Riv. It. Paleont. Strat.	v. 100	n. 1	pp. 9-32	Giugno 1994

DIAGENESIS OF A RHAETIAN PATCH REEF (LOMBARDIAN BASIN, SOUTHERN ALPS)

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Key-words: Rhaetian Reef, Carbonate diagenesis, Lombardian Basin.

Riassunto. In un "patch reef" del Triassico Superiore (Retico) nella Formazione del Calcare di Zu, Bacino Lombardo, sono documentate delle alternanze di condizioni diagenetiche meteoriche e marine, probabilmente causate da fluttuazioni relative del livello del mare. Sono stati individuati tre tipi principali di cemento: 1) cemento calcitico fibroso isopaco che riempie parzialmente o completamente le cavità di dissoluzione secondarie; 2) cemento calcitico radiale-fibroso in cui si possono osservare relitti di preesistenti cementi fibrosi torbidi; questi ultimi suggeriscono un'origine neomorfica; 3) calcite spatica equigranulare che si trova sia come riempimento dello spazio rimasto dopo la cementazione delle cavità secondarie da parte delle calciti fibrose, sia come prodotto neomorfico nei Coralli.

Nel "patch reef" sono presenti sedimenti interni sia marini che non marini. I sedimenti interni marini sono composti da "fecal pellets", peloidi e bioclasti. Essi possono avere una disposizione geopetale o riempire completamente le cavità. Le osservazioni rilevate indicano che la "peloidal texture" (un nucleo di cristalli anedrali HMC da cui si irraggiano cristalli fibrosi) potrebbe risultare dall'introduzione di peloidi/ intraclasti micritici fini nei cementi marini fibrosi durante la loro crescita. I sedimenti interni non marini sono composti da "crystal silts" e la loro deposizione è stata preceduta da una dissoluzione parziale dei cementi fibrosi isopachi.

Abstract. Alternations of marine and meteoric diagenetic conditions, most probably caused by relative sea level fluctuations, are recorded in an Upper Triassic (Rhaetian) patch reef in the Calcare di Zu Formation, Lombardian Basin. Three main types of cements have been distinguished: 1) isopachous fibrous calcite cement, partially to completely filling mostly secondary solution cavities; 2) radial-fibrous calcite cement in which strongly turbid relics of precursor fibrous cements suggesting a neomorphic origin can be observed, and 3) equant spar calcite found both as a last cement occluding the remaining void space after the cementation by the fibrous cements and as a neomorphic product in corals.

Both marine and non-marine internal sediments are present in the patch reef. The marine internal sediments are composed of fecal pellets, peloids, micrite and bioclasts. They could be precedent, successive or contemporaneous to the isopachous marine cement and could have a geopetal disposition or may completely fill cavities. The observations made indicate that a "peloidal texture" (a nucleus of anhedral HMC crystals from which fibrous crystals radiate) could result from the introduction of peloids / fine-grained micritic intraclasts into fibrous marine cements during their growth. This texture has not been observed in geopetal infill peloids. Non marine internal sediments are composed of crystal silts and their deposition was preceded by the partial dissolution of the isopachous fibrous cements.

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Introduction.

The Rhaetian facies of the Lombardian Basin (Southern Alps) consist of syn-rift deposits characterized by a high rate of deposition, considerable variation of thickness and cyclic deposition. The Albenza patch reefs are developed on the upper part of an overall shallowing-upward major cycle composed of a number of vertically stacked thickening-upward minor cycles (microfacies and the cyclicity of the sedimentation are described in Lakew, 1990). The studied patch reef is about 3 m thick and less than 8 m wide. It is located on the Albenza Mountain northwest of Bergamo (Fig. 1) at an altitude of 1100 m, a few meters to the right of the road that goes from Torre de Busi to Val Cava. The base of the patch reef consists of a 30 cm thick *Lithocodium* and *Bacinella* bindstone with crinoids, bivalves and gastropods. The main constituents of the patch reef are corals (*Astraeomorpha crassisepta* Reuss, *Retiophyllia* sp., *Montlivaultia* sp.), solenoporaceans, tabulozoans, "sphinctozoans" (*Paradeningeria* sp., *Colospongia*

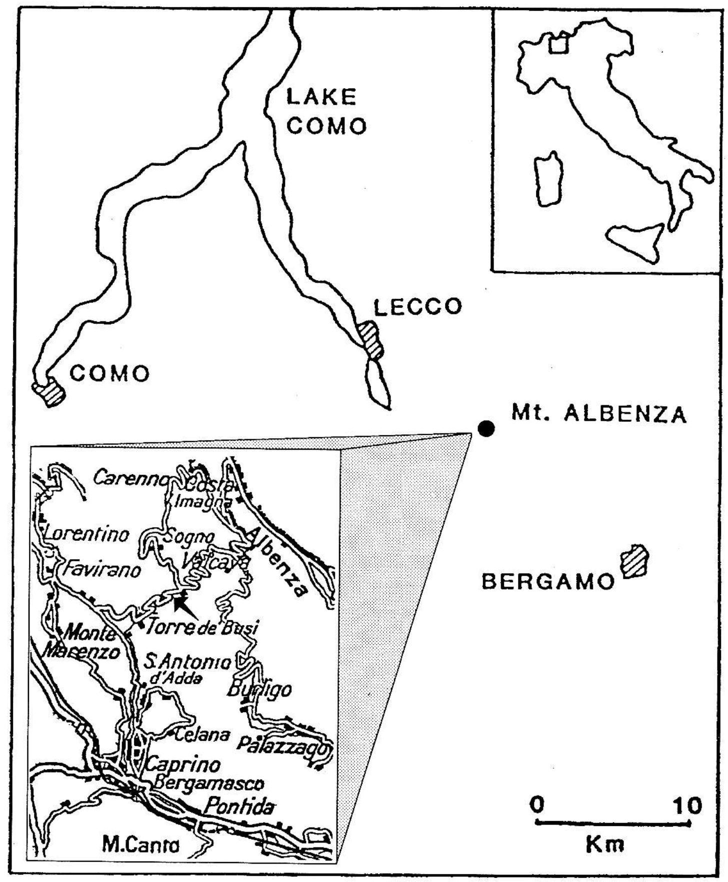

Fig. 1 - Location map of the studied patch reef.

sp., *Solenolmia* sp., *Amblisyphonella* sp.) and less importantly hydrozoans and dasycladaceans. These framebuilders are strongly encrusted by the problematical organisms *Lithocodium* and *Bacinella*, by the porostromata alga *Girvanella* sp. and by some sessile foraminifers. The groundmass is micritic and thus indicates a low-energy depositional condition. The patch reef is overlain by bioclastic peloidal wackestones/ packestones whose top consists of strongly indurated hardgound.

The principal objectives of this paper are: 1) to examine the diagenetic history of a Rhaetian patch reef which could provide insight into marine and meteoric diagenesis fluctuations related to relative sea level variations; 2) to document and compare diagenetic products mostly described from Holocene and Pleistocene sediments with their ancient analogs and 3) to reconsider some previously advanced interpretations of cements and internal sediments.

Geologic setting.

During the Upper Triassic (Norian) shallow-water and peritidal conditions prevailed in most part of the west Tethyan region. In the Southern Alps the Norian is predominantly represented by the "Dolomia Principale". Local intraplatform basins coeval with the upper part of the Dolomia Principale have been identified in the Lombardian Basin and are ascribed to a Norian rifting (Jadoul, 1986). The main phase of rifting preceeding the Piedmont-Ligurian ocean, however, occurred in the Early and Middle Liassic (Bernoulli & Lemoine, 1980; Lemoine & Trümpy, 1987; Sarti et al., 1992).

During the Late Norian and Rhaetian the Lugano Swell/Platform and the Trento Platform (the western and eastern margins of the Lombardian Basin) remained high, while the adjacent blocks subsided. In the Monte Nudo only a few tens of meters of shallow water and intertidal carbonates accumulated (Kälin & Trümpy, 1977). Similarly in the Trento Platform in the east, shallow water peritidal carbonate deposition continued while the Lombardian Basin was subjected to differential subsidence and about 2000 m of syn-rift sediments consisting of shales, marl, limestones and dolomites were deposited (Argilliti di Riva di Solto, Calcare di Zu, Dolomia a Conchodon). The studied patch reef is found in the upper part of the Calcare di Zu Formation which is composed of an overall shallowing-upward cyclic sequence whose top is represented by the Dolomia a Conchodon Formation. The Dolomia a Conchodon can be traced throughout the Lombardian Basin and records the final filling of the Rhaetian intraplatform shallow basin. The vertically stacked asymmetric thickening--upward minor cycles constituing the major shallowing-upward cycle are most probably caused by interactions between differential subsidence of the tectonic blocks and minor eustatic sea level fluctuations (Lakew, 1990).

Methods.

Carbonate cement mineralogy was determined by staining thin sections with Alizarin red-S and potassium ferricyanide (Dickinson, 1966). Petrographic studies were carried out under polarizing microscopy and scanning electron microscopy (SEM).

Major (Ca and Mg) and trace (Fe, Mn, and Sr) element concentrations were determined from a few selected samples using an ARL-SEMQ microprobe. The operational conditions were a voltage of 20 KV, a specimen current (measured on brass) of 0.015 μ A and counting times were 20 seconds.

Diagenesis.

In the Albenza patch reef early marine diagenesis was limited to the encrustation of the frame-building organisms by various problematical organisms, algae and sessile foraminifers. The patch reef was later subjected to meteoric diagenesis before it was overlain by bioclastic peloidal wackestones and packstones whose upper surface consists of strongly indurated hardground with a high concentration of pyrite nodules up to 1.5 cm in diameter.

The following three main types of cements are distinguished in the Albenza patch reef.

Isopachous fibrous calcite cement.

This cement has a characteristic dark color in hand specimen and is honey-coloured in thin section. It consists of multiple bands of densely packed fibrous crystals radiating from the substrate into the cavity (Fig. 2-4). Under crossed nicols the fibrous crystals as bundles exhibit undulose extinction. The thickness of the individual bands may vary from 100 μm to 1 mm and the total thickness of the isopachous rind may reach 3 mm. The isopachous fibrous calcite cement precedes or succeeds internal sediments and fills cavities partially or completely.

Bivalves, gastropods, abundant ostracodes and peloids are also incorporated within the isopachous fibrous cement. In some cases the presence of peloids/fine-grained micritic intraclasts within the isopachous fibrous cement has resulted in a fabric change. The peloids/ micritic intraclasts evidently served as nucleation centers

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Fig. 2 - Neomorphosed corallites consisting of equant spar calcite are circumscribed by an isopachous fibrous calcite cement that shows banding. The presence of relic septa suggests a neomorphic origin for the equant spar calcite. Note that the cementation by the isopachous fibrous calcite cement took place on an irregular and corroded surface. Micritic internal sediments and healed fibrous cement fringes (arrow) indicating a selective dissolution and recementation can also be observed (sample A-19-3). Scale bar 2 mm.

Fig. 3 - Detail of the isopachous fibrous calcite cement showing growth bands. The boundary between the neomorphosed corallites and the isopachous fibrous calcite cement is irregular and corroded (arrow). A marine internal sediment composed of fecal pellets and ostracode fill a cavity. Peloids incorporated within the isopachous fibrous calcite cement can also be observed (sample A-19-3). Scale bar 1 mm.

for the growth of fibrous crystals (Fig. 5). This cement fabric is similar to the fibrous cement type 3 described by Aissaoui et al. (1986).

The cavities cemented by the isopachous fibrous calcite are mostly secondary and were formed by the dissolution of the micritic matrix which could be in part a microbial micritic crust developed on the framebuilding organisms. In some cases however, the isopachous fibrous calcite cement has formed rinds around neomorphosed corals which are composed of equant spar calcite in which some relic septa can

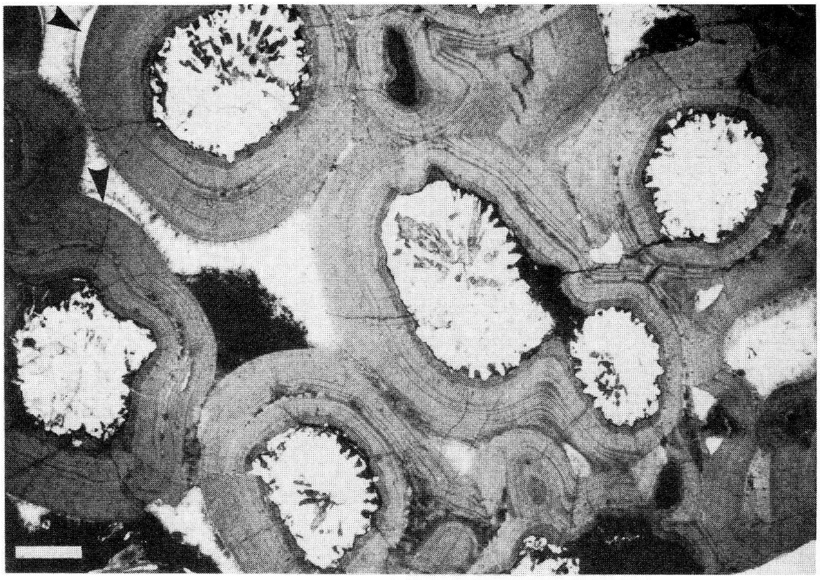

Fig. 2

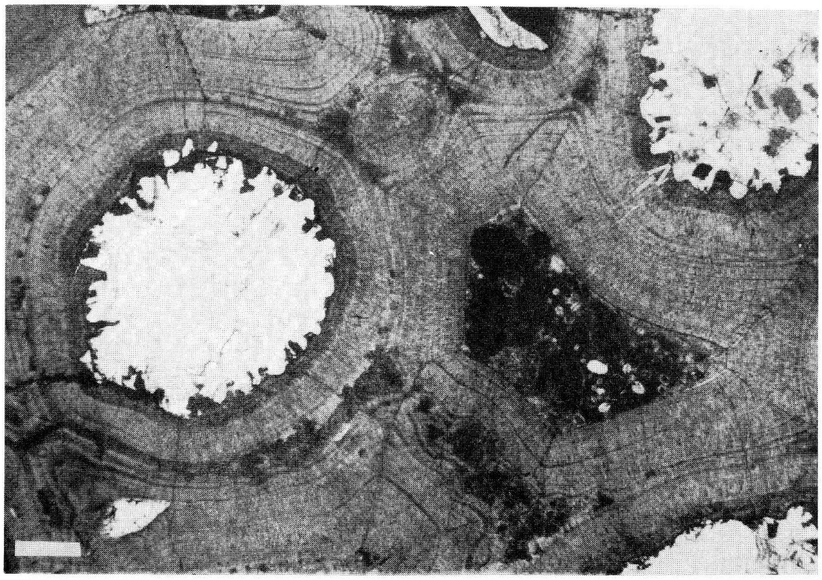

Fig. 3

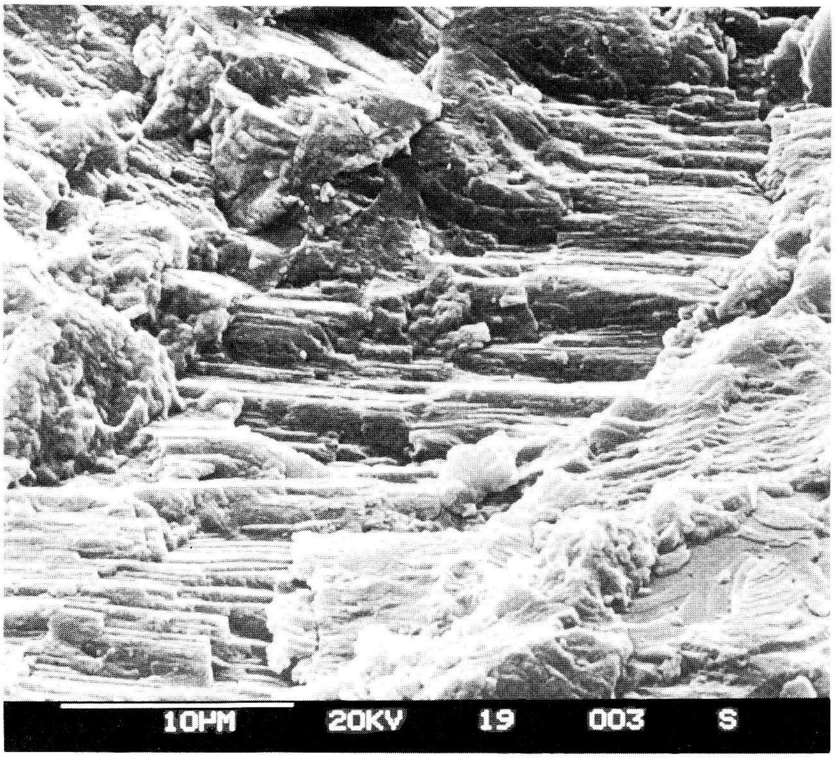

Fig. 4 - The isopachous fibrous marine cement under SEM. The isopachous layer is composed of densely-packed fibrous crystals (sample A-19-3).

still be observed. In such cases it is rather difficult to establish whether the cemented cavities are primary or secondary. However, it can be observed that the cementation by the isopachous fibrous calcite took place on an irregular and slightly corroded surface of corals and in places relics of the micritic matrix are present between the neomorphosed corals and the isopachous fibrous cement as well as between the corallites (Fig. 2, 3) indicating matrix dissolution.

Microprobe analysis of the isopachous fibrous cement has shown that it consists of low-magnesium calcite (average composition of 2.14 mole percent $MgCO_3$). The iron content is of 200 ppm, whereas the strontium and manganese contents are below the detection limit.

Interpretation.

Isopachous fibrous cements with similar petrographic characteristics, but with high magnesium calcite composition (HMC) or dolomitized, have been described from the Mururoa Atoll by Aissaoui et al. (1986) and by Aissaoui (1988) and have been interpreted as early marine cements. HMC fibrous cements in Quaternary and Recent

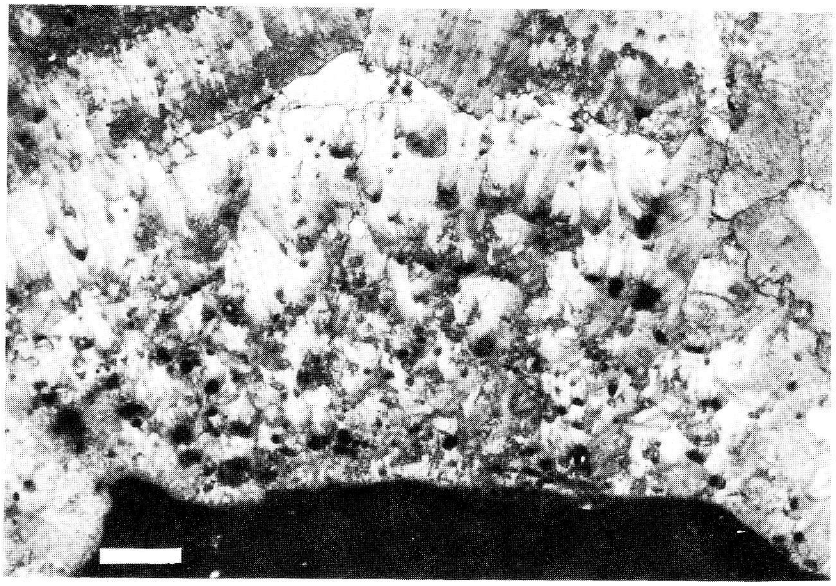

Fig. 5 - Peloids and fine-grained intraclasts introduced during the isopachous fibrous calcite cement growth could cause a change in the growth fabric acting as new nucleation centers (sample A-22). Scale bar 500 μm.

reefs have been commonly attributed to a marine precipitation (Schroeder, 1972; James et al., 1976; Marshall, 1983; Harris et al., 1985; Schroeder & Purser, 1986). Similar fibrous cements have also been described from Devonian sediments and interpreted as marine cements (Playford, 1980; Walls & Burrows, 1985).

The isopachous fibrous cement in the Albenza patch reef is different from those described in the literature in the following aspects: 1) it has cemented mostly secondary solution cavities; 2) it could either preceed or succeed internal sediments.

However, the isopachous fibrous cement in the Albenza patch reef could also be interpreted as a marine cement based on the presence of small bivalves, gastropods, numerous ostracodes and rare foraminifers incorporated within the cement and also because it is found associated with clearly marine internal sediments composed of fecal pellets (Fig. 3). The LMC composition could be attributed to stabilization in the presence of meteoric waters.

The original HMC fibrous marine cements could have been mimically replaced or Mg selectively leached preserving the original microfabric.

Radial-fibrous calcite cement.

In the secondary solution cavities that were not completely filled by the isopachous fibrous calcite cement, the remaining void space is cemented partially or in some cases completely by a radial-fibrous calcite cement (Fig. 6-8). Radial-fibrous cal-

Fig. 6 - A cavity filled with four types of cements. The first type consists of an isopachous fibrous calcite cement (1) while the second type is represented by relics of strongly turbid fibrous cements (2) which have given rise to the radial-fibrous calcite cement (3) by neomorphic substitution. The last phase of cementation consists of equigranular spar calcite (4) which has occluded the remaining void spaces (sample A-19-1). Scale bar 1 mm.

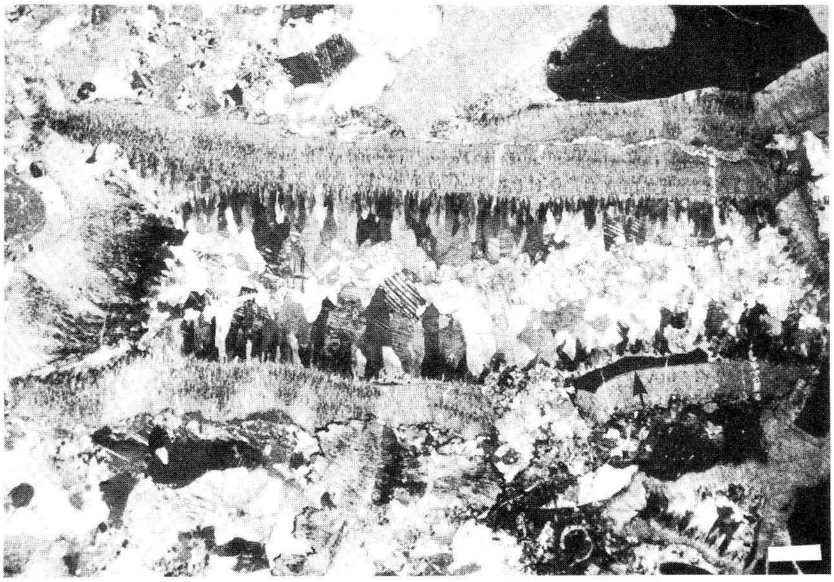

Fig. 7 - The same as Fig. 6 under crossed polars. It can be observed that the various fibrous cements could be in optical continuity (left part) or the fibrous cements could be separated by a micritic internal sediment (arrow) (sample A-1 9-3). Scale bar 1 mm.

Fig. 8 - The same as Fig. 6 under high magnification. Relics of strongly turbid precursor fibrous cements can still be distinguished within the radial-fibrous calcite crystals characterized by planar twin planes and by the absence of marked undulose extinction (sample A-19-1). Scale bar 250 μm.

cite cement is distinguished from radiaxial fibrous calcite and fascicular-optic calcite cements by the absence of a marked undulose extinction and for having planar optic axis and twin-planes (Davis, 1977; Mazzullo, 1980; Kendall, 1985).

The radial-fibrous calcite cement consists of slightly turbid fibrous to bladed crystals with a maximum length of 4 mm grown perpendicularly (in some cases in optical continuity) above the isopachous fibrous calcite cement or less commonly above peloidal/ micritic internal sediments (Fig. 7, 12). It can be observed that strongly turbid precursor fibrous crystals have been neomorphically altered to bigger and relatively less turbid crystals with a more or less bladed crystal morphology. In the basal parts of these bigger crystals, relics of precursor fibrous crystals can still be distinguished by the presence of abundant inclusions (Fig. 8-11).

In places different cement sequences are observed in adjacent connected cavities (Fig. 9). The first cement in such cavities is an isopachous fibrous calcite and it is either followed by a fibrous cement, similar to the isopachous fibrous calcite, or a radial/fibrous calcite cement that occlude the cavity.

Microprobe analysis indicates that the radial-fibrous calcite cement consists of low-magnesium calcite (average composition 1.96 mole percent MgCO3). The strontium and iron contents are 400 ppm and 250 ppm respectively.

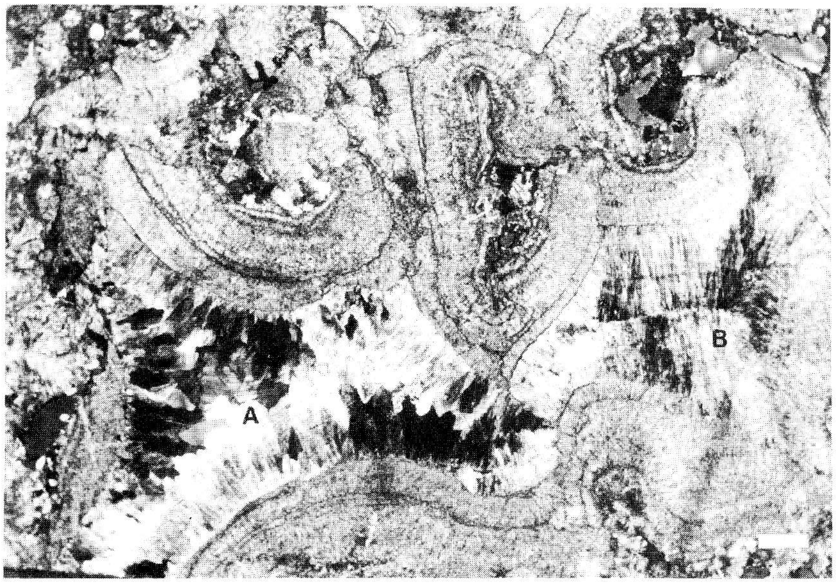

Fig. 9 - Different cement sequences are observed in adjacent connected cavities. The first cement in both cavities is the isopachous fibrous calcite. In the cavity B, a fibrous cement has completely filled the cavity, while in the cavity A the isopachous fibrous calcite cement has been followed by a radial fibrous calcite cement that occluded the cavity. Precursor fibrous cements, interpreted as having given rise to the radial fibrous calcite cement by neomorphic substitution, can be recognized by their high content of inclusions. This variation of diagenesis in adjacent connected cavities could have been caused by microenvironmental differences resulting perhaps from the difference in the cavity size (sample A-24) (x nicol). Scale bar 500 μm.

Interpretation.

Radial fibrous calcite and similar cements (radiaxial fibrous calcite, fascicular-optic calcite) have been interpreted as neomorphic products of precursor fibrous marine cements (Kendall & Tucker, 1973; Kendall, 1977; Mazzullo, 1980; Prezbindowsky, 1985).

Kendall & Tucker (1973) indicated the petrographic characteristics such as the presence of non planar intercrystalline boundaries, the absence of competitive growth fabric and the presence of cross-cutting relationship between crystal boundaries and inclusion patterns as a proof for a neomorphic growth.

Kendall (1985) reinterpreted radiaxial fibrous calcite cements as primary (commonly of Mg calcite) formed as composite crystals in the marine phreatic environment. The composite character of the crystals is attributed to split-crystal growth which is probably caused by crystal poisoning or by growth from highly super-saturated solutions.

In spite of Kendall's reinterpretation, the radial fibrous calcite cements in the Albenza patch reef are here interpreted as neomorphic products of precursor fibrous marine cements.

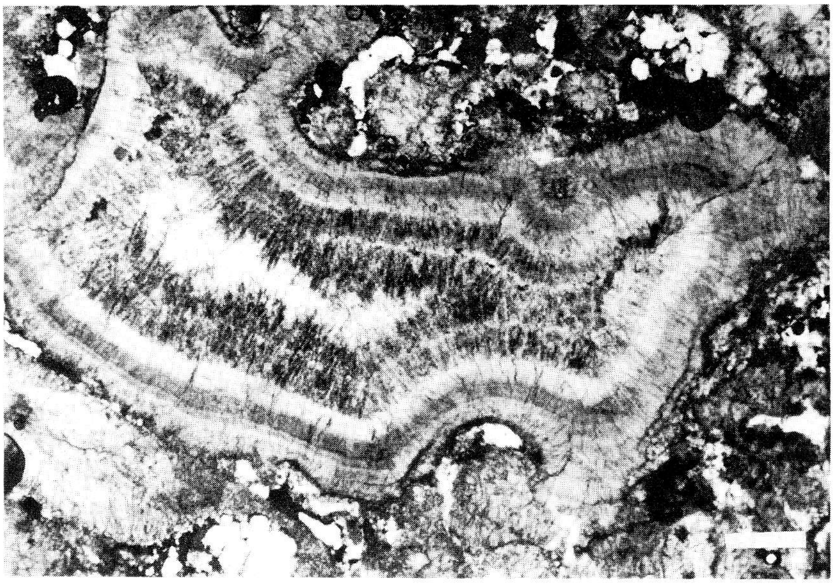

Fig. 10 - A cavity filled first by isopachous fibrous calcite cement with growth bands consisting of inclusion rich (dark) and inclusion poor (lighter) layers, followed by a radial fibrous calcite cement that occluded the cavity. The precursor fibrous cements can be recognized by their strong turbidity. Note that the equant spar calcite which is commonly the last cement that occludes cavities is absent (sample A-24). Scale bar 500 μm.

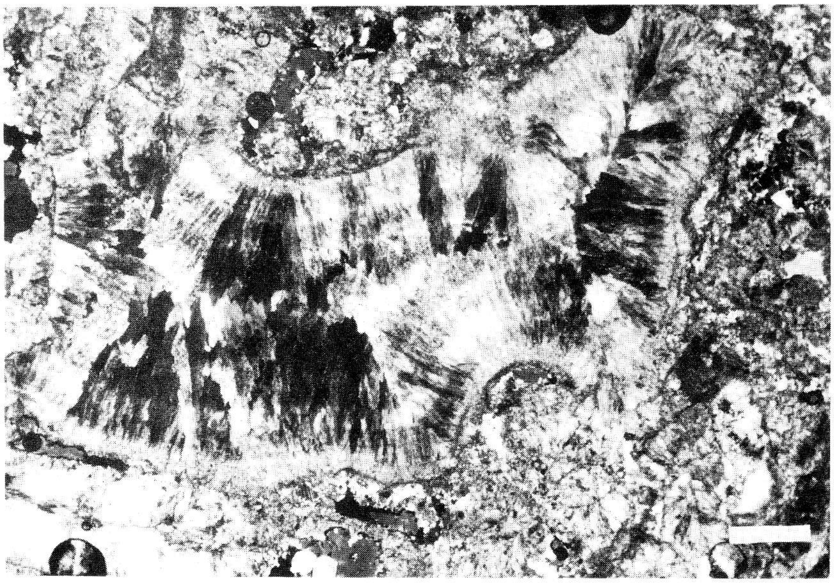

Fig. 11 - The same as Fig. 10 under crossed nicols. It can be observed that the radial fibrous calcite cement, which is interpreted as a neomorphic product, is in optical continuity with the isopachous fibrous calcite cement (sample A-24). Scale bar 500 μm.

Fig. 12 - Peloidal internal sediment with a geopetal fabric deposited over the isopachous fibrous calcite cement and overlain by relics of strongly turbid fibrous cements. Note that in the rest of the cavity the two fibrous cements are found in sequence (sample A-23). Scale bar 1 mm.

Relics of strongly turbid precursor fibrous cements can still be recognized within the bigger and relatively less turbid radial fibrous calcite crystals clearly indicating a neomorphic origin. Quite spectacular examples of the intermediate stage of substitution of Kendall & Tucker (1973), in which the crystal habit of the precursor turbid fibrous cement can be recognized, are present (Fig. 8). Neomorphic alteration may be controlled by microenvironmental conditions that could give rise to different types of diagenetic products inside adjacent cavities (Fig. 9).

Equant spar calcite cement.

Equant spar calcite is the last cement that occluded the remaining void space after the cementation by one or both types of fibrous calcite cements (Fig. 6, 8). Equant spar calcite is also found in corals that have undergone neomorphic recrystallization (Fig. 2, 3) and filling fractures that cut across all types of cements. The petrographic characteristics of these cements are similar. They are composed of limpid equigranular crystals that exhibit sharp extinction. The average size of the crystals is 2-3 mm and crystal boundaries are mostly irregular and some are serrated. In the neomorphic equant spar calcite, some crystal boundaries cut across septal relics, while others coincide with them.

Although the petrographic characteristics of the neomorphic equant spar calcite in the corallites and the equant spar calcite which is the last cement occluding remaining void spaces are similar, microprobe analysis has shown some differences in their chemical composition reflecting their possible origin. Both types of spar calcite consist of LMC with average compositions of 1.42 and 1.0 mole percent $MgCO_3$ respectively.

The average strontium and iron contents of the neomorphic spar calcite are of 200 ppm and 850 ppm respectively, whereas in the spar calcite cement the iron content is of 500 ppm and no strontium has been detected.

Interpretation.

The interpretation of equant spar calcite cements is often rather difficult because they can be formed both in near surface and deep burial conditions. A low content of ferrous iron suggests that the cement precipitated from oxidizing waters in subaerial conditions, whereas a significant presence suggests a late precipitation in a deep burial environment. However, a high content of ferrous iron alone is not sufficient to identify late burial cements because ferroan cements could also be formed early in near surface anoxic conditions (Evamy, 1969; Scholle & Halley, 1985). In the Albenza patch

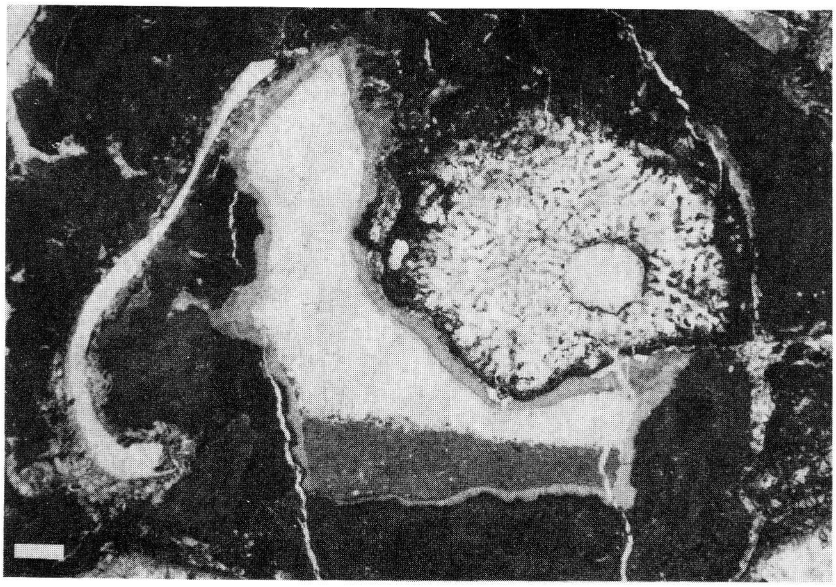

Fig. 13 - A secondary solution cavity with a geopetal non marine internal sediment composed of crystal silts. The isopachous fibrous calcite which constitutes the first cement has different thicknesses in different parts of the cavity wall indicating that it has undergone some dissolution before the deposition of the non marine internal sediment. Note that the radial fibrous calcite cement is absent and the remaining void space has been occluded by an equant spar calcite. Note also that the coral (*Astraeomorpha crassisepta* Reuss), which is bored and strongly encrusted by *Lithocodium* and microbial micrite, has first undergone neomorphic recrystallization before the surrounding micritic matrix was subjected to leaching forming the secondary cavity (sample A-20). Scale bar 1 mm.

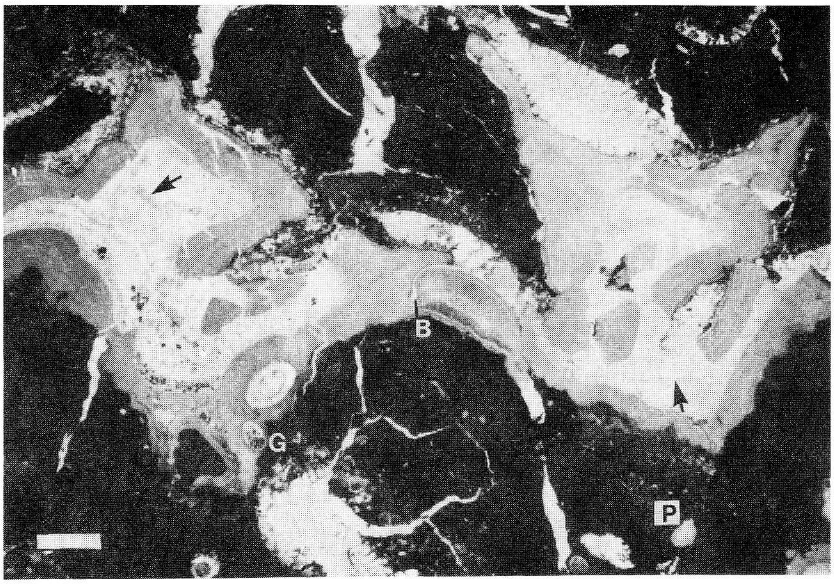

Fig. 14 - Selective dissolution of the isopachous fibrous calcite cement resulted in a partial collapse and the cement fragments were recemented by an equant spar calcite (arrows). At least two dissolution phases separated by marine fibrous cements could be distinguished. The first resulted in the formation of the secondary solution cavities, whereas the second one resulted in selective dissolution and partial collapse of the isopachous fibrous calcite cement. Note that a peloidal internal sediment (P) predates the isopachous fibrous calcite cement and that bivalve (B) and gastropod (G) shells are found incorporated within the isopachous fibrous calcite cement (sample A-22). Scale bar 2 mm.

reef the equant spar calcite cement occluding void spaces remaining after the cementation by the fibrous cements could be interpreted as a product of meteoric phreatic environment because it is found in close association with dissolution features caused by meteoric waters. It can be observed that the fibrous marine cements have undergone selective dissolution and collapse, and broken pieces of these fibrous cements are found floating in the equant spar calcite cement (Fig. 14). This indicates that the re-cementation by the equant spar calcite after the selective dissolution and collapse of the fibrous calcite cements took place soon after the dissolution in near surface environments because the fibrous cement fragments must have remained in suspension within the cavities before being recemented. A deep burial origin can therefore be excluded.

The equant spar calcite found within the corals can be interpreted as a product of neomorphic recrystallization because some relic structures of septa can still be recognized within it. The timing of this neomorphism can be constrained by the following observations: 1) the isopachous fibrous cement is the first cement filling secondary dissolution cavities indicating that the patch reef has already been subjected to meteoric diagenesis; 2) the secondary dissolution cavities are commonly found bordering neomorphosed corals (Fig. 13, 14).

These observations suggest that the corals being composed of aragonite and therefore more prone to neomorphic alteration/dissolution than the micritic matrix, must have already undergone neomorphism and stabilization to LMC becoming relatively less susceptible to subsequent dissolution, before the formation of the secondary dissolution cavities. The equant spar calcite cement filling fractures is clearly a late cement because the fractures cut across all the other cements.

Internal sediments.

Internal sediments are mainly produced by decantation of sedimentary particles in cavities of lithified sediments (Shinn, 1969; Aissaoui & Purser, 1983). Autochthonous peloids that are found in reef cavities are considered to be of bacterial origin (Playford, 1984; Kerans et al., 1986). In the Albenza patch reef internal sediments mostly have a geopetal disposition and could consist of peloids, pellets, bioclasts, crystal silts and micrite. Moreover, internal sediments could either preceed, be contemporaneous or succeed the fibrous marine cements (Fig. 12, 14). In this study particular attention has been paid to peloids found incorporated within marine fibrous cements. An attempt is made to show that the "peloidal texture" (a central core of anhedral crystals from which fibrous/ bladed crystals radiate), interpreted as a result of repeated nucleation in the formation of peloids (Macintyre, 1977, 1985; Lighty, 1985; Aissaoui, 1988), could result from the introduction of peloids or fine-grained sub-rounded micritic intraclasts into fibrous marine cements during their growth.

In the Albenza patch reef both marine and non marine internal sediments could be distinguished.

Marine internal sediments.

The main characteristics of marine internal sediments are the presence of bioclasts and geopetal fabric (Aissaoui & Purser, 1983).

In the Albenza patch reef there are distinctly marine internal sediments composed of ovoidal fecal pellets having a maximum diameter of 1.4 mm (Fig. 3). However, the most common internal sediments are fine-grained peloids that may be geopetally disposed or may completely fill cavities along with some micrite.

Geopetal infill peloids could be found between two types of marine fibrous calcite cements that can also be found in sequence in the same cavity, in some cases in optical continuity, without the intervening peloidal sediment (Fig. 12). Moreover, peloids are also found incorporated within the isopachous fibrous calcite cement and the presence of peloids in some cases has caused a change in the growth fabric of the fibrous cement (Fig. 5). SEM study of the peloids shows that geopetal infill peloids are accumulations of aggregates of spherical carbonate particles (Fig. 18), while peloids found incorporated within fibrous cements commonly serve as new nucleation centers for fibrous/bladed crystals. These peloidal nuclei may reach up to 80 μm in diameter and the crystals radiating from them can attain up to 200 μm in length. However, it

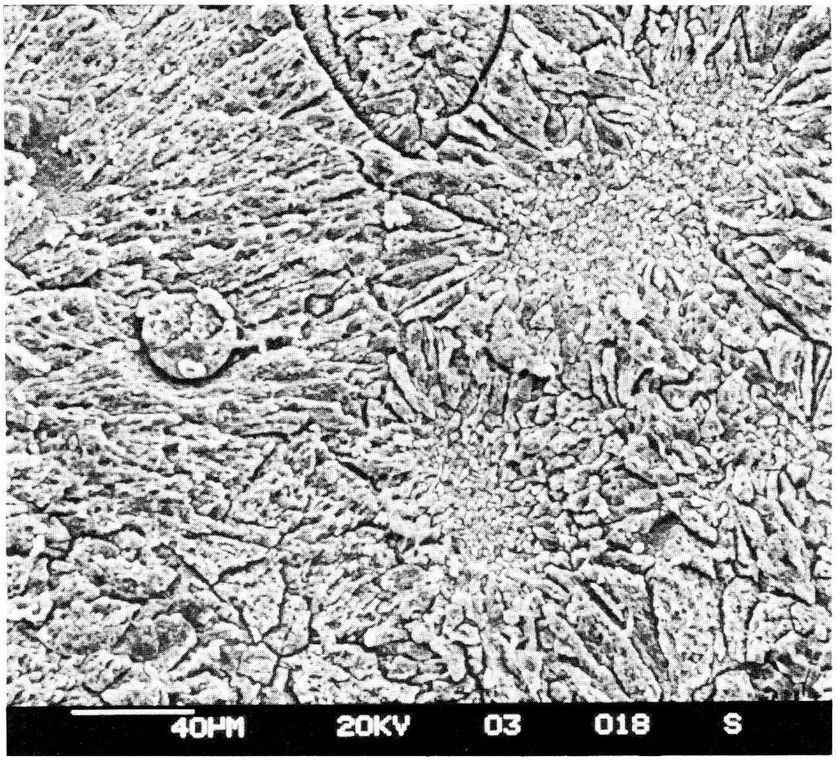

Fig. 15 - SEM photomicrograph showing a fibrous cement and dense cores of anhedral crystals on which fibrous to bladed crystals have nucleated forming a peloidal texture. Note that the ostracode shell (top part) has not served as a nucleation center (sample A-22a).

seems that the size of these crystals depends on the availability of space for growth which may in turn depends on the nearness of other peloids serving as nucleation centers and fine-grained bioclasts (ostracodes, bivalves, and rare foraminifers) which may hinder crystal growth in a certain direction (Fig. 15-17).

Bioclasts incorporated within the fibrous cement generally do not serve as nucleation centers. Ostracodes in rare cases may serve as substrates for outward radiating crystals, but mostly the fibrous crystals grow inwards to the center of the shells (Fig. 17).

Interpretation.

The origin of peloidal internal sediments is controversial. Some of the hypotheses advanced include: pellets formed by organisms (Macintyre et al., 1968; Land & Goreau, 1970); calcified algal filaments (Schroeder, 1972; Ginsburg & Schroeder, 1973; Friedman et al., 1974); and HMC cements formed by repeated nucleation (Macintyre, 1977, 1985; Lighty, 1985; Aissaoui, 1988).

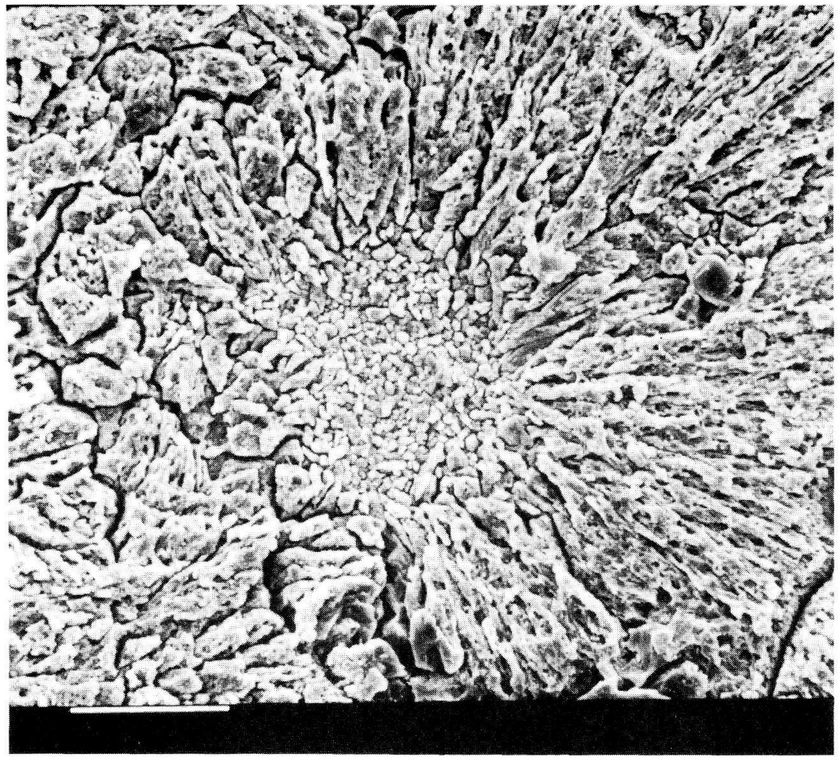

Fig. 16 - SEM photomicrograph showing a single anhedral core that has served as a nucleation center for radiating fibrous crystals (sample A-22a). Scale bar 40 μm.

In the Albenza patch reef peloids occurring as geopetal sediments are composed of aggregates of spherical carbonate particles and in some cases peloidal and micritic internal sediments completely fill cavities suggesting a microbial origin. SEM observation of the peloids incorporated within the isopachous fibrous cement shows that they are not cements, but are carbonate particles introduced into the fibrous cement along with small bioclasts (ostracodes, bivalves, foraminifers) and have served as a new substrate for the growth of radiating fibrous/bladed crystals.

Non marine internal sediments.

Non marine internal sediments consist of crystal silts characterized by a relatively light colour and by the absence of bioclasts. The crystal silts are essentially composed of crystalline fragments resulting mainly from the partial dissolution of cements. It seems that the deposition of these non marine internal sediments was preceded by a partial dissolution of the isopachous fibrous cements which are the first cements filling secondary dissolution cavities. This is suggested by the difference in thickness, in different parts of the same cavity, of the otherwise isopachous cement

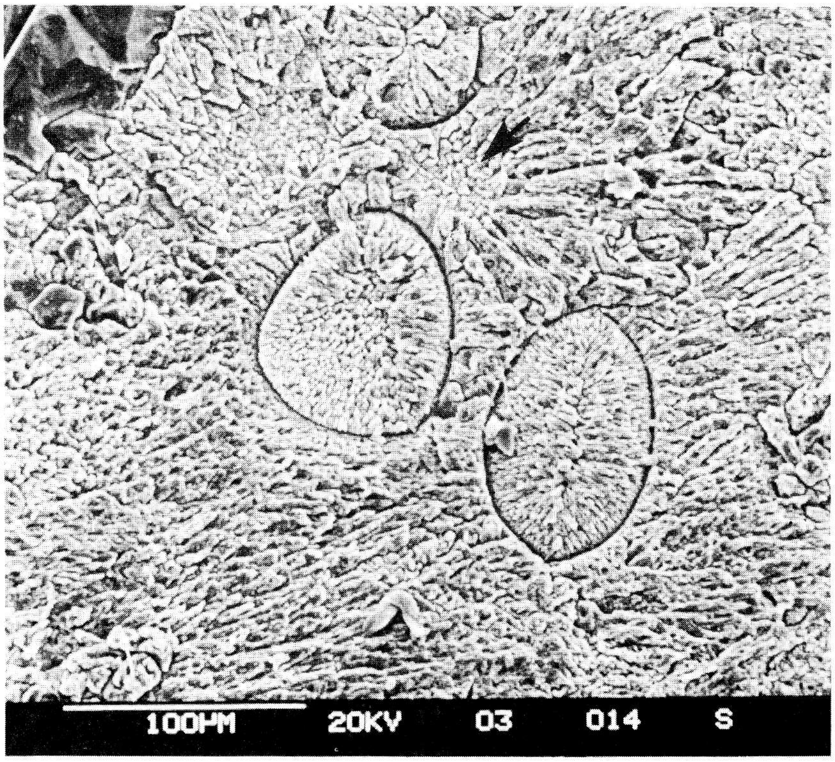

Fig. 17 - SEM photomicrograph showing a fibrous cement in which ostracode shells and fine-grained micritic intraclasts were introduced during its growth. It can be observed that the micritic intraclasts (arrows) have served as new nucleation centers for fibrous crystals, while on the ostracode shells fibrous crystals have grown only inwards to the center of the shells (sample A-22a).

(Fig. 13). On the other hand, where the isopachous fibrous cement is overlain by marine internal sediments, no dissolution of the substrate is observed (Fig. 12).

Dissolution.

The Albenza patch reef was exposed to meteoric waters and was affected by neomorphism and different phases of dissolution. The reef-building organisms were mostly subjected to neomorphism, while the micritic matrix was leached forming dissolution cavities which were later cemented by different types of fibrous calcite and equant spar calcite cements. Selective dissolution has also affected earlier cements indicating that diagenetic products are also liable to diagenesis (Schroeder, 1979; Aissaoui et al., 1986; Aissaoui, 1988). The isopachous fibrous cements have been selectively dissolved resulting, in some cases, in the collapse of the isopachous rind. Fragments of

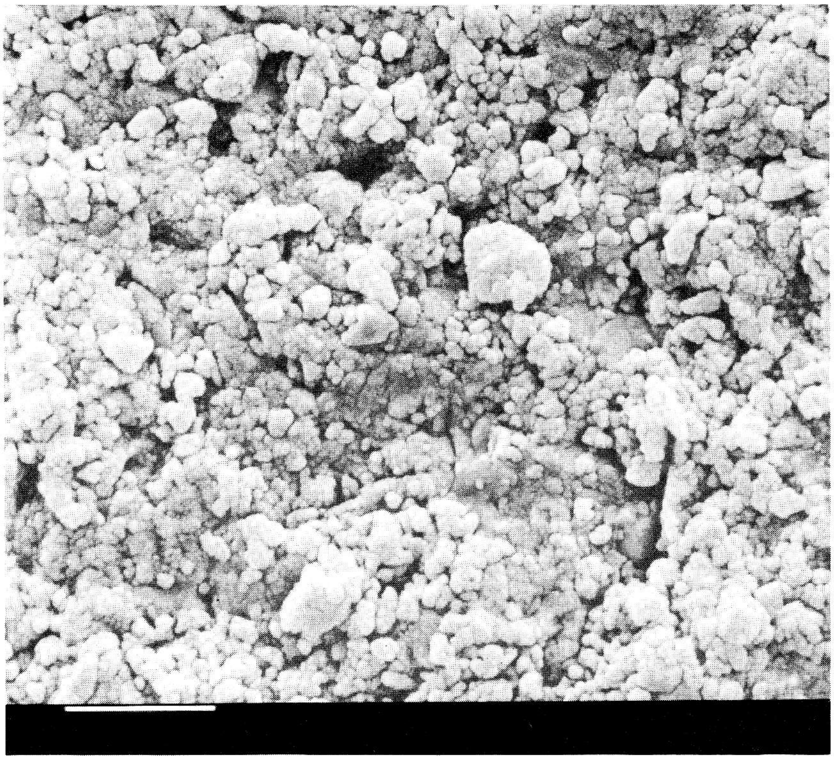

Fig. 18 - SEM photomicrograph of a peloidal internal sediment with a geopetal disposition consisting of aggregates of spherical carbonate particles (sample A-23). Scale bar 4 μm.

these fibrous cements can be observed floating in the equant spar calcite cement (Fig. 14) indicating a recementation of partially and selectively dissolved earlier cements.

Fracturing.

Fracturing was an important process that produced secondary porosity. However, all fractures were subsequently cemented by equant spar calcite. Fracturing is a late process in the diagenetic history of the patch reef. Fractures cut across all types of cements, neomorphic spar calcite and internal sediments (Fig. 6,13,14), but predate stylolitization.

Stylolitization.

Some pressure solution took place at a late stage in the diagenetic history of the patch reef. Sutured contacts can be observed between biotic constituents and the micritic matrix, between cements and neomorphic spar calcite or within cements (Fig.

6). Fractures die out at sutured contacts indicating that stylolitization postdate fracturing. Both horizontal and more or less vertical stylolites are present. The latter ones most probably resulted from tectonic stress.

Summary and conclusions.

The Rhaetian patch reef of Albenza passed through various diagenetic environments ranging from marine to meteoric and back to marine and once again to meteoric then followed by a slightly deep burial. As the patch reef was formed on the upper part of a major shallowing-upward cycle composed of a number of superimposed thickening-upward minor cycles, the alternation of marine and meteoric diagenetic conditions was most probably related to relative sea level fluctuations.

Early marine diagenesis was limited to the encrustation of the primary framebuilders by various problematical organisms (*Lithocodium* sp., *Bacinella* sp.) and sessile foraminifers.

The first effect of exposure to meteoric waters was a neomorphic recrystallization of the reef-building organisms. This was followed by various phases of dissolution that affected mostly the micritic groundmass forming secondary cavities.

Marine cements are represented by banded isopachous fibrous calcite (now of LMC composition) which has cemented mostly secondary dissolution cavities and by relics of strongly turbid fibrous cements which underwent neomorphic alteration producing a radial fibrous calcite cement.

Marine and non marine internal sediments could be distinguished. The marine internal sediments are composed of fecal pellets, peloids, micrite and bioclasts. They could be precedent, successive or contemporaneous to the isopachous marine cement and could have a geopetal disposition or may completely fill cavities. Peloidal internal sediments could cause a change in the growth fabric of the isopachous fibrous cement acting as new nucleation centers. The observations made suggest that the "peloidal texture" (a nucleus of anhedral HMC crystals from which fibrous crystals radiate) could result from the introduction of peloids/ fine--grained micritic intraclasts into fibrous marine cements during their growth.

Non marine internal sediments are composed of crystal silts and their deposition was preceded by the partial dissolution of the isopachous fibrous cement forming the substrate.

The isopachous fibrous marine cement was subjected to selective dissolution and recementation indicating that diagenetic products are also susceptible to diagenesis. All the remaining void spaces, after the cementation by one or both types of fibrous calcite cements, were occluded by equant spar calcite.

Acknowledgements.

I am grateful to Prof. M. Gaetani, Prof. F. Jadoul and Dr. S. Frisia for discussions. Thanks are also due to Prof. J.H. Schroeder and Dr. H. Weissert for helpful reviews of earlier versions of this paper. The manuscript has benefited from the comments of Prof. E. Flügel and Prof. F. Jadoul.

I am also grateful to C. Malinverno, A. Rizzi and G. Chiodi for technical assistance and M. Montella for typing the manuscript.

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Received October 29, 1993; accepted January 28, 1994