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NON-MARINE CALCAREOUS ALGAE OF UPPER JURASSIC TO LOWER CRETACEOUS SEQUENCES FROM THE WESERBERGLAND (NORTHWEST GERMANY)

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This paper is dedicated to the Dr. Hans Füchtbauer, Professor Emeritus of the Institute of Geology, Ruhr University Bochum (Germany) with the occasion of 80th years anniversary.

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Abstract: The Upper Jurassic/Lower Cretaceous brackish carbonate sequences of the Weserbergland area (NW Germany) contain numerous calcareous algae and cyanobacteria closely associated with layers dominated by serpulids and ooids. Algae are an essential tool for the interpretation of brackish environments. Several new taxa of Chlorophyta (*Pseudopenicillus weseri* n.sp., *Springerella bifurcata* n.gen. n.sp., *S. fuchtbaueri* n.sp., *Brachydactylus reisi* n.sp.) and one new species of Cyanobacteria (*Ponsella freyteti* n.sp.) are described.

Key words: Germany, Jurassic–Cretaceous, non-marine, calcified, cyanobacteria, algae.

Introduction

Little is known about fossil fresh or brackish water algae (e.g. Toomey & Nitecki 1985). Furthermore, specific data about chlorophytes and cyanobacteria of the serpulid containing series of Upper Jurassic to Lower Cretaceous age in NW Germany do not exist. This seems surprising because the series often contain deposits of non-marine environments within the widespread area of the so-called Portland Trough (Fig. 1).

Recently, Freytet (1997, 1998, 2000) and Freytet et al. (1999) reviewed the record of non-marine algae from the Permian to the present-day — some of them found in travertine and tufa — establishing 16 new genera and 56 new species.

The study of the fossil non-marine algae has long been neglected, altough Reis (1923) published and described new taxa from the Miocene of Rheinpfalz (Donnerberg Sheet) as follows: *Ternithrix compressa* — a girvanelloid cyanobacterium (Oscillatoriaceae), *Dimorphostroma palatinum*, *D. diffusum* (Rivulariaceae), *Chlorellopsis coloniata*, *Microchorton claviger*, *Dendractis brevis*, *D. compacta*, *Brachydactylus radialis*, *Cladophorites incrustans* and *C. dubius* (Chlorophyta).

More recently, *Chlorellopsis coloniata* was also found in the Miocene of the northern Rhine Valley by Stapf (1988) and in the Ries Crater by Arp (1995). *Cladophorites incrustata* was decribed from the Miocene of the Ries Crater by Riding (1979) and Arp (1995).

Geological setting

Uppermost Jurassic to Lower Cretaceous sequences containing serpulids are typical of the final carbonate facies of the E-W striking Portland Trough in northwestern Germany (Fig. 1). This facies characterizes the more or less marine parts of the so-called Malm group (Fig. 2) until the non-marine Wealden facies extends with the Bückeberg Formation far over the coastline of the Upper Jurassic basin (Gramann et al. 1997). Compilations (Gramann et al. 1997) emphasize that the < 100 m thick Serpulit Formation correlates with the youngest bed (OM 6) of the Malm group. Biostratigraphically, the Serpulit Formation is assigned to ostracod zones 22/23 and charophyte zones 7/8 (Berriasian of Gramann et al. 1997). The “Serpulit” sensu stricto corresponds with the Upper Serpulid Limestone of Casey et al. (1975) and Schonfeld (1979). The Münder Marl ranges from Tithonian (OM 3 and OM 4) to Lower Berriasian (OM 5) (Gramann et al. 1997).

The first description of serpulid limestones from the southern coast of the Portland Trough (Fig. 1) was published by Blumenbach (1803). Hoyer (1965) interprets these as a near-coastal facies with serpulid biostromes, while Huckriede (1967) explains the same sedimentary succession by transportation and sedimentation of tubes of the phytal living *Serpula coacervata*. According to the Huckriede (1967), serpulid facies of Hannover reflects meio- to pleiomesohaline conditions of brackish water (3–18 ‰ salinity) and only the marly intercalations were oligohaline (0.5–3 ‰). For the Upper Serpulid Limestone in the area south of Hannover, Schonfeld (1979) supposes a predominant alternation of limnic (partly subaerial with desiccation) and brackish/marine (10–18 ‰) conditions, whereas some local celestine intercalations probably indicate episodically higher salinity environments. Based upon well-known anhydrite and halite layers in the deepest parts of the sedimentary basin (Brand 1954), Gramann et al. (1997) assume a salinity stratification during sedimentation of the serpulid (OM 6) sensu Schott (1951) and Jordan (1971). Due to increasing humidity of the climate the limnic to terrestrial

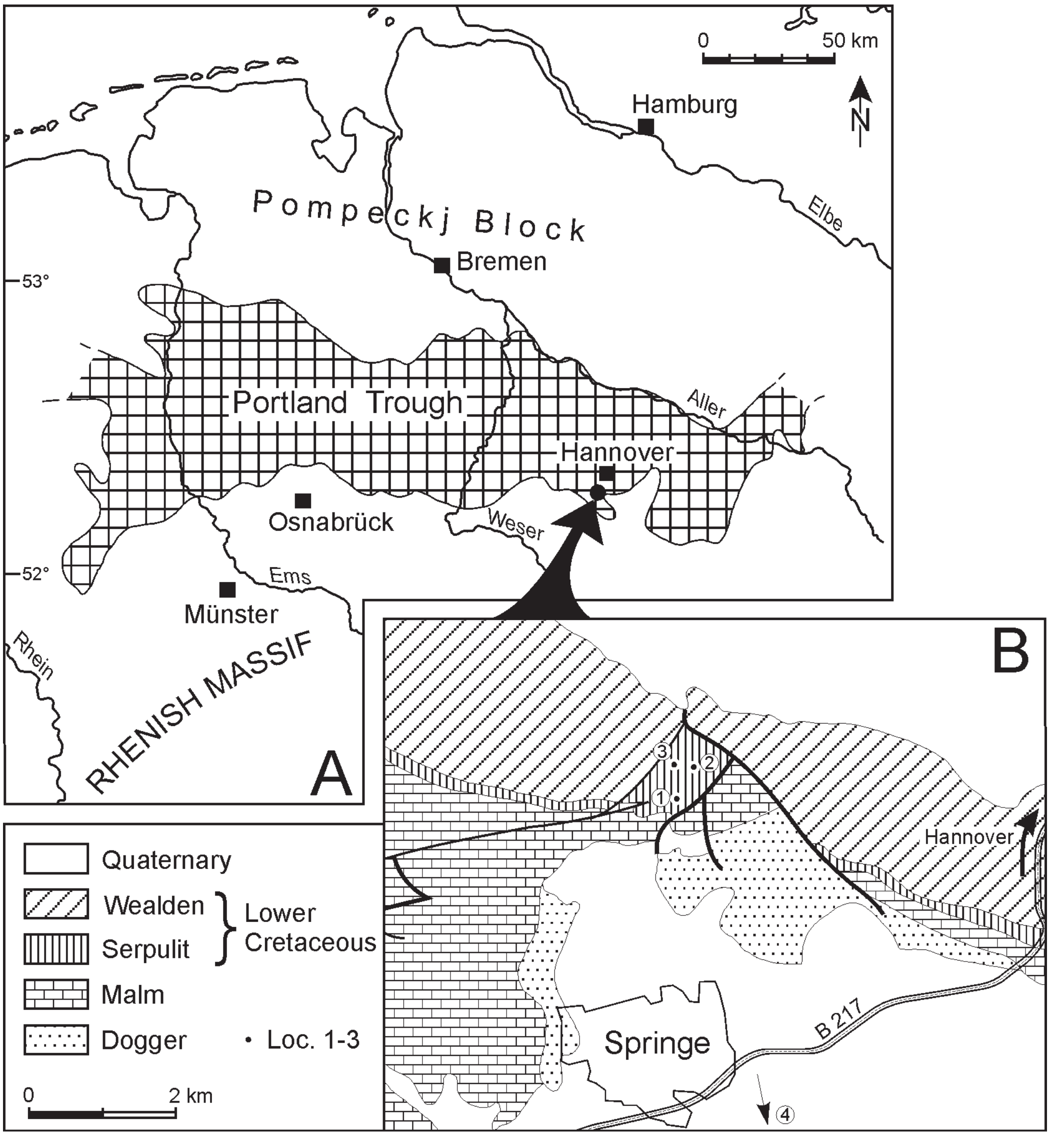

Fig. 1. Sketch map showing the position of the localities 1–4. **A** — Paleogeographic distribution of the Portland Trough in northwestern Germany according to Betz et al. (1987). **B** — Geological map for the eastern part of the Deister area, north of Springe (Geologische Wanderkarte 1:100,000-Landkreis Hannover, 1977).

Wealden facies finally overlaps the dominantly carbonate marine facies with variable salinity within the Portland Trough of northwestern Germany.

The paleoecology of serpulid outcrops in northwestern Germany are described by Jahnke & Ritzkowski (1980), focusing on the uppermost Jurassic deposits, and by Ten Hove & Van Den Hurk (1993) dealing with lowermost Cretaceous.

The localities of our study represent the serpula-dominated facies of the southern coastal zone of the Portland Trough situated southwest/south to Hannover (Fig. 1). The bulk of the samples was taken from three disused quarries in the Deister Mountains north of Springe:

Locality 1 — Lower Serpulid Limestone (samples Bre 1–2) overlain by marls and fine-grained siliciclastic sediments containing thin and partly nodular limestone intercalations (sample A3); map and Gauss-Krüger coordinates — MTB 3723 Springe, H 5789800, R 3538160; the locality corresponds to Loc. 142 of Hoyer (1965), Loc. 1 of Schönfeld (1979) and Loc. 132 of the geological tourist map of the rural district of Hannover (1977).

Locality 2 — Upper Serpulid Limestone (samples 835 and 38/1–5); MTB 3723 Springe, H 5790210, R 3538480; the locality corresponds to Loc. 143 of Hoyer (1965) and Loc. 38 of Schönfeld (1979).

Locality 3 — Upper Serpulid Limestone (samples 37/1–5); MTB 3723 Springe, H 5790370, R 3538070; the locality corresponds to Loc. 141 of Hoyer (1965) and Loc. 37 of Schönfeld (1979).

A minor part of the samples was taken from an active quarry (Schütte Company) situated ESE of Thüste village (about 20 km SSE of Springe):

Locality 4 — Oolitic Serpulid Limestone (samples F1–3); MTB 3923 Salzhemmendorf, H 5765650, R 3545100; the locality corresponds to Loc. 21 of Herrmann (1968 — calcare-

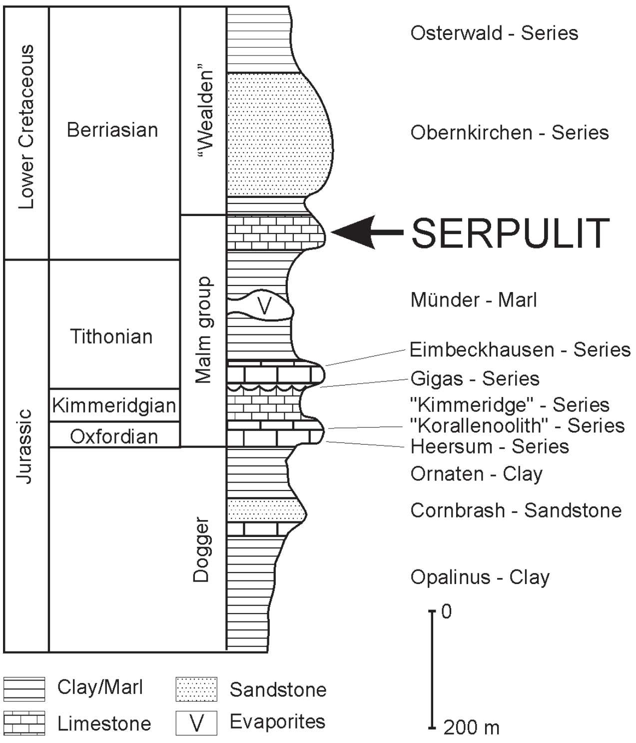

Fig. 2. Stratigraphic column for the Jurassic to Lower Cretaceous in the investigated area (Jordan 1979; Gramann et al. 1997).

ous facies of the Münder Marl) and Loc. 57 of Jordan (1979 — Upper Jurassic "Serpulit"). According to Jahnke & Ritzkowski (1980) all sampled limestones can be assigned to the middle part of the Münder Marl (OM 4) below a stromatolitic horizon and, consequently, they are assumed to be stratigraphically lower than the Serpulit Formation. Gramann et al. (1997) place the serpulid limestones from the Hils Syncline near Thüste in ostracod zone 19, which corresponds to lithostratigraphic position OM 4.

Microfacies and diagenesis

In order to understand microfacies and diagenesis of the samples some information is necessary concerning the environmental and stratigraphic situation at the southern coast of the Portland Trough (Fig. 3). We assume a restricted sea with tidal effects influenced by deltaic sedimentation. Normally, the supratidal flats were followed in a seaward direction by stromatolitic to oncolitic facies, mud facies (wacke/mudstones), bar facies (grain/packstones) and mud facies wacke/mudstones). Furthermore, we assume channels as a connection between river and basin areas (Fig. 3). This sedimentological scenario moves with transgression and regression corresponding to the rule of Walther (see Jahnke & Ritzkowski 1980). This simple paleogeographic situation was complicated by changing salinities caused by deltaic influence and evaporation.

Grain/packstones

The Lower Serpulid Limestone at Loc. 1 and the limestone facies of the Münder Marl at Loc. 4 consist predominantly of grain/packstones rich in bioclasts and/or ooids (bar facies in Fig. 3). In some cases elongated clasts of serpulids, bivalves and algae trace plane and cross bedding. At the top the Ser-

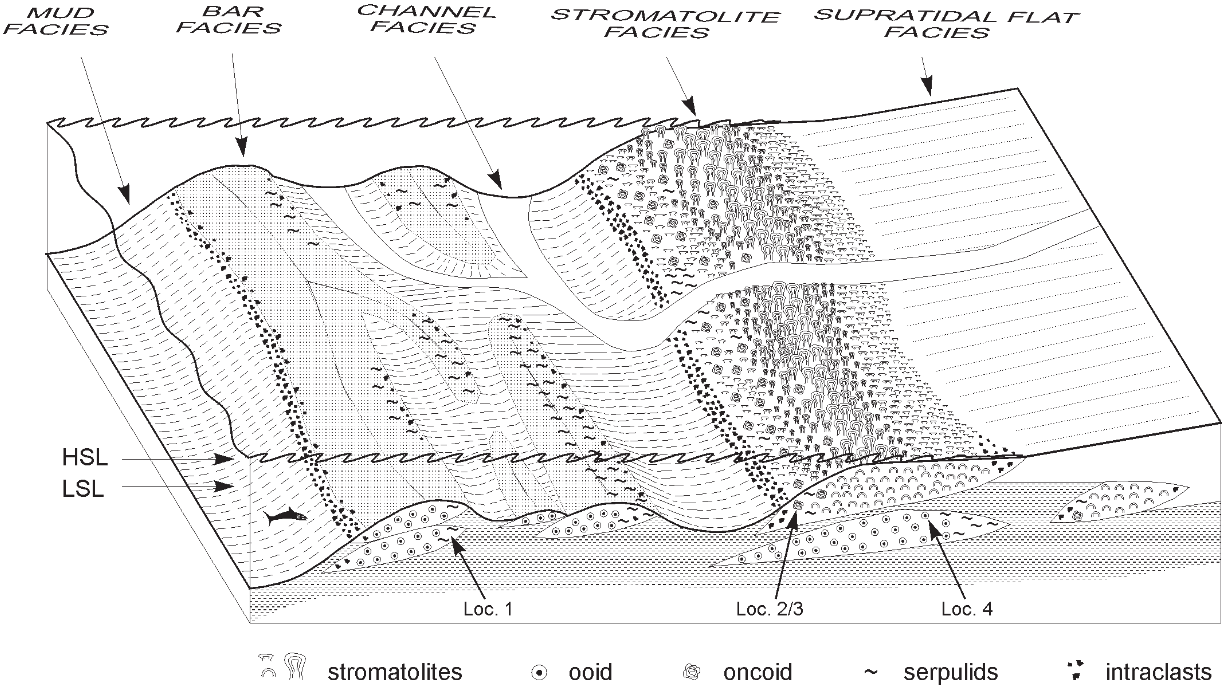

Fig. 3. Schematic facies pattern for the Upper Jurassic to Lower Cretaceous coastal area, south of Hannover following the models of Logan et al. (1970) and Jahnke & Ritzkowski (1980) — with supplements. The positions of the localities 1–4 correspond to the horizontal and vertical facies pattern but not to the stratigraphical position.

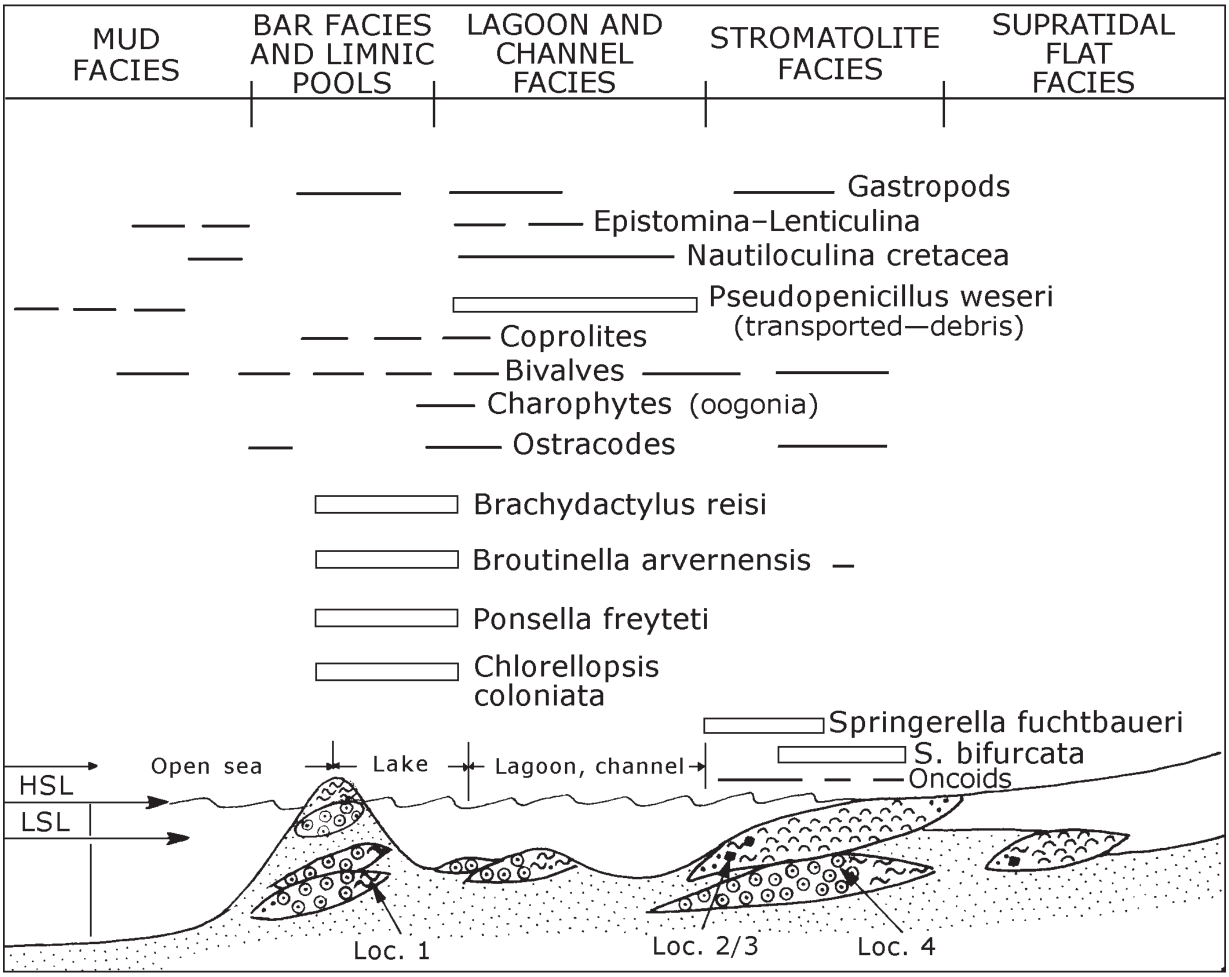

Fig. 4. Distribution of algae and the paleocommunities during the Upper Jurassic and Lower Cretaceous in Weserbergland, NW Germany.

pulid Limestone of Loc. 1 a remarkable velocity of flow is impressively indicated by current ripples. This typical feature for near coastal sedimentary environments is in good agreement with the paleogeographic position of the investigated localities at the margin of the Portland Trough (see Fig. 1).

More or less broken tubes of serpulids (*Serpula coacervata* according to Schönfeld 1979 and Ten Hove & Van Den Hurk 1993) are the main bioclasts. Often, these tubes show telescope-like interlocking (Fig. 8.3) so that using only a bandlens they can be misinterpreted as ooids. In addition, there are thalli and fragments of green algae and cyanobacteria (see paleoalgological description) as well as different types of shells. Monolayered prismatic shells and doublelayered shells — primarily calcitic as well as formerly aragonitic layers — can be assigned to bivalves, whereas shells which are completely composed of calcitic fibres or formerly aragonitic shells cannot be clearly identified. Particularly the samples from Loc. 4 (Thüste) contain gastropods and ostracods in addition to bivalves. Foraminifers and ostracods in the samples from Loc. 4 seem to be reworked from older beds (see paleogeographic situation in Fig. 1) because of their distinctive diagenetic composition — e.g. Fe-calcites in skeletons and intraparticle pores which differ from those of the surrounding particles and cements.

Ooids are common in all studied microfacies types from Tithonian to Berriasian and in some layers they can be regarded as rockforming (Fig. 8.4). This is especially the case at Loc. 2 and Loc. 4 as well as in the marly beds between the Lower and Upper Serpulid Limestones (Loc. 1) according to Schönfeld (1979).

Aside from normally structured ooids with spherical nucleus and cortex (Fig. 8.4), more complex ooids (Fig. 8.5) and hiatus ooids (broken and regenerated ooids; Fig. 8.4) occur (see Richter 1983). Within the beds of Loc. 4 with its relatively high proportion of formerly aragonitic bioclasts, “eggshell diagenesis” (Wilkinson & Landing 1978 — dissolution of aragonitic nuclei before compaction of the sequence) can be observed in some cases (Fig. 8.6). Generally, all ooids of the studied localities have a radialcalcitic structure which is typical for marine ooids in the “calcite time” from Lower Jurassic to Upper Cretaceous sensu Sandberg (1983). Fe-calcitic ooid cortices point to a primary composition of radially structured Mg-calcite (according to Richter & Füchtbauer 1978; Richter 1984). However, an exact value of the primary Mg portion cannot be determined. But, taking into account the abundant non-marine green algae and cyanobacteria, and the (brackish)/ marine serpulids, brackish conditions with oscillating salinity (fine cathodoluminescence zonation in the ooid cortices indicating a primary geochemical fluctuation) seems likely. This interpretation is further supported by the distribution of radial-calcitic ooids in the Neogene/Quaternary sequences of the Isthmus of Corinth (Richter & Neuser 1998) where ooids occur within a Neogene/Quaternary cyclic sequence of glacial-eustatic origin — marine conditions with seawater highstands and lacustrine-brackish conditions with sea-level lowstands and isolation of seas neighbouring the Mediterranean (in this case, the Gulf of Corinth). Ooids with aragonitic cortices (replaced by secondary isometric calcite) are limited to marine episodes whereas radial Mg-calcitic cortices (often replaced by Fe-calcite) occur in lacustrine-brackish periods.

The groundmass of the grain/packstones is predominantly formed by cement, whereas matrix — a. micritic, b. pelmicritic (clotted limestone sensu Bathurst 1971, peloidal structure due to crystallization with participation of bacteria according to Chafetz 1986) — can be exclusively observed in packstones. The first cement generation consists of calcitic palisades, which can be observed, mostly in intraparticle pores — especially in serpulids. This was probably an early cement, but it is impossible to reconstruct the primary Mg content or the salinity. The normal sequence of cements is formed by isometric calcite with an ideal succession calcite I, Fe-calcite, calcite II. The same cement succession can also be observed in dissolution pores of formerly aragonitic particles if they were not previously calcitized in situ (compare Fig. 8.7).

Wacke/mudstones

Wacke/mudstones are common especially in the Upper Serpulid Limestone of localities 2 (Fig. 8.2) and 3, and also in the marly sequences between Lower and Upper Serpulid Limestone at locality 1 and in the upper part of the calcareous facies of the Münder Marl at locality 4 (mud to stromatolite facies in Fig. 3). The wacke/mudstones occur as beds and as intraclasts. With respect to ooids and biogenic components the wacke/mudstones are similar to the grain/packstones, but the predominantly micritic facies contains a distinctly higher proportion of green algae and cyanobacteria (see paleoalgological description). Partly, the wacke/mudstones have a strongly increased proportion of intraclasts and oncoids. At locality 3 these oncoids can reach diameters in the range of decimeters (Fig. 8.1) and in some cases are composed of a complex algal community. Detrital quartz grains complete the component spectrum of the wacke/mudstones. Few of these grains show authigenic rims of quartz.

The groundmass is dominated by a micritic to peloidal, sometimes microsparitic matrix (according to Füchtbauer & Richter 1988). Often the calcareous content of the matrix is more or less substituted by clay and silt, so that the petrographical composition corresponds to marls or marly clays.

Residual spaces of interparticle pores, intraparticle pores (especially in serpulid tubes) and shrinkage cracks were mostly cemented by calcite. Normally, a sequence of calcite I, Fe-calcite and calcite II can be observed corresponding to the cementation sequence in the grain/packstones. Rarely, in some intraparticle pores (serpulid tubes, completely preserved ostracod shells) an initial palisade-shaped cement generation may occur.

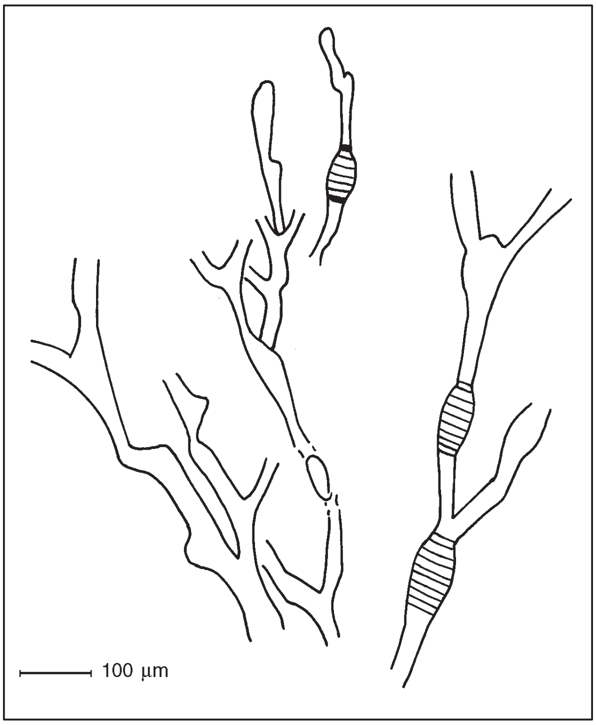

Fig. 5.

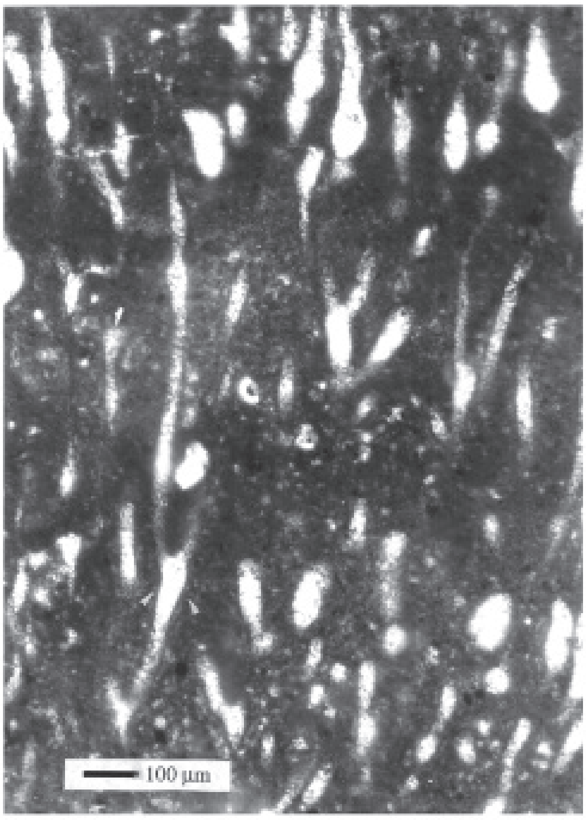

Fig. 6.

Figs. 5–6. *Springerella bifurcata* nov. gen. nov. spec., thallus with long Y-shaped dichotomously branched tubes and swellings in the area of branching, also rare swellings between the successive dichotomies.

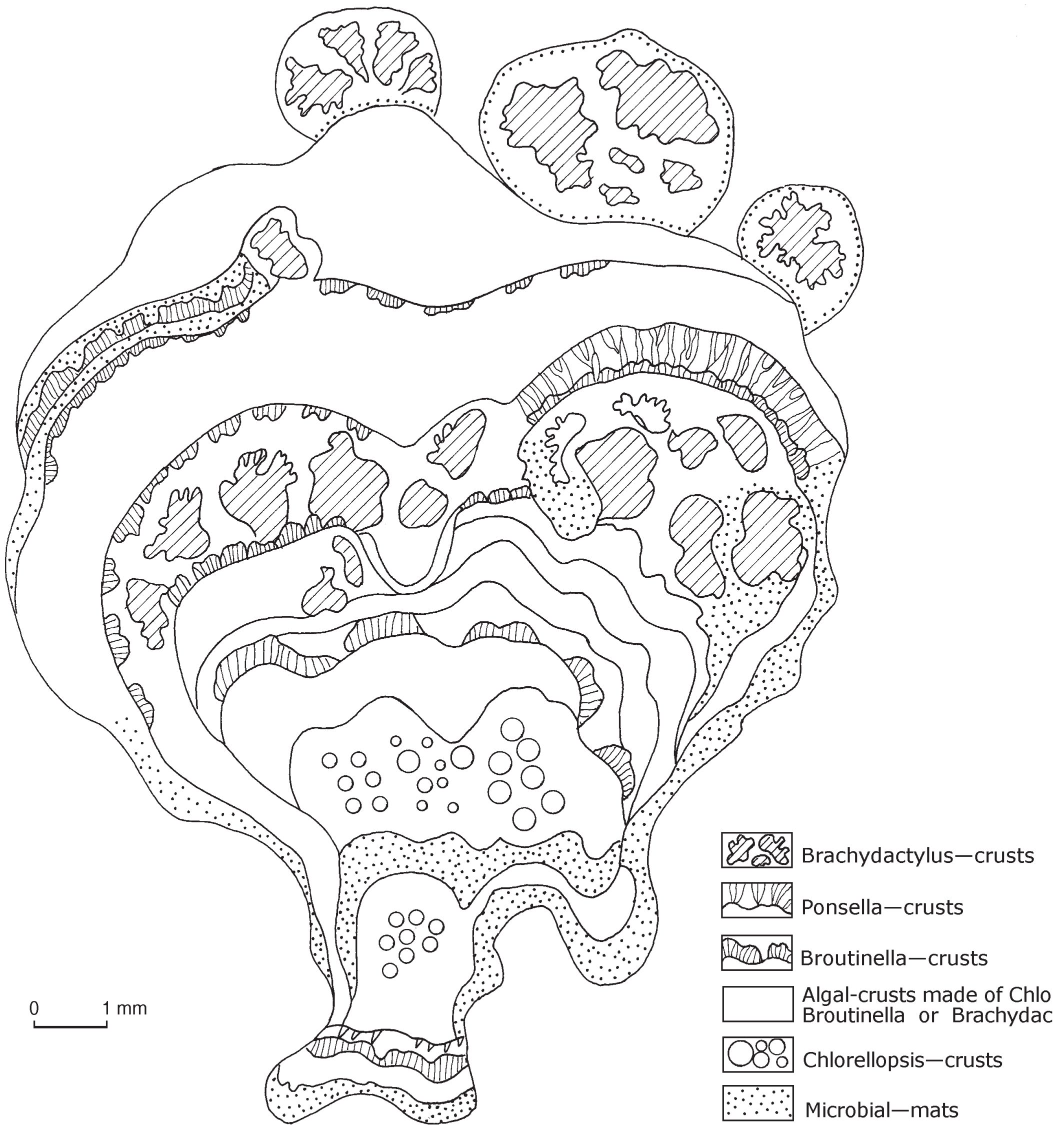

Fig. 7. Reconstruction of a stromatolitic nodule built by various algae and microbes: in the basal part algal-micrite, microbialite, covered by *Chlorellopsis coloniata* Reis composed of spherical cells, then *Broutinella arvernensis* Freytet, mainly represented by monostrata crust, interlayered with *Ponsella freyteti* nov. spec. and in the upper part, laminated layers with protuberances of *Brachydactylus reisi* nov. spec. and *Broutinella arvernensis*.

In thin sections of the Upper Serpulid Limestone of localities 2 and 3 the blocky calcite cement is often pigmented by opaque material and exhibits internal zones of calcite and Fe-calcite. The presence of lentil-shaped calcite pseudomorphs after gypsum in the matrix, showing the same features as the calcite mentioned above, a pseudomorph origin also seems to be probable for the blocky calcite areas in the inter- and intraparticle pores. This blotchy distribution of calcite can be explained by changes of the redox conditions in the pore fluid during calcification of gypsum.

Paleoecology of non-marine algae

The communities recorded at the Jurassic-Cretaceous boundary within the Weserbergland region, NW Germany, included marine and non-marine algae, serpulids, bivalves, gastropods, ostracods and coprolites. These occurred in shallow basins at coast lines with a varied morphology: subtidal, intertidal with limnic pools and supratidal, crossed by tidal or fluviatile channels (Fig. 3).

In an attempt to reconstruct the paleoecological conditions of this time interval, correlated with the depositional environments, three characteristic communities can be recorded:

a) **Community dominated by Halimedaceae** (*Pseudopenicillus weseri*) confined to the subtidal, marine realm, corresponding to the depositional environment of the Oolitic Serpulid Limestone (locality 4) of the Münder Marl Formation (= OM 4), Upper Tithonian in age.

The occurrence of broken algal segments, as elongate, parallel bioclasts, indicates that they were transported by "tidal streams" especially within the channel facies where they accu-

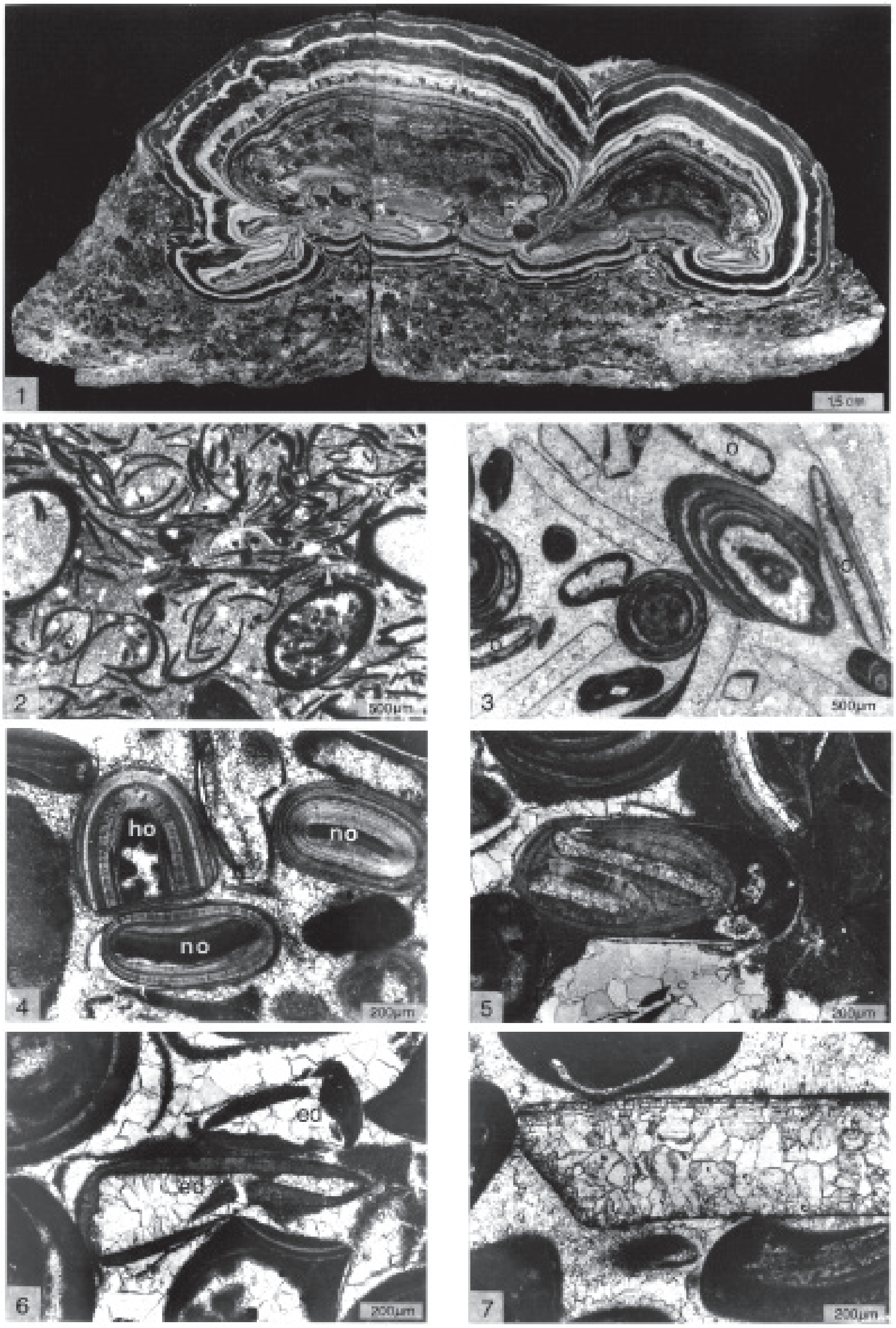

Fig. 8. **1:** Megaoncoid of the Upper Serpulid Limestone (Lower Berriasian), Loc. 3. Sample courtesy of Hans Füchtbauer. **2:** Wackestone with debris of serpulids and some ostracods (arrows) — Upper Serpulid Limestone (Lower Berriasian), Loc. 2. **3:** Grainstone containing calcitized bivalves, ooids (o) and tubes of serpulids with telescope-like interlocking — Lower Serpulid Limestone (Lower Berriasian), Loc. 1. **4:** Oolitic grainstone — normal ooids (no) and hiatus ooids (ho). Münder Marl (OM 4), Loc. 4 (Upper Tithonian). **5:** Packstone containing a complex ooid — Lower Serpulid Limestone (Lower Berriasian), Loc. 1. **6:** Ooids with eggshell diagenesis (ed) — Lower Serpulid Limestone (Lower Berriasian), Loc. 1. **7:** In situ calcitized molluscan fragment (see residual structures) — Lower Serpulid Limestone (Lower Berriasian), Loc. 1.

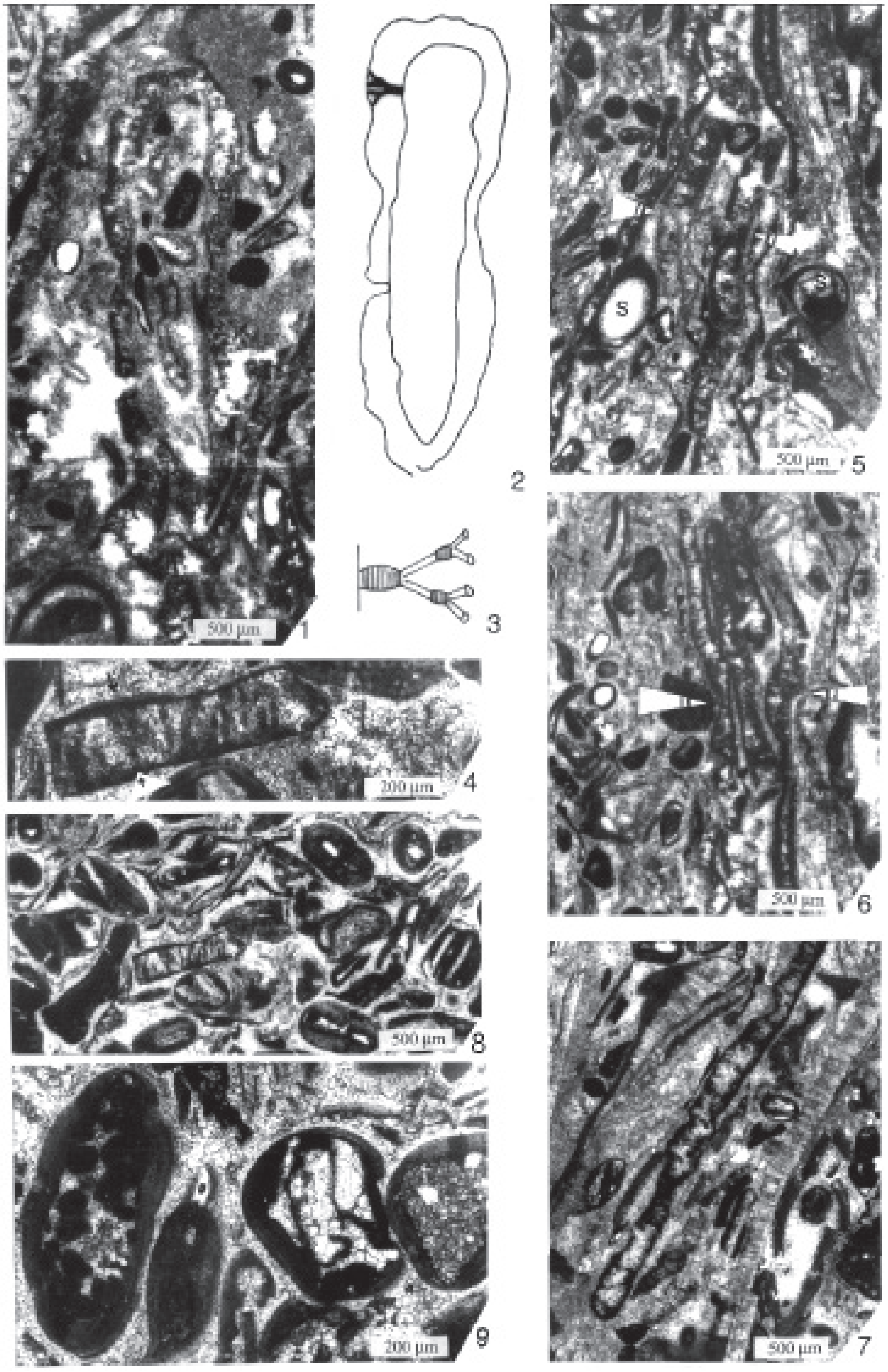

Fig. 9. 1–3: *Pseudopenicillus weseri* n.sp., 1. Holotype, Coll. L.P.B. V, No. 1120, sample F3A, vertical, axial section in cylindrical segments of thallus; 2–3. Thallus morphology with cylindrical segments separated by constrictions and type of cortical utricle siphons. **4:** *Pseudopenicillus weseri* n.sp., Isotype, debris in a broken thallus showing the shape and ramification of the utricle siphons in the cortical area (see arrows). **5–6:** *Pseudopenicillus weseri* n.sp., Isotypes, vertical axial sections; thalli cylindrical with constrictions between segments (see arrows), sometime broken between tubes of serpulids or fixed on one side of the thallus. **7:** *Pseudopenicillus weseri* n.sp., Isotype, broken thallus, which preserves only one side of the cylindrical segment. **8–9:** Oolite with ooids, oncoids, debris of *Pseudopenicillus weseri* n.sp., gastropods, bivalves and serpulids, sample F2. Upper Tithonian, Oolitic Serpulid Limestone (Münder Marl = OM 4), Salzhemmendorf, Weserbergland, NW Germany.

mulated during slow sedimentation, as a function of their shape, dimensions and weight. They produced bioclastic accumulations as micro-rhythmites.

The marine deposits with normal salinity reached the interior by repeated marine "invasions" along the tidal channels, generating "micro-rhythmitic" deposits of thallus fragments (only cortical parts), together with rare serpulid tubes, benthic foraminifers (*Lenticulina*, *Epistomina*, *Nautiloculina*) and bivalve shells (Fig. 4).

Small oncoids, 0.2–0.4 mm in diameter occur rarely and algal pellets were deposited in "quiet" environments, after their transport.

b) **Community dominated by *Serpula coarcervata***, tubes embedded in micrites (locality 1) (Ten Hove & Van Den Hurk 1993).

The matrix is made of pure micrites and biogenic micrites resembling algal pellets and stromatolites, fine quartz grains (0.010–0.10 mm) and clasts (clay, marls or micrite).

In addition to serpulid tubes, the community includes shells and shell fragments of bivalves, ostracods and rare charophyte gyrogonites, together with coprolites deposited in shallow intertidal, bar and limnic pool areas. In these "ponds" oncoids formed with dimensions of 2–10 mm.

From a paleoalgological point of view, 4 morphospecies are identified: *Chlorellopsis coloniata* Reis, *Broutinella arvernensis* Freytet, *Ponsella freyteti* n.sp. and *Brachydactylus reisi* n.sp. (Fig. 7).

Two types of stromatolites can be observed: homogenous and heterogenous sensu Freytet (2000). Both categories are abundant, reflecting the growth of flat laminae, hemispheres, small domes and columns, like *Broutinella arvernensis*.

The microbial encrustation *B. arvernensis* is initially micritic, followed by radial sparite palissades type in laminated micro-build-ups. The microlaminations are interpreted as a result of bacterial activity with a daily rhythm and a fabric made of cyanobacterial filaments.

The **homogenous stromatolites** have nodular-ellipsoidal shapes, 2.5–3.0 mm in diameter, enclosing gastropod shell fragments and, in the outer part, microbial crusts of *Broutinella arvernensis*.

The **heterogenous stromatolites** are larger (4.5–10.0 mm in diameter) and have nodular-ellipsoidal shapes bearing external protuberances with a vertical growth tendency, initially temporarily fixed to the substrate, finally generating in place build-ups.

There are oval-ellipsoidal algal nodules with cerebroid external surfaces and diameter of 3.0–4.0 mm. They include a core of *Chlorellopsis coloniata*, covered by microbial laminae and an external succession of crusts made by *Broutinella arvernensis* and small protuberances of *Brachydactylus reisi*.

These compound nodules are typically formed by the superposition of 2–4 algal-microbial generations. At the base of the nodular build-ups, *Chlorellopsis coloniata* is common frequent, composed of isolated, spheroidal cells embedded in a bacterial micritic mass, generating microlaminations. In the middle part of the nodules, crusts of *Broutinella arvernensis* occur coated by or intermingled with *Brachydactylus reisi*. Towards the exterior, the successive microlaminations contain a biocoenosis of *Broutinella arvernensis*, *Ponsella freyteti* and, at the outer margin, many small protuberances made by *Brachydactylus reisi* (Fig. 7).

The occurrence of these algal-stromatolite structures within the Lower Serpulid Limestone is recorded here for the first time.

They represent lacustrine stromatolites accumulated on the lacustrine shores. The stromatolitic nodules incorporate serpulid tubes, disrupted ostracod valves, gastropod coprolites (0.3–0.4 mm in length), and microbial pellets. At the top, or between the algal nodules, occur clay and limestone clasts, 3.0–4.0 mm in length, elongated and flattened in shape, together with abundant detritic quartz, 0.010–0.10 mm in diameter.

The Lower Serpulid Limestone (LSL) includes tubes of *Serpula* selectively transported and deposited in monospecific banks, some of them being incorporated in stromatolite nodules or serving as substrates for other algal-microbial nodules.

The community belonging to the LSL indicates a fluctuating salinity, from hypersaline to limnic, in the peritidal environment (Fig. 4).

c) **Stromatolite community** (localities 2, 3) of the intertidal and proximal supratidal zones.

This community was dominated by algae and represented by spheroidal or ellipsoidal nodules with or without a core of 1–2 tubes of serpulids on which were fixed thalli crossed by dichotomous tubes with swellings of *Springerella bifurcata* n.sp. or rarely *S. fuchtbaueri* n.sp.

The majority of these algal nodules were free on the substratum or were temporarily anchored when larger.

The spheroidal thalli of *Springerella bifurcata* (Figs. 5–6), with or without a core, never surpassed 2.5–3.0 mm. The thalli had ellipsoidal shapes, when the substratum or the core was made of two serpulid tubes, and dimensions larger than 4.0–5.0 mm.

The majority of the nodules of the Upper Serpulid Limestone can be regarded as homogenous, monospecific stromatolites. Nodules larger than 6.0–10.0 mm, with an irregular outline, with small external protuberances, occur rarely. They are constructed by *Springerella bifurcata* to the central part followed externally by laminated crusts of *Broutinella arvernensis*. In most cases, the serpulid tubes provided the better substratum for algae, such as dichotomously ramified tubes of *Springerella*. The *Springerella* nodules incorporate serpulid tubes, and angular quartz grains with a diameter of 0.05–0.06 mm.

In addition to *Springerella* and *Broutinella*, the community includes bivalve shells, ostracod valves and microgastropods (4.0–5.0 mm). The gastropod shells were filled with numerous small serpulid tubes. Ooids also occur with cores of angular quartz (0.05–0.06 mm in diameter) or of well rounded quartz grains with a diameter larger than 0.80–1.0 mm.

Clusters of dead serpulids provided the initial substrates for the nodules and laminated crusts. These crusts incorporate empty tubes of serpulids, algal pellets, ostracods, gastropod shells, and quartz grains with a reduced diameter.

This community belonging to the Upper Serpulid Limestone can be compared with the spirorbid algal stromatolites and Recent stromatolites in hypersaline (50–70 ‰) lagoons near Shark Bay, W. Australia (Ten Hove & Van Den Hurk 1993). The algal nodules of the Upper Serpulid Limestone incorporated re-deposited tubes of serpulids generated in lagoons fringing an inland sea, within the intertidal and lower supratidal zones.

Paleoalgological description

Phylum Chlorophyta
Class Bryopsidophyceae
Order Bryopsidales
Family **Udoteaceae** Endlicher 1834 emend. Agardh 1887

Genus *Pseudopenicillus* Dragastan, Richter, Kube, Popa,
Sârbu et Ciugulea 1997

Pseudopenicillus weseri nov. spec.
(Fig. 9.1–8)

Derivatio nominis: from the Weser River, Germany.

Holotype: Fig. 9.1, Coll. L.P.B. V, No. 1120, Upper Tithonian, sample F3A, Oolitic Serpulid Limestone (Münder Marl = OM 4) Salzhemmendorf.

Isotypes: Fig. 9.4–8, Coll. L.P.B. V, No. 1121, No. 1122, No. 1123, No. 1124, Upper Tithonian, Oolitic Serpulid Limestone.

Diagnosis: Thallus composed by cylindrical segments separated by constrictions. The segments have a central medullary hollow, without preserving siphons, and a thin cortex crossed by cylindrical primary, secondary and tertiary siphons. Primary siphons have in the proximal part an inflated swollen "vesicle", and the secondary siphons also have small "vesicles" in the distal parts. Tertiary siphons, dichotomic, are very short and narrow.

Description: Thallus formed by small narrow, cylindrical segments separated by deep constrictions (Fig. 9.1,6). The segments, entire or broken, have an axial cavity with an uneven and sinous contour. The central cavity is narrow and corresponds to the medullary zone, in which the siphons are not preserved. The cortex is not thick, and partially is only incomplete preserved. It was not strongly calcified and sometimes is broken (Fig. 9.4–8).

The cortical zone is crossed by very fine, cylindrical, primary siphons continued by secondary siphons, both dichotomously branched. The vesiculiferous inflated proximal part of primary, and of the distal part of secondary siphons, are clearly visible on the Fig. 9.4 (see arrow).

Dimensions in mm: length of thallus: 2.0–3.0; diameter of thallus: 0.90–0.95; diameter of thallus between segments: 0.70–0.75; diameter of the axial cavity or medulla: 0.50–0.55; thickness of cortex: 0.15–0.20; length of primary cortical siphons: 0.080–0.10; length of secondary cortical siphons: 0.040–0.060; length of tertiary siphons: 0.020–0.030; diameter of primary cortical siphon: in the proximal part 0.030 and in the median and distal part: 0.020; diameter of secondary cortical siphons in the distal part 0.010–0.015; diameter of tertiary siphons: 0.010.

Discussion: *Pseudopenicillus weseri* n.sp. differs from *P. jurassicus* (Dragastan), *P. orientalis* (Dragastan), *P. elongatus* (Dragastan), *P. texana* (Johnson) and *P. dragastani* (Bucur) of Late Jurassic–Early Cretaceous age, by the small size of the segments and by the presence of "vesicle" in the proximal parts of the primary siphons and in the distal parts of the secondary cortical siphons.

P. peloponnesiacus Dragastan et Richter from Tithonian, Corinth area (Grecee), is similar in the small segment size and presence of cylindrical primary and secondary cortical siphons, but lacks "vesicle" in the proximal and distal parts of the siphons.

Phylum Chlorophyta

Springerella nov. gen.

Derivatio nominis: from Springe locality and from the ending "rella".

Type species: *Springerella bifurcata* nov. gen. nov. spec.

Diagnosis: Nodular thallus crossed by only one kind of long tube, open or Y-shaped, dichotomously branched, having a strong calcified swelling in the area of branching. Due to the reduced number of swellings (1–2) between the successive dichotomies and in the branching area, the thallus is slightly moniliform.

Discussion: The new taxon is comparable with non-marine genera *Purserella* Freytet 1997 (Oligocene), *Ponsinella* Freytet 1998 (Ludian–Recent) and *Sarfatigirella* Freytet 1998 (Campanian–Oligocene–Recent).

Purserella has erect filaments, regular, flexuously sinuous, dichotomous branches diverging at 30°, but lacks swellings in the branching area and along the filament tubes.

Ponsinella has two types of filaments, prostrate, then inclined and erect, rarely branched with a lateral tube making an angle of 60° (Freytet 1998, p. 21).

Sarfatigirella shows intricate filaments, arcuate, flexuous, having a "pinch and swell" aspect, forma *torulata*, which differs in shape and thickness from the new taxon.

The new taxon is also comparable with the Jurassic species of the marine *Mitcheldeania* Wethered 1886 and with *Pseudomitcheldeania* Schlagintweit 1990 (Jurassic–Cretaceous) and *Perachoraella* Dragastan, Richter, Gielisch et Kube 1998 (Late Jurassic–Early Cretaceous). These genera also have dichotomously branched tubes (siphons) with a small angle of divergence (mainly 10°) and variable swellings, occurring in number, higher than two, and another shape of swellings, which differ from the new genus.

The taxonomic attribution of the new genus within the Chlorophyta remains open. The presence of swellings in the tube siphons is a characteristic feature of Bryopsidophyceae.

Posinella is considered close to modern Scytonemataceae (Cyanobacteria) and *Purserella* still remains in an open taxonomy (Freytet 1997 and 1998).

The genera *Mitcheldeania, Pseudomitcheldeania* and *Perachoraella* belong the Family Avrainvilleaceae, Class Bryopsidophyceae, Chlorophyta.

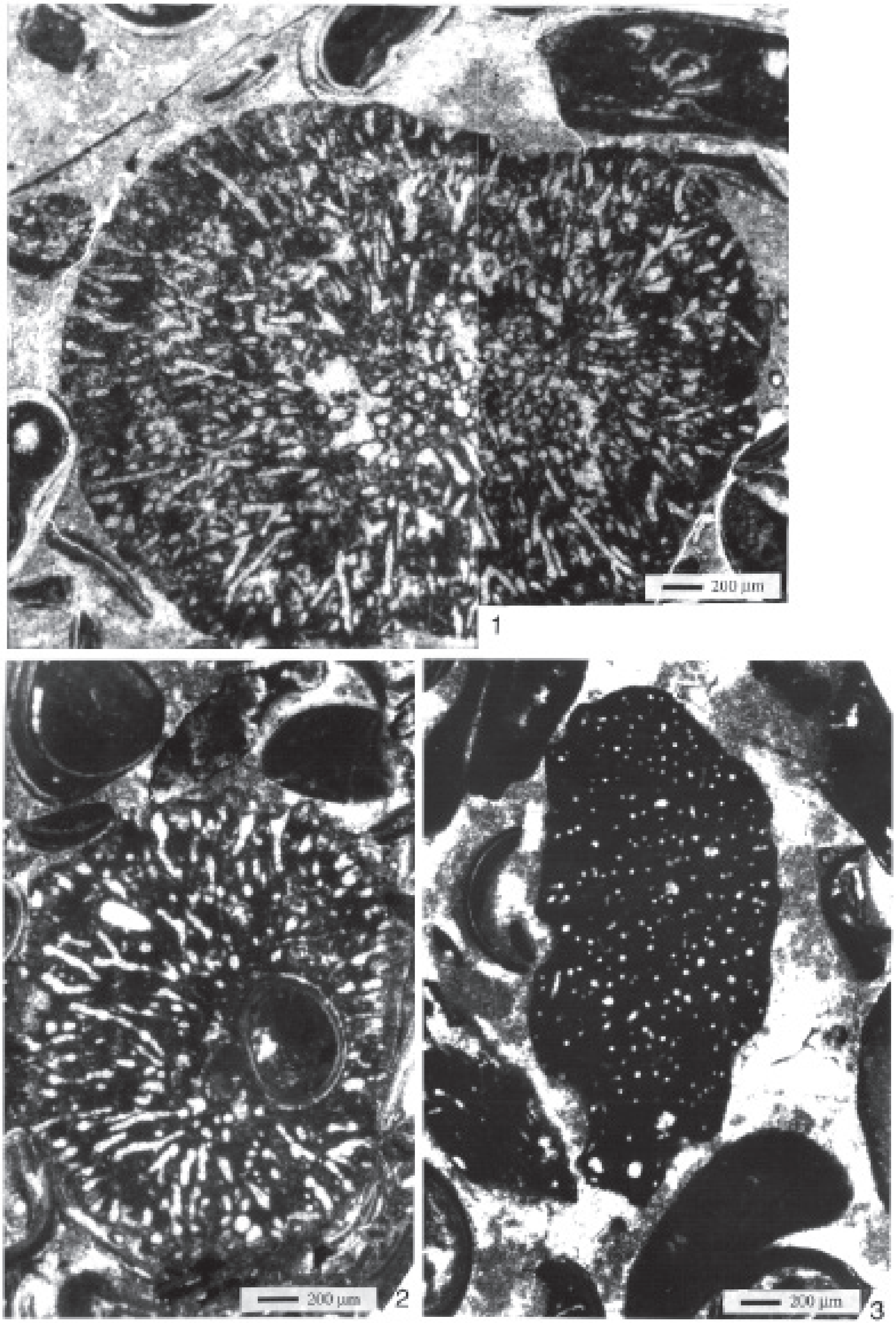

Fig. 10. 1: *Springerella bifurcata* nov. gen. nov. spec., Holotype, Coll. L.P.B. V, No. 1125, cross-section of a nodular oval–ellipsoidal thallus, sample 835. **2:** *Springerella bifurcata* nov. gen. nov. spec., Isotype, a vertical section of a nodular, spheroidal thallus attached to a serpulid tube, showing the characteristic dichotomic branched tubes with swellings separated by constrictions. **3:** *Springerella bifurcata* nov. gen. nov. spec., Isotype, cross-section of an ellipsoidal thallus, showing the distribution pattern of the tubes, locally with large, circular swellings, strongly calcified. Lower Berriasian, Upper Serpulid Limestone, Springe locality, Weserbergland, NW Germany.

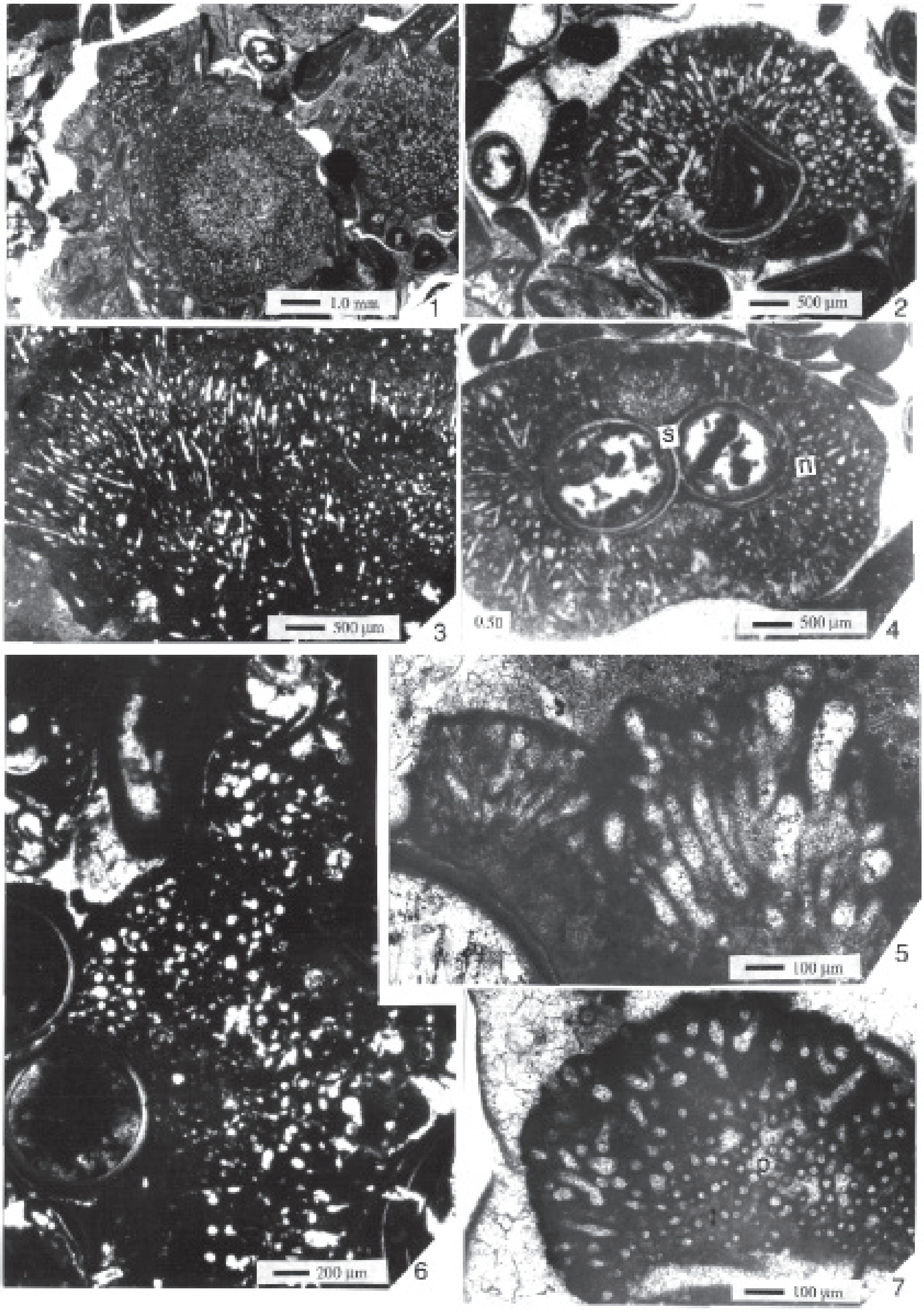

Fig. 11. 1–4: *Springerella bifurcata* nov. gen. nov. spec., Isotypes; 1–3. Thalli variously sectioned with or without nuclei, mainly occurring on serpulids tubes, showing the Y-shaped dichotomic tubes, like *Ortonella*, slightly moniliformous, with marked swelling, in the branching area; 4. Two generations of thalli covering the serpulids tubes: normal thalli growing to the extremities (n) and small, young thalli (s) occupying the "depression" formed between the tubes of serpulids, sample 835. **5–7:** *Springerella fuchtbaueri* nov. spec.; 5. Holotype, Coll. L.P.B. V, No. 1132, vertical axial section, in bushes attached to serpulid tubes and showing characteristic shape of swellings, sample 38; 6. Isotype, horizontal cross-section, showing the shape of thallus and characteristic distribution pattern of the tubes; tubes disposed in a petaloid — subpolygonal structure with large diameter (light spots); 7. Isotype, oblique cross-section in thallus composed of strongly calcified, dichotomously branched tubes. Lower Berriasian, Upper Serpulid Limestone, Springe locality, Weserbergland, NW Germany.

Springerella bifurcata nov. spec.
(Fig. 10.1–3, Fig. 11.1–4)

Derivatio nominis: from the open dichotomously branched tubes.

Holotype: Fig. 10.1, Coll. L.P.B. V, No. 1125, Lower Berriasian, sample No. 835, Upper Serpulid Limestone, locality Springe.

Isotypes: Fig. 10.2–3, Coll. L.P.B. V, No. 1126, No. 1127; Fig. 11.1–4, Coll. L.P.B. V, No. 1128, No. 1129, No. 1130, No. 1131, Lower Berriasian, Upper Serpulid Limestone.

Diagnosis: Nodular thallus composed of Y-shaped, open, dichotomously branched tubes, having in the area of branching a strongly calcified swelling and 1–2 swellings along the tubes in the area between two successive dichotomous branches.

Description: Nodular spheroidal or ellipsoidal thallus. The shape of the thallus reflects the shape of the core or substratum. If the alga is attached on a serpulid tube, the shape of thallus is spheroidal (Fig. 10.2). When it is attached on an elongate ooid, the shape of thallus becomes ellipsoidal or if is embedded on a double serpulid tubes, the shape of thallus is also ellipsoidal (Fig. 11.4). The thallus is crossed by long, Y-shaped open dichotomously branched tubes, which present an angle of divergence of 30°–40°. In vertical (Fig. 10.1–2) and horizontal sections (Fig. 10.3) the Y-shaped, dichotomous tubes present in the branching area a strong swelling and also 1–2 swellings along the tubes, between two successive dichotomously branched areas (Fig. 10.2; Fig. 11.3). The shape of swellings is ovoidal to ellipsoidal between the dichotomies and subtriangular in the branching area (Figs. 5–6).

The pattern of distribution of the tubes is another characteristic feature of this species. In cross-section, the tubes are disposed in a regular network, round, quadrangular or polygonal in shape, separated from each other by coarsely crystalline calcite (Fig. 10.3). The distribution of tubes is in a more or less regular sparitic “muff”, represented by 4 (quadrangular) or 8 tubes, when the shape of “muff” is round to polygonal, the tubes having a petaloid disposition (Fig. 10.3). Sometimes in horizontal section, the swellings appear circular with a large diameter, like white sparitic spots (Fig. 10.3).

Dimensions in mm: maximum diameter of thallus: 3.5–4.0; normal diameter of thallus: 2.20–3.0; diameter of tube in the dichotomous branching area: 0.075–0.080; diameter of tube after the dichotomous branching area: 0.035–0.040; diameter of swellings along the tube: 0.040–0.050; angle of divergence: 30°–40° (50°).

Discussion: *Springerella bifurcata* n.sp., differs from *Purserella gracilis* Freytet (Oligocene) by the presence of swellings in the branching area and in other kinds of dichotomy. From *Ponsinella rupestris* Freytet (Recent), it differs in the absence of two kinds of filaments, prostate and then erect.

Sarfatigirella fallacia Freytet from the Campanian differs in its small diameter of more or less erect filaments, that are not undulose. In common with the new species swellings are present, but these are not distributed in the branching area, and they also have a spheroidal shape.

The marine species *Mitcheldeania americana* (Johnson) from the Jurassic differs from the new taxon by the presence of siphons, dichotomously branched after an angle of divergence of less than 10°, and by the presence of many swellings along the siphons.

The marine species of *Pseudomitcheldeania* such as *P. dragastani* Schlagintweit (Upper Aptian), *P. akrokorinthica* Dragastan et Richter (Tithonian) and *P.* sp. (Valanginian) are different from *S. bifurcata,* in their shape and in the number of swellings along the tube. The first of these species has many swellings along the tube and the second species has long, large swellings arranged at different levels. The third species has ellipsoidal swellings, distributed at irregular intervals along the tubes. The species of *Pseudomitcheldeania* belongs to the Family Avrainvilleaceae, Class Bryopsidophyceae.

Springerella fuchtbaueri nov. spec.
(Fig. 11.5–7)

Derivatio nominis: Species dedicated to Dr. Hans Füchtbauer, Professor Emeritus of the Institute of Geology, Ruhr University Bochum, who first studied the algal-microbial nodules of Weserbergland, NW Germany.

Holotype: Fig. 11.5, Coll. L.P.B. V, No. 1132, Lower Berriasian, sample No. 38/1, Upper Serpulid Limestone, Springe locality.

Isotypes: Fig. 11.6–7, Coll. L.P.B. V, No. 1133 and No. 1134, Lower Berriasian, Upper Serpulid Limestone.

Diagnosis: Thallus ellipsoidal, composed of several fan-shaped bushes. Each bush crossed by short, dichotomously branched tubes with strongly calcified sub-triangular or claviform swellings, before the branching zone (Fig. 11.5c). The tubes show many spheroidal swellings between successive dichotomies (Fig. 11.5, see arrows). The angle of divergence varies from 10° to 40°.

Description: Thallus irregular ellipsoidal, formed by several spheroidal or fan-shaped bushes fixed on the serpulid tubes (Fig. 11.6). Thallus is crossed by dichotomously branched tubes, having a subtriangular or claviform swellings (Fig. 11.5). In the horizontal and oblique-horizontal sections (Fig. 11.6–7), the arrangement of tubes is subpolygonal, composed of over 8 circular tubes (Fig. 11.7). The swellings before the branching area have a large diameter.

Dimensions in mm: height of thallus: 0.30–0.70; width of thallus: 0.40–0.90; tube diameter, in the dichotomic branching area: 0.040–0.060; tube diameter after dichotomic area: 0.020–0.030; diameter of basal swelling before branching: 0.080–0.10.

Discussion: *Springerella fuchtbaueri* nov. spec. differs from the non-marine species, *Purserella gracilis* Freytet, *Ponsinella rupestris* Freytet and *Sarfatigirella fallacia* Freytet by the presence of dichotomic tubes which in the branching area have a strong calcified swelling and many small swellings separated by constrictions along the tubes crossing the thallus. *S. bifurcata* nov. spec. is different in the shape of thallus, pattern distribution of tubes, angle of divergence and pattern of distribution of swellings along the thallus.

In comparison with marine species, the new species is comparable with *Mitcheldeania americana* (Johnson) of the Upper Jurassic, but differs in having a different kind of branching and fewer swellings along the tubes. It differs from *Pseudomitcheldeania dragastani* Schlagintweit (Upper Aptian), in the shape of the thallus and the shape and distribution of swellings crossing the thallus.

Genus *Chlorellopsis* Reis 1923

Chlorellopsis coloniata Reis 1923
(Fig. 12.1–2)

1923 *Chlorellopsis coloniata* n.gen. n.sp., Reis, p. 107, Tafel III, Figs. 1–2, 9; Tafel IV, Figs. 3,6; Tafel V, Figs. 2–6 and Fig. Text 1, p. 105
1997 *Chlorellopsis coloniata*, Freytet, p. 13, Pl. 1, Figs. a–c
2000 *Chlorellopsis coloniata*, Freytet, p. 9, Pl. I, Fig. c

Paratype: Fig. 12.2, Coll. L.P.B. V, No. 1135, Lower Berriasian, sample A3, Lower Serpulid Limestone, Deister Mts, Weserbergland, NW Germany.

Description: Thallus small, nodular, in biomicritic masses or included in laminations. Thallus is composed of spherical bodies (cells), 0.060–0.110 mm in diameter. The spherical "cells" are preserved in coarsely crystalline calcite surrounded by microcrystalline calcite, polygonal in shape (Fig. 12.2). The microcrystalline calcite "layer" is covered by coarse crystalline calcite like a "muff" which preserves the polygonal shape of the cells (Fig. 12.1/c–2).

Dimensions in mm: diameter of thallus: 1.0–2.0; diameter of spherical bodies or cells: 0.060–0.110.

Remarks: *Chlorellopsis coloniata* is a frequent alga in the brackish and freshwater facies mainly associated with stromatolitic build-ups.

A discussion and interpretation of *Ch. coloniata* was well presented by Freytet (2000) who shows that *Chlorellopsis* is never free in the sediment when building stromatolitic masses showing diverse aspects and morphologies.

The systematic position of *Ch. coloniata* is and remains controversial:

— Reis (1923) considered that the species belongs to Chlorophyta, Order Protococcales and compared it with the Recent marine genus *Halosphaera* and with freshwater genera *Eremosphaera* and *Chlorella*;

— Lindqvist (1994) considers that these thalli with spheres are "endogonaceous fungal spores" and

— Freytet (1997) shows that a precise attribution of *Chlorellopsis coloniata* remains open.

Genus *Brachydactylus* Reis 1923

Brachydactylus reisi nov. spec.
(Fig. 12.1, Fig. 13.1–6)

Derivatio nominis: Species dedicated to Otto M. Reis, who was the first to discover and describe the Miocene non-marine algae.

Holotype: Fig. 13.1, Coll. L.P.B. V, No. 1138, Lower Berriasian, sample A3, Lower Serpulid Limestone, Deister Mts, Weserbergland, NW Germany.

Isotypes: Fig. 13.4–6, Coll. L.P.B. V, No. 1139, No. 1140 and No. 1141, Lower Berriasian, Lower Serpulid Limestone, Weserbergland, NW Germany.

Diagnosis: Thallus crossed by a bunch of filaments grouped in fascicles composed of finger-like, short dichotomic filaments. The fascicles grow over each-other. They have a fan-shape, being cauliflower-like in structure, and minidigitate at the distal part of the fascicles.

Description: Thallus nodular with many small, spheroidal protuberances. The thallus is crossed by grouped filaments with microdigitate distal ends of the fascicles (Fig. 13.1–6). Each filament fascicle is strongly calcified with a fan-shaped aspect and comprise many, small, dichotomic filaments at the distal part (Fig. 13.3–6). The fascicle filaments form spherical nodules (Fig. 13.1,4) or planar laminated crusts (Fig. 13.6).

Dimensions in mm: diameter of the thallus nodule: 2.0–2.5; diameter of isolated protuberances: 1.0–1.5; width of the filament fascicles: 0.70–0.75; height of the filament fascicles: 0.40–0.50; diameter of minidigitate filaments in the distal part: 0.035–0.040.

Discussions: *Brachydactylus reisi* n.sp. differs from the Miocene *B. radialis* Reis in the shape and size of filament fascicles, which contain dichotomic filaments at the distal parts of the fascicles.

B. reisi n.sp. is one the most important builders of the stromatolitic nodules, being associated with and a generator of crusts (protuberances), together with *Chlorellopsis coloniata* Reis, *Broutinella arvernensis* Freytet and *Ponsella freyteti* n.sp. (Fig. 7).

Cyanobacteria

Genus *Ponsella* Freytet 1997

Ponsella freyteti nov. spec.
(Fig. 12.3–5)

Derivatio nominis: Species dedicated to Dr. Pierre Freytet for his contributions in the field of non-marine algae.

Holotype: Fig. 12.3, Coll. L.P.B. V, No. 1136, Lower Berriasian, sample A3, Lower Serpulid Limestone, Deister Mts, Weserbergland, NW Germany.

Isotype: Fig. 12.5, Coll. L.P.B. V, No. 1137, Lower Berriasian, Lower Serpulid Limestone, Weserbergland, NW Germany.

Diagnosis: Thallus laminated, crustose, composed of filaments grouped in fascicles at the base, inclined, then erect, being slightly dichotomously branched; adjacent fascicles forming layers or lamination.

Description: Thallus crustose, laminated, not very thick, formed by fascicles. The filaments disposed at the base, prostate short, then erect (Fig. 12.4–5). The fascicles are wide, cylindrical, composed of 2 or 4 slightly dichotomic branched filaments.

Dimensions in mm: thickness of thallus: 0.30–0.50; width of the fascicles: 0.070–0.10; diameter of filament tubes: 0.015–0.020.

Discussion: *Ponsella freyteti* nov. spec. is close to *P. castellandonica* Freytet 1997 from Ludian, in filament size, but differs in the shape and the size of the fascicles, which are not so wide. The species *P. sezanensis* Freytet 1997 and *P. cupulata* Freytet 1997 from the Eocene have different size and shape of

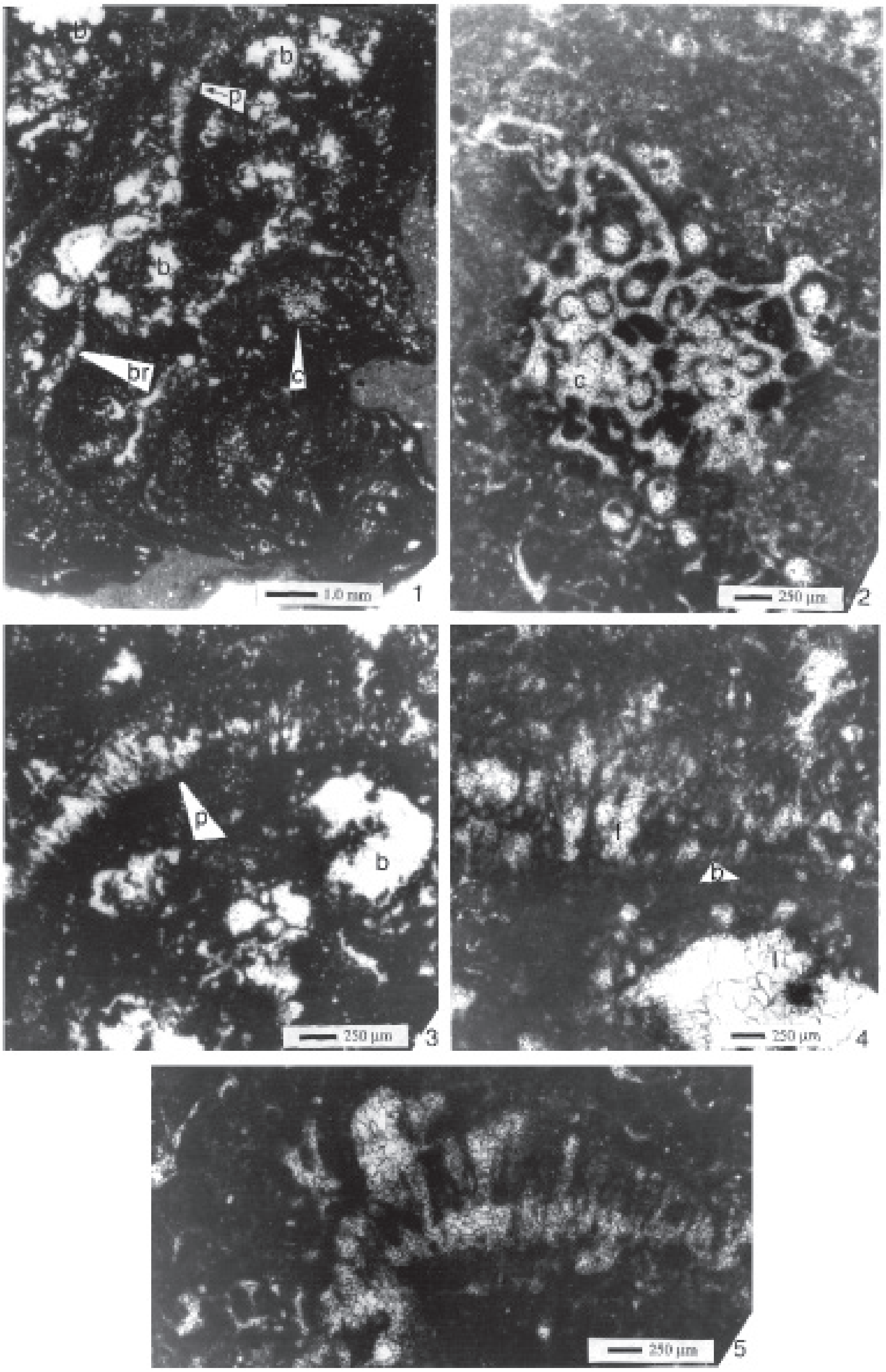

Fig. 12. 1: Stromatolitic nodule formed by algal crusts and different generations of algae as follows: at the base *Chlorellopsis coloniata* Reis (c), in the middle and up to the upper part of the nodule *Brachydactylus reisi* nov. spec. (b), *Broutinella arvernensis* Freytet (br), *Ponsella freyteti* nov. spec. (p) appear successively and at the top of the nodule some protuberances with *Brachydactylus reisi* nov. spec. (b). **2:** *Chlorellopsis coloniata* Reis, Paratype, thallus subspheroidal formed by spherical cells (c), which shows a polygonal, microcrystalline calcite inter-space and a sparitic outer "muff". **3–5:** *Ponsella freyteti* nov. spec.; 3. Holotype, Coll. L.P.B. V, No. 1136, vertical section, a laminated crust, crossed by micritic tubes filaments (p), homogenous, slightly inclined to the base, subsequently erect, grouped in fascicles. *Ponsella* grew over *Brachydactylus reisi* nov. spec. (b); 4. Detail in Holotype, typical aspect of the base with micritic filaments (b) and very narrow fascicles (f) with erect coarsely crystalline calcite filaments; 5. Isotype, thallus laminated at the base, prostate with micritic filaments and subsequently erect filaments grouped in fascicles. Lower Berriasian, Lower Serpulid Limestone, Dreister Mts., Weserbergland, NW Germany.

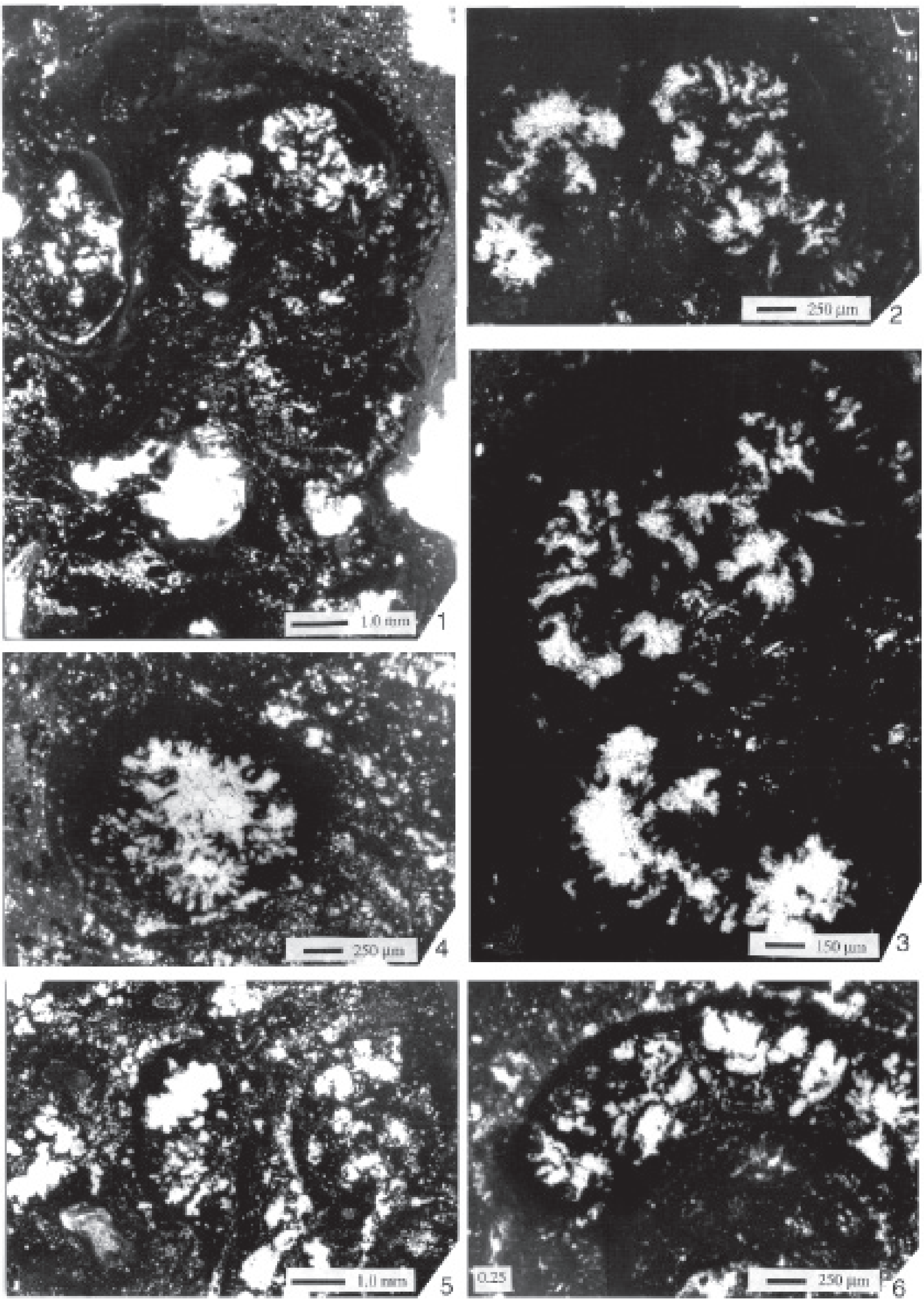

Fig. 13. 1–3: *Brachydactylus reisi* nov. spec.; 1. Holotype, Coll. L.P.B. V, No. 1138, vertical section, thallus nodular built by small, cauliflower, spheroidal fascicles overgrowing each other, sample A3; 2–3. Detail of Holotype showing the distribution of cauliflower-like, spheroidal fascicles; fascicles appear dichotomic short fingers, tubular filaments. **4–6:** *Brachydactylus reisi* nov. spec.; 4. Isotype, cross-section in a nodule formed by radially disposed cauliflower-like fascicles which have distal finger-like short, dichotomic filaments; 5–6. Vertical section, in laminated nodule showing the overgrowing of the cauliflower-like, filamentous fascicles. Lower Berriasian, Lower Serpulid Limestone, Dreister Mts, Weserbergland, NW Germany.

fascicle, and also are different from the new taxon in filament diameter.

Genus *Broutinella* Freytet 1998

Broutinella arvernensis Freytet 1998
(Fig. 12.1/br, Fig. 7)

1998 *Broutinella arvernensis* n.gen. n.sp. Freytet, p. 11, Pl. XII, Figs. a–i, Oligocene–Recent

Paratype: Fig. 12.1/br, Coll. L.P.B. V No. 1142, Lower Berriasian, sample A3, Lower Serpulid Limestone, Weserbergland, NW Germany.

Description: Thallus crustose, laminated, formed by only one layer (forma *monostrata*) with fascicles various in shape, including diverse shapes of coarse crystalline calcite (sparite radial, palisadic). The crust shows frequent intervals of microlaminations. Filaments very thin, 3–5 µm in diameter.

Remarks: *Broutinella arvernensis* is the main organism of the stromatolitic build-ups, forma *monostrata*, and it is frequently associated with *Chlorellopsis coloniata*, *Ponsella freyteti* nov. spec. and *Brachydactylus reisi* nov. spec.

Freytet (2000) shows that the three discriminating characters of *B. arvernensis* are the scarce presence of erect, more or less radiating filaments; lamination of radial, palisadic sparite; and the frequent presence of microlaminations in the light laminae. The presence of radial palisadic type of calcite in freshwater facies suggests travertines or sinter crusts with periodic proliferation of population of cyanobacteria or other bacteria.

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