PRJ, Vol. 2 (January 1990); P. 42–56, 9 FIGS, 1 TABLE.

STRATIGRAPHY AND LITHOFACIES OF FARWAH GROUP AND ITS EQUIVALENT: OFFSHORE – NW LIBYA

A.M. Sbeta*

طبقيات وسحنات مجموعة فروة وما يعادلها بالمنطقة البحرية شمال غرب ليبيا

د. علي محمد سبيطة

مجموعة فروه والتكوينات الأخرى الموازية : تاجوراء وحلاب (عصر الأيوسين) المبكر ترسبت على الرف الأرضي المستقر شمال اللوحة الأفريقية.

بدأت عملية الترسب لمجموعة فروة بالسحنات (1، 2) من تكوين بلال في رفوف الهور المتوسط الداخلي حيث تقع هذه السحنات في المنطقة الجنوبية والجنوبية الغربية من منطقة الدراسة.

وعند منتصف منطقة الدراسة كان رف الهور المتوسط مناسباً لترسب السحنة رقم (3) لتكوين بلال. وفي إتجاه الشمال توجد سحنات تكوين حلاب في رف بحري عميق.

بعد تكوين بلال نجد تكويني تالجة وجيراني الذين ترسبا في ظروف بيئة ضحلة ومحجوزة في الجزء الجنوبي من الرف البحري، ولكن في وسط الرف كانت الظروف البيئية أحسن وملائمة لترسب صخور غنية بالحفريات (المنخربات الكبيرة)، وهذا يدل على بداية تعميق هذا الرف البحري.

إن زيادة عمق مياه هذا الرف البحري أدت إلى تكوين وتجميع ترسبات من الصخرية الغنية بالنيومولیت (تكوين جدير)، مغطية أولاً حافة الرف ثم إنتشرت إلى باقي أجزاء الرف، هذه الرسوبيات كان يحدها جنوبا سبخات بها صخور تكوين حلاب، ولكن نتيجة الظروف الملائمة المحلية حول البئر ف 1 – ن س 41 تكونت عند عقد مرجانية خلال عصر الأيوسين الأول.

بنهاية ترسيب صخور تكوين جدير حدث توقف في العملية الترسيبية، وهو حدث جيولوجي معروف ومؤكد، بعدها بدأت صخور تليل في الترسيب وإبتداء دورة إنحسار ترسيبية مع بداية عصر الأيوسين المتوسط والأعلى.

ABSTRACT

The Farwah Group of Early Eocene age and its equivalents Tajoura, Hallab Formations were deposited on the continental stable shelf along the northern margin of the cratonic African plate.

The deposition started with shallow water facies that range in depositional environment from inner to middle shelf lagoon, where the inner shelf lagoon setting is represented by facies belts 1 and 2 of Bilal Formation and occupy the southern and the southwest part of the shelf. In the centre the less restricted middle shelf lagoon prevailed where facies belt 3 of Bilal Formation was deposited. These facies grade into a deeper shelf environment in the north direction, as indicated by the deposition of the basinal facies of Hallab Formation.

This is followed by the sedimentation of Taljah and Jirani dolomite type facies, which indicate rather shallow and a more restricted condition and dominate the southern edge of the shelf; on the other hand, the centre and the north part of the shelf is characterized by a less restricted condition where sediments rich in large foraminiferas were very common, thus indicating the start of the transgression which began in the Lower Ypresian in the north and reached the south during the Upper Ypresian to Lutetian.

During that time, the increase of water depth initited a favourable condition for nummulite accumulation (Jdeir Formation) along the shelf margin, and later spreading over the rest of the shelf, forming a large, broad nummulitic bank with a bank-back condition, bordered by Sabkhah setting in the southern part of the shelf. These

*Geology Dept., Al-Fateh University, Tripoli, Libya, G.S.P.L.A.J.

nummulitic facies grade northward into basinal facies of Hallab Formation which dominate the deep basin off the shelf. Locally, within the back-bank, a bryozoan build-up and high energy facies developed, suggesting a local condition to such deposition existed near the F1-NC41 well during the Early Eocene time.

The termination of Late Palaeocene-Early Eocene cycle is marked by a widespread break in sedimentation that is widely recognised. This break between the Ypresian and Lutetian, signalled the beginning of the Middle and Upper Eocene regressive cycle. This cycle is represented by the shales and limestones of Tellil Group.

INTRODUCTION

The Farwah Group of late Paleocene to Early-Middle Eocene age is encountered in many wells drilled in the offshore Tarabulus basin. The nummulitic and dolomitic units of this group are the main target for oil exploration in the basin and they are the producing pay zone in the offshore Bouri Field.

This paper covers only part of the study conducted on the Eocene of the continental shelf offshore Tripoli and deals mainly with the Farwah Group and its lateral equivalent in the offshore.

The objective of this work is to define the different lithofacies, map their distribution in space and time and construct a model for the depositional environment of Early Eocene. This was achieved by detailed log analysis and correlation with synthesis of the available data of over 30 wells drilled in the offshore concessions, NW Libya (Fig. 1). Wilson (1975) Models for carbonate facies is used for interpreting the different carbonate setting.

GENERAL STRATIGRAPHY

The oldest rocks encountered in the offshore Tarabulus is Bir Al Ghanam Formation of Late Triassic to Middle Jurassic age and was reached at L1-137 well one of the southern most of the offshore wells just north of Sabratah. On the other hand, wells drilled in the onshore close to the coast, in the Jifarah, for example A1-38 well have penetrated over 8000 feet thick pre-Jurassic rocks that range in age from Late Permian to Middle Jurassic. The formations from base to top are Bir Al Jaja (Late Permian), Al Guidr (Early to Middle Triassic), Kurrush (Middle Triassic), Al Aziziyah (Middle to Late Triassic), Abu Shaybah (Late Triassic to Early Jurassic), Abu-Ghaylan (Late Triassic to Early Jurassic) and Bir Al Ghanam (Late Triassic to Middle Jurassic). These Formations probably extended northward into the pelagian block as suggested by Pitman et al (1981), and in general they exhibit lithologies and stratigraphic relationship similar to the well described units in the surface outcrop in Jabal Nefusah. However Bir Al Jaja and Al Guidr Formations are only known from the subsurface

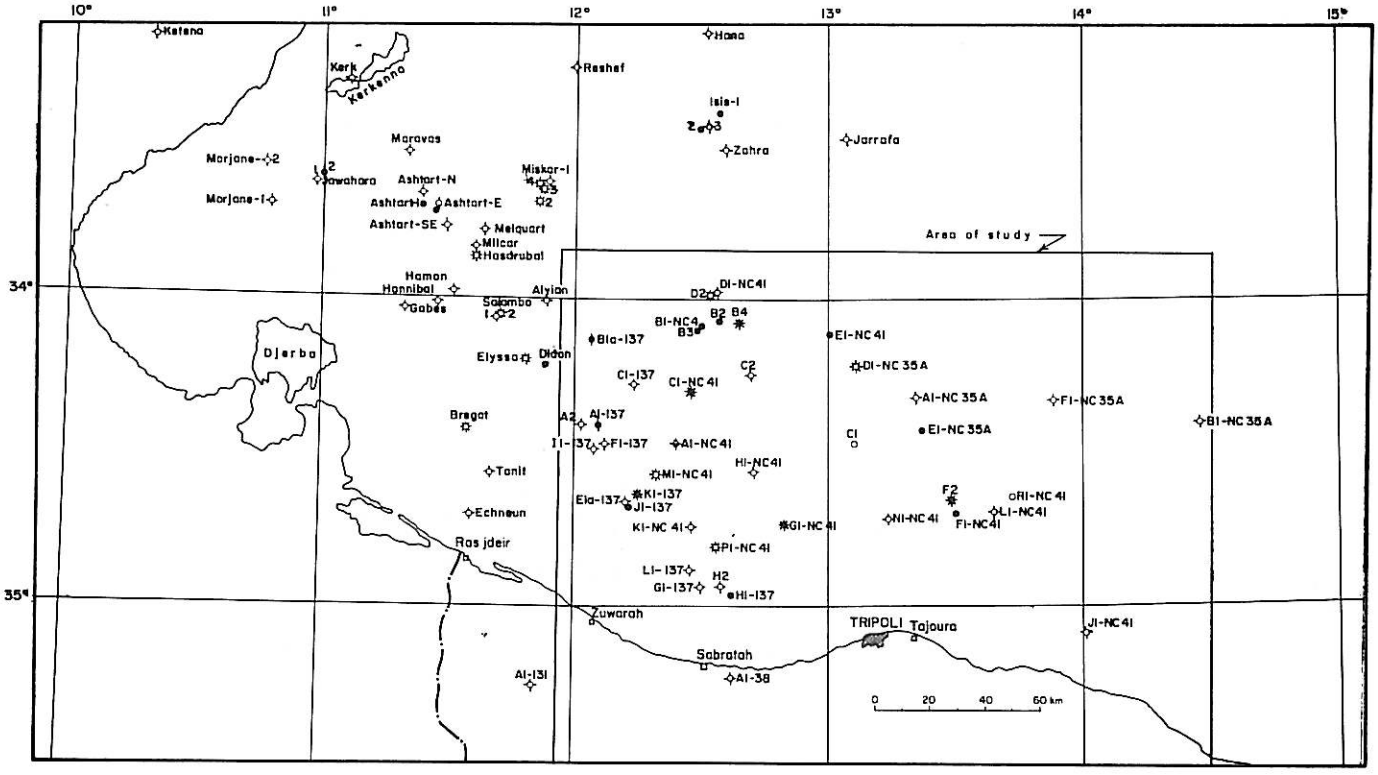


FIG. 1. Location Map and area of study.

of the onshore wells. Mesozoic rocks of Jabal Nafusah are well discussed and described in many recent publications that include: Hinnawy and Chesthiteve (1975); Fatmi et al (1978); Bannerjee (1980); Fatmi, *et al* (1980).

Busson 1967, Fourni 1978 publications cover the Cretaceous, Paleogene and Neogene of the Tunisian onshore and offshore stratigraphy. Hammuda et al 1985 dealt mainly with the stratigraphic nomenclature of the NW. offshore basin of Libya with correlation of the Tunisian sequence.

The Stratigraphy of the Early Eocene

No record of Eocene rocks are known from the northwestern onshore Libya (The Jifarah plain). On the other hand Eocene sequence corps out further inland in the Hamadah al Hamra and Hun Graben region. The only reported Eocene rocks are in the offshore Tarabulus basin. However Eocene rocks are reported from the onshore and offshore Tunisia by many authors (Bishop 1975, Founrie 1975.)

The general Eocene stratigraphy of the offshore Tarabulus basin and its correlation with the Tunisian section is summarized in Table 1.

During Late Cretaceous a major tectonic movement started and continued till Late Paleocene where most of the southern flank of the Tarabulus basin was uplifted and eroded; resulting in the erosion of some Upper Cretaceous and most of the Paleocene rocks in the south. This movement is less apparent in the north where Paleocene rocks are overlain by Lower Eocene sediments. Locally, Lower Eocene overlie volcanic rocks (Fig. 2).

The Early Eocene Transgression started from the north and advanced southward overstepping (onlapping) the Paleocene, Maastrichtian, Campanian and Santonian units (Fig. 2). According to work done by Aquitain using the nummulities the transgression started in the Upper Paleocene to Lower Ypresian in the north and reached the south during Upper Ypresian to Luthetian.

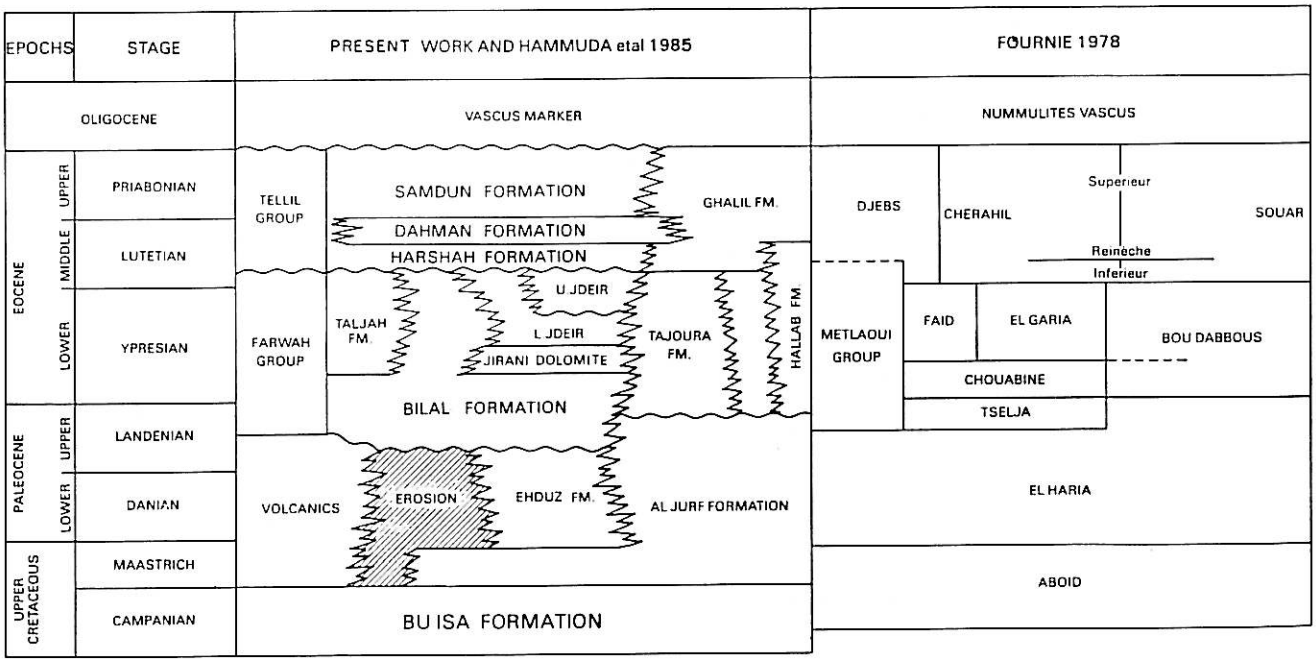
This followed by Middle and Late Eocene regression where restrictive shallow water shales, limestone and evaporite dominated most of the shelf. Northward, the shallow water facies grades into basinal facies of shale, marl and mudstone.

The Eocene as recognised in Tarabulus basin consist mainly of two major lithologic sequences. Farwah Group and Tellil Group which mainly cover the centre and west of the Basin. Ghalil and Hallab Formations are laterally equivalent to Farwah and Tellil, and occur mainly in the north and northeast. However towards the east, shallow water facies of Tajoura Formation are encountered in few wells. Here in this paper Farwah Group and its equivalent are dealt with.

Farwah Group

The Farwah Group, first introduced by Sbeta (1981) in a report presented to N.O.C. Stratigraphic committee which later incorporated with the other committee member work in their publication (1985) entitled "The Stratigraphic Nomenclature of the Northwestern Off-

Table 1 Correlation chart of the Eocene in the offshore N.W. Libya and Tunisia.



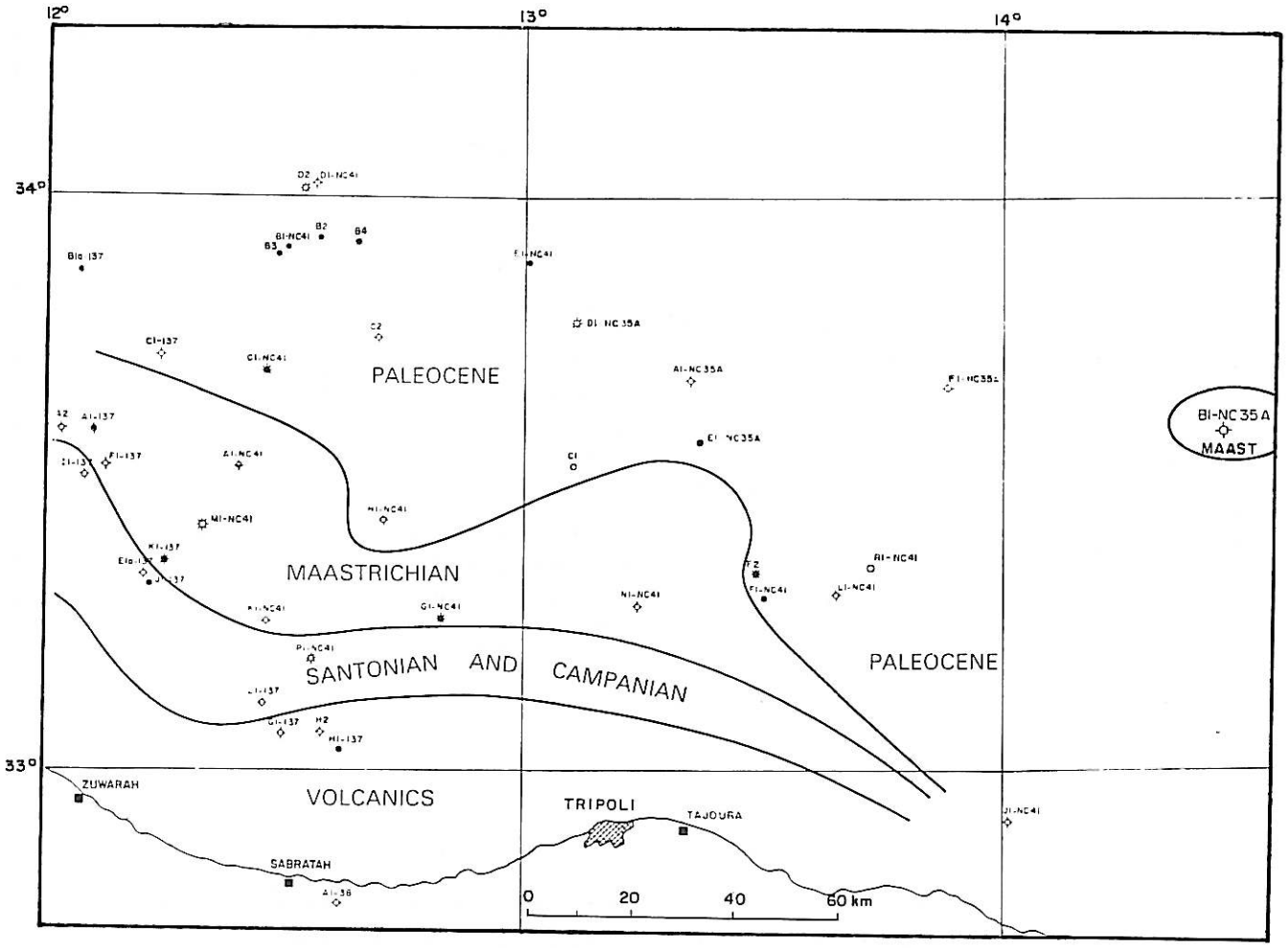


FIG. 2. Pre-Eocene Paleogeographic map.

shore Libya", edited by Hammuda O.S. *et al.* and published by ESSL. The new name introduced after it was apparent that correlation with the Tunisian section is not always possible or correct. Names used by oil company operators are not clearly defined and in many cases, arbitrary names were used from the Tunisian onshore section. On the other hand, the operators are emphasising the biostratigraphic aspect of the units rather than their lithostratigraphic character. For these reasons new formational names were introduced to cover the Libyan section of the Palagian block.

The Farawah Group that range in age from Landenian to Early Lutetian is composed of thick sequence of carbonate locally shalley, dolomitic and evaporitic. It is underlain by the Paleocene shale of Al-Jurf Formation in the northern sector. In the centre of the basin, limestone and shales of Bu Isa and Jamil Formations of Late Cretaceous unconfortably underlie the Farwah Group. In the far south, Farwah overlie volcanics. This unconformity is widely recognised, but it is less apparent in the north and east where the contact between Farwah Group and the underlying rocks of Paleocene is graditional.

The Farwah Group is conformably overlain by the regressive sequence of Tellil Group of shales and limestones and locally the pelagic facies of Ghalil Formation. Laterally towards the north and east Farwah Group passes into single Formation Tajoura or Hallab.

The thickness of Farwah Group range from over 1400 feet at H1-NC41 in the centre of the basin and thins towards the north and south, where it reaches only 7 feet at L1-137 and locally at M1-NC41 the Farwah Group is absent.

The Farwah Group consists of maximum three formations that are present in the northern section of concession NC41 (Fig. 3). They are in descending order: Jdeir Formation, Jirani Dolomite and Bilal Formation. In the southern edge of the basin Taljah Formation replaces Jdeir and Jirani Dolomite and grades into Bilal Formation, so that the Farwah sequence is Taljah Formation at the top and Bilal at the base. After detailed work two members recognised

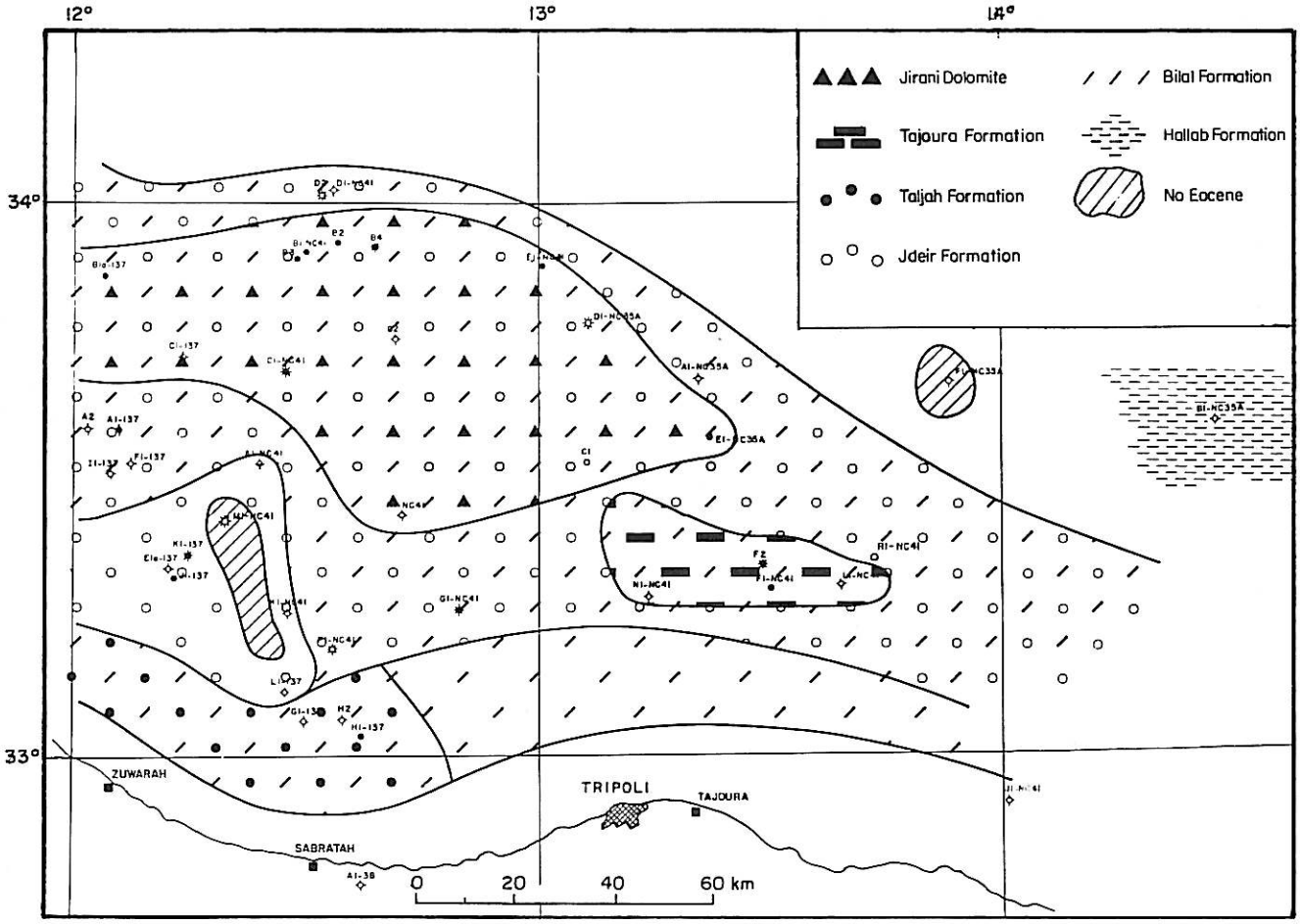


FIG. 3. Distribution of the different formation of Farwah Group; Tajoura and Hallab Formations.

within the Jdeir Formation, namely, Upper Member rich in Nummulite and Lower Member rich in Orbitolities and Alveolina.

These formations, within Farwah Group, are easily recognisable by their lithological and log character. They are mapable and widely distributed (Fig. 3).

Hallab Formation

The Hallab Formation is encountered in well B1-NC35A and interpreted to be widely spread in the eastern and northern sector of Tarabulus Basin. The Formation is mainly shale, marl, limestone and chalky limestone with abundant planktonic Forams and has a thickness of 160 feet.

The Hallab Formation at B1-NC35A unconfortably overlie Masstrichtian shallow water limestone and is overlain by deep platform shales of Ghalil. The faunal assemblage in Hallab indicate Early to Middle Eocene age and is considered to be lateral equivalent to Tajoura Formation and Farwah Group and perhaps equivalent to Bou Dabbous Formation in the Tunisian section.

Tajoura Formation

Introduction by Sbeta (1981) for the shallow water facies of bryozoan and oolitic limestone that was encountered at F1-NC41. It is over 570 feet thick and is overlain by the shales and carbonates of Tellil Group and underlain by the Paleocene carbonate of Al-Jurf Formation. The Tajoura Formation is also encountered at L1, F2 and N1-NC41. The stratigraphyic position of Tajoura suggests Early Eocene age and could be correlated with Hallab Formation in the east and probably with Jdeir and Jirani Formations in the centre.

LITHOFACIES ANALYSIS OF FARWAH GROUP (LATE PALEOCENE TO EARLY EOCENE)

Eleven wells from concessions NC41 and 137 have been examined in detail, using all available information. Data from other drilled wells are also consulted and analysed. Consequently several lithofacies belts are recognised within each formtion and their thick-

ness and lateral distribution are recorded in isopack and lithofacies map.

Lithofacies and Environment of Bilal Formation

Bilal Formation is widely distributed and present in most of the studied area except in the area between L1-137 and K1-137 and in the vicinity of J1-NC41 area and F1-NC35A (Fig. 4). It lies at the base of Farwah Group and normally is overlain either by Taljah Formation in the south or Jirani dolomite or Jdeir Formation in the centre and north of the area. Generally it is unconfortably underlain either by Paleocene or older rocks.

The formation shows great variation in thickness, the thickest section is at H1 and C2 NC41 which is over 500 feet, however, the formation thins to about 33 feet at II-137 and 50 feet at G1-137 in the southern and western parts respectively (Fig. 4). It also thins towards the east and the north. The depositional axes run along NW-SE direction from C1-NC41 to C1-NC35A. Bilal Formation is missing in the southwestern part along a line from G1-NC41 and is replaced either by Jdeir Formation or Tajoura Formation. In the southwestern part Bilal is missing due mainly to erosion and/or lithofacies change.

Bilal Formation shows appreciable variation in sedimentary lithofacies and generally comprise a mixture of lithologies that include mudstone, wackestone, packstone, shale, marl, dolomite, anhydrite, sandstone, conglomerate and phosphatic horizons.

By closer examination of these lithologies and their distribution, the following major lithofacies belts are recognised (Fig. 4).

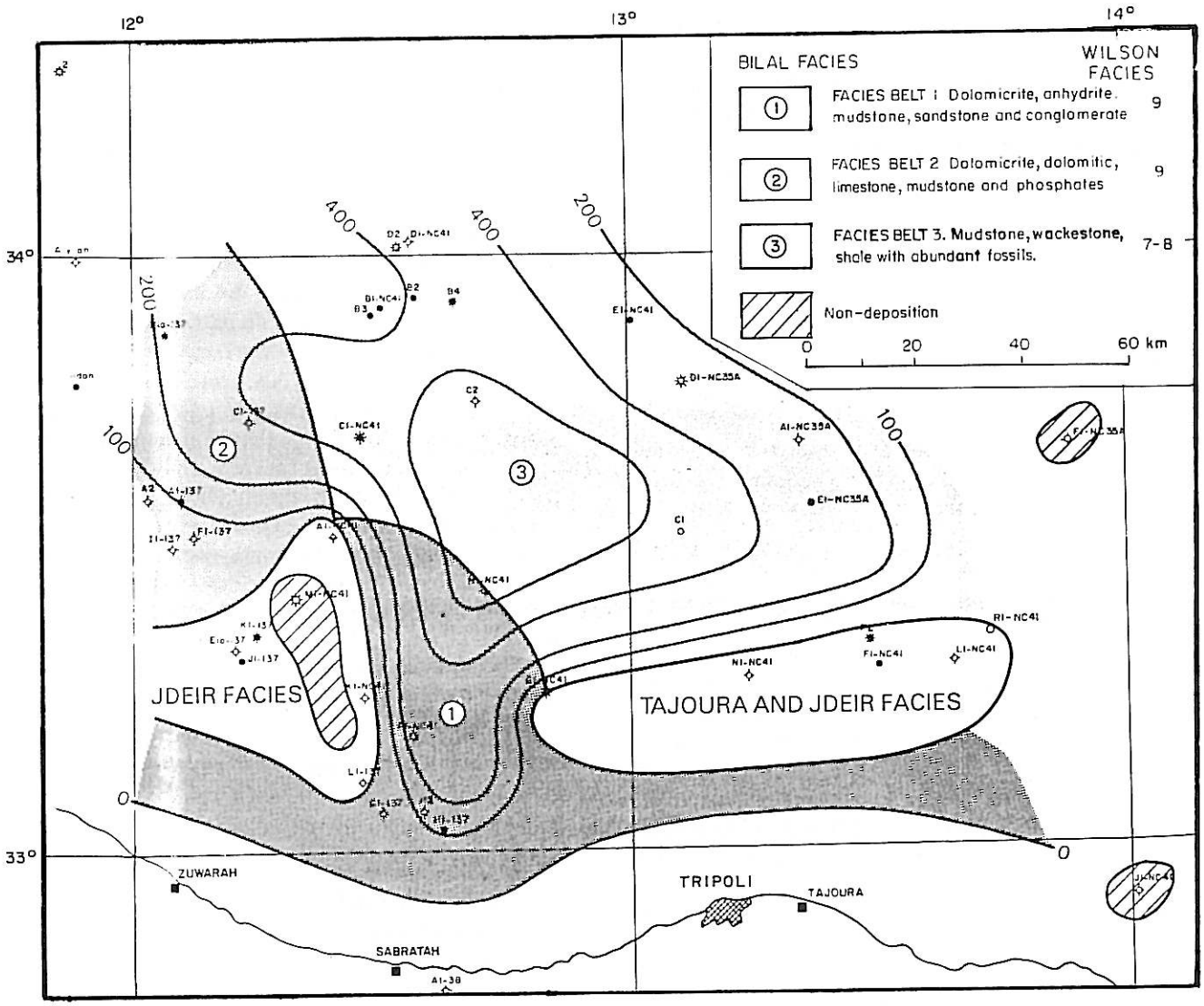


FIG. 4. Farwah Group. facies and thickness of Bilal Formation.

Lithofacies Belt 1

The lithofacies belt 1 composed of, in order of importance, dolomicrite, anhydrite, mudstone, sandstone and conglomerate at H1 and NC41 levels of phosphatic rocks occur and shale locally dominate at P1-NC41.

This lithofacies becomes very sandy and conglomeratic at H2-137 with levels of grey sandy dolomicrite and streaks of bitumonous shale; thin beds of anhydrite also common. At the base polygenic conglomerate becomes the dominant lithology. At H1-137 and G1-137, this lithofacies is represented by sandy dolomicrite, dolomicrosparite whitish light tan locally silty. In places coarse sandstone level occur and few beds of shale and anhydrite are observed. Northward, this lithofacies becomes more shaley with thin beds of wackestone-packstone and locally dolomitic and slightly sandy. In the transition area between lithofacies belt 1 and 3, few phosphatic beds occur at G1 and H1-NC41.

Lithofacies 1 is encountered in the wells drilled in southern part of concession 137 and is located between two area of non-deposition of Bilal Formation and perhaps extends eastward and westward along the present shoreline. This lithofacies is interpreted to represent shoreline lithofacies of sabkha and alluvial fan setting.

Lithofacies Belt 2

This lithofacies consists predominantly of dolomicrite, dolomitic limestone and mudstone with levels of phosphatic rocks. Shales, marls, and sandy horizons are subordinate, locally thin beds of anhydrite occur. Lithofacies 2 become more dolomitic at A2 and I1-137 wells with grey green silty argillaceous mudstone, at A1-137 well thin beds of sandy packstone are observed. However, at Bla-137 and C1-137 this lithofacies is found to contain wackestone, abundant grey brownish shale and marl interbedded with anhydrite. At C1-137 well sand, grey brownish shale and red silty marl with trace of lignite dominate this lithofacies.

Lithofacies 2 is reported from the wells drilled in the NW part of concession 137. It is interpreted to be deposited in shallow water shoreline between supratidal to intertidal with less restriction than facies 1. In lithofacies 1 anhydrite is dominant whereas facies 2 the phosphatic level is common. At lithofacies 2 the coarse clastic is less important than in the case of facies 1, though sandy and silty levels do occur. Lithofacies 2 is only 23 feet thick at I1-137 well and thickness northward in the direction of Bla-137 and C1-137 wells. South of I1-137 well no Bilal lithofacies is present, but grades into the Jdeir type lithofacies as shown in Fig. (4).

Lithofacies Belt 3

It consisted mostly of brown to dark brown mudstone, wackestone interbedded with shale and locally becomes chalky, pyritic and gluaconitic. At D2 and B2-NC41 wells marl with planktonic foraminifera appear. This lithofacies dominate the rest of NC41 concession (Fig. 4). It is interpreted to be probably deposited at shelf lagoon that is slightly restricted southward and becomes more open northward with the influence of deep shelf and perhaps deep marine conditions as indicated by the presence of planktonic marly facies at D2 and B2-NC41 wells.

This lithofacies is the most dominant and covers the centre and the northern sector of the shelf. It reaches a thickness of over 500 feet at C2-NC41 and thins towards the east and south.

Depositional Environments of Bilal Formation

In general, Bilal lithofacies are deposited in arid shallow water shelf lagoon which is very restricted in the south, with the deposition of dolomicrite, anhydrite, sandstone and conglomerate. The source of such coarse clastic perhaps is an alluvial fan or fluvial deposits from the close by land where a large channel is located just east of the positive area that border lithofacies 1. The restricted lithofacies 1 is suggested also to occur parallel to the Eocene shoreline.

The Bilal lithofacies becomes slightly less restricted in the northwest part, where dolomicrite and phosphorite rocks are common, and only locally anhydrite beds are observed. On the other hand, Bilal lithofacies becomes less restricted with marine condition in the centre and north where wackestone and packstone lithofacies with abundant skeletal fragments and small formas are common. A deeper shalf environment perhaps border the shelf lagoon north of D2-NC41.

Two large areas of Bilal non-deposition is interpreted to occur in the east and west of the southern edge of the basin leaving a corridor where lithofacies 1 occur. In the eastern section Bilal is perhaps partially replaced by either Jdeir or Tajoura formations. Bilal is missing in the western section due to the erosion of most of the Farwah Group.

Lithofacies and Environment of Jirani Dolomite

Two main facies are recognised:

1. Dolomatized wackestone/mudstone with beds of wackestone and dolomicrite.
2. Dolomatized wackestone and dolomicrite with anhydrite nodules.

The thickest section of this formation is along a line extending from C1-NC35A to Bla-137 wells and rea-

ches a maximum thickness of over 500 feet near C2-NC41 (Fig. 5).

Lithofacies Belt 1

It is the most widely recognised lithofacies and it is of interbedded mudstone dolomitic mudstone, dolomicrosparite and dolosparite with levels of wackestone and mudstone that become common at the base. The limestone is light grey to brown slightly argillaceous, the dolomite is light grey to light brown micro-crystalline, vuggy with good intercrystalline porposity. Locally at E1-NC25A dolomitic limestone beds have nummulite and other fossil fragments. This lithofacies show some variation where phosphatic and pelycepods beds are present at Bla-137 and peloidal lithofacies at E1-NC35A and C1-137.

At B2-NC41 the dolomite is very finely crystalline with some kaolinitic clays and black laminea. Sometimes abundant burrows and birdseye structures are observed and fossils are absent. The dolomite is interbedded with peloidal and skeletal wackestone with few miliolid, ostracods and algae. Similar facies are encountered at B1 and B3-NC41, but the dolomite become coarse, friable and argillaceous at C1-NC41.

Lithofacies Belt 2

This lithofacies is described from three wells only C1-137, C1 and H1-NC41. Lithofacies 2 are not much different from lithofacies 1, but it is characterized by the occurrence of anhydrites, silty and sandy horizons and varicoloured silty marls with poorly fossilliferous wackestone.

At H1-NC41 this lithofacies is light brown to grey dolomicrosparite to dolosparite with beds of poorly fossilliferous mudstones and wackestones and few horizons of anhydrites, at C1-NC41 the sandy, silty varicoloured marly levels appear with trace of anhydrite. The upper beds of C1-137 have mainly mudstones and wakestones which is locally peloidal, whereas the lower and thicker section is mainly dolomicrosparite interbedded with anhydrites, mudstones, dolomicrites with few beds of wackestones.

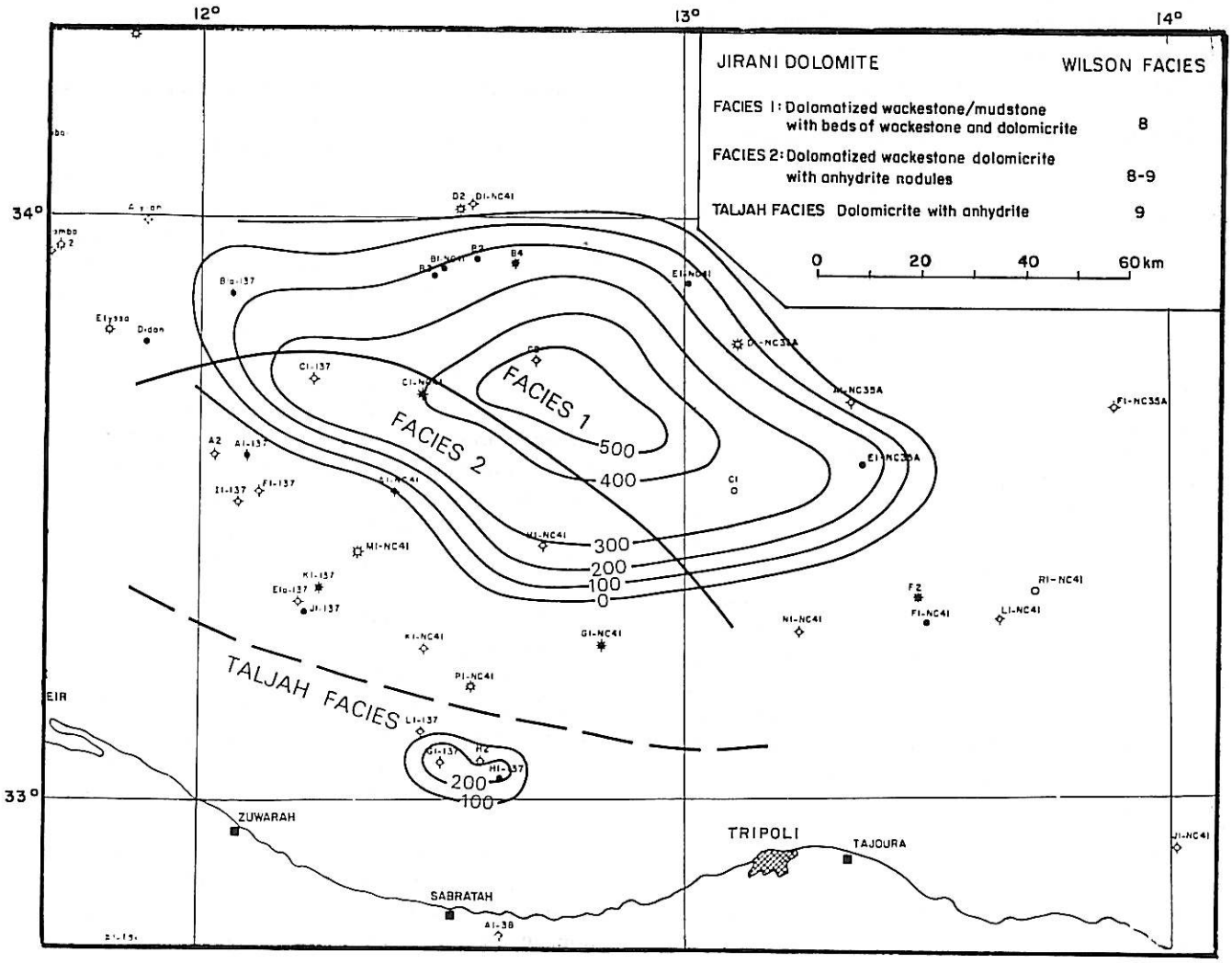


FIG. 5. Farwah Group. facies and thickness of Jirani and Taljah.

Depositional Environment of Jirani Dolomite

From Fig. 5 one can see that facies 1 of Jirani Dolomite are present in wells drilled in the northern and northwestern section of Tarabulus basin, where the middle shelf lagoon condition prevailed which is probably slightly restricted with intermittent inner shelf condition affecting the area that dominates the southern part of the basin.

The wackestone lithofacies with skeletal fragments of pelycepods, nummulite and locally milioloid and ostracods would suggest that lithofacies 1 is deposited in the slightly sometimes restricted middle shelf lagoon that later uplifted and dolomitized as the presence of kolinitic clays, phosphates and dolomite would suggest. The occurence within this lithofacies of supratidal dolomite, birdseye and perhaps stromatolite indicate the fluctuation of sea level and the proximity of inner shelf condition which actually border this middle shelf condition in the landward direction.

As for the lithofacies 2 which dominate the basin, it is interpreted to be deposited in the inner shelf condition in semi-arid to arid climate where anhydrite, dolomite and mudstone lithofacies would predominate. This lithofacies are located not far from land as the presence of sandy and silty level would suggest.

Lithofacies and Enviromnent of Taljah Formation

These lithofacies are present only at 3 wells in the southern edge of the shelf (Fig. 5). The wells are H1, H2 and G1-137 and the section is mostly composed of grey to beige dolomicrite with thin beds of white crystalline anhydrite. At H2 and H1 thin streaks of bitumenous shale occur within the dolomite beds and the anhydrite is nodular at H1-137. The lithofacies becomes argillaceous with whitish, light beige, light brown mudstone, locally sandy at G2-137. They range in thickness from 165 feet at G1-137 to 125 feet at H1-137 and only 84 feet at H2-137.

Taljah lithofacies are interpreted as shoreline sediments of the inner shelf environment that border the Lower Eocene rocks of Jirani, lower and upper Jdeir lithofacies. The Taljah Formation lithofacies are deposited in sabkha and supratidal conditions where stromatolite horizons with birdseye structures and mudstone were laid down and then penecontamporanously dolomatized. The hypersaline condition initiate the deposition of evaporites which made it intolerable from marine life. In addition, the presence of silty and sandy facies suggest proximity to land.

Lithofacies of Jdeir Formation

The shallow water carbonates of Jdeir is characterized by two major lithofacies suites which correspond to the two members of the Jdeir Formation; Lower Jdeir and Upper Jdeir. The Lower Jdeir lithofacies consists mainly of large foraminifers and skeletal wackestone and packstone and the Upper Jdeir is mainly nummulitic packstone to grainstone. These two major lithofacies suites show some variation in thickness and sedimentary lithofacies (Fig. 6).

The Jdeir Formation is encountered in most of the wells drilled in Tarabulus basin and the Isopach Map (Fig. 6) shows an over 600 feet thick lithofacies of Jdeir deposited along a line extending from D2-NC41 to A1-NC35A with a gentle gradual thinning in the west and southwest direction, suggesting the existence of the gentle sloping shelf during the deposition of Jdeir Formation. However, Jdeir lithofacies thins towards the north, northeast an locally south of A1-NC35A in a rather abrupt way. The local thick sequence of Jdeir represent the margin of the bank that extended along the shelf margin at the early Eocene time, where it is suggested a higher rate of sedimentation dominated the shelf bank. The possible sudden thinning, in the north direction, perhaps indicate a lower rate of sedimentation for the basinal mudstone, shale and marls that dominate the shelf margin.

Lower Jdeir Lithofacies (Fig. 7)

These lithofacies are mainly wackestone and wackestone packstone grading to mudstone and in places argillaceous, chalky an dolomitic and range in colour from light brown to dark brown. The Lower Jdeir lithofacies is characterized by the abunant occurrence of large foraminifers that include Alveolina, Orbitolite, Discocyclina and locally small forminifers, Miliolid and Ostracods. Fragments of pelecepods, gastropods echinoids and in places traces of nummulite debris are present.

These lithofacies show some sedimentological variation as it becomes chalky mudstone argillaceous and slightly dolomitic at C1-137 well. It grades to foraminifers packstone where large foraminifers are abundant including some nummulites at A1-NC35A. In many wells wackestone/packstone lithofacies is the dominant one with variable percentage of large foraminifers and skeletal debris of different fossils. At C1-NC35A, 154 feet of foraminifers packstone and wackestone is encountered and at D1-NC35A over 250 feet of skeletal packstone wackestone lithofacies occur interbedded with thin beds of chalky mudstone. This mudstone facies is more common at the northern edge replacing the packstone at E1 and B2-NC41 wells and the lower Jdeir lithofacies becomes dolomitic at C1-NC41 and peloidal at B2-NC41 well.

The Lower Jdeir lithofacies occur in most wells in the central part of the basin and generally passes into restricted near shore facies of Bilal and Taljah Formations in the southwest and south direction or into the high energy and reefoidal lithofacies of Tajoura Formation in the southeast direction (Fig. 7). Towards the

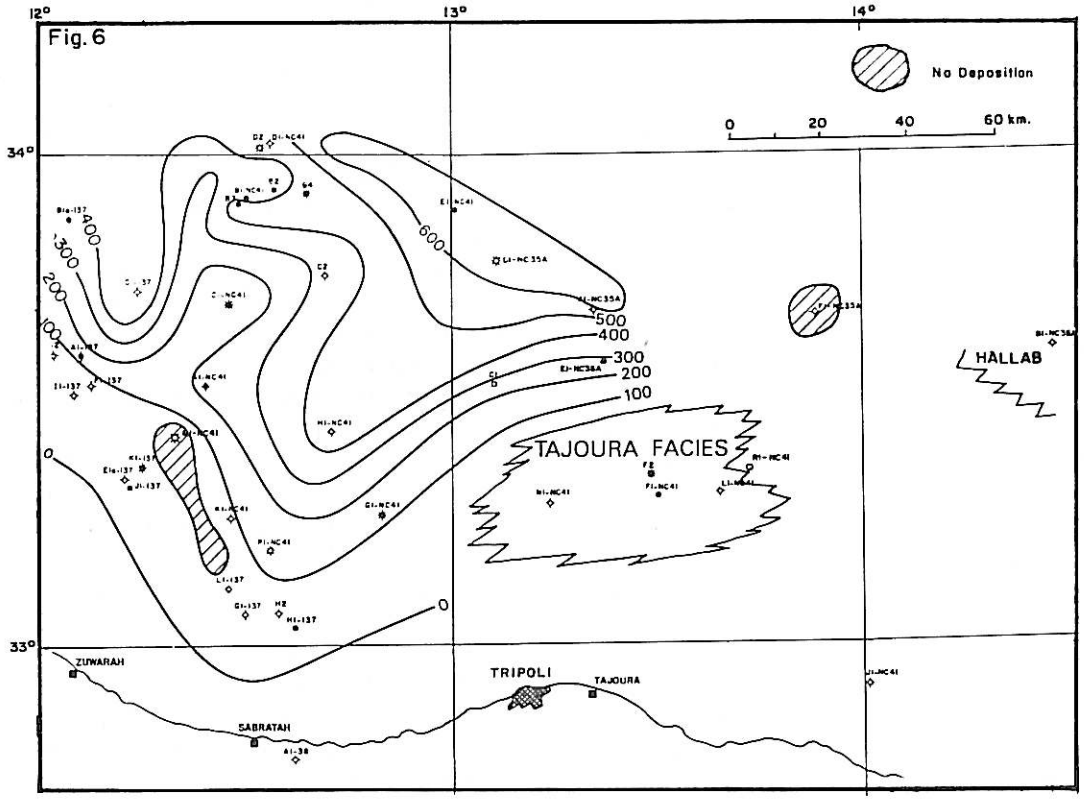


FIG. 6. Isopach map of Jdeir Formation.

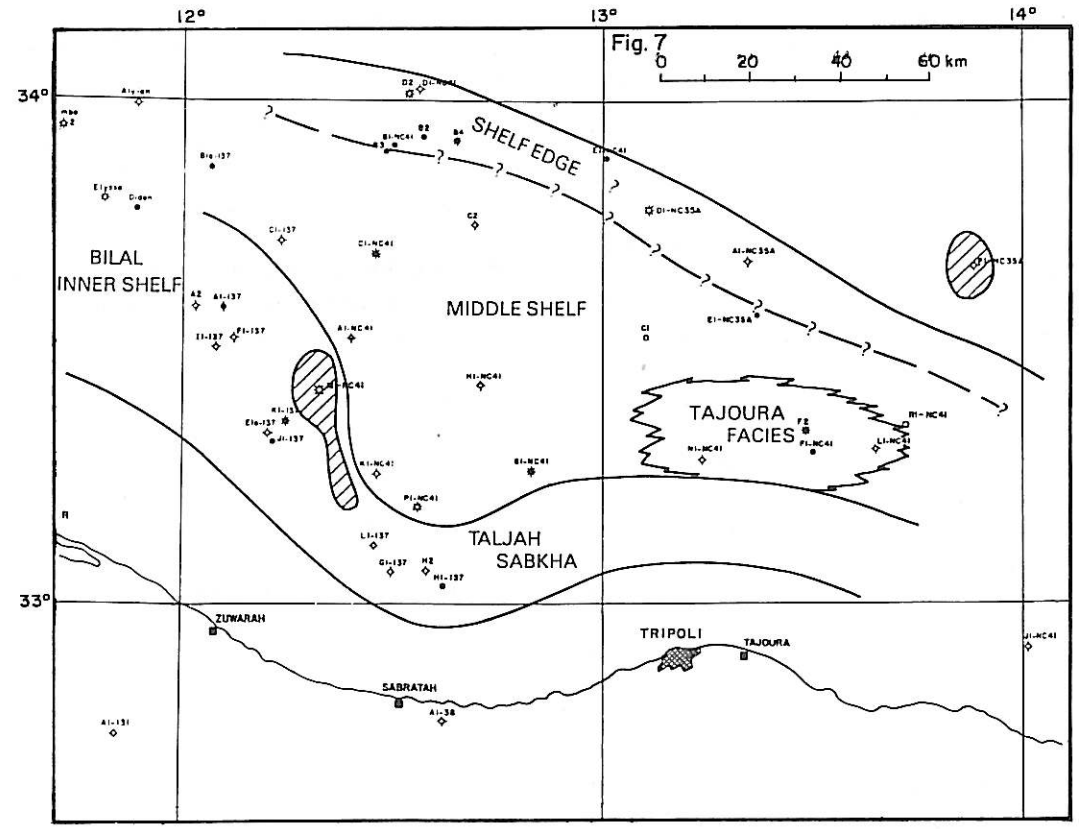


FIG. 7. Farwah Group. facies and environment of Lower Jdeir.

north and northeast it changes to the deep water lithofacies of Hallab and Ghalil Formations.

Normally, these lithofacies represent the Lower Jdeir Member but there are a few wells where the Upper Jdeir Members are missing. Therefore the Jdeir Formation consists mainly of lithofacies of Lower Jdeir Member only in G1, P1, K1 and R1-NC41 wells.

Environment

The lithofacies and fauna of the Lower Jdeir Member suggest a deposition in broad shallow water carbonate shelf which is dominated by middle shelf lagoon. In the slightly restricted middle shelf lagoon, the pelecepods are the major skeletal components. In the middle shelf lagoon, the dominant lithofacies is large foraminifers wackestone-packstone, where Alveolina, Orbitolites, Discocyclina with skeletal debris of echinoids, pelecepods and algae are very common.

These shelf lagoon lithofacies of the middle shelf probably represent back-bank setting during lower Jdeir deposition, with foraminifers/pelecepods bank, probably developed along the shelf edge extending from D1 and B1-NC41 wells to E1-NC41 wells to E1-NC41 and A1-NC35A. This bank and back-bank perhaps represent the substratum for the later nummulite bank system to be developed during Upper Jdeir deposition. If the foraminifers/pelecepods bank did exist this will result in some restriction behind the bank thus explaining the presence of some restricted lagoon and sabkha type lithofacies in the wells located at the southern edge of the shelf. The other explanation is the restriction in the southern edge of the shelf is as a result of a damping effect of the vast expanse of shallow waters of this board carbonate shelf that prevailed during the deposition of the Lower Jdeir Member (Fig. 7).

However, the Lower Jdeir lithofacies continued to be deposited in the southern edge of the shelf while the nummulitic bank lithofacies of the Upper Jdeir begin to develop along the north margin of this shelf which makes the Lower Jdeir lithofacies in the south equivalent to the Upper Jdeir lithofacies in the north.

The Lower Jdeir lithofacies are laid down in shelf lagoon of water depth that range from 10 to 50 m, as recent work on large foraminifers indicated that they generally live in water of such a depth in tropical to sub-tropical shelf water and they are especially abundant in the reef environment as the case of the Great Barrier Reef Hottinger (1977). For example, Orbitolites lives in warm calm seas among seaweeds and down to 50 m depth, and Alveolinids seldom are a major part of most foraminifers faunas in shallower waters of 50 to 15 m deep and they are most common in water depth from 25 m to about 80 m, and they prefer quiet condition and fine-grained soft sediments.

Upper Jdeir lithofacies (Fig. 8)

The Upper Jdeir lithofacies are found to contain mainly nummulitic lithofacies that range from packstone to grainstone locally wackestone with mudstone interbeds. It is beige to cream, light tan in colour, porous, vuggy sometimes chalky. The main constituents of these lithofacies are nummulite large and small and they are *Nummulite rollandi*, *N. irregularis* and *N. gizaensis*. Locally at B2 and E1-NC41 Assilina and Operculina are present. However, nummulites tend to be less significant in the lower beds. Fragments of gastropods pelecepods, echinoids and algae also occur in different proportions. Locally at A1-NC35A broken fragments of nummulite and echinoids and pelecepods dominate these lithofacies. A1-NC41 it appears that pelecepods and gastropods debris become rather important but nummulitis still very abundant and prolific and cores from this well show that many nummulite are oriented towards the horizontal plane.

The nummulitic packstone-grainstone facies of the Upper Jdeir Member are widespread in the study area and they are the main lithofacies of the member in most of the well drilled in the offshore. In concession 137 these lithofacies are found in B1a, A2 and C1 wells and in concession NC41 they dominate B1, B2, E1, D1 wells and E1, C1, D1 and A1 in concession NC35A. These high energy lithofacies grades to wackestone/packstone and wackstone at C1, A1 and H1-NC41 and A1-137 locally at F1-137 changes into wackestone/mudstone facies. The thickness of Upper Jdeir lithofacies vary greatly from one well to another for example, they are 60 feet at B1-NC41 and 230 feet at B2-NC41 and they are only 6 km apart. Similarly, they are 88 feet at E1-NC41,257 feet at D1-NC35A well and 157 feet at A1-NC41, and only 62 feet thick at C1-NC35A. The nummulitic lithofacies of the Upper Jdeir member is locally poorly developed and tend to be very thin and represented in some wells by reworked conglomerate nummulitic lithofacies as the case in I1, K1 and L1-137 and H1-NC41. These poorly developed and thin lithofacies probably indicate the southern and western limit of the nummulite bank.

Further, southward the bank lithofacies grades into the back-bank lithofacies of Alveolina-Orbitolite wackestone/packstone of lower Jdeir with local development of high energy and reefoidal facies of Tajoura Formation which becomes more restricted southward with Sabkha and supratidal lithofacies of Taljah and Bilal sequences (Fig. 8).

Environment

The lateral and vertical analysis of the Upper Jdeir lithofacies suggest the existence of a wide broad Nummulitic Bank during the Upper Jdeir time that dominated most of the central part of the offshore basin

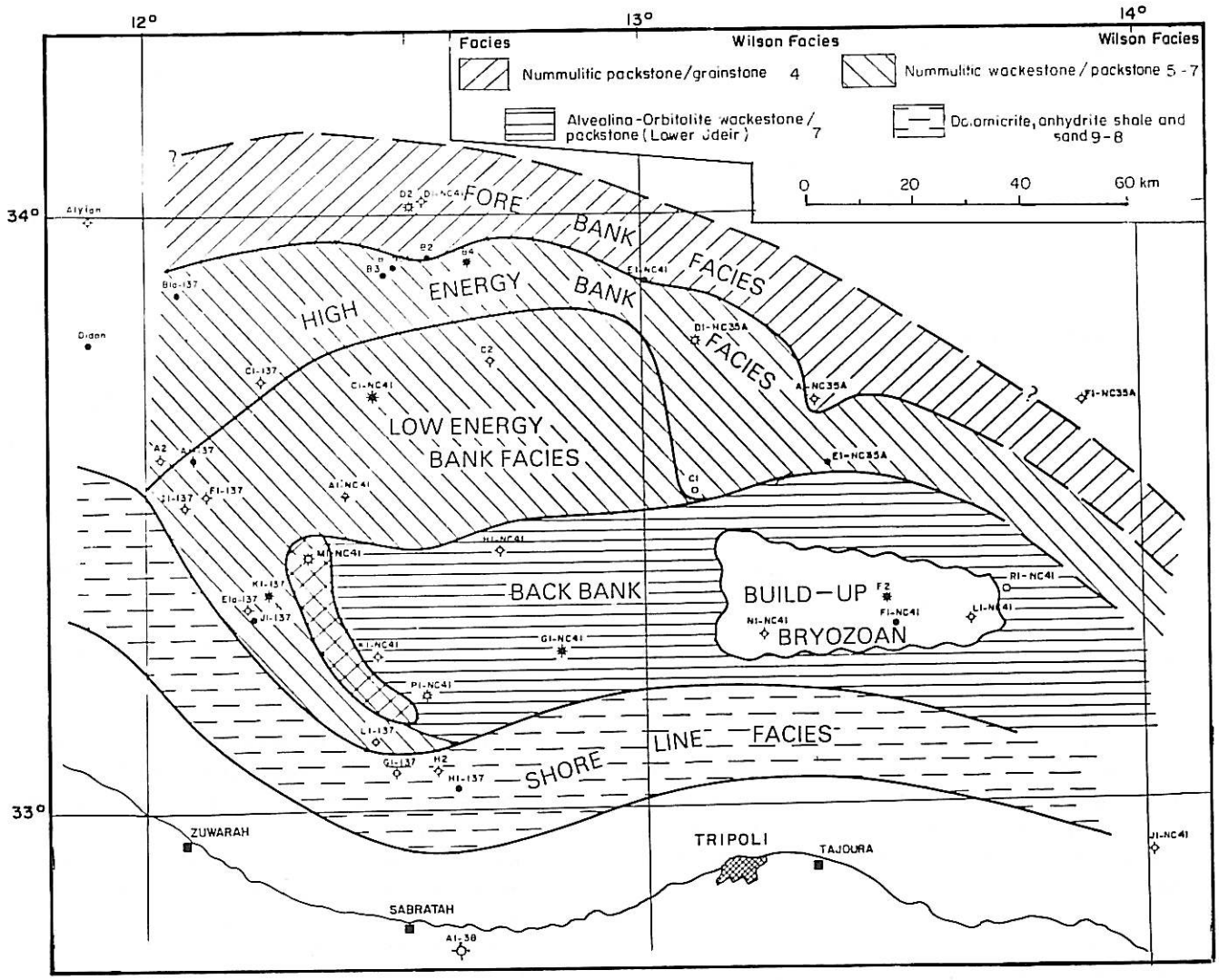


FIG. 8. Farwah Group. Upper Jdeir nummulitic bank facies.

and cover a belt extending from E1-NC35A in the east of Bla and A2-137 in the west. This bank is widest in the centre just offshore Sabratah where it is 70 km wide from H1-NC41 to D2-NC41. This bank becomes narrower in the eastern section between R1-NC41 and F1-NC35A where it is estimated to be only 25 km wide and extending perhaps due south-east. In the western section offshore Zuwarah the south-western limit of this bank is A2-137 and the northern edge of this bank is probably north of Bla-137 well (Fig. 8).

A back-bank setting is located landward behind the bank covering the area between H1-NC41 in the centre and H2-137 in the south, R1-NC41 to the east and K1-NC41 to the west, in turn the back-bank condition changes southward to an inner shelf restricted supratidal to sabkha condition that prevailed along a narrow belt that extends parallel to the present shoreline.

Two main lithofacies make up the bank sequence: nummulite packstone/grainstone and nummulite wackestone/packstone. The higher energy lithofacies are commonly found along the northern edge of the bank extending from E1-NC35A to Bla 137, whereas the relatively lower energy lithofacies are located just in the centre of the bank. Such a distribution would perhaps indicate that the high energy nummulitic lithofacies in fact represent a shoal setting as the case in the Ypresian nummulite sequence in the onshore Tunisia as reported by Fournie (1975) or a for-bank environment similar to the Eocene of Turkey (Henson 1950). This point is discussed further in the following pages.

Discussion

The problem is whether the high energy nummulitic facies of grainstone and packstone are deposited along the bank margin or the fore-bank is not helped by the different reporting of nummulite lithofacies depositional environment.

The Eocene nummulites in the north-east Iraq is reported to be of a reef, back-reef and fore-reef where large nummulite with abundant echinoid remain dominant the fore-reef shoals, similarly nummulitic grainstones are interpreted to form fore-reef shoals in the Eocene of Turkey (Henson 1950) and in the case of Ypresian sequence from the onshore Tunisia (Fournie 1975), the nummulitic lithofacies are interpreted to deposit in the outer platform as a shoal, resembling in many aspects the oolitic shoals. Whereas (Arni 1965) in his study on the Eocene nummulite rocks of Sirt Basin, suggested the nummulite lithofacies to be deposited in banks, back-bank and fore-bank environments, and different nummulite tend to occupy different setting within the bank complex. There are also reports of nummulitic rocks associated with coarse cross-bedded classic rock that are deposited in the littoral zone (Roniewcz 1969). However, in recent study of the nummulitic beds in the Eocene of Egypt (Aigner 1982) pointed out that most nummulitic accumulation is in situ build-up that tends to be reworked, winnowed and redeposited very close to its original site of accumulation, normally at a lower depression within the bank complex. Aigner also suggested that such removal and reworking can happen at depth of up to 100 m. water depth where storm induced wave currents are strong enough to move the nummulite tests and he added that nummulite accumulation does not necessarily reflect an actual habitate condition and their local presence is not direct reflection of in situ accumulation. If this holds true in the case of the Upper Jdeir nummulite lithofacies then one should not only look for the best condition of nummulite accumulation but also to the likely place where it may be removed to and redeposited. This of course will be within the bank complex.

Studies of recent large foraminifers in the Red Sea of the type resembling nummulite are found to live in water depth that range from 50 m to over 100 m (Hottinger 1977) and they prefer quite muddy water, this range of water depth of the deposition of the nummulitic lithofacies is reported by many workers on their studies of Eocene nummulite accumulations.

In conclusion, the presence of larger foraminifera in the Upper Jdeir such as Assilina and Operculina at E1 and B1-NC41 and the abundant broken fragments of nummulites and echinoids at A1-NC35A, perhaps make it safe to suggest the occurrence of fore-bank lithofacies belt that extends from B1 to E1-NC41 to A1-NC35A. The line separating the bank from the fore-bank is very arbitrary and the width of this fore-bank is very difficult to outline at this stage fore-bank setting is followed by wide broad bank that dominated most of the shelf which is characterized by nummulitic packstone, grainstones and wackestones. In turn back-bank lithofacies condition prevailed behind the bank where foraminifers/skeletal wackestone is dominating the rest of the area. This is flanked by Inner shelf deposits of dolomicrite, mudstone, shale with anhydrite and levels of sandy beds and sandstone that indicate close by shorelines.

Lithofacies and Environment of Tajoura Formation

This formation comprises bryozoan packstone/grainstone and oolitic packstone/grainstone with dolomitic wackestone and nummulitic pelecypod wackestone at F1-NC41 (Fig. 9). It grades eastward at L1-NC41 into argillaceous skeletal grainstones and packstones; dolomite and dolomitic wackestones, locally with anhydrite nodules and fossiliferous wackestone/mudstone. Further east, towards R1-NC41, Tajoura Formation changes into Lower Jdeir lithofacies of Farwah Group which consists mainly of Alveolina/Orbitolite packestone with perhaps deep shelf influence. These high energy lithofacies extends eastward and grades into algal grainstone lithofacies near N1-NC41 and towards and northwest where oolitic and interclastic lithofacies are interbedded with the nummulitic lithofacies of the Jdeir Formation at C1-NC35A.

This suggests, as shown in Figure 9 the presence of bryozan organic buid-up at or near F1-NC41 which grades north and northwest into a probable shelf lagoon lithofacies at F2-NC41 and nummulitic bank lithofacies at C1 and E1-NC35A. South of the E1 at the winnowed edge, oolitic grainstone lithofacies developed which extended towards L1-NC41 where argillaceous skeletal grainstone predominate which is less restricted. At N1-NC41 the high energy lithofacies is mainly algal grainstone, suggesting perhaps some algal development within the bryozan build-up which supply of algal debris for the grainstone at N1-NC41. Behind the organic build-up and winnowed edge, a shelf lagoonal belt was developed protected by the organic build-up and the oolitic barrier, but however some water circulation must have been possible. The shelf lagoon lithofcies which is dominated by quite water facies, rich in fauna are characterized by pelecypod, nummulite, alveolina and orbitolite wackestone and packestone lithofacies. These lithofacies are present south, east and west. At R1-NC41 the Alveolina/Orbitolite packstone/wackstone lithofacies exhibit shelf influence as they are not protected and perhaps directly grades into the nummulitic bank lithofacies and open sea lithofacies. Between the shortline and the shelf lagoon a wide belt of restricted lagoon and supratidal/Sabkha lithofacies possibly existed as the vertical section at L1-, F1 and N1-NC41 suggest.

The development of this shallow water carbonate lithofacies at F1-NC41 area could be a reflection of tectonic high or swell which persisted during Eocene which is perhaps related to Tripoli Nose, other explanation could suggest that the reason for such organic

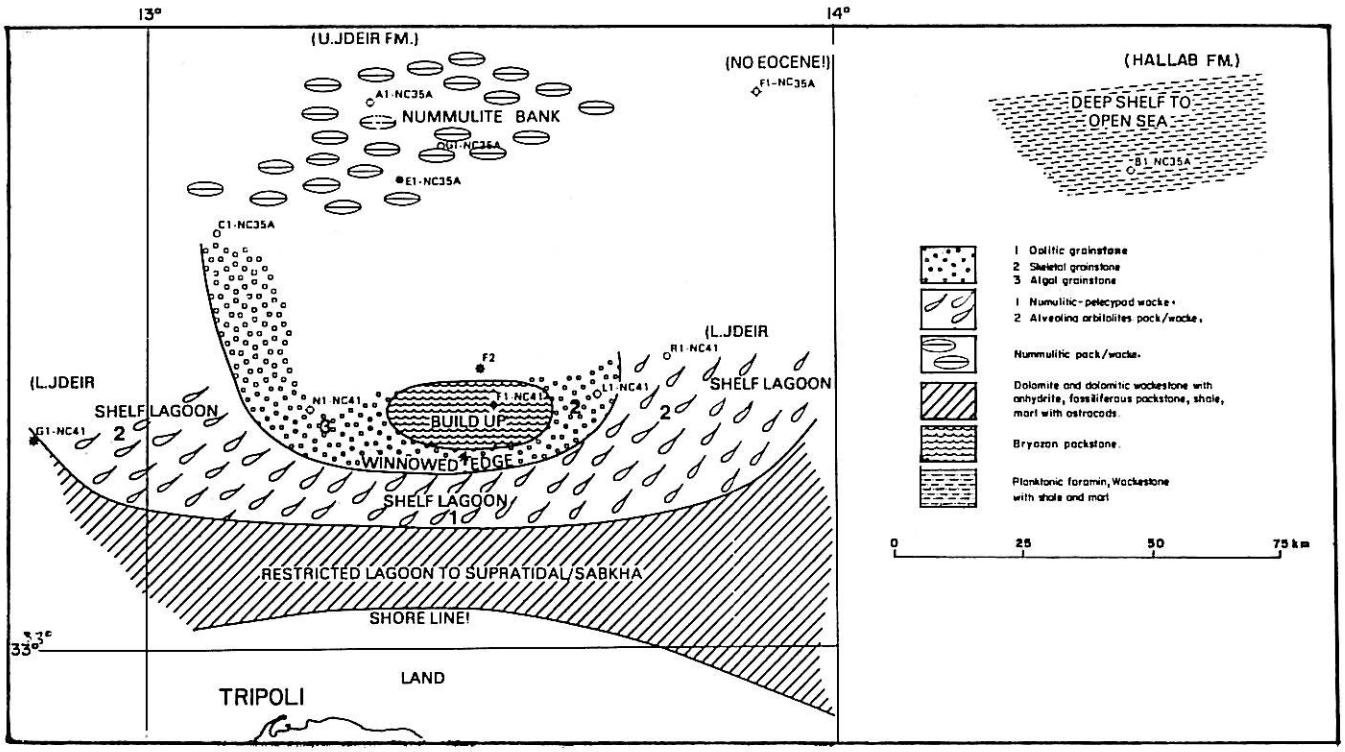


FIG. 9. Facies and environment of Early Eocene, Tajoura Formation.

build-up is the local development of carbonate Bank during the Paleocene time near the F1 area, which is probably the case, because a thick Paleocene carbonate sequence is locally developed at F1-NC41, or most likely is due to the combination of both tectonic and sedimentological factors.

It is important to note that Bryozoans are not known to be a significant build up contributor in the geological time, and only reported to be of some importance in the Middle Ordovician and locally during the Silurian and in the brackish late Miocene and Pliocene of Eastern Europe. (Heckel P.H., 1974).

Lithofacies and Environment of Hallab Formation

Hallab Formation is encountered only in one well that is B1-NC35A. It is composed of mainly alternating shales, calcareousl shales, marl and limestones that are rich in planktonic foraminiferas. The limestones are white, cream, chalky and consist of pelagic mudstone, wackestone to packestone lithofacies.

The lithofacies and faunal assemblage suggest a deposition in quite deeper water environment, where rate of sedimentation were low. This condition of deposition is found to prevail in the open sea shelf or basinal environment that dominated the northeast part of the basin.

ACKNOWLEDGEMENT

I would like to express my thanks to N.O.C. for the support and permission to publish this work.

The work was conducted during my stay as an academic visitor at Imperial College, London, 1982–1985.

REFERENCES

Aigner. T, 1982, Event-stratification in Nummulite, Accumulation and in Shell Beds from the Eocene of Egypt. In: *Cyclic and Event Stratification* (Ed) Ensele and Seilacher. Published by Springer Verlag.

Arni P., 1965, L, Evolution des Nummulites en tant Que Facteur de Modifications des Deposits Littoraux. In: *Memories du Bureau de Recherches Geologique at Mineres*, Paris, No. 32.

Bannerjee. S., 1980, Stratigraphic Lexicon of Libya, *Department of Geological Researches and Mining Bulletin* No. 13, Industrial Research Centre, Tripoli.

Bishop, W.F. 1975, Geology of Tunisia and adjacent part of Algeria and Libya *A.A.P.G. Bull.* Vol. 59, n. 3, p. 413–458.

Busson, G., 1967, Mesozoic of Southern Tunisia in Martin L. (Ed), Guide book to the geology and History of Tunisia, P.E.S.L., Tripoli.

Fatmi, A.N., Sbeta, A.M., and Eliagoubi, B.A., 1978, Guide to the Mesozoic Stratigraphy of Jabal Nefusa, Libyan Jamahiriya. *Arab. Dev. Inst.*, Tripoli, Pub. no. 7, 35p.

Fatmi, A.N., Eliagoubi, B.A., Hammuda, O.S., 1980, Stratigraphic Nomenclature of the pre-Upper Cretaceous Mesozoic Rocks of Jabal Nafusah, NW Libya. In: *The geology of Libya Volume I* (Eds.

Salem; M.J. and Busrewil) Academic Press, London, pp. 57–65.
Fournie, D., 1975, L'Analyse-sequentielle et la sedimtologie de L'Ypresian de Tunisie: Bull. Centre Rech. Pau., *SNPA* V9, p. 27–75.
Fournie, D., 1978, Nomenclature Lithostratigraphique Des Series Du Cretace Superieur Au Tertiaire De Tunisie: *Bull. Cent. Rech. Explor. Prod.* Elf Aquitaine.
Hammuda O.S., Sbeta A.M., Mouzughi A.J., and Eliagoubi B.A., 1985, The Stratigraphic Nomenclature of the Northwestern offshore Libya Published by ESSL, Tarabulus–Libya.
Heckel, P.H., 1972, Recognision of ancient shallow marine environments, In: Recognision of Ancient Sedimentary Environments, In: Rigby, J.L., Hamblin, W.K. Eds., Soc, Econ. *Paleonto logists mineralogists Spec. Publ.* 16, 226–286.
Henson, F.R.S., 1950, Cretaceous and Tertiary Reef formations and associated sediments in Middle East Bull. *Amer. Ass. Petrol. Geol.* v. 34, no. 2, pp. 215–236.
Hinnawy, M. and Chechitev, G., 1975, Geological Map of Libya, Sheet Tarabulus (N1-33-13) *Explanatory Booklet* Industrial Research centre, S.P.L.A.J., Tripoli.
Hottinger L., 1977, Distribution of larger peneruplidae, Borelis and Nummulitidae in the Gulf of Agaba Red Sea in Utrecht, Micropal. *Bull. 15*, p. 35–109.
Pitman, III, W.C., Cochran, J.R.; Ryan, W.B.F. and Ladd, J.W., 1981, Evolution of the Libyan Margin, Annex II–6 in (*Continental Shelf, Technical Annexes to the Reply* Vol. II SPLAJ).
Roniewicz, P. 1969, Sedimentation of the nummulite Eocene in the Tara Mnt. *Acta. Geol.* Polon, 19:503,601.
Sbeta, A.M. 1981, the stratigraphic nomenclature of the Lower Eocene. The offshore of the northwest Libya: *N.O.C. Internal Report.*
Sbeta, A.M., 1983, The main results of the Investigation on the Eocene of the Offshore northwest Libya: *N.O.C. Internal Report.*
Wilson, J.L., 1975, Carbonate Facies in Geologic History published by Springer-Verlag.