillaceous limestone. The sample analysed from this well was a muddy limestone. The composition of these Pliocene samples most probably suggests a lagoonal depositional environment. In El-Mazar–1 well the pliocene sequence is thicker with 400 m, composed mainly of shale. Five samples analysed were of calcareous mud and mud.

The Pliocene sediments in the Bardawil–1 well are not differentiated from the Quaternary deposits, they consist of shale, with siltstone and sandstone beds having a total thickness 123 m. In general, the Quaternary deposits of the Malha–1 well and El-Mazar–1 well are mainly of sand with clay interbeds.

Six samples analysed from the Quaternary sequence of the Malha–1 well, were generally of calcareous clay and calcareous muddy sand (Fig. 5A). The carbonate and mud contents show no rhythmic variation with depth. Sand decreases with depth whereas mud and carbonate increase Fig. 6A. A coarsening upward sequence is recorded possibly of continental to shore environments.

The eighteen samples analysed from the Quaternary sequence of the El-Mazar–1 well are composed mainly of calcareous muddy sand and calcareous sandy mud (Fig. 5B). The carbonate and sand content show an erratic rapid variation with depth (Fig. 6B). While the mud is dominant at top, it diminishes rapidly downward and then gradually increases again. However, a fining upward sequence is recorded possibly of fluvial environment.

The Pliocene-Quaternary succession of the Bardawil–1 well is composed mainly of sand interbedded with shale and thin layers of gypsum especially at the top. Fourteen

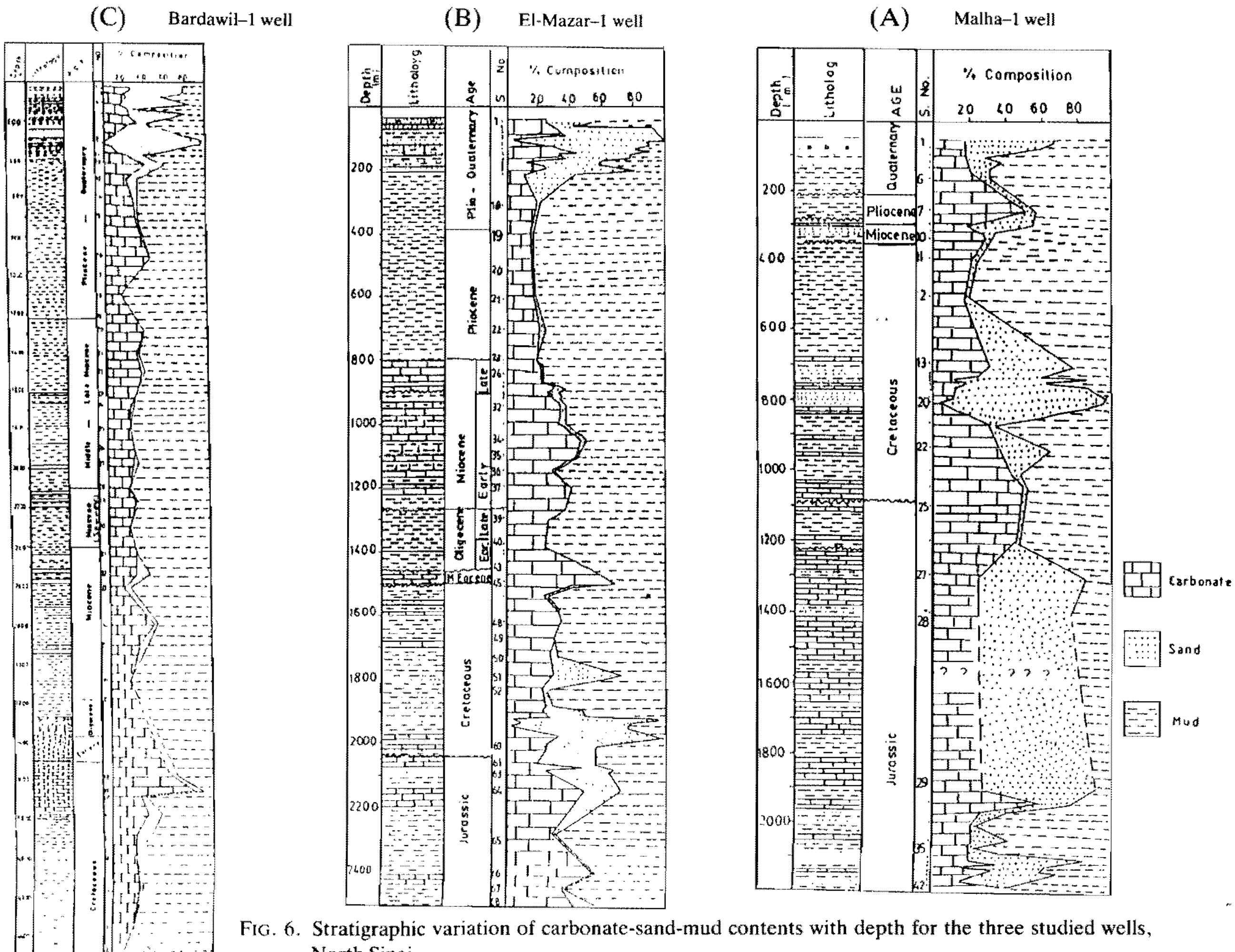


FIG. 6. Stratigraphic variation of carbonate-sand-mud contents with depth for the three studied wells, North Sinai.

samples were analysed and have a composition of calcareous muddy sand, calcareous sandy mud, calcareous mud and sand. The sand and mud contents show rhythmic variations with depth (Fig. 6C). However, the top of the sequence is characterised by a composition varying from calcareous sand to calcareous sandy mud. The mud content generally increases with depth while sand mostly increases upwards. A coarsening upward sequence is observed, reflecting continental to nearshore deposits.

## Discussion and Conclusions

### *(A) Thickness and Facies Variations*

The lithostratigraphic profile passing through the three studied wells; Malha–1, El-Mazar–1 and Bardawil–1 and shown in Fig. 4 illustrates distinct thickness, and lithologic variations. The combination of tectonic elements (subsiding, rising and stable) and the degree of tectonism play a part in controlling the nature and thickness of accumulating sediments (Krumbein and Sloss 1963).

There is an increase in thickness particularly for the Cenozoic towards the north and north-west when going from Malha–1 well to Bardawil–1 well. The total thickness of the section varies from 2198 m at Malha–1 to 2492 m at El-Mazar–1 partly penetrating the Jurassic rocks. The thickness of the section of the Bardawil–1 well is highly developed, reaching about 4490 m penetrating the Cretaceous rocks. Thus the section of El-Mazar–1 is considered to be in a transitional position between Malha–1 and Bardawil–1.

The abrupt change in thickness from south Bardawil lake at Malha–1 toward the north at Bardawil–1 well suggests that the sediments filled the floor of a basin down faulted toward the Mediterranean Sea. Examination of Fig. 4 indicates that the Cretaceous sediments are almost equally developed in the three wells with average thickness of nearly 1800 m.

The Tertiary deposits indicate abrupt changes in thickness, being least thick in the south (Malha–1) nearly 200 m and thicker in the north-west (Bardawil–1), where more than 2000 m of sediment is drown as indicating rapid filling of the rapidly subsiding basin (Barrell 1917). At El-Mazar–1 the thickness has an intermediate value.

The conditions described suggest a post-Mesozoic northwards subsidence or down-to-basin Cenozoic displacement possibly along step faults of the coastal preexisting hinge zone (Fig. 6). This is a structural situation which is very similar to that of the Nile Delta as demonstrated by Sestini (1989).

The lithostratigraphy of northern Sinai is characterized by rapid lateral and vertical changes in facies. Clastic sediments are the predominant Cenozoic sediments in the north. Further south, towards the suspected Mesozoic high block these become dominantly calcareous. This may be a result of Pre-Cretaceous tectonic uplift that affected the southern area forming a structural high at the site of Malha–1 well and a structural low or embayment in the north. The tectonism was possibly associated with the Syrian Arc folding movement. Faults during the Neogene and probably the

Quaternary took place producing the observed marked northward thickening.

The Plio-Quaternary sediments also show thickness changes but are variously composed of shale, sand (beach and bar sandstone), conglomerate, dunes and occasional bioclastic sand limestone.

However, it appears that the hinge zone of Fig. 2 behaves as a flexure zone separating north Sinai into a northern depression and a southern high block. This flexure zone separates bedded carbonate platform sediments in the south from fine grained basinal facies in the noth. It might be considered as transitional zone between a continental crust and the basinal or oceanic crust of the Mediterranean.

### *(B) Stratigraphic Model and Lithofacies Change in North Sinai*

The carbonate, sand and mud variation in the sediments are represented in the geological cross-section given in Fig. 7. Special attention has been given to the relationship between sedimentation and possible tectonic controls.

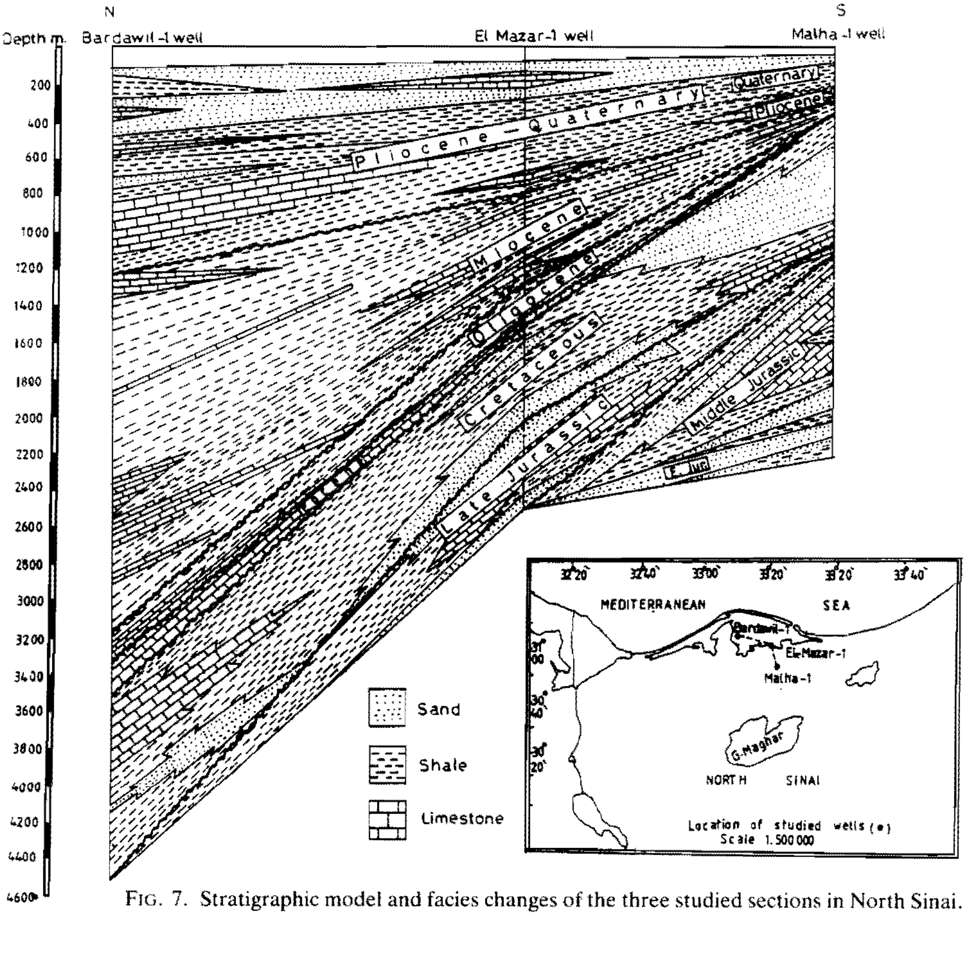


FIG. 7. Stratigraphic model and facies changes of the three studied sections in North Sinai.

1. Clastic sediments, mainly sand and mud, with thin limestone interbeds, distinguish the Jurassic sequence of Malha–1 well representing a landward location of deposition. Environmental dominance by clastics was probably the results of low eustatic sea level possibly coupled with tectonic uplift. The tectonic uplift that effected the region in the pre-Jurassic formed a relatively high morphological zone at the site of Malha–1 well. Thus the high content of sand facies is due to a prolonged shelf recharge time related to tectonism that permitted extensive erosion of the uplifted shelves and deposition along the basin margins on the sides of the paleohighs.

2. Fine-grained sediments mainly of mud intercalated with thin layers of sand and carbonate whose depositional environments range from intertidal to open shelf and platform margin characterise the Jurassic sequence of the El-Mazar–1 well. It is interesting also to notice the rapid vertical change in facies and the lateral variation of thickness in response to uplifting. This generated a varied paleogeography and consequently a wide variety of environments of deposition.

3. Rapid lateral and vertical changes in lithofacies are represented in the Cretaceous sections of the three studied wells. Earlier tectonic uplift possibly affected the depositional environments in the Early Cretaceous. Detrital sediments of sand and mud accumulated with earlier sea regression and emergence of a Cretaceous shelf, as suggested in the El-Mazar–1 well. The Cretaceous sediments in the Malha–1 well seem to be composed mainly of mud with sand interbeds especially in the lower part of the sequence. Above this the facies changed into limestone and mud indicating a shallow shelf facies depositional environment. Similar depositional conditions are disclosed by the Cretaceous sequence of Bardawil–1. Clastics dominate in the lower part of the section changing upwards to limestone indicating a deeper marine environment, and marked marine transgression.

4. The relatively smaller content of sand deposited during the Cretaceous time is probably as result of the rise of relative sea level associated with subsidence of the area through tectonic activity. The scenario of sedimentation documented here going from the sand dominated Malha–1 well towards the El-Mazar–1 and Bardawil–1 wells illustrates a transition facies change from nearshore sands to the predominantly fine grained offshore mud sequences to bedded shelf carbonates.

5. General uplifting of the area especially in the southern part was responsible for the non-deposition or erosion of the Eocene and Oligocene sequences in the Malha–1 well. The latter appear as rather thin sequence in the El-Mazar–1 well composed of carbonate and shale. This facies is changed towards the Bardawil–1 well to become more calcareous indicating a deep marine environment.

6. During the Miocene time, transgression from the Tethys became significant. However, lateral facies and thickness changes can be observed going from the Malha–1 well towards the Bardawil–1 well took place, with rather calcareous and muddy sediments with thin streaks of sand. This suggests rapid accumulation or isostatic loading in a quickly subsiding basin with a transgressive aspect.

7. The Pliocene and Quaternary sediments in general are well represented. Their thickness varies strongly from Malha–1 to Bardawil–1 well indicating also strong subsidence northwards. However, the facies distribution of the Pliocene deposits show a basal sandy beds grading upwards to mud, interbedded with carbonate in Malha–1

well. In case of El-Mazar–1 and Bardawil–1 wells the Pliocene section is mainly calcareous mud.

### *Acknowledgement*

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# سيناريـو الترسيب وعلاقتـه بالـتراكيب عنـد بحـيرة الـبردويل - الحافـة الساحليـة لشمال سيناء بمصـر .


أمين غيث* ، محمود الشربيني و رجب حسب الله

*قسم الجيولـوجيا البحـرية ، كلية علوم البحـار بجامعة الملك عبد العزيز ، جــدة ، المملكة العربية السعودية و قسم الجيولوجيا ، كلية العلوم ، جامعة المنصورة ، مصـــر



المستخلص . تمت دراسـة التتـابع الترسيبي تحت السطحي في ثلاثة آبار عميقة هي : (مالحة رقم ١ و المازار رقم ١ والبردويل رقم ١) حفرت في منطقة بحيرة البردويل بشمال سيناء بواسطة الشركة الدولية للزيت المصري .

ولقد لوحظ أن السمك الكلي للتابع تحت السطحي يتغير من سمك **٢١٩٨** متر في بئر مالحة بينما يكون **٢٤٩٢** مترًا في بئر المازار حيث يصل إلى صخور الجوراسي بينما يقفز فجأة إلى سمك **٤٤٩٠** مترًا حيث يصل فقط إلى صخور العصر الطباشيري في بئر البردويل .

ولقد تم فحص التركيب الصخري بهدف توضيح التغير في السحنة والسمك ومعرفة بيئة الترسيب وإلقاء الضوء على الجغرافيا القديمة للمنطقة .

ولقد لوحظ أن هناك تغير مفاجيء في السمك للعصر الثلاثي وطفيف بالنسبة لصخور الحقب المتوسط ليصل إلى أدنى سمك (حوالي **٢٠٠** متر) عند بئر مالحة ، وأعلى سمك (حـوالي **٢٠٠٠** متر) في الشمال الغربي عند بئر البردويل مما يدل على ملء سريع لحوض الترسيب الذي يهبط بسرعة تجاه البحر المتوسط نتيجة الفوالق .

أيضًا هناك تغير جانبي وعمودي سريع في السحنة نتيجة للحركات التكتونية كما قام الباحثون بتفسير العلاقة بين الترسيب والتراكيب الممكنة .