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Aptian, Albian and Cenomanian microbialites from the condensed phosphatic deposits of the Helvetic shelf, Western Alps

By Michel Delamette[1]

ABSTRACT

In the upper Aptian to middle Cenomanian condensed phosphatic deposits of the Helvetic shelf, small (max. 10 cm thick) microbial buildups (=microbialites) have been detected. There are phosphatic films, stromatolites, oncolites and thrombolitic structures. Detailed correlations between outcrops show that the sedimentation rates partly controlled the development, the shape and the mineralogic nature of the benthic microbial communities. Planar phosphatic microbialites only occur in areas with very low sedimentation rate (i.e. <10 cm $\cdot$ 10^6 y^{-1}); with increasing sediment accumulation, the highly mineralized microbialites grade laterally into columnar microbialites rich in detrital particles. The virtual absence of calcified benthic metazoans closely associated to the microbialites as well as their extensive development throughout the entire shelf may indicate the periodic development of an oxygen-minimum zone in the Helvetic domain.

RÉSUMÉ

Dans les dépôts condensés à phosphorites de l'Aptien supérieur au Cénomanien moyen du domaine helvétique, plusieurs types d'édifices microbiens (=microbialites) de petite taille (max. 10 cm de hauteur) ont été identifiés: des voiles phosphatés, des stromatolites, des oncolites et des édifices strombolitiques. Des corrélations précises entre affleurements montrent que les taux d'accumulation sédimentaire ont contrôlé partiellement le développement, la forme et la nature minéralogique des communautés microbiennes benthiques. Les microbialites planes et riches en phosphate existent seulement dans des zones à très faible taux d'accumulation sédimentaire (<10 cm/10^6 ans); avec un taux d'accumulation croissant, ces microbialites évoluent latéralement vers des formes columnaires riches en particules détritiques et pauvres en phosphate. La quasi-absence de métazoaires benthiques calcifiés étroitement associés aux microbialites ainsi que leur développement extensif sur l'ensemble de la plate-forme témoigneraient de l'existence périodique d'un environnement à oxygène minimum dans le domaine helvétique.

Introduction

During the mid-Cretaceous (Aptian-Cenomanian), condensed deposits including phosphorites were widespread on the shelves of the European Tethyan margin (Delamette 1985, 1988). Most of these deposits contain microbial structures or *microbialites*. According to the recent definition of Burne & Moore (1987), the term *microbialite* refers to "organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment and/or forming the locus of mineral precipitation". Discovered in the condensed Albian Tatric

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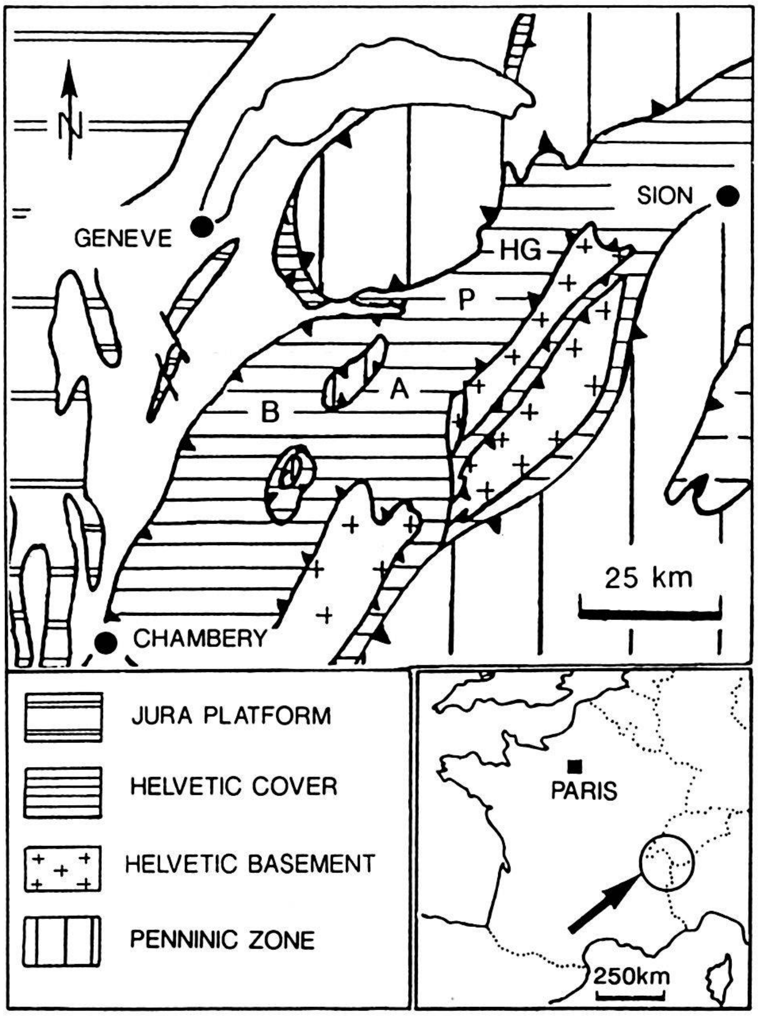


Fig. 1. Location maps (geological sketch map adapted from DEBELMAS & KERCKHOVE 1980). Letters refer to the massifs cited in the text: HG = Haut-Giffre; P = Platé; A = Aravis; B = Bornes.

deposits of Poland by NIEGODZISZ (1965) and described by KRAJEWSKI (1981 a–c, 1983), Aptian-Cenomanian microbialites were also identified in Spain (Betic domain CHAUVE et al. 1968; GARCIA-HERNANDEZ et al. 1982; GONZALEZ-DONOSO et al. 1983), in France (Helvetic domain: DELAMETTE 1981, 1986; North Provençal domain: GEBHARD 1983; COTILLON 1985), and in Switzerland and Austria (FÖLLMI & OUWEHAND 1987).

The purpose of this paper is to give a description of the microbialites found in the Aptian, Albian and Cenomanian deposits of the Helvetic domain between Annecy (Haute-Savoie, France) and Sion (Valais, Switzerland) (Fig. 1).

Geological and stratigraphical settings

During the Mesozoic, the Helvetic domain represented the outer part of a wide shelf including the Jurassian, the Dauphinois and the Helvetic areas. This shelf was bordered to the West and the North by lands such as the Armoric massif and the Bohe-

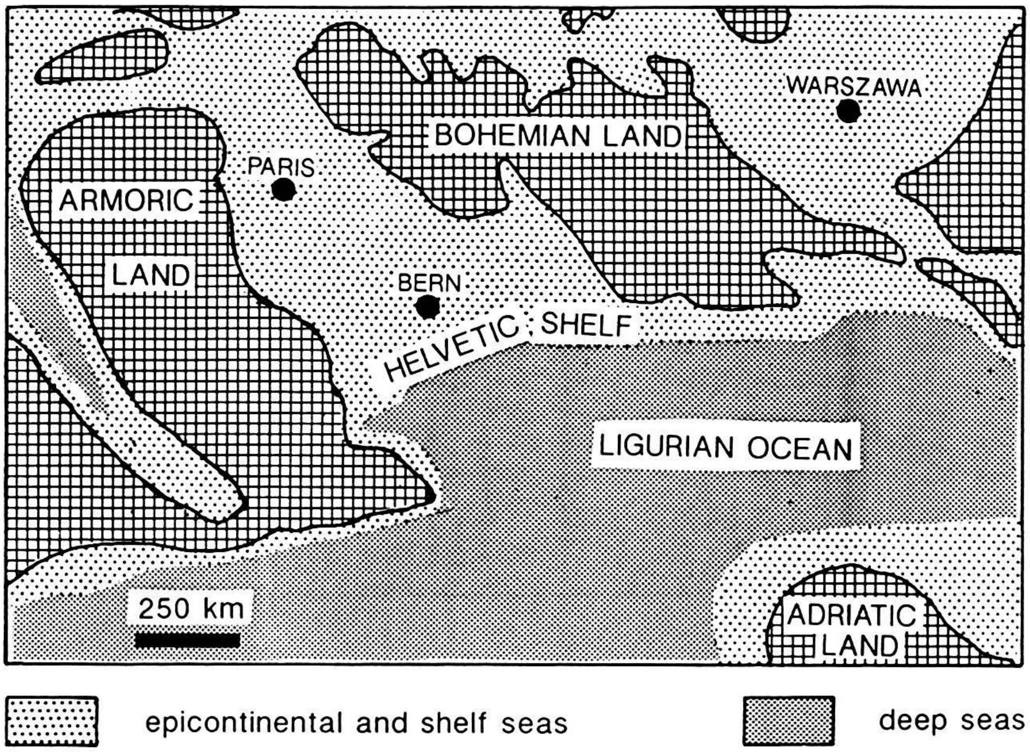


Fig. 2. Mid-Cretaceous palaeogeographic map of the European Tethyan margin to show the position of the Helvetic shelf (adapted from Michalik & Kovac 1982).

mian massif, and to the East and the South by deeper seas such as the Ultrahelvetic basin (Fig. 2).

The microbialites here described are found in thin (5 to 50 m thick) siliciclastic and calcareous deposits rich in glauconite and phosphorites desposited from the late Aptian *(Cheloniceras martinioides* Zone) to the middle Cenomanian *(Acanthoceras rhotomagense* Zone). These deposits rest upon the hardened top of shallow water rudistid Urgonian limestones and are overlain by pelagic biomicrites of Seewen limestones.

Microbialites have been detected within four stratigraphic levels (M1 to M4 in Fig. 3):

- M1 at the base of upper Aptian deposits, incrusting the hardground that caps Urgonian limestones,
- M2 at the base of lower to middle Albian phosphatic conglomerates,
- M3 at the top of lower to middle Albian sandy-phosphatic condensed deposits,
- M4 on phosphatized ammonites and lagnodules of early to middle Cenomanian age.

Morphology and fabric of the Helvetic microbialites

The Helvetic microbialites rarely exceed 10 cm in size, the largest being oncolites of more than 50 cm in diameter (including nuclei of over 40 cm in diameter).

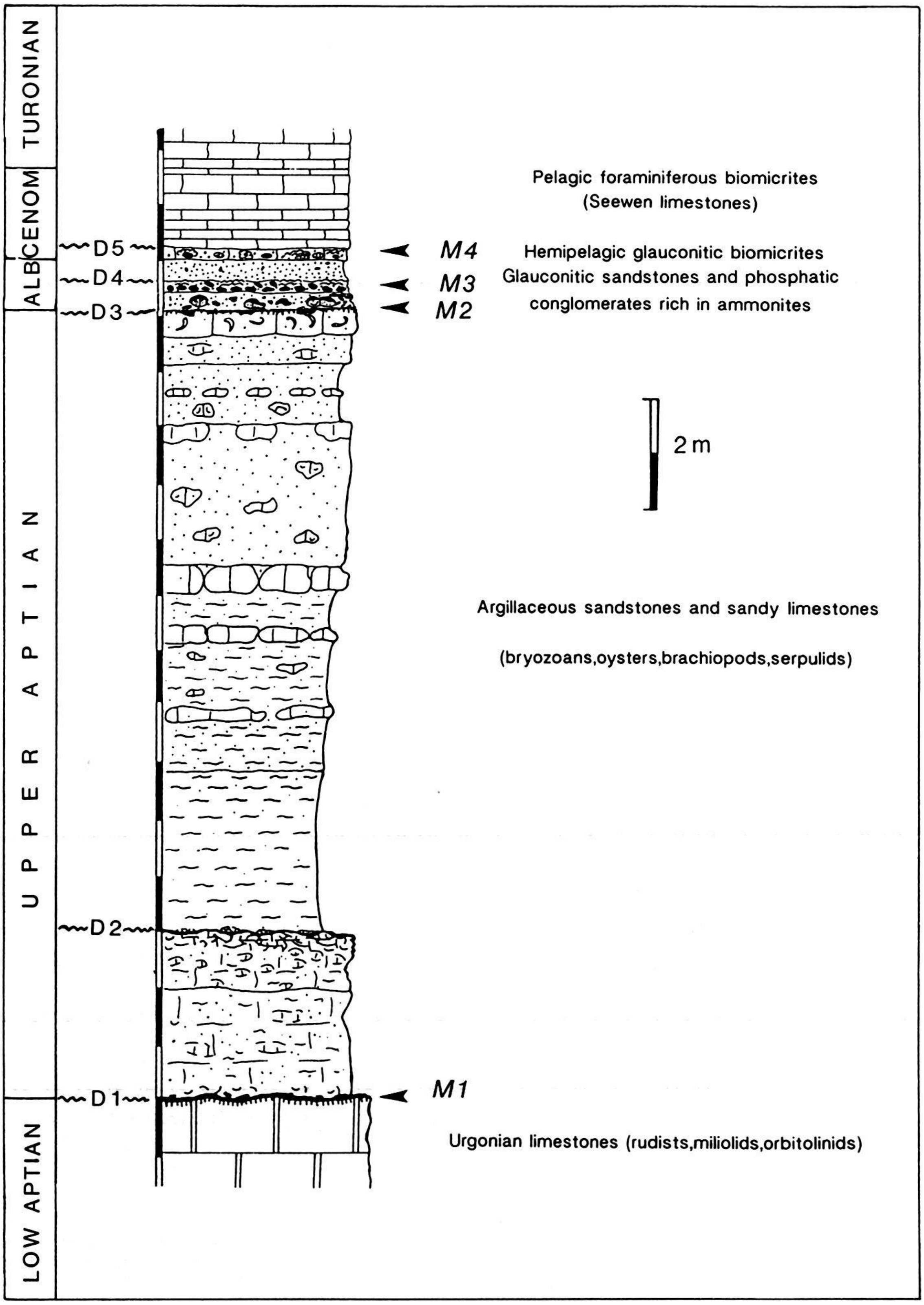


Fig. 3. Section of the Mid-Cretaceous Helvetic series with the stratigraphic distribution of the microbialites (M1 to M4) indicated by arrows. D1 to D5 refer to the main unconformities. Black blobs indicate phosphorites. Note that the microbialites are limited to condensed beds related to the unconformities.

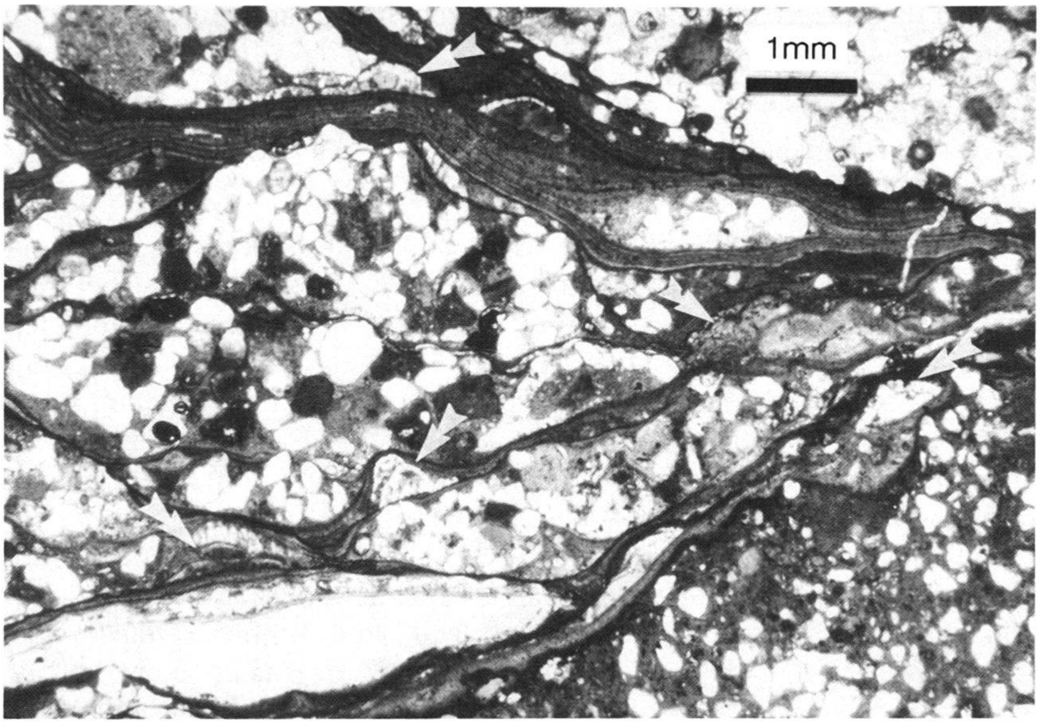


Fig. 4. Microphotograph of Albian phosphatic films anchored on sandy phosphatic basement (lower right corner). Note sessile foraminifera (white arrows) within the microbial structure. (Thin section MD 410a; Fenêtres à Grappins, Haut-Giffre massif).

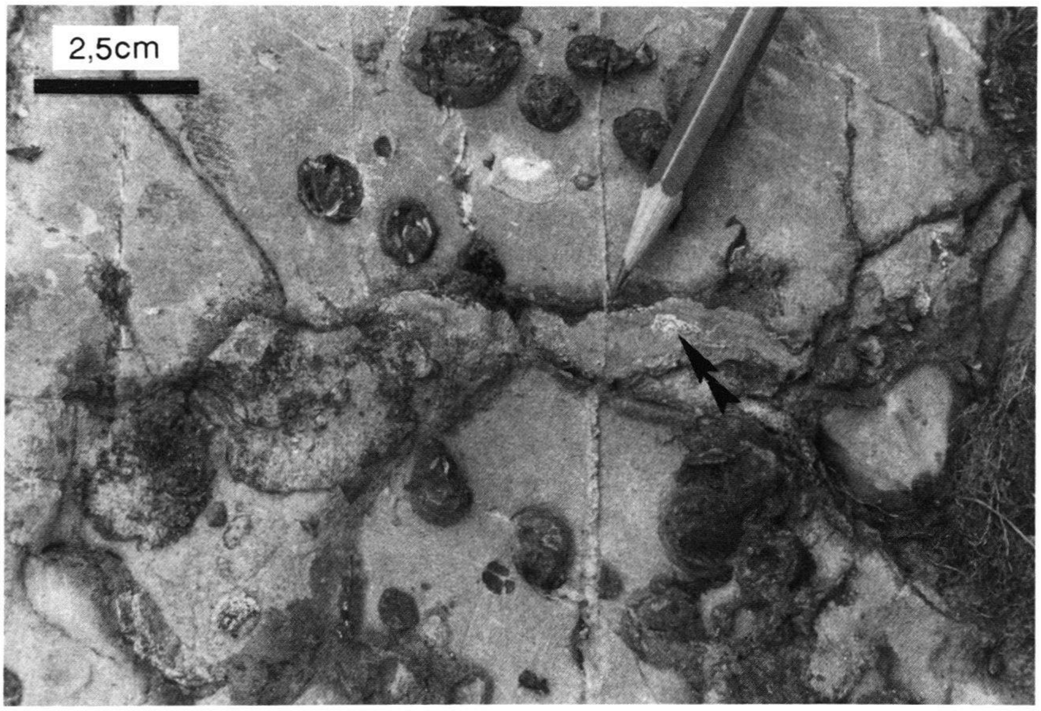


Fig. 5. Upper Aptian stromatolites (at the head of the pencil) encrusting the hardground at the top of Urgonian limestones. This microbial structure is anchored to the phosphatized walls of small pockets filled up by biocalcarenite rich in bryozoans and calcisponges. The arrow points to small serpulids enclosed in the stromatolite. Black circles in Urgonian limestones are phosphatized borings of bivalves (Chalets d'Aujon, Platé massif).

Based on their external shape and their internal fabric, three main types of microbialites are distinguished:

1. phosphatic films,
2. stromatolites (including oncolites),
3. thrombolitic structures.

Phosphatic films consist of millimeter thin coatings that veener upper Aptian lag-nodules and lower to middle Albian phosphorites. These phosphatic structures, often invisible to the naked-eye, are built up by repetitive lamination of micrometer sized individual films, each 10 to 40 μm thick (Fig. 4). The films are enveloping sedimentary particles (e.g. quartz grains) and organisms (e.g. sessile foraminifera and miniserpulids). They bifurcate laterally to enclose small lenses of sediment, sometimes enriched in heavy minerals. At high magnification, some of these films contain remains of horizontally elongated filaments (length 100 μm, diameter 2 μm).

Stromatolites are, by far, the most common microbialites found in the mid-Cretaceous Helvetic deposits. They are known from an area that exceeds several 10^3 sqkm from France to Austria. In the area considered here (see Fig. 1), the upper Aptian stromatolites are detected only in one outcrop. They are represented by small (<5 cm) calcitic mats encrusting the hardground associated with the basal unconformity of the mid-Cretaceous deposits (Fig. 5). The upper Aptian stromatolites are better developed in more distal

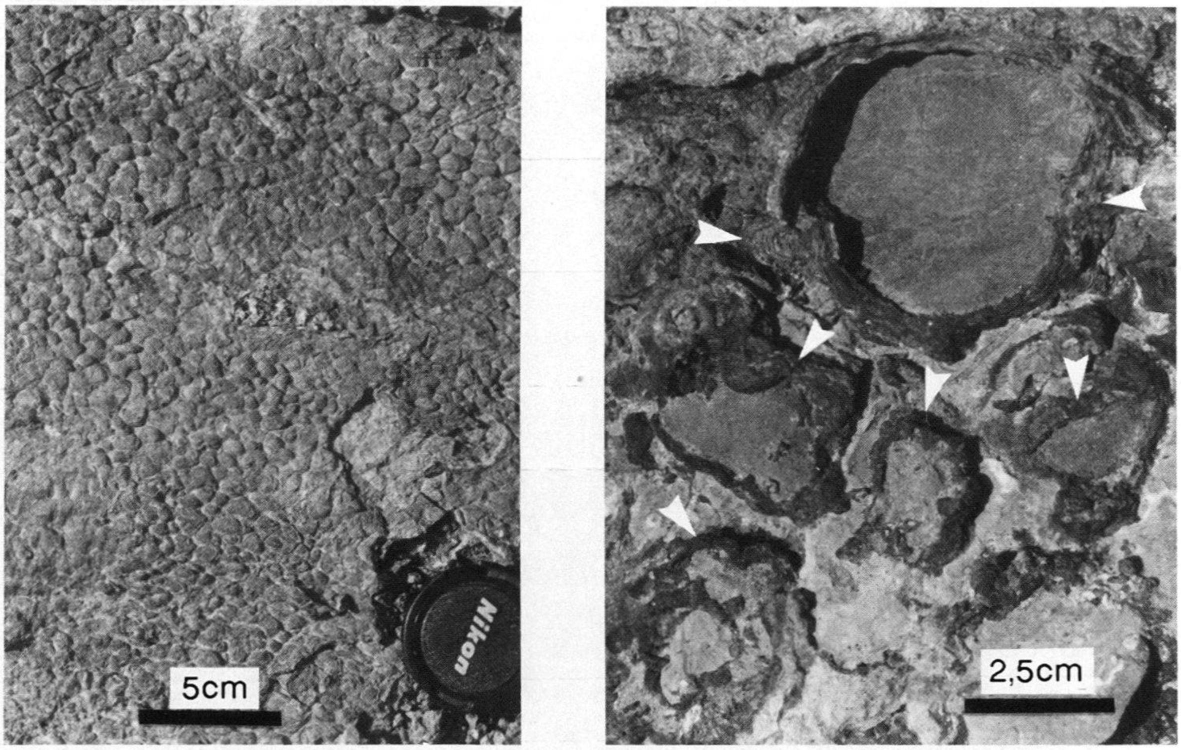


Fig. 6. Lower to middle Albian phosphatic microbialites in the basal conglomerate that overlays the upper Aptian unconformity surface (=D3 on Fig. 3). 6a: stromatolitic mat anchored to the bored top of upper Aptian sandy limestone; 6b: Upper Aptian bored lag nodules encrusted by phosphatic stromatolites (white arrows). (Combe aux Puaires, Haut-Giffre massif).

parts of the Helvetic shelf, i.e. in the Austrian Vorarlberg area where Föllmi (1986) found phosphatic stromatolites including agglutinated sessile foraminifera.

The Albian and Cenomanian stromatolites are more widespread on the Helvetic shelf. In hand specimens, the basic growth form is a small column of 1 to 3 cm width and 3 to 5 cm height. The ratio of height/width ranges from 0.5 to 5. The reticulate forms (i.e. LLH-SH type *sensu* Logan et al. 1964) is the most common growth form and may grade upward or downward to columnar (=SH type) and planar (=LLH type) forms (Fig. 6a). Another widespread growth form is represented by composite oncolitic structures (=SH-SS type). In these composite oncolites, the nuclei consist of upper Aptian lag nodules in the case of Albian microbialites (Fig. 6b) and phosphatic steinkerns of ammonites or ferruginized lag nodules in the case of Cenomanian microbialites (Fig. 7a, b, 8).

All the stromatolites contain phosphate identified as carbonate fluorapatite by x-ray investigations (Delamette 1986). However, the phosphate content is highly vari-

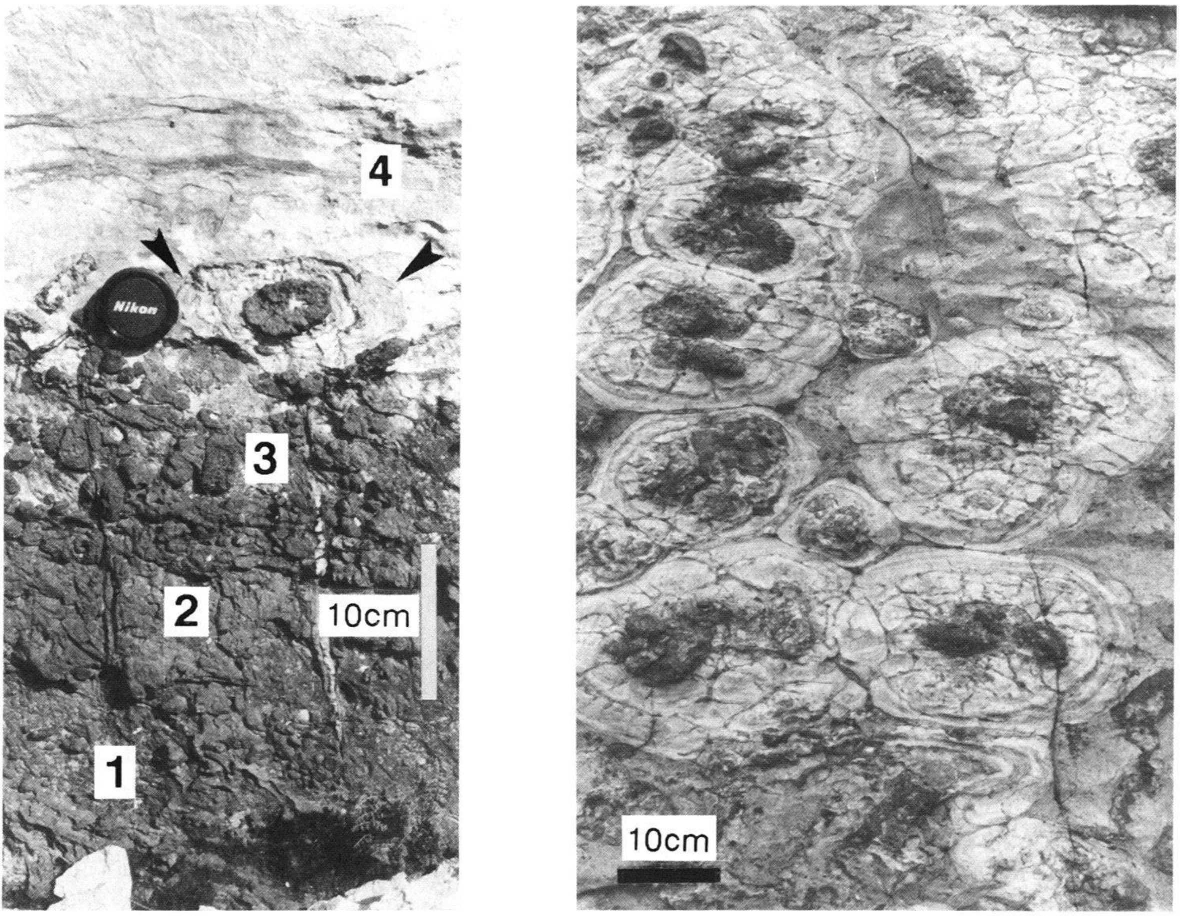


Fig. 7. Middle Cenomanian oncolites. 7a shows the stratigraphic position of the oncolites: 1=lower-middle Albian phosphatic conglomerate; 2=upper Albian phosphatic conglomerate; 3=uppermost Albian and lower Cenomanian glauconitic biomicrites with phosphatic nodules and stromatolites (arrows); 4=upper Cenomanian pelagic biomicrite. 7b illustrates the shape of the oncolites in an horizontal view. Nearly all the oncolite nuclei consist of phosphatized lower Cenomanian ammonites. Two distinct stages of growth can be identified in the oncolite: an early columnar stage and a late planar stage (Rochers des Fiz, Platé massif).

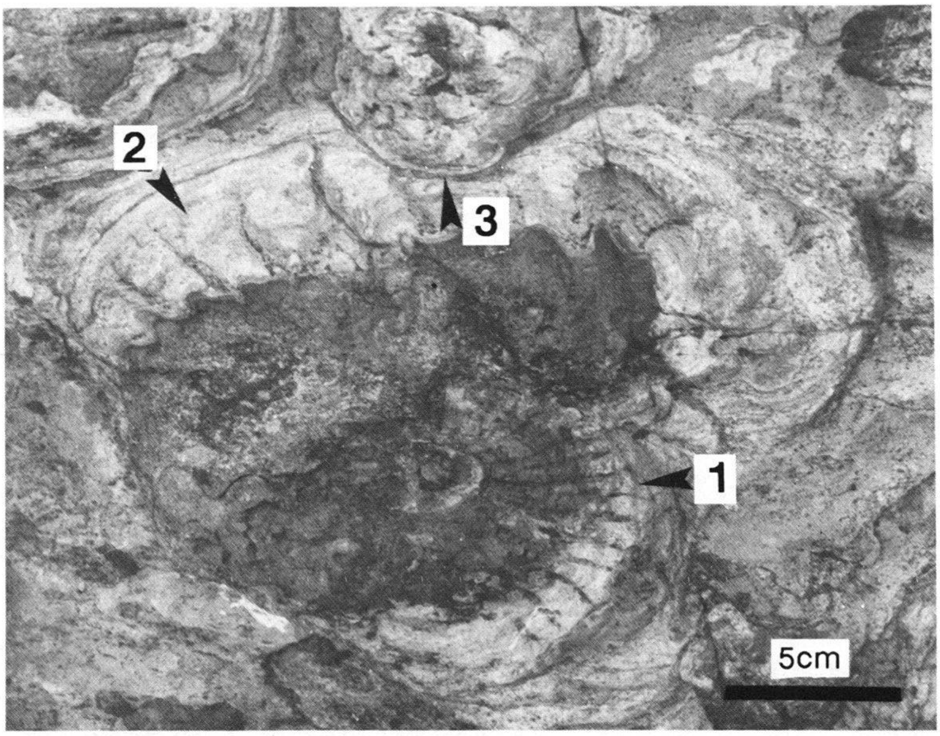


Fig. 8. Close up of the Cenomanian oncolites showing the influence of the nucleus shape on the stromatolitic growth. The early stromatolitic columns are exclusively anchored to the ribs of the ammonites. The size of the columns correlates to the size of the ribs, i.e. they are small in the inner whorls (1) and larger in the outer whorls (2). Note that the upper oncolite has grown before the lower one (arrow 3). This relationship indicates *in situ* growth without any reworking (Rochers des Fiz, Platé massif).

able, the Albian stromatolites being commonly richer than the Cenomanian ones. Based on their dominant mineralogy, four types of stromatolites can be distinguished:

1. *Siliciclastic calcareous stromatolites* are rare and only present in some lower-middle Albian occurrences.
2. *Phosphatic siliciclastic stromatolites* are the most common forms. In the field, they appear as dark microbialites (Fig. 6a, b).
3. *Calcareous-phosphatic stromatolites* are composed of slightly phosphatized biomicrites. The Albian forms commonly contain quartz grains but few glauconite grains. In the Cenomanian forms (Fig. 9a, b), the quartz is subordinate and glauconite grains and bioclasts (i.e. calcisphaerulids and planktic foraminifera) prevail (up to 20%). In some outcrops, these stromatolites show a red colour due to diagenetic ferruginization that affects also the enclosing matrix.
4. *Calcareous stromatolites,* only detected in the Cenomanian deposits, are very difficult to see in the field because they do not contrast with the enclosing micritic matrix.

The internal structure of the stromatolites is usually represented by simple or composite repetitive lamination *(sensu* MONTY 1976), each lamina being millimetric to submillimetric in thickness. However, simple alternating lamination may be also present. No simple correlation exists between the macroscopic lamination and the microscopic

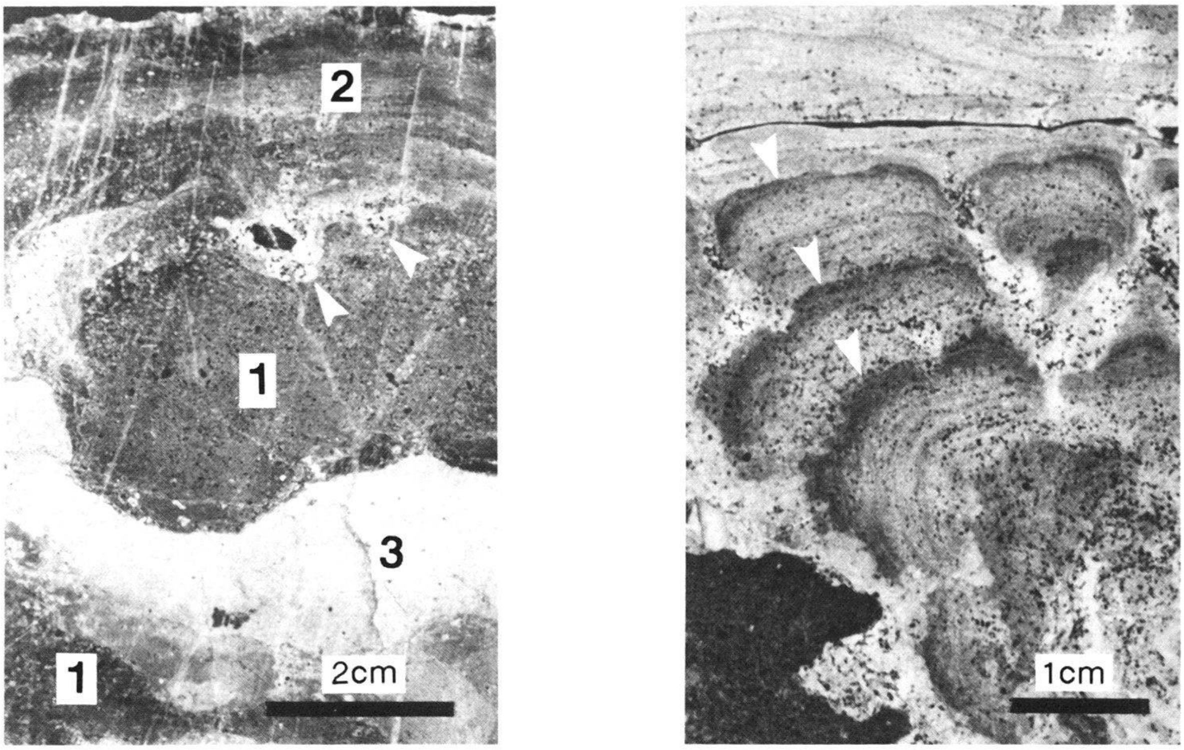


Fig. 9. Polished sections showing the geometry and the internal structure of the Cenomanian stromatolites. 9a: middle Cenomanian *(Rotalipora reicheli* Zone) stromatolites (2) enveloping lag nodule (1). The arrows point to sponges borings. (3) is an upper Cenomanian *(R. cushmani* Zone) biomicrite, filling up a sheltered cavity. The intimate superposition of thin layers of different ages indicates very low sediment accumulation during the stromatolitic growth. 9b: stromatolitic columns rich in black glauconite grains. Note periodic early enrichment in phosphate (arrows) during the microbial growths. 9a is MD 3061 from Sales, Platé massif and 9b is MD 2689 from Chérente, Aravis massif.

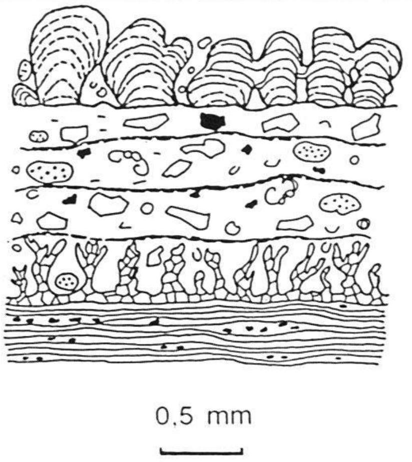
LAMINATION FABRICS	SCHEMATIC ILLUSTRATIONS	MICROBIAL COMMUNITIES
colloformic		coccoid cyanophytes
grain-supported		not preserved
dendroid		erect cyanophytes
microlaminated		filamentous bacteria

Fig. 10. Diversity of the lamination fabrics in the Helvetic microbialites and their biological interpretation.

one: well developed laminations in hand specimens may be invisible in thin sections and vice-versa.

Analyses of thin sections reveal four fabrics within individual stromatolitic laminae (Fig. 10):

1. *A microlaminated fabric* composed of stack of microscopic laminae, 5 to 30 μm thick (Fig. 11a).
2. *A grain-supported fabric* that lacks internal microstructure except for an alignment of elongate particles parallel to the growth surface of the actually extinct mat (Fig. 11b). This fabric comparable to the laminoid boundstone fabric of Monty (1976) is the most common microstructure.
3. *A dendroid fabric* composed of erect microstructures, 200 to 500 μm height and 40 to 80 μm width. These erect structures are usually sparitic (Fig. 12) but may contain phosphate as well as calcite.
4. *A colloformic fabric* composed of many juxtaposed microstromatolites *(sensu* Hofmann 1969) (Fig. 13), each of them built up by a peeling of steeply convex microlaminae of up to 50 μm thickness. The microlaminae are separated from one another by dark microjoints (organic matter ?).

The two last fabrics contain few or no particles except for small dark inclusions which may be pyrite and/or organic remnants.

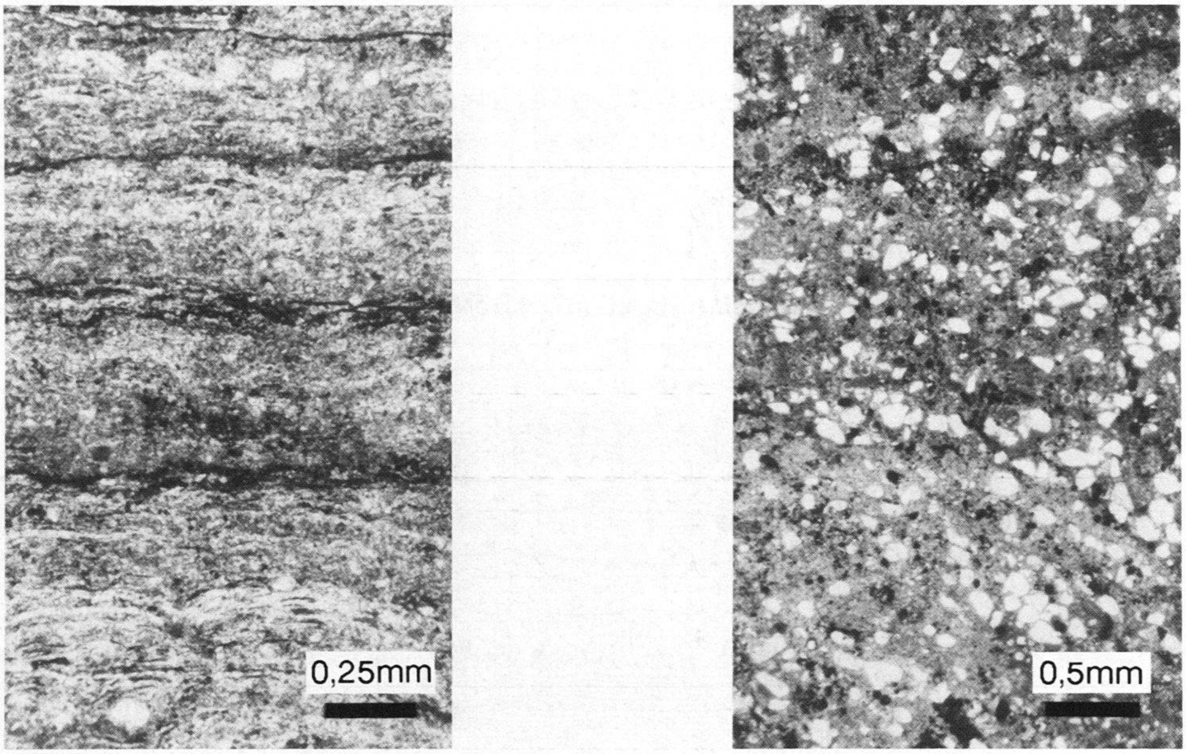


Fig. 11. Lateral evolution of the stromatolitic lamination with increasing sedimentation rate (from left to right). 11a: the lamination is single and repetitive with virtually no trapped particles (microlaminated fabric). 11b: the lamination is hardly visible. Abundant particles, mostly quartz grains, are present within the stromatolite (grain-supported fabric). 11a: thin section MD 2650 from CHE 1 (see Fig. 17). 11b: thin section MD 2638 from CHE 2.

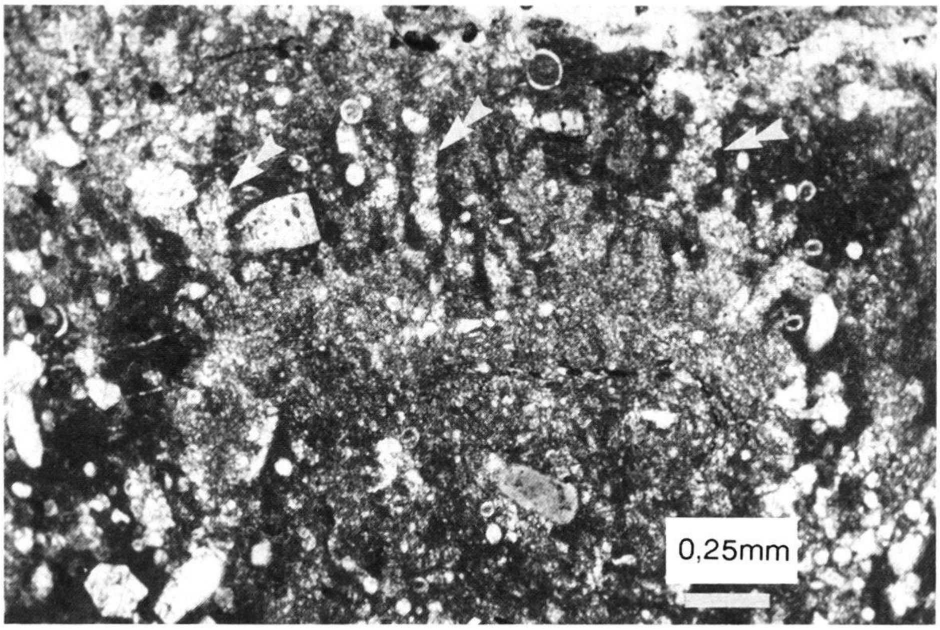


Fig. 12. Dendroid fabric in a Cenomanian micrite stromatolite. The arrow points to erect sparitic microstructures interpreted as fenestras opened in the surrounding micrite after oxidation of an original organic frame. Thin section MD 630b, Sommier d'Aval, Aravis massif.

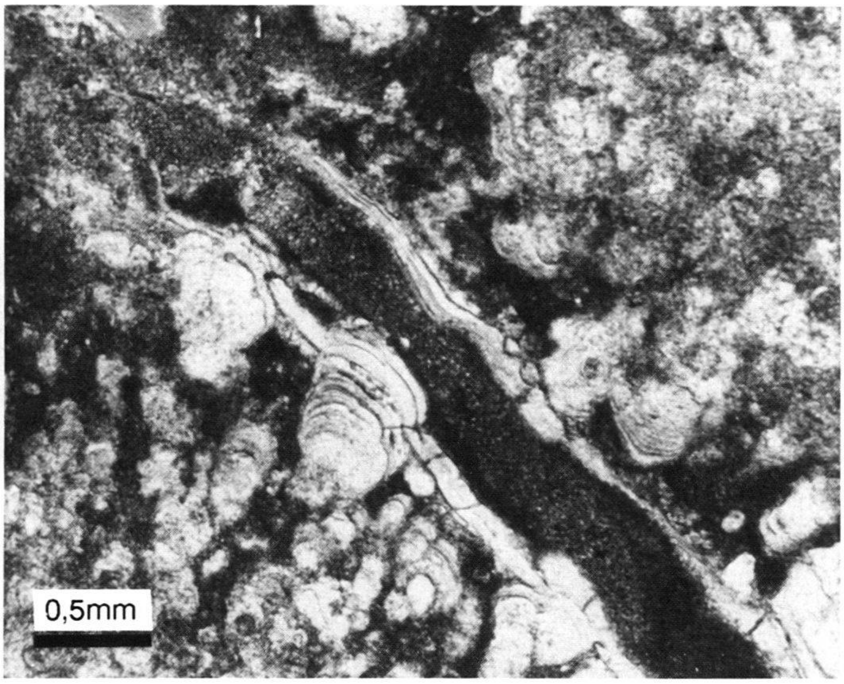


Fig. 13. Phosphatic microstromatolites developed at the periphery of micritic stromatolitic columns (not visible on the picture). The dark band in the center of the picture is upper Cenomanian biomicrite that overlays the middle Cenomanian stromatolite. Thin section MD 754, Sommier d'Aval, Aravis massif.

Thrombolitic structures are characterized by a clotted fabric (Aitken 1967). In the Helvetic domain, they have been detected only in the strongly condensed sections where two kinds of thrombolitic growth are recognized. The first one occurs in close association with the Albian phosphatic stromatolites resulting in composite microbialite which may be named, following Kennard & James (1986), thrombolitic stromatolites (Fig. 14). The thrombolitic structure results from the development of centimeter to millimeter sized phosphatic clots in an enclosing microsparitic matrix. Evidence of their early lithification is indicated by the presence of bivalve's borings sealed by a late stromatolite growth (Fig. 14). The second type of thrombolitic structure has only been observed in internal cavities within the Albian phosphorites and stromatolites. Its microfabric consists of peloids and clots of micrite enclosed in a microspary calcite cement. Most of the cavities containing thrombolites resulted from the boring activity of organisms such as sponges.

Diversity and spatial distribution of the microbialites

On the Helvetic shelf, the spatial distribution of the microbialites is not uniform. During the Albian, the microbialites developed only in areas of very low sedimentation rates where the deposits were almost represented by phosphatic conglomerates only (Fig. 15). These phosphatic areas were surrounded by glauconitic sandy areas without microbialites. During the Cenomanian, the distribution of the microbialites was also

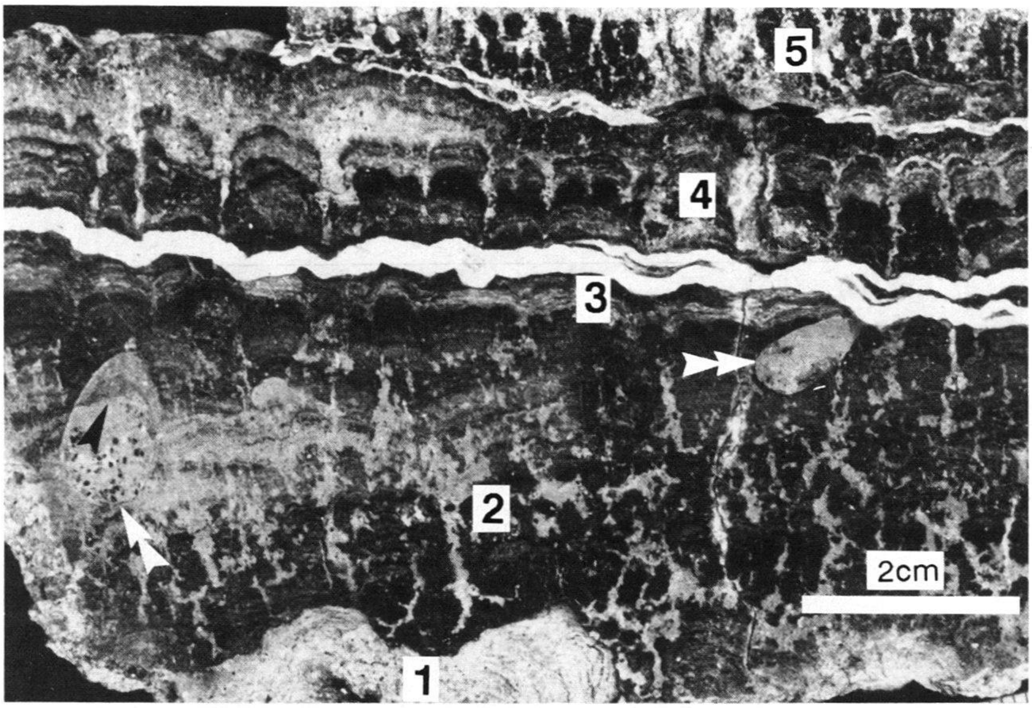


Fig. 14. Composite microbial structure exhibiting multiple microbial stages of growth. From bottom to top: 1 = sandy stromatolite, 2 = phosphatic stromatolitic thrombolites, 3 = phosphatic planar stromatolite, 4 = phosphatic columnar stromatolites, 5 = phosphatic stromatolitic thrombolites. The white arrows point to borings of bivalves, some of them are encrusted by calcitic endostromatolites (black arrow). Polished section MD 2313, Combe aux Puaires, Haut-Giffre massif.

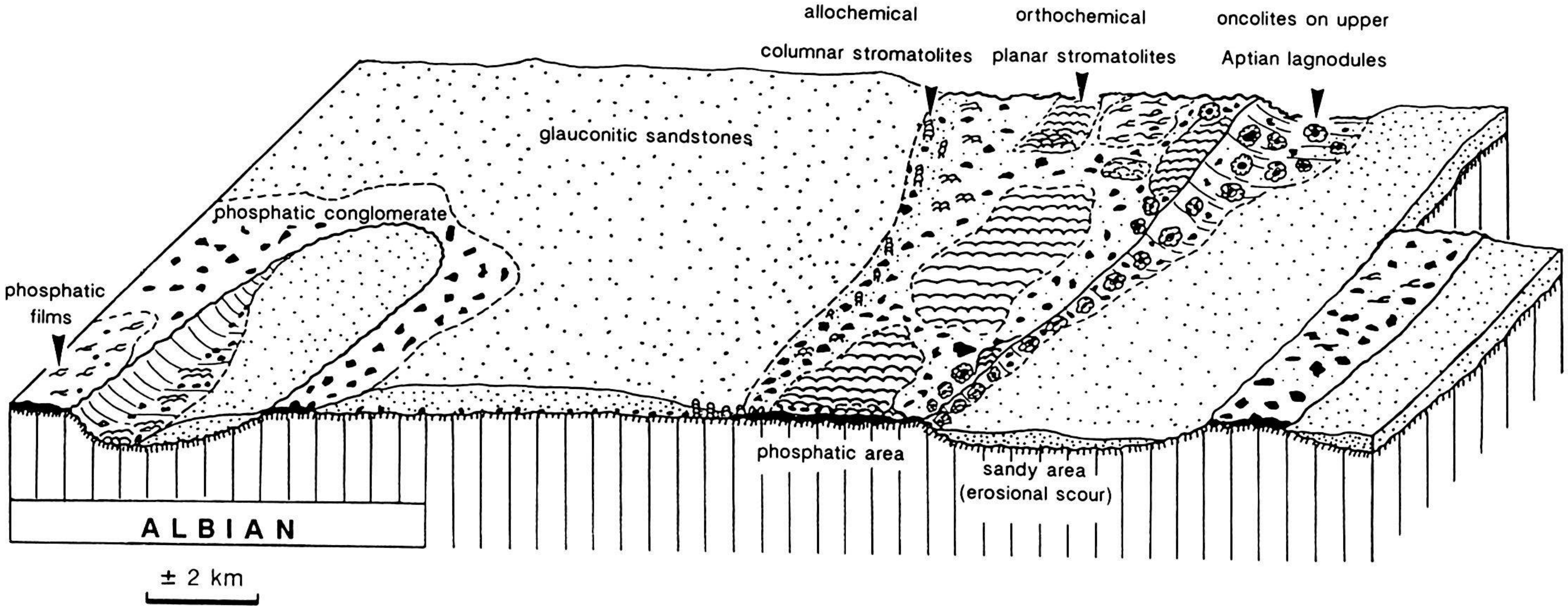


Fig. 15. Schematic distribution of the Albian microbialites on the Helvetic shelf (without vertical scale).

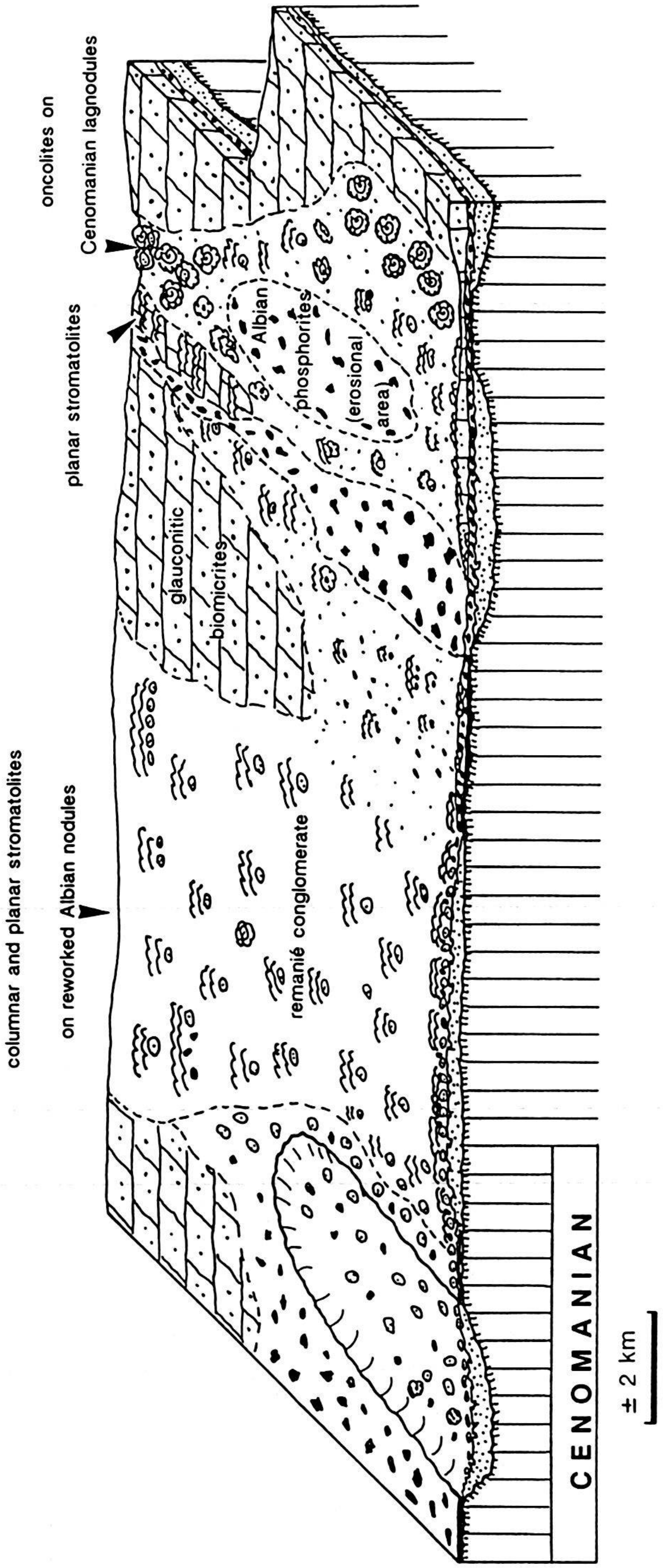


Fig. 16. Schematic distribution of the Cenomanian microbialites on the Helvetic shelf (without vertical scale). Note the extensive development in comparison with the distribution of the Albian microbialites (Fig. 15).

patchy but more extensive because of the general decrease in sediment accumulation rate throughout the entire shelf (Fig. 16).

In order to illustrate the factors that influenced distribution, mineralogic nature and shape of the microbialites, two examples are described below.

Morphological and mineralogical variations with increasing sedimentation rate: the example of the Albian stromatolites of Chérente

In the northern part of the Aravis massif (see Fig. 1), the lower to middle Albian deposits show a thickening from the South (outcrop CHE 1) to the North (outcrop CHE 4) in a distance of about 500 m (Fig. 17). In the same time, the shape of the stromatolites changes from planar structures in the most condensed outcrop (CHE 1) to columnar structures (outcrops CH 2 and CHE 3). The columnar stromatolites evolve from low and wide columns to high and narrow columns (ratio H/W ≃ 5). In the northernmost outcrop (CHE 4), stromatolites are lacking. Besides these lateral changes of the morphology of the stromatolites, the thin sections study reveals that the laminae of the planar buildups are nearly free of detrital particles, and consist of phosphate and calcite (Fig. 11a). According to Monty (1973), these planar stromatolites are orthochemical forms, i.e. they mineralized by mineral precipitation. On the contrary, the columnar buildups contain a great amount of quartz grains and bioclasts (Fig. 11b) and are allochemical forms, i.e. they mineralized by trapping and binding of detrital particles.

These observations show that the microbial colonies adapted to the increasing sediment accumulation by reducing their horizontal growth in favour of a vertical growth. This change in growth patterns prevented the burial of the microbialites. Par-

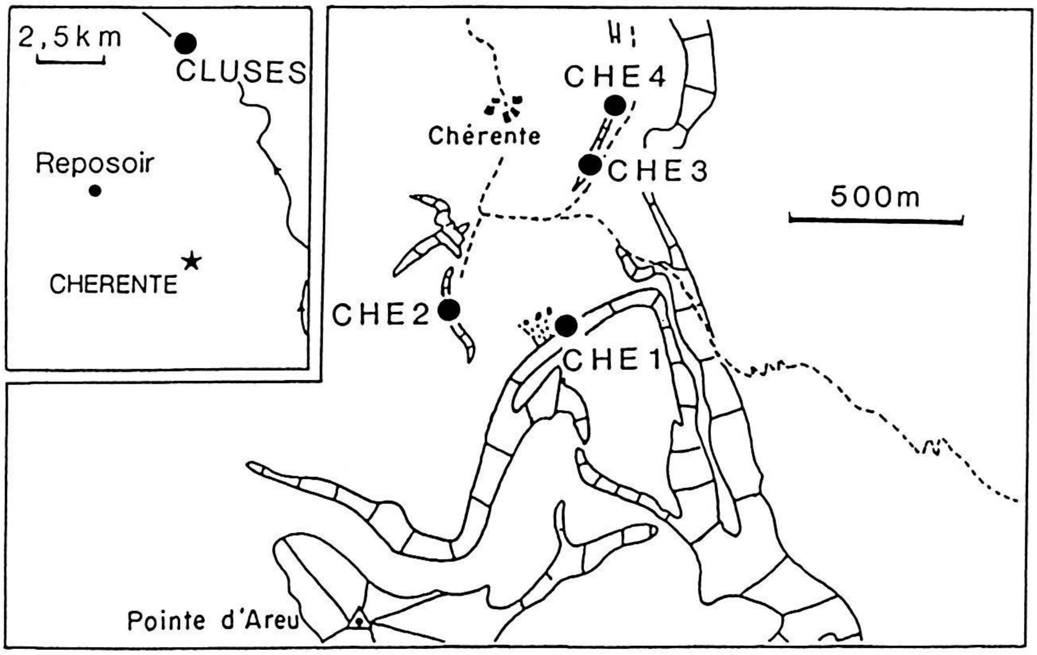


Fig. 17. Location of the Chérente outcrops (CHE 1 to CHE 4) in the northern part of the Aravis massif (Haute-Savoie). Broken lines indicate foot paths; hatchings are walls of Urgonian and Seewen limestones.

allel to this morphological change, the stromatolites evolved from orthochemical planar forms to allochemical columnar forms. This lateral evolution is schematized in Figure 18.

Composite and multiple microbial growths near sea-bottom topography: the example of the Albian-Cenomanian microbialites of the Combe aux Puaires

In the northern part of the Haut-Giffre massif (see Figs. 1 and 19), the outcrop of the Combe aux Puaires exposes the western limit of an erosional scour cut into the upper Albian deposits. During the Albian and the Cenomanian, two kinds of series were deposited:

- a relatively expanded Albian sand-rich series capped by Cenomanian biomicrites within the erosional scour (Fig. 2);
- an ultracondensed Albian phosphate-rich series lacking superposed Cenomanian deposits outside the erosional scour.

In the phosphate-rich series, the microbialites are numerous and make up most of the Albian deposits. Nearly all microbial types are represented ranging from planar

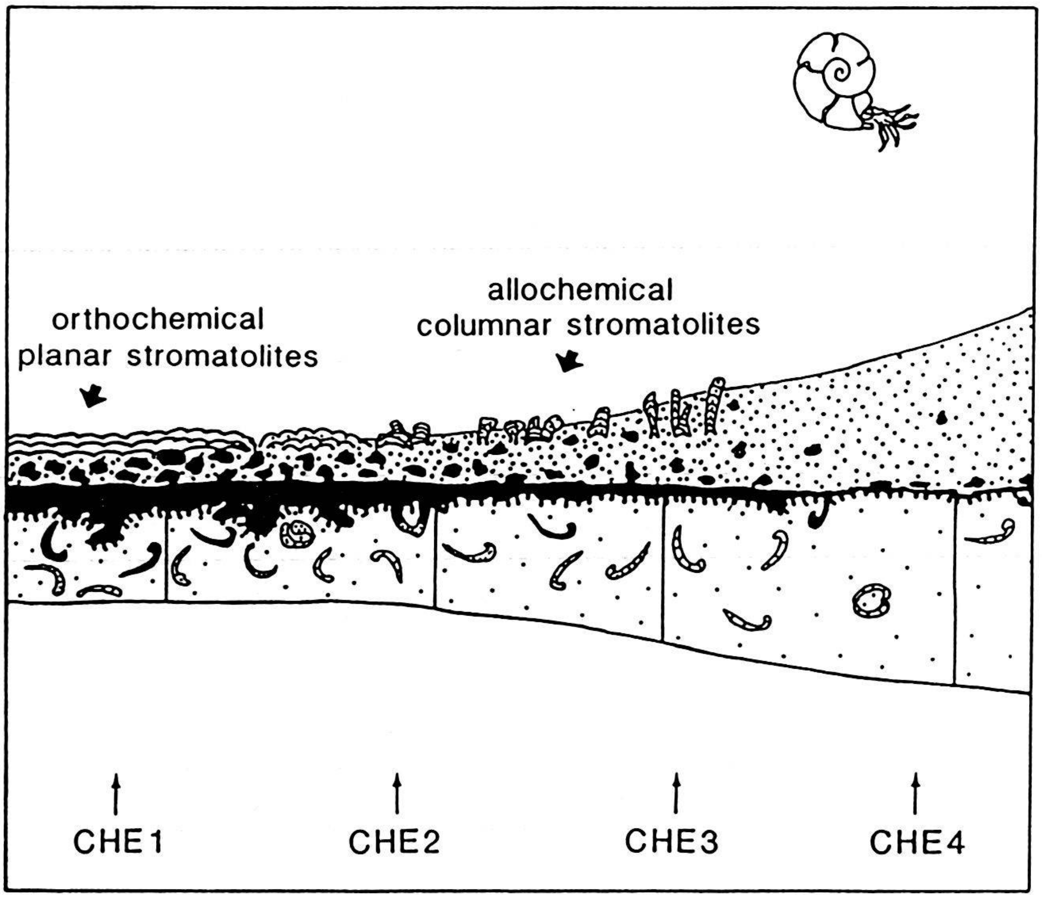


Fig. 18. Lateral evolution of the Albian stromatolites from outcrop CHE 1 to outcrop CHE 4 (without scale; for location, see Fig. 17). Illustrations of microfacies are given in Fig. 11a–b.

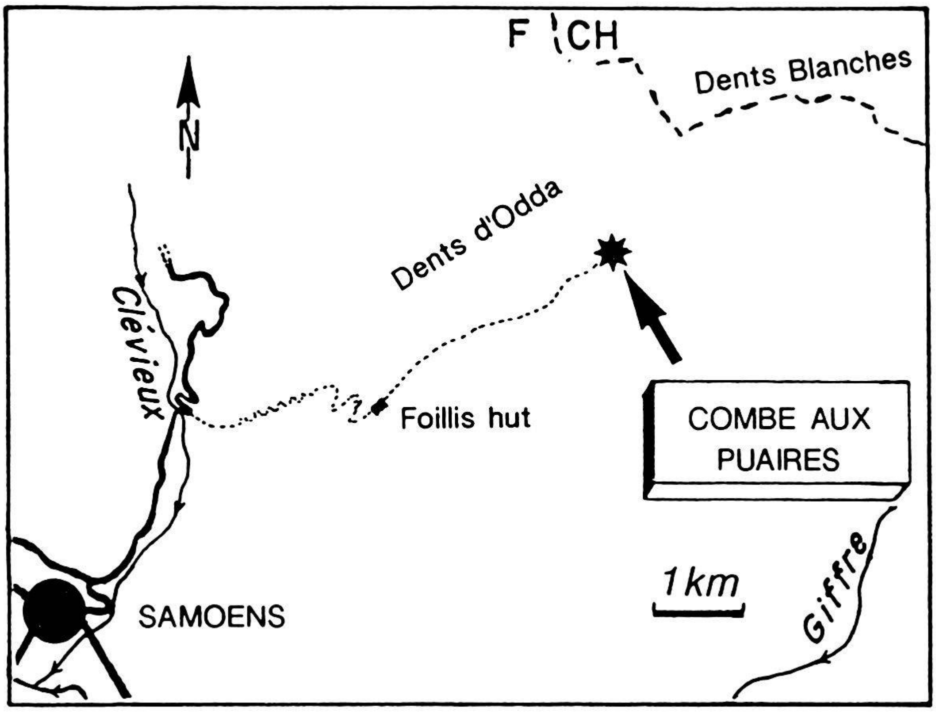


Fig. 19. Location of the Combe aux Puaires outcrop in the Haut-Giffre massif (Haute-Savoie). Broken lines indicate foot paths; black lines are roads.

stromatolites incrusting the upper Aptian substratum (Fig. 6a) to oncolites usually developed around perforated upper Aptian lagnodules (Fig. 6b). The majority of microbialites are composite microbial structures reflecting different stages of growth, some of which bear borings indicating their early lithification (Fig. 14). The borings are in turn colonized by late endostromatolites *(sensu* Monty 1982). The Cenomanian deposits, lacking in bedded form within the phosphate-rich serie, have been detected as internal sediment trapped within Albian phosphorites. Some of these internal Cenomanian deposits are represented by micritic thrombolites.

In the sand-rich series within the erosional scour, the microbialites are present in two distinct stratigraphic levels. The older one is of Albian age and similar to those seen in the phosphate-rich series. This first level is restricted to the erosional surface and disappears little by little towards the center of the scour. The younger level of microbialites caps and upper Albian phosphatic conglomerate and is represented by Cenomanian calcareous-phosphatic oncolites. Near the erosional notch, these oncolites grade into planar stromatolites developed upon lower Cenomanian deposits (Fig. 20).

Discussion

Depositional environments

As claimed by Monty (1971, 1977) and illustrated by Playford & Cockbain (1969) for instance, the presence of microbial structures, particularly stromatolites, is not indicative *per se* of water depth. In the case of the mid-Cretaceous Helvetic micro-

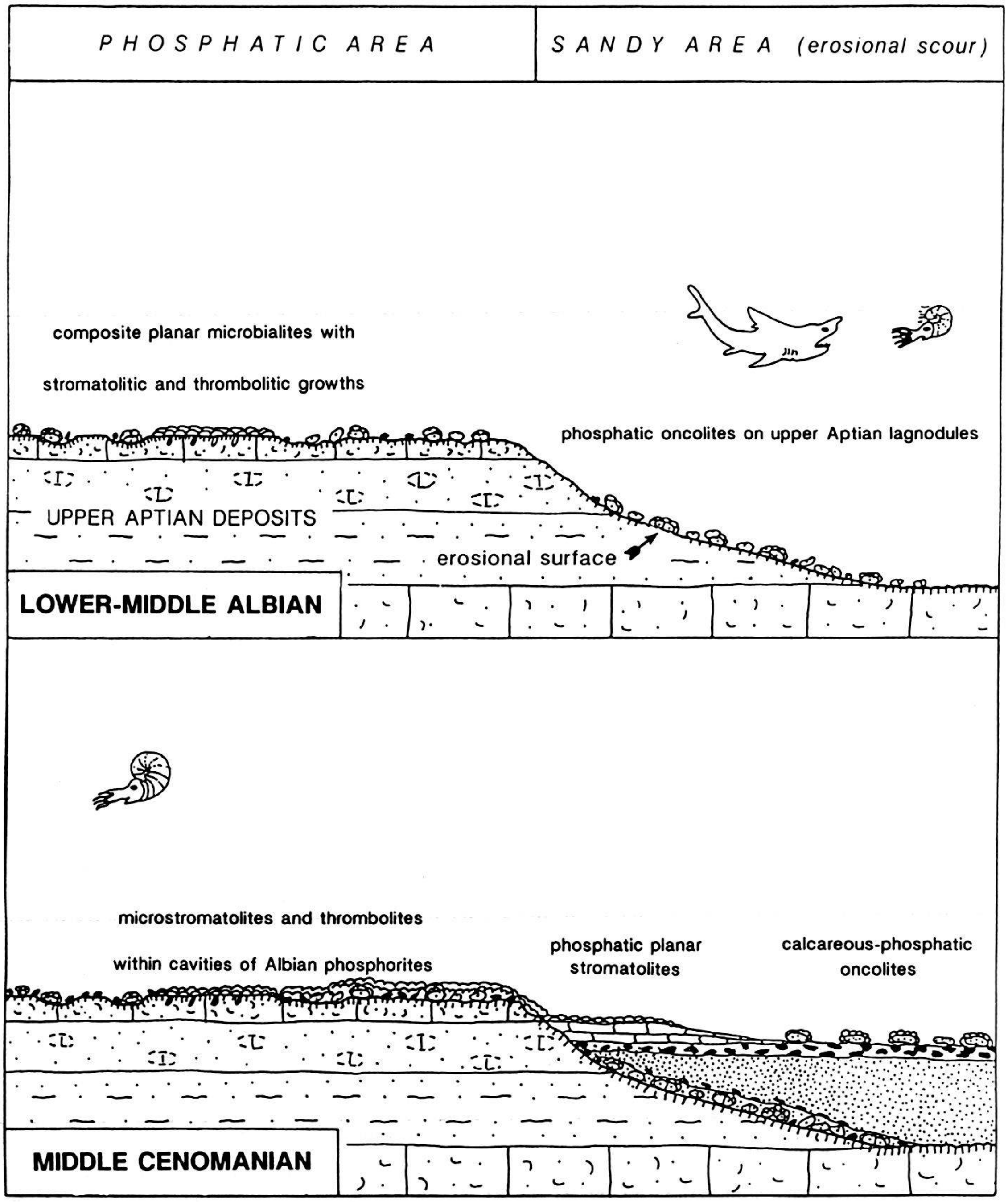


Fig. 20. Schematic reconstruction (without scale) of the mid-Cretaceous deposits and their microbialites in the Combe aux Puaires outcrop, Haut-Giffre massif (Haute-Savoie). Explanations in the text.

bialites, the faunal and facies associations with ammonites and planktic foraminifera testify an open shelf environment. The lack of any sedimentary structures indicates a deposition below the action of fair weather waves. However, the water depth was not the same for the three stratigraphic levels with microbialites.

The upper Aptian stromatolites occur in sandy bioclastic limestones containing an association of calcisponges and bryozoans together with belemnites and rares ammonites. This faunal association suggests a water depth of about 30 to 50 m.

For the Albian microbialites, the estimation of the water depth is difficult because of their inclusion in circum-condensed beds. But it is evident from the small circa-littoral benthic macrofauna and the abundance of ammonites present in these beds that the water depth was probably not shallower than 100 m.

For the Cenomanian microbialites, the water depth seems to have been more important because a nektonic fauna (i.e. planktic foraminifera and ammonites) is abundant while benthos is poor and almost monospecific (endobionth echinids). A water depth of about 250 to 300 m is proposed.

Environmental factors controlling the growth

The stratigraphic distribution of the Helvetic microbialites shows a good correlation between their occurrences and the major discontinuities affecting the mid-Cretaceous sedimentation on the Helvetic shelf (see Fig. 3). The upper Aptian stromatolites were developed on top of the regional discontinuity surface that separates the orbitolinid-rudistid Urgonian limestones from the upper Aptian overlaying bryozoan-sponges limestones. The Albian microbialites capped phosphatic conglomerates or incrusted hardgrounds associated with the late Aptian and early late Albian unconformities. The Cenomanian stromatolites incrusted lagnodules that rested on the sea-floor during an interruption in sediment accumulation.

The most visible effect of these sedimentary breaks was to provide hard substrates suitable for the initiation of the microbial growths. Another factor is the rate of sediment accumulation. The spatial distribution of the microbialites as shown in the two examples described above indicates that a low sedimentation rate was required. This is clearly shown by the extensive and repetitive development of Albian microbialites in the ultracondensed series developed near sea-bottom irregularities (Fig. 21). However, the rate of sedimentation was not the only environmental factor; microbialites are lacking for instance in contemporaneous areas with similar sedimentation rates such as the Jurassian platform. It appears that another factor played a role. The extensive microbial growth over the entire shelf during the early and the middle Albian and the middle Cenomanian associated with the almost complete absence of calcified benthic macrofauna indicates special environmental conditions near the sea-bottom. Following the biofacies model of THOMPSON et al. (1985), it is suggested that the periods of extensive microbial growths are indicative of a low dissolved oxygen concentration in the bottom water of the Helvetic shelf. In such dysaerobic environments, the calcified macrofauna and particularly grazing gastropods, potential predators of microbial communities (PRATT 1982) were absent, thus allowing the development of benthic microbial communities associated with adapted protozoans (i.e. agglutinated sessile foraminifera). The Albian and Cenomanian microbialites could be interpreted as dysaerobic communities proliferating within an oxygen-minimum zone that periodically evolved in the outer part of the wide Jurassian-Helvetic shelf.

Building organisms

In spite of their early lithification supported by borings and repetitive encrustations of sessile organisms, the Helvetic microbialites contain very few remnants of building

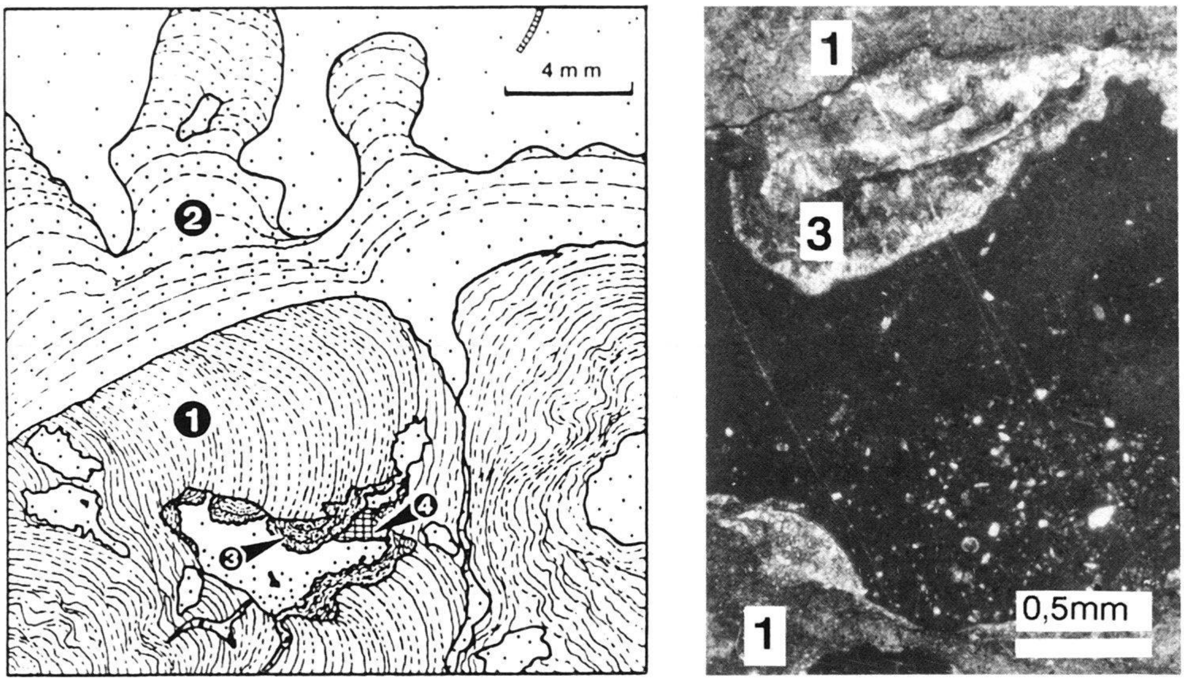


Fig. 21. Albian composite stromatolite with multiple and unconformable microbial growths developed near an erosional scour. 1 = tilted early phosphatic stromatolite without trapped particles (orthochemical microbialite); 2 = sandycalcareous stromatolite (allochemical microbialite); 3 = calcitic endostromatolite encrusting the wall of a sheltered cavity with a geopetal infilling; 4 = geopetal sparite. The picture on right side is a close-up of the sheltered cavity. Note the accumulation of quartz grains and bioclasts at the bottom of the cavity and the endostromatolites (3) encrusting the walls. Thin section MD 2901c, Véran, Platé massif.

microorganisms. Preliminary SEPM investigations are disappointing, probably due to a diagenetic recrystallization of the material. Most of the laminations seen in field observations and in hand specimens contain only detrital particles. However, some internal fabrics of the laminae as described above allow a tentative biological interpretation to be given (Fig. 10).

The microlaminated fabric may reflect the growth of prostate microbial communities. The abundance of small particles of pyrite as well as the presence of filaments within the microlaminae suggest that the microbial builders may have been filamentous sulfur-oxidizing bacteria such as the *Beggiatoaceae.* Similar recent examples of moderate- to deep-water (50 to 650 m) bacterial mats have been noted by GALLARDO (1977) and WILLIAMS & REIMERS (1983).

According to MONTY (1976), the dendroid fabric is interpreted as vertical tubular microfenestrae after oxidation of erect microbial communities. These communities could have been filamentous, multicellular cyanophytes such as the *Scytonemataceae* or the *Rivulariaceae,* both belonging to the Nostocales (GOLUBIC 1976).

The colloformic fabric could be interpreted following KRAJEWSKI (1981) as colloidal microstromatolites built up by coccoid cyanophytes. Since many of them have also been observed within cavities, i.e. in non-photic areas, they were probably heterotrophic.

On the basis of the examples described above, the diversity in the laminae's fabrics probably reflect not only different groups of microbes but also adaptations of the microbial communities to environmental changes such as changes in sedimentation rates.

Origin of the phosphate

At the present state of knowledge of the Helvetic microbialites, it is premature to elucidate the relationship between microbial organisms and phosphate mineralization. The field observations showed that the development of the microbial communities did not occur within the phosphatic beds but slightly later. However, the phosphate mineralization occurred early during the stromatolitic growth as demonstrated by periodic enrichment within a single column (Fig. 9b). Recent experimental work on microbial mediation in apatite precipitation (LUCAS & PREVOT 1985; PREVOT & LUCAS 1986) and fossil examples (e.g. KRAJEWSKI 1983, 1984; DAHANAYADE & KRUMBEIN 1985; SOUDRY & LEWY 1988) indicate that the microbial benthic communities may have played an active role in phosphate mineralization.

Conclusions

In the mid-Cretaceous phosphatic deposits of the Helvetic domain, three main types of microbialites are identified:

- phosphatic films comparable to recent deep-water bacterial mats made by the *Beggiatoaceae*,
- stromatolites with reticulate, planar and composite concentric forms,
- composite and endolith thrombolitic structures.

All these microbial structures have been developed in an outer shelf environment under very low sedimentation rates. This environmental factor influenced the spatial distribution, the shape, the mineralogic composition and the internal fabric of the microbialites. Under a decreasing sedimentation rate, for instance, columnar allochemical stromatolites change laterally into planar orthochemical forms. The majority of the microbialites seems to have grown on top of major unconformities, probably during pauses in sediment accumulation. The virtual absence of benthic calcified macrofauna suggests a dysaerobic environment during the extensive Albian and middle-Cenomanian periods of microbial growth.

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