Cyanophyte Calcification Morphotypes and Depositional Environments (Alenquer Oncolite, Upper Kimmeridgian?, Portugal)

Kalzifikationsmorphotypen und Ablagerungsmilieu von Cyanophyten (Alenquer Onkolith, Oberes Kimmeridgium?, Portugal)

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S U M M A R Y

Terrigenous red siliciclastics of Upper Kimmeridgian(?) to Portlandian age around Alenquer, Portugal, comprise a narrow level of oncoid-bearing limestones. Oncoid cortices are composed of cyanophytes which appear in different calcification morphotypes according to changing physico-chemical parameters. Recent examples reveal that in most cases each calcification morphotype is related to one single species or one defined association. Hence, the characteristic calcification patterns are mostly biologically rather than abiogenetically controlled. Oncoid shapes, sizes and arrangement, on the other hand, are mainly determined by the hydraulic parameter within the depositional environment.

Accompanying biota as well as sedimentological and diagenetic characteristics suggest a combination of paralic, lacustrine, marsh and fluvial environments with salinities ranging from hypersaline to freshwater conditions. This variety of subenvironments was created by a rapid but short-lived transgression into a graben- or half-graben-like subsiding depression along the active fault system of Vila Franca de Xira.

Z U S A M M E N F A S S U N G

Terrestrische rote Klastika des Oberkimmeridgium? und Portlandium in der Gegend von Alenquer (Portugal) führen einen schmalen Horizont von sandigen, onkolithischen Kalksteinen. Der Aufbau der Onkoidrinden erfolgte durch Cyanophyten, welche analog zu rezenten Verhältnissen je nach Lage der physikalisch-chemischen Umweltbedingungen in morphologisch unterschiedlichen Kalzifikationstypen auftraten. Rezentbeispiele zeigen, daß dabei in den meisten Fällen jeder Kalzifikationstyp einer einzigen Algenart oder einer definierten Assoziation zuzuordnen ist und somit die charakteristischen Verkalkungsmuster meist biologisch und nicht rein abiogen kontrolliert werden. Bei den untersuchten Onkolithen wurden die Form, Größe und Anordnung der Onkoide jedoch hauptsächlich von den hydraulischen Ablagerungsparametern bestimmt.

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Begleitfauna und -flora sowie sedimentologische und diagenetische Merkmale deuten auf eine Kombination von Ablagerungsräumen in paralischen, lakustrinen, fluviatilen Bereichen und in Marschen unter einer von hypersalinar bis zu Süßwasser reichenden Salinitätsspanne.

Verursacht wurde diese Vielzahl von unterschiedlichen Milieus durch einen schnellen, jedoch kurzlebigen Meeresvorstoß in eine graben- oder halbgrabenartige Absenkungsstruktur entlang des aktiven Störungssystem von Vila Franca de Xira.

1 INTRODUCTION

The Mesozoic Lusitanian Basin of Portugal, a marginal basin of the slowly developing Atlantic, unterwent intensive silting-up in the course of the Upper Jurassic in an overall southward direction (e. g., WILSON 1979). During the Upper Kimmeridgian and Portlandian, the coast was shifting around a line north of Lisbon. It extended somewhere from Torres Vedras in the west to Alenquer in the east, with the northern part dominated by the clastic regime and grading southwards into marly and calcareous deposits (LEINFELDER 1985).

The general regression is reflected in a sequence of reefoid and lagoonal limestones, the Corálico and the Ota unit, which is overlain by deltaic silts and sandstones, the Sobral unit, and by red terrestrial sandstones and caliche-bearing silts of the Torres Vedras unit. Superimposed are some oncolitic beds, which we term Alenquer Oncolite because they are distributed around the town of Alenquer in the district of Vila Franca de Xira (Fig. 1). The beds are overlain by coarse red siliciclastics of the Upper Sandstone unit which extends to the Cretaceous. Hence, the oncolite beds represent a calcareous intercalation within a siliciclastic terrestrial sequence. Actually, they correspond to the marly calcareous "Pteroceriano" unit developed further south.
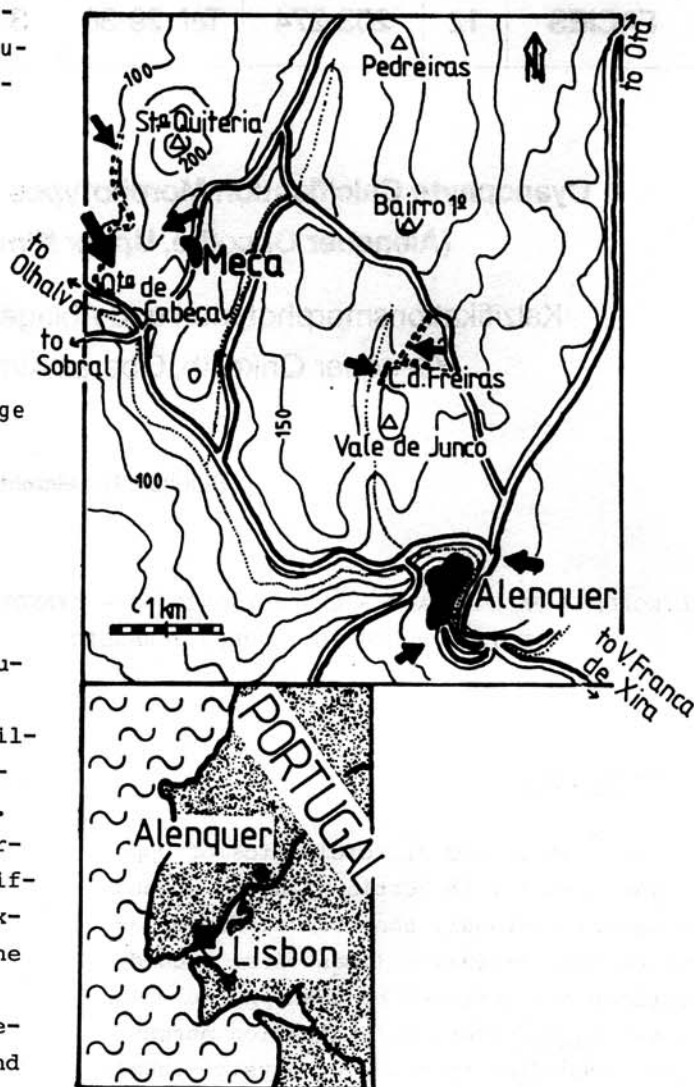

Fig. 1. Locality map. Black arrows, outcrops of the Alenquer Oncolite. Large arrow, location of section shown in Fig. 2.

The purpose of this paper is to discuss this peculiar oncolite under genetic aspects, with special emphasis on establishing and interpreting cyanophyte calcification morphotypes. Furthermore, the development of the oncolites within a continuous terrestrial clastic series reflects an interference in delicate environmental conditions which will be analysed and discussed with regard to their paleogeographic implications.

2 THE HOST ROCK

Brownish gray to predominantly reddish, medium to thick-bedded oncolites form a
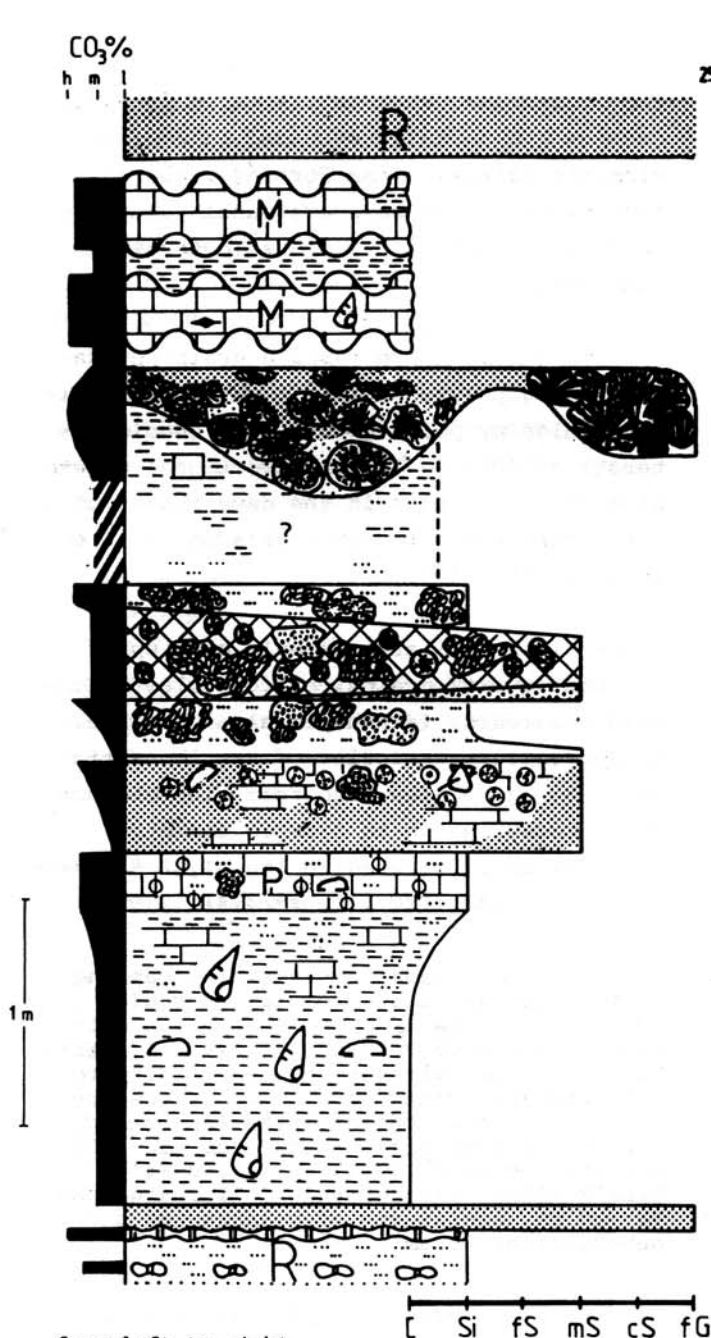
Fig. 2. Detail at Quinta de Cabeça, west of Meca (see Fig. 1): The Alenquer Oncolite, represented here by two horizons of variable thicknesses, embedded in marine to brackish marl and micritic limestone. The entire set is intercalated within red terrestrial clastics. For further explanations see text. Determinations of carbonate and siliciclastic content as well as grain size are qualitative/semiquantitative.

from left to right

<u>Carbonate content</u>

CO_3% l=low, m=medium, h=high

micritic limestone, M=mudstone, P=packstone

sparitic limestone

marl

siliciclastics, a=silt, b=sandstone and gravel, R=red coloration

<u>Components and fabric</u>

gastropods

ostracodes

peloids

radial ooids

Bacinella? sterni nodules

thrombolitic algal lumps

micritic oncoids, *Schizothrix*, *Scytonema* and/or *Dichothrix* Morphotypes

micritic oncoids and algal lumps of the *Rivularia haematites* Morphotype

microsparitic oncoids, mostly of the *Phormidium incrustatum* Morphotypes

caliche nodules

birdseyes

nodular bedding surfaces

<u>Grain size</u>

C=clay, Si=silt, fS/mS/cS=fine/medium /coarse sand, fG=fine gravel

<u>Content of siliciclasts</u>

q% black: free quartz, cross-hatched: encrusted quartz

<u>Size parameters</u>

S_q sorting of free quartz

R_q roundness of free quartz

S_o sorting of oncoids

N_o nucleus of oncoids, q=quartz, o= organic

D_o mean diameter of oncoids, largest values in brackets

2 - 3 meter thick set of two calcareous horizons, which are usually separated by several decimeters of, usually unexposed, silty marl. Occasionally the transition from the clastics to the lower oncolite horizon is represented by one meter of marl with rare tiny cerithiid gastropods, grading into a several decimeter thick bed of silty microsparitic peloid packstone with scattered intraclasts and ostracods. The oncolite set may be overlain by 150 centimeters of gray, nodular, slightly marly, lime mudstone with rare gastropods, isolated spar-filled fenestrae (birdseyes) and irregular shrinkage cracks (Fig. 2). More commonly, however, only the proper oncolites are intercalated into the red clastics or only one oncolite horizon is developed.

Though the oncolites most commonly exhibit distinct bedding planes and constant thicknesses, they may also thin out gradually, display downcutting surfaces or change into sandstone beds. Terrigenous detrital quartz, both free and algal-encrusted, occurs throughout the set, varying largely in amount, grain size and sorting (Fig. 2).

3 ONCOIDS

Oncoids and their clasts may float as individual particles in a sandy, calcareous matrix. More often, however, they form a closed packstone/rudstone fabric. A closed fabric is sometimes restricted to downcuts with fining-up of components in the trough filling, whereas sands lacking oncoids are deposited on the trough shoulders (Fig. 2).

Fractured oncoids and cyanophyte lumps are apparently more common in the lower horizon. In the upper level oncoids may form autochthonous algal pillows characterized by a polygonal component fit.

Oncoid shapes differ widely, yet individual beds are usually dominated by one prevailing shape. Round and ovoid oncoids often form rudstones with a partly spari-

tic groundmass, whereas flattened irregular oncoids are normally embedded in a silty micritic matrix, often forming a closed fabric. Common as well are subcircular oncoids with bumpy protrusions (botryoidal oncoids).

From all of these types a grain-boundary-fitting polygonal fabric may occasionally develop by polar growth into oncoid interstices (Pl. 30/1). Unidirectional growth also rarely results in the development of large stromatolitic structures up to 15 cm in size (Pl. 29/1).

Oncoid nuclei are commonly made up of detrital quartz grains, caliche clasts, oncoid fragments, fan-shaped algal bundles, or aggregates consisting of a bulbous tissue. The aggregates also form discrete nodules measuring up to 3 cm in diameter. They may be attributed to the alga? *Bacinella? sterni* RADOIČIĆ (Pl. 29/3,4).

Bacinella? sterni has vesicles ranging from 40 to 140 μm in diameter, normally 80 um, as can be understood from the original figures of RADOIČIĆ (1972) who attributes the form with great uncertainity to this probably codiacean genus. In the *Bacinella? sterni* nodules of the Alenquer Oncolite, vesicle sizes range from 45 - 105 μm, most commonly 70-75 μm (Pl. 29/4). ELLIOT (1966) interpreted similar aggregates as an intergrowth of cyanophytes and nubecularian foraminifers.

Different sorts of nuclei are related to different oncolite beds. In some localities, the upper oncolite horizon bears considerable numbers of oncoids with nuclei composed of poorly preserved *Chara*-stems (Pl. 29/8). Small, thin-shelled, low trochospiral and planispiral gastropods and thin bivalve shells, serving rarely as nuclei, are also restricted to a few sites only.

Oncoid diameters range from 0.4 to 35 mm, normally 5 to 10 mm. Cortices are generally much thinner than oncoid cores. The lower oncolite horizon, however, may start with a bed of very superficially encrusted quartz grains (Pl. 29/9). Oncoidal cortices display a more or less pronounced layered microfabric. Thicknesses of the individual laminae vary from very fine, several μm

thick coats up to 1 cm thick sheets. Laminae may be smooth, crenulate or show botryoidal protrusions on their distal surfaces. Regular concentric oncoids with smooth outer layers may nevertheless exhibit strongly crenulate laminae in their inner parts (Pl. 30/3). Sometimes laminae are missing on one side of the oncoids.

Thus, the oncoid configuration types C (vertically stacked regular concentric layers), R (randomly stacked subconcentric layers with protrusions) and I (inverted stacked layers with discordances) of LOGAN (1964) and RADWANSKI & SZULCZEWSKI (1966) are developed.

Individual laminae form three main microfabrics, a predominantly micritic, a spongy and a microsparitic/sparitic microfabric.

4   CYANOPHYTE ASSOCIATION

Most of the cortical structures of the oncoids are clearly organogenic, being derived from cyanophyte growth:

Modern calcifying cyanophyte associations have undergone thorough examination during the last decade so that knowledge has increased considerably in this respect. Of special interest are calcifying forms of the Hormogoniae algae. They are characterized by organic filaments with simple structures which reproduce by false branching, due to auto-fragmentation of trichomes, into short, mobile pieces (FOTT 1971).

Most currently cited are the genera *Schizothrix* and *Phormidium* of the order Oscillatoriales and *Scytonema, Calothrix, Dichothrix* and *Rivularia* of the Order Nostocales (taxonomic classification after GOLUBIĆ 1976):

MONTY (1976) reported cyanophyte structures from the freshwater tidal marshes of Andros Island, Bahamas and Shark Bay, Australia, which he attributed to *Scytonema, Schizothrix* and *Phormidium incrustatum*. SCHÄFER & STAFF (1978) investigated freshwater oncolites from Lake Constance, West

Germany formed by *Phormidium - Calothrix/ Dichothrix, Schizothrix* and *Rivularia* cf. *haematites*. MONTY & MAS (1981) described oncoids composed of calcified *Phormidium foveolarum* and *P. incrustatum* from the Bois d' Hautmont Creek, Belgium. SCHNEIDER et al. (1983) mention crusts of *Rivularia* and *Schizothrix* from the Attersee, Austria.

Fossil examples are interpreted in an analogous way: *Rivularia haematites* is described from brackish water oncoids of the Pleistocene in the eastern Mediterranean (RICHTER & SEDAT 1983). Freshwater oncolites exhibiting *Rivularia-* and *Phormidium*-like structures also occur in the Eocene of Spain (ANADON & ZAMARRENO 1981, NICKEL 1983). Oncolites and stromatolites with similar microstructures from the Spanish Wealden (Lower Cretaceous) are also interpreted as freshwater deposits (MONTY & MAS 1981). HUDSON (1970) compared *Cayeuxia nodosa* from Middle Jurassic limestones of Scotland to Recent *Scytonema* and also detected *Schizothrix*-like structures. He suggested a supratidal freshwater marsh environment which occasionally underwent hypersaline conditions.

Since exact taxonomic differentiation of Ancient cyanophyte structures is virtually impossible, particularly in rocks older than the Pleistocene, normally only comparisons with Recent algae are carried out, without attributing the Ancient forms to Recent taxa.

However, when evaluating studies of Recent examples, it becomes evident that certain cyanophytes form certain calcareous morphotypes which may be recognized in the fossil record. *Scytonema*, for instance, never seems to be intensively calcified. It apparently acts as a sediment binder rather than a lime "producer" and often forms a micritic fabric with large fenestrae due to organic decay (MONTY 1976). On the other hand, heavily calcified laminae are preferably produced by several species of *Phormidium*: *P. incrustatum* becomes prominently calcified only in Spring. This enhanced calcification might be dependent upon a sudden increase in alkalinity, a

Calcification of cyanophytes due to	Environmental change (p/T, chem., hydraulic) causing	Resulting in	Calcification change due to
physiological behaviour (CO_2/ HCO_3^- - uptake)	no biotic change	different calcification pattern, same species	abiogenetic factors alone
physiological behaviour (CO_2/HCO_3^- uptake)	establishing of new species	different calcification pattern, different species	new species with differing physiological behaviour (CO_2/HCO_3^--uptake)
non-calcified but calcifying associated microbes	change in the microbial association	different calcification pattern, same species	different microbial association triggering different calcification pattern
species-determined direct calcification	establishing of new species	different calcification pattern, different species	species-determined direct calcification differing from former species

Tab. 1. Possible paths leading to different algal calcification morphotypes in relation to changing environmental parameters. Note that only case 1 would be induced solely inorganically and is possibly not realized in nature. See examples in text.

drop in temperature and a decrease in the magnesium/calcium ratio of interstitial waters, the latter of which is most often due to intermittently agitated bottom waters (CROSS & KLOSTERMAN 1981, see also RIDING 1982). Thus, the species exhibits different calcification patterns related to seasonally differing physico-chemical characteristics.

On the other hand, however, *Phormidium foveolatum* generally occurs only in a coarsely calcified way with crystal orientation determined by the tiny organic filaments (MONTY & MAS 1981). One may theorize that the species is rather micro-environment-selective or that it controls carbonate precipitation directly.

It is widely assumed that calcification of the prokaryote cyanophytes is only a chemical response to organically altered microenvironments, particularly due to CO_2/ HCO_3^- uptake during photosynthesis (e.g. FLÜGEL 1982:336, SCHNEIDER 1976). KRUMBEIN (1978), however, showed that in Recent subtropical cyanophyte mats calcification is managed by bacteria and is not necessarily related to photosynthesis. Moreover, GOLU-BIC & CAMPBELL (1981) could prove that calcification of two Recent marine *Rivularia*

species takes place within the extracellular mucilaginous sheath in such a way that species-diagnostic, biologically controlled carbonate aggregates are produced (Tab. 1).

4.1 CYANOPHYTE CALCIFICATION MORPHOTYPES

It can be concluded that one or a few calcifying cyanophyte taxa lead to a distinct and characteristic calcification morphotype apparently controlled by growth form, by selective environmental and related physico-chemical preferences, by non-calcified microbes, and, at least partially or occasionally, by species-determined direct organic precipitation. Hence, it appears useful to establish distinct calcification morphotypes, most of which are named here after the most typical Recent cyanophyte representative producing a similar fabric: yet we must also bear in mind that other cyanophytes and even chlorophytes may account for the same pattern as well (see, e.g., GOLUBIĆ & CAMPBELL 1981), particularly in the fossil examples.

Nevertheless, a parataxonomic morphological classification based on Recent taxa is preferred to a paleontological "ortho"-taxonomy, since in the present example not only the morphotypes but also their environmental distribution are apparently

Microfabric	Name	Characteristics	Relation in Oncoids	Environmental Interpretation
micritic				
~	condensed *Schizothrix* Morphotype	tangential micritic films of various thicknesses	thin concentric sub-regular films or laminae may occur in any other morphotype as well	high energy fresh-water, continuously covered by water
	Schizothrix Morphotype	thin tangential micritic films (10-20 μm), separated by micro-spar of the same thickness		
	Schizothrix-Scytonema Morphotype	as above, with additional radial filaments (5-15 μm, rarely measurable		
	Scytonema/Calothrix Morphotype A	dense structure of thin micritic radial, partly diverging filaments, generally 0.3-0.4 mm long	mostly regular laminae, often predominant	freshwater, rarely exposed
spongy	*Rivularia haematites* Morphotype	bushes of radially diverging, partly branching sparitic filaments (Ø 20-30 μm) in micrite	isolated bushes within other morphotypes or mono-typic algal pillows	brackish? regularly exposed and flooded
	Scytonema Morphotype B	elongate preferably radial spar fenestrae, 0.2-0.5 mm wide, in micrite. Probably due to organic decay and oriented vadose leaching; individual layers up to 1 cm thick	dominating in small stromatolites	frequently exposed freshwater marsh
	Coccoid Algae Morphotype	micritic, poorly confined clots (Ø 20-50 μm) in microspar	in thin layers, also serving as nuclei or forming algal lumps	non-freshwater environment, probably hypersaline
	Dichothrix Morphotype	radiating, paint-brush like micritic tufts (0.5 mm wide, 2-10 mm high), starting from narrow base; interstices sparitic	often confined to inner parts of the oncoids	pioneer form, partially in hypersaline conditions
sparitic/microsparitic	*Phormidium incrustatum* Morphotype A	strongly calcified (microsparitic) mimic radiating filament bundles, forming fan-arrays with botryoidal protrusions	forming distinct sparitic/ microsparitic rings	hardwater ponds, swamps and channels, flooded intermittently
	Phormidium incrustatum? Morphotype B	neomorphic overprint of type A		

Tab. 2. The cyanophyte calcification morphotypes of the Alenquer Oncolite.

strongly resembling the Recent counterparts.

The ten morphotypes occurring in the Alenquer Oncolite are listed and characterized in Table 2.

4.1.1 MICRITIC MICROFABRIC

Schizothrix Morphotype

The micritic microfabric is most difficult to interpret. Dense films in Recent freshwater oncoids are most often formed by heavily encrusted blooms of *Schizothrix*, an endo/epilithic taxon which micritizes the substratum by boring and triggers calcification by CO_2/HCO_3^- uptake (SCHNEIDER et al. 1983). Micritic rinds may, however, also represent interruptions in the growth of other cyanophytes e.g. *Phormidium incrustatum* or be caused by abrasion (MONTY & MAS 1981). In the latter case, a regular concentric rind will develop. In any case, these rinds, here called *Schizothrix* Morphotype (cf. MONTY 1976, Fig. 21E, 22B; SCHÄFER & STAPF 1978, Fig. 15), mark interruptions of a continuous cyanophyte sheet development due to slightly changing environmental conditions and are most probably related to phases of higher energy.

Rivularia haematites Morphotype

Bushes of radiating spar-filled tubes with diameters of 20-30 μm may form macroscopic pillows composed of densely packed cyanophyte nodules (Pl. 29/2). The documented organism closely resembles *Rivularia haematites* which now occur in lakes, mainly in the splash zone, and rivers but also tolerated brackish and shallow subtidal marine water (*Rivularia haematites*-Morphotype, cf. SCHÄFER & STAPF 1978, Fig. 19; RICHTER & SEDAT 1983, Fig. 4).

Schizothrix-Scytonema Morphotype, *Scytonema/Calothrix* Morphotype A

Micritic laminae composed of erect, often diverging micritic filaments or filament bundles are one of the most predominant laminae types, accounting for the bulk of regular oncoids (Pl. 30/3, 9). They may be compared well compared to Recent micritic cemented *Scytonema* or *Calothrix* crusts (*Scytonema/Calothrix* Morphotype A, cf. MONTY 1976, Fig. 24). Often interpenetrating micritic films form a fine reticulate pattern (*Schizothrix-Scytonema* Morphotype, cf. MONTY & MAS 1981, fig. 12C, 16B).

4.1.2 SPONGY MICROFABRIC

Scytonema Morphotype B

A primary lower calcification led to the spongy microfabric commonly found in large oncoids and small stromatolites (*Scytonema* Morphotype B: cf. MONTY 1976, Fig. 19, 25, 34; MONTY & HARDIE 1976, Fig. 11). Elongate tubular microfenestrae (Pl. 29/1) are most probably due to oxidation of filament bundles as is common in *Scytonema* mats growing in Recent freshwater marshes of the Bahamas. Fenestrae formation is also most probably intensified by internal solution and bioerosion (see MONTY 1976, SCHNEIDER et al. 1983). Further vadose diagenetic solution, as evidenced by internal crystal silt in solution vugs, may destroy the original fabric completely.
Primary and early vadose solution features coupled with a high degree of organic decay indicate that this kind of cyanophyte crust underwent periodic subaerial exposure.

Coccoid Algae Morphotype

Coccoid algae or bacteria may be responsible for layers or even whole nodules of thrombolitic fabric which is mainly created in non-freshwater settings (HALLEY 1976, MONTY & MAS 1981) and is assigned here as the Coccoid Algae Morphotype (cf. MONTY 1976, Fig. 26; FOLK & CHAFETZ 1983, Figs. 2-5). Internal solution of micritic microfabric, however, could also lead to similar structures.

Dichothrix Morphotype

The most common spongy microfabric of on-colites is represented by arrays of radiating, paintbrush-like micritic tufts which start from a narrow base and extend locally up to 1 cm without interruption (Pl. 30/7). Interstices between the individual tufts are filled with clear spar (*Dichothrix* Morphotype: cf. SCHÄFER & STAPF 1978, Fig. 12; GOLUBIĆ 1976, Fig. 4, p. 138).

Originally, the fabric was rather open with empty, non-calcified spaces between the strongly erect growing filament bundles, resembling the modern freshwater cyanophyte *Dichothrix* (Pl. 30/6). Often the *Dichothrix* Morphotype is interbedded between coarse crystalline crusts of the *Phormidium incrustatum* Morphotypes (Pl. 30/8) (see below). Hence, the *Dichothrix*-like cyanophyte may represent a fast-growing pioneer form, with growth starting from selected points on a hard surface layer after changed environmental parameters, radiating and branching rapidly to occupy the available space. Changing environments then led to the re-establishment of the *Phormidium incrustatum* Morphotypes. The fact that oncoid nuclei are often represented by the *Dichothrix* Morphotype also strengthens the pioneer character of the related cyanophyte taxon.

Small dolomite rhombohedrons which occur at times in these core-zones indicate that complete calcification of the crust was perhaps primarily inhibited by an elevated Mg-content which led to later diagenetic dolomite formation (Pl. 30/7). Common is also a collapsed microfabric with algal fragments lying in a sparitic groundmass, often associated with crystal silt. Because of occasionally very straight, often low-angle boundaries of the spar areas, and because structural collapse does not occur in the overlying or underlying laminae, one may assume that gypsum crystals were formed which were subsequently leached (Pl. 30/2).

4.1.3 SPARITIC MICROFABRIC

Phormidium incrustatum Morphotypes A & B

Microsparitic to sparitic laminae are of major importance in almost all oncoids. They are dominant in regular concentric oncoids with quartz nuclei. The upper boundary of the individual laminae often shows convex bumpy protrusions (botryoidal), whereas the lower surface is smooth or indistinct (Pl. 30/3). Laminae also frequently wedge out.

The small crystals composing the crust are arranged roughly radially, forming fan arrays which extinct in diffuse radial lines under cross-polarized light. Normally these cement-like crusts resemble certain caliche or coniatolite deposits (e.g., JAMES 1972, PRUSER & LOREAU 1973, HARRISON 1977, BRAITH-WAITE 1979). Although an occasional vadose diagenetic inorganic accretion during exposure times cannot be excluded completely, CROSS & KLOSTERMAN (1981) impressively demonstrated that radially oriented algal tufts may recrystallize entirely to form neomorphic botryoidal crusts. This explanation is also valid here, since most microsparitic laminae exhibit mimic radiating filament bundles (Pl. 30/8).

A predominantly radial arrangement of microsparitic crystals is also quite visible under the scanning electron microscope (Pl. 30/4). The radiating fabric is crossed by tangential linear voids, representing decayed tangential cyanophyte films. Of special interest are also the frequent round voids (Ø 1-5 µm) which in accordance with Recent examples should represent former organic filaments (Pl. 30/6, compare strikingly similar features from freshwater cyanophyte formations in Green Lake, New-York, as illustrated by EGGLESTON & DEAN 1976, Figs. 4-6).

The fabric may be best compared with similarly calcified mats of modern *Phormidium incrustatum* (*Phormidium incrustatum* Morphotype A: MONTY & MAS 1981, Fig. 18; CROSS & KLOSTERMAN 1981, Fig. 5D).

Note that the taxon determined as *Phormidium incrustatum* in Figs. 7 and 8 in MONTY (1976) is most probably a *Lyngbya martensiana* var. *calcarea* (MONTY & MAS 1981, p. 111, footnote). This might also be the case for the alga pictured in Fig. 11 in SCHÄFER & STAPF (1978), assigned as a probable *Phormidium*, since the tube diameters are too large to justify this generic determination (cf. MONTY & MAS 1981).

Strongly neomorphic crusts (Pl. 30/2) may be termed *Phormidium incrustatum?* Morphotype B (cf. CROSS & KLOSTERMAN 1981, Fig. 4b).

Crusts of the *Phormidium incrustatum* Morphotypes may also exhibit micritic tangential films, attributed to the *Schizothrix* Morphotype, and horizontally elongated, 1 mm wide, 0.5 mm high, spar-filled convex fenestrae, situated on top of or in the upper part of the crusts (Pl. 29/7). These fenestrae could well be compared with chironomid or similar larvae (ANADON & AMAR-RENO 1981, pl. 1/2, MONTY 1976, Fig. 7: note that the scale in the photograph is not 200 µm but 6 mm, after MONTY & MAS 1981, p. 111).

As already outlined above, these crusts probably developed during altered chemical and physical environmental conditions, thus promoting the growth or at least the intensive calcification of a *Phormidium incrustatum*-like form.

Occasional gradual transitions from the *Dichothrix* Morphotype to a superimposed *Phormidium incrustatum* Morphotype (Pl. 30/8) could, however, lead to the interpretation that the same cyanophyte was responsible for the formation of both types of crusts, differing only in the degree of calcification due to different ecological conditions.

Such a point of view automatically leads to taxonomic problems. Prokariotic cyanophyte "algae" are grouped together with bacteria into a common phylum, the Schizophyta (e.g., MASSE 1979), which is a largely asexually reproducing group, so that even for modern taxa the application of the species concept is difficult. Often the pragmatic ecological niche concept (one species - one niche) of HUTCHINSON (1968) is applied. If this concept is logically developed, a difference in environmental conditions and thus in habitat would also imply that two different "taxa" were responsible for the formation of the respective crusts.

Habitat, however, may be broadly defined.

The Recent *Phormidium hendersoni*, for instance, occurs in a variety of coastal environments, yet always produces similar crusts (GOLUBIC & FOCKE 1978).

Nonetheless, a wide range of morphologic variation and transition from one "taxon" to another may also be recognized by the occasional transition from coccoid algal (or cyanobacterial) shrubs to the *Dichothrix* Morphotype (Pl. 29/6). Actually modern bacteria exist, e.g. *Thiothrix, Thioploca*, which appear to be apochlorotic (i.e., unpigmented) forms of cyanophytes, appear in this case *Phormidium* and *Schizothrix* (STANIER & vanNIEL 1941, in TAPPAN 1980:29).

Sparitic, mainly Isopachous, Radial Fibrous Crusts

These 30-70μm thick, clear crusts composed of radially oriented prismatic crystals occasionally occur on top of crusts of the *Phormidium incrustatum* Morphotypes and could be explained as early cementation during an interruption in algal growth or sometimes as syntaxial diagenetic overgrowth starting from the sparitic morphotype and growing into the surrounding micritic lamina.

Most commonly these radial-fibrous crusts occur as simple (rarely double or triple) rings around detritic sand-sized quartz grains in sparitic sandstones directly underlying the Alenquer Oncolite (Pl. 29/9). Because of the rather high regularity of the envelopes, the grains have to be identified as ooids with a radial fabric. In cross-bipolarized light, however, one occasionally detects a fan-like, radially diverging arrangement of microcrystals which also transsects the boundary between adjacent rings (Pl. 29/10) Consequently, these radial-fibrous crusts might also represent strongly recrystallized *Phormidium incrustatum* Morphotypes which obtained their smooth regular surface through abrasion in turbulent water, an interpretation which is also backed up by transitions to *Phormidium*-type oncoids.

Very interesting in this aspect is the modern coastal hypersaline Solar Lake at the Gulf of Elat. Interestingly enough, in the Solar Lake both oncoids with fibrous and transparent layers and radial ooids occur together and also exhibit transitions into each other (FRIEDMAN 1978). FRIEDMAN's interpretation is that the radial ooids are also a product of algal precipitation. This also seems valid for the example given here, yet we are aware that this is probably not a general explanation for the apparently multigenetic existence of radial ooids (for survey see RICHTER 1983).

Further development of calcareous organic nodules was then eventually prohibited by the influx of fine-grained clastics.

5 ENVIRONMENTAL INTERPRETATION

All the cyanophyte calcification morphotypes described here with the exception of the coccoid type are based on modern freshwater counterparts and do not occur in modern marine environments (for restrictions, see above). Bearing in mind that filamentous cyanophytes, particularly the "cayeuxians", occur widely in the fossil record, one must be cautious about transfering modern examples to the past.

Actually, comparable freshwater communities had already existed at least from the Middle Jurassic onwards and remained unaffected until the Recent (HUDSON 1970, MONTY & MAS 1981), whereas cyanophytes almost completely disappeared from marine environments in the course of the Cretacous (BIGNOT 1981, RIDING 1982). Consequently, environmental interpretation of the Alenquer Oncolite cannot be based on the cyanophyte associations alone.

Indications of a predominantly freshwater origin of the oncolites are:
- Recent examples
- good preservation and calcification of cyanophytes. In saltwater environments calcification normally results only in the formation of thrombolitic aggregates.
- charophyte stems serving as oncoid nuclei, rare gyrgonites. (Although modern charophytes may rarely grow in brackish and very rarely even in marine settings, CORILLION 1957. Moreover, they may be easily transported over short distances).

- rare thin-shelled, globoid and **planispi**-ral gastropods resembling freshwater *Val-vata* and *Planorbis* type, serving as oncoid nuclei
- trough fillings and fining-up sequences of oncoids
- common reddish coloration of oncolite beds
- solution features and "vadose" silt
- intercalation of oncolites between clearly terrestrial clastics
- total difference to marine oncoids of the equivalent "Pteroceriano"-unit nearby (LEINFELDER 1985)

Indications of saline influence are:
- oncoid nuclei and whole nodules composed of *Bacinella? sterni*
- thrombolitic oncoid nuclei and nodules
- locally, gray "*Cerithium*" marls at the base of oncolites
- dolomite crystals and questionable pseudomorphs after gypsum in the *Dichothrix* Morphotype
- locally, the top of oncolites formed by marine nodular lime mudstone
- possible connection of the Alenquer Oncolite with marine oncolites, in any case with marine sediments further South

Rare ostracod and bivalve shells are no help in the determination of **salinity.**

Consequently, the section given on Fig. 2 may be interpreted in the following way:

Salinity increased from the basal flood-plain deposits to brackish "*Cerithium*"-marls to eventually more saline basal peloid pack-stones. Freshwater input was then increased considerably as is well documented by the high influx of siliciclastics but was intermittent enough to allow incipient oncoid formation in non-clastically influenced periods. The degree of salinity during these periods is unclear but was certainly variable.

The nodules composed of *Bacinella? sterni* as well as thrombolitic nodules occurring then may have grown under rather saline, perhaps even hypersaline conditions. Together with radial ooids, here interpreted as su-

perficial oncoids, they were swept together to form a subsequently spar-cemented, poorly sorted closed fabric with a high fragmentation rate of *Bacinella? sterni* nodules. The superimposed upper oncolite horizon is very complex. Large parts are represented by outthinning cyanophyte pillows composed of closely packed, boundary-fitting nodules of the *Rivularia haematites* Morphotype. These pillows grew under freshwater or brackish conditions (RICHTER & SEDAT 1983) in a shallow, often exposed position (TAPPAN 1980:59). This algal pillow **swamp,** which **was** free of quartz, was cut by fluvial hardwater downcutting channels in which a particular cyanophyte association composed of well-rounded oncoids dominated by dense *Schizothrix-Scytonema* and *Scytonema/Dichothrix* Morphotypes grew during interruptions in clastic input and possibly during partial subaerial exposure. When heavily flooded, fragments of the surrounding algal pillows as well as coarse to very coarse quartz sand were admixed and components were deposited to form a fining-up sequence.

Renewed marine conditions are once more evidenced by the overlying, very shallow subtidal, restricted marine nodular lime mudstones, before the fluvial regime took over completely.

Other sites of the Alenquer Oncolite show different **characteristics.** Usually, there is no framework of marine deposits which may, however, be due to very early reworking of the overlying clastics.

Again channels are developed fairly often. After they were complete filled up, small domal stromatolites composed of the spongy *Scytonema* Morphotype B occurred occasionally and are preserved in-situ.

Beds with large quartz-cored concentric oncoids composed of smooth fine micritic layers represent fillings of larger channels where oncoids grew under more constant conditions of fairly high energy.

In the nearby suburbs of Alenquer, regularly bedded reddish oncolite beds with framboidal oncoids composed predominantly of an interlayering of spongy *Dichothrix* Morphotype and microsparitic *Phormidium in-*

crustatum **Morphotypes** are typical. Oncoid nuclei are often missing; sometimes, however, they are composed of charophyte stem fragments. Oncoids are frequently flattened or of the I-type and occasionally form a fitting fabric without distinct outer oncoid boundaries (Pl. 29/6). Tiny stromatolites occur as well.

These deposits clearly represent a supratidal algal marsh environment with seasonally flooded ponds and lakes developing on a former clastic fluvial plain. The *Dichothrix* Morphotype-crusts with possible pseudomorphs after gypsum and common vadose solution features developed during dry periods, whereas the *Phormidium incrustatum*-type layers are interpreted as freshwater flooding stages, arising after heavy seasonal rainfalls or fluvial floodings. The oncoids show all the signs of in-situ

growth, such as bumpy protrusions, flat shapes, outthinning or lack of laminae on lower sides of oncoids as well as polygonal component fit.

In-situ growth of oncoids is particularly possible on coarse-grained substrata because of their ability to reflect diffuse light (MONTY & MAS 1981), though it may also occur on fine-grainded sediments, a process which is not fully understood yet (JONES & WILKINSON 1978).

This mixed hypersaline/freshwater algal swamp with many ponds and lakes grades several hundred meters further north into a charophyte freshwater marsh (Vale do Junco, see Fig. 1.).
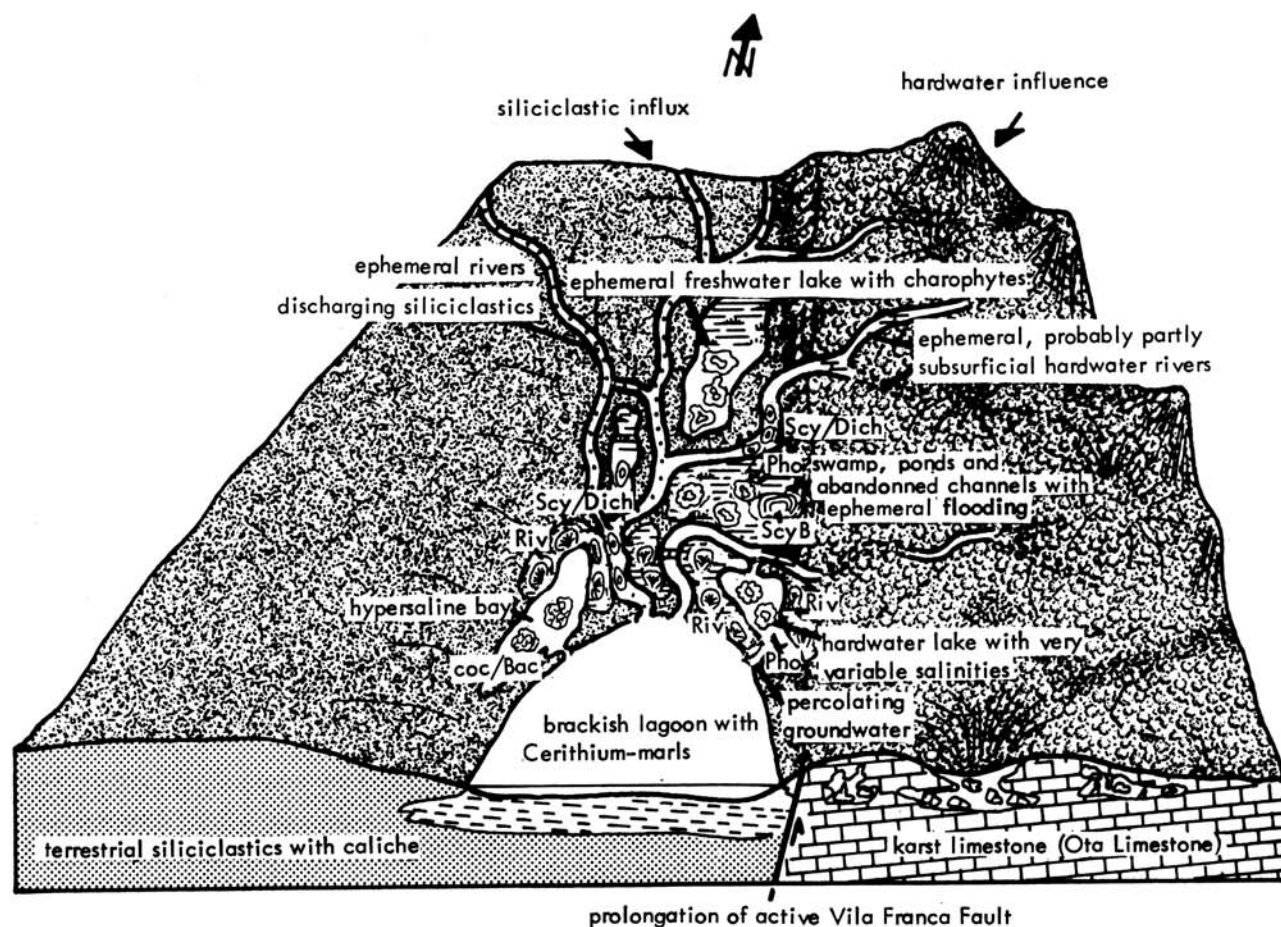

Fig. 3. Depositional environments at the time of oncolite formation and distribution of cyanophyte calcareous morphotypes to different environments. coc/Bac: lumps of the Coccoid Algae Morphotype and *Bacinella? sterni*-nodules; Riv: nodules of the *Rivularia haematites* Morphotype A; ScyB: oncoids and algal pillows of the *Scytonema* Morphotype B; Pho: oncoids dominated by the *Phormidium incrustatum* Morphotypes.

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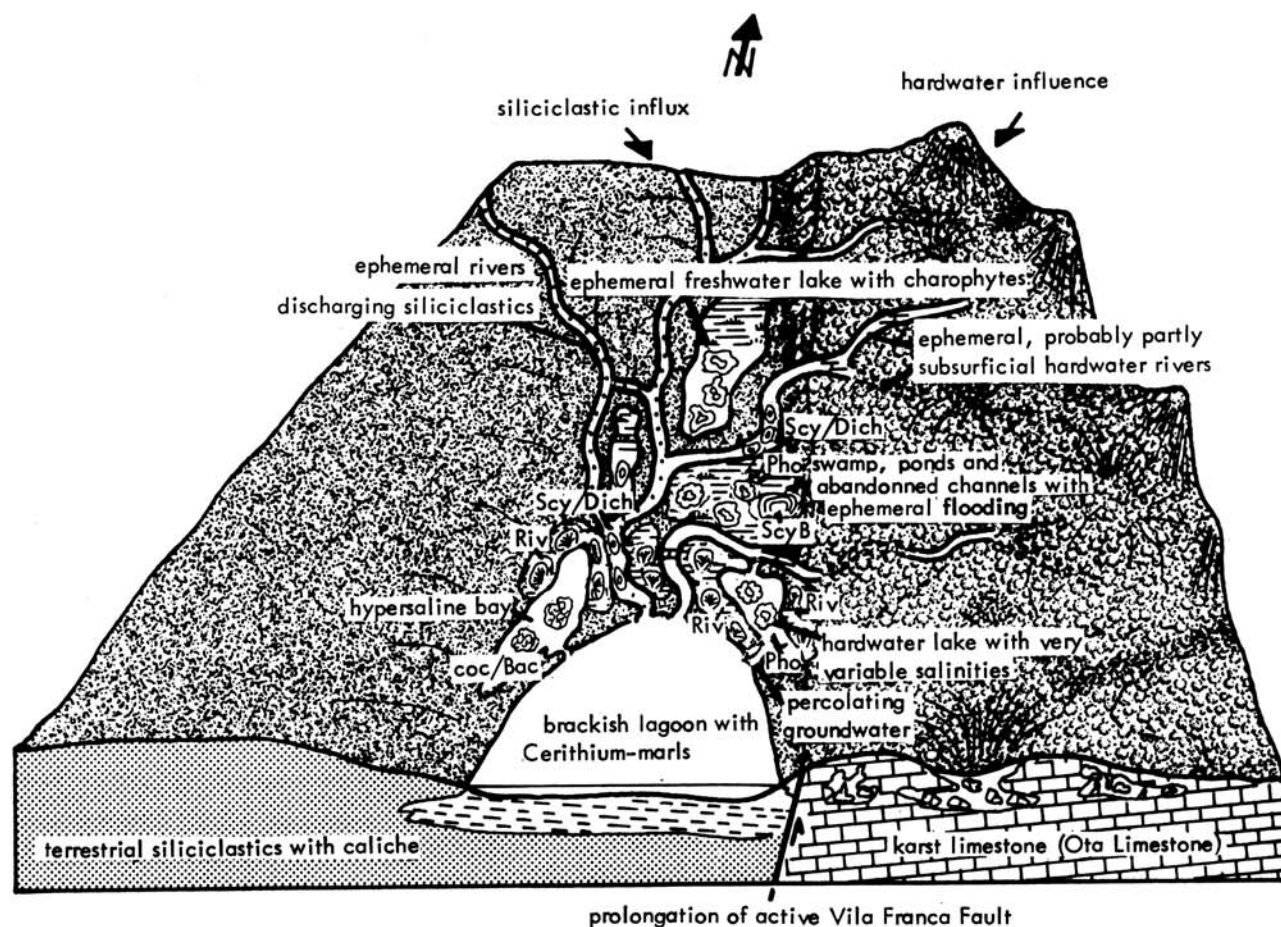

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6 CONCLUSIONS

1. The development of the unique Alenquer Oncolite is restricted to a belt around the town of Alenquer and along the western margin of the Serra da Ota, thus setting very delicate environmental prerequisites for its formation. This formation is most likely structurally related to a graben- or half graben-like subsidence of the area, allowing the sea to prograde locally in an otherwise generally regressive period.

After the initial deposition of lagoonal to estuarine "*Cerithium*" marls, the dominant progression of clastic sedimentation led to paralic-lacustrine conditions in the abandoned lagoonal bay. This happened in such a way that more or less sea-connected, relic, ephemeral lakes and ponds with salinity values varying from hypersaline to freshwater conditions developed in a fluvial/marsh environment (Fig. 3).

2. Oncoids grew during times of clastic non-deposition. The apparently purest freshwater conditions are represented by oncolites with charophyte and *Valvata/Planorbis*-type oncoid nuclei. Partial drying up of some ponds, on the other hand, led to occasional hypersaline conditions as evidenced by dolomite and gypsum? precipitation. Radial ooids, genetically interpreted as superficial oncoids, and *Bacinella? sterni* nodules are also attributed to these conditions.

3. Oncoid shapes are largely controlled by the hydrodynamic and thus physico-graphic characteristics of the depositional environment. Regular concentric oncoids developed in river channels, whereas framboidal oncoid shapes are related to lower energy shallow lake, pond and flooded swamp environments. Low-energy in-situ growth also resulted in the formation of cyanophyte pillows composed of oncoids and nodules with a component-fitting fabric. These pillows and the rarely occurring stromatolites are attributed predominantly to exposed areas, such as river banks, lake shores, swamps, abandoned channels and ephemeral shallow lakes.

4. The oncoid- and nodule-forming organism can well be compared to modern calcifying cyanophytes, if comparison is restricted to calcification morphotypes alone.

The old concept that cyanophyte calcification is determined merely by abiogenetic factors is becoming more and more undermined with the increase in studies on cyanophyte calcification mechanisms. Hence, a shift to another micro-environment would appear to be accompanied by a shift to another calcification morphotype, reflecting the organic response to the altered conditions.

This response may be due to
- a compositional change in the microbial association
- the establishment of a genetically different cyanophyte taxon with similar organic morphologies (filament diameter, radiation pattern), yet with differing calcification or calcification-triggering characteristics, or
- a very high variability in one genotype, with the ability to reorganize itself into different phenotypes (Tab. 1).

Environmental interpretation based on sedimentological and oncoid shape analysis supports the theory that the environmental demands of the morphotypes discussed here have apparently remained fixed since Upper Jurassic times. Hence, the *Schizothrix* Morphotype represents fairly agitated freshwater conditions, whereas the *Scytonema/Calothrix* Morphotypes tolerate frequent subaerial exposure. The *Phormidium incrustatum* Morphotypes represent increased hardwater conditions of moderate to high energy levels and possibly more tolerance of hypersalinity. The *Dichothrix* Morphotype is interpreted as a pioneer type, also highly tolerant of occasional drying-up.

The *Rivularia haematites* Morphotype is commonly found near brackish deposits, suggesting it was predominantly distributed in swamps adjacent to the shoreline.

Finally, the Coccoid Algae Morphotype is most closely related to marine, probably hypersaline environments.

While the use of a morphotype classification based on comparison with Recent taxa is justified for freshwater and coastal environments, the establishing of an analogous morphotype concept for the marine realm is handicapped by the lack of modern counterparts in the same setting. Hence, description of ancient calcareous marine cyanophytes is classically carried out by using "paleontological" taxa, which are, however, also solely determined by the morphological features of their calcareous remains.

For the last years, marine "paleontological" taxa, such as *Cayeuxia, Ortonella, Girvanella* etc., are also compared with modern fresh-water forms (e.g., RIDING 1977a, b, WRAY 1977, SCHÄFER & SENOWBARI-DARYAN 1983), without reasonably giving up the Ancient taxa. SCHÄFER & SENOWBARI-DARYAN (1983), however, also established morphological/ecological form groups ("formgruppen 1-9") for Upper Triassic marine porostromate algae (cyanophytes and some chlorophytes). Astonishingly, different species of one single "paleo"-genus have to be grouped under different form groups, also indicating the artificial character of formal paleotological cyanophyte taxonomy.

Applying SCHÄFER & SENOWBARI-DARYAN's more general form group concept to the here established morphotypes, the *Schizothrix*

Morphotype may be attributed to "Formgruppe 1", the *Scytonema/Calothrix* Morphotype A to "Formgruppe 2", the *Scytonema* Morphotype B to "Formgruppe 4", the *Dichothrix* Morphotype to "Formgruppe 4" or "5", and the *Phormidium incrustatum* Morphotype A eventually to "Formgruppe 5". Naturally, the ecological interpretation of the form groups differs completely from that of the here established morphotypes (see SCHÄFER & SENOWBARY-DARYAN 1983, fig 8).

5. In rivers in warm climates transport of calcium carbonate is hindered by high water temperatures. Hence, the local exceptional availability in the case of the Alenquer Oncolite was certainly due to a sporadically high input of river water carrying dissolved carbonate from a nearby, subsequently eroded limestone province (Fig. 3), which is represented most likely by the uplifted and heavily paleokarstified Ota Limestone (LEINFELDER & RAMALHO in prep.).

The samples illustrated in this paper are stored in the collections of the Institut für Geowissenschaften, Mainz, under GPIM-XS 1-6, GPIM-XP 1-2, GPIM-XH 1 and GPIM-REM 1.

R E F E R E N C E S

ANADÓN,P. & ZAMARRENO,I. (1981): Paleogene nonmarine algal deposits of the Ebro Basin, Northeastern Spain.- In: C. MONTY (ed.): Phanerozoic stromatolites, 140-154, 2 figs., 4 pls., Berlin (Springer)

BIGNOT, G. (1981): Illustration and paleoecological significance of Cretaceous and Eocene *Girvanella* Limestones from Istria (Yugoslavia, Italy).- In: C. MONTY (ed.): Phanerozoic stromatolites, 134-139, 2 figs., Berlin (Springer)

BRAITHWAITE,C.J.R. (1979): Crystal textures of Recent fluvial pisolites and laminated crystalline crusts in Dyfed, South Wales.- Journ.Sed.Petrol., **49**, O181-O194, 5 figs., Tulsa

CORILLION,R. (1957): Les Charophycées de France et d'Europe Occidental.- 499 p., Rennes (Imprimerie Bretonne)

CROSS,T.A. & KLOSTERMAN,M.J. (1981): Primary submarine cements and neomorphic spar in a stromatolitic-bound phylloid algal bioherm, Laborcita Formation (Wolfcampian), Sacramento Mountains, New Mexico, USA.- In: C. MONTY (ed.): Phanerozoic stromatolites, 60-73, 6 figs., Berlin (Springer)

EGGLESTON,J.R. & DEAN,W.E. (1976): Freshwater stromatolitic bioherms in Green Lake, New York.- In: M.R. WALTER (ed.): Stromatolites, Developm.Sediment., **20**, 479-488, 8 figs., Amsterdam (Elsevier)

ELLIOT,G.F. (1966): Algal nodules from the Lias of the Middle East.- Geol. Romana, **5**, 291-301, 3 pls., Rome

FLÜGEL,E. (1982): Microfacies analysis of limestones.- 633 p., 53 pt., 78 figs., 58 tab., Berlin (Springer)

FOLK,R.L. & CHAFETZ,H.S. (1983): Pisoliths (pisoids) in Quarternary travertines of Tivoli, Italy.- In: T. PERYT (ed.); Coated grains, 474-487, 17 figs., Berlin (Springer)

FOTT,B. (1971): Algenkunde.- 581 p., 304 figs., Stuttgart (Fischer)

FRIEDMAN,G.M. (1978): "Solar Lake": a sea-marginal pond of the Red Sea (Gulf of Aqaba or Elat) in which algal mats generate carbonate particles and laminites.- In: W.E. KRUMBEIN (ed.): Environmental Biogeochemistry and Geomicrobiology, **1**, 227-235, 4 figs., Collingwood (Ann Arbor)

GOLUBIĆ,S. (1976): Organisms that build stromatolites.- In: M.R. WALTER (ed.) Stromatolites.- Developm. Sediment., **20**, 113-140, 5 figs., Amsterdam (Elsevier)

GOLUBIĆ,S. & CAMPBELL,S.E. (1981): Biogenically formed aragonite concretions in marine *Rivularia*.- In: C. MONTY (ed.): Phanerozoic stromatolites, 209-229, 2 figs., 3 p., 1 tab., Berlin (Springer)

GOLUBIĆ, S. & FOCKE,J.W. (1978): *Phormidium hendersoni* HOWE: Identity and significance of a modern stromatolite building microorganism.- J. Sed. Petrol., **48**, 751-764, 16 figs., Tulsa

HALLEY,R.B. (1976): Textural variations within Great Salt Lake algal mounds.- In: M.R. WALTER (ed.): Stromatolites, Developm. Sediment., **20**, 435-445, 10 figs., Amsterdam (Elsevier)

HARRISON,R.S. (1977): Caliche profiles: indicator of near-surface subaerial diagenesis, Barbados, West Indies.- Bull.Canad.Petrol.Geol., **25**, 123-173, Calgary

HUDSON,J.D. (1970): Algal limestones with pseudomorphs after gypsum from the Middle Jurassic of Scotland.- Lethaia, **3**, 11-40, 11 figs., Oslo

JAMES,N.P. (1972): Holocene and Pleistocene calcareous crust (Caliche) profiles: Criteria for subaerial exposure.- Journ. Sedim. Petrol., **42**, 817-836, 12 figs., Tulsa

JONES,F.G. & WILKINSON,B.H. (1978): Structure and growth of lacustrine pisolites from Recent Michigan marl lakes.- Journ.Sedim. Petrol., **48**, 1103-1110, 3 figs., Tulsa

KRUMBEIN,W.E. (1978): Algal mats and their lithification.- In: W.E. KRUMBEIN (ed.), Environmental Biogeochemistry and Geomicrobiology, **1**, 209-225, 11 figs., Collingwood (Ann Arbor)

LEINFELDER,R.R. (1985): Facies, stratigraphy and paleogeographic analysis of Upper? Kimmeridgian to Upper Portlandian sediments in the farther surroundings of Arruda dos Vinhos, Estremadura, Portugal.- Mainz, in prep.

LOGAN,B.W., REZAK,R. & GINSBURG,R.N. (1964): Classification and environmental significance of algal stromatolites.- J. Geol., **72/1**, 68-83, 5 figs., Chicago

MASSE,J.-P. (1979): Schizophytoides du CrétacéInférieur. Charactéristiques et Signification Écologique.- Bull. Centr. Rech. Explor.- Prod. Elf-Aquitaine, **3**, 685-703, 3 figs., 3 pls., Pau

MONTY,C.V. (1976): The origin and development of cryptalgal fabrics.- In: M.R.WALTER (ed): Stromatolites.- Developments Sediment., 20, 193-249, 36 figs., Amsterdam (Elsevier)

MONTY,C.V. & HARDIE,L.A. (1976): The geological significance of freshwater blue-green algal calcareous marsh.- In: M.R.WALTER (ed.): Stromatolites.- Development, Sediment., 20, 447-477, 16 figs., Amsterdam (Elsevier)

MONTY,C.V. & MAS,J.R. (1981): Lower Cretaceous (Wealdian) blue-green algal deposits of the Province of Valencia, Eastern Spain.- In: C. MONTY (ed.): Phanerozoic stromatolites. 85-120, 27 figs., Berlin (Springer)

PURSER,B.H. & LOREAU,J.P. (1973): Aragonitic supratidal encrustations on the Trucial Coast, Persian Gulf.- In: B.H. PURSER (ed.): The Persian Gulf, 343-376, 20 figs., Berlin (Springer)

RADOIČIC,R. (1972): *Bacinella? sterni* nov. sp. (Codiaceae?) from the Cenomanian of the environs of Orahovac (Metohija).- Bull. Scient. Yougoslav, Sect. A, 17, 228-229, 1 fig., Zagreb

RADWANSKI,A. & SZULCZEWSKI,M. (1966): Jurassic stromatolites of the Villany Mountains (Southern Hungary).- Ann. Univ. Sci. Budapest Rolando Eötvös, Sect. Geol., 9, 87-107, 6 pls., Budapest

RICHTER,D.K. (1983): Calcareous ooids: a synopsis.- In: T. PERYT (ed.): Coated grains: 71-99, 4 figs., 2 tab., Berlin (Springer)

RICHTER,D.K. & SEDAT,R. (1983): Brackish-water oncoids composed of blue-green and red algae from a Pleistocene terrace near Corinth, Greece.- In: T. PERYT (ed.): Coated grains, 299-307, 4 figs., Berlin (Springer)

RIDING,R. (1977a): Calcified *Plectonema* (blue-green algae), a Recent example of *Girvanella* from Aldabra Atoll.- Paleont., 20, 33-46, 5 figs., 1 pl., Oxford

-- (1977b): Problems of affinity in Palaeozoic calcareous algae.- In: E. FLÜGEL (ed.), Fossil Algae, 202-211, 2 tab., Berlin (Springer)

-- (1982): Cyanophyte calcification and changes in oceanic chemistry.- Nature, 299, 814-815, 1 fig., London

SCHÄFER,A. & STAPF,K.R.G. (1978): Permian Saar-Nahe Basin and recent Lake Constance (Germany): two environments of lacustrine algal carbonates.- In: A. MATTER & M.E. TUCKER (eds.): Modern and ancient lake environments.- Spec. Publ. Intern. Ass. Sediment., 2, 83-107, 22 figs., Oxford (Blackwell)

SCHÄFER,P. & SENOWBARI-DARYAN (1983): Die Kalkalgen aus der Obertrias von Hydra, Griechenland.- Palaeontographica, Abt. B, 185, 83-142, 8 figs., 1 tab., 11 pls., Stuttgart

SCHNEIDER,J. (1976): Biological and inorganic factors in the destruction of limestone coasts.- Contrib. Sedimentol., 6, 1-122, 25 figs., 19 tab., 11 pls., Stuttgart

SCHNEIDER,J., SCHRÖDER,H.G. & LeCAMPION-ALSUMARD,T. (1983): Algal micro-reefs - coated grains from freshwater environments.- In: T. PERYT (ed.): Coated grains, 284-298, 7 figs., Berlin (Springer)

TAPPAN,H. (1980): The paleobiology of plant protists.- 1028 pp., numerous figs and tab., S. Francisco (Freeman)

WILSON,R.C.L. (1979): A reconnaissance study of Upper Jurassic sediments of the Lusitanian Basin.- Ciencas de Terra (UNL), 5, 53-84, 11 figs., 3 pls., Lisbon

WRAY,J.L. (1977): Calcareous Algae.- Developm. Palaeont. Stratigr., 4, 185 pp, 170 figs., Amsterdam

Plate   29   The Alenquer Oncolite (Portugal): Sediment, Oncoids and Algal Nod-
ules, their Microfabrics and Corresponding Calcification Morphotypes.

Der Alenquer Onkolith (Portugal): Sediment, Onkoide und Algenknol-
len, deren Mikrostrukturen und entsprechende Kalzifikationsmorpho-
typen.

Fig. 1.   Stromatolitic cyanophyte pillow, x 0.6. Detail, exhibiting the *Scytonema*
Morphotype B. x 2.5. Freshwater swamp, north of Bairro. Polished slab, GPIM-
XH 1; acetate peel GPIM-XP 1

Fig. 2.   Nodule of the *Rivularia haematites* Morphotype. Brackish to freshwater bay,
lake or river banks, Qta. de Cabeça. Acetate peel, GPIM-XP 2. x 30.

Fig. 3.   Large nodules of the questionable codiacean alga *Bacinella? sterni* float-
ing in a lime-rich sandstone. Hypersaline? bay, Qta. de Cabeca, Thin-sec-
tion, GPIM-XS 1. x 9.

Fig. 4.   Detail of Plate 29/3. x 40.

Fig. 5.   Charophyte stems, rare ostracods and planorbid gastropods (arrow) in a sil-
ty, pelmicritic matrix. x 8.5. Detail: *Chara*-gyrogonite. x 35. Ephemeral
freshwater lake/swamp, north of Vale do Junco. Thin-section, GPIM-XS 2

Fig. 6.   Slightly flattened, spongy oncoid; note indistinct outer boundary. Morphoty-
pe sequence from central region to distal parts: Coccoid Algae Morphotype;
microsparitic *Phormidium incrustatum?* Morphotype B; Coccoid Algae Morphoty-
pe, partially grading into *Dichothrix* Morphotype; thick protrusional micro-
sparitic *Phormidium incrustatum* Morphotype A; *Dichothrix* Morphotype. Sea-
sonally marine influenced hardwater pond, south of Alenquer. Thin-section
GPIM-XS 4. x 3.5.

Fig. 7.   Detail of another oncoid with same sequence of morphotypes as in Plate
29/6. Note spar-filled half-moon voids within and on top of a *Phormidium in-
crustatum* Morphotype A layer, resembling Recent chironomid larvae (white
arrow), and microstromatolitic projections (black arrow). Same sample as
Plate 29/6. x 5.

Fig. 8.   Sandy algal packstone, consisting predominantly of strongly recrystallized
charophyte stems partially encrusted by cyanophytes. Ephemeral river,
south of Alenquer. Thin-section, GPIM-XS 3. x 8.

Fig. 9.   Coated quartz grains, resembling radially structured ooids. c: nodule of the
Coccoid Algae Morphotype. Shoreline of hypersaline? bay, Qta. de Cabeca.
Thin-section, GPIM-XS 4. x 40.

Fig. 10.   Coated quartz grain with radially structured cortex, resembling microspari-
tic cyanophyte layer. Arrow: crystals arranged in fan array. Same sample as
Plate 29/9. x 35.
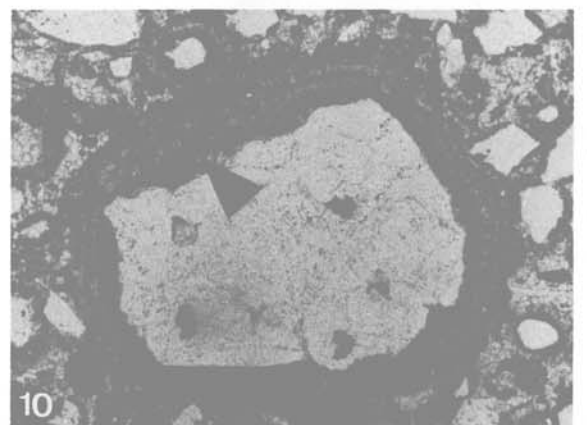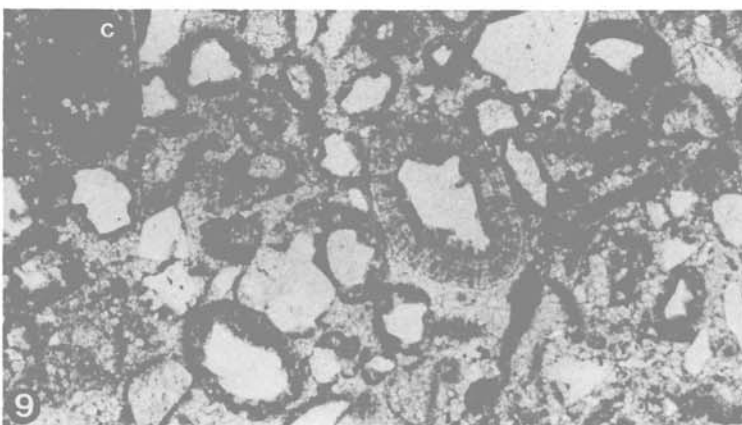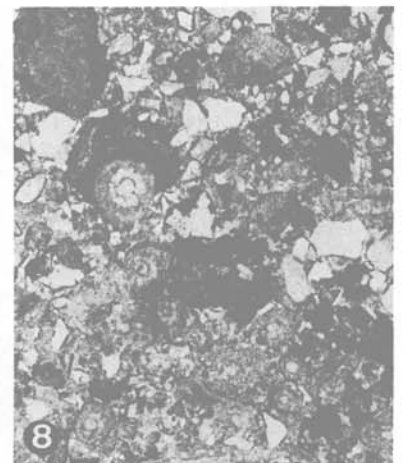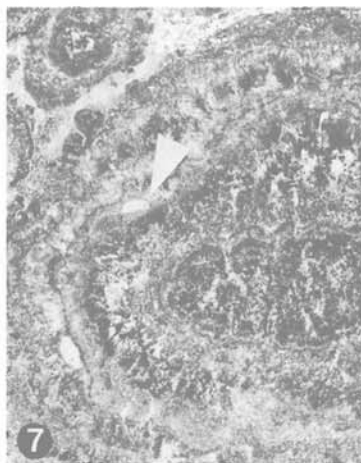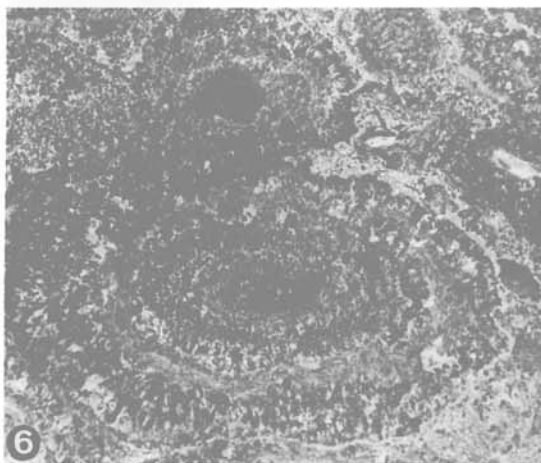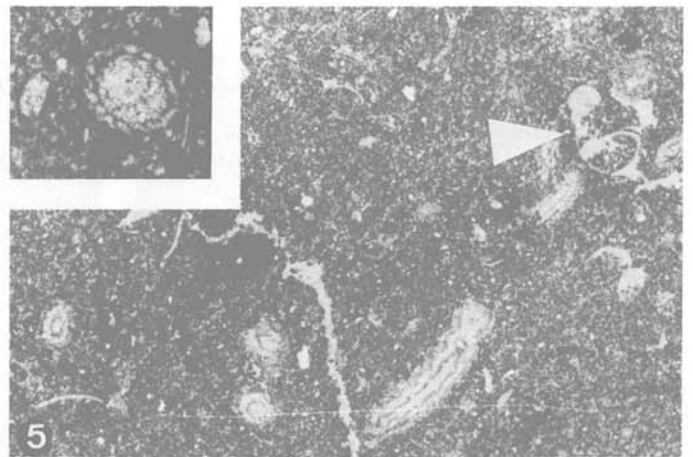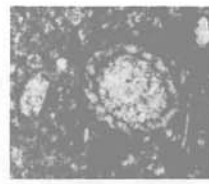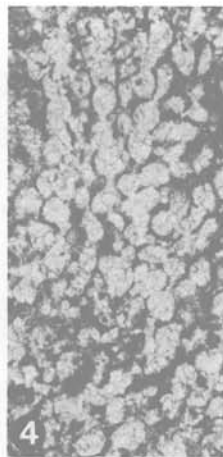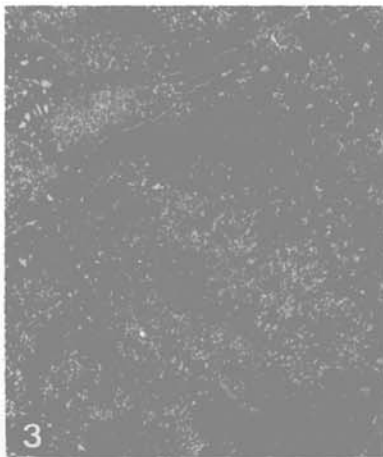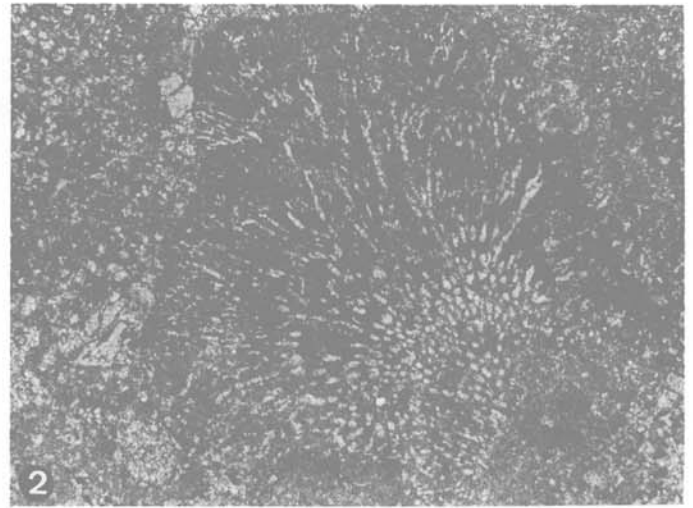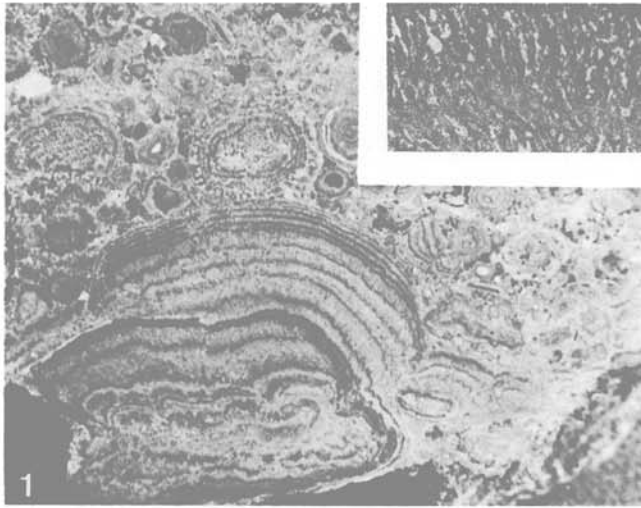
P l a t e   30   The Alenquer Oncolite (Portugal): Oncoidal Micro- and Nannofabrics and Corresponding Calcification Morphotypes.

Der Alenquer Onkolith (Portugal): Onkoidische Mikro- und Nannostrukturen und deren entsprechende Kalzifikationsmorphotypen.

Fig. 1.   Component fitting fabric of oncoids due to cortical digitate protrusion (center). Leached spongy fabric on top. x 5. North of Alenquer. Thin-section GPIM-XS 6. x 4.5.

Fig. 2.   Collapsed *Dichothrix* Morphotype with questionable pseudomorphs after gypsum. Note crystal silt (arrow). Superimposed is a microsparitic/sparitic crust of the *Phormidium incrustatum?* Morphotype B. Same sample as before. x 25.

Fig. 3.   Large regular oncoid. Outer part is mainly composed of the *Scytonema/Calothrix*-Morphotype A (see 9), whereas core area is represented by the *Dichothrix* Morphotype (see 7) surrounded by a protrusional layer of the *Phormidium incrustatum* Morphotype A (arrow). Hypersaline pond (central core), fluvial channel, Qta. de Cabeça. Thin-section, GPIM-XS 5. x 3.

Fig. 4.   Nannofabric of microsparitic crust, exhibiting elongate arrangement of crystals. Horizontal voids probably represent *Schizothrix*-like films (arrow). Qta. de Cabeca. Scanning electron microscope, GPIM-REM 1. x 1650.

Fig. 5.   Microvoids in microspar and spar crystals, representing decayed cyanophyte filaments (arrow). Sample as Plate 30/4. x 875.

Fig. 6.   Detail of oncoidal cortex sequence, from base to top: *Bacinella? sterni* interwoven with cyanophytes (a), overlain by *Scytonema/Calothrix* Morphotype A with *Schizothrix*-like films (b). Superimposed are a thin crust of *Phormidium incrustatum* Morphotype (c) and bush-like tufts of the *Schizothrix* Morphotype with growth starting from selected points (d). Top represented by another *Phormidium*-like crust (e). Note vadose leaching structures on left side. Ephemeral hardwater lake, south of Alenquer. Thin-section, GPIM-XS 6. x 15.

Fig. 7.   Tufts of the *Dichothrix* Morphotype. Note paintbrush-like growth habit and pronounced upward growth. Arrow: Dolomite crystals. Core of oncoid as shown in Plate 30/3. x 27.

Fig. 8.   *Dichothrix* Morphotype, slightly collapsed, intercalated between two layers of the *Phormidium incrustatum* Morphotype A. Note mimic filament bundles (arrow). Hardwater pond, south of Alenquer. Thin-section, GPIM-XS 4. x 20.

Fig. 9.   Micritic fabric composed of the *Scytonema/Calothrix* Morphotype A. Note horizontal micritic sheets representing the *Schizothrix* Morphotype. Cortical region of oncoid as shown in Plate 30/3. x 40.