Stratigraphy, diversity and palaeobiogeography of the Upper Viséan (Lower Carboniferous) rugose corals from northwestern Turkey

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Abstract: In northwestern Turkey, the Viséan part of the Yılanlı Formation is dominated by shallow-water limestones containing rugose corals, tabulate corals and brachiopods. In the Zonguldak and Bartın areas based on six sections two assemblages are recognized. The lower one includes numerous lithostrotionids (*Siphonodendron martini*, *S. irregulare*, *S. pauciradiale*, *S. asiaticum*, *S. scaleberense*, *S. kleffense*, and *Lithostrotion araneum*) associated with the solitary rugose corals *Palaeosmilia murchisoni*, *Clisiophyllum keyserlingi*, *Aulophyllum fungites*, *Siphonophyllia siblyi* and *Koninckophyllum interruptum*. This first assemblage is typical of the lower Warnantian RC7β rugose coral zone of Western Europe and is dominated by taxa with a wide spatial distribution within the Western European province. This assemblage is common both in the Bartın and Zonguldak areas. The second assemblage is known in Zonguldak, but not in Bartın, where the upper part of the Yılanlı Formation is lacking. This assemblage is composed of are the colonial species *Siphonodendron martini*, *S. irregulare*, *S. pauciradiale*, *S. asiaticum*, *S. scaleberense*, *S. rallii*, *Lithostrotion decipiens*, *Palastraea koninckі*, *Corwenia* cf. *vaga*, *Nemistium* cf. *affine* and the solitary species *Aulophyllum fungites*, *Palaeosmilia murchisoni*, *Axoclisia* cf. *cuspiforma* and *Pseudozaphrentoides* cf. *juddi*. *Palastraea*, *Corwenia* and *Nemistium* are the guide taxa of the upper Warnantian RC8 biozone. The palaeobiogeographic affinity of these two assemblages is clearly European and they are similar to the Upper Viséan coral fauna of Belgium and England. Only *S. asiaticum* indicates a greater Asian influence making it similar to the Donets Basin. The absence of the genera *Diphyphyllum*, *Dibunophyllum*, *Axophyllum*, *Gangamophyllum* and *Lonsdaleia* is a singularity of the Zonguldak and Bartın area and is not explained by any facies issue so far.

Key words: Mississippian, Viséan, Asbian, Brigantian, Turkey, Palaeotethys, stratigraphy, palaeobiogeography.

1. Introduction

The Carboniferous of northwestern Turkey, known as the '*Bassin Houiller d'Héraclée*' (now Ereğli coal district, near Zonguldak) was described for the first time in the middle of the 19th Century. Schlehan (1852) and Garella & Huyot (1854) first listed the Carboniferous fauna and flora, while Zeiller (1895) and Ralli (1895) gave the first geological descriptions of the area. The latter focused on the palaeontological content of the Upper Carboniferous coal seams, but also the Lower Carboniferous limestone. Ralli (1895) was the first to recognize coral taxa in the Viséan of the Black Sea coast: *Zaphrentis cylindrica*, *Lithostrotion irregulare*, *Amplexus coralloides*, *Lithostrotion caespitosum*? in the Kokaksu valley, and *Syringopora distans*, *Clisiophyllum turbinatum* and *Lithostrotion irregulare* from Tarla-Ağzı, near Amasra, northeast of Bartın. Following the discoveries of Ralli, F. Charles, professor at the '*Ecole Supérieure des Mines de Zongouldak*' was enrolled to study the Devonian and Carboniferous succession in the Zonguldak,

Ereğli, Amasra and Bartın coal districts. He rapidly published his regional study together with a monograph on the corals (Charles 1933). He recognized 11 rugose coral species in the Viséan, five being new after him. In the Kokaksu and Gökgöl sections, he identified the D1 and D2 corals zones of the British authors (Asbian/Brigantian, Late Viséan) and already noticed the similarity of the Turkish fauna with those of Belgium, the British Isles and Russia.

After Charles, only Tokay (1954) gave a list of fossils including corals found in the Viséan limestone of Bartın, but unfortunately, never figured them and his collection was not preserved. Later, Dîl (1975, 1976); Dîl et al. (1976) and Dîl & Konyali (1978) described several sections in the Zonguldak area and provided the first biostratigraphical scheme of the latest Devonian to Early Carboniferous, based on foraminifers. Dîl recognized the Belgian biozones 'Fa2d' and 'Tn1' (Upper and uppermost Famennian), 'Tn2–3' (Tournaisian), 'V1a', 'V1b–V2a' (Lower Viséan) and the Upper Viséan 'V3', with some difficulties. Recently, the coral assemblage of the Strunian (Denayer 2016), Tournaisian (Denayer 2015, 2016) and Lower Viséan (Denayer 2011, 2014) were documented, but the Upper Viséan coral faunas are still poorly known. This paper aims to describe the Upper Viséan rugose corals of the Bartın and Zonguldak areas, including Charles's (1933) collection, to document their stratigraphical distribution and to discuss their palaeobiogeographic affinity.

2. Geological settings

Lower Carboniferous sedimentary rocks crop out in the Istanbul vicinity – where they display flyschoid facies – and in the Zonguldak and Bartın areas (Fig. 1a, b). There, the Yılanlı Formation includes all the carbonate rocks of Upper Devonian and Lower Carboniferous age. The Upper Viséan succession is exposed more or less continuously in the Kokaksu, Gökgöl, Ulutam and Kisla sections (Zonguldak area, Fig. 1c) and in the Topluca and Süzek sections (Bartın area, Fig. 1d). The Yılanlı Formation consists of variegated limestone, often cherty or silicified and rich in macrofauna. It is overlain by the shale and sandstone of the Namurian Alacaağzı Formation. A complete lithological and stratigraphical description of these sections is available in Denayer (2014) and here summarised in Fig. 2.

The Kokaksu section is situated in the Kokaksu Creek valley, near the Çaydamar hamlet, 2 km south of Zonguldak town (41° 25′ 59.72″ N 31° 48′ 25.40″ E, K in Fig. 1c). F. Charles collected several specimens in this valley in the 1930ies but these outcrops were erased by urbanisation. The Upper Viséan is dominated by bioclastic limestone, often silicified, with abundant but scattered *Siphonodendron* colonies (up to 2 m in diameter). Syringoporids and solitary rugose corals (*Koninckophyllum interruptum*, *Palaeosmilia murchisoni*, *Aulophyllum fungites*) are common. One horizon yielded colonies of *Palastraea koninckі*. The upper part of the section exposes silicified shale alternating with limestone beds. *Pseudozaphrentoides* cf. *juddi* specimens were probably collected in this shale by Ralli (1895) based on his description. The Ulutam section is a succession of discontinuous outcrop in a narrow valley closed by the Ulutam dam, 2.5 km south of Zonguldak (41° 25′ 57.08″ N 31° 47′ 52.07″ E, U in Fig. 1c). Charles (1933) referred to this section as the Tach-Kessen section. Only colonial corals (*Siphonodendron* and *Corwenia*) were collected there.

The Gökgöl section is situated along the road D750 Devrek-Zonguldak, near the Asma hamlet, 4 km south of Zonguldak (41° 26′ 19.28″ N 31° 50′ 05.43″ E, G in Fig. 1c). This section corresponds to the Asma section of Charles (1933) and was studied in detail by Dîl (1975, 1976) for foraminifers. The Upper Viséan is exposed in the western flank of the Gökgöl River valley. Recently, the road was transformed into a motorway and parts of the sections disappeared. The lithology is dominated by bioclastic limestone with chert, bedded at the base, then massive up-section. The solitary rugose corals *Palaeosmilia murchisoni* and *Koninckophyllum interruptum*, as well as *Lithostrotion araneum*, are particularly common in the bedded facies. Large colonies *of Siphonodendron*, *Palastraea koninckі* and syringoporids occur in the massive facies. *Axoclisia* cf. *cuspiforma*, collected by Charles possibly comes from these units, as the microfacies of the surrounding matrix are similar. The silicified shale observed in Kokaksu is lacking here and the contact with the overlying Namurian shales is sharp. The Kisla section is located along a small road, 3 km southwest of Zonguldak (41° 24′ 58.01″ N 31° 43′ 12.53″ E, R in Fig. 1c). The succession is similar to that observed in Gökgöl, but only the top of the Viséan was sampled.

The Topluca section is a road cut situated 7 km northwest of Bartın town, along a new track created between the Topluca earth pit and the valley road (41° 41′ 15.41″ N 32° 17′ 00.54″ E, T in Fig. 1d). The

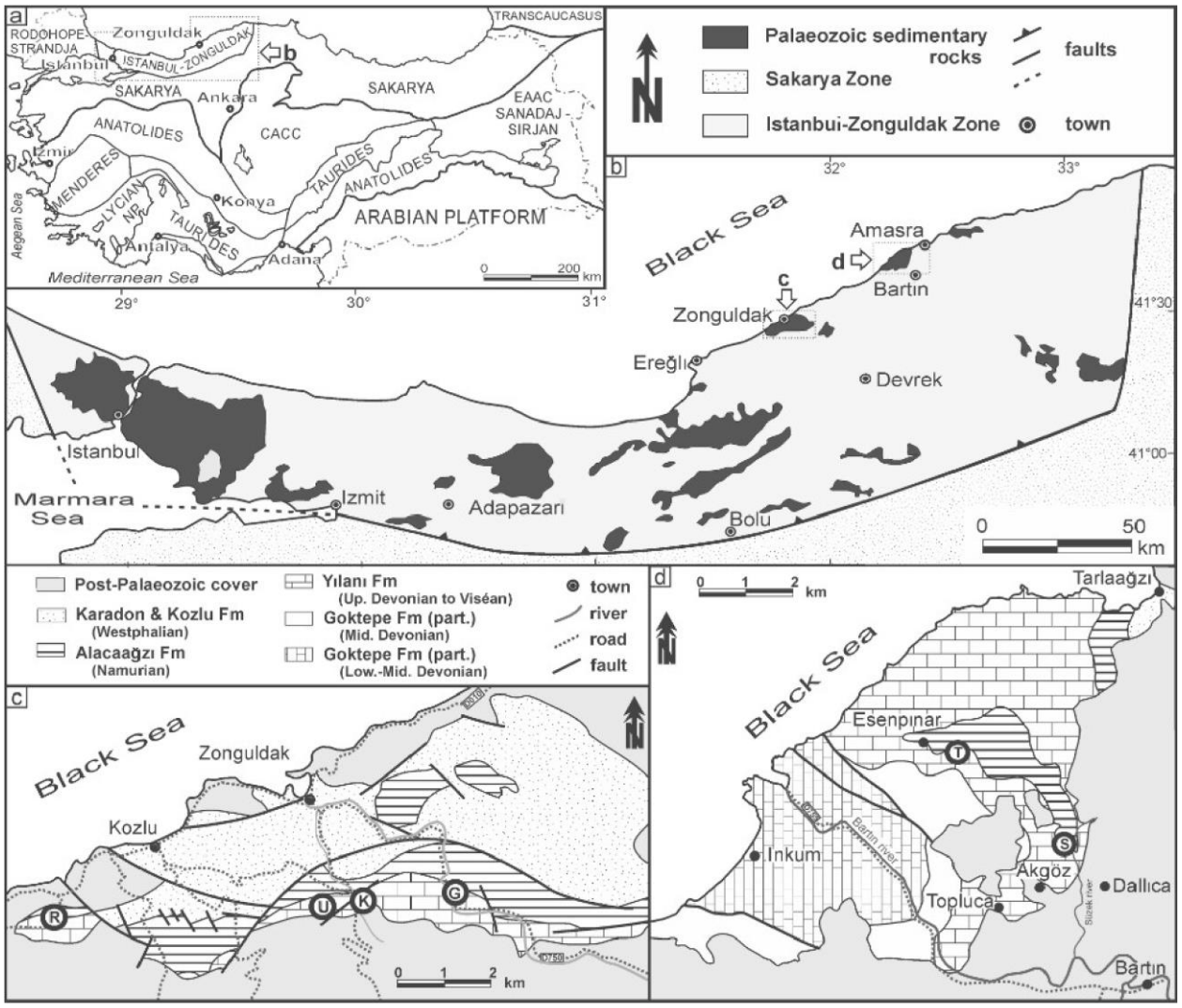


Fig. 1. **a** – General structural map of Turkey (modified after Görür & Tüysüz 2001, Moix et al. 2008 and Okay 2008). **b** – Geological map of the Istanbul-Zonguldak Zone (modified after Okay et al. 2006) with the position of the Zonguldak and Bartın areas. **c** – Simplified geological map of the Zonguldak area (redrawn after Hosgörmez 2007 and Charles 1933) with the location of the sampled sections (R = Kisla section, U = Ulutam section, K = Kokaksu section, G = Gökgöl section). **d** – Simplified geological map of the Bartın area (redrawn after Tokay 1954) with the location of the sampled sections (T = Topluca section, S = Süzek section). Legend: CCAC = Central Anatolian Crystalline Complex, EAAC = East Anatolian Accretionary Complex (Sanadaj-Sirjan Block), Lycian Np. = Lycian Nappes.

Upper Viséan is dominated by light-grey medium- to thick-bedded bioclastic limestones (grainstone and rudstone) and contains abundant fossils. Colonies are usually broken and fragmented. The solitary corals (*Koninckophyllum interruptum*, *Siphonophyllia siblyi*, *Palaeosmilia murchisoni* and *Clisiophyllum keyserlingi*) are abraded as well. The overlying Alacaağzı shale rests disconformably upon an erosive (karstic) surface capping the top of the limestone. The Süzek section (Süzek Deresi of Tokay 1954) is located in the western flank of the valley, 1 km northwest of the Dallıca hamlet near Bartın (41° 40′ 04.72″ N 32° 18′ 58.19″ E, S in Fig. 1d). The lithology of the Upper Viséan is identical to that of Topluca, but some chert occur and corals are sometimes silicified.

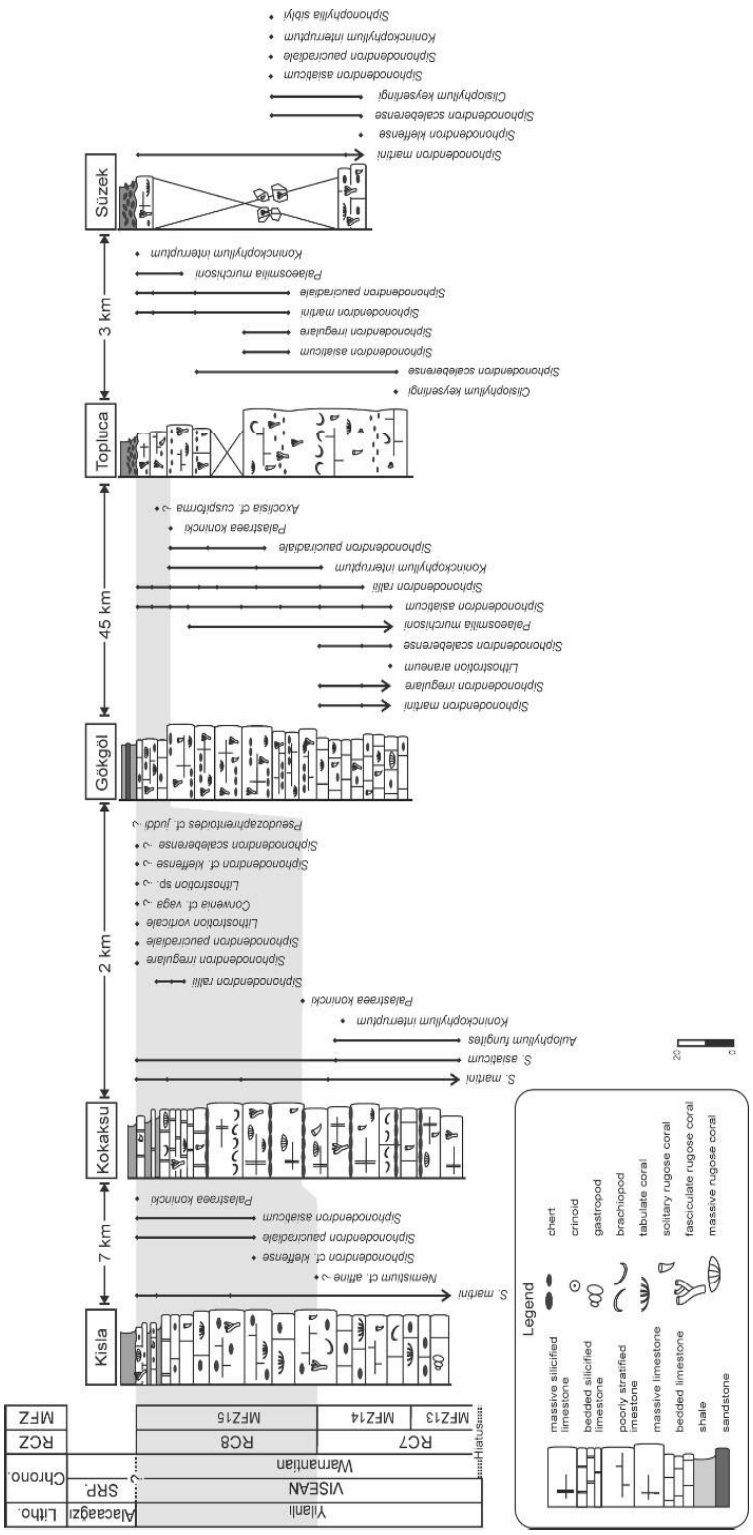


Fig. 2. Schematic log of the studied sections with the stratigraphical distribution of selected coral species discussed in the main text. The Ulutam section is not represented here and its fauna is projected on the nearby Kokaksu section. Abbreviations: Litho. = lithostratigraphy, Chrono = chronostratigraphy, RCZ = Rugose coral zones of POTY et al. (2006), MFZ = foraminiferal biozones of POTY et al. (2006), SRP. = Serpukhovian. The shaded area correspond to the upper Warnantian (RC8 biozone). The hiatus at the base of the column covers the entire Livian (Middle Viséan) (DENAYER 2014).

3. Systematic palaeontology

The newly collected material is housed in the Animal Palaeontology Collection of the University of Liège in Belgium (collection PA.ULg). RALLI's specimens are also housed in the historical collection of the University of Liège under the label ULg.H.63X. CHARLES's specimens are housed in the Invertebrates Collection in the Institut royal des Sciences naturelles de Belgique, Brussels, under numbers IP-10861-XX and IP-15123-XX. The lithostrotionids (species belonging to the genera *Siphonodendron*, *Lithostrotion* and *Nemistium*) have been recently revised (DENAYER 2014); they are not described here.

Subclass Rugosa MILNE-EDWARDS & HAIME, 1850
Order Stauriida VERRILL, 1865
Suborder Caniniina WANG, 1950
Family Cyathopsidae DYBOWSKI, 1873

Siphonophyllia siblyi SEMENOFF-TIAN-CHANSKY, 1974
Fig. 3j

*1906 'A campophyllid'. – SIBLY, p. 369, pl. 31, fig. 3.
2005 *Siphonophyllia siblyi* SEMENOFF-TIAN-CHANSKY. – ARETZ & NUDDS, p. 171, pl. 1, figs. 1–3. [*cum. syn.*]
2011 *Siphonophyllia siblyi* SEMENOFF-TIAN-CHANSKY. – DENAYER et al., p. 158, pl. 7, fig. L.
2016 *Siphonophyllia siblyi* SEMENOFF-TIAN-CHANSKY. – RODRÍGUEZ et al., p. 192, fig. 6c, d.

Material: Two specimens from the Topluca and Süzek section.

Description: The two specimens are 25 and 30 mm in diameter (16 and 19 mm for the tabularium) and have 46–50 septa of each order respectively. The major septa are long, wavy in the dissepimentarium and relatively thin. The minor septa are reduced to septal crests. The cardinal fossula is open and shallow. The dissepimentarium is made of 5–7 rows of small interseptal concentric dissepiments and –10 rows of lonsdaleoid dissepiments.

Discussion and distribution: The dimensions, number and size of septa and the septa thin in the tabularium are characteristic of *S. siblyi*. The rudimentary minor septa are an important difference with *S. cylindrica* SCOULER in MCCOY, 1844, *S. rivagensis* POTY & BOLAND, 1994 and *S. hettonensis* (WILMORE, 1910) which have similar dimensions. The species occurs in the RC6 biozone (Middle Viséan) in Belgium (DENAYER et al. 2011), in the RC7 (lower Warnantian) in Turkey, in England (ARETZ & NUDDS 2005), in southwestern Spain (RODRÍGUEZ & FALCES 1992; RODRÍGUEZ et al. 2016) and in the RC8 (upper Warnantian) of Algeria (SEMENOFF-TIAN-CHANSKY 1974), Ireland (SOMERVILLE 1997) and Poland (KHOA 1977).

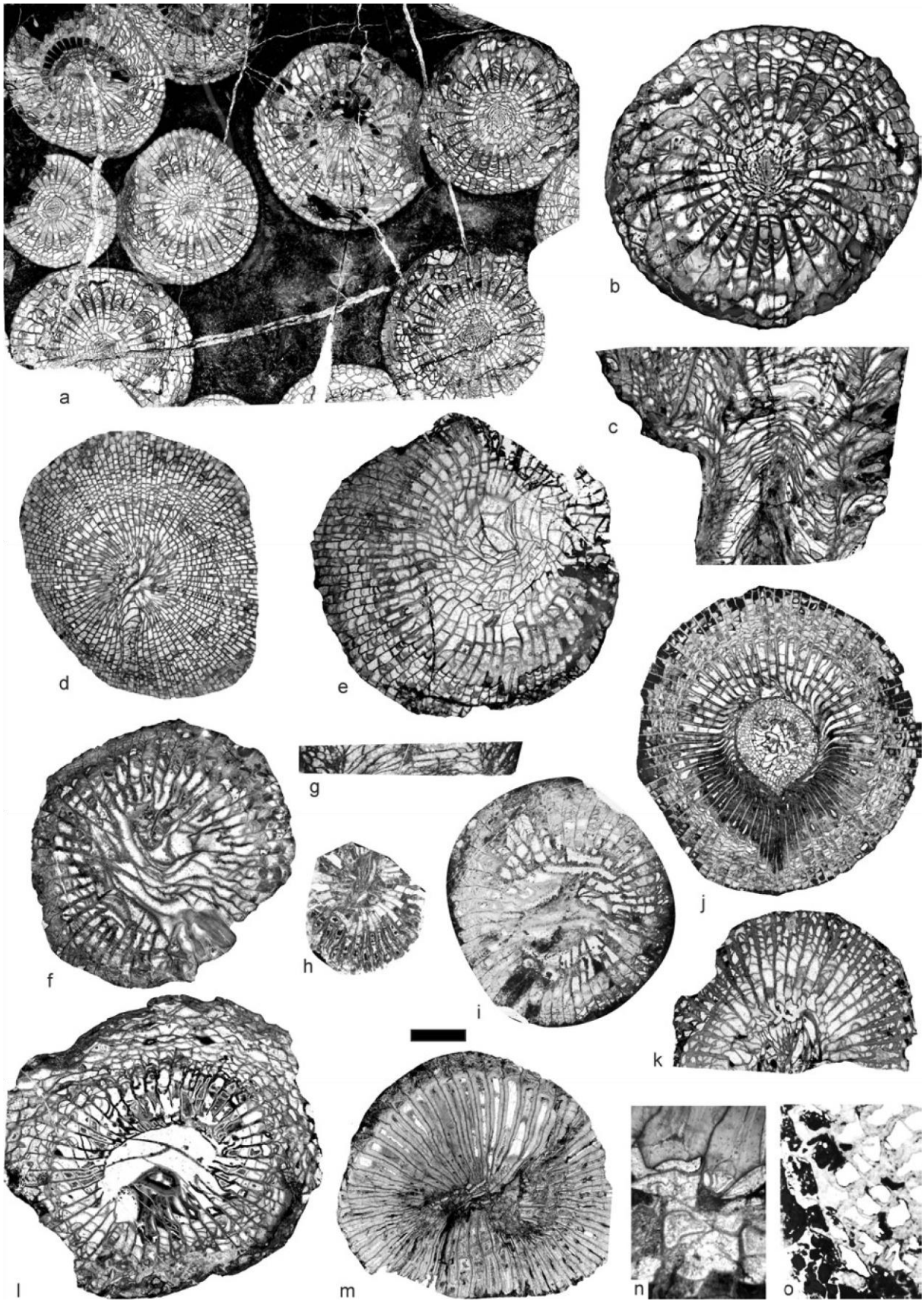
Pseudozaphrentoides cf. *juddi* (THOMSON, 1893)
Fig. 3m,n

1895 *Zaphrentites cylindrica* SCOULER. – RALLI, p. 195.
1895 *Clisiophyllum turbinatum* MCCOY. – RALLI, p. 195.

Material: Two specimens collected by RALLI in the upper part of the Kokaksu section (RALLI 1895).

Description: Both specimens are crushed and abraded. They are 36–40 mm large, the tabularium is maximum 34 mm wide. There are 44 major septa, very thick in the juvenile stages then progressively thinner and more sinuous. The minor septa are thin, very short and confined to the outer dissepimentarium. The cardinal septum is shorter. The dissepimentarium is badly preserved and only 4 rows of small irregular, concentric and V-shaped interseptal dissepiments are observed. The inner row is very thick (Fig. 3n).

Discussion and distribution: These specimens are similar in dimension and number of septa with *P. juddi* (THOMSON, 1893) but differ by septa thickened in the whole tabularium, whereas the thickenings are confined to the cardinal quadrants in *P. juddi*. This point make these specimen close to Siphonophyllia spp. But the dissepimentarium of the later is usually made of concentric dissepiments and lonsdaleoid dissepiments. They also differ from *P. alloiteaui* SEMENOF-TIAN-CHANSKY, 1974 by the poor develepment of lonsdaleoid dissepiments and a lower septa/diameter ratio. Again, the lack of lonsdaleoid dissepiments of course might be due to the abrasion of the present specimens. *Pseudozaphrentoides juddi* occurs in the Upper Viséan of Western Europe (HILL 1938–1941; POTY 1981; RODRÍGUEZ et al. 2004) and extends into the Serpukhovian in Spain (GÓMEZ-HERGUEDAS & RODRÍGUEZ 2005), the Donets Basin, (VASSILJUK 1960), the Russian Platform (DOBROLJUBOVA 1958) and Algeria (SEMENOFF-TIAN-CHANSKY 1974). The Turkish specimens are supposed to be uppermost Viséan in age, but the exact level from where RALLI collected them was not identified in the Kokaksu section.


a
b
c
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Aulophyllum fungites (Fleming, 1828)
Fig. 3j

*1849 *Clisiophyllum prolapsum* McCoy, p. 3.
1981 *Aulophyllum fungites* (Fleming). – Poty, p. 38, pl. 18, fig. 5. [*cum. syn.*]
2008 *Aulophyllum fungites* (Fleming). – Said & Rodríguez, p. 15, fig. 2a–e.
2011 *Aulophyllum fungites* (Fleming). – Denayer et al., p. 164, pl. 11, fig. J.
2015 *Aulophyllum fungites* (Fleming). – Rodríguez et al., p. 178, fig. 4a–c.
2016 *Aulophyllum fungites* (Fleming). – Rodríguez et al., p. 193, fig. 7a.

Material: Three silicified specimens from Kokaksu and one fragment from Charles's (1933) collection.

Description: The mean diameter of the specimen is 21 mm whereas the tabularium is 13.5 mm wide in average. There are 47–50 septa of each order, the major ones reach the edge of the axial structure. They are slightly sinuous in the dissepimentarium and thickened in the cardinal parts of the tabularium. The minor septa are thin and enter slightly into the tabularium. The cardinal fossula is conspicuous. The axial structure is 5.5–6.5 mm wide, i.e. 1/3 of the corallite diameter. It is made of a dense mesh of irregular curved septal lamellae intercepted by upturned axial tabellae. In transverse section, slightly cuspidate towards the cardinal fossula. There are 6–9 rows of concentric or rarely herringbone interseptal dissepiments *c.* 1 mm large and *c.* 1 mm high in longitudinal section. The axial tabellae are domed and densely packed whereas the periaxial tabellae are declined towards the dissepimentarium.

Discussion and distribution: The species is known in the Upper Viséan of Western Europe (Smith 1913; Fedorowski 1971; Poty 1981; Rodríguez et al. 2001), the Donets Basin (Vassiljuk 1960) and North Africa (Semenoff-Tian-Chansky 1974; Said & Rodríguez 2008; Rodríguez et al. 2015). In these regions, the species is a guide taxa for the Upper Viséan (top of the RC7β and RC8 biozones, Poty et al. 2006), but it also occurs in the Serpukhovian (Hill 1938–1841; Semenoff-Tian-Chansky 1974; Rodríguez et al. 2015).

Clisiophyllum keyserlingi McCoy, 1849
Fig. 3e

*1849 *Clisiophyllum keyserlingi*, McCoy, p. 2.
?1958 *Clisiophyllum keyserlingi* McCoy. – Ünsalaner-Kiragli, p. 54, pl. 2, fig. 4.
2011 *Clisiophyllum keyserlingi* McCoy. – Aretz, p. 600, fig. 7B. [*cum. syn.*].
2011 *Clisiophyllum keyserlingi* McCoy. – Denayer et al., p. 162, pl. 9, figs. C, W.
2015 *Clisiophyllum keyserlingi* McCoy. – Rodríguez et al., p. 78, fig. 4i, k.

Material: Five specimens (three from Topluca and two from Süzek).

Description: The mean diameter of the corals is 33 mm (maximum 42 mm) with a tabularium 24 mm wide on average (maximum 34 mm). There are 55 septa of each order (maximum 60). The major septa are thin and wavy in the tabularium and thickened in the dissepimentarium. The minor septa enter into the tabularium for up to 2 mm and are also thick. They are commonly contratingent. The cardinal septum is short and situated in a shallow cardinal fossula. The counter septum is long and connected to the axial plate. The axial structure is variable, often loose, made of an axial plate often curved and numerous whirled septal lamellae, intercepted by upturned axial tabellae or connected to the major septa. The dissepimentarium is composed of 4–10 rows of small concentric or herringbone interseptal dissepiments, the inner row being thickened. In longitudinal section, they are narrow and steeply disposed. The axial tabellae are cone- or tent-shaped and densely packed (15 per centimetre) whereas the peri-axial tabellae are irregular and less inclined.

Discussion and distribution: These specimens share the characters of the *Clisiophyllum keyserlingi* group of species. They have the dimensions and number of septa of *C. keyserlingi* McCoy, 1849, but show a more irregular axial structure with less septal lamellae. However, Hill (1938–1841) documented a wide morphological variability within this species, its axial structure varying from a regular symmetrical web-like structure to a loose mesh of irregular lamellae with no dominant axial plate. The Turkish material thus can be included in *C. keyserlingi*. The species occurs in the Late Viséan RC7 zone in Western Europe (Hill 1938–1841;

Fig. 3. Solitary and colonial rugose corals from the Upper Viséan of Bartın and Zonguldak (NW Turkey). **a–c** – *Corwenia* cf. *vaga* Smith & Ryder, 1926 from the upper Warnantian of Ulutam, specimen U.1.1, a, b: transverse section (TS), c: longitudinal section (LS). **d** – *Palaeosmilia murchisoni* Milne-Edwards & Haime, 1850 from the lower Warnantian of Gökgöl, G.2.6, TS. **e** – *Clisiophyllum keyserlingi* McCoy, 1849 from the lower Warnantian of Süzek, SR.7.6, TS. **f–i** – *Koninckophyllum interruptum* Thomson & Nicholson, 1876 form the lower Warnantian of Gökgöl and Topluca respectively, f, i: G.15.7.2, TS, g: same specimen, LS, h: ET.1.2, TS. **j** – *Aulophyllum fungites* Fleming, 1828 form the lower Warnantian of ?Kokaksu, IP-15123-06, TS. **k, o** – *Axoclisia* cf. *cuspiforma* Semenoff-Tian-Chansky, 1974 from the upper Warnantian of ?Gökgöl, IP-15123-05, TS, o: close-up view of the lonsdaleoid dissepiments. **l** – *Siphonophyllia siblyi* Semenoff-Tian-Chansky, 1974 from the lower Warnantian of Süzek, SR.7.5, TS. **m, n** – *Pseudozaphrentoides* cf. *juddi* (Thomson, 1893), from the upper Warnantian of Kokaksu, m: ULg.H.635, TS, n: ULg.H.636, TS, close-up view of the dissepimentarium. – Scale bar equals 20 mm for a, equals 40 mm for b, c, equals 30 mm for d–m, equals 80 mm for n–o.

FEDOROWSKI 1971; POTY 1981), in the Balkans (KOSTIČ-PODGORSKA 1957 and in North Africa (SEMENOFF-TIAN-CHANSKY 1974; ARETZ 2011). ÜNSALANER-KIRAGLI (1957) reported *C. keyserlingi* from the Eastern Taurides, but the exact origin of this coral is unknown. *C.* aff. *keyserlingi* documented by DENAYER (2012) in the Anatolides is closer to *C. garwoodi* than *C. keyserlingi*. In northwestern Turkey the species occurs only in the Bartın area, in the RC7 biozone.

Koninckophyllum interruptum THOMSON & NICHOLSON, 1876
Fig. 3f–i

*1876 *Koninckophyllum interruptum* THOMSON & NICHOLSON, p. 121, pl. 12, fig. 3, 3a.
1933 *Caninia* cf. *colossea* LUDWIG. – CHARLES, p. 124, pl. 5, figs. 20, 21.
2011 *Koninckophyllum interruptum* THOMSON & NICHOLSON. – ARETZ, p. 604, fig. 8B. [*cum. syn.*].
2011 *Koninckophyllum interruptum* THOMSON & NICHOLSON. – DENAYER et al., p. 165, pl. 11, fig. C.
2015 *Koninckophyllum interruptum* THOMSON & NICHOLSON. – RODRÍGUEZ et al., p. 84, fig. 6a, b.
2016 *Koninckophyllum interruptum* THOMSON & NICHOLSON. – RODRÍGUEZ et al., p. 199, fig. 8d.

Material: Nine specimens: six from Gökgöl (including CHARLES's specimen), one from Kokaksu, one from Süzek and one from Topluca.

Description and discussion: The average diameter is 27.4 mm (maximum 30 mm) and the tabularium is 20 mm wide in average (maximum 27 mm). There are 43 septa of each order on average (maximum 50), commonly thickened. The major septa are long and wavy, the minor septa are restricted to the dissepimentarium and their length varies form specimen to specimen. The cardinal septum is connected to the axial plate but is short where the axial structure is absent (Fig. 3f–h). The cardinal fossula is conspicuous. The axial structure is a long (4–9 mm) and thickened plate, commonly curved. The axial structure is vertically discontinuous (Fig. 3g) and diphymorph stages are frequent (Fig. 3f). The dissepimentarium is made of 8–10 rows of concentric, angulo-concentric, V-shaped, herringbone and arched interseptal dissepiments. The inner rows are herringbone. The peripheral rows are more densely packed than the inner ones.

Discussion and distribution: Several *Koninckophyllum* species are characterised by a weakly developed and often lacking columella but only *K. interruptum* has the dimensions and number of septa similar to the Turkish corals. The complexity of the dissepimentarium is also diagnostic for the species and allows its identification in diphymorphic specimens. *K. interruptum* is an occasional species in the Upper Viséan of Belgium (POTY 1981, top of RC7β and RC8 zones), England (MITCHELL 1989), Scotland (HILL 1938–1841), Poland (FEDOROWSKI 1971), southwestern Spain (RODRÍGUEZ et al. 2001, 2016) and North Africa (SEMENOFF-TIAN-CHANSKY 1974; RODRÍGUEZ et al. 2013). The species is common in the RC7 in Gökgöl and occasional in the Bartın area.

Axoclisia cf. *cuspiforma* SEMENOFF-TIAN-CHANSKY, 1974
Fig. 3k, o

Material: One fragmented specimen from CHARLES's collection, probably from the upper part of the Gökgöl section (based on similarity of the microfacies).

Description and discussion: The observed diameter is 18 mm (9 mm for the tabularium) and there are 40 major septa (number estimated on the half of the preserved specimen), irregular in length and thickness. They are longitudinally dissected in the dissepimentarium and their axial ends are tortuous. The minor septa enter into the tabularium for 1 mm and are as irregular as the major. The axial structure is made of a thick axial plate bearing irregular septal lamellae. The dissepimentarium is composed of 5–10 rows of interseptal dissepiments, the outer rows being concentric, concave either towards the axis or towards the wall, the inner rows being herringbone and arched. Second order lonsdaleoid dissepiments occur (Fig. 3o).

Discussion and distribution: The poverty of the material prevents a suitable discussion but the morphology of the axial structure recalls *Axoclisia cuspiforma* SEMENOFF-TIAN-CHANSKY, 1974 from the Lower Viséan of Algeria, the later having similar dimensions (26–29 mm in diameter for 41–44 major septa). Beside Algeria, *Axoclisia* is known from the Upper Viséan of South Spain (RODRÍGUEZ et al. 2016), Belgium (DENAYER et al. 2011), Morocco (SAID & RODRÍGUEZ 2008; ARETZ 2010). *Axoclisia* spp. is often represented by a few specimen is all these localities.

Corwenia cf. *vaga* SMITH & RYDER, 1926
Fig. 3a–c

Material: A fragment of a large colony from the Ulutam section.

Description and discussion: The mean corallite diameter is 16.7 mm (maximum 20 mm) and the tabularium diameter is 9 mm (maximum 11 mm). There are 31 septa of each order on average (maximum 35). The major septa are long and spindle-shaped but can be wavy in the dissepimentarium. Their axial ends are curved near the axial structure. The minor septa are short (less than 1/3 of the major length) and sometimes discontinuous in the dissepimentarium. The cardinal fossula is shallow and marked by the withdrawal of the dissepimentarium and the curved cardinal lateral septa. The axial structure is 3–5 mm wide, i.e. 1/4 of the corallite's diameter and symmetrical. It is made of a strong axial plate bearing up to 20 irregular septal lamellae. Most of them are connected to the axial ends of the major septa. The dissepimentarium is wide and includes rows of concentric and herringbone interseptal dissepiments in the inner part, and second order lonsdaleoid dissepiments. The inner rows are commonly thickened. In longitudinal section, they are almost horizontal in the outer dissepimentarium and gently declined towards the axis in the inner part. The axial tabellae are cone-shaped, steeply upturned towards the axial

plate (Fig. 3c). The periaxial tabellae are depressed and form a peripheral gutter. There are, on average 15 tabellae and 15–18 dissepiments per vertical centimetre of section. The external wall is 0.2–0.3 mm-thick and arched.

Discussion and distribution: *C. vaga* SMITH & RYDER, 1926 is similar to the Turkish specimen by its regular axial structure; septal lamellae connected to the septa and second order lonsdaleoid dissepiments. However, *C. vaga* has less septa (30–32) and a similar diameter (15–17.5 mm). The spindle-shaped septa and the symmetrical axial structure of the Turkish specimens are similar to those of *Corwenia rugosa* (MCCOY, 1849), but the latter has smaller corallites (12.5 mm in diameter) and more septa (up to 40). *C. vernueilli* (STUCKENBERG, 1904) has similar dimensions and number of septa, but is less thickened and has an irregular axial structure. *Corwenia* sp. 1 from the Brigantian of Adarouch (Morocco) has similar dimensions and number of septa and possibly is conspecific with the Turkish colony as suggested by SAID & RODRÍGUEZ (2008). *Corwenia* is a guide taxa of the Late Viséan RC8 biozone (POTY et al. 2006). The species *C. vaga* occurs in the Brigantian of England (SMITH & RYDER 1926).

Palaeosmilia murchisoni MILNE-EDWARDS & HAIME, 1848
Fig. 3d

*1848	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME, p. 261.
1933	*Cyathophyllum murchisoni* MILNE-EDWARDS & HAIME. – CHARLES, p. 129, pl. 5, figs. 28, 29.
1957	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – ÜNSALANER-KIRAGLI, p. 57, pl. 12, fig. 2a–d.
2011	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – ARETZ, p. 596, fig. 6F. [*cum. syn.*].
2011	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – DENAYER et al., p. 161, pl. 6, fig. C.
2012	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – SOMERVILLE et al., p. 311, fig. 3.
2012	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – DENAYER, p. 320, fig. 4 K.
2012	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – LIN et al., p. 333, pl. 1, figs. N–O.
non 2012	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – FEDOROWSKI & BAMBER, p. 352, fig. 3C–E.
2015	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – RODRÍGUEZ et al., p. 86, fig. 6 h–j.
2016	*Palaeosmilia murchisoni* MILNE-EDWARDS & HAIME. – RODRÍGUEZ et al., p. 197, fig. 8a.

Material: Eight specimens (two from Süzek, one from Topluca, two from Kokaksu, including CHARLES's specimen, three from Gökgöl).

Description and discussion: The Turkish specimens, with their diameter of maximum 30 mm and up to 70 septa of each order, have all the characters of *P. murchisoni*. This species having been described and discussed in many previous works, therefore it is not described herein.

Palastraea koninckí (CHARLES, 1933)
Fig. 4a–d

*1933 *Endophyllum koninckí* CHARLES, p. 135, pl. 6, figs. 37, 38.

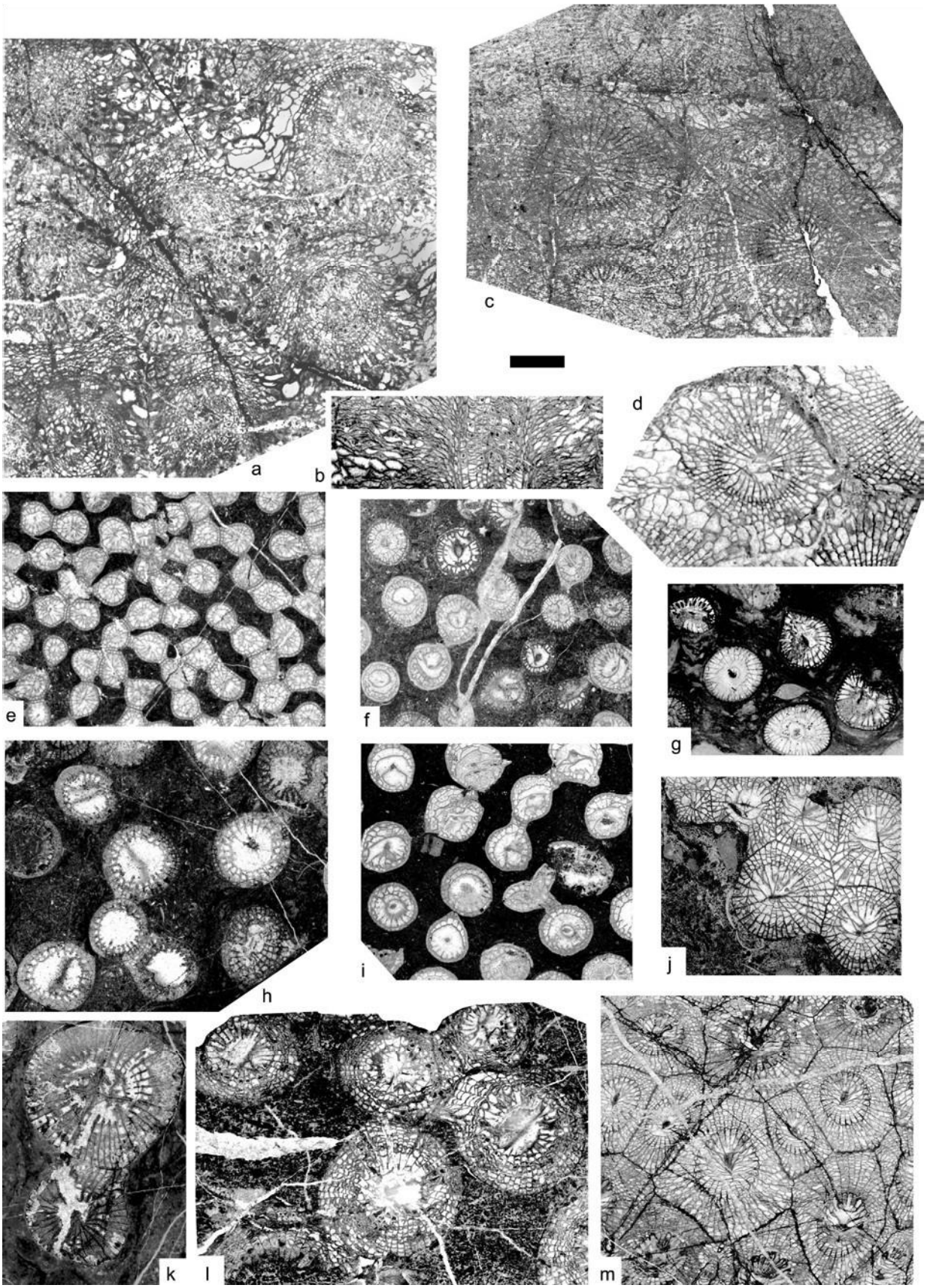
Lectotype: Here designated: specimen IP-10861-05 from the Upper Viséan cherty limestone of Kokaksu, Turkey; collection CHARLES, Institut royal des Sciences naturelles de Belgique, Brussels. CHARLES's specimen being very badly preserved, it is almost unusable for any further analysis (Fig. 4c). As topotypic material was recently collected from Kokaksu and Gökgöl, they can be used as a good plesiotypes, particularly the colony G.16.4 (Upper Viséan of Gökgöl section, Fig. 4a, b). The provided diagnosis and description are based on this colony.

Material: Four colonies: two from Kokaksu (including the lectotype of CHARLES's collection), one from Gökgöl (plesiotype) and one from Kisla.

Diagnosis: Astreoid to aphroid *Palastraea* with small-sized corallites, 18–20 mm wide, with a tabularium 7–8 mm wide and 30 septa of each order. Major septa spindle-shaped, long but leaving a free zone in the middle of the corallite. Minor septa entering slightly into the tabularium. Dissepimentarium wide, composed of interseptal and lonsdaleoid dissepiments.

Description: The colonies are up to 50 cm large and high, sometimes with contraction and rejuvenescence producing ragged margins. The corallites are polygonal and 19 mm wide on average (maximum 28 mm). The mean tabularium is 7.5 mm (maximum 9 mm). There are 30 septa of both orders on average (maximum 38). The major septa are long, commonly joined in bundles of 4 or 5. The minor septa are long (half as long as the major or longer) and enter slightly into the tabularium. All the septa are thickened, their maximum thickness is reached near the tabularium edge but they are thinner and wavy in the dissepimentarium. Some specimens have carinate septa. The cardinal fossula is variably marked. The dissepimentarium is composed of 4–15 rows of concentric and V-shaped interseptal dissepiments and 2–5 rows of irregular, angular or rounded lonsdaleoid dissepiments, some being almost naotic. In longitudinal section, the interseptal dissepiments are steeply inclined whereas the lonsdaleoid ones are almost horizontal. There are 15–20 dissepiments of each type per centimetre. The outer wall is thin and disappears commonly between the corallites. The tabulae are highly divided. The axial tabellae are mesa-shaped or domed and densely packed (more than 20 tabulae per centimetre). The peripheral tabellae are globose, less densely packed and declined toward the dissepimentarium.

Discussion and distribution: CHARLES's (1933) description of his new species is relatively superficial and its figuration is very bad. In consequence, *Endophyllum koninckí* remained unused and unrecognised until the collection of the topotypic material allowed an accurate description. *P. kon-*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incki differs from *P. carbonaria* (McCoy, 1851) and *P. regia* (Phillips, 1836) by its smaller dimensions (respectively 40 and 15 mm in tabularium diameter) and from *P. weiningensis* Wu & Zhao, 1989 and *P. planiscula* Wu & Zhao, 1989 (both of similar dimensions) by a less developed lonsdaleoid dissepimentarium. So far the species is endemic to the Zonguldak area.

4. Discussion

4.1. Coral assemblages and biostratigraphy

In northwestern Turkey, the Warnantian (Upper Viséan) rugose coral biozones RC7 and RC8 of Poty et al. (2006) are recognized. The guide taxa are not present but the other common taxa allow good correlations. The age of the assemblage is supported by foraminiferal data (unpublished) indicating respectively the MFZ13–14 biozones. The MFZ15 was recognized with some difficulty because of the absence of the guide *Janischewskina* and the poor preservation of the archaediscids. However, the local abundance of *Warnantella* spp. and *Biseriella parva* points to the MFZ15.

Lower Warnantian (RC7): This assemblage is identified in four studied sections. The dominant species are *Siphonodendron asiaticum* (Fig. 4e) and *S. martini* that are abundant in all the sections. Diphymorphic *S. martini* colonies (Fig. 4h) are moreover abundant at Kokaksu, but rare in other sections. The other common taxa are *S. irregulare* (Fig. 4i), *S. pauciradiale* (Fig. 4f), *S. scaleberense* (Fig. 4l), *Koninckophyllum interruptum* and *Palaeosmilia murchisoni*. *S. rallii* (Fig. 4g), *Aulophyllum fungites*, *Lithostrotion araneum* (Fig. 4m) and *Lithostrotion* sp. are common or occasional in Zonguldak, but absent in the Bartın sections (see Denayer 2014). They are replaced in the latter area by *Siphonodendron kleffense*, *Siphonophyllia siblyi* and *Clisiophyllum keyserlingi*. Syringoporids are abundant in all studied sections. In total, the lower Warnantian of Zonguldak yielded 12 species whereas 10 species are recovered from the Bartın area. Rarefaction curves (Fig. 5) show that a larger sample would not yield a more diverse fauna, which provides stronger support to the interpretation of a depleted coral fauna in Bartın compared to Zonguldak during lower Warnantian times.

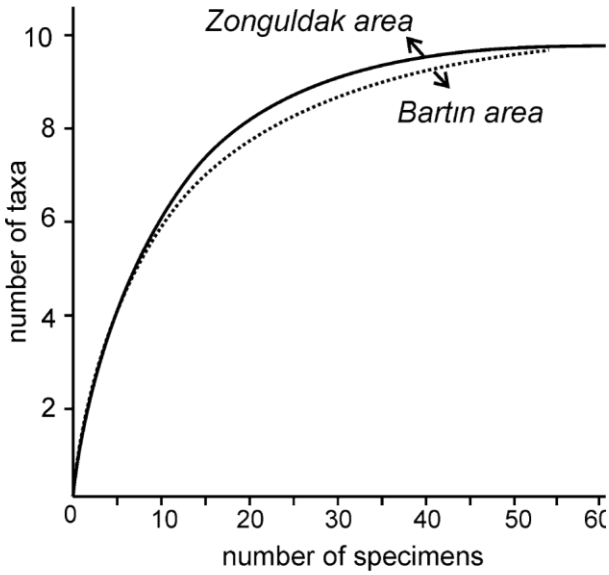

Fig. 5. Individual rarefaction curves for the lower Warnantian (RC7 biozone) time slice in Zonguldak and Bartın areas

Upper Warnantian (RC8): The rugose coral assemblage is not very different from the previous one, but contains taxa not recorded before. The dominant species are still *S. asiaticum* and *S. martini*, but the second one is less abundant than previously. On the other

Fig. 4. Colonial rugose corals from the Upper Viséan of Bartın and Zonguldak (NW Turkey). **a–d** – *Palastraea konincki* (Charles, 1933) from the upper Warnantian of Gökgöl, Kokaksu and Kisla, a: specimen G.16.4, transverse section (TS), b: G.16.4, longitudinal section (LS), c: IP-10861-05 (lectotype), TS, d: R.5, TS. **e** – *Siphonodendron asiaticum* (Yabe & Hayasaka, 1920) from the lower Warnantian of Topluca, ET.2.5, TS. **f** – *Siphonodendron pauciradiale* (McCoy, 1844) from the lower Warnantian of Topluca, ET.2.3, TS. **g** – *Siphonodendron rallii* Denayer, 2014 from the upper Warnantian of Gökgöl, G.16.5.1, TS. **h** – Diphymorphic *Siphonodendron martini* (Milne-Edwards & Haime, 1851) from the lower Warnantian of Gökgöl, G.5.12, TS. **i** – *Siphonodendron irregulare* (Phillips, 1836) from the upper Warnantian of Kokaksu, K.12.1, TS. **j** – *Lithostrotion vorticale* (Parkinson, 1808) from the upper Warnantian of Kokaksu, K.12.6, TS. **k** – *Nemistium* cf. *edmonsi* Smith, 1928 from the upper Warnantian of Kisla, S.1.1. **l** – *Siphonodendron scaleberense* Nudds & Somerville, 1987 from the lower Warnantian of Topluca, ET.3.5, TS. **m** – *Lithostrotion araneum* (McCoy, 1844) from the lower Warnantian of Gökgöl, G.4.1, TS. – Scale bar equals 20 mm for all specimens.

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Table 1. Distribution and abundance of the coral species in the studied sections. Legend: • = occasional, •• = common, ••• = abundant, ? = stratigraphic level not precisely known.

Species	Sections							
	Zonguldak area						Bartın area	
	Kisla		Kokaksu		Gökgöl		Süzek	Topluca
	RC7	RC8	RC7	RC8	RC7	RC8	RC7	RC7
Siphonodendron martini	•••	•••	•••	•••	••		•••	•••
Siphonodendron asiaticum	••	••	••	•••	•••	••	•••	•••
Siphonodendron irregulare				••	••		•	•
Siphonodendron pauciradiale				••	••	•••	•	••
Siphonodendron rallii				••	•	•••		
Siphonodendron scaleberense			•		•••		••	•••
Siphonodendron kleffense							•	
Siphonodendron aff. *kleffense*	•		•					
Lithostrotion araneum					•			
Lithostrotion vorticale				•				
Lithostrotion sp.				•				
Nemistium cf. *affine*		•						
Corwenia cf. *vaga*				•				
Palastraea konincki		•		•		•		
Palaeosmilia murchisoni				•	••			•
Clisiophyllum keyserlingi							•	••
Aulophyllum fungites			•	••				
Koninckophyllum interruptum			•		••	•	•	•
Siphonophyllia siblyi							•	•
Pseudozaphrentoides cf. *juddi*				•				
Axoclisia cf. *cuspiforma*						•?		

hand, *S. pauciradiale* and *S. rallii* are more common. *Palastraea koninckі* is also present in all sections in the Zonguldak area, allowing the recognition of the RC8 biozone. *S. irregulare*, *Lithostrotion decipiens* (Fig. 4j), *Aulophyllum fungites*, *Palaeosmilia murchisoni*, *Corwenia* cf. *vaga*, *Nemistium* cf. *affine* (Fig. 4k), *Axoclisia* cf. *cuspiforma* and *Pseudozaphrentoides* cf. *juddi* are occasionally observed. Thirteen species are thus recorded in Zonguldak. The RC8 zone is absent in the Bartın area after the erosion of the top of the Viséan deposits as a result of the drastic Serpukhovian sea-level drop (Poty et al. 2006).

4.2. Ecological distribution

Even if the Zonguldak and Bartın coral association are similar, the distribution and abundance of taxa (see Table 1) seems to be driven by the local environmental conditions. The facies witness high-energy depositional settings in the Bartın area and a less energetic, slightly more distal environment in Zonguldak. Moreover, the higher extension of the erosional gap at the top of the Viséan limestone in Bartın also pleads for a more proximal position of the eastern part compared to the western Zonguldak area. *Siphonophyllia siblyi* and *Clisiophyllum keyserlingi* seem to be preferentially related to high-energy facies, whereas *Aulophyllum fungites* is confined to lower energetic environments in Kokaksu. *Koninckophyllum interruptum* and *Palaeosmilia murchisoni* show no such trend. The wide distribution of large-size species of *Siphonodendron* (*S. martini*, *S. scaleberense*) witnesses their adaptability in different hydrodynamic settings. The occurrence of the small-sized species *S. asiaticum* in all settings is interesting, because at first sight such a delicate species should prefer calmer environment, as does *S. junceum* (Aretz et al. 2010). Nevertheless, the small size might result from competition with syringoporids that drove them to adapt to turbulent environments. Both solitary and colonial corals form a coral mead-

ow (type B of Aretz 2010) with a moderate diversity. The colonies are locally abundant in some levels, but no biostrome was noticed. In the Zonguldak area, the colonies (including syringoporid tabulate corals) can reach respectable dimensions (up to 0.5 m high and and wide), but in the Bartın area, they are often broken in fragments, less than 20 cm large.

land and Wales (Mitchell 1989), 21 genera in the Donets Basin (Ukraine, Vassiljuk 1960), 35 genera in SW Spain (Rodríguez et al. 2016) and up to 20 genera in the Azrou-Khenifra Basin (Morocco; Said et al. 2011, 2013). This relative poverty is partly explained by the palaeoecological issues discussed above but also by the absence of typical Upper Viséan genera.

4.3. Palaeobiogeographic affinity and correlation

Almost all taxa observed in northwestern Turkey are the typical taxa recorded in Western Europe in similar facies (see Aretz et al. 2010; Somerville & Rodríguez 2007; Rodríguez et al. 2016). Northwestern Turkey thus belongs to the Western Europe Province (sensu Hill 1981; Fedorowski 1981; Sando 1990). However, there are exceptions, such as *S. asiaticum*, that indicates an Asian influence (the taxon is known from China to the Donets Basin) and *S. rallii* which is a local, endemic? Species. *Nemistium* cf. *affine*, *Axoclisia* cf. *cuspiforma* and *Pseudozaphrentoides* cf. *juddi* are not local species, but were identified with some doubt, because the available material is too poor or badly preserved. Several genera commonly observed in the Upper Viséan of Europe, such as *Diphyphyllum*, *Dibunophyllum*, *Axophyllum*, *Gangamophyllum* and *Lonsdaleia* are surprisingly absent from northwestern Turkey. *Lonsdaleia* is climate dependant and its specific abundance decreases from north (Russia, Donets) to south (South France, North Africa, Aretz 2002; Rodríguez et al. 2013) and its absence in Turkey may be the result of local climatic settings. Nevertheless, *Lonsdaleia* is present in the Upper Viséan of the Donets Basin from which northwestern Turkey is supposed to be close to at this time (Görür et al. 1997). The lack of *Dibunophyllum*, *Axophyllum* and *Gangamophyllum* is as yet unexplained, but constitutes an interesting singularity for the recognition of the Zonguldak and Bartın identity as a palaeobiogeographic unit.

Compared to better known areas exposing fossiliferous Upper Viséan un Europe and North Africa, the Istanbul-Zonguldak Zone is rather poorly diverse in rugose corals. Whereas the Upper Viséan strata of NW Turkey yielded 12 rugose coral genera in the RC7 and RC8 zone, there are 10 genera in the Upper Viséan strata of the Turkish Anatolides (Denayer 2012), up to 30 genera in time-equivalent limestones in Belgium (Denayer et al. 2011, 2016), 21 genera in South Eng-

5. Conclusions

1. The Warnantian (Upper Viséan) rugose corals assemblages of northwestern Turkey are here documented. *Palastraea koninckі* is re-described based on Charles's holotype and newly collected material. A brief description of some interesting taxa is also provided.
2. The Upper Viséan rugose coral assemblages of northwestern Turkey are dominated by the colonial lithostrotionids (*Siphonodendron martini*, *S. asiaticum*, *S. irregulare*, *S. pauciradiale*, *S. ralli*, *S. scaleberense*), *Palastraea koninckі* and the solitary corals *Palaeosmilia murchisoni*, *Koninckophyllum interruptum*, *Aulophyllum fungites*, *Siphonophyllia siblyi*, and *Clisiophyllum keyserlingi*. Occasional species are *Corwenia* cf. *vaga*, *Nemistium* cf. *affine*, *Siphonodendron kleffense*, *S.* aff. *kleffense*, *Lithostrotion araneum*, *L. vorticale*, *L.* sp., *Pseudozaphrentoides* cf. *juddi*, and *Axoclisia* cf. *cuspiforma*.
3. Two stratigraphic assemblages more or less equivalent in diversity are identified respectively correspoding to the rugose corals biozones RC7 and RC8. The first is lower Warnantian in age and shows slight differences in composition between Bartın and Zonguldak. These changes are explained by variations in the environmental (hydrodynamic) settings. The second assemblage, based on the occurrence of *Corwenia*, *Nemistium* and *Palastraea*, is upper Warnantian (Brigantian) in age and is preserved only in the Zonguldak area. In the Bartın area, the upper Warnantian beds were eroded at the end of the Viséan when the global sea level dropped sharply.
4. Both assemblages are dominated by taxa typical of the Western European Province. The abundance of *S. Asiaticum*, however, indicates an Asian influence. The absence of *Axophyllum*, *Dibunophyllum*, *Diphyphyllum*, *Gangamophyllum* and *Lonsdaleia* are only partly explained, but defines the singularity of the Bartın and Zonguldak areas.

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