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Rugose corals and associated carbonate microfossils from the Brigantian (Mississippian) of Castelsec (Montagne Noire, southern France)

Coraux rugueux et microfossiles carbonatés associés, du Brigantien (Mississippien) de Castelsec (Montagne Noire, Sud de la France)

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Abstract

The disused quarry east of Castelsec offers a view of shallow-marine carbonates of the poorly known Uppermost Mississippian of the Montagne Noire. At Castelsec, sections are studied in two characteristic facies types (bioclastic wackestone and microbial dominated boundstone) of the Upper Mississippian. The succession is rich in rugose corals and carbonate microfossils. Six genera with seven species belonging to a rugose coral fauna consisting of at least eight genera with several species are described herein; *Dibunophyllum castelsecensis* sp. nov. is described as new. Twenty-seven carbonate microfossils of different groups have been identified. The Castelsec succession is Brigantian in age, based on the stratigraphic occurrence of rugose corals, foraminifers, and calcareous algae observed in both sections. The rugose coral fauna shows relationships with the well-known fauna of northwestern Europe and the Ouralian–Asian Province. Typical elements of northwestern Europe are missing at Castelsec and vice versa. This differentiation between north and south is interpreted as responses to different palaeolatitudes and tectonic settings.

Résumé

La carrière abandonnée située à l'est de Castelsec permet l'observation des carbonates peu connus du Mississippien supérieur de Montagne Noire. Du point de vue sédimentologique, les sections étudiées comprennent deux des faciès caractéristiques (wackestones bioclastiques et boundstones microbiens) du Mississippien supérieur de Montagne Noire. La succession y est riche en coraux et microfossiles carbonatés. Huit genres de Rugueux y ont été reconnus; six d'entre-eux et sept espèces, dont une nouvelle *Dibunophyllum castelsecensis* sp. nov., sont décrits en détail dans ce travail. Vingt-sept microfossiles carbonatés de groupes différents ont également été identifiés. L'étude des Rugueux, des foraminifères et des algues, nous a permis de rattacher ces terrains au Brigantien. La faune à Rugueux montre des relations avec les faunes bien connues de la province Nord (Europe nord-ouest) et de la province Ouralo-Asiatique. Des éléments typiques de la province Nord manquent à Castelsec et inversement. Ceci résulterait des différences d'environnements tectoniques et de paléolatitudes.

Keywords: Visean; Taxonomy; Rugosa; Algae; Foraminifera; *Dibunophyllum castelsecensis*

Mots clés: Viséen; Taxonomie; Rugueux; Algues; Foraminifères; *Dibunophyllum castelsecensis*

1. Introduction

Compared with other Mississippian deposits, little work has been done on deposits of this age in the Montagne Noire. It is the focus of this paper to demonstrate exemplarily the richness of an Upper Visean deposit in this area. The Castelsec succession yields an exceptionally rich fauna of microorganisms and a rich coral fauna.

Further, it allows a comparison with the relatively well-known rugose coral faunas from north-central Europe (British Isles and Belgium), and also allows comparison be-

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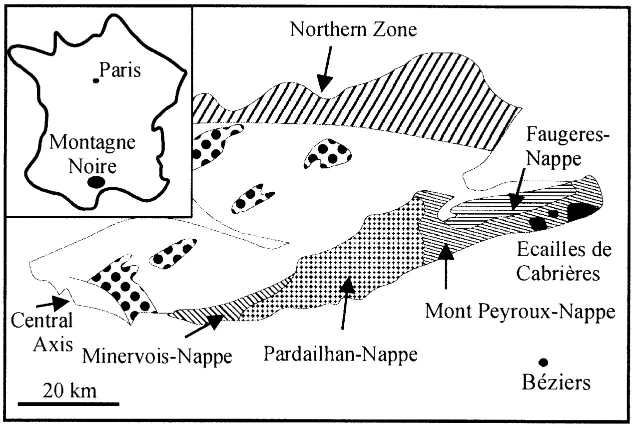

Fig. 1. Structural units of the Montagne Noire (modified after Gèze, 1949).
Unités structurales de la Montagne Noire (modifié d'après Gèze, 1949).

tween two geotectonic settings—stable inner shelf environment and active margin setting.

Böhm (1935), Gèze (1949), Maurel (1966), Mamet (1968), Vachard (1977), and Engel et al. (1981) established a stratigraphic and tectonic framework. In addition, these works provided a lot of information on biostratigraphy, and taxonomy of goniatites, brachiopods, foraminifers and algae. More recently, Barchy (1994) gives information on the composition and distribution of rugose coral faunas in the Montagne Noire.

All described material is deposited in the Geologisches Institut of the Universität Köln under the collection numbers GIK 1730–1760.

2. Setting

The Montagne Noire—a Paleozoic massif—is divided into three zones (Fig. 1). The northern zone consists of Cambro-Ordovician deposits, the axial zone is formed by metamorphic rocks, and a southern zone comprises several nappes with Precambrian to Mississippian strata. The studied sections at Castelsec are situated in the 'Ecailles de Cabrières' olistoliths (southern zone) (Figs 1 and 2).

The Uppermost Mississippian of the southeastern Montagne Noire (Mont Peyroux-Nappe and Ecailles de Cabrières) is characterised by the co-occurrence of orogen-derived siliciclastics, mostly sandstones, turbiditic limestones, deep- and shallow-water limestones. The 'Ecailles de Cabrières'-olistoliths occur as isolated blocks within a siliciclastic flysch matrix (Engel et al., 1981).

Although the gravitational transport of the Ecailles de Cabrières was just shown in 1952 by De Sitter and Trümpy in Geze et al. (1952), the interpretation of the original position and the direction of this transport is controversial. Arthaud et al. (1976) connected flysch sedimentation in the Montagne Noire with their structural model for the Massif de Mouthoumet, thus supporting transport from the south towards the north. Engel et al. (1981) interpreted the 'Ecailles de Cabrières' as the largest grains of their flysch

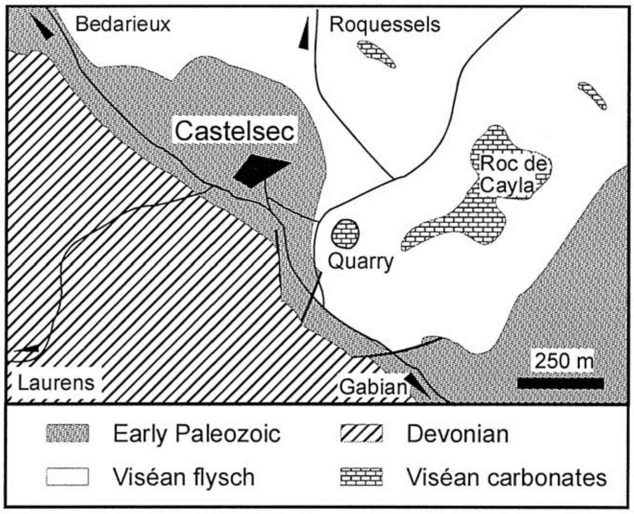

Fig. 2. Simplified geological map of the Castelsec area (after Engel et al., 1981).
Carte géologique simplifiée dans la région de Castelsec (d'après Engel et al., 1981).

matrix suggesting that during the Variscan orogeny, these 'grains' had been transported form the north—an unstable shelf south of the Variscan orogen—towards the south into an adjacent flysch basin. The original position of the Ecailles was concluded to be north of the axial zone (Engel et al., 1981) or south of the axial zone (Arthaud, pers. com. in Engel et al., 1981).

On the siliciclastic-dominated shelf, patchy carbonate systems developed only in isolated positions. The fragments of these carbonate systems are today summarised under the name 'Calcaire à Productus'. According to the research on foraminifers and calcareous algae, deposition of the 'Calcaire à Productus' started in the V3b and ended in upper V3c (Mamet, 1968) or lower V3c (Vachard, 1977). The rugose coral fauna indicates that most of the 'Calcaire à Productus' belongs to the rugose coral zone RC8 (Poty in Conil et al., 1990). This zone indicates at least a Brigantian age. Based on lithostratigraphic work (Poty et al., submitted), the 'Calcaire à Productus' is divided into a lower Roque Redonde Formation and an upper Roc de Murviel Formation separated by a paleokarst surface (Fig. 3). Following the depositional model of Hance et al. (2001), the paleokarst marks a major regression near the Visean–Serpukhovian boundary. The Roque Redonde Formation comprises the top of the Belgian sequence 9 (Hance et al., 2001) and the Roc de Murviel Formation would be the lower part of the following sequence not preserved in Belgium.

The studied sections are exposed in a disused quarry ($x = 672{,}55$; $y = 137{,}35$) south-east of Castelsec village (Fig. 2), along the road Pézénas–Bédarieux (D 13). Nearly all of the total limestone lens was removed by quarrying. Therefore, only the former edge is documented (today 0.5–4.0 m in height). More or less continuous sections are observed north of the former entry, and in the southeastern corner. Following Poty et al. (submitted), the limestones

Age			Forams M	Forams C	Coral P	Mamet 1968	Vachard 1977	Poty et al.
Upper Mississippian	Serp.		18-17	Cf7	RC 9			Roc de Murviel Formation
Upper Mississippian	Viséan	Brigantian	16s	Cf6δ	RC 8	Calcaire de Vailhan		Karst; Roque Redonde Formation
Upper Mississippian	Viséan	Brigantian	16i	Cf6δ	RC 8	Bioherms de Cabrières	Calcaire à *Productus*	Roque Redonde Formation
Upper Mississippian	Viséan	Asbian	15	Cf6γ	RC7β	Bioherms de Cabrières	Calcaire à *Productus*	Asbian fauna in reworked material in the lower part of Roque Redonde F.

Fig. 3. Stratigraphic overview on the Upper Mississippian, data from Mamet (1968), Vachard (1977) and Poty et al.; M = Mamet and Skipp, 1971, C = Conil in Conil et al., 1990, P = Poty in Conil et al., 1990.
Stratigraphie du Mississippien supérieur, données de Mamet (1968), Vachard (1977) et Poty et al.; M = Mamet et Skipp, 1971, C = Conil in Conil et al., 1990, P = Poty in Conil et al.,1990.

belong to the Roque Redonde Formation. The section north of the entry is the type section for the bioclastic dominated Castelsec Facies within this formation.

3. Succession and facies analysis

North of the entry (Fig. 4), the succession starts with massive grainstones and wackestones, rich in *Eovelebitella occitanica* VACHARD, 1977. Partly, fining upward sequences are observed. This 1.2 m thick unit, is followed by limestones (1.5 m thick) enriched in corals (*Lithostrotion decipiens* (MCCOY, 1849), *Siphonodendron* cf. *irregulare* (PHILLIPS, 1836), *Axophyllum nanum* POTY, 1981 and *A.* cf. *nanum* POTY, 1981) interpreted as coral patch-reef (Aretz and Herbig, in press). The number and size of corals increases towards the top of the horizon. Coral-boundstones dominate the reefal horizon. The influence of calcimicrobes is seen in various microbial bindings and encrustations around corals and intraclasts. Within the horizon, an input of bioclasts (intra- and extraclasts) fills the space in between the corals and bindings. A significant higher input of bioclasts stopped the reef development.

Three units of well-bedded, partly argillaceous bioclastic limestones top the coral unit. The lower thick-bedded unit (2.8 m thick) comprises small clisiophyllids and axophyllid rugose corals, associated with productids, *Palaeosmilia*

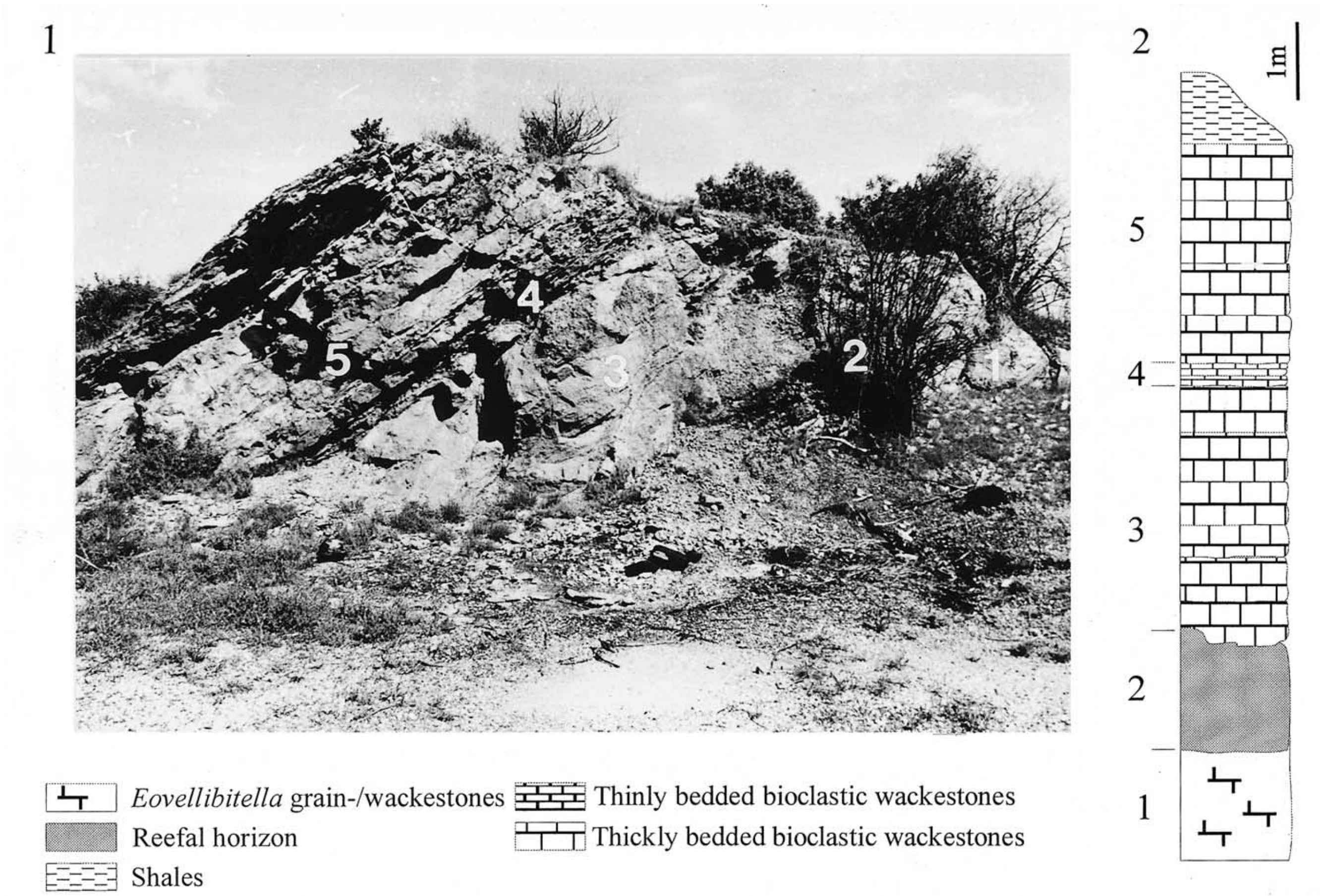

Fig. 4. The section north of the former entry. 1. Photo of the outcrop in Mai 1999 and 2. Log of the section.
La section au nord de l'ancienne entrée. 1. Photo de l'affleurement en mai 1999 et 2. Log de la succession.

murchisoni MILNE-EDWARDS & HAIME, 1851 and *Siphonodendron pauciradiale* (MCCOY, 1849). The forth unit comprises thin-bedded wackestones, sometimes argillaceous, varying in thickness from 10 to 25 cm. Macrofauna is less abundant. Again, thick-bedded wackestones characterise the fifth unit (2.4 m thick). Compared to the third, macrofauna is obviously less abundant. Grey-brownish shales indicate the onset of the flysch sedimentation over the limestones.

The succession in the southeastern corner differs highly from that described above. The succession starts with limestones hardly affected by tectonics (numerous quartz veins). Overall, microbial induced boundstones dominate the succession. Bioclastic limestones are rare, more common are well-separated bioclastic infillings [mm- to 1 cm thick intercalations of bioclastic debris consisting of various fragments (brachiopods, pelmatozoan, bryozoans, and corals)]. Nevertheless, these organisms occur also in varying number in the microbial limestones. Rugose corals are enriched in some horizons when they cover about 1.5% of the rock surface compared to more than 35% in the reef-horizon.

The composition of the rugose coral fauna in this succession differs from the northern section by the scarcity of compound corals and the increased size of solitary corals. *Axophyllum nanum* and *Kizilia* cf. *concavitabulata* DEGTJAREV, 1965 are common in these microbial limestones. The onset of the flysch sedimentation is not seen yet at the top.

4. Systematic description of rugose corals

Subclass RUGOSA Milne Edwards and Haime, 1850
Order STAURIIDA Verrill, 1865
Suborder STAURIINA Verrill, 1865
Family KIZILIIDAE Degtjarev, 1965
Genus ***Kizilia*** DEGTJAREV, 1965
Kizilia cf. *concavitabulata* DEGTJAREV, 1965
Fig. 5.1,2

* cf. 1965: *Kizilia concavitabulata* DEGTJAREV, p. 49, pl. 3, figs. 1–5.

1971: *Melanophyllum* aff. *crassiseptatum* KROPATCHEVA; 1966: Perret and Semenoff-Tian-Chansky, p. 579, pl. 3, figs. 1–5.

? 1980: *Kizilia* sp. - Buchroitner et al., p. 31, pl. 1, figs. 1, 2, 6.

cf. v. 1981 *Kizilia* cf. *concavitabulata* DEGTJAREV - Poty, p. 56, pl. 24, fig. 3, 4.

? 1986: *Kizilia concavitabulata* DEGTJAREV - Herbig, p. 192, Abb. 6, fig. 6.

? 1991 : *Kizilia* sp. - Fontaine et al., p. 28, pl. 25, fig. 3, pl. 26, fig. 6.

Material: four transverse sections and two longitudinal sections of poorly preserved corallites, samples GIK 1730, GIK 1731 and GIK 1735.

Diagnosis: small-sized *Kizilia* having corallite diameters of 14–16 mm and 26 major septa in mature stages, clear bilateral symmetry, cardinal and counter septa shortest; narrow dissepimentarium.

Description: the corals are small and cylindrical, with a diameter of at least 14 mm. In mature stages, there are 26 major septa. Sinuous major septa are subradially arranged about shorter cardinal and counter septa, thus not connected in the centre and accentuating the bilateral symmetry. Thickness of major septa varies between 0.3 and 0.5 mm, thickenings are observed at their base as well as at the end. Minor septa reach about 1.0 mm into the tabularium.

The relatively narrow dissepimentarium (1.5–2.7 mm) comprises up to three rows of lonsdaleoid dissepiments of first and second order. Its composition varies depending on the development of the lonsdaleoid dissepiments.

The longitudinal section studied was cut from the proximal end of the corallite. One to two rows of globular to somewhat elongate dissepiments form a narrow (1.5 mm wide) dissepimentarium. Tabellae are discontinuous, probably inclined towards the axis.

Remarks: lonsdaleoid dissepiments are not observed in the type material figured by Degtjarev (1965). Nevertheless, Hill (1981) included forms with sparse lonsdaleoid dissepiments in this genus. In contrast Perret and Semenoff-Tian-Chansky (1971) described kizilid specimens with large lonsdaleoid dissepiments from the Pyrénées under the name *Melanophyllum* aff. *crassiseptatum*. Their figured specimens are very similar to the Castelsec material. Otherwise, the material from Castelsec has strong similarities to the figured material of Degtjarev 1965 regarding size, number of septa, and number of dissepimentarial rows, but it has clear lonsdaleoid dissepiments, which are regarded as useful specific characters.

The material recovered at Castelsec is not sufficient to explain the relationship of the two genera. A re-examination of the type specimens of *Kizilia* and *Melanophyllum* is needed.

Suborder AULOPHYLLINA Hill, 1940
Family AULOPHYLLIDAE Dybowski, 1873
Genus ***Dibunophyllum*** THOMSON & NICHOLSON, 1876

Discussion: The definition of the genus *Dibunophyllum* is linked with a number of problems. Following the definition of Hill (1938–1941), later amended by Semenoff-Tian-Chansky (1974), the main characteristics of this genus are highly variable. The genus was derived from many rapidly evolving phylogenetic branches and its separation from related genera, such as *Clisiophyllum*, *Koninckophyllum*, and *Arachnolasma*, maybe sometimes highly questionable (Federowski, 1971).

Therefore, many species in different genera are synonymous (see Hill, 1938–1941). Most earlier described specimens are referred to one of three subspecies of *Dibunophyllum bipartitum*.

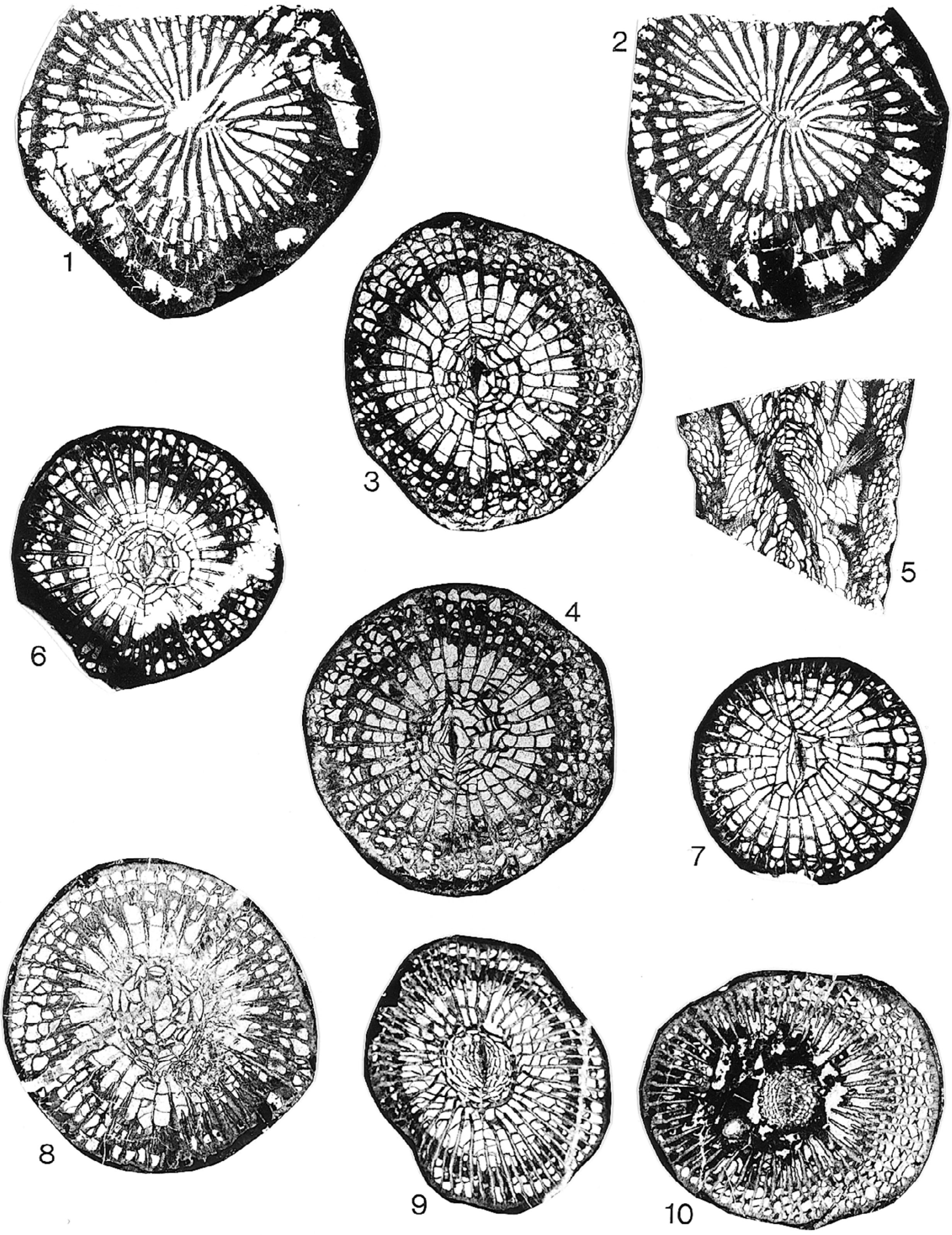

Fig. 5. 1, 2. *Kizilia* cf. *concavitabulata* DEGTJAREV, 1965 (Specimen GIK 1731), transverse sections, 1: 3 mm higher in the calice than 2, ×4. 3-8 *Dibunophyllum castelsecensis* sp. nov.; 3-5 transverse and longitudinal sections of holotype (Specimen GIK 1732), 6-8 transverse sections of paratypes (GIK 1733, GIK 1735), ×4.5, ×3. 9, 10. *Clisiophyllum garwoodi* (SALÉE, 1913) transverse sections of GIK 1738 (×3.5) and GIK 1737 (×4).
1, 2. *Kizilia* cf. *concavitabulata* DEGTJAREV, 1965 (Spécimen GIK 1731), coupes transversales, 1: 3 mm plus haut dans le même calice que 2, ×4. 3-8 *Dibunophyllum castelsecensis* sp. nov.; 3-5 coupes transversales et longitudinales de l'holotype (Spécimen GIK 1732), 6-8 coupes transversales des paratypes (GIK 1733, GIK 1735), ×4.5, ×3. 9, 10. *Clisiophyllum garwoodi* (SALÉE, 1913) coupe transversale de GIK 1738 (×3,5) et GIK 1737 (×4).

One main difference to the closely related genus *Clisiophyllum* is the arrangement of the axial structure. *Dibunophyllum* is characterised by four to eight lamellae on each side of the median plate, whereas in *Clisiophyllum* the number of lamellae is more than the half of the number of major septa.

Dibunophyllum castelsecensis sp. nov.
Fig. 5.3–8

Holotype: specimen GIK 1732, two transverse sections and one longitudinal section; Brigantian, Roque Redonde Formation; middle part of the southeastern succession in the old quarry of Castelsec. (Fig. 5.3–5)

Locus typicus: old quarry south-east of Castelsec.

Stratum typicum: Roque Redonde Formation (RC 8, Brigantian).

Derivatis nominus: from the neighbouring village of Castelsec.

Paratypes: transverse and longitudinal sections of corallites; samples GIK 1733–1736.

Diagnosis: small-sized *Dibunophyllum* with a corallite diameter ranging from 11 to 13 mm, 28–32 major septa in mature stages. Columella formed by a simple spider-web with prominent axial plate. Inconspicuous cardinal fossula. Minor septa rudimentary or ending within the dissepimentarium.

Description: the corals are small and cylindrical, with a diameter of 10.2–13.6 mm. In mature stages, there are 28 to 32 major septa. The septa are straight or sinuous, usually dilated in the tabularium (up to 0.5 mm), and sometimes interrupted within the dissepimentarium.

The cardinal fossula is inconspicuous or absent, but in the latter case, the cardinal and counter septa are shorter than the other majors. The length of minor septa is variable, from rudimentary to a maximum of 0.9 mm into the tabularium. They are mostly restricted to the dissepimentarium.

Five to six lamellae are arranged on each side of a long median plate, forming a simple spiderweb with some tabellae. This axial structure is slightly oval and comprises about 3/10 of the corallite diameter. Tabularium and dissepimentarium have more or less the same dimensions related to the diameter. The inner wall of the dissepimentarium is dilated. The dissepimentarium is composed mostly of irregular dissepiments, which may be arranged in a herringbone-pattern. It consists of three to seven rows of slightly elongated dissepiments, declining up to 70°, with 21–24 dissepiments per centimetre. The tabularium consists of various discontinuous tabellae, often globular to slightly elongated. The axial tabellae incline steeply (70–80°). The periaxial tabellae are less inclined (max. 60°) and become nearly horizontal towards the margin. Usually there are 16–20 tabellae per centimetre.

Discussion: the arrangement of the axial structure in the Castelsec specimens is dibunophylloid. The younger stages (8–9 mm diameter) on sample GIK 1733 show a less complex structure, with a tendency to be koninckophylloid. The number of lamellae is never more than half of the number of major septa. This suggests the assignment to the genus *Dibunophyllum*.

The *Dibunophyllum* species considered to be valid by Federowski (1971) and Semenoff-Tian-Chansky (1974) are all at least twice as large as the Castelsec species and differ by their complexity. The species *D. confertum* GORSKY, 1938 (pl. 12, fig. 1,2) described form the Upper Visean and Lower Namurian of Novaya Zemlya is about twice as large, has shorter minor septa, and a higher number of septa. *D. tenuiculum* GORSKY, 1938 (pl. 12, figs. 7–9) differs in having a larger number of septa, the absence of thickenings and a narrower dissepimentarium. Following the definition of Hill (1940), these two species are probably synonymous with *D. bipartitum*.

Dibunophyllum castelsecensis is similar to species of the same age (uppermost Visean to lowermost Serpukhovian) from eastern Canada and Belgium (Poty, pers. comm.).

Genus ***Clisiophyllum*** Dana, 1846
Clisiophyllum garwoodi (Salée, 1913)
Fig. 5.9, 10

* 1913: *Carruthersella garwoodi* - Salée, p. 274, pl. 11, figs. 4 a–c, 5, 6.

1929: *Clisiophyllum* sp. - Neaverson, pl. 3, figs. 3, 5.

? 1957: *Carruthersella garwoodi* SALÉE - Kostic-Podgorska, p. 69, pl. 1, fig. 3, pl. 3, fig. 2.

v 1981: *Clisiophyllum garwoodi* (SALÉE) - Poty, p. 39, pl. 17, figs. 2–5.

1986: *Clisiophyllum garwoodi* (SALÉE) - Herbig, p. 194, Abb. 3, figs. 4, 5.

v 1994: *Clisiophyllum garwoodi* (SALÉE) - Poty and Hanney, p. 59, pl. 2, fig. 2,3, pl. 5, fig. 3.

Material: transverse and longitudinal section of GIK 1737 and a transverse section, high in the calyx of sample GIK 1738.

Diagnosis (after Poty, 1981): small *Clisiophyllum*, 10–14 mm in diameter, 31–41 major septa in mature stages, compact complex axial structure comprising up to 1/3 of the corallite.

Description: the coral is small and cylindrical. The transverse sections are slightly oval (10.2–11.6 mm). In this stage, there are 34 major septa. They are 2.8–4.1 mm long and slightly sinuous, but less so in the dissepimentarium due to thickenings. An open fossula is developed with a cardinal septum 1/3 shorter than the other major septa. The counter septum and neighbouring septa are connected to the columella. The minor septa are maximal 1.8 mm long and end 0.3–0.5 mm within the tabularium.

A stereozone is developed in the inner dissepimentarium, which continues partly towards the thick wall. The dissepimentarium consists of one to three rows of simple globular dissepiments. There are 18–20 dissepiments per centimetre. The tabellae are discontinuous. At the peripheral side of the tabularium, they are nearly horizontal and incline up to 40° to the axial structure.

The columella comprises 3/10 of the diameter. It is a complex structure composed of an axial plate, 17 lamellae and some tabellae. A partial thickening is developed at the outer side of the columella.

Discussion: the smallest Laurussia species belonging to *Clisiophyllum* is *C. delicatum nanum* Federowski, 1971. The Castelsec specimen differs from it by the development of a fossula, the larger diameter, and a larger dissepimentarium. Poty (1981) reports a number of small *Clisiophyllum* specimens from the Belgian V2b and V3a, attributed to *C. garwoodi*. The Castelsec specimen fits this definition. This would extend the stratigraphic distribution of this species to the uppermost Visean (Belgian V3c). For a discussion on *C. garwoodi* see Poty (1981).

Suborder LITHOSTROTIONINA Spasskiy and Kachanov, 1971
Family LITHOSTROTIONIDAE D'Orbigny, 1852
Subfamily LITHOSTROTIONINAE D'Orbigny, 1852
Genus ***Lithostrotion*** FLEMING, 1828
Lithostrotion decipiens (MCCOY, 1849)
Fig. 6.3, 4

* 1849: *Nemaphyllum decipiens* MCCOY, p. 18.

1849: *Nemaphyllum clisoides* MCCOY, p. 18.

1851: *Nematophyllum decipiens* (MCCOY) - McCoy, p. 99.

1851: *Nematophyllum clisoides* (MCCOY) - McCoy, p. 98, pl. 3B, fig. 2–2b.

1851: *Lithostrotion decipiens* (MCCOY) - Milne-Edwards and Haime, p. 441.

1851: *Lithostrotion portlocki* (BRONN) - Milne-Edwards and Haime, p. 443.

1852: *Lithostrotion decipiens* (MCCOY) - Milne-Edwards and Haime, p. 196.

1852: *Lithostrotion portlocki* (BRONN) - Milne-Edwards and Haime, p. 194, pl. 42, fig. 1-1g.

1940: *Lithostrotion decipiens* (MCCOY) - Hill, p. 178, pl. 10, fig. 2–4.

1962: *Lithostrotion* cf. *decipiens* (MCCOY) - Caldwell and Charlesworth, p. 379, pl. 15, fig. 3, 3a.

1980: *Lithostrotion decipiens* (MCCOY) - Nudds, p. 386, fig. 3b.

v 1981: *Lithostrotion decipiens* (MCCOY) - Poty, pl. 22, figs. 12, 13, 15, 16, pl. 6, figs. 1–3, pl. 7 1,2.

1991: *Lithostrotion decipiens* (MCCOY) - Fontaine et al., p.49, pl. 3, fig. 4, pl. 4, fig. 5, pl. 13, fig. 2, pl. 17, fig. 1–2.

Material: six colonies (transverse and longitudinal sections) from the coral horizon of the northern section and numerous isolated corallites from the same level; samples GIK 1739–1745.

Diagnosis: cerioid *Lithostrotion* having 17–19 major septa in mature stages, and a tabularium less than 3 mm wide.

Description: cerioid corallum with slightly cylindrical corallites. Increase is lateral.

Transverse section: the corallites are of irregular polygonal shape (3–7 sides, usually 5–6) and separated by a thin wall (0.2 mm). Diameters of mature corallites range from 0.4 mm to 1.1 mm. Corallites display 17–19 major septa. Major septa are straight to sinuous and partly connected to the columella. Cardinal and counter septa are predominately connected to the columella. Septa are thin, with rare thickenings observed at the base at the outer wall.

The dimensions of the tabularium are more constant. The mean diameter is about 2.7 mm, ranging from 2.3 to 3.3 mm. The minor septa end within the tabularium. Lonsdaleoid dissepiments are sometimes developed in large corallites.

Longitudinal section: the dissepimentarium is very much variable. It consists of irregular rows of two to six globular dissepiments (0.5–1.1 mm long and 0.2–0.4 mm high). The dissepiments are inclined from the external wall towards the tabularium at 20–40°. The dissepimentarium comprises 1/2 to 2/3 of the radius.

Tabellae are usually incomplete, being axially dome-shaped (incline 20–60°) and periaxially flat or downsloping. There are 27–33 tabellae and 33–40 (mean 35) dissepiments per centimetre.

Remarks: the mean number of major septa and the dimensions of the corallites are slightly higher than in the Belgian species (Poty, 1981). The Castelsec specimens slightly extend the ecological variation shown by the same author. An attribution to *L. vorticale* (PARKINSON, 1808) is prevented by the narrower tabularium, the lower number of septa and the generally smaller dimensions of the corallites.

Genus ***Siphonodendron*** MCCOY, 1849
Siphonodendron cf. *irregulare* (PHILLIPS, 1836)
Fig. 6.1,2

* cf. 1836: *Lithostrotion irregulare* PHILLIPS, p. 202, pl. 2, figs. 14, 15.

Material: two colonies (GIK 1746, GIK 1747) with transverse and longitudinal sections from the northern section (unit 2), and some isolated sections from different levels.

Diagnosis: phaceloid *Siphonodendron* with corallites about 5 mm in diameter, 21 major septa, and one to three rows of dissepiments. Most major septa are connected with the columella.

Description: dendroid corallum with slightly cylindrical corallites. Increase is lateral.

Transverse section: usually, the diameters of mature corallites are between 4.5 and 5.6 mm, with a maximum of 6.1 mm, and a mean of 5 mm. They display 20–22 major septa, with a mean of 21. Major septa are straight to sinuous and most are connected to the columella. No differentiation of major septa is seen; the orientation of the columella distinguishes the cardinal and counter septa. The columella

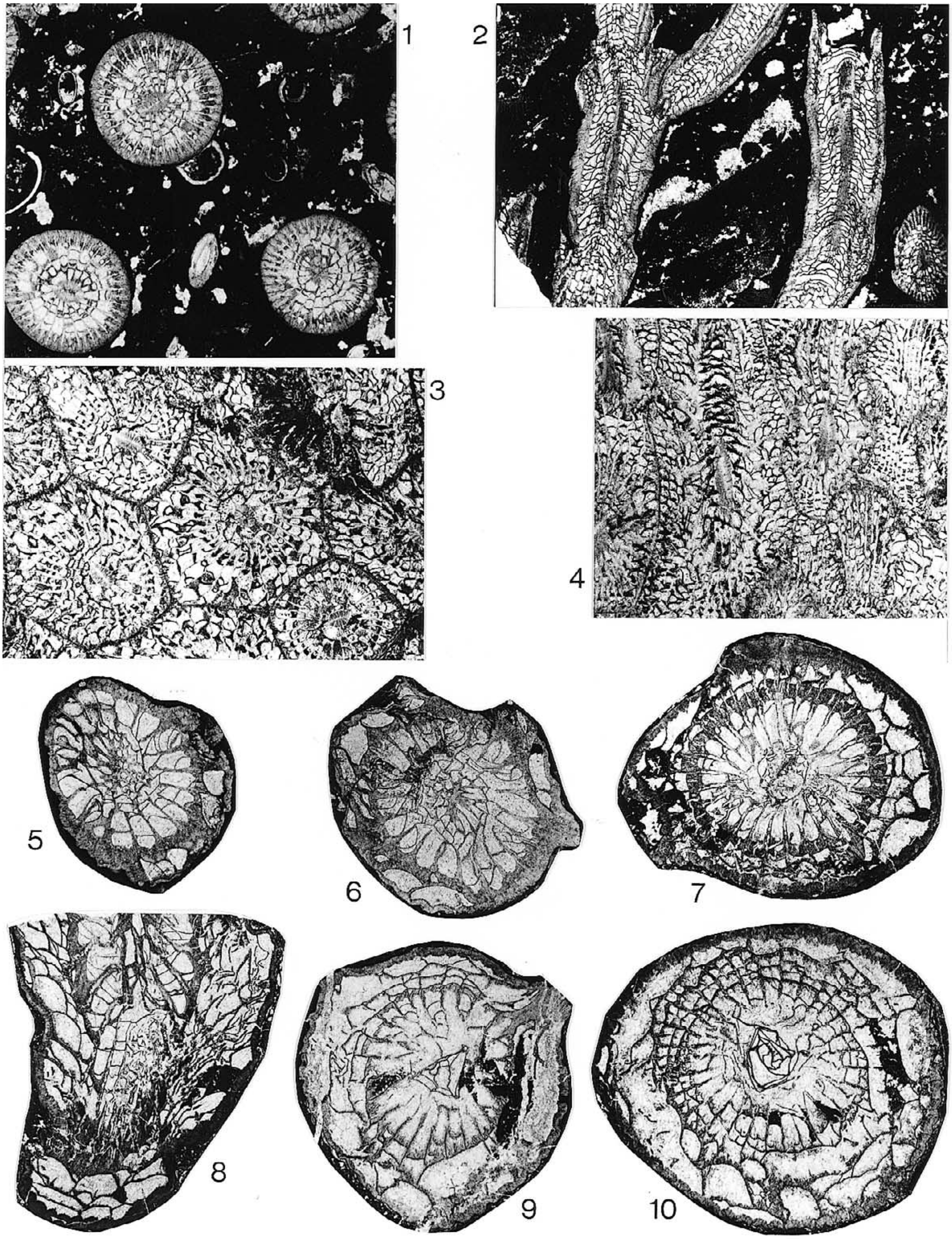

Fig. 6. 1. *Siphonodendron* aff. *irregulare* (PHILLIPS, 1836), transverse section, GIK 1746, ×4. 2. *Siphonodendron* aff. *irregulare* (PHILLIPS, 1836), longitudinal section, GIK 1747, ×3. 3. *Lithostrotion decipiens* (MCCOY, 1849), transverse section, 10-I_3, ×5. 4. *Lithostrotion decipiens* (MCCOY, 1849), longitudinal section, GIK 1745, ×4.5. 5, 6. *Axophyllum nanum* POTY, 1981, transverse sections, GIK 1748, ×4. 7-10. *Axophyllum* aff. *expansum* (MILNE-EDWARDS & HAIME, 1850), longitudinal (8, ×3) and transverse (7, 9, 10 all ×4) sections, specimens (GIK 1754 (8), GIK 1753, GIK 1751, GIK 1752).

1. *Siphonodendron* aff. *irregulare* (PHILLIPS, 1836), coupe transversale, GIK 1746, ×4. 2. *Siphonodendron* aff. *irregulare* (PHILLIPS, 1836), coupe longitudinale, GIK 1747, ×3. 3. *Lithostrotion decipiens* (MCCOY, 1849), coupe transversale, GIK 1743, ×5. 4. *Lithostrotion decipiens* (MCCOY, 1849), coupe longitudinale, GIK 1745, ×4.5. 5, 6. *Axophyllum nanum* POTY, 1981, coupes transversales, GIK 1748, ×4. 7-10. *Axophyllum* aff. *expansum* (MILNE-EDWARDS & HAIME, 1850), coupe longitudinale (8, ×3) et coupes transversales (7, 9, 10, tous ×4), spécimens GIK 1754 (8), GIK 1753, GIK 1751, GIK 1752).

is a simple axial plate. A simple spiderweb structure is formed with the septa. They are thin within the tabularium, but very much variable in thickness (0.2–0.9 mm) at their base where a stereozone is developed.

The minor septa end within the tabularium. Their length is 1/4 to 1/3 of the radius.

Longitudinal section: due to the wide stereozone the dissepimentarium is not often seen, but generally, it consists of irregular rows of one or two, sometimes three globular dissepiments (0.5 mm long). The dissepiments are inclined from the external wall towards the tabularium at 70°. The dissepimentarium comprises up to 1/5 of the radius.

The tabellae are dome-shaped axially (incline 45°) and sloped periaxially. There are approximately 26 tabellae and 38 dissepiments per centimetre.

Remarks: the holotype of *Siphonodendron irregulare* (PHILLIPS, 1836) is regarded as being lost. Differences in the figured specimen and the description of Philips evoked some confusion. Hill (1940) regarded *S. irregulare* as synonymy of the closely related *S. pauciradiale* (MCCOY, 1849). Later Poty (1981, 1993) re-erected the species and described a topotype from one of the type localities, Ash Fell in Cumbria. Nudds and Day (1997) suggested that the Ash Fell specimens, which appear superficially identical to *S. pauciradiale* and *S. irregulare*, are actually eco-types of *S. martini* (MILNE-EDWARDS & HAIME, 1851).

S. intermedium POTY, 1981 differs from *S. irregulare* by its slightly larger diameter, slightly more septa, and one more row of dissepiments.

The described specimens from Castelsec fit well with the number of major septa and size range of *S. irregulare* given by Poty (1981). They have affinities to *S. intermedium* by the size of the corallites and the number of dissepiments, but Poty (1981) also reported corallites of *S. irregulare* with up to four rows of dissepiments. With exception of the simple spiderweb structure formed by the connection of the major septa to the columella, the Castelsec material is close to the ecotype 2 of Poty (1981).

Suborder LONSDALEIINA Spassky, 1974

Family AXOPHYLLIDAE Milne-Edwards and Haime, 1851

Genus ***Axophyllum*** MILNE-EDWARDS & HAIME, 1850

Axophyllum nanum POTY, 1981

Fig. 6.5,6

e.p. 1911: *Carcinophyllum* σ VAUGHAN - Delépine, pl. 14, fig. 9.

e.p. 1913: *Carcinophyllum vaughani* SALÉE, p. 256, pl. 10, figs. 7–10, 11 (?), 12a, 12b.

* v 1981: *Axophyllum nanum* POTY, p. 59, Fig. 53, pl. 29, figs. 1–3.

v 1994: *Axophyllum nanum* POTY - Poty and Hanney, p. 66.

Material: four transverse sections on sample GIK 1748.

Diagnosis: small *Axophyllum*, 8–11 mm in diameter and 20 major septa. Minor septa absent. Relatively simple axial structure comprises 3/10 of the corallite. (see also Poty, 1981).

Description: the coral is small, 8–11 mm in diameter, and there are 19–20 major septa. Minor septa are absent. The septa are relatively straight and do not reach the axial structure, leaving a space of 0.5–1.0 mm. The length of the septa is 2–3 mm. Within the tabularium they are 0.1 mm thick, but are thicker at the outer side of the tabularium, where a stereozone (0.5 mm thick) is developed. The thickness of the stereozone is reduced where the dissepimentarium consists of large lonsdaleoid dissepiments. The thin outer wall undulates and could sometimes hardly be differentiated from the stereozone.

The axial structure is slightly oval (2.7 mm long and 2.3 mm thick), and consists of a prominent axial plate, four to five lamellae on each side and three tabellae. Thickenings are observed on the axial plate and some lamellae.

Discussion: the simplicity of the small *Axophyllum* specimens is characteristic for the upper part of the northern succession at Castelsec. The description of similar forms known from Belgium fits well. The ratio of number of septa to diameter is slightly higher at Castelsec than in Belgium, but seems not to be a specific character. Therefore, the Castelsec specimens are referred to the same species.

Axophyllum aff. *expansum* (MILNE-EDWARDS & HAIME, 1850)

Fig. 6.7–10

* aff. 1850: *Axophyllum expansum* MILNE-EDWARDS & HAIME, p. 72.

Material: seven transverse sections of GIK 1749-1753, and longitudinal section of sample GIK 1754.

Diagnosis: small *Axophyllum*, 11–16 mm in diameter and with 25–29 septa in mature stages. Isolated axial structure is relatively simple and may be pronounced by a thicker axial plate. Organisation of the dissepimentarium is highly variable.

Description: the specimens placed in this group are highly variable in the complexity of the axial structure and the dissepimentarium. The corallites are generally small, having diameters of 11.1–16.0 mm. In mature stages the number of major septa ranges from 25 to 29. They are slightly sinuous, 2.2–4.0 mm long and rarely connected to the axial structure. In part they arise from a stereozone at the inner side of the tabularium (0.6–0.7 mm thick). Within the tabularium, they are 0.1–0.25 mm thick. Minor septa reach up to 1.0 mm into the tabularium.

The 1.0–2.0 mm wide dissepimentarium consists of lonsdaleoid dissepiments of first and second order. There are two to four rows of elongate dissepiments in various sizes (0.5–2.2 mm long). A second stereozone may be developed at the outer side of the dissepimentarium (up to 0.3 mm thick). Due to these variations, 10–15 dissepiments are counted per centimetre.

The prominent axial plate (0.5 mm thick) characterises the axial structure. Six to seven lamellae and some tabellae are seen on each side of the axial plate. In longitudinal section, the axial structure is dominated by vertical elements, and tabellae are very rare. The periaxial tabellae are discontinuous and nearly horizontal. Twenty tabellae are seen per centimetre. In other specimens a simplified arrangement of the axial structure occurs with less accentuation of the axial plate and a reduction in number of tabellae and lamellae.

Discussion: these specimens have some common characters with *Axophyllum nanum*, but they are larger, have more septa, the ration axial structure/diameter is lower and their lonsdaleoid dissepiments are better developed. In most sections, the axial structure is isolated as in *A. expansum*, but its organisation is significantly more simple. Moreover, in *A. expansum* the pronounced lonsdaleoid dissepiments and the naotic septa are common, but in general this species has fewer septa and a simpler axial structure.

Axophyllum sp.
Fig. 7.1,2

Material: transverse and longitudinal section of sample GIK 1755.

Diagnosis: large *Axophyllum* with a prominent axial structure. A mature stage has 30 major septa and a diameter of at least 2.1 cm. The dissepimentarium comprises more than 3/10 of the diameter.

Description: the specimen was partly eroded. Therefore, the outer wall and dissepimentarium are only partly preserved. The measurable diameter is at least 21 mm. In this stage, 30 slightly sinuous major septa were counted. They are partly connected to an oval axial structure. Within the dissepimentarium, they become naotic. A thickening (2 mm) is developed at the base of the tabularium, later the septa are 0.2 mm wide. Minor septa are 1/2–2/3 as long as the major septa. The oval (5.5–7 mm) axial structure consists of a prominent axial plate surrounded by at least 15 lamellae and 4–5 rows of tabellae. Herringbone dissepiments are developed in the inner part of the dissepimentarium; near the wall lonsdaleoid dissepiments of first and second order are common.

The lonsdaleoid dissepiments are elongated up to several millimetres and are declined at 70°. Inner dissepiments are somewhat globular. The tabellae are dome-shaped, starting from 0° on the outside to 60° on the inside.

Discussion: the Castelsec specimen shows some resemblance to *A. lonsdaleiforme* (SALÉE, 1913), *A. kirsopianum* (THOMSON & NICHOLSON, 1876), and *A. pseudokirsopianum* SEMENOFF-TIAN-CHANSKY, 1974. It differs from *A. lonsdaleiforme* (SALÉE, 1913) by its larger diameter, its lower number of septa, and its longer septa, especially the minor septa. Compared to *A. kirsopianum* (THOMSON & NICHOLSON, 1876) the ratio of axial structure to diameter is smaller (2/7) and the lonsdaleoid dissepiments are more pronounced. The Castelsec specimen differs from the type material of *A. pseudokirsopianum* SEMENOFF-TIAN-CHANSKY, 1974 by its lonsdaleoid dissepiments, its smaller diameter and a simpler axial structure.

In addition to the material described, the occurrence of *Palaeosmilia murchisoni* with a transverse section seen in the middle part of the northern succession (Fig. 8) was recognised, but it was impossible to recover this specimen. *Siphonodendron pauciradiale* occurs rarely in the level above the coral-horizon in the northern succession. Specimens of both these species and of *Nemistium* SMITH, 1928 recovered at Castelsec are housed in the collection of Professor E. Poty (Université de Liège) and will be described later.

5. Carbonate microfossils

Calcimicrobes are represented by clotted and vesicular forms (‘spongiostromids’ and ‘*Bevocastria*’). Rare *Renalcis* have been observed.

Dasyclads (and/or other green algae) are not abundant, excepted *Eovelebitella occitanica*. The other genera are *Orthriosiphonoides* (?) sp., *Windsoporella* sp., *Anatolipora carbonica* KONISHI, 1956, *Koninckopora inflata* (DE KONINCK, 1842) (rare but well preserved) and very rare *Saccamminopsis* sp., which, in our opinion, belong to the Caulerpales or Dasyclads.

The Algospongia pseudo-algae (Moravamminids, Aoujgaliids and Calcifoliids) are relatively abundant and diversified. The most interesting taxa are: *Praedonezella* aff. *carbonica* KULIK, 1973, *Claracrusta* sp., *Roquesselsia radians* TERMIER, TERMIER & VACHARD, 1977, *Ungdarella conservata* KORDE, 1951, and a new genus more or less similar to *Fasciella*.

The main foraminifera are: *Earlandia vulgaris* (RAUZER-CHERNOUSOVA & REITLINGER, 1940), *Magnitella praecursor* VACHAND, 1975, *Lituotubella magna* RAUZER-CHERNOUSOVA, 1948, *Endothyra spira* (CONIL & LYS, 1964), *Mikhailovella* cf. *gracilis* (RAUZER-CHERNOUSOVA, 1948), *Omphalotis minima* (RAUZER-CHERNOUSOVA & REITLINGER, 1936), *Globoendothyra* ex gr. *globulus* (EICHWALD, 1860), *Cribrospira panderi* MOELLER 1878, *Bradyina rotula* (EICHWALD, 1860), *Janichewskina* sp., *Mediocris mediocris* (VISSARIONOVA, 1948), *Eostaffella mosquensis* VISSARIONOVA, 1948, *Koskinotextularia* ex gr. *bradyi* (MOELLER, 1880), *Climacammina* sp., *Archaediscus convexus* (GROZDILOVA & LEBEDEVA, 1953).

6. Discussion

Uppermost Visean strata and the transition to the Serpukhovian are poorly exposed in shallow-water carbonates in western Europe due to the first phases of the Variscan

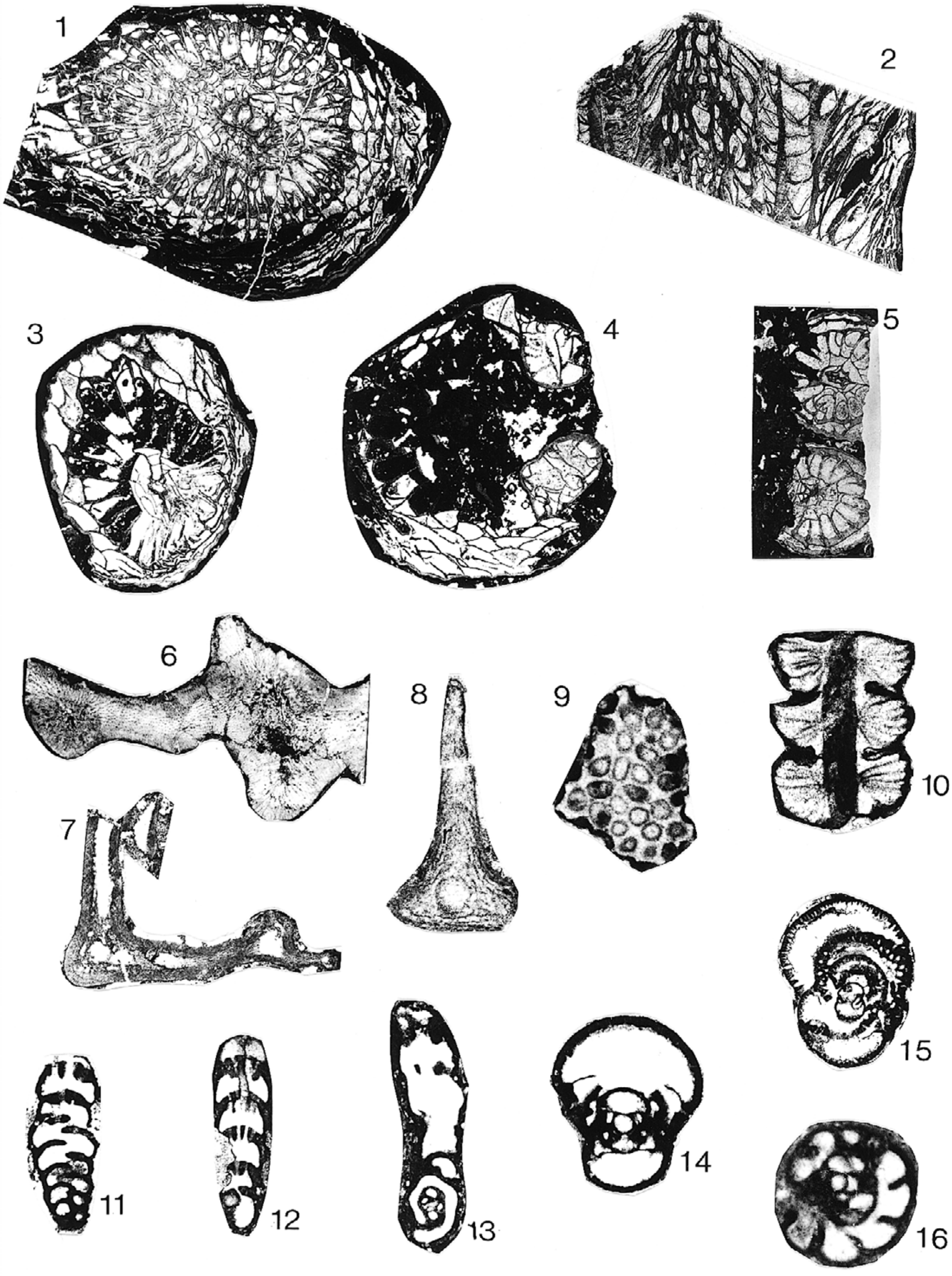

Fig. 7. 1, 2. *Axophyllum* sp., transverse section ×4 and longitudinal section ×3 (incomplete), Specimen GIK 1755. 3-5. The splitting of a mother corallite of *Axophyllum* sp. into two daughter corallites (4), transverse sections, GIK 1732, ×3. 6. *Epistacheoides* sp., GIK 1756, ×15. 7. *Roquesselsia radians* TERMIER, TERMIER & VACHARD, 1977, GIK 1757, ×10. 8. *Epistacheoides* cf. *nephroformis* PETRYK & MAMET, 1972, GIK 1757, ×10. 9. Dasycladale indet., GIK 1758, ×25. 10. *Eovelebitella occitanica* VACHARD, 1974, GIK 1759, ×20. 11. Palaeotextulariidae indet. (Climacammina or Koskinobigenerina), GIK 1757, ×20. 12. *Haplophragmella irregularis*, GIK 1758, ×15. 13. *Lituotubella magna* RAUSER, 1948 GIK 1758, ×60. 14. *Bradyina rotula* (EICHWALD, 1860), GIK 1760, ×10. 15. *Bradyina* cf. *rotula* (EICHWALD, 1860), GIK 1758, ×20. 16. *Endothyranopsis* sp., GIK 1757, ×30.

1, 2. *Axophyllum* sp., coupe transversale section ×4 et coupe longitudinale ×3 (incomplet), Spécimen GIK 1755. 3-5. Bourgeonnement périphérique dans *Axophyllum* sp. La polypiérite mère est divisée en deux (4), coupes transversales, GIK 1732, ×3. 6. *Epistacheoides* sp., GIK 1756, ×15. 7. *Roquesselsia radians* TERMIER, TERMIER & VACHARD, 1977, GIK 1757, ×10. 8. *Epistacheoides* cf. *nephroformis* PETRYK & MAMET, 1972 GIK 1757, ×10. 9. Dasycladale indet., GIK 1758, ×25. 10. *Eovelebitella occitanica* VACHARD, 1974, GIK 1759, ×20. 11. Palaeotextulariidae indet. (Climacammina or Koskinobigenerina), GIK 1757, ×20. 12. *Haplophragmella irregularis*, GIK 1758, ×15. 13. *Lituotubella magna* RAUSER, 1948, GIK 1758, ×60. 14. *Bradyina rotula* (EICHWALD, 1860), GIK 1760, ×10. 15. *Bradyina* cf. *rotula* (EICHWALD, 1860), GIK 1758, ×20. 16. *Endothyranopsis* sp., GIK 1757, ×30.

Fig. 8. *Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME, 1850, could not be excavated from the 3rd unit, diameter of photo cover about 5.5 cm.

Palaeosmilia murchisoni MILNE-EDWARDS & HAIME, 1850, pas extrait de la troisième unité, diamètre de la couverture de l'appareil-photo, environ 5,5 cm.

orogeny. In addition, correlation with the Russian type sections is still in progress. Nevertheless, after the Late Asbian highstand and following Early Brigantian regression, the fauna recovered and flourished with each transgressive pulse during Brigantian time. The English Brigantian is very diversified and a number of 'eastern' taxa arrived during this time in western Europe (i.e. *Nemistium* in rugose corals).

The rugose coral fauna at Castelsec consists mostly of taxa known from the Upper Visean. *Lithostrotion decipiens* indicate at least an Asbian age. The occurrence of *Nemistium* (Coll. Poty) indicates rugose coral zone RC8 and indicates therefore a Brigantian age.

Among the foraminifera, several taxa appear in the Asbian (V3bγ): *Mikhailovella*, *Endothyranopsis crassa* (BRADY, 1869), *Cribrospira*, *Bradyina rotula*, but they can also survive until the late Serpukhovian (E2). In the Brigantian, *Janischewskina* appears, and *Koninckopora* disappears. Therefore, the age of the assemblage of Castelsec is probably Brigantian, but some algae or pseudo-algae are mostly indicative of a Serpukhovian age: *Anatolipora carbonica*, *Praedonezella* aff. *carbonica*, and *Claracrusta* sp. Finally, *Roquesselsia radians* and *Fasciella* (?) sp., respectively, developed from primitive *Epistacheoides* and true *Fasciella* and can be interpreted as advanced forms. In this case, they are also indicative of the Brigantian age. Supplementary work is needed. As well as for the investigated Bradyinids: *Bradyina*, *B.* (?), *Cribrospira*, *Janischewskina*. This assemblage is more similar to the Russian stage Mikhailovsky than to the Venevsky, the last stage of the Visean in Russia. The question of the Venevsky/Stechevsky (i.e. Visean/Serpukhovian) boundary and the correlation to western Europe is important to specify (Izart, Kossovaya, Vachard and Berkhli, work in progress).

Jones and Somerville (1996) reported a 'notable extinction of the calcareous algae *Koninckopora* close to the boundary interval Asbian/Brigantian' in the Asbian of Ireland. At Castelsec, this genus extends into the Brigantian.

Summarising the occurrence of rugose corals and carbonate microfossils, it is likely that the Castelsec olistolith is Brigantian in age. Markers of the Latest Visean foraminifera and rugose coral biozones (Cf6δ and RC 8, both Brigantian) occur rarely. This rarity, probably caused by unfavourable facies conditions, gives a misleading interpretation of an Asbian age of the Castelsec olistolith. The appearances of somewhat younger taxa indicate the transitional character of the Brigantian and the difficulty of a biostratigraphical differentiation of the Uppermost Visean and Lowermost Serpukhovian.

On the generic level, the rugose coral taxa described herein are known from the Upper Visean of northwestern Europe. Taking into account the species level and the frequency of the occurrence of some characteristic taxa, differences are apparent. Typical elements of the Northern province, such as *Koninckophyllum*, *Thysanophyllum* and small lithostrotionids [*S. junceum* (FLEMING, 1828), *L. maccoyanum* MILNE-EDWARDS & HAIME, 1851] are missing at Castelsec. *Koninckophyllum* had been reported from southern France form the Corbières by Semenoff-Tian-Chansky and Ovtracht (1965) and the Massif d'Ardengost by Perret and Semenoff-Tian-Chansky (1971). The Corbières specimens differ significantly with a thicker wall, very short minor septa and larger dissepiments from specimens of northwestern Europe and it is doubtful whether they belong to *Koninckophyllum*.

In contrast to these northern taxa, *Kizilia*, very uncommon in the north, is abundant at Castelsec. This genus is common on the Russian platform, locally known from southern Europe (Perret and Semenoff-Tian-Chansky, 1971; Buchroitner et al., 1980; Herbig, 1986) and is rarely reported from northwestern Europe (Poty, 1981). It suggests a connection to the Ouralian–Asian province through the Paleotethys.

Koninckophyllum and small lithostrotionids seem to be more adapted to the carbonate platforms of the inner shelf and are expelled from the southern shelf of Armorica by frequent changes of the sea level and siliciclastic input. This interpretation would suggest, the rugose corals recovered at Castelsec are more resistant to these changes. Alternatively, the occurrence of rugose coral taxa is a response to climate and ocean currents (respectively palaeolatitudes) and therefore the Northern province is adapted to a somewhat colder water (subtropical) compared to the tropic conditions in the Paleotethys. This interpretation is favoured by the gradual disappearance of *Koninckophyllum* from the north (Scotland) to south (Belgium) and the same pattern in the opposite direction of *Kizilia* (Montagne Noire: south, Belgium: north). Therefore, the Belgian rugose coral fauna would be intermediate between a warmer southern province and a colder northern province.

It seems likely that both factors, changing environment and palaeolatitudes, controlled the distribution and occurrence of rugose corals during Late Visean and Serpukhovian. The overall trend is controlled by palaeolatitudes, respectively the surface water temperature, but on a regional scale, local factors as input of siliciclastics and tectonic activity are major limiting factors.

The relations of the Montagne Noire to Gondwana are relatively uncertain. Some similarities are observed, but further work on the rugose coral faunas of the both regions (Northern Africa; Semenoff-Tian-Chansky, 1974) is needed to achieve a reliable comparison.

7. Conclusion

The Castelsec fauna and flora is rich and diversified. Distinguishing taxa (*Janischewskina* and *Nemistium*) suggest a Brigantian age of the limestones. Remarkable are the high amounts of microbial bindings and a relatively diverse and flourishing flora of calcareous algae and microproblematica. Probably, this is a response to high nutrient input through orogen-derived siliciclastics and/or a more tropical climate in the Montagne Noire compared to the British Isles and Belgium.

Differences in the composition of the rugose coral fauna between the stable inner shelf environment of north-central Europe and the active margin setting of the Montagne Noire, indicated at generic level, become obvious at species level. Typical elements of the Northern province are lacking at Castelsec, whereas *Kizilia*, abundant at Castelsec, marks the connection to the Ouralian–Asian province through the Paleotethys. The differences could be explained by a differentiation along palaeolatitudes and/or differences in the setting.

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