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PROGRESSIVE DIAGENETIC SEQUENCE OF PLEISTOCENE CORAL REEFS IN THE AREA BETWEEN QUSEIR AND MERSA ALAM, RED SEA COAST, EGYPT

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Pleistocene coral reefs along the Red Sea coast occur in three stratigraphically different units. They form terraces of different elevations above the present sea level and are characterized by fringing reef types, comparable to their recent counterparts. The three reef units show a progressive diagenetic sequence. The lower unit (youngest) is characterized by almost unaltered primary microstructure. Meteoric leaching in only documented is the form of open trabecular centers of coral skeletons. Marine micritic linings of aragonitic biota are frequent features. marine cements of aragonite and high-magnesium calcite (HMC) are well-preserved. The middle unit is characterized by an increased leaching of the trabecular centers. Low magnesium calcite (LMC) started to prcipitate, while aragonitic biota show an intense leaching. They are frequently recorded as molds with meteoric lining. The upper unit (oldest) is characterized by complete loss of any primary microstructure, a continuous reduction of biota from the fossil record, an increase in meteoric LMC cements and a decrease in porosity. A number of stable isotope data from selected coral species underline these changes.

INTRODUCTION

Several authors discussed the stratighraphy, paleontology, diagenetic alteration and tectonic evolution of the Tertiary and Quaternary deposits along the western and the eastern side of the Red Sea Gulf of Suez and Gulf of Aqaba e.g. Beadnell (1924), El- Akkad & Dardir (1966), Friedman (1968), Hassan et al. (1975), Gvirtzman & Friedman (1977), Gvirtzman et al. (1992), Dullo (1983, 1984, 1986, 1990), Abou- Khadrah & Abdel Wahab (1984), Ali (1985), Abou Khadrah & Darwish (1986), Bayer et al. (1988), Al-Rifaiy & Cherif (1988), Purser & Hotzl (1988), Youssef (1988), M'Rabet et al. (1989), Plaziat et al. (1989), El-Sorogy (1994),

Hoang & Taviani (1991), Strasser et al. (1992), Ahmed et al. (1993), Heiss et al. (1993), El -Moursi & Montagioni (1994), Ziko & El-Sorogy (1995), and El-Asmar & Attia (1996).

Dullo (1986) recorded three terrace units at Sharm Al - Harr area, Red Sea coast, Saudi Arabia, probably expressing major sea level highs. On the Jordanian coast of thr Gulf of Aqaba, Al-Rifaiy and cherif (1988)recognized three major cycles of form ossil coral reef development in the form of seven distinct terraces, related to eustatic changes in sea level, coastal erosional processes and faulting.

On the Sinai coast of the Gulf of Aqaba, Gvirtzman et al. (1992) recorded three emerged fossil reefs, comparable to the global oxygen isotope stages 9, 7 and 5. In the Quseir-Ghadir district of the northwestern Red Sea, Ahmed et al. (1993) studied five coral reef terraces, developed locally during the Quaternary period during transgressive phases.

The study area represents a strip of about 125 km length along the Red Sea coastal plain of Egypt, extending from Quseir in the north to Mersa Alam in the south (Fig. 1). Three reefal units in the form of six morphological terraces were recognized, form these reefal units are separated from each others by conglomerates, quartz sands and gravels (Fig. 2). the width of thses reefs range from 150 to 600 m. These reffs forming discontinuous strips along the coast, interrupted in front of the wadi mouthes, where they are replaced by gravel of alluvial fans (P1.1/E).

lithologically these reefs are formed of coral algal limestone. In some localities a transitions to mixed carbonate - siliciclastic rocks are developed, indicating deposition of considerable continental siliciclastic influx transported to the coastal area by numerous wadis fed by the red Sea movntains in the reef areas. The primary frame-builders are scleractinian corals and few hydrozoans. The secondary binders and encrusters are coralline algae, foraminifers. alcyonarian corals, and few bryozoans, as well as bivalves and gastropods. The latter represent the marco vagile benthos together with echinoderms.

The vertical development of the different reef units can be studied in wadi cuts through the bodies. Both lower and upper reef units are characteried by a pure regressive facies pattern (Fig. 2), while the middle unit shows a transgressive pattern at its base. However, the insight into

vertical facies evolution in some terraces is difficult to see in the field because the sections are mostly covered by gravel accumulations, which even overtop the marine sequences as well.

The prime objective of the present study is to document the progressive diagenetic alteration of the Pleistocene coral reefs on the western side of the Red Sea coast. It is essential to base this kind of study on selected biogenic skeletons of known microfabric, therefore, the scleractinian corals *Porites lutea* and *Goniastrea pectinata* have been selected.

MATERIALS AND METHODS

Seven stratigraphic sections have been measured and sampled from Sharm El-Bahari, Ras Abu Awied, Mersa Umm Gheig, Mersa Mubarak, Mersa Abu Dabbab, Mersa Shagra and Mersa Alam (Fig. 1). 210 thin sections were prepared to establish the quantitative composition of skeletal and non skeletal grains (point counting). Most coral sample were very porous, therefore they were impregnated with resin under vacuum for preparation. Thin sections of corals were stained for identification of aragonite, using Feigl's solution (Friedman, 1959) and for high-magnesium calcite using titan yellow (Winland, 1971). Microstructure and diagenetic alterations of *Porites lutea* and *Goniastrea pectinata* were examined by means of thin sections and SEM. In SEM fresh fractures, cleaned with pressured air have been used. 18 samples of corals were subsampled for carbon and oxygen isotopes.

GEOLOGIC SETTING AND BIOTIC COMPOSITION

Lower reef unit (youngest):

It is easily traced allover the study area, just along the Red Sea coast (P1.1/A), with width 50 to 60m . It exhibits three prominant morphological steps at elevations of 1.5, 3.5 and 7.5 m respectively above the present sea level. The lower unit rests on 0.45 to 1.25 m thick, varicolored conglomerate, composed of pebbles and cobbles, some of them reach the boulder size. the most aboundant scleractinians (P1.1/B,C) are *Porites lutea, P. solida, Goniastrea retiformis, G. pectinata, Favia pallida, F. speciosa, Favites flexuosa, Platygyra daedalea, Stylophora* pistillata, *Galaxea fascicularis, Acropora pharaonis, Fungia fungites, Pocillopora*

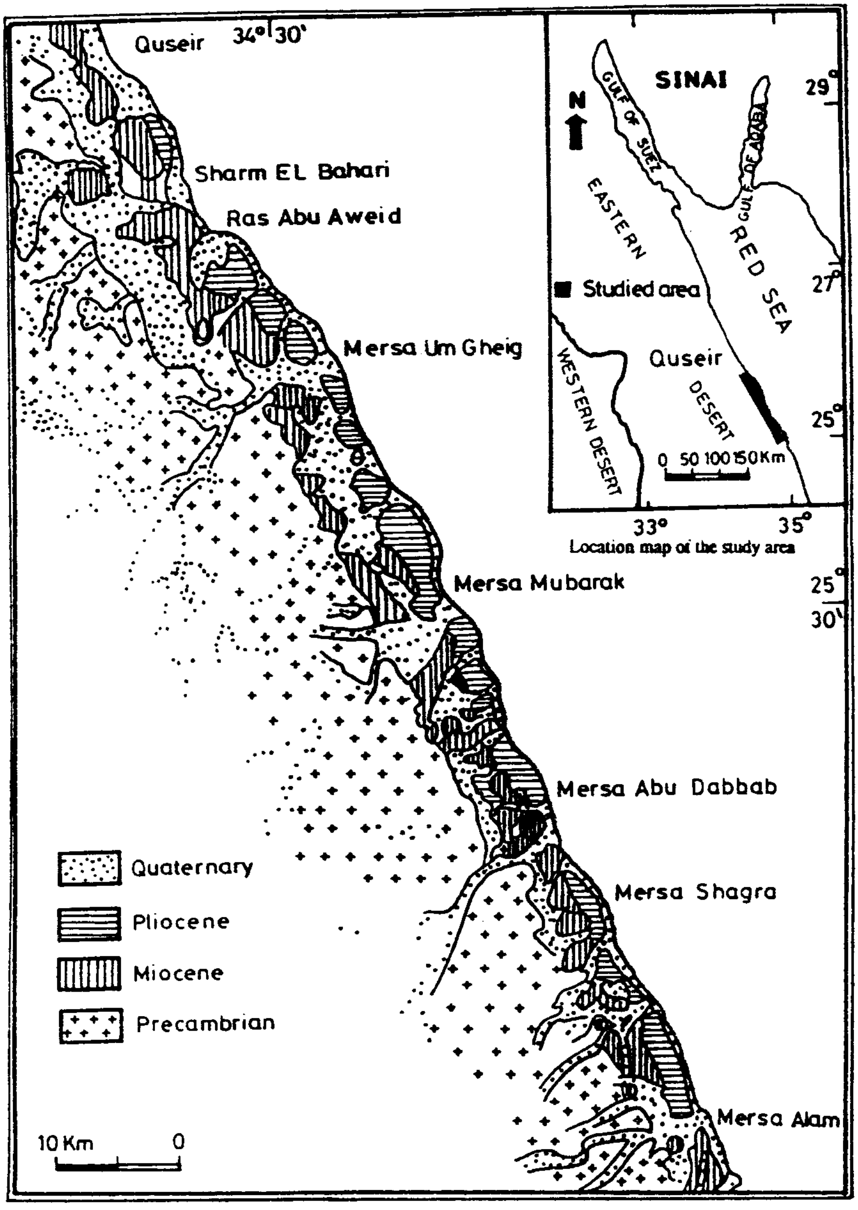


Fig. 1: Simplified geological map of the study area (after the Egyptian General Petroleum Corporation 1987).

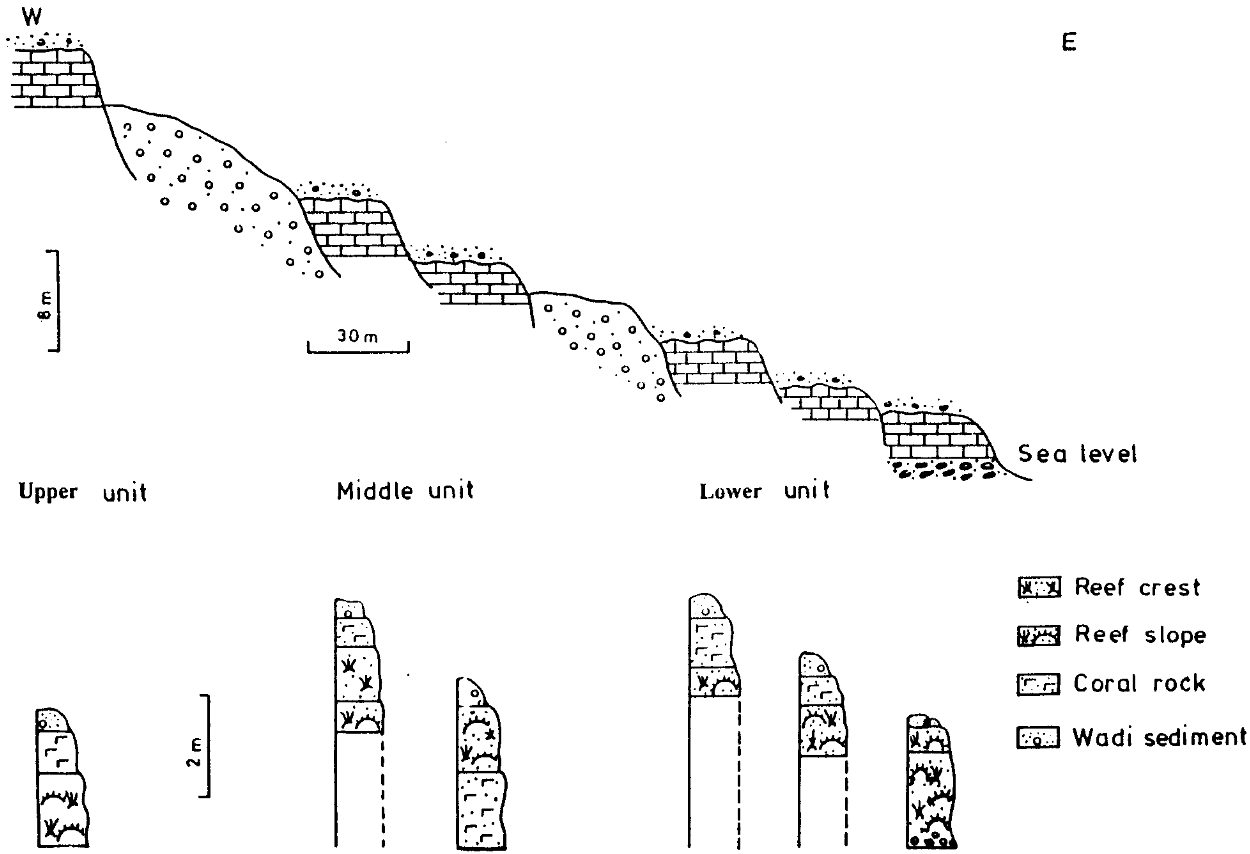


Fig. 2: Generalized sketch diagram and vertical zonation of the Pleistocene reefal units exposed in the study area.

damicornis as well as preserved pelecypods, gastropods and echinoides such *Periglypta reticulata, spondylus (S.) gaedropus, Dosinia (D.) radiata, Turbo (Batillus) radiatus and Echinometra mathaei*. The vertical sequence shows shallowing upward development (Fig. 2), starting at the base with a coral assemblage of upper reef slope commuinty and overlained by reef crest facies, which grades into the coral rock zone. The sequence is finally covered with sands and alluvial fan deposits. This shallowing upward facies development indicates diminishing water depth, which was controlled by a combination of changes in sea level, subsidence rate and sediment accumulation (Strasser et al., 1992)

Middle reef unit:

It comprises two morphological terraces of about 8 m thick with elevations of 14 and 19 m above present sea level and with tectonic vertical displacement of 5m. The most abundant fossils (P1.1/F,G) are *Porites lutea. Goniastrea retiformis, G. pectinata, Favia pallida, Favites flexuosa, Platygyra daedalea, Leptoria phrygia, Acanthastre echinata, Lobophyllia corymbosa, Stylophora pistillata, Galaxea fascicularis, Acropora pharaonis, Fungia fungites, Pocillopora damicornis, Millepora* sp., *Periglypta reticulata, spondylus (S.) gaedropus, Cardites antiquata, Dosinia (D.) radiata, Turbo (Batillus) radiatus* and *Magillus antiquus*. the depositional sequence shows a transgressive phase at the base and is again regressive towards the top. It starts with coral community of coral rock zone, followed with reef crest and upper reef slope community and then grades regressively again to coral rock zone facies. Finaly it is overlain with wadi gravels. The obvious contradicting facies patterns (transgressive and regressive) result from erosional and conatructional processes during slight rises or a still stand of sea level, also governed by terrigenous sediment input (Dullo 1983, Strasser & Davaud 1986, Vail et al., 1984).

Upper reef unit (oldest):

It overlies unconformably the Pliocene rocks (P1.1/D) which include frequent pectinids (*Chlamys senatoria*) and irregular sea-urchins (*Clypeaster reticulatus* and *Laganum depressum*). It has an elevation of 33 m above the present sea level and forms only one morphological terrace of about 5m thick. The fossils are represented by badly preserved coral colonies. molluscan and echinoids shells such *Porites lutea, Favia pallida, Goniastrea pectinata, Fungia fungites. Trachycardium* (T.) *isocardia.*

Tridacna squamosa, *Heterocentrotus trigonarius*. The whole sequence of the upper reef unit is regressive and shown again a shallowing upward development. Also it is overlained with alluvial sands and gravels.

DIAGENESIS AND ISOTOPE ANALYSIS

The present study is based on quantitative analysis of skeletal and non skeletal grains (Fig. 3) and the diagenetic alteration of the primary composition in thin sections (point counting) depending on two coral species *Porites lutea* and *Goniastrea pectinata* (figs. 4 and 5).

Lower reef unit:

The investigated samples of *Porites lutea* and *Goniastrea pectinata* show no alteration of the primary micostructure (P1.2/A,F, P1. 3/A). Marine aragonite cement occurs as rods and needles, syntaxially grown on the trabecular structure (P1.2/B) and also on micrite envelopes. Peloidal Mg-calcite is also detected within parts of the coral skeleton. The micritic envelopes are casued by dissolution and reprecipitation of carbonate on the micron scale along perforations of endolithic organisms (Bathurst, 1971). The cryptocrystalline high-magnesium calcite and aragonite cement strongly suggest that early cementation occurred exclusively under marine environment (Folk, 1974).

Early meteoric leaching strats on the trabecular structure, which results in open trabecular centers (P1.2/C, P1.3/B). These leached cavities are rimmed by chalky layer of partly dissolved aragonite needles of sklerodermits. Few *Porites* shows minor leaching of the trabecular centers and newly formed blocky calcites (P1.2/D). This diagenetic pattern occurs especially in the upper terrrace of the lowcr reef unit. It may be related to superficial run off related to intergranular water movement.

Stable isotope values of samples from the lower reef unit (Fig. 6) ranging from +0.33 to +2.09 ‰ δ^{13}C PDB. and from -3.07 to -2.37‰ δ^{18}O PDB for *Porites lutes* and ranging from + 1.30 to + 2.10‰ δ^{13}C PDB and from -3.28 to -3.18 ‰ δ^{18}O PDB for *Goniastrea pectinata*. These isotope values are typical for normal marine limestone (Hudson 1977) and are comparable to the data obtained from corals in the youngest reef of southern Sinai (Strasser et al. 1982)

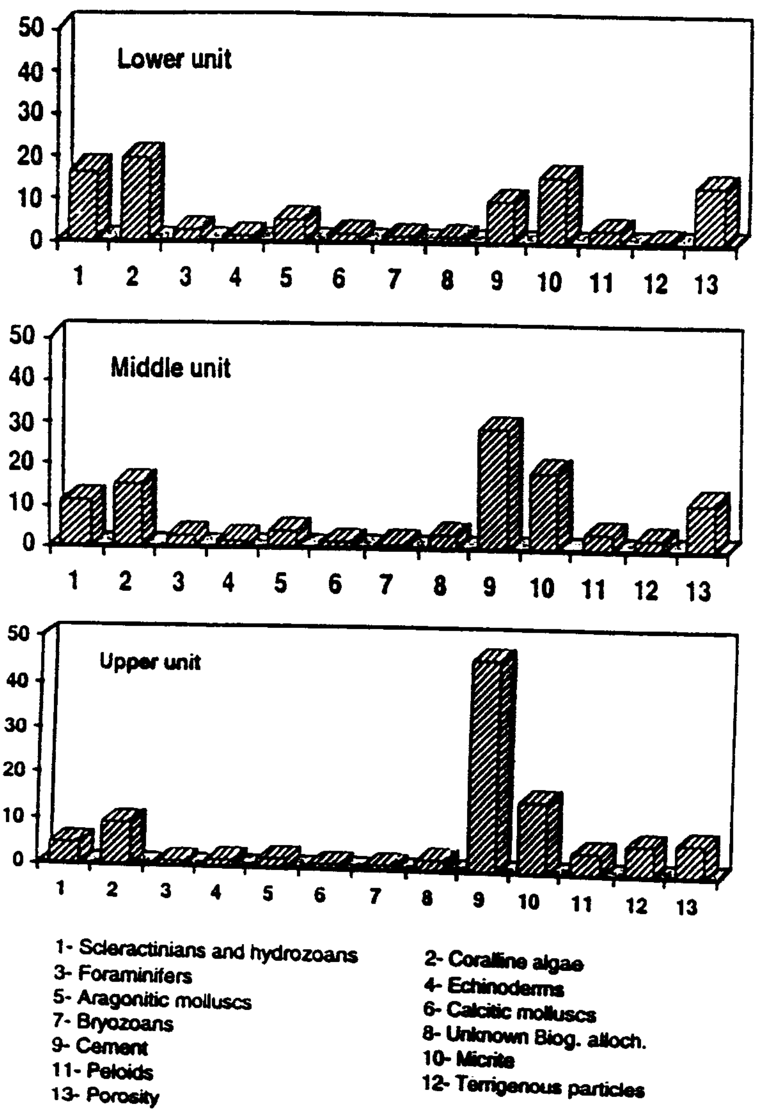
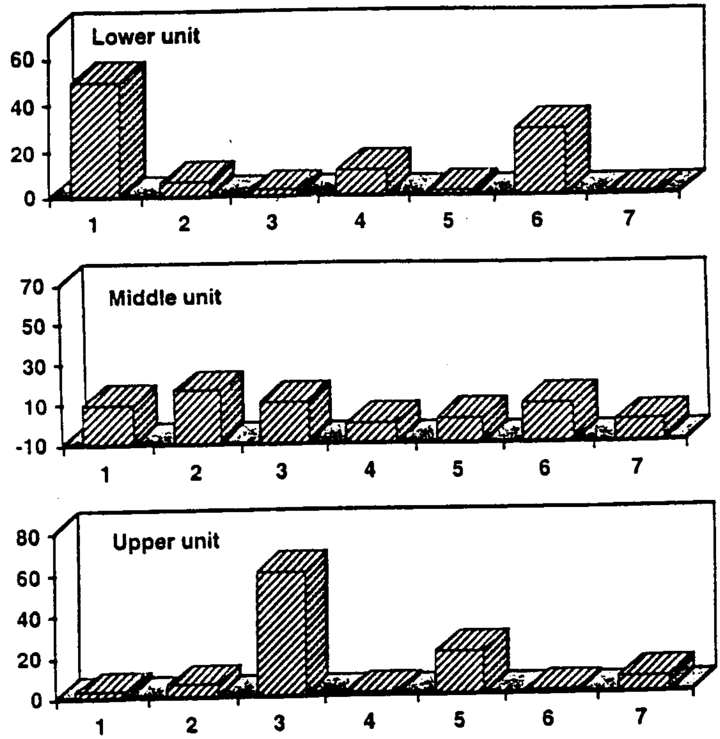


Fig. 3: Quantitative composition of skeletal, non-skeletal grains and cement for the three reefal units.



1- Unaltered microstructure 2- Leached trabecular center
3- Completely altered microstructure
4- Micrite linings with marine cement growing on them
5- Micrite linings with fresh water calcites (dog + blocky) growing on them
6- Marine cement 7- Terrigenous particles

Fig. 4: Quantitative composition of diagenetic fabrics of *Porites lutea* through the three reefal units.

Plate 1

Fig. A: General view of the lower unit at Sharm El-Bahari area.

Fig. B: Close up of A, showing collonies of *Goniastrea pectinata* (G) and *Favia pallida* (F) in their life position

Fig. C: Close up of A, showing large collonies of *Galaxea fascicularis* in the life position indicating upper reef slope zone.

Fig. D: The upper reef unit rests on conglomeratic bed (unconfermable surface). Mersa Abu Dabbab area.

Fig. E: Alluvial deposits which are replaced the coral reefs in front of the wadi mouthes.

Fig. F: *Millepora* sp., in the life position. Middle reef unit, Mersa Shagra area.

Fig. G: *Goniastrea pectinata* in the life position, Middle reef unit, Mersa Shagra area.

Plate 2

Fig. A: Unaltered microstructure of *Porites lutea* with the trabecular centers (T) lower unit, Sharm El-Bahari area. SEM.

Fig. B: Unaltered microstructive of *Porites lutea* with marine aragonite cements (M) occur as syntaxial extensions of trabecular aragonite needles (M). lower unit. Mersa Shagra area, SEM.

Fig. C: Leached trabecular centers (L) of *Porites lutea*, which rimmed by challky layer. Lower unit, Ras Abu Aweid area. SEM.

Fig. D: Newly formed calcites (C) occur in the leached trabecular centers of *Porites lutea*, Middle unit, Mersa Abu Dabbab area, SEM.

Fig. E: Completely altered microstructure of *Porites lutea*, Upper unit. Mersa Abu Dabbab area, SEM.

Fig. F: Unaltered microstructure of *Goniastrea pectinata*. Lower unit, Mersa Umm Gheig area. Thin section, crossed nicols.

Plate 3

Fig. A: Unaltered trabecular centers of *Goniastrea pectinata*. Lower unit, Sharm El-Bahari area. SEM.

Fig. B: Typical chalky layer of *Goniastrea pectinata*. Lower unit, Sharm El-Bahari area. SEM.

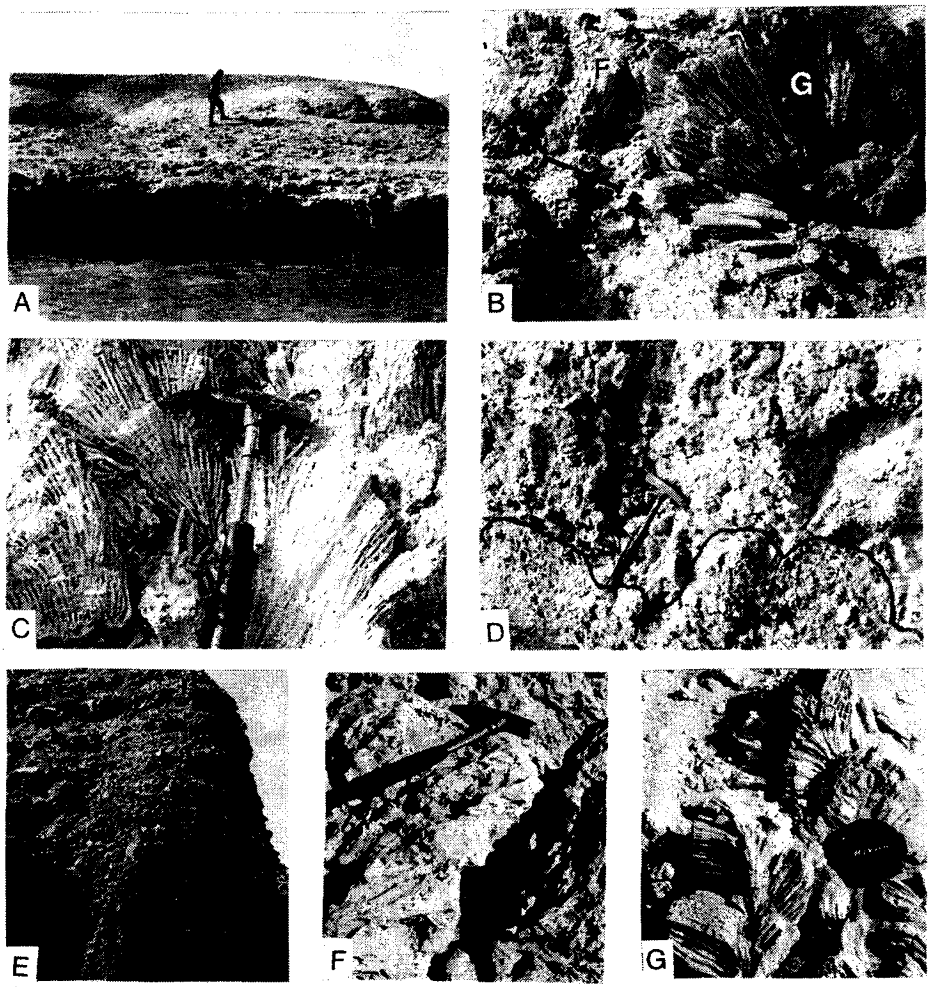
Fig. C: Trabecular centers partly replaced by neomorphic calcites (C) in *Goniastrea pectinata*. Middle reef unit. Mersa Abu Dabbab area, Thin section. crossed nicols.

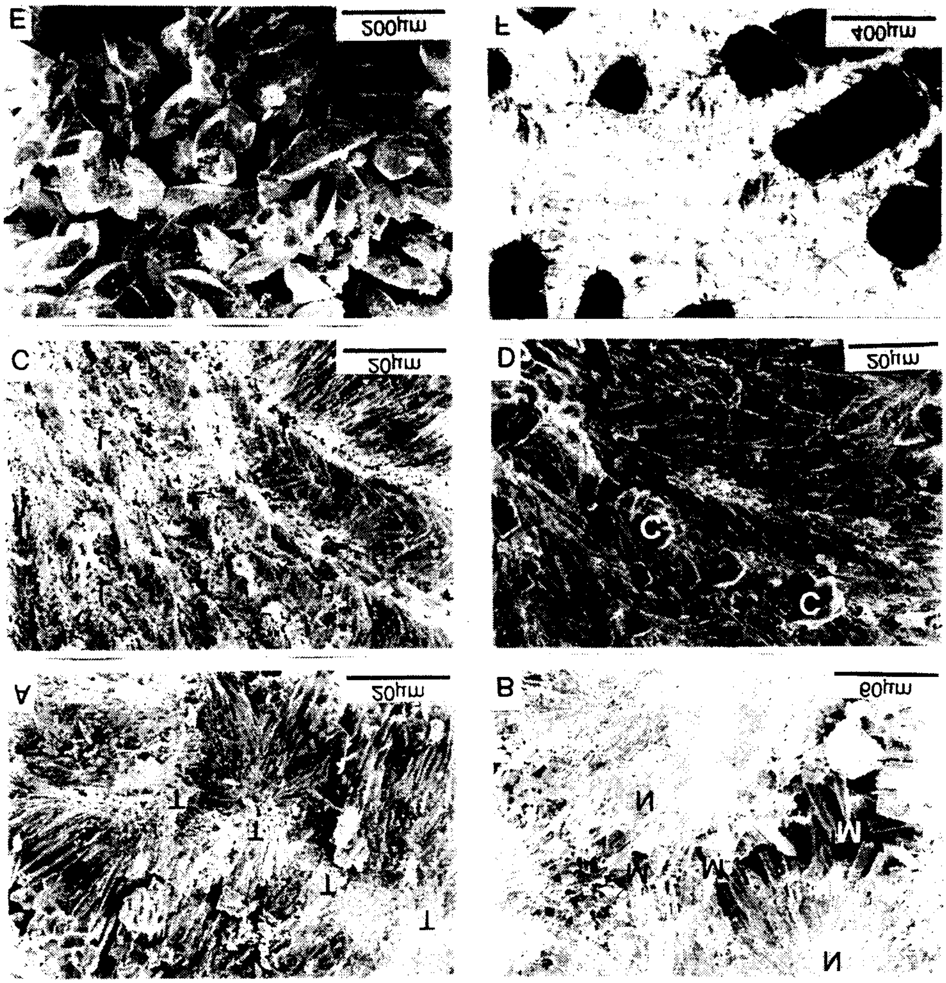
Fig. D: Meteoric calcite cements (C) on the trabecular structure of *Goniastrea pectinat*. Middle unit, Mersa Abu Dabbab area, SEM.

Fig. E: Thin fragile micrite linings (M) act as substratum for meteoric blocky calcite centers (C) in *Porites lutea*. Middle unit. Mersa Shagra area, SEM.

Fig. F: Septa and dissepiments of *Goniastrea pectinata*, are completely altered. Upper unit, Mersa Shagra area, thin section, crossed nicols.

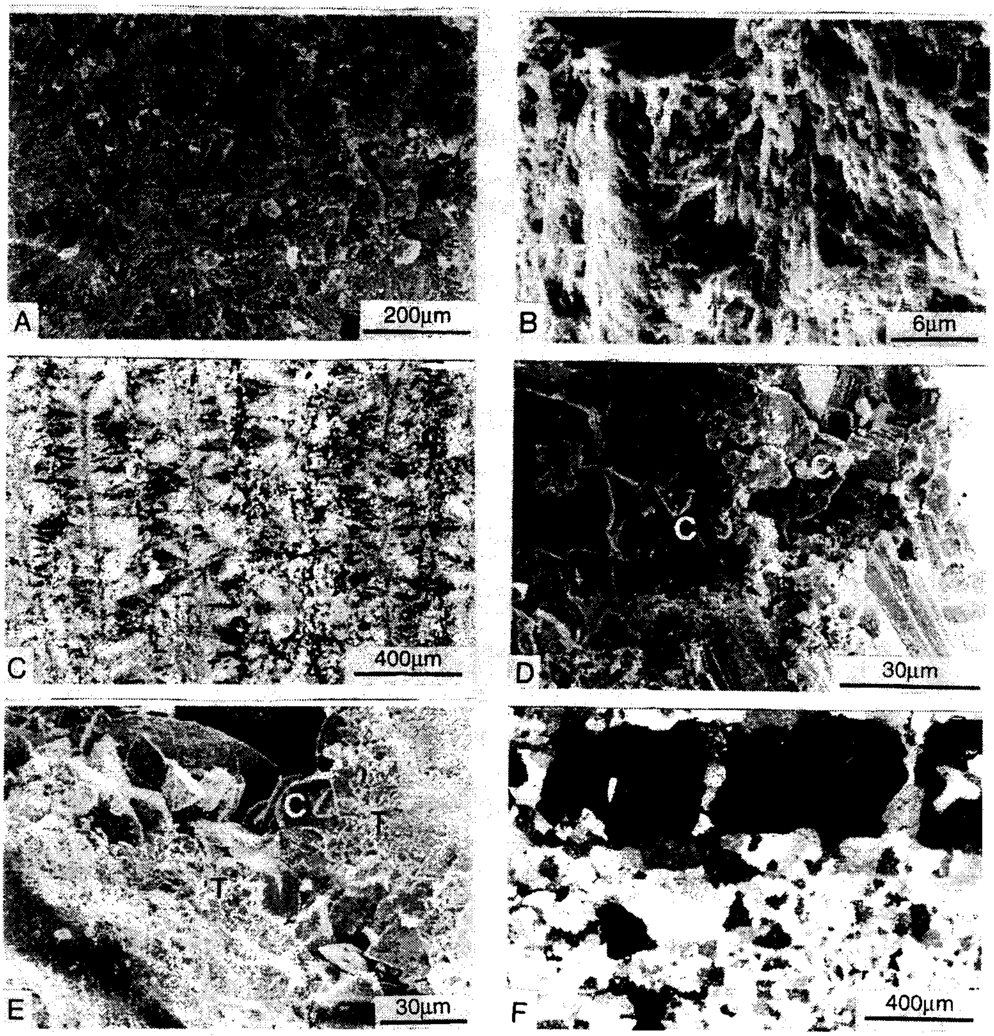
PL.1





PL.2

PL.3



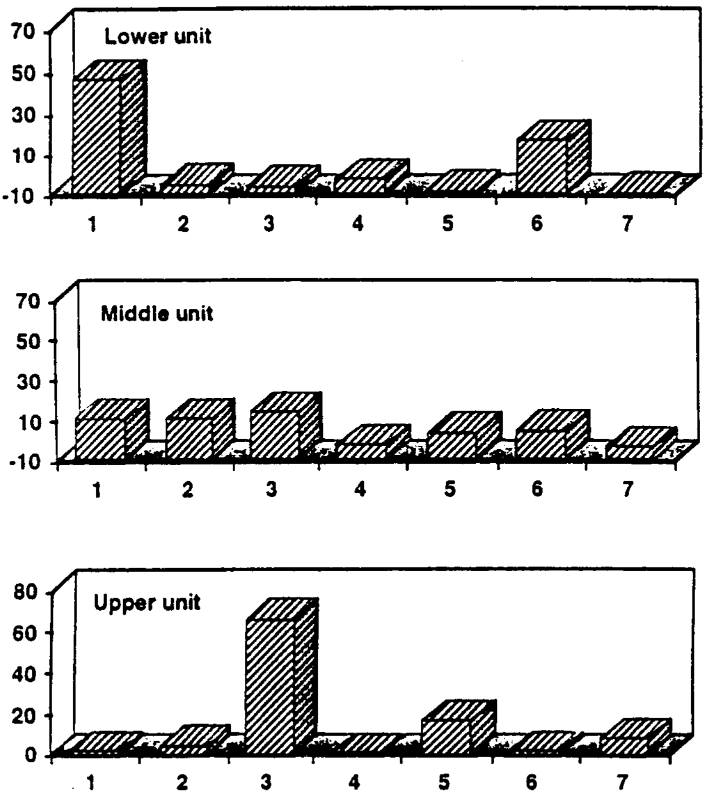


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Fig. 5: Quantitative composition of diagenetic fabrics of *Goniastrea pectinata* through the three reefal units.

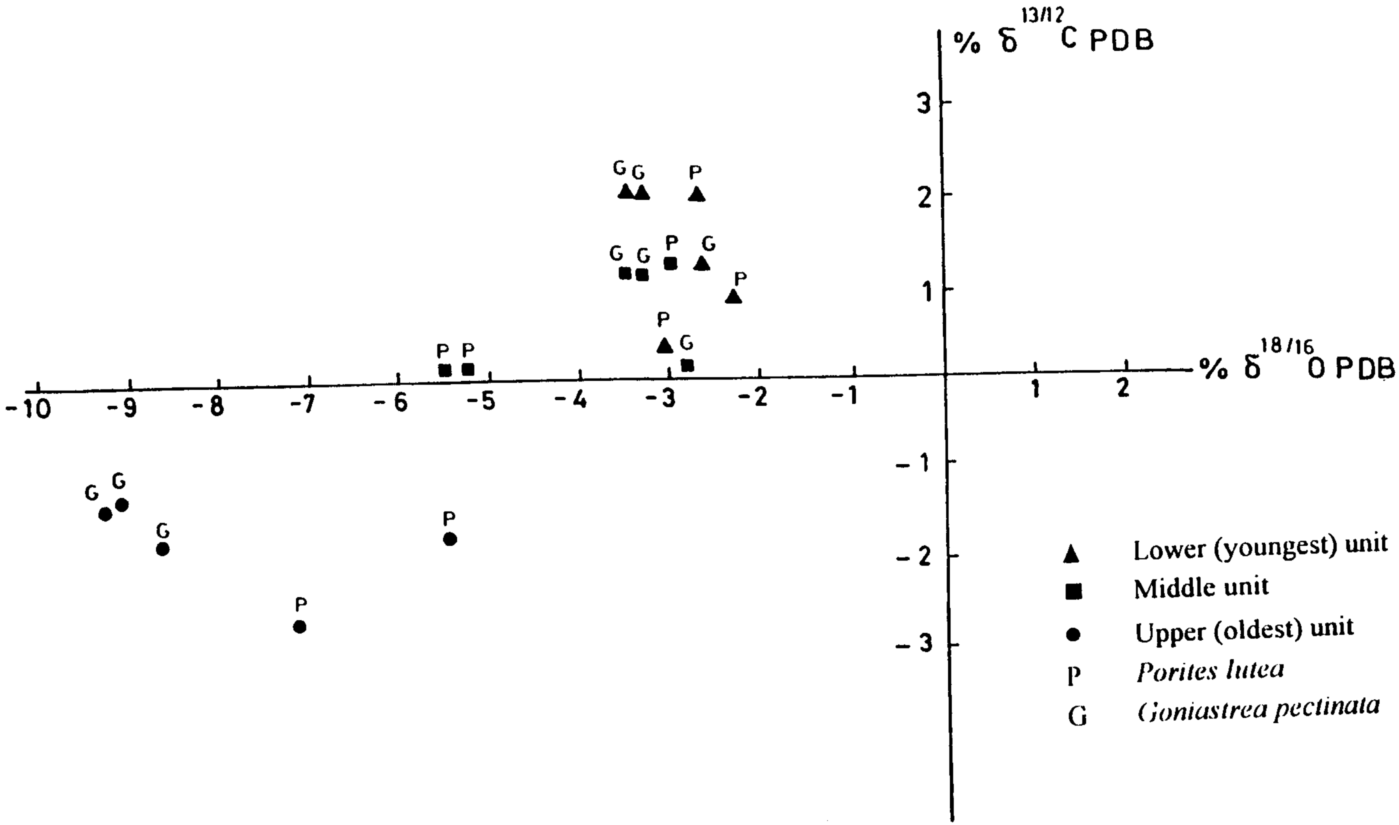

Fig. 6 : Isotope analysis of samples from the studied reefal units.

Middle reef unit:

The transition to the middle unit is marked by an increased leaching of the trabecular structure. It is 28.90% in *Porites lutea* (Fig. 4) and 19.30% in *Goniastrea pectinata* (Fig. 5), which is already replaced by calcite (P1.2/D, P1.3/C). Furthermore several parts of the other coral skeletons are leached and replaced as well by low magnesium calcite.The micrite envelopes form the substrate on which blocky and dog teeth cement start to precipitate (P1.3/D,E). Dog - tooth cement provides the best evidence that cementation has occurred within air-filled marine environment (Longman, 1980). The middle unit is also characterized by an intense leaching of most of the other biota, especially of aragonitic mineralogy and an increased cementation by blocky calcite.

Corals of middle unit show isotope values ranging from +0.10 to +1.37 %o δ^{13} C PDB and between -5.46 and -3.04%o δ^{18} O PDB for *Porites lutea* and between +1.24 and +2.41 % o δ^{13} C PDB and -3.14 and -2.90%o δ^{16} O PDB for *Goniastrea pectinata*. The values for *Goniastrea* are still within the bulk range of marine limestone, however, already showing a distinct fresh water signal, while those of *Porites* are defenitely lighter in carbon than normal marine cements and corals. This difference is also documented in the slightly different preservation style of the two corals.

Upper reef unit:

It is characterized by a completely altered microstructure (P1.2/E, P1.3/H). Skeletal grains and cements were selectively dissolved and reprecipitated in situ as a sparry calcite mosaic and only rare tiny relics of aragonite needles of the former coral skeleton are found as inclusion within the low magnesium calcite in *Goniastrea*. In most cases only the micrite envelopes preserve the outline of the original corallities.

The upper reef unit also is characterized by a continuous reduction of biogenic skeletons due to leaching. The equant calcite spar (low magnesium calcite) lining or compeltely filling the primary and secondary voids or replacing ealier aragonite skeletal grains, leads to decrease porosity.

Samples of the upper reef show isotope values between -2.75 and -1.80%o δ^{13} C PDB and -7.16 and -5.44%o^{18} O PDB for *Porites lutea* and

between -1.55 and -1.34 ‰ δ^{13}C PDB and-9.20 to -8.77‰ δ^{18}O PDB for *Goniastrea pectinata*. These negative isotope values of coral samples indicate a stong fresh water infuence and are comparable with the data of the oldest reef of the southern Sinai (Strasser et al., 1992) and with Pleistocene limestones of Enewetak atoll, western Pacific Ocean (Saller and Moore 1991)

DISCUSSION AND CONCLUSIONS

Based on the information gained from the field observation, the quantitative analysis (point counting) of skeletal and non-skeletal grains in thin sections and isotope anaylses, the following results can be made:-

- The Pleistocene coral reefs along the Egyptian Red Sea coast between Quseir and Mersa Alam constitute three units, occuring in six morphological terraces at different elevations above present sea level. The number of terraces varies from locality to other, probably due to local morpho-tectonic and sedimentary conditions or is also partly a response to eustatic change in sea level.
- The reef units show a progressive diagenetic sequence. Although they are displaced tectonically, the portion of the fossil record and the stage of diagenetic alterion are comparable to the various outcrops of the same unit studied. Therefore this overall similarity among the distinct reef units themselves may be used according to time as a proof for the existence of three different reff formations.
- Due to the increase in fresh water influence with time, the stable isotopes of coral samples from the three reef units demonstrate the diagenetic sequence as well.
- The two studied coral species show a slightly different behaviour during diagenesis. *Porites lutea* strats to alter before *Goniastrea pectinata*. The difference in the rate of diagenetic alteration depends on the microstructure and their relation to the reactive surface area (Constantz 1986, Dullo 1986). Septa of *Porites lutea* (Suborder Fngiina) consist of small, loosely arranged sticks with isolated trabecular centers and are characterized by loose crystal packing and high amounts of intragranular porosity, these give the skeletons high total surface area. In contrast septa of *Goniastrea pectinata* (Suborder Faviina) consisting of massive and linear arrangement of the trabecular centers with tight crystal packing, which combined

with wide aragonite fiber diameter reduce the amounts of reactive surface area and shiled the bulk aragonite from dissolution.

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التغير اللاحق لشعاب البليستوسين المرجانية فى المنطقة بين القصير ومرسى علم - ساحل البحر الاحمر-مصر

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تتناول الدراسة شعاب البليستوسين المرجانية بساحل البحر الاحمر والتى تتكون من شعاب هدابية مشابهة لمثيلاتها الحديثة

وتتواجد فى ثلاث وحدات استراتجرافية مكونة من ستة مصاطب ذات ارتفاعات مختلفة عن منسوب البحر الاحمر الحالى.

أكدت الدراسات الميكروسكوبية ودراسات النظائر المشعة للاكسجين والكربون أن كل وحدة تتميز بمرحلة من التغير الاحق.

الوحدة السفلى (الاحدث): تتميز بعدم تغير معدن الاراجونيت المكون لهياكل المرجانيات ويظهر فقط التاثير النادر للمياه العذبة فى وجود فتحات بـTrabecular centers. والمادة اللاحمة فى هذه الوحدة تتكون من الاراجونيت ذات الاصل البحرى والكالسيت ذو الماغنسيوم عالى النسبة.

الوحدة المتوسطة : تتميز بزيادة اذابة ال Tracbecular centers وبداية تكون الكالسيت قليل الماغنسيوم فى أماكن المراكز المذابة وكذا تتميز بزيادة فى اذابة الحفريات التى تتكون من الاراجونيت.

الوحدة العليا (الاقدام): تتميز بتغير كامل فى تركيب مادة الهياكل لتصبح كالسيت بدلا من الاراجونيت . والمادة اللاحمة من الكاليست قليل الماغنسيوم الناتج من تأثير هذه الوحدة بفعل المياه العذبة.

التاثير الكبير لجنس *Porites lutea* بالعمليات اللاحقة قبل جنس *Goniastrea pectinata* ربما يرجع الى علاقة ذلك سائل بالتركيب الهيكلى الدقيق لكل منهما وعلاقة ذلك بالمناطق السطحية النشطة

وقد أكدت نظائر الكربون والاكسجين الثابتة النشاة البحرية للوحدة السفلى بينما تدل قيم النظائر فى الاتجاه السالب بالوحدتين المتوسطة والعليا على التاثير الكبير بالمياه العذبة.