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Facies development and environments of Miocene reefal limestone, Wadi Hagul, Cairo-Suez District, Egypt

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With 6 figures

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Abstract: The reef limestones, of Langhian (Middle Miocene) age; were formed during regressive-transgressive episodes. They were subdivided into four main depositional facies: 1) fore-reef, made up of bioclastic marly limestone with broken skeletons and debris, 2) reef-core, constructed of a framework exclusively of branched colonies of *Porites* sp. coated by micrite submarine cements, 3) back-reef, consisted of friable limestone, rich in shell hash with flodded *Heterostegina praecostata* and, 4) beach and nearshore, made up of fossiliferous cros-bedded pebbly sandstone. The complete leaching and alteration of the original aragonitic scleractinian corals microstructure, and the cements into low Mg-calcite mosaic by fresh water in the subaerial environment, is the main diagenetic process which affected the reef. Micrite is the most important constituent in the reef-core sediments (40-70 %) and allover the sequence in general.

Zusammenfassung: Die mittelmiozänen Riffkalke wurden während regressiv-transgressiver Phasen gebildet. Sie lassen sich in 4 Fazies gliedern: 1. Vorriff, aus bioklastischen Mergelkalken; 2. Riffkern, aus einem Gerüst verzweigter *Porites*-Kolonien mit submariner Zementkruste; 3. Hinterriff, aus lockerem Kalk mit Schalenresten und *Heterostegina praecostata*; 4. Ufernähe und Strand, mit fossilreichen, schräggeschichteten, geröllführendem Sandstein. Haupt-Diagenese-Vorgang ist die Auslaugung sowie die Umwandlung der ursprünglichen aragonitischen Korallen-Strukturen und der Zemente in Niedermagnesium-Kalzit in subaerischer Umgebung. 40-70 % des Gesteins haben mikritische Korngröße.

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Introduction

Two coral reef bodies are recorded from the early Middle Miocene sediments exposed in Wadi Hagul, Cairo-Suez district, Egypt (Fig. 1). They are well exposed at 25 km and 27 km from the northern entrance of the asphaltic road of Wadi Hagul, just beside the road. The coral reef bodies form symmetric mounds, up to 13 m high, and 90-150 m across (Figs. 2 and 3/A), with their long axis trending northwest-southeast (i. e. of clysmic trend).

The objectives of the present work are the study of the genesis of these coral reef structures, their development, depositional environment, paleogeographic setting, and the diagenetic processes affecting them.

Previously known Miocene reefs from the Cairo-Suez district and the area west of the Gulf of Suez are of Early to Middle Miocene age. These reefs and their associated skeletal sediments have been designated as nullipore rock (MOON & SADEK, 1923), reefal limestones (SADEK, 1965 and ABUL ELA, 1968), or algal limestone (EL-BELASSY, 1986). ABU KHADRAH et al. (1993) pointed out that these reefal limestones may represent biogenic structures such as biostroms (or bioherms) and small patches of coral buildups.

Stratigraphic setting

The Miocene sediments are exposed on both sides of the Cairo-Suez road. The stratigraphy of these sediments in the study area has been dealt

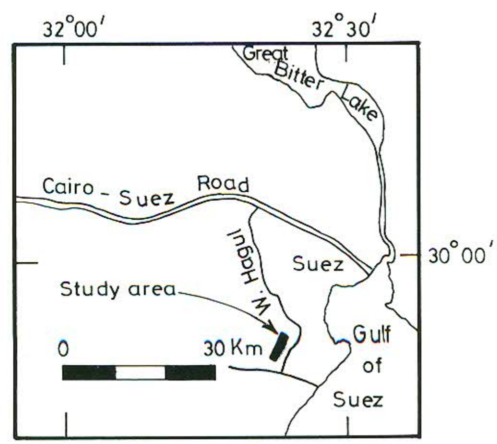

Fig. 1. Location map of the study area.

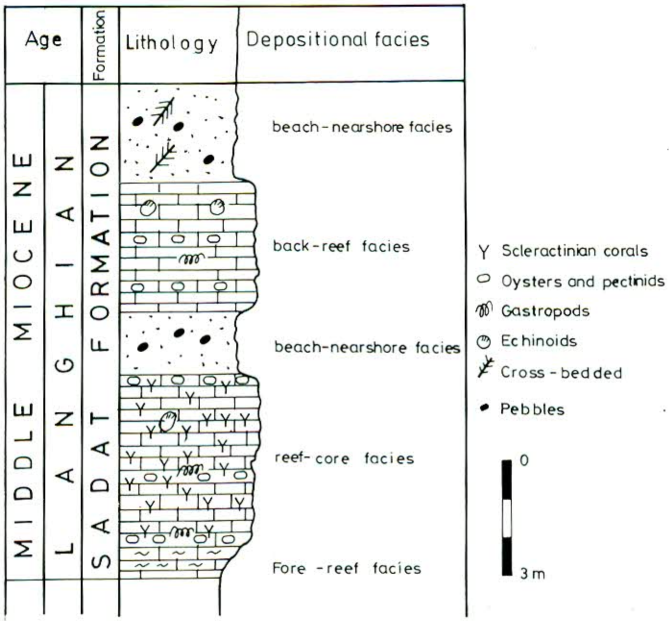

Fig. 2. Depositional facies of the studied reefal limestone and their characteristics.

within numerous previous works, including: SADEK (1965), ABDALLAH & ABDELHADY (1966), CHERIF & YEHIA (1977), ABU KHADRAH et al. (1987, 1993), HAMZA et al. (1990).

The marine Miocene sequence in the study area is currently classified into two rock units, from base to top as follow:

1. Sadat Formation (ABDALLAH & ABDELHADY 1966): It is of late Burdigalian to early Langhian age, mainly composed of white, pale yellow, coralline limestone, partly siliceous at the base, with few marl interbeds. The Sadat Formation unconformably overlies the coarse clastics of the Upper Eocene and represents the oldest Miocene unit in the area.

2. Hommath Formation (ABDALLAH & ABDELHADY 1966): It is of late Langhian- Serravalian age, overlies conformably the Sadat Formation, and is mainly composed of limestone, yellow friable sandstone, yellow brown sandy marl, with interbeds of calcareous grits in its lower part.

The studied sections are consisting of the following stratigraphic sequence (Fig. 2), from base to top as follow:

1. Coralline reefal limestone — up to 5 m
   with scleractinian colonial corals, oysters, pectinids, gastropods, echinoids, bryozoans and algae.
2. Pebbly sandstone — up to 2 m
   ill sorted with shell fragments
3. Fossiliferous limestone — up to 4.5 m
   with less scleractinian corals, oysters, pectinids, gastropods, echinoids, bryozoans and algae.
4. Fossiliferous sandstone — up to 4 m
   cross-bedded, pebbly, with fragmented shells

According to their stratigraphic position, the studied sections represent the uppermost part of the Sadat Formation, and are therefore of Langhian age. This age assignment is confirmed by the presence of the following fossils: *Heterostegina praecostata, Heterostegina costata*, and *Borelis melo*.

Depositional facies and environments

On the basis of field observations and the study of thin sections, four facies belts were distinguished within the studied reefs: fore-reef, reef-core, back reef and beach.

1. Fore-reef facies

It represents the lowermost part of the sequence, its base is not exposed. It consists of 70 cm thick yellow marly limestone, laminated, with disarticulated larger *Ostrea* sp., turreted gastropods, pectinids, corals and echinoids. The coral colonies are relatively rare in comparison to the reef-core and consist exclusively of poritid corals. In thin section fore-reef sediments are represented by bioclastic, foraminiferal (partly planktonic) wackestone and

Fig. 3
A - General view of the reefal limestone in the study area. **B** - Coralline limestone (reef-core sediments), with empty cavities of altered coral branches. **C** - Molds of dissolved coral branches. **D** - Large oyster and pectinids in the reefal limestone. **E** - Bioclastic limestone (back reef sediment) in the lower, followed abruptly by sandstone. **F** - Cross-bedding in the sandstones of the beach facies.

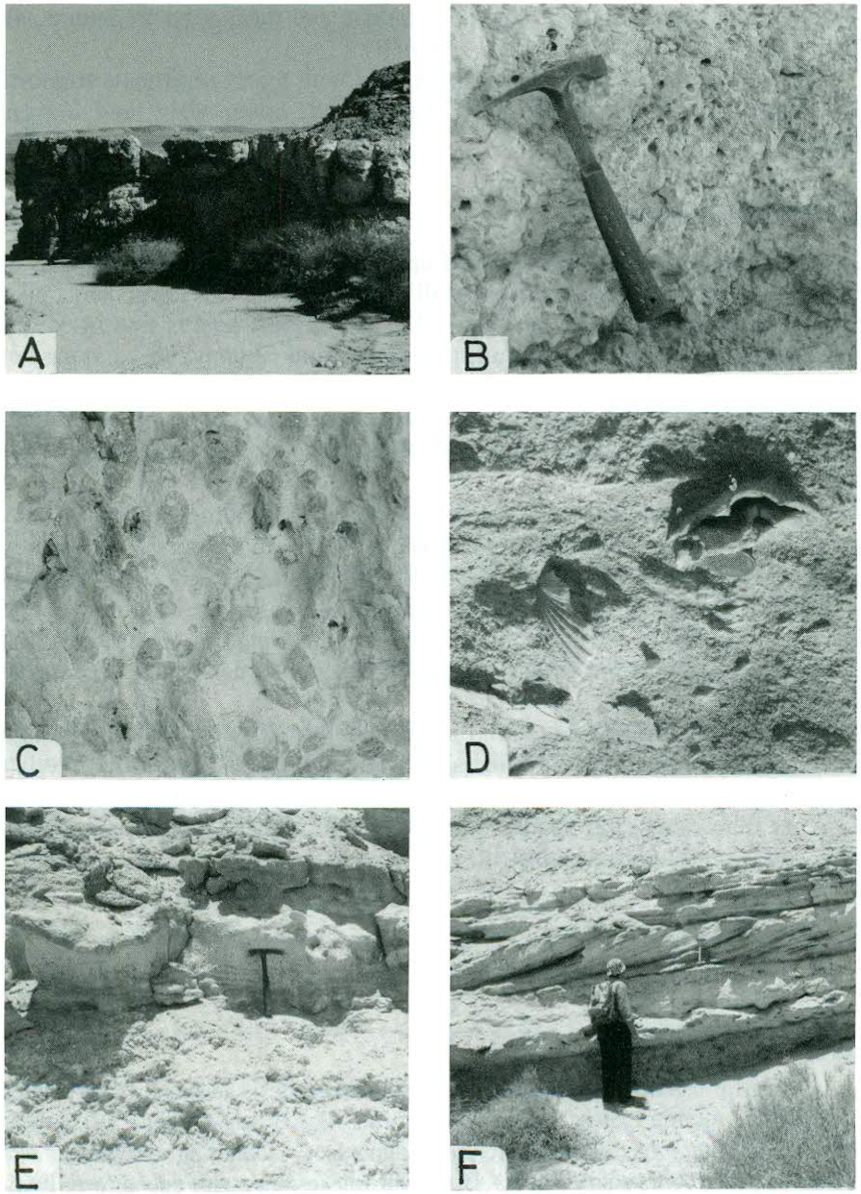

Fig. 3 (Legend see p. 216)

floatstone with fragments of corals, red algae and molluscan fragments, all embedded in micritic matrix (Fig. 4/B, 6/B).

The close association of the algal deposits with marly sediments supports the deposition in deeper fore-reef waters with lower wave and current energy.

2. Reef-core facies

The sediments of reef-core followed upward the fore-reef. They consist of 4-5.50 m thick, very hard white coralline limestone. The lower and upper part is rich in large *Ostrea* sp. (Fig. 3/D). The middle part is rich in corals, with echinoid, byrozoans, pectinids (*Pecten* sp. and *Chlamys* sp.) and gastropods, all in their life-position. The corals are represented exclusively by *Porites* sp., except the presence of small colonies of *Acropora* sp., *Stylophora* sp. All coral branches are dissolved and leaving only their molds (Fig. 3/B, C).

The corals in the core-reef are the major frame-building organism. They are badly preserved and constituting about 50 % (in volume), dominantly constructed of small nearly monospecific thickets and cylindrical branches or sticks of *Porites* sp. Coralline red algae are of subsidiary importance, and playing a significant role in the construction of the reef core, where they bind and connect coral colonies and other skeletal constituents into a coherent mass.

Encrusting foraminifers and bryozoans also form binding crusts, although to a lesser extent than the coralline algae. The molluscs, echinoids and other fauna found in the reef-core sediment act as essential rock forming constituents. The remaining spaces between the framework buildup are filled with micrite and internal sediment.

Fig. 4

A - Bioclastic echinoid wackestone, the echinoid spine is leached at the center, embedded in micrite matrix; reef-core sediments. **B** - Bioclastic algal wackestone with branch of *Lithophyllum* sp., fore-reef sediments. **C** - Coralline wackestone with *Porites* sp., reef-core sediments. **D** - Bryozoan wackestone, with adeoniform bryozoan colonies and internal sediment, reef-core sediments. **E** - Bioclastic wackestone, note the planktonic foraminiferal biomorpha in the upper left part and other bioclasts with quartz grains; reef-core sediments. **F** - Bioclastic sandy grainstone with algal rhodolites and fine to medium poorly sorted quartz grains; back-reef sediments.

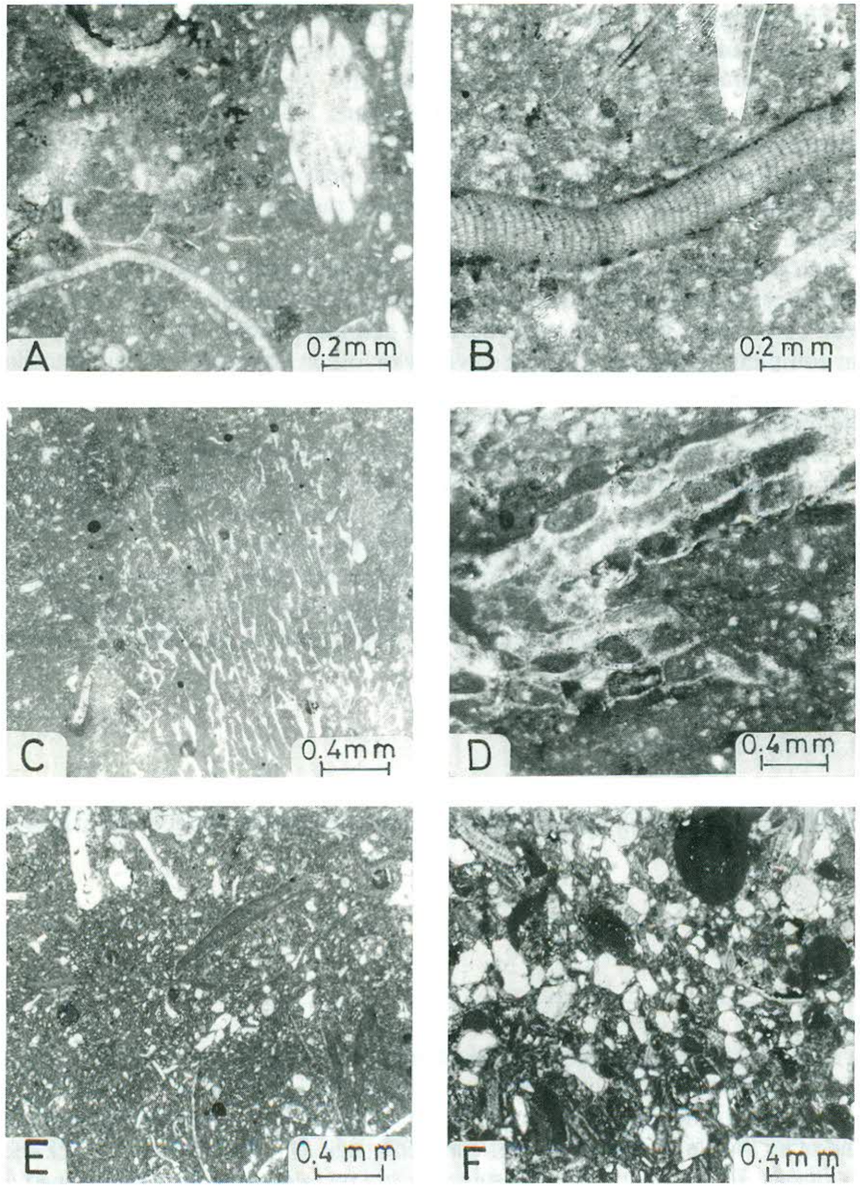

Fig. 4 (Legend see p. 218)

The terrigenous clastics are most abundant in the uppermost part of the reef-core sediment, where scattered quartz grains occur.

In thin sections, the reef-core sediments are represented -in descending order- by sorted to poorly sorted wackestones, floastones, packstones, and framestones in the form of coralline (Fig. 4/C, 5/H, I, 6/A), bioclastic (Fig. 4/E), bryozoan (Fig. 4/D), oyster (Fig. 6/D), peloidal (Fig. 5/A, F) and foraminiferal (Fig. 4/E), skeletal grains. Most of them are embedded in micrite matrix.

Micrite is the most important feature especially in the reef-core, and in all sequences in general. Micrite coatings constitute as much as 40-70 % of the reef core. They have a poorly defined peloidal texture, appear as partial or complete filling of corallite cavities or other organism interspaces like bryozoan zooecia and gastropod whorls. In the case of partial void filling, the micrite form distinct geopetal fabrics.

These micrite may originated through the common process of deposition and entrapment of lime mud in coral cavities or derived from the calcified algal filaments (Buchbinder, 1977), which were first described by Schröder (1972) from Recent corals of the Bermuda reefs.

The micrite cement is quantitatively important within the Miocene carbonates (Aissaoui et al. 1986). Similar coatings have also been observed in Miocene reef of Nijar (Dabrio et al. 1981) and in the Recent reefs of Panama (Macintyre 1977).

3. Back-reef facies

The back-reef sediments are represented by 3.5 m thick, white yellowish, friable limestone, rich in shell hash at the base and top, flooded with *Hetero-*

Fig. 5

A - Peloidal packstone with fine to medium pellets with algal and other bioclasts; reef-core sediments. **B** - Foraminiferal packstone with *Heterostegina praecostata* and other bioclastic fragments; back-reef sediments. **C** - Bioclastic packstone with corals and other bioclastic fragments, reef-core sediments. **D** - *Borelis melo* in back-reef sediments. **E** - Leached echinoidal spine in reef-core sediments. **F** - Enlarged part of A. **G** - Embryonic gastropod shell filled with micrite and quartz grains; reef-core sediments. **H** - Coralline framestone of *Porites* sp., the coral cavities are filled with micrite; reef-core sediments. **I** - Enlarged part of H, the original aragonitic structure of the coral is altered by diagenesis into mosaic calcite.

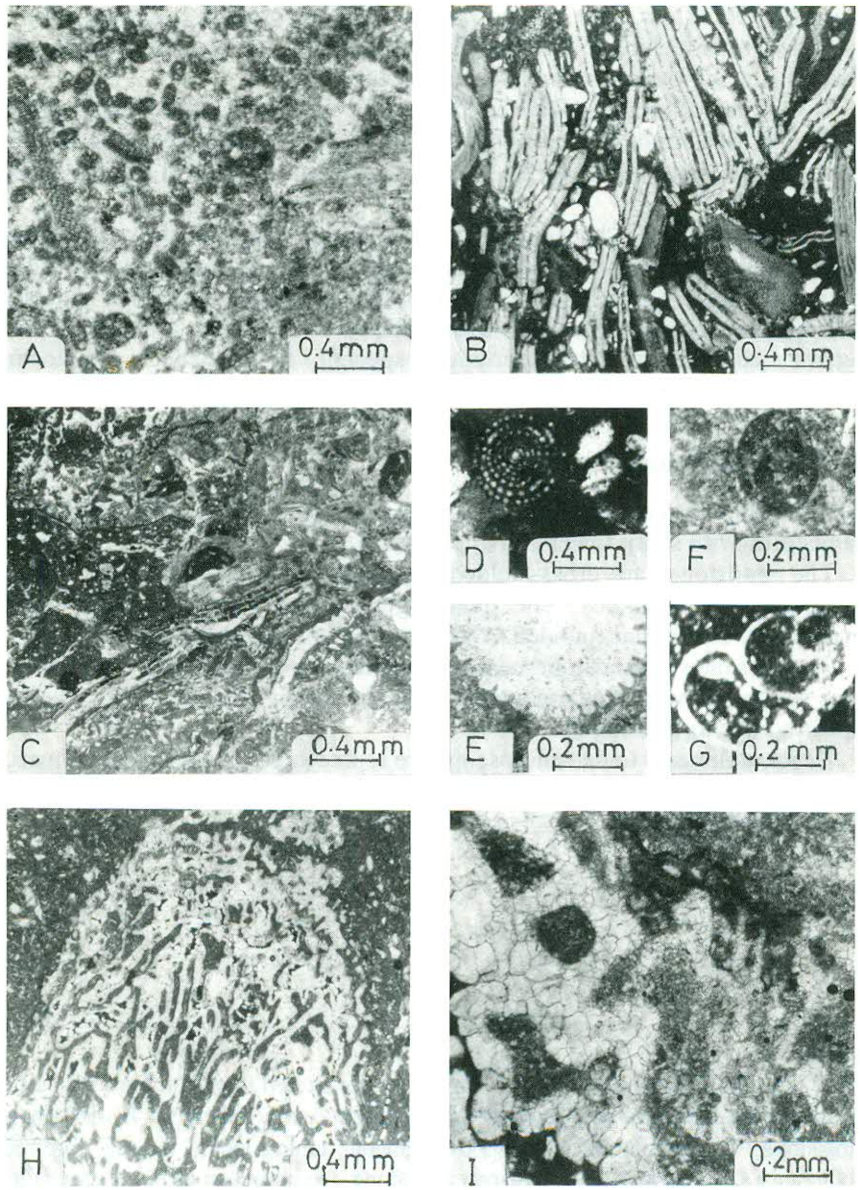

Fig. 5 (Legend see p. 220)

stegina praecostata. The middle part is characterized by bivalves (*Ostrea* sp.), pectinids, echinoids are chiefly clypeasterids which inhabit soft substrates. Also bryozoans and algae are present.

Two zones of well-rounded pebbles are present in the lower and middle parts. The rich foraminiferal population is acting as sedimentary baffler for the carbonate mud, which forms the matrix of many biomicrities in the study area.

The microfacies of back-reef belt are foraminiferal packstone, bryozoan foraminiferal floatstone, coralline wackestone and occasionally sandy algal grainstone (Fig. 4/F, 5/B, 6/C). The presence of clastic sediments (pebbles and quartz grains) associated with back-reef sediments segregated into separate zones indicate transportation especially by hurricanes and storms (MONTADERT et al. 1978) during regression.

4. Beach and nearshore facies

Beach sediments consist of about 5 m thick friable, brownish yellow, pebbly sandstone, with sharp lower and upper contacts.

The sandstones are cross-bedded, fossiliferous with shell hash, oysters, pectinids and echinoids. The quartz grains are fine to medium sized, moderately sorted and rounded. All are cemented by sparitic cement.

The presence of sandstone-beach sediments above the reef-core and back-reef sediments with sharp contacts indicate abrupt change in sea level or uplifting due to tectonism.

Beach sediments under microscope are represented by fossiliferous quartz arenite (Fig. 6/E, F). The fossils are elongated shell fragments, algal fragments and foraminifers.

Fig. 6
A - Coralline framestone, the aragonitic cement is altered to calcite mosaic and the coral cavities are filled with internal sediments; reef-core sediments. **B** - Bioclastic floatstone, with corals and pelecypod fragments, embedded in micrite; fore-reef sediments. **C** - Foraminiferal bryozoan floatstone, the bryozoan chambers are filled with micrite; back-reef sediments. **D** - Oyster floatstone, the oyster fragments show their original microstructure; reef-core sediments. **E** - Fossiliferous quartz- arenite with pelecypod and foraminiferal fragments; beach and near shore sediments. **F** - Enlarged part of E.

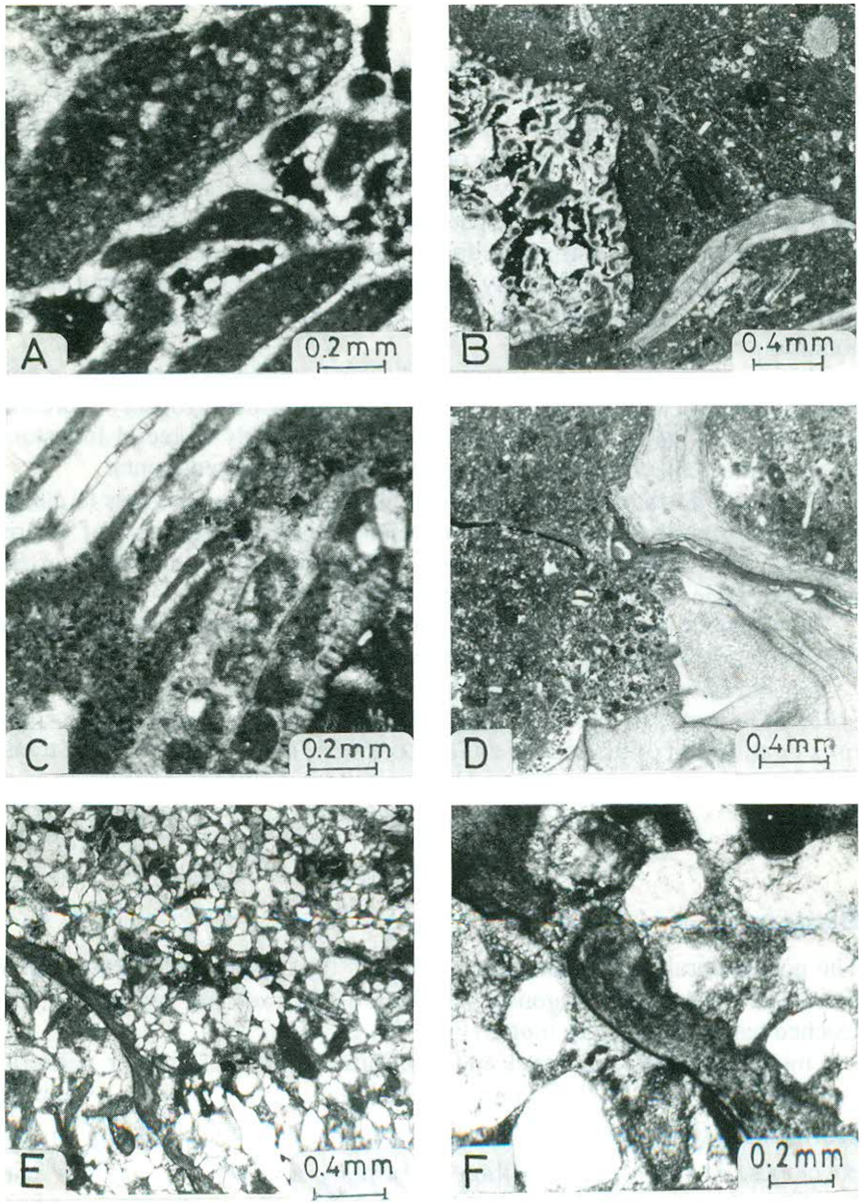

Fig. 6 (Legend see p. 222)

Genesis and development

During Miocene times the Tethys was a tropical sea, and coral reefs flourished in its shallow waters. They did not form a continuous fringing reef but rather occurred as isolated buildup, may be as barrier islands, parallel to the paleoshoreline. By tracing the occurrences of the nullipore rocks on the paleogeographic map given by SAID (1990, fig. 24.14, page 481), it is obvious that they are distributed parallel to the paleoshore line, which has a Clysmic trend, and are forming a line of barrier reef islands.

The development of the early Middle Miocene reefal limestone in the study area was essentially due to the existence of favorable shallowing conditions.

The sequence (Fig. 2) is deposited during regressive- transgressive episodes. It begins with bioclastic marly sediments, which probably represent deep fore-reef facies, and changes upward regressively to reefal limestone (reef-core facies), which represent initial shallow water sediments.

The reefal limestones of the reef-core change abruptly upwards to clastic sandstones (beach facies) which presumably represent the peak of the regression. The sandstones are in turn overlain by skeletal limestone of the back-reef facies seemingly during a new transgression.

The skeletal limestone is abruptly overlain by sandstone clastic sediment (beach facies), indicating a regressive phase.

Transgressive and regressive sequences within the same reef unit may occur as a result of erosional and constructional processes during slight rises or stillstand of the sea-level (DULLO 1983). These regressive and transgressive patterns are also governed by terrigenous sediment input (VAIL et al. 1984).

Diagenesis

The poritid corals do not show any relicts of the dark centers of the sclerodermites. The original aragonitic structure of the wall and septa are totally leached leaving the empty molds (Fig. 3/B, C).

Emergence above sea-level and exposure to the fresh water subaerial environment, lead to the complete leaching of the coral wall and the previously deposited aragonite- cement, leaving only supporting micrite envelopes. The subsequent filling of primary and secondary voids with low-Mg calcite mosaic (Fig. 5/I) follows this process.

The complete alteration of poritid corals by diagenesis is related to their microstructure. They consist of perforated walls and septa (high porosity and permeability). This increases the reactive surface area and the coral walls

were subjected to intensive flushing by meteoric water leading to the destruction of the original microstructure.

Most pelecypod fragments are leached and their molds are filled with low Mg- calcite. Few of them, such as oysters, show their original microstructure (Fig. 6/D).

Echinoid fragments have dusty inclusions, and external syntaxial cement is also common. Some fragments transformed into spary calcite loosing their mono-crystal characteristics (Fig. 4/A, 5/E).

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