PRJ, Vol. 3 (January 1991); P. 44–52, 13 FIGS.

# DIAGENETIC HISTORY OF EARLY-MIDDLE EOCENE JDEIR FORMATION, FARWAH GROUP, NORTHWESTERN LIBYAN OFFSHORE

Ibrahim Y. Mriheel*

# تغيرات المنشأ في تكوين أجدير — الرف القاري شمال غرب ليبيا

إبراهيم يوسف مريحيل

يمثل تكوين أجدير رسوبيات جيرية ضحلة تكونت أثناء عصر الايوسين المبكر — الأوسط بالمنطقة المغمورة بمياه البحر والواقعة شمال غرب ليبيا. أظهرت الدراسة البتروغرافية أن تغيرات المنشأ التي طرأت على تكوين أجدير، كانت معقدة وقد حدثت هذه التغيرات في ثلاث بيئات أو مراحل أساسية:

**المرحلة البحرية:**

لقد نجم عن هذه البيئة تكون مادة لاحمة مبكرة وظاهرة التحول إلى الطفل الجيري.

**المرحلة القارية:**

نشأ أثناء هذه المرحلة مادة لاحمة ذات أحجام وأشكال متباينة مثل مادة لاحمة متساوية الأبعاد، ومادة متزايدة الأحجام ناحية مركز الفراغات. كما يرجع تكوين المسامية العالية بتكوين أجدير للإذابة الشديدة التي تعرض لها أثناء بروز هذا التكوين للظروف القارية، وذلك أثناء تراجع مياه البحر.

**مرحلة الدفن:**

تميزت هذه البيئة عن غيرها بتكوين مادة لاحمة كبيرة الأحجام، وتشققات وظواهر الضغط، والتحول إلى السليكا.. كما صاحب نضوج المادة النفطية زيادة في مسامية تكوين أجدير.

نتائج تاريخ تغيرات المنشأ المختلفة يعكس التباين في كمية ونوعية المسامية بتكوين أجدير، كما أن المسامية في الخزان معقدة وتشمل أنواع أولية وثانوية.

---

## ABSTRACT

*The Jdeir Formation, a shallow carbonate platform deposit, was developed during Lower-Middle Eocene in the northwestern Libyan offshore. The diagenesis of the Jdeir Formation mainly involves marine phreatic, meteoric phreatic and burial stages. The phenomena vary from crystalline degradation (micritisation, dissolution) to crystalline aggradation (cementation, neomorphism). Stylolitisation and fracturing is common, the former mostly filled by bitumen and the later with calcite. The result of different diagenetic histories reflects the variation in the amount and kind of porosity within the formation. Porosity in the reservoir is complex and contains primary and secondary types.*

*Concentration of calcite spar, fracturing, compaction and pressure solution caused destruction of porosity.*

## INTRODUCTION

The Jdeir Formation, a shallow carbonate platform deposit, was developed during Lower-Middle Eocene in the Gabes–Tripoli–Misratah basin over extreme northern parts of the passive continental margin of the African Plate. This shallow platform was bounded by restricted platform deposits of Taljah Formation toward the then land and a deep platform-basinal facies of the Hallab Formation toward the sea side. The formation comprises the upper unit of the Farwah Group and is the main target for hydrocarbon exploration in the offshore area.

*Petroleum Research Centre, Tripoli, G.S.P.L.A.J.

Lithologically, the Jdeir Formation is subdivided into three main facies. These are, from landward to seaward, Orbitolites-Alveolina facies, Nummulitic facies, Fragmental-Discocyclina-Assilina facies. A fourth facies, the dolomitised limestone, is also observed but it has a very limited distribution. It is present in the extreme southwestern part of the area (Fig. 2).

Geologic studies commenced mainly during the last decade after a number of wells had been drilled. Available published work on the Jdeir Formation (Farwah Group) of the northwestern offshore Libya is very scarce although being petroliferous, it is fairly well studied by the operating companies e.g., Aquitaine, Sirt, and Agip.

Bernasconi *et al.* (1984) studied the petrography and diagenesis of the Farwah Group at the Bouri oil field and divided it into three main lithofacies i.e. nummulitic, dolomitic and micritic and proposed a nummulitic bank model.

Sbeta (1984) conducted a comprehensive sedimentological study of the Eocene sequence in the northwestern offshore Libya and related the lithofacies to depositional environments according to the standard facies model of Wilson (1975). The depositional environments of Jdeir Formation and the relationship between its lithofacies and structural framework of northwestern Libyan offshore have been described in greater detail by Etourbi, 1989.

This paper presents the diagenetic history of the Jdeir Formation as interpreted from petrographic analyses.

Data from fifty wells (Fig. 1) drilled in Agip NC41, Sirt NC35A and Aquitaine 137 concessions were utilised and cores from wells (B2, E1-NC41, E1, and I1-NC35A) were studied. The present study employs the stratigraphic terminology proposed by Hammuda *et al.* (1985) but with an emphasis on author's lithologic subdivisions of the Farwah Group (Etourbi, 1989).

## STRATIGRAPHY OF THE JDEIR FORMATION

The Jdeir Formation ranges in age from Late Ypresian to Early Lutetian and represents the upper unit of the Farwah Group. It is the main target for hydrocarbon exploration in the region. The formation consists of three major facies distributed from south (landward) to north (seaward) as given below:

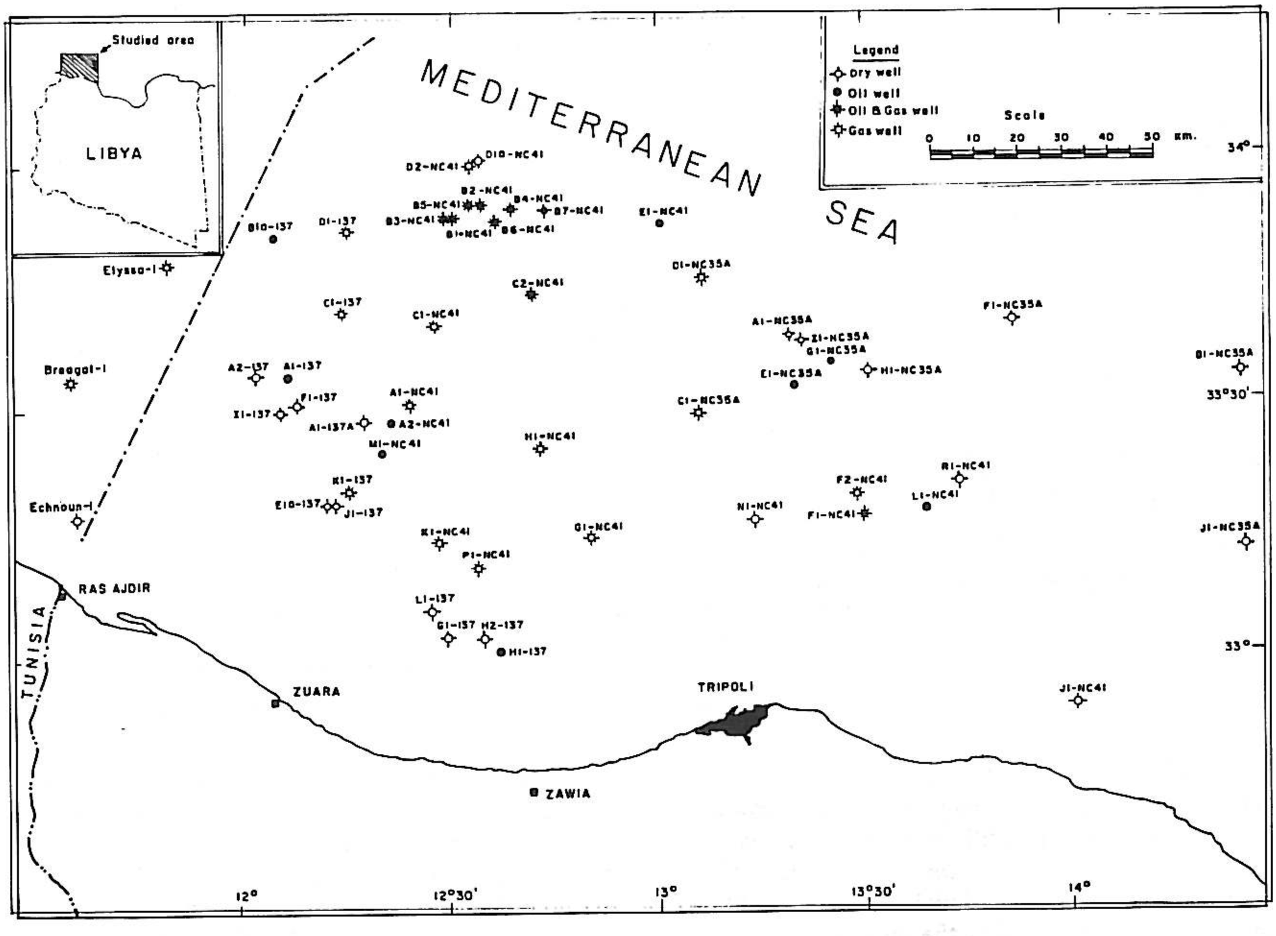

FIG. 1. Location map of the studied area.

(1) *Orbitolites-Alveolina back bank facies* (southernmost)

It comprises whitish-light brown and light grey, medium hard to hard compact wackestone-packstone occasionally grading to wackestone-mudstone. The facies is interpreted to have been deposited in a lagoon and/or a bay environment over an open shallow platform where a moderate water circulation of a few tens of meters depth and normal marine water salinity predominated the environment. This facies is structurally controlled by the main trough of Jifarah (Etourbi, 1989) and is absent over the Jifarah platform as well as the "saltic" high (Fig. 2).

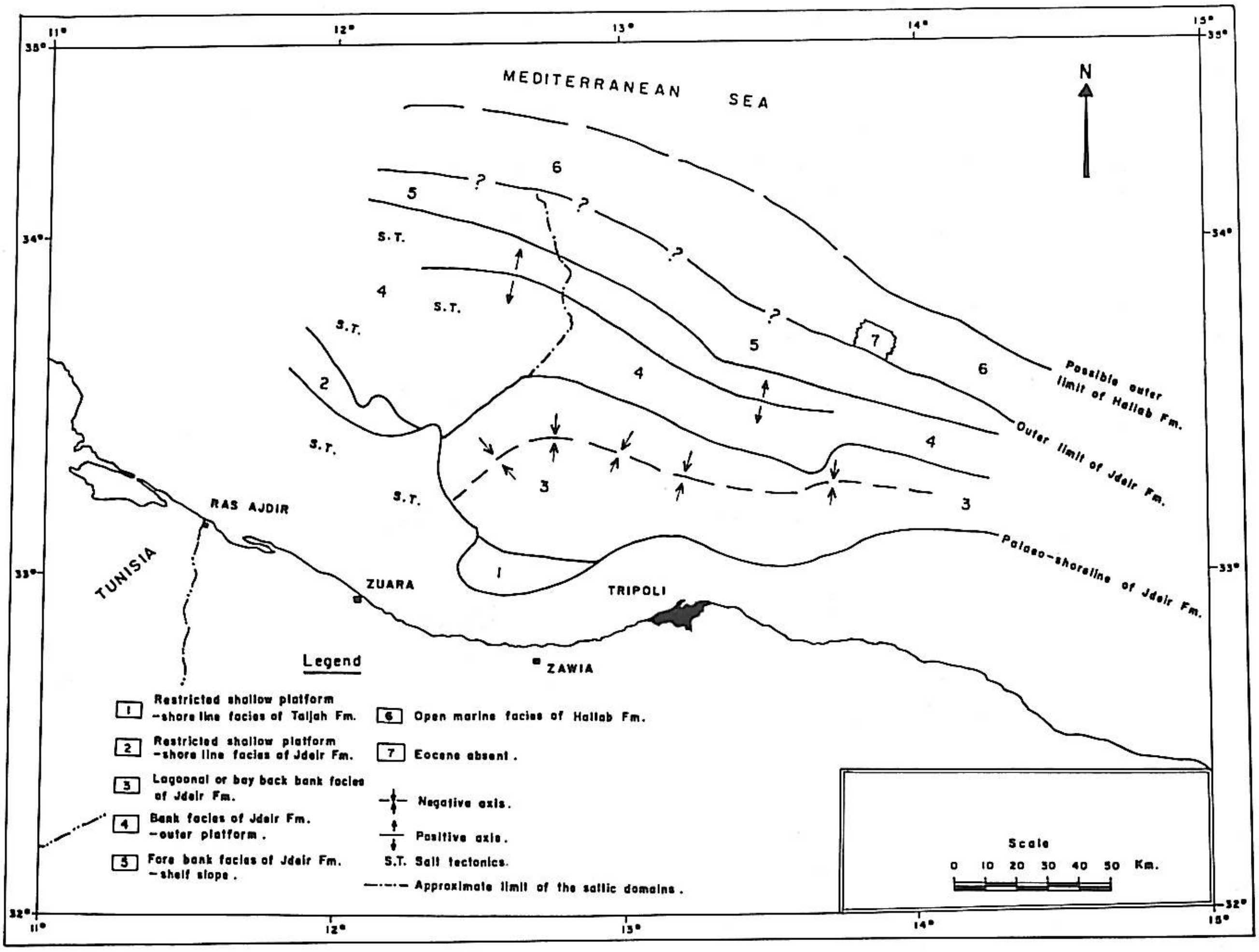

FIG. 2. Facies, structural setting and depositional environment of Jdeir Fm. and its equivalents (Taljah Fm. and Hallab Fm.).

(2) *Nummulitic bank facies* (central)

This facies consists predominantly of light brown-grey, medium hard, nummulitic packstone-grainstone and wackstone-packstone. Levels of wackestone-mudstone are present occasionally. The nummulitic bank facies was deposited at the outer platform in a water depth ranging from wave base to low tide level. Its position was structurally controlled by paleohighs (Etourbi, 1989), namely "saltic" uplift and Jifarah platform (Fig. 2).

(3) *Fragmental-Discocyclina-Assilina fore bank facies* (northernmost)

It is comprised of a thick sequence of light grey and tan to bluff, medium to coarse grained, medium hard wackestone-packstone with intercalated levels of grainstone. The facies is associated with abundant Nummulites and echinoderm fragments and is characterized by the presence of *Discocyclina spp. Assilina spp.*, and Operculina. The fore bank facies was deposited on the northern flanks of the outer platform (Etourbi, 1989) probably at the shelf slope margin (Fig. 2).

The Jdeir Formation is generally unconformably overlain by the Harshah Formation in the southern part and overlain by the Ghalil Formation toward the northern parts (Bouri oil field) of the area. It overlies the Bilal Formation in the north and in the south. In N1 and K1-NC41 wells it overlies unconformably the Late Cretaceous deposits.

## DIAGENESIS

This section presents a brief outline of the main diagenetic process and their products which were recognized in the course of the petrographic study of the Jdeir Formation. Detailed petrography and relationship between the depositional environment and diagenesis is to be the aim of the later research.

The different diagenetic events and their response to both time and diagenetic setting in the studied sections of the Jdeir Formation are shown in Fig. 3.

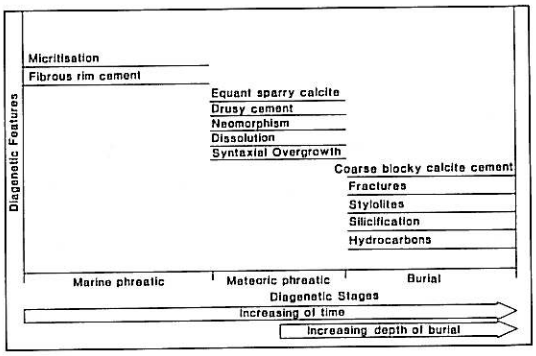

FIG. 3. Diagenetic events observed in the Jdeir Formation in relation to time and diagenetic environments.

The term diagenesis in this study refers to all natural processes acting on sediments since their initial deposition to the time of erosion. These include, dissolution, replacement, neomorphism, cementation, micritisation, and compaction. Other processes such as metamorphism and weathering are excluded from the definition.

To avoid confusion and/or further repetitive work, the reader is referred to (Longman, 1982 p. 92–105) for the classification of the diagenetic environment. For the main characteristic products of each environment, the reader is referred to Longman (1980 p. 461–487); Wilson (1975 p. 69–71); Flugal (1982 p. 62–95), Bathurst (1975) and Scoffin (1987 p. 89–130). The porosity classification of Choquette and Pray (1970) is used in this study.

The Jdeir Formation underwent severe diagenetic processes which have altered the original components and texture since the time of their initial deposition until the present time. The diagenetic history of Jdeir Formation commenced in the early marine phreatic environment as most of the carbonate rocks started their diagenetic history there, then passed via a fresh water phreatic environment to the last stage, the burial phase. The previously mentioned diagenetic environments have been distinguished one from another by their own characteristic processes and the resultant features such as procésses enhancing porosity initiation (dissolution) and processes obliterating the porosity (cementation).

In this section the processes are described and subsequently their effects on the Jdeir Formation explained.

## MARINE PHREATIC

### Micritisation

This is one of the first stages of diagenesis seen in these sediments and it occurred during deposition. Micritisation of grains by boring algae and fungi result in the formation of a micrite envelope similar to those described by Bathurst (1966, 1975) and Kendall and Skipwith (1969). This has been observed throughout the studied sections except in the well E1-NC35A, where it has been observed mainly in the upper portion (Fig. 4). The process goes on centripetally within the grain and may completely convert it to micrite. These encrusting algae and boring organisms micritize the outer portions and occasionally the inner portions of the bioclastics as has been observed in Recent sediment of Abu Dabi by Kendall and Skipwith (1969).

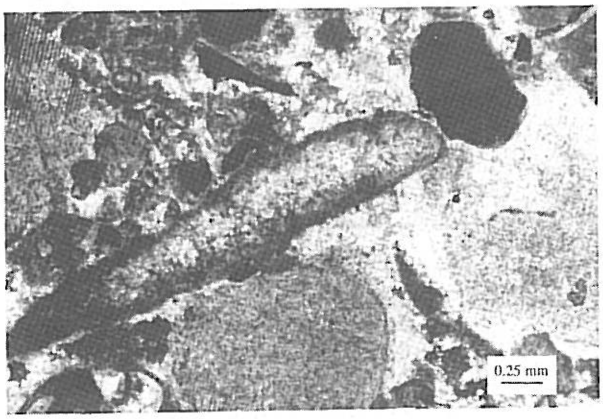

FIG. 4. Micritized molluscan envelope formed by fungi or algae boring, adjacent to echinoderm fragments rimed by syntaxial overgrowth.

Bathurst (1966, 1975) and Kobulk and Risk (1977) believe that this processes takes place in a marine phreatic zone, while May and Perkins (1979) consider it happens from near the sediment-water interface to a meter beneath the interface.

Absence of broken envelopes indicates that the dissolution and void-filling were completed before compaction, or both have occurred after the early (pressure-solution) phase of compaction similar to that described by Bathurst (1964).

### Fibrous Calcite Crust

Isopachous crusts of fibrous calcite are observed in the upper parts of well E1-NC35A and are believed to be a very early post-depositional submarine cement (Becher and Moore, 1979) of the phreatic environment. Folk (1974) believes that the high Mg/Ca ratios found in normal marine water is responsible for these fibrous habits of marine calcite cement. A thin rim of calcite crystals (normal to grain surface) surrounding grains as observed in some thin sections is followed by blocky calcite which represents different stages of cementation, as discussed below.

Intraclasts which preserve a generation of radial-fibrous (Fig. 5) or -prismatic cement not observed in the host sediment have been observed only in one sample. This is interpreted not as a Jdeir Formation cement, but one formed in a laterally equivalent environment, which was the provenance of the intraclasts. This interpretation is similar to that of Schofield (1982).

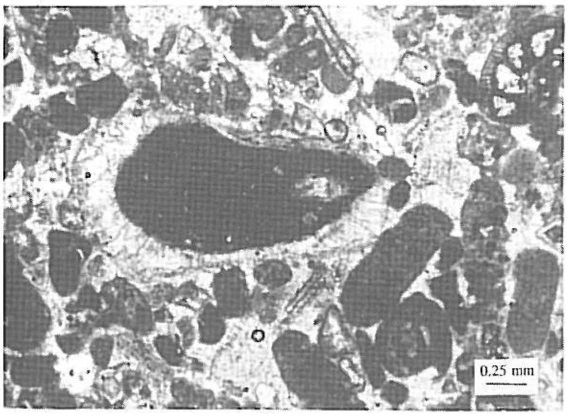

FIG. 5. Early radial fibrous cement around lithoclasts in grainstone. Well E1-NC35A, PPL.

## METEORIC PHREATIC

### Neomorphism

The dissolution and reprecipitation of the aragonite of shells (mainly molluscs) as a mosaic of sparry calcite is very rare in the upper parts of Jdeir Formation at well El-NC35A. In some intervals, Jdeir Limestone is observed associated with recrystallisation of some portions such as micritic matrix into microcrystalline calcite (Fig. 11). Relics of the original grains can be faintly seen.

Neomorphism is defined by Folk (1965) as transformation between one mineral and itself or a polymorph which results in the growth of new crystals that are larger or different in shape from the previous crystals. Carbonate minerals are very suceptible to such recrystallisation. Neomorphism in the limestones described in this paper was proceed by micrite enlargement, a process by which crystals that measure only a few microns in diameter enlarge to a size measuring tens of microns in diameter. This micrite enlargement creates neomorphic products similar to cement in crystal size. The new crystals are known as pseudospar (Folk, 1965) or neospar (Nichols, 1967 and Flugal, 1982). Depending on water chemistry and rates of water flow, micrite may recrystallize and neomorphose to coarser grains in a fresh water phreatic environment or in a fresh water vadose environment (Longman, 1980; Flugal, 1982).

This type of diagenesis has been observed in some of the studied sections of Jdeir Formation. The size distribution of the individual crystals is usually random and devoid of any regular pattern. This neosparite exists as isolated patches and thus appears to be floating in the rock. The parts of limestone which have undergone extensive micrite enlargement display relic patches of non replaced micrite. These patches reveal that the limestone originally was a micrite rather than a sparite.

### Dissolution

Evidence of extensive dissolution is found in most of the studied sections of Jdeir Formation. It has a broad range of intensity and generally increases the pore system. Dissolution forms solution vugs and moldic voids (Fig. 6) which are locally interconnected by the enlargement of the basic intergranular porosity.

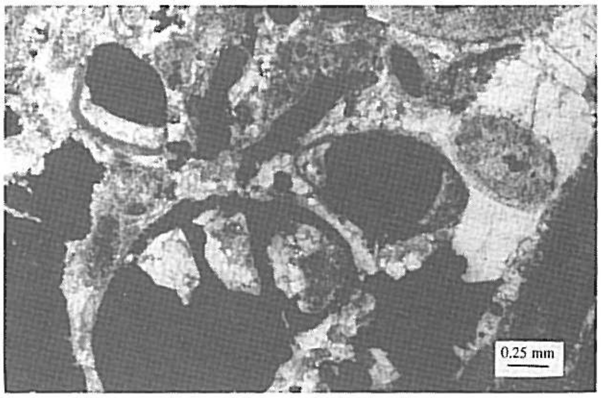

FIG. 6. Packstone showing good moldic and vugy porosity. Note syntaxial overgrowths around echinoderm. Well El-NC35A, XN.

As a matter of fact, the dissolution process has created a vast amount of vugy and moldic secondary porosity. In some intervals of Jdeir Formation, it reaches more than 20% of mesopore size which in turn has enhanced its reservoir potential and the entrapment of hydrocarbon in the northwestern Libyan offshore. Similar hydrocarbon entrapment was discovered toward the Tunisian offshore in the nummulitic facies of El-Garia Formation within the same secondary porosity type (see Bishop, 1975).

### Cementation

Syntaxial overgrowths on echinoderm fragments and/or crinoid fragments (Fig. 7) have been described in many sections of Jdeir Formation. Syntaxial calcite growing in optical continuity with echinoderm fragments generally surrounds the grains and is elongated along the C-axis similar to that described by Evamy and Shearman (1965, 1969). Because of the large crystal nucleus and absence of competitive crystal growth, they grew much faster than cements around adjacent non-echinoderm grains and locally lead to a polkilotopic texture as described in Bathurst (1975). Lucia (1962) and Evamy and Shearman (1975) have found that the volume of rim cement on echinodermal grains normally exceeds the volume of cement mosaic on the associated multicrystalline grains. These syntaxial overgrowths are developed in a meteoric phreatic environment, and Longman (1980) suggests that, although syntaxial overgrowths form most commonly in fresh water phreatic environment, they may also form, but rarely, in vadose and deeper subsurface diagenetic environments.

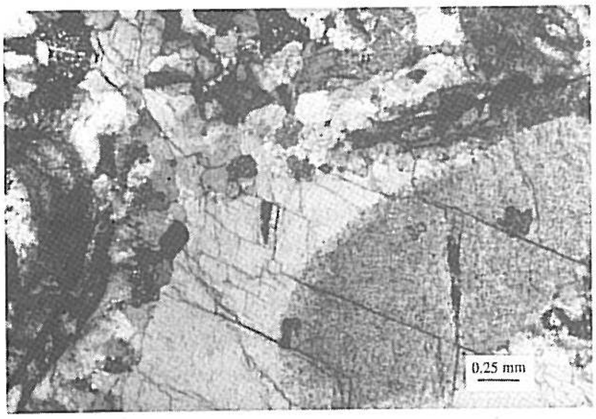

FIG. 7. Syntaxial overgrowth around echinoderm fragments adjacent to equant mosaic cement of non-ferroan calcite. Well El-NC35A, XN.

Drusy cement mosaics (Fig. 8), increasing in crystal size regularly to the centre of the former void-space, are not common. The pore-filling calcite is commonly an equant mosaic of non ferroan calcite (Fig. 9). The morphology of these crystals is similar to those described by Longman (1982), i.e. crystals of void-filling cement which are optically continuous over large areas and showing almost irregular boundaries. They were probably deposited in the fresh water phreatic environment during exposing of Jdeir Formation to subaerial conditions.

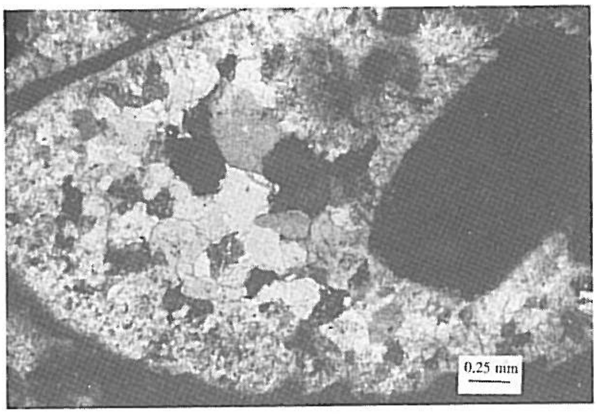

FIG. 8. Geopetal infilled by drusy mosaic of non-ferroan calcite cement. Well El-NC35A, XN.

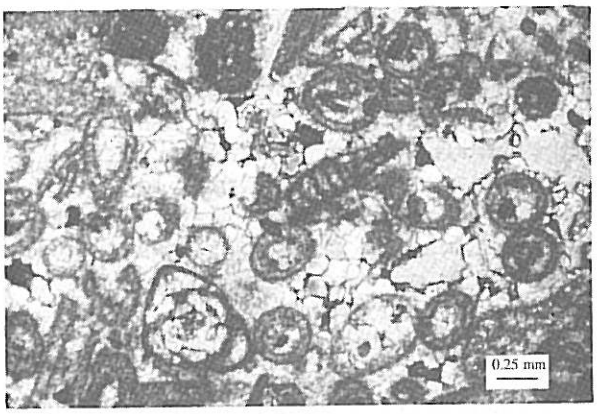

FIG. 9. Grainstone composed largely of dasycladacean algae and cemented by equant mosaic of non-ferroan calcite. Well I1-NC35A, PPL.

## BURIAL PHASE

### Coarse Crystalline Calcite

Coarse crystalline calcite (Fig. 10) found in the Jdeir Formation probably formed during deep burial of sediment at a relatively late stage in their diagenetic history. These calcite crystals are commonly euhedral and partly fill the voids which remained. This cement is Fe-poor which indicates it formed in an oxidizing setting, which could include the deeper subsurface as described by Sultan (1985). Land (1971) observed the more rapid pore filling of coarse calcite in the phreatic environment than in the adjacent vadose environment.

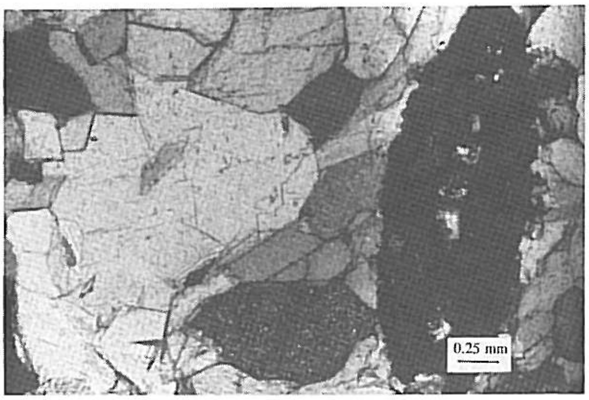

FIG. 10. Coarse crystalline non-ferroan calcite filling the voids adjacent to Nummulites. Well El-NC35A, XN.

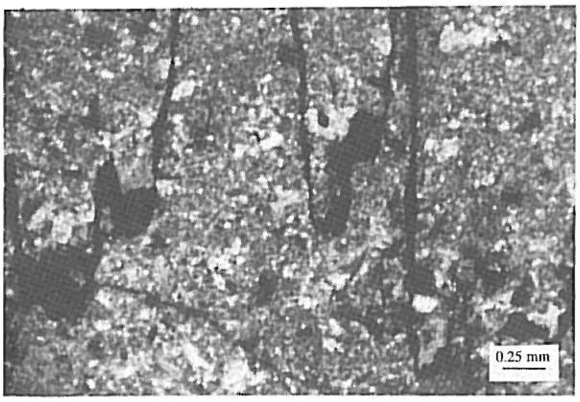

FIG. 11. Stylolites stained with oil in nemorphosed micritic substrate. Well I1-NC35A, XN.

## Stylolites and Fractures

Several generations of stylolites affect the Jdeir Formation. The observed pressure-solution phenomena throughout most of the studied sections are represented by horizontal stylolites of simple or primitive wave-like type and sharp-peak type. The seams of the stylolites usually consist of residues of dark organic matter or bituminous substance occasionally with small-sized quartz grains. The maximum amplitude observed is 1 cm although the length of the stylolites peaks is variable and ranges down to 1 mm.

Dunnington (1967) suggested that undersaturated pore fluids play a role in the formation of stylolites and are necessary for solution-compaction processes. This requires increased overburden pressure or undersaturated water from an outside source (Becher and Moore, 1979). Solution resulted in the formation of stylolitic boundaries between clasts in response to the overburden pressure. Compaction and tight packing of clasts could be the result of this pressure solution (Longman, 1980).

Stylolitisation significantly affects carbonate reservoirs by providing pathways for hydrocarbon migration as is clearly indicated by the residue of bitumens (Fig. 11) found along most stylolites in the present area. Stylolites were formed after burial probably from dissolution associated with decarboxylation (the release of $CO_2$ during thermal maturation of organic matter and hydrocarbon generation) (see Longman, 1982).

At the Bouri oil field stylolites are frequently associated with open microfractures. The observed microfractures within Jdeir Formation at well E1-NC35A are predominantly associated with the lime wackestone intervals and resemble calcite veining (Fig. 12). The most characteristic features of most of them are their sharp edges and the type of infill which is usually pink-stained non-ferroan calcite, although, in a few instances, secondary silica is substituted for small amounts of the calcite mineral in the vein. The fractures are generally small ranging up to several centimetres in length and ranging from 0.3 mm to 0.7 mm in width. Some of the fractures run parallel to each other and a few show cross-cutting relationships. In a few samples, however, they tend to cut bioclasts with recognizable "microdisplacement". At the Bouri oil field, stylolites are frequently associated with the open microfractures (Bernasconi *et al.* 1984). The microfractures within are interpreted as mechanical fractures that developed after lithification, probably during localized uplift or compression. It is, however, difficult to assess the potential contribution of these microfractures to production. It is likely that the very small scale fractures which are often measured in centimetres would not en-

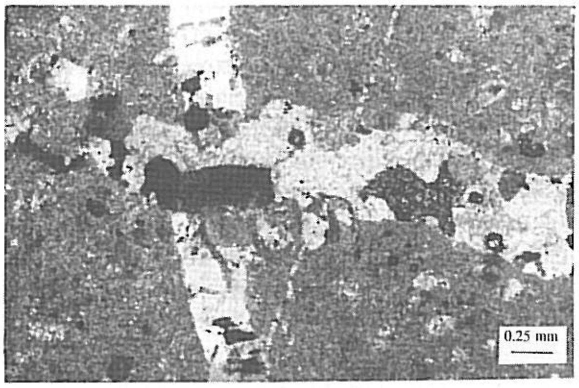

FIG. 12. Mudstone showing cross-cutting fractures represented by calcite veins. Note that some parts of the calcite vein are replaced by authigenic silica. Well E1-NC35A,XN.

hance the permeability of the reservoir significantly. The contribution of the large fractures to permeability can be expected to be significant provided these are open under reservoir conditions.

### Silicification

Evidence of replacement by authigenic silica is rarely found in a few thin sections in the form of anhedral replacement of bioclasts (Fig. 13), void-infilling and in few cases secondary silica substitution of small intervals of calcite minerals in veins.

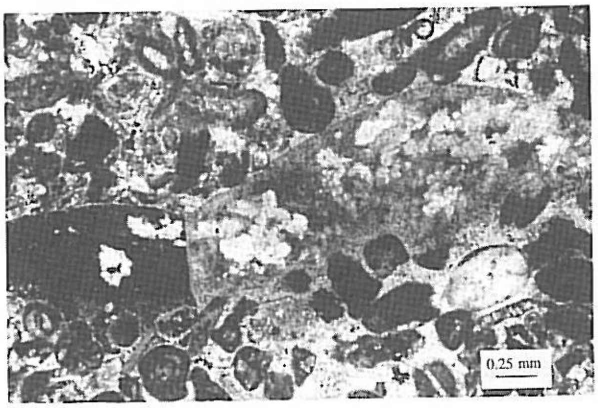

FIG. 13. Bioclasts replaced partially by authigenic silica in grainstone. Well E1-NC35A, XN.

Silicification took place after submergence following sub-aerial exposure, however, the source of silica which replaced parts of the component allochems in the Jdeir Formation is unknown.

### Hydrocarbon Occurrence

The hydrocarbon accumulations in the northwestern Libyan offshore have mainly been discovered in carbonate reservoirs ranging in age from Late Cretaceous to Early Tertiary.

The Early Eocene nummulitic facies of the Jdeir Formation and the dolomitic facies of the Jirani Formation (Farwah Group) are the main reservoir rocks in the investigated area. A major hydrocarbon accumulation, discovered at the Bouri oil field produces from both the Jdeir Formation and the Jirani Dolomite. The Tellil Group of Middle-Late Eocene age and the Alalgah Formation of Cenomanian age are considered to be the second carbonate reservoirs, particularly in the central and the southern parts of the Libyan offshore.

As yet, all of the hydrocarbon plays were found in structural traps of anticline type. Detailed investigation of facies distribution and the relationship between its environment of deposition and diagenesis will undoubtedly enhance the exploration of the stratigraphic traps at the studied area.

The main source rocks of hydrocarbon at the Libyan offshore are the micritic facies of the Bilal Formation (Farwah Group) and the Maastrichtian-Paleocene Al Jurf Formation. The latter is considered to be mainly gas-borne over all the studied area.

The organic carbon content of the micritic facies of Bilal Formation ranges from 0.5–2.3% of amorphous type. The overall source potential of the Farwah Group corresponds to the zone of oil and gas window. The Farwah Group in the northern parts of the Libyan offshore contains oil-borne organic matter which becomes gradually gas-borne southward where the main Trough of Jifarah is located. This can be explained because in these southern parts the geohydrothermal gradient is high as the Farwah Group occupied deep areas (structurally low land or trough) therefore, the thermal maturation is very high and any oil generated would not be preserved as liquid as the heat would transfer it into a gas or condensate state.

Oil generation in the Libyan offshore basin commenced after the Miocene and is still continuing (Benelli *et al.*, 1985). These authors have distinguished three areas of hydrocarbon generation. In the northern parts, oil generation occurred in the Farwah Group and that of gas and condensate in the Al Jurf Formation of Late Cretaceous-Paleocene age. Only gas and condensate with minor oil were generated by the Al Jurf Formation and Farwah Group in the central southern parts. A third oil-bearing sequence existed in the southeastern part but its source rock is yet not known.

From the diagenetic point of view, the hydrocarbon generation and migration is undoubtedly the last diagenetic stage, which affected the Jdeir Formation. The decreasing of $CO_2$ during thermal maturation of the organic matter with the source rocks increased the dissolution diagenetic processes and consequently enhanced the formation of the secondary porosity.

## SUMMARY AND CONCLUSIONS

Petrographic evidence reveals that diagenesis of the Jdeir Formation was complex and included: the marine phreatic (micritisation and fibrous rim cement), meteoric phreatic (equant sparry calcite, drusy cement, neomorphism, dissolution and syntaxial overgrowth), and burial diagenesis (coarse blocky calcite cement, fractures, stylolites, silicification and hydrocarbon).

The result of different diagenetic histories reflects the variation in the amount and kind of porosity within the formation. Concentration of calcite spar, fracturing, compaction and pressure solution caused porosity destruction. Porosity in the reservoir is complex and contains primary and secondary types. These different types may have been modified by solution and cementation.

## ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to the Petroleum Research Centre for the Financial support. Thanks are also extended to N.O.C. for the permission to publish this paper. Dr. J.M. Anketell gave helpful advice during the work. He also critically reviewed the first draft of the manuscript and offered many suggestions.

## REFERENCES

Bathurst R.G.C., 1964. The replacement of aragonite by calcite in the molluscan shell wall. In: IMBRIE, J. and NEWELL, N.D. (Editors), *approaches to palaeoecology*, Wiley and Sons, New York, p. 357–376.

Bathurst R.G.C., 1966. Boring algae, micrite envelope and lithification of molluscan biosparites. *Geological Journal*, 5: p. 15–32.

Bathurst R.G.C., 1975. *Carbonate sediments and their diagenesis.* Elsevier, Amsterdam, 2nd Edition, 658p.

Becher J.W. and Moore C.H., 1979. The Walker Creek field: a Smackover diagenetic trap. In: Moore, C.H. (Editor), *Geology of carbonate porosity.* Am. Assoc. Petrol. Geologists continuing education, course notes series #11, p. A24–A46.

Benelli F., Mcavaggion M. and El Ashuri O. 1985. *Oil and gas habitat in concession NC41.* Agip N.A.M.E., Tripoli. (Unpublished report).

Bernasconi A., Noguera A.M. and Poliani G., 1984. *Sedimentology, petrography and diagenesis of Metlaoui Formation at the Bouri oil field.* Agip N.A.M.E., Tripoli. (Unpublished report).

Bishop W.F., 1975. Geology of Tunisia and adjacent parts of Algeria and Libya. *Bull. Am. Assoc. Petrol. Geologists*, 59: p. 413–450.

Choquette P.W. and Pray L.C., 1970. Geologic nomenclature and classification of porosity in sedimentary carbonates. *Bull. Am. Assoc. Petrol. Geologists*, 54: p. 207–250.

Dunnington H.V., 1967a. Aspects of diagenesis and shape change in stylolitic limestone reservoirs. *7th world petroleum congress*, 2: 339–352.

Etourbi I.Y., 1989. *Study of the main facies of the Farwah Group (Late Paleocene-Early Middle Eocene) of the Northwestern Libya offshore.*, Unpubl. M.Sc. thesis, University of Manchester.

Flugel E., 1982. *Microfacies analysis of limestones.* Springer-Verlag, Berlin-Heidelburg-New York, 633p.

Folk R.L., 1965. Some aspects of recrystallisation in ancient limestones. *Soc. Econ. Palaeontologists Mineralogists, Spec. Publ.*, 13: p. 14–48.

Folk R.L., 1974. The natural history of crystalline calcium carbonate: effect of magnesium content and salinity. *J. Sediment. Petrol.*, 58: p. 40–53.

Hammuda O.S., Sbeta A.M., Mouzughi A.J. and Eliagoubi B.A., 1985. Stratigraphic Nomenclature of the northwestern offshore of Libya. *The Earth Sciences Society of Libya*, Tarabulus, Libya.

Kendall C.G.St.C. and Skipwith Sir P.A. d'E., 1969. Holocene shallow water carbonates and evaporite sediments of the Khor and Bazam, Abu Dhabi, southwest Persian Gulf. *Bull. Am. Assoc. Petrol. Geologists*, 53: p. 841–870.

Kobluk D.R. and Risk M.J., 1977. Micritisation and carbonate-grain binding by endolithic algae. *Bull. Am. Assoc. Petrol. Geologists*, 61: p. 1069–1082.

Land L.S., 1971. Phreatic versus meteoric diagenesis of limestones: Evidence from a fossil water table in Bermuda. In: Bricker, O.F., (Editor), *Carbonate cements.* John Hopkins Press, Baltimore, MD, pp. 133–136.

Longman M.W., 1980. Carbonate diagenetic textures from near-surface diagenetic environments. *Bull. Am. Assoc. Petrol. Geologists*, 64: p. 461–487.

Longman M.W., 1982. *Carbonate diagenesis as control on stratigraphic traps (with examples from the Williston Basin)*, Education course note series #2. Am. Assoc. Petrol. Geologists, Tulsa, Okla., 159pp.

Nicholas R.A.H., 1967. The sparite complex: Eosparite V. Neosparite. *J. Sediment. Petrol.*, 37: p. 1247–1248.

Sbeta A.M., 1984. *Sedimentology of the Eocene rocks of the offshore-Northwestern Libya.* Internal report, N.O.C., Libya. (Unpublished report).

Schofield K., 1982. *Sedimentology of the Woodale limestone Formation of Derbyshire.* Unpubl. Ph.D. thesis, Univ. Manchester.

Scoffin T.P., 1987. *An introduction to carbonate sediments and rocks.* Chapman and Hall, New York. 274p.

Sultan A.A., 1985. *Petrography, sedimentology, diagenesis and reservoir characteristics of the Shuaiba and Kharaib Formations (Barremian-Mid Aptian) carbonate sediments of Abu Dhabi.* Unpubl. Ph.D. thesis, University of South Carolina.

Wilson J.L., 1975. *Carbonate facies in the geological history.* Springer-Verlag, Berlin-Heidelburg-New York. 471p.