ACTA GEOLOGICA HISPÀNICA T. 17 (1982), nº 3, pàgs. 169-178

Constructive micrite envelope developed in vadose continental environment in pleistocene eoliantes of Mallorca (Spain)

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SUMMARY

In this study we analyze and explain the formation of the constructive micrite envelope in the vadose continental environment. This constructive micrite envelope shows a wide variety of textural components. The principal textural components are: microorganisms, micritic and microspar LMC cement, whisker crystals, microfibres and aggregates of LMC acicular crystals. The main microorganisms are hyphae fungi, although actynomicetes and bacteries also occur.

The constructive micrite envelope is due to the action of calcified filaments (hyphae fungi) which collapse and coalesce forming an intertwined mesh as well as due to the precipitation of micritic and microspar cement. The whisker crystals, microfibres and aggregates of LMC acicular crystals are secondary microtextures.

Constructive micrite envelopes does not indicate a specific diagenetic environment.

The constructive micrite envelopes present irregularities or bumps at the outer surface of the grains, and the destructive micrite envelopes present irregularities towards the grain interior. This morphologic criterion is useful to differenciate the micrite envelope origin, constructive or destructive, in the fossil record.

RESUMEN

En este trabajo se analiza y explica la formación de la envuelta micrítica constructiva en el medio continental vadoso. Esta envuelta muestra una gran variedad textural: microorganismos, cemento de LMC (Low magnesian calcite) de tamaño micrítico y microesparítico, cristales whiskers, microfibras y agregados de cristales aciculares de LMC. Los principales microorganismos son las hifas fúngicas, presentándose también actinomicetos y bacterias.

La envuelta micrítica constructiva es debida a la acción de los filamentos calcitizados (hifas fúngicas) los cuales colapsan y coalescen formando una red, así como a la precipitación de cemento micrítico y microesparítico. Los cristales whisker, microfibras y cristales aciculares son microtexturas secundarias.

Las envueltas micríticas constructivas no indican un medio diagenético específico.

Las envueltas micríticas constructivas presentan irregularidades o engrosamientos hacia la superficie externa de los granos, mientras que las envueltas micríticas destructivas presentan las irregularidades hacia el interior de los granos. Este criterio morfológico es útil para diferenciar el origen de las envueltas micríticas, constructivo o destructivo, en el registro fósil.

INTRODUCTION

The presence of a brownish envelope (or rim), almost opaque, on the external borders of carbonate grains, of variable thickness, and made up of cryptocrystalline crystals, is very common in carbonate grains throughout the geologic record. Its existence permits the morphologic identification of certain carbonate constituents in fossil rocks (Friedman, 1964, 1975; Friedman et al., 1971; Bathurst, 1971, 1979).

These opaque rims in carbonate grains have been observed for a long time (Sorby, 1879; Cullis, 1904; Ginsburg, 1957; Illing, 1954, etc.). They have been named dark lines (Cullis, 1904), micritic corrosion rim, micritic rim, circumcrust, lime-mud envelopes, etc., but the term more largely accepted is micrite envelope. A certain terminologic confusion in micrite envelope concept exist because a descriptive-genetic meaning is given by some authors while an exclusively descriptive meaning is given by others. Bathurst (1964, 1966, 1971) restricted the term micrite envelope to those opaque rims caused by boring and filling mechanism. Gvirtzman and Friedman (1977) defined the micrite envelope as "any cryptocrystalline opaque outline of a particle or a skeleton, whether the opaque parts originated as filling of bored outer regions of the skeletons or as coatings extending beyond the original outline of the skeletal parts, whose other parts may or may not have been bored".

The formation of the micrite envelope is intimately associated with the micritization process. This process may be produced by different mechanisms of which we point out the following: a) Boring and filling mechanism (Bathurst, 1966, 1971; Winland, 1968; Swinchatt, 1969; Lloyd, 1971; Margolis and Rex, 1971; Alexandersson, 1972; Gunalitaka, 1976, etc.). b) Dissolution-reprecipitation within an organic muscilaginous sheath (Kendall et al., 1966; Kendall and Skipwith, 1969). c) Constructively generated micritic envelopes (Kobluk and Risk, 1977 a, 1977 b). d) Other mechanisms such as "recrystallisation" (Purdy, 1968), "sparmicritization" (Kahle, 1977), etc.

According to Kobluk and Risk (1977 a, 1977 b) microorganisms may produce a constructive micrite envelope in sea water. These envelopes are due to the calcified filaments of the algae *Ostreobium* which are coalesced forming an interwined mesh and the precipitation of micritic and microspar cement inside the micropores. These authors were the first to explain the formation of the constructive micrite envelopes.

In spite of the constructive micrite envelope does not previously explain their formation in the continental environment, some authors (Logan et al., 1970; James, 1972; Ward, 1975; Knox, 1977) have observed the presence of micrite envelopes (or micrite coatings) on the outside of the grains, in the upper part of the vadose continental environment.

In this study we analyse and explain the formation of micrite envelopes in the edaphic and vadose continental environment, whereas they were only described from the marine environment (Kobluk and Risk, 1977 a; 1977 b), in the eolianites of Pleistocene age from Mallorca.

GEOLOGICAL AND DIAGENETIC SETTING

The island of Mallorca is located to the east of Spain in the Mediterranean Sea (Fig. 1). On the island there are three main areas where Pleistocene and Recent eolianites are well developed (Fig. 1), named area A (Palma Bay), area B (Colonia Sant Jordi), and area C (Alcudi Bay). These three areas have different climates. Areas A and B are semiarid whilst area C has a dry-subhumid climate.

The stratigraphy of the Mallorcan Pleistocene is well known thanks to the works of Cuerda (1957, 1975), Butzer and Cuerda (1960, 1962), etc.

The samples studied correspond to carbonate eolianites of Flandrian age (2.000 to 7.000 years BP), Wurm (approximately 25.000 years BP), Riss (approximately 300.000 years BP) and Mindel (approximately 500.000 years BP).

Fig. 2 shows an idealized and simplified diagenetic model of the Pleistocene in Mallorca based on Calvet (1979). The diagenetic evolution is divided into two stages: a first stage in marine conditions and a second stage in continental conditions.

– Stage 1 (in marine conditions): A great part of the carbonate components (molluscan, coralline algae and foraminifera, principally) in the eolianites (either recent or fossil) originated on the marine platform. These components, whole or fragmentated, are transported by wave action, currents, etc. to the beach. The typical marine diagenetic processes acted on these grains and when they reach the continental environment show inhereted marine diagenetic features. The most important inherited diagenetic features, refering to the fossil micrite envelopes, is naturally the result of boring and filling in the marine environment.

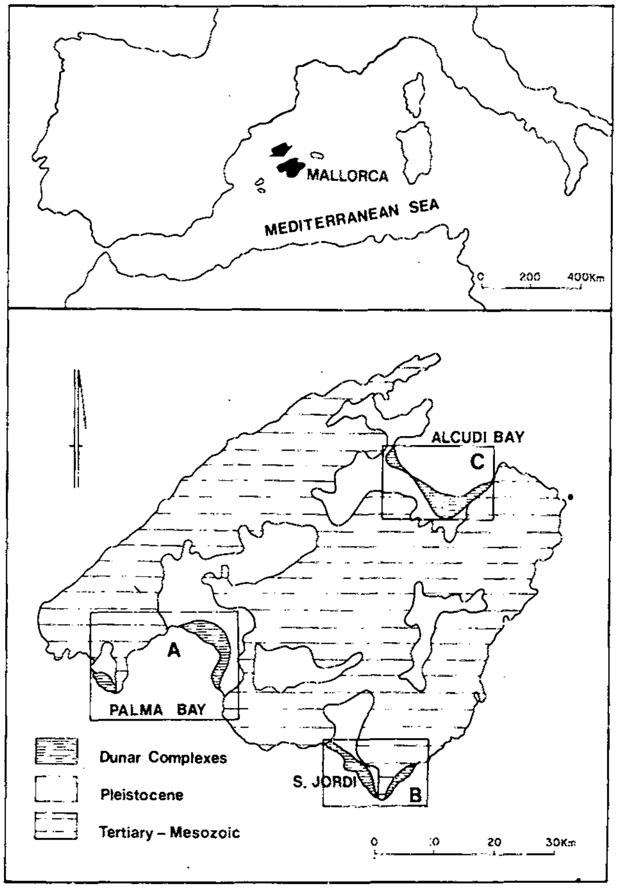


Fig. 1. a) Map of the west of the Mediterranean Sea showing the location of Mallorca.
b) Map of Mallorca showing the three main areas where the Pleistocene and Recent eolianites are well developed and studied in this paper.

– Stage 2 (in continental conditions): The sands of the beaches are carried selectively by the wind and form the dunes and dune complexes. In these new conditions the sands will be transformed in to hard, compact fossil rocks following the diagenetic evolution in continental environment. The principal continental environments are: a) edaphic zone, with the formation of laminated caliches, rizoliths, etc., b) vadose continental environment and c) phreatic continental environment.

Thirty outcrops were analized sistematically in the fossil dune complex shown on Figure 2. Each outcrop was sampled from the lower zone cropping out generally situated at the middle part of the vadose zone to the edaphic zone.

The active constructive mechanisms of the micrite envelope was observed basically in the Flandrian eolianites and locally in the Wurm eolianites, in particular, in the upper part of the vadose environment. In the Riss and Mindel eolianites this process is a fossil product.

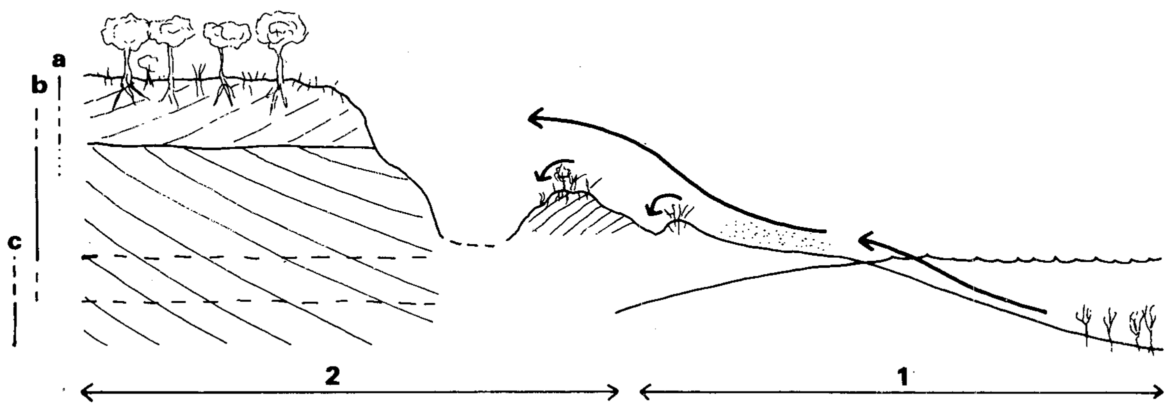


Fig. 2. Diagenetic model of the Pleistocene of Mallorca. *1* marine environment. *2* continental environment. *a* edaphic environment. *b* vadose continental environment, *c* phreatic continental environment.

TEXTURAL COMPONENTS OF THE CONSTRUCTIVE MICRITE ENVELOPE

The principal textural components of the constructive micrite envelope in the vadose continental environment are the following:

a) Microorganisms. The principal microorganisms observed in the constructive micrite envelope are:

1/ Hyphae fungi. They present two dispositions:

I) Well calcified filaments, measuring 6-13 μm thick and up to 80 μm in lenght, on the grains and forming an interwined mesh in the interparticle porosity (Plate 1-1, 1-2, 1-3). This filaments are calcified by small LMC (low magnesian calcite) crystals, less than 3 μm, with the c-axis perpendicular to the filament. According to E.I. Friedmann (1979, written communication) they can be probably attributed to hyphae fungi.

II) Filaments coating the grains. These filaments measure 3-7 μm thick and up to 1 mm length. The filaments grade from uncalcified to totally calcified, and locally they are collapsed (Plate 3-1). They present some dicotomic bifurcations. The internal diameter varies from 1,5 to 3,5 μm, and the crust (according to Schroeder, 1972, 1973) is 0,3 - 1 μm thick (Plate 1-5). The crust is made up of LMC crystals which measure between 0,1 μm (or less) and 1 μm. The crystals are anhedric to subhedric and the c-axis tend to be perpendicular to the filament (Plate 1-5). According to E. I. Friedmann (1979, written communication) the filaments can be interpreted as hyphae fungi. Is possible that the form II) will be a initial stage of form I).

Similar calcified filaments have been cited by Knox (1977) and Klappa (1979) in caliche profiles in South Africa and in coastal regions of western Mediterranean respectively.

2/ Filaments measuring 1 μm thick (Plate 1-6, 2-6) which can be attributed to actinomycetes, according to the description in Klappa (1979).

3/ Bacterias. We have observed rarely chains of cocal bacterias, 0.3 μm thick (Plate 2-6).

b) Micritic and microspar LMC cement (Plate 2-1, 2-2). The cement crystal size varies from 0.1 μm to 10 μm. The crystals are subhedral, and some of them present pseudorhombic morphology. The micritic cement is observed in the inner parts of the envelope. The cement precipitates in the micropores of the interwined mesh formed by the filaments, and on the grains. Knox (1977) cited similar cement on detrital grains and allochems. The mineralogy was determinated by selective tincions and EDAX.

c) Whisker crystals. The measure 3-40 μm long and 0.5-1.2 μm thick. Their mineralogy is LMC. They present two dispositions: 1) Tangential disposition, the whisker crystals are tangential to the grains. The volumetric importance of the tangential whiskers varies from some scattered between the microorganisms (Plate 1-6) to occupy practically all the micrite envelope in some caliche profiles (Plate 2-3, 2-4). James (1972) cited similar envelopes in caliche profiles. 2) Random disposition betwenn the micropores of the intertwined mesh and on some grains.

d) Acicular LMC tiny crystals that measure up to 1 μm long and 0.1-0.2 μm thick. We name them microfibres (Plate 2-5).

e) Aggregates of LMC acicular crystals ordered in a certain pseudoradial disposition. The individual crystals measure tenths of a micron thick and 2-5 μm long. They have a subhedral habit. (Plate 2-6).

FORMATION MECHANISM OF THE CONSTRUCTIVE MICRITE ENVELOPE

The first stage of this process is the colonization of eolianites by chasmolithic and endolithic microorganisms (principally fungi). It is known that some microorganisms can act as endolithic, chasmolithic and epilithic (Moret, 1934; Schroeder, 1972; Golubic, 1973; Kobluk and Risk, 1977b; Knox, 1977; Klappa, 1979).

The microorganisms envolve the grains, and may produce small borings on them. In some microorganisms a calcitization process of the filaments begins. In this case, the calcitization begins outside the filament, and occurrs when the microorganism is still alive. The calcitization of filaments in caliche profiles had been carefully analized by Klappa (1979).

The thickness of the calcitization varies according to the microorganism which is calcified. Calcitizations from 0.3 μm up to 3 μm have been observed. It is rare to see filament with crystals inside them, they are generally empty. This feature, together with the small thickness of the calcified external part facilitates the collapse in many filaments (Plate 3-1). At the same time as this collapse occurs new filaments grow, some of which will be calcified and some of which will collapse and so on successively (Plate 2-1). Kobluk and Risk (1977a) observe coalescences of 2 to 30 filaments. Both the filaments which do not-collapse as well as the collapsed form an intertwined mesh, and micropores remain between them.

We can conclude that the constructive micrite envelope is due to the calcified filaments which collapse and coalesce forming an intertwined mesh. Inside the micropores of the intertwined mesh micritic and microspar LMC cement precipitates (Plate 2-1, 2-2). At the same time the formation of whisker crystals (Plate 1-6), microfibres (Plate 2-5) and aggregates of LMC acicular crystals (Plate 2-6) occurs. See Figure 3.

Locally, we have observed that where caliche development exists in the upper part of the vadose continental environment, the constructive micrite envelope is formed principally by tangential whisker crystals (Plate 2-3, 2-4) and consequently the volumetric importance of the calcified filaments decrease.

The thickness of the micrite envelopes is variable even in the same grain (Plate 3-2). It varies from a few μm in the initial stages of micrite envelope formation to 40 μm or more. The width of the initial stages of micrite envelopes increases progressively as well as the complexity of their formation, until they fill the whole of the interparticle porosity as they approach areas of a more edaphic activity.

DISCUSSION

The importance of the continental constructive micrite envelope is determinated by its relation to the continental environment (in contrast the marine constructive micrite envelope) and by its relation in the original porosity reduction.

Micrite envelopes made up by constructive mechanisms are considered as indicators of shallow marine environment (Klobuk and Risk, 1977a). However this conclusion should be reviewed because in this paper, the micrite envelope formation in the vadose continental environment has been demostrated. Several reasons indicate that the constructive micrite envelope were originated in the vadose continental environment:

(I) The geological setting of the different studied outcrops, dune complexes, shows a vadose continental environment.

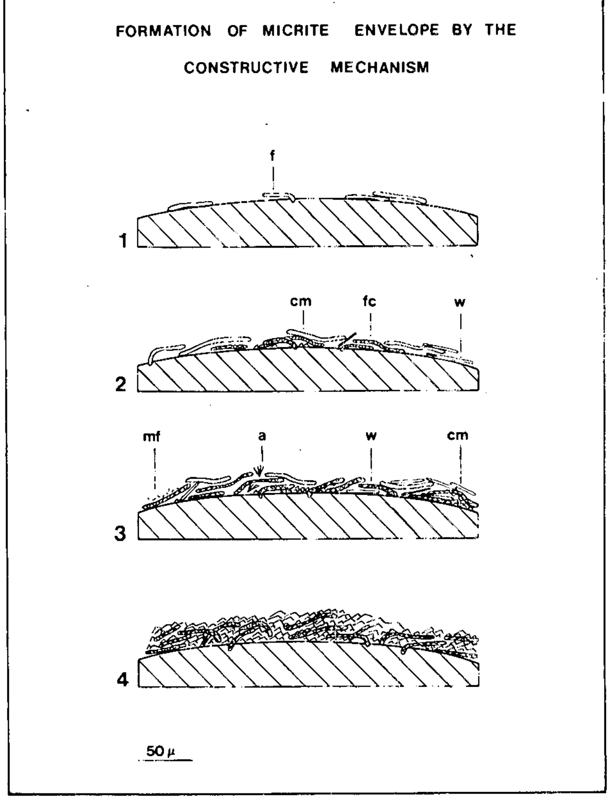


Fig. 3. The constructive micrite envelope in vadose continental environment is due principally to the action of calcified filaments (fc) which will be collapsed and coalesced forming intertwined mesh and also due to the precipitation of micritic and microspar cement (cm). Non-calcified fungi filaments (f), whiskers (w), aggregates of LMC acicular crystals (a) and microfibres (mf).

PLATE 1

Phot. 1. Fungi filaments on grain (s) forming a constructive micrite envelope (m).

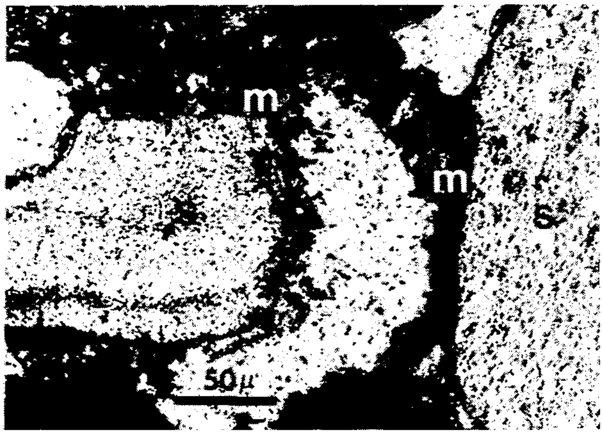
Phot. 2. Detail of photo 1. The fungi filaments are calcified by small crystals with the c-axis perpendicular to the filament.

Phot. 3. Calcified fungi filaments (f) forming an interwined mesh in the interparticular porosity.

Phot. 4. Eolianite with fungi filaments (f) that begin to recover the grains.

Phot. 5. The fungi filament is calcified by anhedral and subhedral LMC crystals.

Phot. 6. Initial stage of micrite envelope formation process by constructive mechanism. The grains are colonized by fungi filaments (f), from uncalcified to totally calcified. Presence of whiskers (w).



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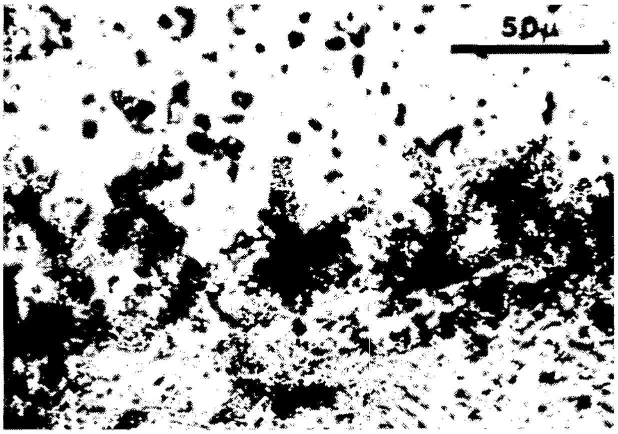

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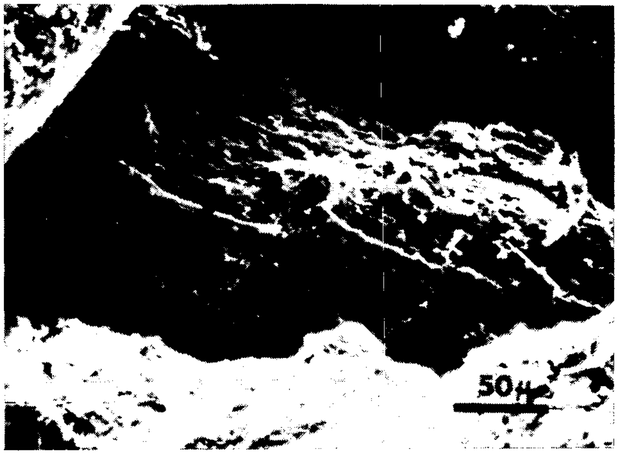

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Age	Number of quantified samples	% micrite envelope total volume	% original porosity	% micrite envelope original poros.
Flandrian	31	0,8	34,9	2,3
Wurm	32	3,0	35,1	8,5
Riss	56	4,5	39,6	11,4

Fig. 4. Table showing the reduction of the original interparticle porosity. This reduction is due to the constructive micrite envelope.

(II) The microorganisms (hyphae fungi, actinomycetes,...) observed in the construction of this micrite envelope are common in the continental environment.

(III) The relation to edaphic processes is well established in the studied outcrops, where the amount and thickness of the micrite envelope increases progressively at the top of dune complexes where the edaphic processes have been stronger. The microtextures (whiskers, microfibres, calcified filaments) from the constructive micrite envelope and the microtextures of recent caliches (laminar and pisolitic) are similar (Calvet and Julià, 1981).

(IV) A geometric relation exists between the constructive micrite envelopes and the cements of the vadose continental environment (principally meniscus and gravitational cements). The meniscus cement presents the typical characters (LMC mineralogy, pore rounding, some crystals with blunt termination, etc.) of the vadose continental meniscus cement (Dunham, 1971; Schroeder, 1973; Friedman, 1975; Calvet, 1979; etc.). The gravitational cements presents (LMC mineralogy, morphological habit, disposition) typical of the vadose gravitational cements (Muller, 1971; Ward, 1975; Calvet, 1979; etc.). We found micrite envelopes both before the beguining of the cementation and between stages of cementation. The Plate 3-3 shows the micrite envelope between a first stage of meniscus cement and a second stage of spar cement. The Plate 3-4 shows different micrite envelopes of variable thickness in diverse stages of growing gravitational cement. The existance and preservation of constructive micrite envelopes formed in vadose continental environment permit the recognition of the different cements in the first stages of sediment cementation. If it were not for the micrite envelope, for exemple in the Plate 3-3, it would be impossible to recognize the meniscus cement because the subsequent cement would have grown obliterating any geometric character of initial cement which is the most usual case (Dunham, 1971; Ward, 1975).

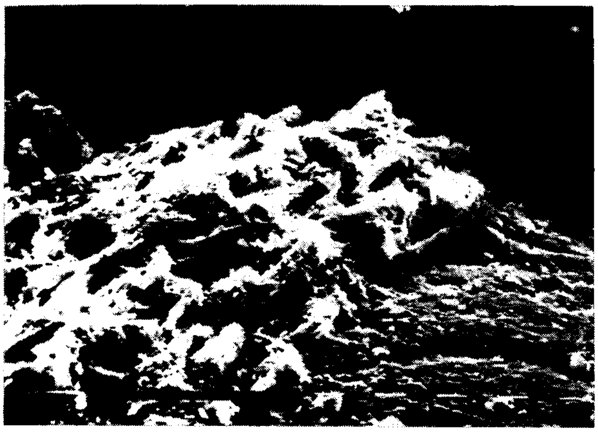
The formation of the constructive micrite envelope implies a reduction of the original interparticle porosity. The reduction increases progressively at the top of the dune complexes, and also increases progressively with the age of the eolianites (until the eolianites of Riss age) where the calichification process have been stronger. This last reduction has been quantified in some studied samples (Fig. 4) in order to stress the importance of these envelopes in the reduction of original porosity in the material studied.

MORPHOLOGIC CHARACTERS OF THE FOSSIL MICRITE ENVELOPE

The fossil micrite envelopes in the Riss and Mindel eolianites of Mallorca are produced by two mechanisms. The first mechanism is destructive and occurs by means of a boring and filling process in marine environment, and consequently this envelope will be inherected when the marine sediments reach the continental environment. The second mechanism is constructive and occurs in the vadose continental environment. The recognition of the exact micrite envelope mechanism (destructive or constructive) in the fossil micrite envelope is very difficult. The micrite envelopes of a destructive origin presents ir-

PLATE 2

Phot. 1. Stage more advanced of Phot. 1-6 of micrite envelope formation where we observe the interwiened mesh made up of fungi filaments and the micritic LMC cement inside the micropores.
Phot. 2. Detail of photo 1. Subhedral micritic LMC cement (c) and fungi filaments (f).
Phot. 3. Initial micrite envelopes made up of whisker crystals (arrows) and calcified filaments (1). Alveolar matrix (a) made up of whisker crystals. Grain (g).
Phot. 4. Detail of a pisoid from a caliche profile. The envelope is made up of whisker crystals with tangential disposition. Nucleus (n).
Phot. 5. Fungi filaments collapsed (fc), whiskers (w) and very small sized acicular crystals that we name microfibres (arrow).
Phot. 6. Aggregates of LMC acicular crystals showing some pseudoradial disposition (a). Cyanobacterie filament (y), whiskers (w), micritic cement (c) and bacteries (arrow).



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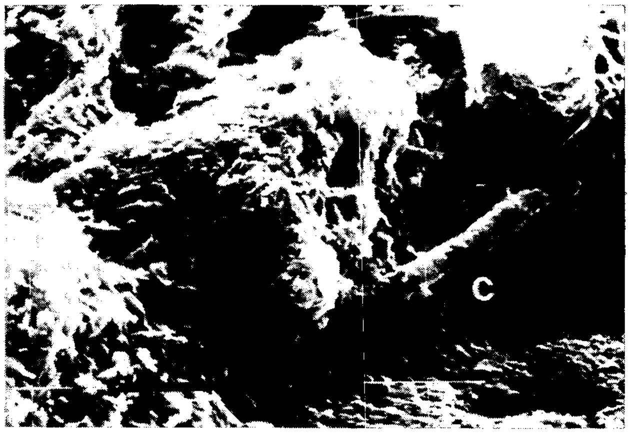

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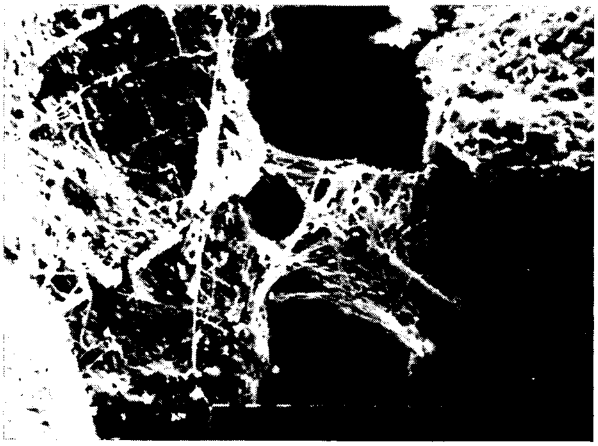

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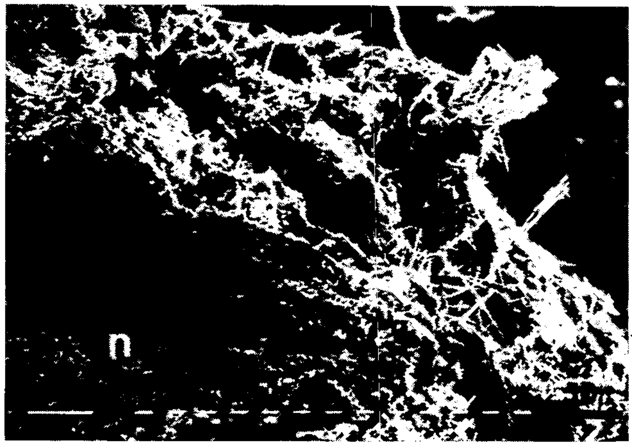

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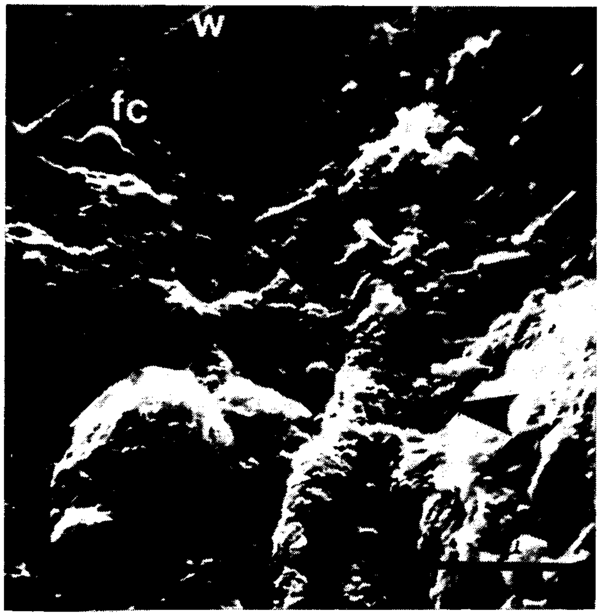

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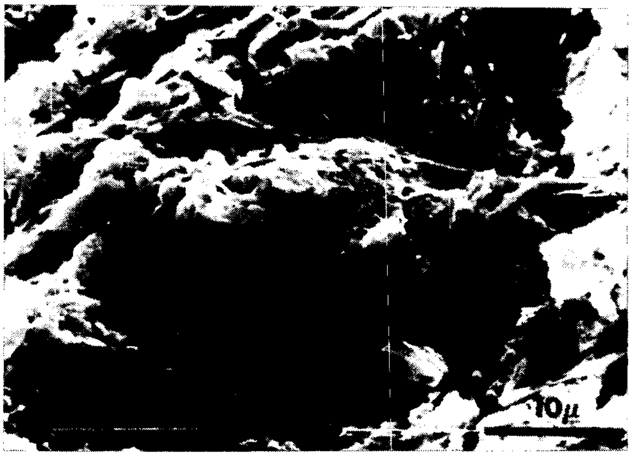

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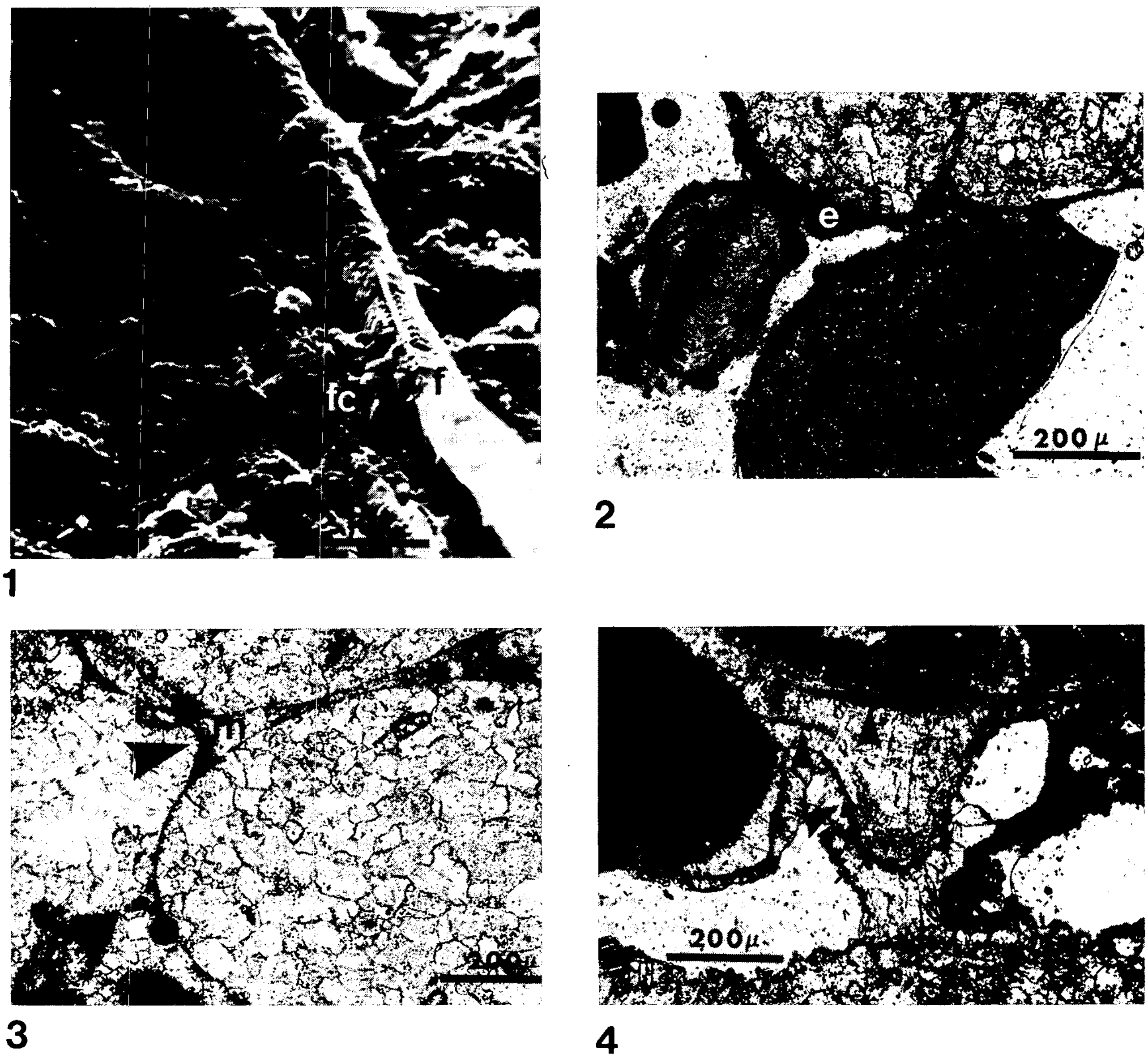

PLATE 3

Phot. 1. Fungi filaments not-collapsed (f) and collapsed (fc).
Phot. 2. Micrite envelope (e) made up of the constructive mechanism showing the variability of the thickness.
Phot. 3. The micrite envelope (arrows) separates the first cementation stage of meniscus cement (m).
Phot. 4. Micrite envelopes (arrows) in diverse stages of growing gravitational cement.

regularities or bumps towards the grain interior (Plate 4-1). If they have a constructive origin the irregularities occur at the outer surface of the grains (Plate 4-2) and the contact envelope-grain is smoth. But frequently it is impossible to determine the origin of the envelope (Plate 4-3. 4-4).

CONCLUSIONS

1. A constructive micrite envelope was developed in the upper part of the vadose continental environment.

2. The constructive micrite envelope in the vadose continental environment is due to the action of the calcified filaments and the micritic-microspar cement. Whisker crystals, microfibres, aggregates of LMC acicular crystals are secondary microtextures.

3. The formation of the constructive micrite envelope will be a first stage of the pisoids formation. A great similarity exits between the microstructures of the constructive micrite envelope and the microstructures of the recent caliche pisoids.

4. The constructive micrite envelope does not indica-

te a specific environment, it can be shallow marine or vadose continental.

5. The constructive micrite envelope produces a reduction of the original interparticle porosity.

6. Some petrographic characters can be mentioned to differentiate, in the fossil record, the different origins (destructive or constructive) of micrite envelopes. The destructive micrite envelopes present irregularities or bumps towards the grain interior and the constructive micrite envelopes present irregularities at the outer surface of the grains.

ACKNOWLEDGMENTS

We are indebted to R. G. C. Bathurst, M. Esteban, E. I. Friedmann, L. Pomar and I. Zamarreño for their helpful suggestions.

The S.E.M. work has been carried out with the help of Ramon Fontarnau from Electronic Microscopic Service of the Barcelona University and of Montserrat Marsal from Metallurgy Department of Barcelona Polytechnic University. We also express our thanks to J.M. Ros who drew the figures.

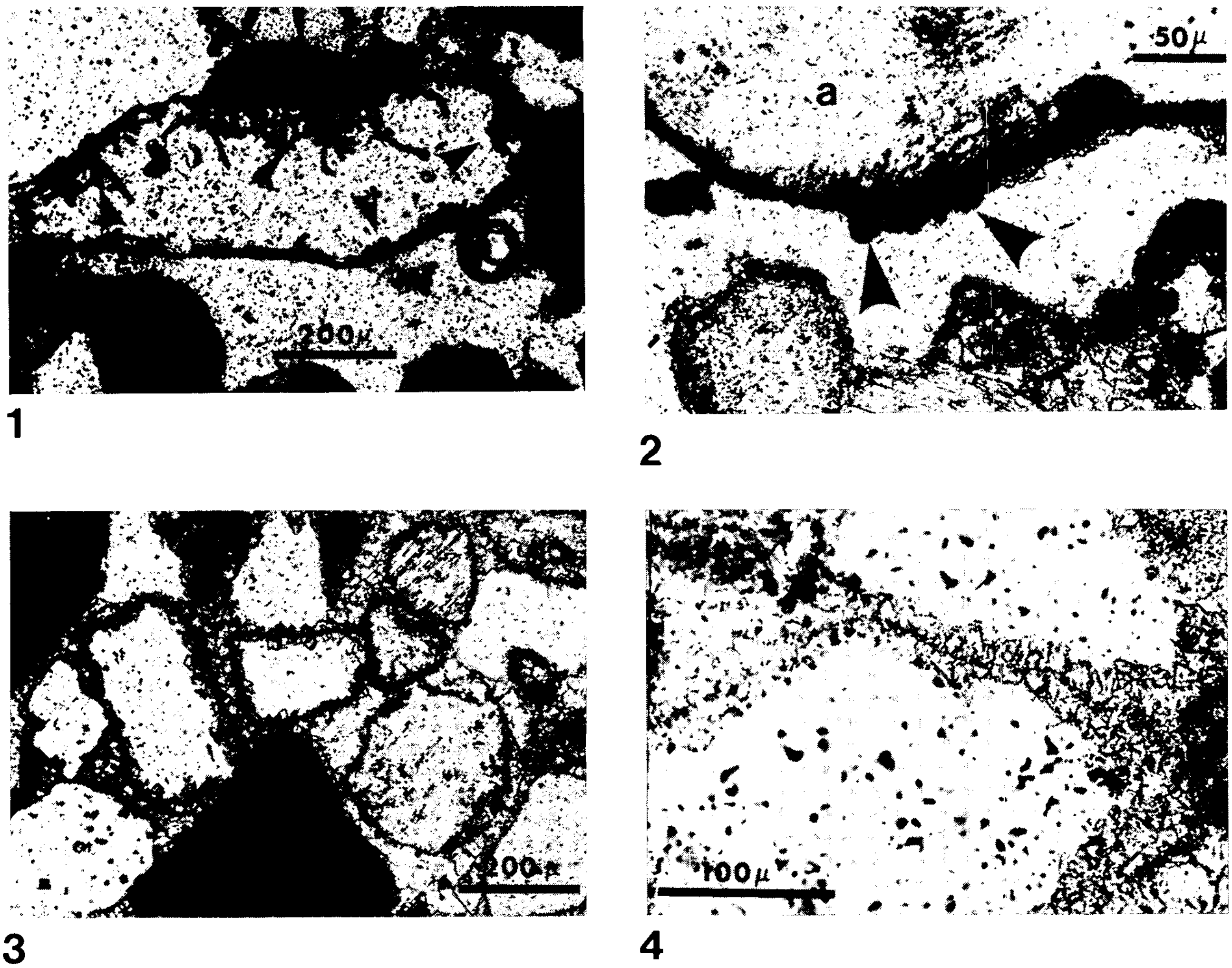

PLATE 4

Phot. 1. Initially aragonite mollusc fragment which has suffered a total dissolution process with the consequent displaying of the micrite envelope and natural casts. Micrite envelopes of destructive origin present the irregularities of the thickness towards the inside of the grain (arrows).
Phot. 2. Constructive micrite envelope on an almost totally dissolved aragonite fragment (a). These types of micrite envelopes show the irregularities of the thickness towards the outside of the grain (arrows).
Phot. 3. Micrite envelopes of an uncertain origin.
Phot. 4. Detail of photo 3, where we observe the micrite envelope and the first generation of cement made up of micritic-microspar rhomboedral crystals of LMC.

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