Rugose Corals Across the Devonian—Carboniferous Boundary in NW Turkey

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An uppermost Famennian (Strunian) coral assemblage has been recovered in the middle part of the Yılanlı Formation of the Istanbul Zone (Zonguldak and Bartın areas, NW Turkey). In the Bartın area, the studied fossiliferous interval corresponds to a c. 30 m-thick unit of bioclastic to peloidal wackestone to packstone grading to grainstone and including two stromatoporoid biostromes. In the Zonguldak area, 60 km westward, the bioclastic facies is dominant. The rugose corals are mainly solitary taxa belonging to the genera *Campophyllum*, *Bounophyllum*, *Amplexocarinia*, and ?*Metriophyllum*, and only one colonial genus occurs: *Pseudoendophyllum*. This fauna is similar to that documented in Europe. The campophyllids and dibunophyllids are the main component of the uppermost Famennian assemblages in S Belgium, N France, W Germany, NW and S Poland. The endophyllids occur in S Poland, Novaya Zemlya, and in the Ural Mountains. The Istanbul Zone is supposed to be situated in the central part of the Palaeotethys Ocean, along the southern margin of Laurussia during the uppermost Devonian and Carboniferous. The rugose corals indicate some relationship with the eastern part of Laurussia, or that both areas were under a common marine influence at this time. The global Hangenberg event was not recognized in the Turkish localities, except for the disappearance of the corals, occurring less than 19 m below the Devonian–Carboniferous boundary based on the foraminifers. There is no major facies change through the boundary and the first Carboniferous corals (small *Uralinia* and *Caninophyllum*) appear 6 m above the D–C boundary. The new species *Caninophyllum charli* sp. nov. is described from the upper part of the lower Tournaisian.

Key words: Rugosa, palaeobiogeography, Hangenberg event, Strunian, Hastarian, Famennian, Tournaisian, Turkey.

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Introduction

The uppermost Famennian (Strunian) was a transitional period between the slow faunal recovery following the Frasnian–Famennian crisis and the ecological crisis associated with the Devonian–Carboniferous boundary. It was also a period of rapid diversification of corals probably linked with the Strunian transgression prefiguring the Lower Carboniferous high sea level that followed the worldwide low sea level of the Famennian. During this transgressive phase, several events occurred, among which the Hangenberg is the most important because of the associated extinctions. This biotic event is recognised as one the six largest mass extinctions in geological times. The origin of the crisis is still debated but eustatic and climatic changes resulting in perturbations in the carbon cycle are suggested as the main causes (see Kaiser et al. 2008, 2010 and references therein for recent compilation). The Hangenberg event is often associated with the deposition of euxinic black shale in basin and shelf facies, and a common positive shift of $\delta^{13}C_{carb}$ (Kumpan et al. 2014 for recent review). The crisis strongly affected the marine ecosystems with severe losses within the ammonoids, trilobites, conodonts, ostracods, foraminifers, tabulate, and rugose corals, and the total extinction of the stromatoporoids and placoderm fishes (Kalvoda 1986; Korn 1986; Simakov 1993; Benton 1993; Walliser 1996; Poty 1999; Nicollin and Brice 2004). The modalities of radiation and extinction of rugose corals at the Devonian–Carboniferous boundary were documented by Poty (1999) and Berkowski (2001, 2002) based mainly on data from Europe, South China, and Eastern Siberia. In the Middle East, uppermost Famennian corals were unknown but shallow water carbonates were documented by Dîl (1975) and Dîl et al. (1976) in the Istanbul Zone (NW
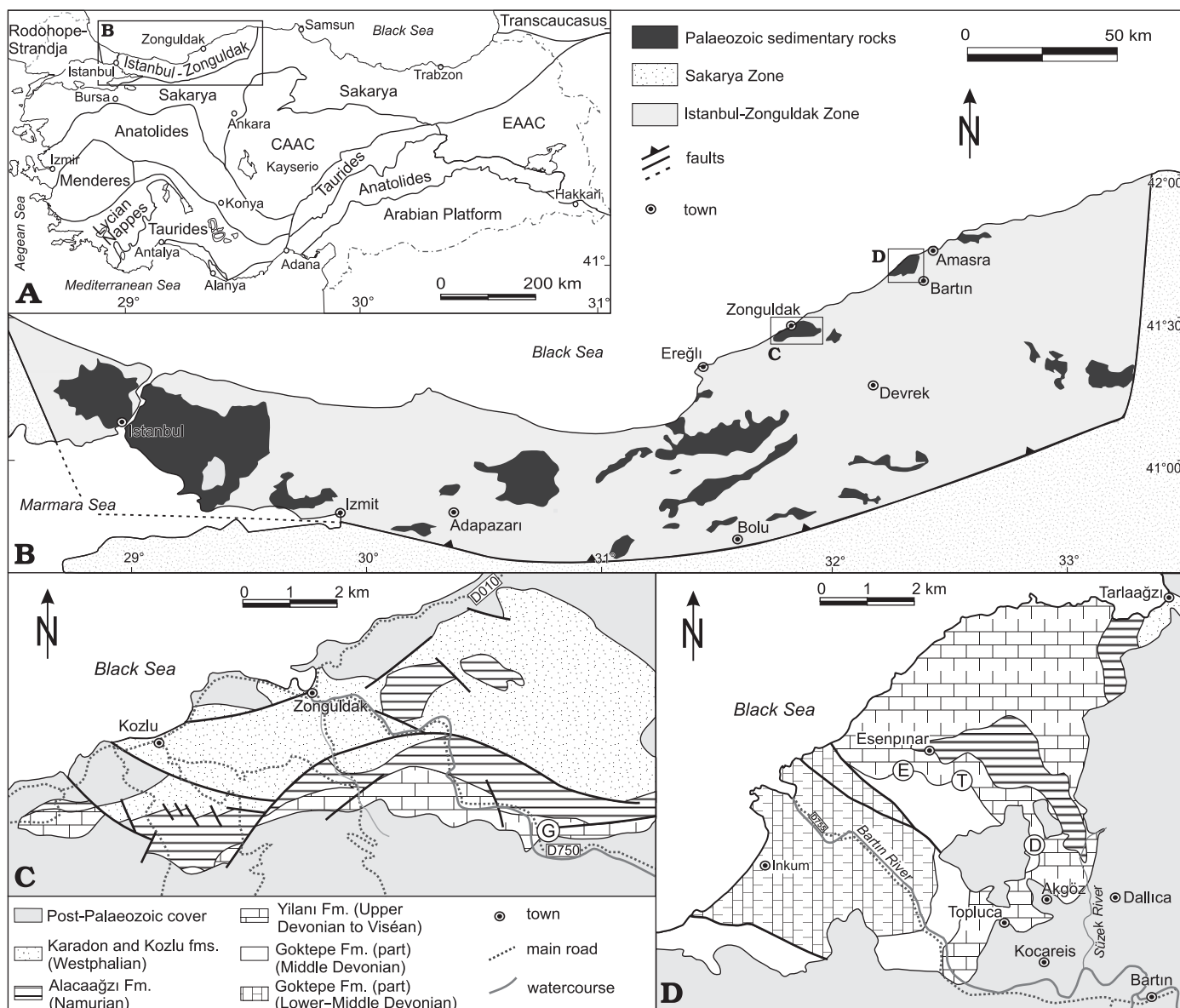
Fig. 1. **A**. General structural map of Turkey (modified after Görür and Tüysüz 2001; Moix et al. 2008; Okay 2008). CCAC, Central Anatolian Crystalline Complex; EAAC, East Anatolian Accretionnary Complex (Sanadaj-Sirjan Block); Lycian Np., Lycian Nappes. **B**. Geological map of the Istanbul-Zonguldak 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 Hoşgörmez 2007 and Charles 1933) with the location of the sampled sections (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; D, Dallıca section; E, Esenpınar section).

Turkey), within the Yılanlı Formation. The recent investigation of Dîl's localities (Dîl 1975; Dîl et al. 1976) yielded an abundant coral fauna and associated foraminifers. The aims of this paper are (i) to document sections covering the Devonian–Carboniferous boundary in NW Turkey and (ii) to describe the uppermost Famennian (Strunian) and lower Tournaisian (Hastarian) rugose corals from these sections. The new data allow a comparison of the faunal assemblage of Turkey with some previously described rugose coral faunas of Eurasia.

In Western Europe, the uppermost Famennian is often synonymised with the term "Strunian". Initially, "Strunian" was used in a time-facies sense (fossiliferous marine carbonate facies overlying the siliciclastics of the Middle–Upper Famennian). The term is currently used in a stratigraphic way only and corresponds to the uppermost Famennian (fourth and last substage of the Famennian) that covers the upper *Palmatolepis expansa* and *Siphonodella praesulcata* conodont zones (Conil et al. 1986; Streel et al. 2006). Similarly, the lower Tournaisian substage, defined in Belgium as "Hastarian" and its sequence-, litho-, and bio-stratigraphic identity (Poty et al. 2013) can be recognized in NW Turkey. Since no stratigraphic scheme is available in Turkey, the stratigraphic canvas of Poty et al. (2006), established for Western Europe succession, was successfully applied.
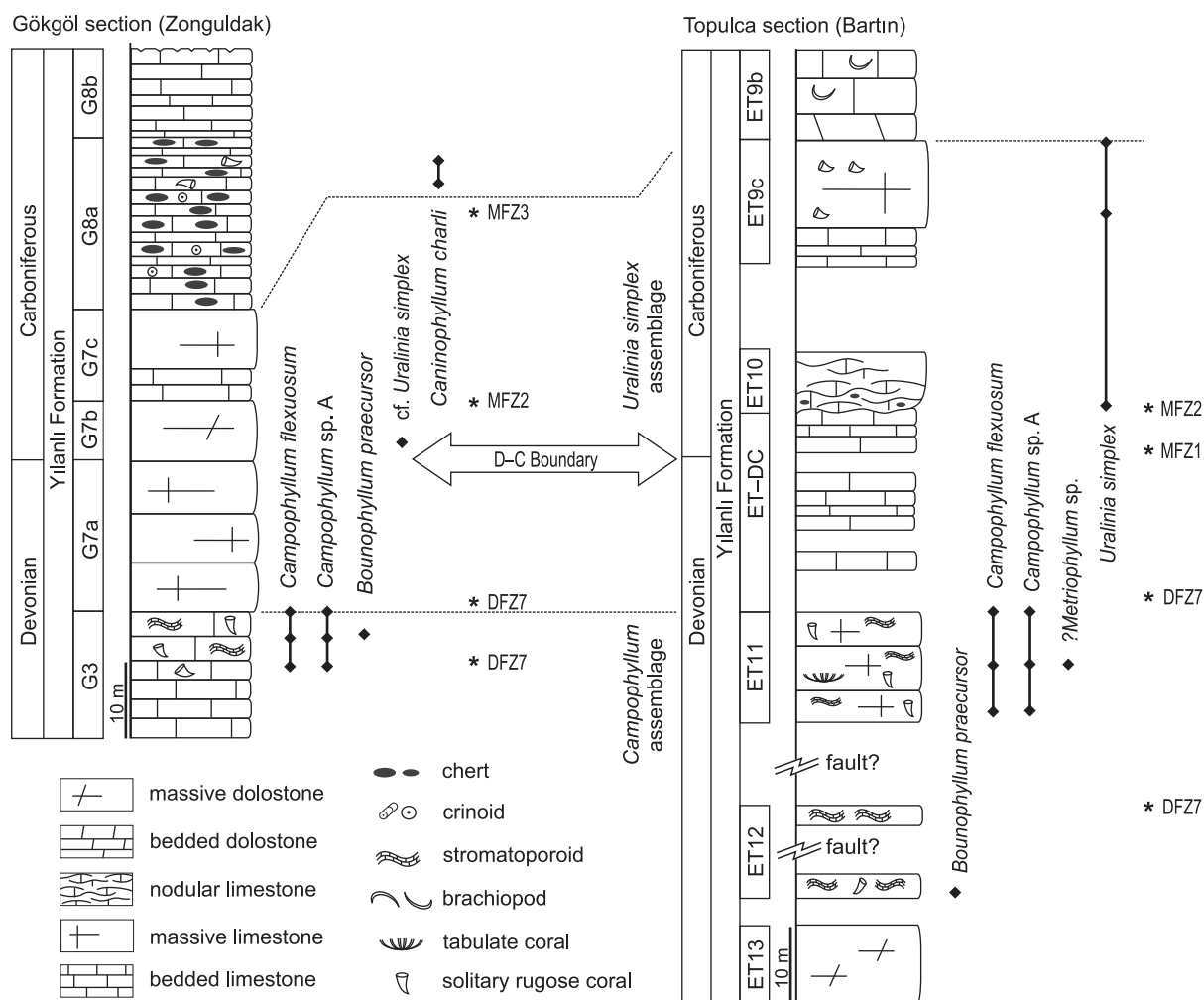
Fig. 2. Simplified lithological columns of the main sampled sections with the stratigraphic range of the rugose corals in the Yılanlı Formation and the position of samples with foraminifers (DFZ7, MFZ1, MFZ2, MFZ3 referring to the biostratigraphic zones of Poty et al. 2006). The position of the D–C boundary, based on foraminiferal assemblage, is indicated by the double arrow.

Institutional abbreviations.—PA.ULg, Laboratory of Animal and Human Palaeontology, University of Liège, Belgium; IPG, Institute of Palaeontology and Geology, Nanjing, China.

Other abbreviations.—G.xx (Zonguldak 2008/2011, Gökgöl section), ET.xx (Bartın 2010/2011, Topluca section), D.xx (Bartın 2010, Dallıca section), EV.xx (Bartın 2010, Esenpınar section); D–C, Devonian–Carboniferous; DFZ, Devonian foraminiferal zones of Poty et al. (2006); LS, longitudinal section; MFZ, Mississippian foraminiferal zones of Poty et al. (2006); TS, transverse section.

Geological setting and description of key sections

The Istanbul Zone is classically divided into Istanbul and Zonguldak areas. During the Late Devonian and Early Carboniferous times, the Istanbul Zone was part of the Laurasian southern margin and had been drifting south-

ward during the Albian when the Western Black Sea Basin opened (Görür 1988). Its former location was demonstrated by the similarity of the tectonostratigraphic records of the zone with the Moesian terranes (see Görür et al. 1997 and Kalvoda and Bábek 2010 for a recent review). In the Istanbul Zone, the D–C transition is situated within the Trakya flysch series (Özgül 2012 and references therein). In the Zonguldak Zone (Zonguldak and Bartın areas; Fig. 1), the Devonian and Carboniferous carbonate rocks are included in the Yılanlı Formation. The D–C transition is exposed in the Gökgöl section (Zonguldak vicinity) and in the Topluca, Dallıca, and Esenpınar sections (Bartın vicinity).

The Gökgöl section is situated along the road D750 Devrek-Zonguldak, upstream of the Asma hamlet, 4 km south of Zonguldak (41°26'19.28" N 31°50'05.43" E; Fig. 1C: G). The uppermost Famennian is dominated by thick-bedded bioclastic floatstone containing fragments of stromatoporoids, solitary rugose corals (*Campophyllum*), syringoporids, and *Pseudochaetetes*. This 3 m-thick fossiliferous horizon (G3) is overlain by a 15 m-thick unit (G7a) composed
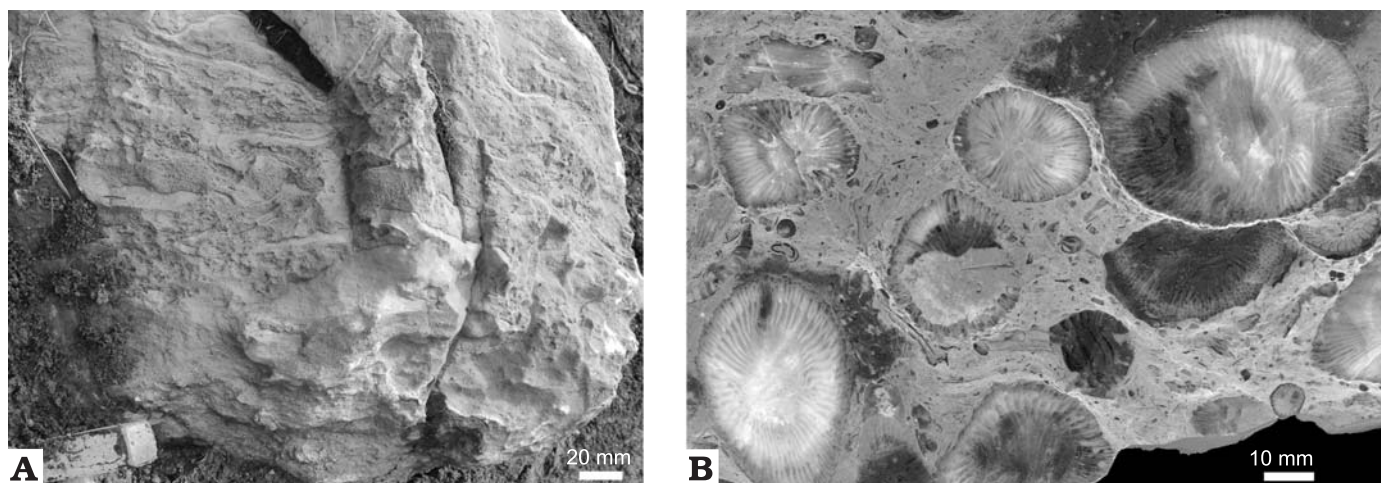
Fig. 3. Uppermost Famennian (Strunian) facies in the Topluca section, Turkey. **A**. Lower stromatoporoid biostrome (unit ET12a in Fig. 2). **B**. Bioclastic facies of the unit ET11 crowded with large campophyllid solitary rugose corals in a packstone matrix.

of pluri-metric (?) massive beds of light dolomitic limestone with no macrofauna (Fig. 2). Several horizons yielded a rich association of foraminifers, including numerous quasiendo-thyrids indicating the Strunian DFZ7 biozone of Poty et al. (2006). The following 10 m (unit G7b) are dolomitic and non fossiliferous. The G7c unit is dominated by massive light bioclastic limestone (packstone and grainstone) that yielded a foraminiferal fauna typical of the MFZ2 biozone of Poty et al. (2006). The D–C is thus situated within the G7a–c interval (Fig. 2). By comparison with the Topluca section (see below), the boundary should be placed in the lower part of the G7a sub-unit. Unfortunately, the sampling was not detailed enough and the frequent dolomitization often hides the microfossils useful for the boundary identification. The next unit (G8) is marked by the appearance of small black cherts and the progressive darkening of the limestone. The sub-unit G8a (c. 20 m-thick) is dominated by thinly bedded crinoidal and bioclastic limestone (mainly packstone) with brachiopods shells layers and small cherts. The overlying unit shows similar microfacies but the cherts are less frequent and some horizons with corals (*Caninophyllum* and fragmented syringoporids colonies) were noticed. Its top is dolomitized and capped by an erosive surface. Foraminifers from the G8b fossiliferous level indicate the MFZ3 biozone, i.e., the upper part of the Lower Carboniferous (Fig. 2). The Gökgöl section exposes almost continuously the Tournaisian and Viséan succession (Dîl 1975; Dîl et al. 1976; Denayer 2011).

The Topluca section is situated 7 km northwest of Bartın town, along a new track created between the Topluca earth pit and the valley road (41°41'10.15" N 32°16'53.54" E; Fig. 1D: T). The section exposes the uppermost Famennian and lower Tournaisian strata near the road to Esenpınar village. The section begins by a thick sequence of greyish coarse-grained dolostone with only ghosts of fossils. The dolomite passes rapidly to bioclastic limestone including two biostromes with stromatoporoids 45 and 60 cm-thick respectively (Fig. 3A). The two levels are separated by c. 8 m

of tectonic breccia probably indicating a fault. The biostromes are boundstone made of decimetric lamellar stromatoporoids separated by dolomitic microspar. The solitary rugose coral *Bounophyllum praecursor* is common in the stromatoporoid facies. More than 80 m of poor outcrop (fault-affected weathered limestone and breccia) separate the biostrome from the rest of the section. After this gap, the facies are bioclastic (packstone-grainstone to rudstone) very rich in rugose corals (*Campophyllum*; Fig. 3B), stromatoporoids and syringoporids. The foraminifers present in these facies indicate the DFZ7 biozone of Poty et al. (2006). The D–C boundary is situated in the following 25 m that were analysed in detail (Fig. 4). Beds 1 to 10 still contain *Campophyllum* and stromatoporoids in bioclasticfacies. Beds 11 to 16 still yielded Devonian foraminifers (DFZ7). Beds 17 to 32 are dolomitized and the original facies are not recognizable. Bed 33, less dolomitized, yielded the last Devonian foraminifers (*Quasiendothyra*; DFZ7). Beds 35–40 yielded only unilocular foraminifers, typical of the lowermost Hastarian MFZ1 biozone. The D–C boundary is placed at the top of bed 33 after the foraminifers. The next unit begins with 4 m of light grey argillaceous nodular limestone containing small black cherts but no corals (Fig. 2). A gap of 12 m separates this unit from the following one, composed of light grey limestone, finely bioclastic with *Uralinia simplex*, the first Carboniferous coral recorded in Topluca. The next 10 m are massive light-coloured limestone that yielded only fragments of brachiopods.

The Dallıca section is composed of a series of small outcrops along a forestry path north of the Akgöz hamlet (41°40'09.58" N 32°18'34.68" E; Fig. 1D: D). The uppermost Famennian is represented by light-coloured limestone with small colonies of *Pseudoendophyllum* sp. and cauliflower-shaped stromatoporoids. The foraminifers are not diversified but the occurrence of the genus *Avesnella* allows the identification of the DFZ5–6 biozones of Poty et al. (2006), i.e., the lower part of the Strunian. The quality of the outcrops was not apropriate for logging.
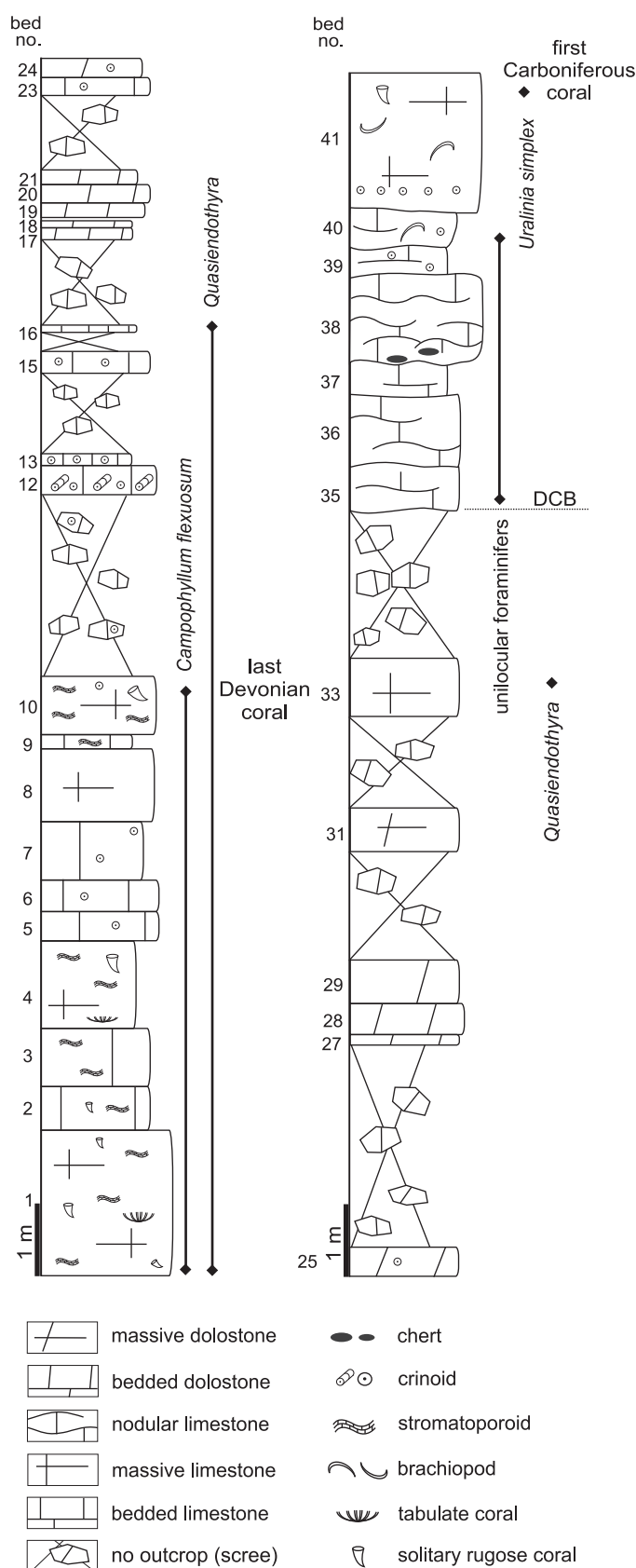
Fig. 4. Detailed lithological column around the D–C boundary (DCB) in the Topluca section (unit ET-DC in Fig. 2). The stratigraphic distribution of some guide taxa is also indicated.

The Esenpınar section is also a succession of small outcrops along the road from Esenpınar hamlet to Bartın. The uppermost Famennian crops out approximately 1.5 km west of the hamlet (41°41'13.11' N, 32°15'26.22' E; Fig. 1D: E). The facies are bioclastic and pelloidic and the faunal content includes *Campophyllum*, syringoporids, and stromatoporoids.

Material and methods

The present paper is based on c. 80 specimens collected in Zonguldak and Bartın areas between 2008 and 2011 and studied in thin section (c. 180 transverse and longitudinal thin sections). The newly collected material is housed at PA.ULg.

Systematic attributions and terminology follow Hill (1981) unless otherwise specified.

Systematic palaeontology

Class Anthozoa Ehrenberg, 1934

Subclass Rugosa, Milne-Edwards and Haime, 1850

Order Stauriida Verril, 1865

Suborder Cyathophyllina Nicholson in Nicholson and Lydekker, 1889

Family Campophyllidae Wedekind, 1921

Genus *Campophyllum* Milne-Edwards and Haime, 1850

Type species: *Cyathophyllum flexuosum* Goldfuss, 1826; Strunian of Stolberg (Aachen, Germany).

Emended diagnosis.—Cylindrical solitary corallum. Major septa long (2/3 of the corallum radius), extending or not to the axis, straight or sinuous, sometimes carinated. Minor septa long, usually contratingent. Cardinal fossula conspicuous. Dissepimentarium narrow to wide, including concentric interseptal dissepiments and occasional lonsdaleoid dissepiments. Tabulae complete, mesa-shaped. Emended from Hill (1981).

Remarks.—According Hill (1981), *Campophyllum* is the only member of the family Campophyllidae, nevertheless, "*Palaeosmilia*" *aquisgranensis* (Frech, 1885) could be included in the same family as it probably evolved from *Campophyllum* (and has no affinity with the Viséan *Palaeosmilia*; see Poty 2010). Goldfuss' (1826) type material of *Campophyllum flexuosum* was considered by this author as Middle Devonian. Schindewolf (1937) and Frech (1885) considered them as Strunian, a view shared by Hill and Jull (1965) in their re-description of Goldfuss' types. Hill and Jull's (1965) paper allowed the definition of the genus to be restrained to Strunian forms. Middle Devonian and Viséan corals attributed to *Campophyllum* should therefore be reinterpreted. *Campophyllum* were described is the Namur-Dinant Basin (Belgium, Aachen

vicinity and Avesnois; Poty 1984), Poland (Pomerania, Chwieduk 2005; Holy Cross Mountains, Berkowski 2002) and in the Omolon Massif (Siberia) under the names *Protocaninia* (Onoprienko 1979a) and *Campophyllum* (Poty and Onoprienko 1984). Famennian corals of New Mexico, attributed to *Campophyllum* by Sorauf (1992) show several morphological differences (minor septa not contratingent, short counter septum, complex dissepimentarium) suggesting a distinct genus and possibly in another family. As discussed in Sorauf (1992), these "campophids" are somewhat older (lower *Palmatolepis expansa* Conodont Zone) than the classic European Strunian *Campohyllum*. In Europe, *Campophyllum* appears in the uppermost Famennian (base of *Siphonodella praesulcata* Conodont Zone) or a little earlier (*P. expansa* Conodont Zone; Berkowski 2002). From the beginning, *Campophyllum* shows a surprising morphological plasticity that can be explained by the quick recovery of numerous empty ecological niches after the demise of corals at the Frasnian–Famennian boundary and the very slow post-crisis diversification during the Famennian (Poty 1984, 2010; Berkowski 2002). Unpublished data of Edouard Poty (personal communication, May 2013) indicate the successive appearance of at least six yet unnamed species in a lineage characterized by an increase of corallum diameter and length of septa (Poty 1999). The final species are very large (30–50 mm), counting numerous long septa prefiguring the morphology of "*Palaeosmilia*" *aquisgranensis* (Frech, 1885), that probably evolved from *Campophyllum* at the end of the uppermost Famennian (Poty 2010). *Campophyllum* and associated genera became extinct at the Hangenberg event preceding the D–C boundary (Poty 1999).

Campophyllum flexuosum (Goldfuss, 1826)

Fig. 5A–M.

1826 *Cyathophyllum flexuosum* sp. nov.; Goldfuss 1826: 47, pl. 17: 3a, b.
1850 *Campophyllum flexuosum* (Goldfuss); Milne-Edwards and Haime 1850: pl. 68.
1885 *Cyathophyllum aquisgranensis* sp. nov.; Frech 1885: 40, pl. 9: 1C.
1885 *Cyathophyllum lindströmi* sp. nov.; Frech 1885: 38.
1913 *Caninia dorlodoti* sp. nov.; Salée 1913: 44: figs. 1, 2, pl. B: 2.
1917 *Cyathophyllum aquisgranensis* Frech; Vaughan 1917: 38, pl. 18: 3, 4.
1929 *Cyathophyllum aquisgranensis* Frech; Dehée 1929: 46, pl. 14: 4a, b.
1932 *Caninia flexuosa* (Goldfus); Schindewolf 1932: 476, fig. 3.
?1935 *Caninia dorlodoti* Salée; Gorsky 1935: 104, pl. 8: 2, 3.
1961 *Palaeosmilia aquisgranensis* (Frech); Conil 1961: 348, pl. 18: 3, 4.
1965 *Campophyllum flexuosum* (Goldfuss); Hill and Jull 1965: 206, pl. 7.
1984 *Campophyllum flexuosum* (Goldfuss); Poty 1984: pl. 2: 1–3.

2005 *Campophyllum flexuosum* (Goldfuss); Chwieduk 2005: 411, pl. 1: 8, pl. 7: 1–3.
2010 *Campophyllum flexuosum* (Goldfuss); Poty 2010: 395, fig. 5.
2011 *Campophyllum flexuosum* (Goldfuss); Denayer et al. 2011: 160, pl. 1: B.
2013 *Campophyllum* sp. 2; Denayer 2013: 36, fig. 1E.

Lectotype: Specimen Goldfuss/197a, collection Goldfuss, Geology and Palaeontology Museum, Bonn, Germany, designated by Hill and Jull (1965).

*Type locality:* Stoberg, near Aachen, Germany.

Type horizon: Strunian limestone "Zone d'Etroeungt".

Material.—Thirty-six specimens and numerous fragments (65 TS, 20 LS); 24 from the Topluca (Bartın), 7 from Esenpınar (Bartın), and 5 from Gökgöl (Zonguldak), uppermost Famennian.

Diagnosis. —See Hill and Jull (1965).

Description.—The corallum is solitary and cylindrical, up to 15 cm high with a maximum diameter of 25 mm in the calyx. The external wall and parts of the dissepimentarium are often eroded in the large specimens. The mean tabularium diameter is 14 mm (maximum 21 mm). There are 45 septa in average (maximum 60; Fig. 6). The major septa are straight or slightly wavy in the dissepimentarium. They are usually long (up to 3/4 of the corallum diameter) but can be withdrawn or amplexoid in some cases (Fig. 5D, G). Despite their length, they do not reach the axis and leave a free zone of about 5 mm in diameter in the centre of the tabularium. The counter septum usually enters into this central zone. The cardinal septum is sometimes slightly shorter than its neighbours. The minor septa are long (1/2–3/4 of the length of the major septa) and sinuous, particularly in the dissepimentarium. They are contratingent or contraclinant. Some of them are intercepted by second order lonsdaleoid dissepiments. The thickness of the septa is variable, even in one specimen. The thickening occurs mainly in the cardinal quadrants but the counter quadrants are also affected in some specimens. The cardinal fossula is variably marked. Alar fossulae occur occasionally in small sized sections (juvenile stages). The dissepimentarium counts 4–6 rows of concentric interseptal dissepiments (maximum 14 in large specimens). In the latter, the inner rows can be V-shaped and herringbone. The inner row is commonly thickened, particularly in the cardinal quadrants. Some incomplete rows of first and second order lonsdaleoid dissepiments are present in large specimens (Fig. 5M). The external wall is regular and thin. In longitudinal section, the tabulae are usually complete and regularly spaced (Fig. 5J$_2$, L). They are typically mesa-shaped, the central part being flat and rising 1–2 mm from the peripheral edge of tabulae. The dissepiments are narrow, often high and

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Fig. 5. Cyathophylline *Campophyllum flexuosum* (Goldfuss, 1826) (**A–M**) and hetophylline *Pseudoendophyllum* sp. (**N–Q**) corals from the uppermost →
Famennian (Strunian) of Zonguldak and Bartin areas, Topulca (A, B, D–I, K), Esenpınar (C, J), Gökgöl (L, M), and Dallıca (N–Q) sections, Turkey.
A. ET.11.16.b, TS. **B**. ET.11.17.I, TS. **C**. EV.3.2, TS. **D**. ET.11.16.V', TS. **E**. ET.11.16.b, TS. **F**. ET.11.16.IV.b, TS. **G**. ET.11.18, TS. **H**. ET.11.18, TS.
I. ET.11.13.II.a, TS. **J**. EV.3.5, TS (J$_1$), LS (J$_2$). **K**. ET.11.16.V, TS. **L**. G.3.17.I, LS. **M**. G.3.15, TS, close-up view of the dissepimentarium. **N**. D.2.1.II,
TS. **O**. D.2.4.I, TS. **P**. D.2.2.I.a, successive TS (P$_1$, P$_2$). **Q**. D.2.2.I.b, LS. Scale bar 5 mm for all specimens except D, 2.5 mm and M, 3.75 mm.
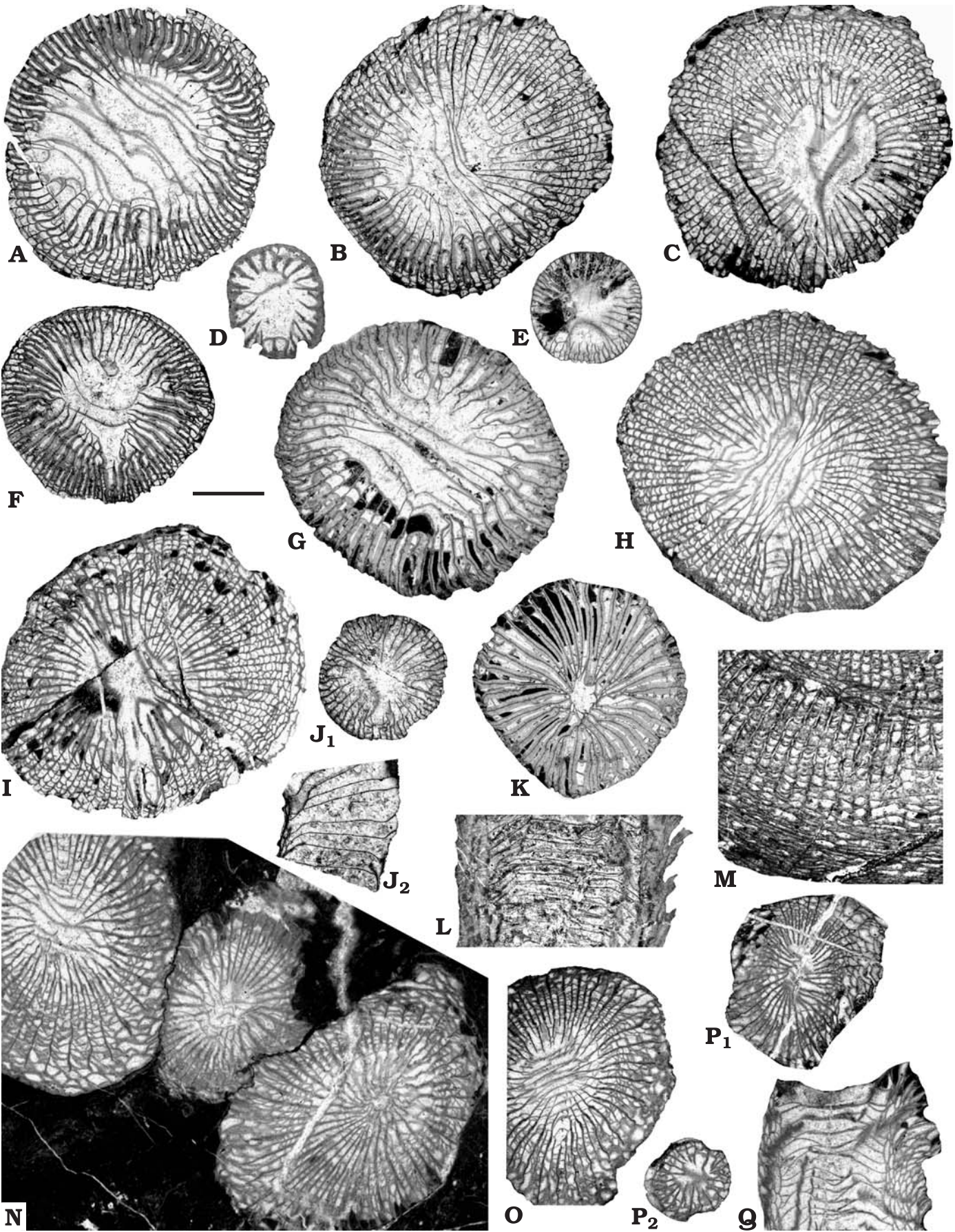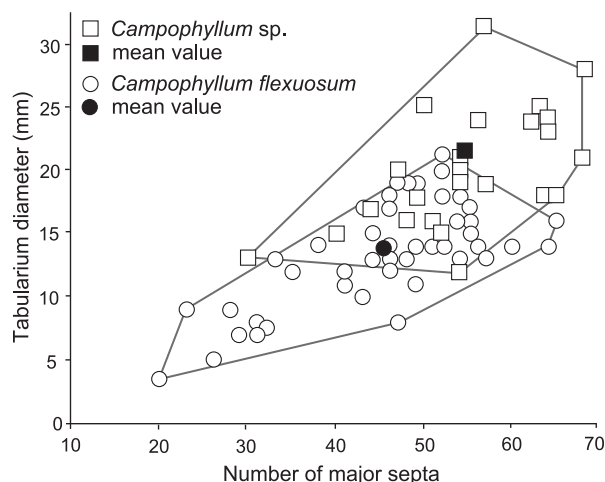
Fig. 6. Scatter diagram showing the number of septa plotted against corallite diameter for *Campophyllum flexuosum* (Goldfuss, 1826) and *Campophyllum* sp.

steeply inclined (70–80°) towards the tabularium. There are 10–12 tabulae and 10–15 dissepiments per centimetre in longitudinal section.

Remarks.—In addition to size variation, the variability is extreme in this species and affects all the skeletal elements. The length and thickness of septa can double, even in the same specimen. The cardinal fossula varies from a shallow depression occupied by a long cardinal septum, to an opened fossula edged by curved cardinal-lateral septa and occupied by short and thick septa, and to a long and narrow key-hole-shaped fossula incised in the dissepimentarium. The morphology of the juvenile stages varies from zaphrentoid pattern to amplexoid forms (Fig. 5D) or stages with radially disposed long septa (Fig. 5K). Also, the dissepimentarium varies from 0 to 20 rows of dissepiments—mainly interseptal but with common lonsdaleoid dissepiments of both orders in large specimens. This plasticity might indicate more than one species but no discrete character allows a clear separation between different forms, all being continuous and all the possible intermediate forms occur. Moreover the quantitative data (e.g., diameter versus number of septa; Fig. 6) form a single continuum. All of them are commonly observed in the topotypic material of *C. flexuosum* (Edouard Poty, personal communication, May 2013). Further analysis based on the abundant French and Belgian material might refine the definition of *C. flexuosum*.

The specimens investigated here share with *C. flexuosum* (Goldfuss, 1826): (i) a long counter septum, (ii) sinuous ("flexuous") septa, (iii) contratingent or contraclinant minor septa, (iv) a narrow dissepimentarium (comparatively to other species, see below). Chwieduk (2005) excluded from *C. flexuosum* corals with long and thick septa in the juvenile stages, a short cardinal and a long counter septum. However

these morphological variations are common within *C. flexuosum* and do not justify a new species. *C. flexuosum* has dimensions similar to those of *C. cylindricum* Onoprienko, 1979b but the latter has straight septa and minor septa less contratingent.

Stratigraphic and geographic range.—*Campophyllum flexuosum* is common in the uppermost Famennian (*Siphonodella praesulcata* Conodont Zone) in the Namur-Dinant Basin, Aachen vicinity (Germany) and Avesnois (N France; Poty 1984), in Pomerania (*Campophyllum* sp. A; Chwieduk 2005) and possibly in the Holy Cross Mountains (juvenile stage named ?*Campophyllum* sp. figured by Berkowski 2002).

Campophyllum sp.

Fig. 7.

2002 *Campophyllum* sp. A, Berkowski 2002: 35, pl. 10: 2–5.
2005 ?*Palaeosmilia aquisgranensis* (Frech); Chwieduk 2005: 424, pl. 14: 2, 3.
2013 *Campophyllum* sp. 1; Denayer 2013: 36, fig. 1C, H.
2013 *Palaeosmilia* cf. *aquisgranensis* (Frech); Denayer 2013: 36, fig. 1F.

Material.—Nine specimens: 7 from Topluca, 1 from Esenpınar (Bartın), and 1 from Gökgöl (Zonguldak), uppermost Famennian.

Description.—The corallum is cylindrical, up to 15 cm high and up to 50 mm in diameter. The mean diameter of the tabularium is 20 mm (maximum 36 mm). There are, in average, 54 septa of each order (maximum 68; Fig. 6). The major septa are straight or slightly wavy in the dissepimentarium. They are long and reach the axis of the corallum but leave a septa-free zone 1–6 mm-wide in the central part of the tabularium. The counter septum is very long (up to 5 mm longer than other major septa) and extends up to the axis but without forming a true columella (Fig. 7C$_2$). The cardinal septum is usually shorter than the other septa. The minor septa are long (1/2–3/4 of the length of the major septa) and straight. They are contraclinant or contratingent. Both series of septa are thickened in the juvenile stages. The thickening decreases during the growth of the coral. In mature stages, the septa are thickened in the cardinal parts of the tabularium. The thickening is not symmetrically distributed in the corallum and specimens with septa thickened in only one alar "quadrant" are common (Fig. 7A$_1$). The cardinal fossula is long, larger in its axial part, and edged by thickened cardinal-lateral major septa shorter than the other septa (Fig. 7C$_3$). In the mature stages, the dissepimentarium counts up to 30 rows of dissepiments: concentric, angulo-concentric, V-shaped or rare herringbone interseptal dissepiments, and some rows of lonsdaleoid dissepiments (Fig. 7B$_2$) that can be naotic. The wall is thin and regular and often eroded. In longitudinal section, the tabulae are complete and associated with numer-

Fig. 7. Cyathophylline coral *Campophyllum* sp. from the uppermost Famennian (Strunian) of Bartın area, Topluca section, Turkey. **A**. ET.11.12.III, successive TS (A$_1$, A$_2$). **B**. ET.11.12.II, successive TS (B$_1$, B$_2$). **C**. ET.11.12, successive TS (C$_1$, C$_2$); close-up view of the dissepimentarium and cardinal fossula, TS (C$_3$); LS, (C$_4$). **D**. ET.11.10, TS. Scale bar 5 mm for all specimens except C$_3$, 3.75 mm.
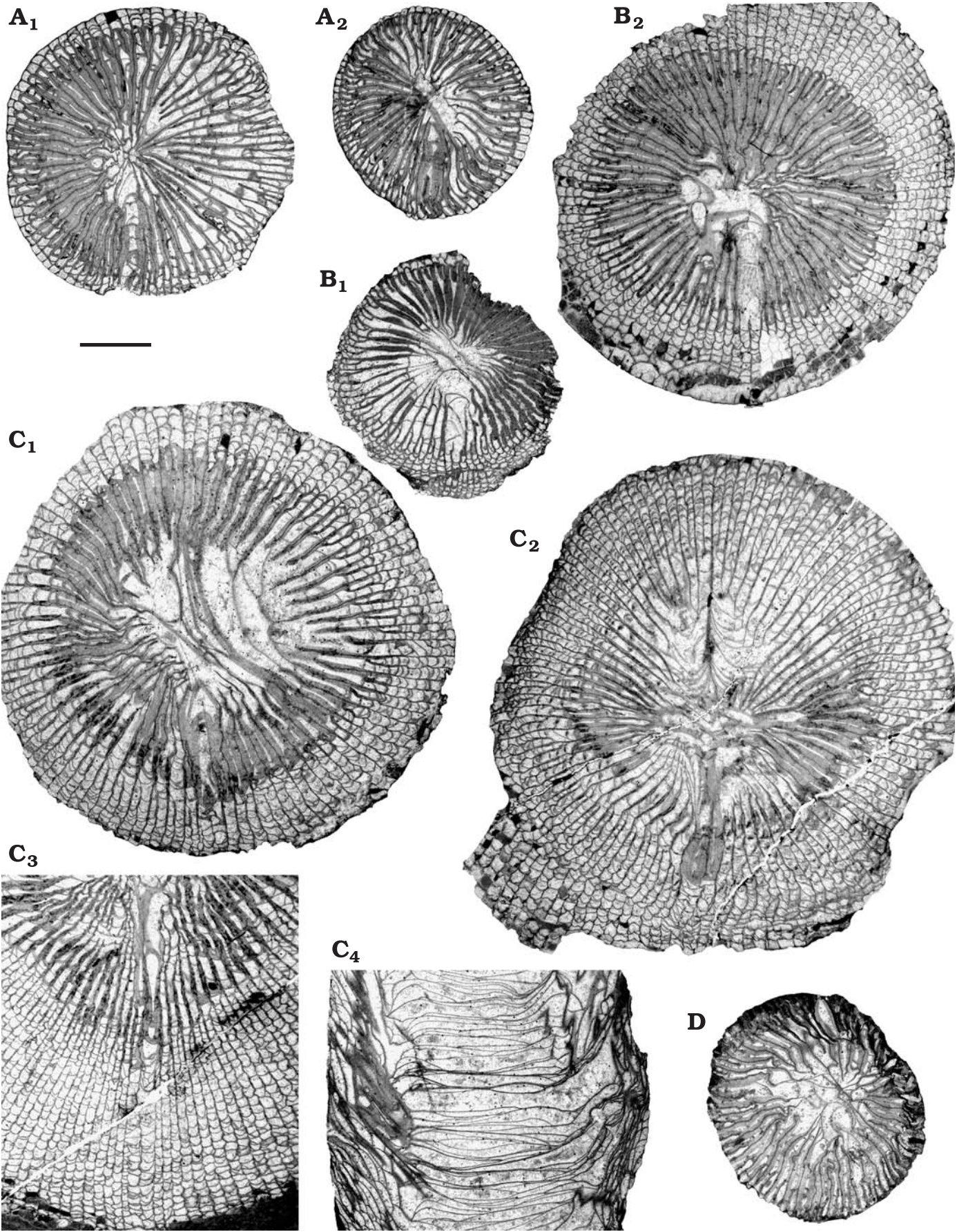
ous densely packed small tabellae. Their shape varies from horizontal, domed to mesa-shaped. Some are concave in the central part and show lateral shoulders (Fig. 7C$_4$). In this case, small tabellae fill the concavity to make the tabularium flatter. The dissepiments are numerous and steeply inclined (70–80°). Two morphologies occur in the same specimen: small globose dissepiments about 1 mm high and long and stretched dissepiments 1–1.5 mm high and 3–5 mm long. There are about 15 dissepiments and 30 tabulae (both complete and tabellae) per centimetre.

Remarks.—The large dimensions, the length of septa and the width of the dissepimentarium are the main characters distinguishing this species from *C. flexuosum* (Goldfuss, 1826). Nevertheless, the juvenile stages of both species are very similar: major septa thickened and flexuous, minor septa short, short counter septum (compare Fig. 5G and Fig. 7D). For a similar diameter, *Campophyllum sp.* usually shows a narrower dissepimentarium but this character rapidly changes during ontogeny. Detailed treatment of this form is pending and will be published elsewhere.

Stratigraphic and geographic range.—The species is known in Belgium (Edouard Poty, personal communication, May 2013) and Poland (*Campophyllum* sp. A of Berkowski 2002). In Turkey, *Campophyllum* sp. occurs in both Bartın and Zonguldak areas.

Suborder Ketophyllina Zhavoronkova, 1972
Family Endophyllidae Torley, 1933
Genus *Pseudoendophyllum* Onoprienko, 1979b

Type species: *Endophyllum nalivkini* Gorsky, 1935; uppermost Famennian of Novaya Zemlya, Russia.

Diagnosis.—See Berkowski (2002).

Remarks.—Onoprienko (1979b) created *Pseudoendophyllum* for the corals attributed to *Endophyllum* Torley, 1933 by Gorsky (1935, 1938) in the uppermost Famennian of Novaya Zemlya. As noticed by Berkowski (2002), Gorsky (1935) described his corals as *Endophyllum* because he could not highlight any difference with the Devonian genus. Nevertheless, no *Endophyllum* is known between the Frasnian and the uppermost Famennian, so the uppermost Famennian *Endophyllum* are possibly homeomorphs of the Middle Devonian ones and should thus be considered as Elvis taxa (Berkowski 2001). In Poland, Berkowski (2002) documented two species from the uppermost part of Middle Famennian (*Palmatolepis marginifera* Zone) to uppermost Famennian (*Siphonodella praesulcata* Zone). The origin of the genus should consequently be situated, at least in the Early Famennian. Onoprienko's (1979b) choice to create *Pseudoendophyllum* is justified if the Middle and Upper Devonian forms have a different origin. Berkowski (2002) proposes two hypotheses for this origin: (i) *Pseudoendophyllum* evolved from *Smithiphyllum* by acquiring a cerioid habit; (ii) *Pseudoendophyllum* is a *Tabulophyllum* that became colonial (this second option is

also favoured by Jell and Hill 1970 for the origin of the Middle Devonian *Endophyllum*). *Tabulophyllum* being present in the Famennian (Poty 1984; Berkowski 2002), it might be at the origin of *Pseudoendophyllum*.

Pseudoendophyllum sp.
Fig. 5N–Q.

2013 cf. *Endophyllum* sp.; Denayer 2013: 36: 1D.

Material.—Fragments of two small colonies (5TS, 1 LS) from Dallıca (Bartın), uppermost Famennian.

Description.—The colonies are small (10 cm in diameter), fasciculate to sub-cerioid (Fig. 5N). The corallites are cylindrical to sub-prismatic. Their mean width is 16 mm and their tabularium diameter is 9 mm in average (maximum 12 mm). There are 33 septa of each order (maximum 36). The major septa are long but do not reach the centre of the tabularium where a free zone of 1–3 mm large is usually present. They are sinuous or zig-zag, often thick at the base and sometimes up to the tabularium. The cardinal septum is short; the cardinal-lateral septa are also shorter and edge the opened cardinal fossula. The minor septa are long (more than half the length of the major) and enter into the tabularium. They are sinuous and thinner than the major. Some are contraclinant. In the outer part of the dissepimentarium, the major septa appear as septal crests on the wall or the lonsdaleoid dissepiments. All the septa are intercepted by first order (1–7 rows) and second order (3–5 rows) lonsdaleoid dissepiments. The interseptal dissepiments are concentric, V-shaped and herringbone. The wall is thin and regular but usually eroded. In longitudinal section, the tabulae are complete, mesa-shaped or domed, some are depressed axially (Fig. 5Q). The lonsdaleoid dissepiments are 1.5–3 mm long and 0.5 mm high. They are flat and gently inclined in the outer part of the dissepimentarium but smaller (1 mm) and more inclined (60–70°) near the tabularium. The inner row is vertical. There are 12–14 tabulae and up to 24 dissepiments per centimetre.

The increase is lateral and non-parricidal. The offsets appear in the peripheral part of the dissepimentarium. The smallest offsets observed are already cylindrical, 3–4 mm in diameter and have less than 20 short sinuous septa (Fig. 5P$_1$). The lonsdaleoid dissepiments appear where corallites reach 4 mm in diameter. Unfortunately, the limited material prevents any blastogenic study of this species.

Remarks.—The Famennian species of *Pseudoendophyllum* described by Berkowski (2002) are cerioid but the Turkish colonies are fasciculate to sub-cerioid. Two hypotheses can explain this habitus. (i) The colonies are really fasciculate and the present specimen might deserve a distinct generic name. This view was supported by Berkowski (2002) in his review of the present genus as he pointed out the bilateral septal arrangement in some specimens. (ii) The fasciculate habit is due to an effect of sedimentation as documented in cerioid colonies of the genera *Lithostrotion*, *Hexagonaria* or *Phillipsastrea* (Scrutton 1998). This second hypothesis

is supported by cauliflower-shaped stromatoporoid, occurring in the same horizon than *Pseudoendophyllum* colonies, both witnessing irregular or seasonal sedimentation. In that sense, the attribution of the Turkish specimens to *Pseudoendophyllum* is consequently acceptable.

Pseudoendophyllum sp. was collected in stromatoporoid beds in the Dallıca section (Bartın). The foraminifer assemblage is poor but the occurrence of *Avesnella* indicates the lower part of the Strunian (DFZ5–6 biozones of Poty et al. 2006).

Subfamily Dibunophyllinae Wang, 1950
Genus *Bounophyllum* Chwieduk, 2005

Type species: *Clisiophyllum* (*Dibunophyllum*) *praecursor* Frech, 1885; Strunian of Stolberg (Aachen, Germany) = *Bounophyllum pomeranicum* Chwieduk, 2005; uppermost Famennian of Poland.

Emended diagnosis.—Solitary corallum. Axial structure irregular, connected to the cardinal and counter septa in juvenile stages. Major septa long, thickened in the tabularium. Axial ends of septa whirled. Minor septa long. Cardinal septum shorter. Dissepimentarium made of simple interseptal dissepiments. Tabulae incomplete, domed. Modified from Chwieduk (2005).

Remarks.—The genus *Bounophyllum* was introduced by Chwieduk (2005) for corals previously named *Dibunophyllum praecursor* (Frech, 1885). *Dibunophyllum* being a Viséan genus with well constrained characters, this name was not suitable for the uppermost Famennian specimens.

Bounophyllum praecursor (Frech, 1885)
Fig. 8H–L.

1885 *Clisiophyllum* (*Dibunophyllum*) *praecursor* sp. nov.; Frech 1885: 47, pl. 17: 3a, b.
1984 "*Dibunophyllum*" *praecursor* Frech; Poty 1984: pl. 1: 1.
2002 *Dibunophyllum* aff. *praecursor* Frech; Berkowski 2002: 37, pl. 11: 2.
2005 *Bounophyllum pomeranicum* sp. nov.; Chwieduk 2005: 418, pl. 12: 4–7, pl. 13: 1–4.
2011 *Bounophyllum praecursor* Frech; Denayer et al. 2011: 164, pl. 1: G.
2013 *Clisiophyllum* cf. *omaliusi* Haime; Denayer 2013: 36: fig. 1: G.

Type material: Frech's (1885) types were destroyed during Second World War. No neotype has been designated yet but numerous topotypes are known (e.g., collection PA.ULg, University of Liège, Belgium).

Type locality: Stolberg, near Aachen, Germany.

Type horizon: Strunian limestone "Zone d'Etroeungt".

Material.—Five specimens (16 TS, 2 LS), four come from Topluca (Bartın) and one from Gökgöl (Zonguldak), uppermost Famennian.

Diagnosis.—See Berkowski (2002).

Description.—The mean diameter of the corallum is 9.5 mm (maximum 11 mm) and the tabularium is 7 mm wide in average (maximum 9 mm). There are 30 septa of both orders (maximum 32). The major septa are long, straight in the tab-

ularium and confluent with the columella. The minor septa are restricted to the dissepimentarium or enter shortly into the tabularium. The cardinal fossula is poorly developed. The axial structure is dibunophylloid or axophylloid, made of an axial plate with 25–30 twisted radial lamellae attached to the axial ends of the major septa. The largest axial structures are not necessarily developed in largest stages. The dissepimentarium counts no more than 2 rows of concentric interseptal dissepiments, several are thickened. The wall is regular. In longitudinal section, the tabulae are domed in the axial part of the tabularium and depressed in periphery. The dissepiments are steeply inclined toward the tabularium.

Remarks.—Chwieduk (2005) created the species *Bounophyllum pomeranicum* for specimens with dimensions and number of septa less than those of Frech's (1885) species. However, these specimens fall in the variability of the topotypes of *B. praecursor* (Frech, 1885). *Bounophyllum pomeranicum* showing no other distinctive character, it is considered as a junior synonym of *B. praecursor*. The Turkish specimens fit in the same morphological field of variability, except for their axial structure showing an axial plate much more individualised than in topotypes. This type of variability is, however, commonly observed in taxa with a complex axial structure that may change during the ontogeny or from one specimen to another (e.g., *Clisiophyllum*, *Dibunophyllum*, *Axophyllum*).

Stratigraphic and geographic range.—*Bounophyllum praecursor* is common in the Strunian stromatoporoid biostromes and associated facies is Belgium, Germany (Poty 1984), and Poland (Chwieduk 2005). Its occurrence in Zonguldak and Bartın areas is the first record outside Europe.

Suborder Caniniina Wang, 1950
Family Cyathopsidae Dybowski, 1873
Genus *Uralinia* Stuckenberg, 1895

Type species: *Heliophyllum multiplex* Ludwig, 1862; Tournaisian of the Ural Mountains, Russia.

Diagnosis.—See Poty and Boland (1994).

Uralinia simplex (Yü, 1933)
Fig. 8F, G.

1933 *Pseudouralinia tangpakouensis* var. *simplex*; Yü 1933: 60, pl. 5: 6.
1963 *Pseudouralinia tangpakouensis simplex* Yü; Yü 1963: 144, pl. 35: 4.
1963 *Pseudouralinia simplex*; Fan 1963: 277, pl. 1: 5a–c.

Holotype: Specimen IPG-4938.

Type locality: Kolaoho, Guizhou, SE China.

Type horizon: Lower Tournaisian Tangpakou Formation.

Diagnosis.—See Yü (1933).

Material.—Nine specimens (12 TS, 2 LS) from Topluca (Bartın), lower Tournaisian.

Description.—The coralla are eroded and the thickened septa of the cardinal quadrants are usually the only pre-
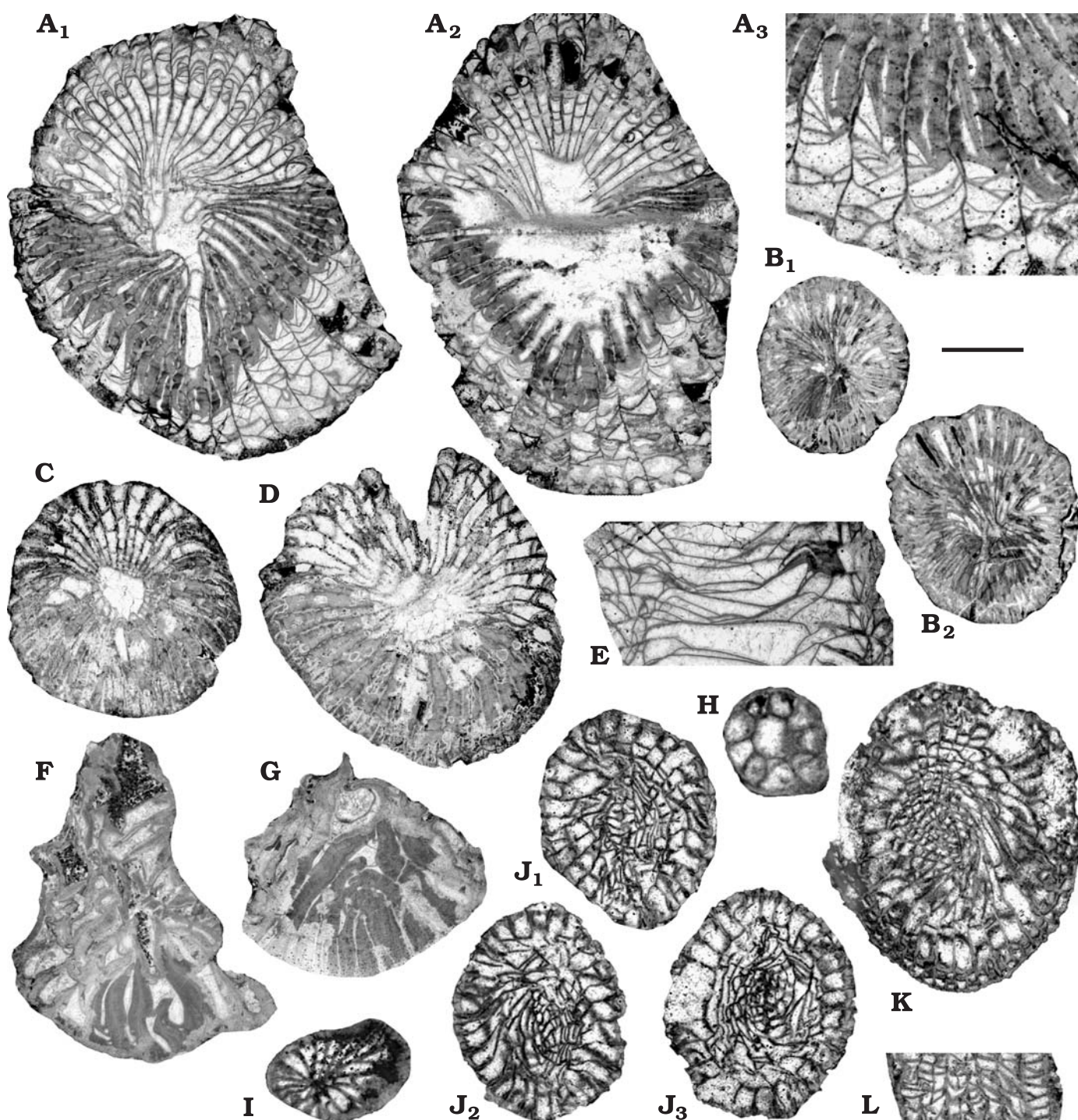
Fig. 8. Devonian–Carboniferous rugose corals from Turkey. **A–E**. *Caninophyllum charli* sp. nov. from the lower Tournaisian (upper Hastarian) of Zonguldak, Gökgöl section. **A**. Holotype, G.8.1.1, successive TS (A_1, A_2); close-up view of the dissepimentarium, TS (A_3). **B**. G.8.6.1, successive TS (B_1, B_2). **C**. G.8.4.3, TS. **D**. G.8.4.2, TS. **E**. G.8.3.2, LS. **F**, **G**. *Uralinia simplex* (Yü, 1933) from the lower Tournaisian (lower Hastarian) of Bartın, Topluca section. **F**. ET.9c.7, TS. **G**. ET.9c.8, TS. **H**. *Amplexocarinia rozkowskae* (Fedorowski, 2003) from the uppermost Famennian (Strunian) of Bartın, Dallıca section, D.2.4.II', TS. **I**. ?*Metriophyllum* sp. from the uppermost Famennian (Strunian) of Bartın, Topluca section, ET.11.X, TS. **J–L**. *Bounophyllum praecursor* (Frech, 1895) form the uppermost Famennian (Strunian) of Bartın, Topluca section. **J**. ET.12a.1.III, successive TS (J_1–J_3). **K**. ET.12a.1.II, TS. **L**. ET.12a.1.V, LS. Scale bar A–G, 5 mm; H, 3 mm; I, 1.9 mm; J–L, 2.5 mm.

served parts. The approximate diameter of the tabularium varies from 12 to 22 mm, depending on the erosion of peripheral parts. There are 28 septa in average (maximum 30). They are undulating, irregularly thickened but separated from each other, some interseptal dissepiments occupying the space between them. Their axial ends are sharp, except for the cardinal-lateral septa that develop rhopaloid ends. The cardinal septum is shorter and quite undulating. The

cardinal fossula is poorly marked. Some interseptal and lonsdaleoid dissepiments are present in the counter side.

Remarks.—*Uralinia simplex* (Yü, 1933) is similar to *U. tangpakouensis* (Yü, 1931) by its irregular form, its sharp septa and its narrow lonsdaleoid dissepimentarium. It differs from the latter by lesser dimensions (12–20 mm versus 30–50 mm for *U. tangpakouensis*) and less septa (30 versus 30–50). Moreover, the septa are shorter and thicker in the cardinal quadrants in *U. simplex*.

Stratigraphic and geographic range.—In S China, *U. simplex* and *U. tangpakouensis* are the guide taxa for the lower Tournaisian *U. tangpakouensis* Zone of Tan et al. (1987), corresponding to the rugose coral RC1γ–RC2 subzones of Poty et al. (2006). In NW Turkey, the species occurs in the light bioclastic limestone of the lower Tournaisian part of the Yılanlı Formation in Bartın area. In equivalent levels of the Gökgöl section, only fragments of tabularium with thickened septa are questionably attributed to *U. simplex*. The foraminifers associated with the corals indicate the MFZ2 biozone of Poty et al. (2006).

Family Bothrophyllidae Fomitchev, 1953
Genus *Caninophyllum* Lewis, 1929

Type species: *Cyathophyllum archiaci* Milne-Edwards and Haime, 1852; Viséan of England.

Diagnosis.—See Poty (1981).

Remarks.—Lewis (1929) created the genus *Caninophyllum* for caniniid corals with septa extending to the axis. This character allows the distinction with *Caninia* Michelin in Gervais, 1840, *Siphonophyllia* Scouler in McCoy, 1844 and *Haplolasma* Semenoff-Tian-Chansky, 1974 which all have withdrawn septa. The presence of a loose axial structure is one of the main differences with *Bothrophyllum* Trautschold, 1879. However, *Caninophyllum* shows sometimes such an axial structure made of the dilated ends of major septa (e.g., *Caninophyllum halkynense* Lewis, 1929). The evolution of the genus follows an increase of size and complexity. The stratigraphic succession of species in the Belgian Namur-Dinant Basin exemplified perfectly this lineage. *Caninophyllum patulum*, the oldest species in Belgium appears early in the Ivorian; *Caninophyllum* sp. A (Denayer et al. 2011: pl. 4J) characterized the upper Ivorian (Poty 1989); *Caninophyllum* sp. B (described as *C. patulum* by Poty 1981) occurs in the Moliniacian; *C. archiaci* is common in the Livian then finally, *C. halkynense* appears in the Warnantian. This lineage possibly carries on in the Late Carboniferous where *Bothrophyllum* Trautschold, 1879 might have evolved from *Caninophyllum* with axial structure (Poty 1981).

Caninophyllum charli sp. nov.
Fig. 8A–E.

Etymology: In honour of François Charles, who first described corals in the Carboniferous of Zonguldak.

Holotype: Corallum included in a rock matrix, specimen G.8.1.1, Zonguldak 2011 (5 TS).

Type locality: Gökgöl section, south of Zonguldak, NW Turkey.

Type horizon: Yılanlı Formation, unit G8, lower Tournaisian (Hastarian, MFZ3 biozone of Poty et al. 2006).

Material.—Eighteen specimens (27 TS, 2 LS): 15, including the holotype, coming from Gökgöl (Zonguldak) and 3 from Dallıca (Bartın), lower Tournaisian.

Diagnosis.—Small *Caninophyllum*, 30–32 mm in diameter (15–20 mm for the tabularium), having 42–46 septa of each order. Major septa extending to the axis in the juvenile stages but withdrawn in the mature stages, thickened in the cardinal parts of the tabularium. Minor septa rudimentary. Dissepimentarium narrow but complex, constituted of concentric, herringbone and arched interseptal dissepiments. Cardinal fossula conspicuous and opened.

Description.—The corallum is cylindrical, 3–5 cm high. The mean diameter is 32 mm (maximum 38 mm) and the tabularium is in average 17 mm wide (maximum 21 mm). There are, on average, 46 septa of each order (maximum 48). The major septa are long, reaching the axis in the juvenile stages but withdraw toward the periphery during the growth, leaving a central zone of 5–6 mm-wide in the centre of the tabularium (Fig. $8A_2$, C, D). They are thickened but their axial ends are sharp. They bend toward the cardinal fossula in the cardinal quadrants but are straighter in the counter quadrants. The initial thickening occurring in the whole tabularium rapidly decreases during the growth but maintains in the cardinal quadrants in the mature stages. The cardinal septum is shorter and thicker than its neighbouring septa. The minor septa are rudimentary or restricted to the peripheral part of the dissepimentarium. The cardinal fossula is well marked. The dissepimentarium counts 5–12 rows of concentric and herringbone dissepiments and several arched dissepiments in the peripheral part. Second order lonsdaleoid dissepiments occur in some specimens. The inner row of dissepiments is thickened in continuity with the septa (Fig. $8A_3$). The wall is thin, regular or slightly undulating. In longitudinal section, the tabulae are incomplete, horizontal or domed in the axial part of the tabularium, domed or mesa-shaped in the peripheral part (Fig. 8E). A peripheral gutter develops in the mature stages. The dissepiments are 1.5–3 mm long, 1 mm high and steeply declined toward the tabularium.

Remarks.—The small size and number of septa are diagnostic of *Caninophyllum charli* sp. nov. and allow its discrimination from *C. archiaci* (Milne-Edwards and Haime, 1852) and *C. tomiense* (Tolmachev, 1931). The new species shares its dimensions with *C. patulum* (Michelin, 1846) but the latter show a larger dissepimentarium usually composed only of concentric and herringbone dissepiments. The septa are less thickened and more withdrawn toward the periphery in *C. patulum* while its cardinal septum is longer in the juvenile stage. The tabularium is also different: the tabulae are flat or slightly domed in the central part in *C. charli*

but are clearly domed in *C. patulum*. Poty and Xu (1996) figured two species of small *Caninophyllum* from the lower Tournaisian *Uralinia tangpakouensis* Zone of S China. *C. cystosum* Jiang, 1982 has 4l–46 septa for a diameter of 25–35 mm but differs from *C. charli* by an inconspicuous cardinal fossula and a long counter septum often connected to the cardinal septum. *C. shaoyangense* Jiang, 1982 is smaller (17 mm and 38 septa of both orders) and has a very large dissepimentarium and septa almost not thickened in the tabularium.

Stratigraphic and geographic range.—*Caninophyllum charli* sp. nov. was collected in a bioclastic level dated of the lower Tournaisian (Hastarian) by foraminifers (MFZ3 biozone) in the Gökgöl (Zonguldak). Crushed specimens were collected in equivalent levels in the Dallıca (Bartın)

Suborder Metriophyllina Spassky, 1965
Family Lacophyllidae Grabau, 1928
Genus *Amplexocarinia* Soshkina, 1928

Type species: *Amplexocarinia muralis* Soshkina, 1928; Upper Permian of Ural Mountains.

Diagnosis.—See Hill (1981).

Remarks.—The oldest species attributed to the genus *Amplexocarinia* is Middle Devonian (Różkowska, 1969; Lütte and Galle 1989) but the genus is particularly common in the Carboniferous (see De Groot 1963). Studies of its ontogeny showed that the genus is probably polyphyletic (Fedorowski 1986; Moore and Jeffords 1986).

Amplexocarinia rozkowskae Fedorowski, 2003

Fig. 8H.

1969 *Amplexocarinia muralis* Soshkina; Różkowska 1969: 82, pl. 3: 5, 8, 9, pl. 8: 6.
2003 *Amplexocarinia rozkowskae* sp. nov.; Fedorowski 2003: 66, pl. 18: 8–10.
2005 *Amplexocarinia rozkowskae* Fedorowski; Chwieduk 2005: 408, pl. 5: 5.
2009 *Amplexocarinia rozkowskae* Fedorowski; Fedorowski 2009: 237, fig. 3E, F.

Holotype: Specimen 3/25a figured as *Amplexocarinia muralis* by Różkowska (1969: pl. 3: 5a, b).

Type locality: Kadzielnia, Holy Cross Mountains, S Poland.

Type horizon: Famennian, Upper Devonian.

Material.—Single specimen (1 TS) from the Dallıca (Bartın), uppermost Famennian.

Diagnosis.—See Fedorowski (2003).

Description.—The corallum is 2 mm in diameter, its aulos is well developed and 0.75 mm in diameter. There are 9 septa, thickened at the base, thin elsewhere. The minor septa are not developed. The cardinal fossula is marked by a slight withdrawal of the aulos edge toward the periphery. There are no dissepiments. The wall is 0.3 mm-thick and regular.

Remarks.—The diameter and number of septa are compatible with these of *Amplexocarinia rozkowskae* Fedorowski 2003,

particularly if considered as a juvenile specimen like those figured by Chwieduk (2005). *A. rozkowskae* Fedorowski 2003 is the sole species of *Amplexocarinia* Soshkina, 1928 described in the Famennian. The other aulos-bearing genera known in equivalent strata are *Syringaxon* Lindström, 1882 (Chwieduk 2005) and *Neaxon* Kullmann, 1965 (Semenoff-Tian-Chansky 1988; Berkowski 2002). Both have a narrow aulos and thickened septa and wall.

Stratigraphic and geographic range.—*Amplexocarinia rozkowskae* occurs in the Famennian of Pomerania (Chwieduk 2005). The present specimen was collected, together with *Pseudoendophyllum* sp., in the Yılanlı Formation in the Dallıca (Bartın). The occurrence of the foraminifer *Avesnella* sp. indicates the lower part of the Strunian DFZ5–6 biozones of Poty et al. (2006).

Family Metriophyllidae Hill, 1939
Genus *Metriophyllum* Milne-Edwards and Haime, 1850

Type species: *Metriophyllum bouchardi* Milne-Edwards and Haime, 1850.

?*Metriophyllum* sp.

Fig. 8I.

Material.—Single specimen from the stromatoporoid biostromes of Topluca (Bartın), uppermost Famennian.

Description.—The section has a diameter of 3 mm and there are 16 septa. The latter are thin and fuse together at the centre of the corallum. No septal spine was observed. There is neither fossula nor dissepiments. The wall is thin.

Remarks.—Small solitary undissepimented and columellate rugose corals occur in the Strunian of Germany and Belgium and in equivalent levels in N Poland. They were never described or classified in an accurate way. Chwieduk (2005) classified his specimen as *Lophophyllum* sp.; Bless et al. (1998) attributed the corals from W Germany to ?*Metriophyllum* sp. while Denayer et al. (2011) named the corals from Belgium *Amygdalophyllum*? sp. This taxon seems to be restricted to stromatoporoid facies of the uppermost Famennian. This specimen is similar to the juvenile stages of corals attributed to ?*Amygdalophyllum* or ?*Metriophyllum* from Belgium and Germany. These taxa are also similar to juvenile stages of the coral figured by Różkowska (1969) under the name *Fasciculophyllum dobroljubovae* from equivalent levels of the Holy Cross Mountains (S Poland).

Distribution of corals across D–C boundary

The Strunian (uppermost Famennian) assemblage of NW Turkey is not particularly diversified (in comparison with those of Belgium and Poland), but two successive assem-

blages can be recognized. Two assemblages are also known in the Hastarian (lower Tournaisian).

***Pseudoendophyllum* assemblage**.—*Pseudoendophyllum* sp. and *Amplexocarinia rozkowskae* are the only rugose corals observed in the Dallıca section. Both are known in S Poland (Berkowski 2002) in level attributed to the "Upper Famennian" (i.e., Upper to uppermost Famennian *Sphaenospira* Brachiopod Zone of Baliński 1995). *Pseudoendophyllum* is also known in similar deposits of Novaya Zemlya (Gorsky 1935, 1938). The genus is unknown in Western Europe except for one colony from the Upper Famennian of Aachen area, cited but not figured by Wulff (1922) and destroyed during the war. Poty et al. (2006) did not used *Pseudoendophyllum* in their biostratigraphic chart but this assemblage can confidently be correlated with the RC0α of these authors. The foraminifer genus *Avesnella* (diagnostic for the lower Strunian DFZ5–6 biozones of Poty et al. 2006) was identified in the *Pseudoendophyllum* horizon in Turkey.

***Campophyllum* assemblage**.—This assemblage is dominated by *Campophyllum flexuosum* and *Campophyllum* sp. These two species occur mainly in bioclastic facies while the solitary *Bounophyllum praecursor* and ?*Metriophyllum* sp. are restricted to the stromatoporoid reefal facies. In the Topluca section, the last *Campophyllum* occurs c. 25 m below the first Tournaisian corals and the interval between the two occurrences is devoid of macrofauna. Nevertheless, the foraminifers are abundant and the DFZ7 biozone is easily identified up to the D–C boundary. The *Campophyllum* assemblage can be correlated with the correlated with the rugose coral RC0β subzone of Poty et al. (2006), i.e., the upper part of the Strunian.

***Uralinia simplex* assemblage**.—The first Tournaisian coral occurs in the limestone and dolostone overlying the D–C boundary. The first occurrence of *Uralinia simplex* in the Topluca section is 6 m above the boundary (based on the last occurrence of the foraminifer *Quasiendothyra kobeitusana*, DFZ7, and the first unilocular foraminifers, MFZ1). In the Topluca section, *Uralinia simplex* is common in the lower part of the lower Tournaisian and the highest specimen was collected about 40 m above the base of the substage. *Uralinia simplex* is the dominant taxon of the assemblage and only one fragment of unidentified zaphrentoid undissepimented rugose coral was noticed. This *Uralinia simplex* assemblage is correlated with the *Uralinia tangpakouensis* Zone of Tan et al. (1987) and the rugose coral RC1γ subzone of Poty et al. (2006).

***Caninophyllum charli* horizon**.—In Gökgöl, the lower Tournaisian is relatively poor and only *Caninophyllum charli* was recognized with some confidence from a single horizon. Crushed specimens were recovered in the Dallıca section of the Bartın area. This occurrence is interesting since in Western Europe, the genus appears in the upper-most Hastarian (Poty 1989; Poty et al. 2006) in the MFZ4 biozone (lower part of Yvoir Formation and equivalents) but seems to appear earlier in Turkey (MFZ3). In Southern China, the genus also appears earlier, in the *Uralinia tangpakouensis* Zone (Poty and Xu 1996).

Summary.—In NW Turkey, the rugose corals do not allow a precise stratigraphy at the D–C boundary due to a lack of material in the critical interval. Nevertheless, the four assemblages recognized on each side of the boundary are useful locally to estimate the position of the boundary and widely, to establish the correlation with Western Europe, Eastern Europe, and Chinese areas. The D–C boundary was identified by the foraminiferal succession (quasiendothyrids, unilocular, tournayellids) but the value of these markers is under discussion as *Quasiendothyra* was documented in the Lower Carboniferous (Kalvoda and Kukal 1987; Kalvoda et al. 2015). The Hangenberg event was not recognized in the Turkish localities from a lithological point of view (no obvious facies or colour change, no black shale) and no geochemical data are available for the investigated sections. The extinction event associated with the Hangenberg is marked by the last occurrences of *Campophyllum flexuosum* and *Campophyllum* sp. in the Topluca section, about 19 m below the D–C boundary based on the foraminifers. The distribution of the foraminifers is still in a preliminary stage and no data on conodonts are available. The first Carboniferous coral (small *Uralinia* and *Caninophyllum*) appear 6 m above the D–C boundary.

Palaeogeographic affinity

Uppermost Famennian (Strunian) rugose corals are not rare and usually thought to form endemic assemblages (Poty 1986, 1999) but actually, some taxa are more widely distributed than previously concluded. For example, the shallow water assemblages of Western Europe (Belgium, N France, W Germany) contain only solitary rugose corals while the Polish (Kraków area), Uralian (including Novaya Zemlya) and Siberian (Omolon Massif) assemblages contain solitary and a couple of colonial genera (Gorsky 1935, 1938; Conil et al. 1982; Poty and Onoprienko 1984) and the coral faunas from South China contain many colonial and solitary genera (Wu et al. 1981; Poty and Xu 1996, 1997). Some assemblages dominated by undissepimented rugose corals are also known (Montagne Noire in S France, Semenoff-Tian-Chansky 1988; Moroccan Anti-Atlas, Weyer 2002; German Thuringia and Rheinish massifs, Weyer 1971, 1989; Korn and Weyer 2003; Holy Cross Mountains in S Poland, Różkowska 1969) but are clearly facies-related "*Cyathaxonia* fauna". The NW Turkey area provides an interesting point of view as it was situated in a transitional biogeographic area during the considered time slice. The Istanbul-Zonguldak Zone was part of the southern margin of Baltica, facing the
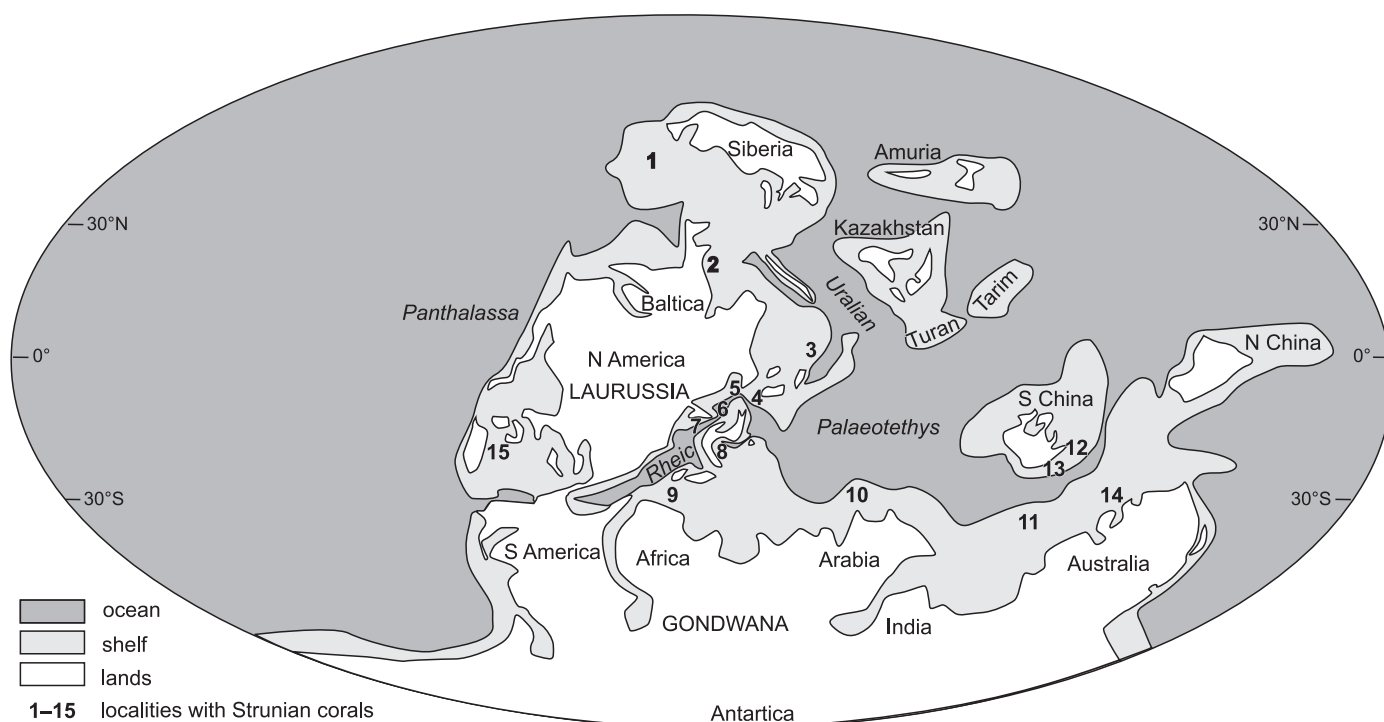
Fig. 9. Palaeogeographic occurrences of uppermost Famennian (Strunian) rugose corals (modified after Chwieduk 2005, map after Golonka et al. 1994). 1, Omolon Massif (E Siberia); 2, Novaya Zemlya; 3, Istanbul Zone (NW Turkey); 4, Kraków, Holy Cross Mountains and Sudetes (S Poland); 5, Pomerania-Rügen area (NW Poland and NE Germany); 6, German Kulm area (Thuringian and Rheinish massifs); 7, Namur-Dinant Basin (S Belgium, French Avesnois, German Aachen area); 8, Montagne Noire (S France); 9, Anti-Atlas (Morocco); 10, Xinzang (Tibet); 11, Transcaucasus (Armenia); 12, Hunan and Guizhou (S China); 13, Viet-Nam; 14, NW Australia; 15, New Mexico.

Palaeotethys Ocean southward and surrounded north-, east- and west-ward by a carbonate shelf (Golonka 2007; Fig. 9).

The compilations of data available in literature led to the building of a database of rugose coral genera occurrences in the uppermost Famennian. A cluster analysis was conducted on this presence/absence database (see SOM: table 1, Supplementary Online Material available at http://app.pan.pl/SOM/app61-Denayer_SOM.pdf) using the paired Simpson coefficient and a bootstrap replicates value of 10 000. The resulting cluster (Fig. 10) shows three clusters: one containing only the New Mexico assemblage (Sorauf 1992) which is based on the single Percha Shale Fauna and is not very well constrained stratigraphically (lower *Palmatolepis expansa* Conodont Zone, i.e., Upper Famennian; Sorauf 1992). This N American Province forms an outgroup to all the other faunas. A second cluster unites Asian localities (Armenia, S China, Vietnam, Tibet, and NW Australia) and corresponds to an Asian Palaeotehyan Province (Asian margin of Gondwana). The third clade groups all the other localities. In the latter, one sub-cluster is clearly separated and include the shallow-water assemblages of the European Palaeotethyan Province while the three localities characterized by their "*Cyathaxonia* fauna" of deeper facies are grouped in two branches. The Namur-Dinant Basin (Belgium, N France, W Germany), Sudetes and Kraków area (S Poland), Pomerania-Rügen (NW Poland and NE Germany) co-occur in this cluster, together with Novaya Zemlya, the Siberian Omolon Massif, and NW Turkey. The

Western and Eastern Europe Provinces of Dubatolov and Vassiljuk (1980), Fedorowski (1981), and Sando (1990) are not clearly separated in the cluster but the distribution of the taxa shows clearly two major provinces: the European Palaeotethyan Province ("*Campophyllum* fauna"; Figs. 9, 10) in which most shallow-water carbonate localities are characterised by the genus *Campophyllum*; and the Asian Paleotethyan Province ("*Cystophrentis* fauna"; S China, Tibet, NW Australia, Vietnam, Armenia), where the genus *Cystophrentis* is diagnostic. The Istanbul Zone of NW Turkey belongs to the European Palaeotethyan Province and shares the genera *Campophyllum*, ?*Metriophyllum*, and *Bounophyllum* with the Namur-Dinant Basin and Pomerania-Rügen (both in the Western Europe Province of Dubatolov and Vassiljuk 1980; Fedorowski 1981; Sando 1990); and the genera *Amplexocarinia* and *Pseudoendophyllum* with the Sudetes, the Ural Mountains, and Novaya Zemlya (eastern part of Laurussia, Eastern Europe Province of Dubatolov and Vassiljuk 1980; Fedorowski 1981; Sando 1990). A "mixed" influence is noticed and may result of an overlapping of the two palaebiogeographic provinces or from convergent dispersal paths in link with oceanic currents. Unfortunately, the poor stratigraphic resolution and the lack of any palaeoceanographic model prevent any precise reconstruction. This similarity may also be due to a geographic closeness of the Istanbul Zone to the considered areas (S Poland, Ural Mountains) situated on the margin of Laurussia at this time. Tari et al. (2012) suggest a closer
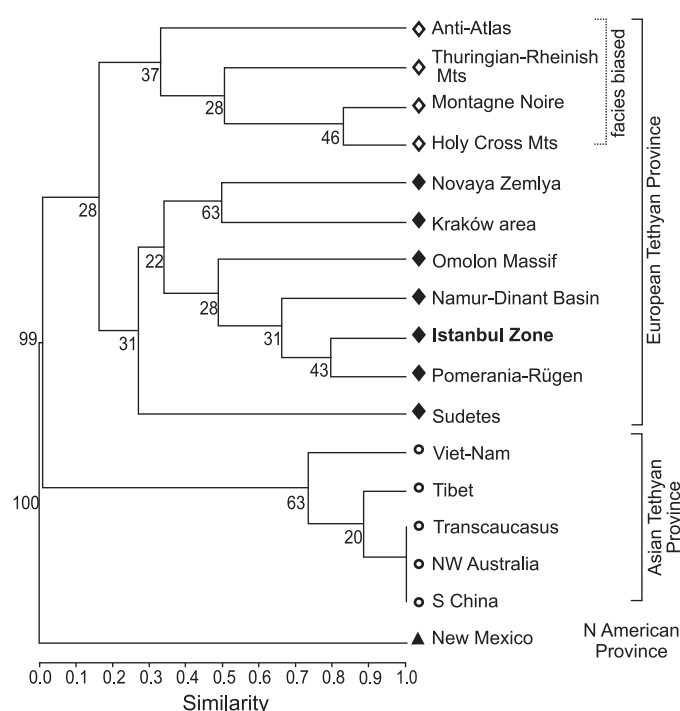
Fig. 10. Palaeobiogeographic cluster (Simpson's coefficient, nodes supported at 10 000 bootstrap replicates) obtained for the uppermost Famennian rugose corals assemblages (data provided in SOM: table 1). North American forms an outgroup. Two clusters are clearly distinct: one with the European Palaeotethyan fauna ("*Campophyllum* fauna") and the second with the Asian Palaeotethyan fauna ("*Cystophrentis* fauna"). The Istanbul Zone belongs to the first cluster.

proximity in positioning the Moesian Terranes and Istanbul Zone close to the Bohemian Massif but this view is not constrained for post-Silurian tectonostratigraphic features.

The similarity of the Omolon Siberian fauna with those of Western Europe is surprising but apparently they are congeneric and have a common origin as it is unlikely that numerous Siberian corals were homeomorphs of the European ones. The occurrence of these taxa as far as the Siberian Omolon might be explained by dispersal ways along existing palaeo-currents. A re-investigation of the uppermost Famennian fauna of Novaya Zemlya and perhaps of the one from the Urals Mountains may contribute here but review of those faunas is still pending. Similarly, the present stage of knowledge of uppermost Famennian rugose corals from central Asia is extremely limited (Simakov 1993). Uppermost Devonian carbonate facies are documented in Kazakhstan, Kirghizistan, Tarim, and Turan (see Soshkina 1960; Streel 2001; Nicollin and Brice 2004, and references therein) but their coral fauna remains unknown. Armenia is the only region of the southern Palaeotethys with a record of the uppermost Famennian coral fauna (Papojan 1975, 1977) though questioned by Rodríguez and Liao (2003). No Strunian corals were described from the Turkish Taurides, the Iranian and Afghan blocks.

The lower Tournaisian assemblage, composed of only two, widely distributed genera (*Caninophyllum* and *Uralinia*) does not allow any accurate palaeobiogeographical analysis.

Conclusions

The uppermost Famennian (Strunian) coral assemblages of Bartın and Zonguldak is dominated by the solitary genera *Campophyllum* and *Bounophyllum*, associated with the colonial genus *Pseudoendophyllum* and the undissepimented genera *Amplexocarinia* and ?*Metriophyllum*. The occurrence of the first two genera indicates a similarity of NW Turkey with the Namur-Dinant Basin (Belgium, N France, W Germany) and Pomerania-Rügen (NW Germany, NE Poland) while *Pseudoendophyllum* indicates an affinity with the Sudetes (S Poland), Novaya Zemlya and the Ural Mountains. All these taxa disappear before the D–C boundary as an effect of the Late Devonian Hangenberg event, while the first Carboniferous coral appear 6 m above the boundary. Nevertheless, the classic facies associated with this global event (black shale) are lacking in the investigated sections in NW Turkey. This can be explained by the shallow-water settings of the studied areas. The proximal position prevented the shelf being reached by the transgressive euxinic water body. Similar situations were documented from other shallow-water sections (e.g., classical sections in the Namur-Dinant Basin, Azmy et al. 2009; Trolp section in the Graz Palaeozoic, Kaiser et al. 2008; Lesnílom section in the Moravian Karst, Kumpan et al. 2014).

Acknowledgements

References

Azmy, K., Poty, E., and Brand, U. 2009. High resolution isotope stratigraphy of the Devonian–Carboniferous boundary in the Namur-Dinant Basin, Belgium. *Sedimentary Geology* 216: 117–124.

Baliński, A. 1995. Brachiopod and conodont biostratigraphy of the Famennian from the Dębnik anticline, Southern Poland. *Palaeontologia Polonica* 54: 3–88.

Benton, M.J. 1993. *The Fossil Record*. 845 pp. Chapman and Hall, London.

Berkowski, B. 2001. Famennian colonial Rugosa from southern Poland: recovery and extinction. *Bulletin of the Tohoku University Museum* 1: 285–290.

Berkowski, B. 2002. Famennian Rugosa and Heterocorallia from Southern Poland. *Palaeontologia Polonica* 61: 1–87.

Bless, M.J.M., Brauckmann, C., Conil, R., Herbig, H.G., Poty, E., Ribbert, K.-H., Streel, M., and Weber, H.M. 1998. Ein Devon/Karbon Grenzprofil im Untergrund der Niederrheinischen Bucht bei Krefeld. *Fortschritte in der Geologie von Rheinland und Westfalen* 37: 55–79.

Charles, F. 1933. Contribution à l'étude des terrains paléozoïques de l'Anatolie du Nord-Ouest (Asie mineure). *Mémoires de la Société Géologique de Belgique* 7: 54–152.

Chwieduk, E. 2005. Late Devonian and Early Carboniferous Rugosa from Western Pomerania, Northern Poland. *Acta Geologica Polonica* 55: 393–443.

Conil, R. 1961. Les gîtes à stromatopores du Strunien de la Belgique. *Mémoires de l'Institut Géologique de l'Université de Louvain* 22: 335–369.

Conil, R., Dreesen, R., Lentz, M.A., Lys, M., and Plodowski, G. 1986. The Devonian–Carboniferous transition in the Franco-Belgian basin with reference to Foraminifera and brachiopods. *Annales de la Société géologique de Belgique* 109: 19–26.

Conil, R., Poty, E., Simakov, K.V., and Streel, M. 1982. Foraminifères, spores et coraux du Famennien supérieur et du Dinantien du massif de l'Omolon (Extrême-Orient soviétique). *Annales de la Société géologique de Belgique* 105: 145–160.

De Groot, G.E. 1963. Rugose corals from the Carboniferous of northern Palencia (Spain). *Leidse Geologische Mededelingen* 29: 1–124.

Dehée, R. 1929. Description de la faune d'Etroeungt. *Mémoire de la Société géologique de France* 11: 1–63.

Denayer, J. 2011. *Dorlodotia* and related genera (Rugosa) from the Viséan (Mississippian; Carboniferous) of Zonguldak and Bartın (North-Western Turkey). *Palaeontology* 54: 1435–1454.

Denayer, J. 2013. Strunian rugose and tabulate corals from Northwestern Turkey. *In*: A. El Hassani, R.T. Becker, and A. Tahiri (eds.), International Field Symposium "The Devonian and Lower Carboniferous of Northern Gondwana" Maroc, Abstracts. *Documents de l'Institut Scientifique Rabat* 26: 35–36.

Denayer, J., Poty, E., and Aretz, M. 2011. Uppermost Devonian and Dinantian rugose corals from Southern Belgium and surrounding areas. *In*: M. Aretz and E. Poty (eds.), 11th International Symposium on Fossil Cnidaria and Porifera, Liege 2011, Field Guides. *Kölner Forum für Geologie und Paläontologie* 20: 151–201.

Dîl, N. 1975. Etude micropaléontologique du Dinantien de Gökgöl et Kokaksu (Turquie). *Annales de la Société géologique de Belgique* 98: 213–228.

Dîl, N., Termier, G., Termier, H., and Vachard, D. 1976. Contribution à l'étude stratigraphique et paléontologique du Viséen supérieur et du Namurien inférieur du Bassin Houiller de Zonguldak (nord-ouest de la Turquie). *Annales de la Société géologique de Belgique* 99: 401–449.

Dubatolov, V.N. and Vassiljuk, N.P. 1980. Coral Paleozoogeography in the Devonian and Carboniferous of Eurasia. *Acta Palaeontologica Polonica* 25: 519–529.

Dybowski, W.N. 1873. Monographie des Zoantharia Sclerodermata Rugosa aus der Silurformation Estlands, Nord-Livlands und der Insel Gotland. *Archiv für Naturkund Liv-, Ehst- und Kurlands* 5: 257–414.

Ehrenberg, C.G. 1834. Beiträge zur physiologischen Kenntniss der Corallenthiere im allgemeinen, und besonders des rothen Meeres, nebst einem Versuche zur physiologischen Systematik derselben. *Abhandlungen der Akademie der Wissenschaften, Berlin* 1832: 225–380.

Fan, Y. 1963. Lower Carboniferous corals from Kueichow (Guizhou) and Hunan [in Chinese]. *Acta Palaeontologica Sinica* 11: 270–291.

Fedorowski, J. 1981. Carboniferous corals: distribution and sequence. *Acta Palaeontologica Polonica* 26: 87–160.

Fedorowski, J. 1986. Permian rugose corals form Timor (Remarks on Schouppé and Stacul's collection and publications from 1955 and 1959). *Palaeontographica* 191: 173–226.

Fedorowski, J. 2003. Anthozoa, Rugosa. *In*: L. Malinowska (ed.), *Budowa geologiczna Polski. Atlas skamieniałości przewodnich i charakterystycznych, Dewon*, 49–124. Państwowy Instytut Geologiczny, Warszawa.

Fedorowski, J. 2009. Morphogenesis and taxonomic value of the circumaxial skeleton in Rugosa (Anthozoa). *Lethaia* 42: 232–247.

Fomitchev, V.D. [Fomičev, V.D.] 1953. Rugose corals and stratigraphy of

the Middle and Upper Carboniferous and Permian deposits of the Donets Basin [in Russian]. *Trudy Vsesoûznogo Naučno-Issledovatel'skogo Geologičeskogo Instituta* 91: 1–622.

Frech, F. 1885. Die Korallenfauna des Oberdevons in Deutschland. *Zeitschrift der Deutschen Geologischen Gesellschaft* 37: 21–130.

Gervais, P. 1840. Astrées, Astrea. *In*: Dictionnaire des Sciences naturelles, *Supplément 1*, 481–487. F.G. Levrault, Strasbourg.

Goldfuss, G.A. 1826. *Petrefacta Germaniae.* 122 pp. Arnz and Co., Düsseldorf.

Golonka, J. 2007. Phanerozoic paleoenvironment and paleolithofacies maps; Late Paleozoic. *Geologia* 33: 145–209.

Golonka, J.R., Ross, M.I., and Scotese, C.R. 1994. Phanerozoic paleogeographic and paleoclimatologic modeling maps. *In*: A.F. Embry, B. Beauchamp, and D.J. Glass (eds.), PANGEA: Global Environments and Resources. *Canadian Society of Petroleum Geologists, Memoir* 17: 1–48.

Gorsky, I. [Gorskij, I.] 1935. Some Coelenterata from the Lower Carboniferous beds of the Nowaya Zemlya [in Russian]. *Trudy Arktičeskogo Instituta* 28: 6–122.

Gorsky, I. [Gorskij, I.] 1938. Carboniferous corals from Novaya Zemlya [in Russian]. *In*: D.V. Nalivkin (ed.), Paleontologiâ Sovetskoj Arktiki. *Vsesoûznij Arktičeskij Institut, Trudy, Leningrad* 93: 1–221.

Görür, N. 1988. Timing of the opening of the Black Sea Basin. *Tectonophysics* 147: 247–262.

Görür, N. and Tüysüz, O. 2001. Cretaceous to Miocene palaeogeographic evolution of Turkey: implications for hydrocarbon potential. *Journal of Petroleum Geology* 24: 119–146.

Görür, N., Monod, O., Okay, A.I., Şengör, A.M.C., Tüysüz, O., Yiğitbaş, E.M.S., and Akkök, R. 1997. Palaeogeographic and tectonic position of the Carboniferous rocks of the western Pontides (Turkey) in the frame of the Variscan belt. *Bulletin de la Société Géologique de France* 168: 197–205.

Grabau, A.W. 1928. Palaeozoic corals of China: Part 1, Tetraseptata, second contribution. *Acta Palaeontologica Sinica* 2 (2): 1–175.

Hill, D. 1939. Western Australian Devonian corals in the Wade Collection. *Royal Society of Western Australia Journal* 25: 141–151.

Hill, D. 1981. *Coelenterata. Supplement 1, Rugosa and Tabulata.* 762 pp. The Geological Society of America and the University of Kansas, Boulder.

Hill, D. and Jull, R.K. 1965. Note on *Campophyllum flexuosum* (Goldfuss). *Geological Magazine* 102: 206–212.

Hoşgörmez, H. 2007. Origin and secondary alteration of coalbed and adjacent rock gases in the Zonguldak Basin, western Black Sea Turkey. *Geochemical Journal* 41: 201–211.

Jiang, S. 1982. *Class Anthozoa. The Palaeontological Atlas of Hunan*. 189 pp. Geological Publishing House, Beijing.

Jell, J.S. and Hill, D. 1970. The Devonian coral fauna of the Point Hibbs Limestone, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 104: 1–16.

Kaiser, S.I., Becker, R.T., Steuber, T., and Aboussalam, S.Z. 2010. Climate-controlled mass extinctions, facies and sea-level changes around the Devonian–Carboniferous boundary in eastern Anti-Atlas (SE Morocco). *Palaeogeography, Palaeoclimatology, Palaeoecology* 310: 340–364.

Kaiser, S.I., Steuber, T., and Becker, R.T. 2008. Environmental change during the Late Famennian and Early Tournaisian (Late Devonian–Early Carboniferous): implications from stable isotopes and conodont biofacies in southern Europe. *Geological Journal* 43: 241–260.

Kalvoda, J. 1986. Upper Frasnian and Lower Tournaisian events and evolution of calcareous Foraminifera—close links to climatic changes. *In*: O.H. Walliser (ed.), Global Bio-Events: A Critical Approach. *Lecture Notes on Earth Sciences* 8: 225–236.

Kalvoda, J. and Bábek, O. 2010. The margins of Laurussia in Central and Southeast Europe and Southwest Asia. *Gondwana Research* 17: 526–545.

Kalvoda, J. and Kukal, Z. 1987. Devonian–Carboniferous Boundary in the

Moravian Karst at Lesní lom, Brno-Líšeň, Czechoslovakia. *Courier Forschungsinstitut Senckenberg* 98: 95–117.

Kalvoda, J., Kumpan, T., and Bábek, O. 2015. Upper Famennian and Lower Tournaisian sections of the Moravian Karst (Moravo-Silesian Zone, Czech Republic): a proposed key area for correlation of the conodont and foraminiferal zonations. *Geological Journal* 50: 17–38.

Khoa, N.D. 1996. The Upper Famennian and Tournaisian Rugosa and stratigraphy of Viet Nam. *Geologos* 1: 19–68.

Korn, D. 1986. Ammonoid evolution in Late Famennian and Early Tournaisian. *Annales de la Société géologique de Belgique* 109: 49–54.

Korn, D. and Weyer, D. 2003. High resolution stratigraphy of the Devonian–Carboniferous transitional beds in the Rhenish Mountains. *Fossil Records* 6: 79–124.

Kullmann, J. 1965. Rugose Korallen der cephalopodenfazie und ihre Verbreitung im Devon des südöstlichen Kantabirichen Gebirges (Nordspanien). *Akademie der Wissenschaften und der Literatur, Abhandlungen der matematisch-wissenschaftlichen Klasse* 2: 1–136.

Kumpan, T., Bábek, O., Kalvoda, J., Fryda, J., and Grygar, T.M. 2014. A high-resolution, multiproxy stratigraphic analysis of the Devonian–Carboniferous boundary sections in the Moravian Karst (Czech Republic) and a correlation with the Carnic Alps (Austria). *Geological Magazine* 151: 201–215.

Lewis, H.P. 1929. On the Avonian coral *Caninophyllum* gen. nov. and *Caninophyllum archiaci* Edw. et H. *Annals and Magazine of Natural History (series 2)* 3: 546–468.

Lindström, G. 1882. Silurische Korallen aus Nord-Russland und Sibirien. *Bihang till Konglig Svenska Vetenskapsakademiens Handlingar* 6: 1–23.

Ludwig, R. 1862. Paleontologie des Ural's: Actinozoen und Bryozoen aus dem Carbon-Kalkstein im Gouvernement Perm. *Palaeontographica* 10: 179–226.

Lütte, B.-P. and Galle, A. 1989. Erster Nachweis der Gattung *Amplexocarinia* (Rugosa) im Eifelium der Nord-Eifel (Rheinisches Schiefergebirge). *Paläontologische Zeitschrift* 63: 165–176.

McCoy, F. 1844. *A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland*. 29 pp. University Press, Dublin.

Michelin, J.L.H. 1841–1848. *Iconographie zoophytologique, description par localités et terrains des polypiers fossiles de Frances et pays environnants*. 348 pp. P. Bertrand, Paris.

Milne-Edwards, H. and Haime, J. 1850–1855. A monograph of the British fossil corals. *Palaeontographic Society Monograph, London* 1850: 1–71, 1852: 147–210, 1853: 211–244, 1855: 245–299.

Moix, P., Beccaletto, L., Kozur, H.W., Hochard, C., Rosselet, F., and Stampfli, G.M. 2008. A new classification of the Turkish terranes and sutures and its implication for the paleotectonic history of the region. *Tectonophysics* 451: 7–39.

Moore, R.C. and Jeffords, R.M. 1986. Description of Lower Pennsylvanian corals from Texas and adjacent states. *University of Texas Publications* 4401: 77–208.

Nicholson, H.A. and Lydekker, R. 1889. *A Manual of Palaeontology, 3rd edition*. 885 pp. Blackwood and Sons, Edinburgh.

Nicollin, J.-P. and Brice, D. 2004. Biostratigraphical value of some Strunian (Devonian, uppermost Famennian) Productidina, Rhynchonellida, Spiriferida, Spiriferinida brachiopods. *Geobios* 37: 437–453.

Okay, A.I. 2008. Geology of Turkey: a synopsis. *Anschnitt* 21: 19–42.

Okay, A.I., Satir, M., and Siebel, W. 2006. Pre-Alpide Palaeozoic and Mesozoic orogenic events in the Eastern Mediterranean region. *In:* D.G. Gee and R.A. Stephenson (eds.), European Lithosphere Dynamics. *Geological Society London, Special Publication* 32: 389–405.

Onoprienko, Y. 1979a. New Rugosa findings in the Devonian–Carboniferous transitional deposits of the Omolon Massif, Field excursions guidebook, tour 9. 73 pp. 16th Pacific Science Congress, Khabarovsk.

Onoprienko, Y. 1979b. Question about relationship between genera *Endophyllum* and *Tabulophyllum* (Rugosa) [in Russian]. *In*: M.N. Gramm (ed.), *Iskopaemye Bespozvonočnye Dal'nego Vostoka (dannye po novym nahodkam)*, 29–32. Akademiâ Nauk SSSR, Dal'nevostočnyj Naučnyj Centr, Vladivostok.

Özgül, N. 2012. Stratigraphy and some structural features of the Istanbul Palaeozoic. *Turkish Journal of Earth Sciences* 21: 817–866.

Papojan, A.S. [Papoân, A.S.] 1975. On systematic position of *Cystophrentis* from the Lower Carboniferous of the south Transcaucasus (Armenia) [in Russian]. *In*: B.S. Sokolov (ed.), *Drevnie Cnidaria*, 205–210. Akademiâ Nauk, Novosibirsk.

Papojan, A.S. 1977. The coral complexes of Early Carboniferous in the Southern Transcaucasus and its relation with some biogeographical provinces. *Mémoire du Bureau de Recherches Géologiques et Minières* 1977: 197–202.

Poty, E. 1981. Recherches sur les Tétracoralliaires et les Hétérocoralliaires du Viséen de la Belgique. *Mededelingen Rijks Geologische Dienst* 35: 1–161.

Poty, E. 1984. Rugose corals at the Devonian–Carboniferous boundary. *Courier Forschungsinstitut Senckenberg* 67: 29–35.

Poty, E. 1986. Late Devonian to Early Tournaisian Rugose Corals. *Annales de la Société géologique de Belgique* 109: 65–74.

Poty, E. 1989. Distribution and palaeogeographic affinities of Belgian Tournaisian rugose corals. *In*: P.A. Jell and J.W. Pickett (eds.), Fossil Cnidaria 5. *Memoirs of the Association of Australasian Palaeontologists* 8: 267–273.

Poty, E. 1999. Famennian and Tournaisian recoveries of shallow water Rugosa following late Frasnian and late Strunian major crises, southern Belgium and surrounding areas, Hunan (South China) and the Omolon region (NE Siberia). *Palaeogeography, Palaeoclimatology, Palaeoecology* 154: 11–26.

Poty, E. 2010. Morphological limitation to the diversification of the rugose and tabulate corals. *In*: O. Kossovaya and I.D. Somerville (eds.), 10th International Symposium on Fossil Cnidaria and Porifera, Saint-Petersburg 2007. *Palaeoworld* 19: 389–400.

Poty, E. and Boland, K. 1994. Révision des Tétracoralliaires caninomorphes de l'Hastarien (Tournaisien) belge. *Annales de la Socété Géologique de Belgique* 117: 201–225.

Poty, E. and Onoprienko, Y. 1984. Rugose corals. *In*: N.A. Shilo, J. Bouckaert, M.J.M. Afanasieva, M.J.M. Bless, R. Conil, O.A. Erlanger, M.H. Gagiev, S.S. Lazarev, Y. Onoprienko, E. Poty, T.P. Razina, K.V. Simakov, L.V. Smirnova, M. Streel, and R. Swennen (eds.), Sedimentological and Palaeontological atlas of the Late Famennian and Tournaisian deposits in the Omolon Region (NE USSR). *Annales de la Société géologique de Belgique* 107: 200–213.

Poty, E. and Xu, S. 1996. Rugosa from the Devonian–Carboniferous transition in Hunan, China. *Mémoires de l'Institut de Géologie de l'Université de Louvain* 36: 89–139.

Poty, E. and Xu, S. 1997. Systematic position of some Strunian and Lower Carboniferous heterocoral-like colonial corals. *Boletín de la Real Sociedad Española de Historia Natural. Sección Geológica* 91: 99–106.

Poty, E., Aretz, M., and Hance, L. 2013. Belgian substages as a basis for an international chronostratigraphic division of the Tournaisian and Viséan. *Geological Magazine* 151: 229–243.

Poty, E., Devuyst, F.-X., and Hance, L. 2006. Upper Devonian and Mississippian foraminiferal and rugose coral zonations of Belgium and northern France: a tool for Eurasian correlations. *Geological Magazine* 143: 829–857.

Rodríguez, S. and Liao, W.H. 2003. A restudy of *Cystophrentis* Yü 1931 (Rugosa) from the Uppermost Famennian (Strunian) of South China. *Geobios* 36: 407–419.

Różkowska, M. 1969. Famennian tetracoralloid and heterocoralloid fauna from the Holy Cross Mountains (Poland). *Acta Palaeontologica Polonica* 24: 1–187.

Salée, A. 1913. Contribution à l'étude des Polypiers du Calcaire Carbonifère de la Belgique, II, Le groupe des Clisiophyllides. *Mémoires de l'Institut de Géologie de l'Université de Louvain* 1: 179–293.

Sando, W.J. 1990. Global Mississippian coral zonation. *Courier Forschungsinstitut Senckenberg* 130: 173–187.

Schindewolf, O.H. 1932. Über Polyparform und septalapparat der Tetrakorallen. *Centralblatt für Mineralogie, Geologie und Paläontologie, Abteilung B* 9: 464–478.

Schindewolf, O.H. 1937. Zur stratigraphie und paläontologie der Wocklumer schichten (Oberdevon). *Vertrieb bei der Preussischen Geologischen Landesanstalt* 178: 1–132.

Scrutton, C.T. 1998. The Palaeozoic corals, II: Structure, variation and palaeoecology. *Proceedings of the Yorkshire Geological Society* 52: 1–57.

Semenoff-Tian-Chansky, P. 1974. Recherches sur les Tétracoralliaires du Carbonifère du Sahara Occidental. *Mémoires du Muséum National d'Histoire Naturelle, série C Sciences de la Terre* 30: 1–316.

Semenoff-Tian-Chansky, P. 1988. Corals from the Devonian–Carboniferous Boundary at La Serre (Montagne Noire, France). *Courier Forschungsinstitut Seckenberg* 100: 129–138.

Simakov, K.V. 1993. Biochronological aspects of the Devonian–Carboniferous crisis in the regions of the former USSR. *Palaeogeography, Palaeoclimatology, Palaeoecology* 104: 127–137.

Sorauf, J.E. 1992. Late Devonian (Famennian) rugose coral fauna of the Percha Shale of Southwestern New Mexico. *Journal of Paleontology* 66: 730–749.

Soshkina, E. 1928. Die unterpermischen Korallen von westlichen Abhang des nördlichen Uralgebriges. *Bulletin de la Société Naturaliste de Moscou, section Géologie.* 63: 339–393.

Soshkina, E. [Soškina, E.] 1960. Tournaisian Rugosa and their relationships with Devonian rugose corals [in Russian]. *In*: V.A. Varsonofeva (ed.), *Sobrannye bumagi na geologii i paleontologii*, 272–328. Adademiâ Nauk SSSR. Sbornik trudov po geologii i paleontologii, Syktyvkar.

Spassky, Y. 1965. Principles of systematics of Devonian tetraradiate corals [in Russian]. *In*: B.S. Sokolov and A.B. Ivanovskij (eds.), Rugozy paleozoâ SSSR, *Trudy I Vsesoûznogo Simpozûma po izučeniû iskopaemyh korallov SSSR*, 80–90. Akademiâ Nauk SSSR, Sibirskoe Otdelenie, Institut Geologii i Geofizikii, Novosibirsk.

Streel, M. 2001. The uppermost Famennian around the World (definition, biostratigraphical and sedimentological context). *Subcommission on Devonian Stratigraphy Newsletter* 18: 55–61.

Streel, M., Brice, D., and Mistiaen, B. 2006. Strunian. *Geologica Belgica* 9: 105–109.

Stuckenberg, A. 1895. Korallen und Bryozoen der Steinkohlen ablagerungen des Ural und des Timan. *Mémoires du Comité de Géologie de Saint-Petersbourg* 10: 1–244.

Tan, Z., Dong, Z., Jin, Y., Li, S., Yang, Y., and Jiang, S. 1987. *The Late Devonian and Early Carboniferous Strata and Palaeobiocenosis of Hunan*. 200 pp. Geological Publishing House, Beijing.

Tari, G., Poprawa, P., and Krzywiec, P. 2012. Silurian lithofacies and palaeogeography in Central and Eastern Europe: Implications for shale gas exploration. SPE/EAGE European Unconventional Resources Conference and Exhibition, Vienna, Austria, 20–22 March. *Society of Petroleum Engineers Journal* SPE 151606: 1–10.

Tokay, M. 1954. Géologie de la Région de Bartin (Zonguldak-Turquie du Nord). *Bulletin of the Mineral Research and Exploration Institute of Turkey (MTA Bulletin)* 46–47: 46–63.

Tolmachev, I.P. 1931. Faune du Calcaire du Bassin du Kuznetsk. *Comité géologique de Leningrad, matériaux pour la géologie générale et appliquée* 25: 1–663.

Torley, K. 1933. Über *Endophyllum bowerbanki* M.-E. and H. *Deutsche Geologische Gesellschaft Zeitschrift* 85: 630–633.

Trautschold, H. 1879. Die Kalkbrüche von Mjatschkowa: Eine Monographie des oberren Bergkalks. *Société Impériale des Naturalistes de Moscou, Mémoire* 14: 1–82.

Vaughan, A. 1917. Correlation of Dinantian and Avonian. *Quaterly Journal of the Geological Society* 521: 1–52.

Verrill, A.E. 1865. Classification of polyps. *Annals and Magazine of Natural History* 16: 191–197.

Walliser, O.H. 1996. Global events in the Devonian and Carboniferous. *In*: O.H. Walliser (ed.), *Global Events and Event Stratigraphy in the Phanerozoic*, 225–250. Springer, Berlin.

Wang, H.C. 1950. A revision of Zoantharia Rugosa in the light of their minute skeletal structures. *Philosophical Transaction of the Royal Society, London* 611: 175–246.

Webb, G.E. 2000. The Palaeobiogeography of Eastern Australian Lower Carboniferous Corals. *Historical Biology* 15: 91–119.

Wedekind, R. 1921. Zur Kenntnis des Stringophyllen des oberen Mittledevon. *Gesellschaft zur Beförd der Gesamten Naturwissenschaften zu Marburg, Schriften* 1921: 1–16.

Weyer, D. 1971. *Neaxon regulus* (Rh. Richter, 1848), ein Leitfossil des mitteleuropäischen Wocklumeria-Stufe (Anthozoa, Rugosa, Oberdevon). *Geologie* 20: 292–315.

Weyer, D. 1989. *Neaxon muensteri*, eine neue Koralle aus dem europäischen Oberfamenne. *Abhanglungen und Berichte für Naturkunde und Vorgeschishte* 14: 3–16.

Weyer, D. 2002. Famennium-Anthozoa aus Marokko, 1, *Czarnockia* Różkowska, 1969 (Rugosa). *Fossil Records* 5: 75–92.

Wu, W., Zhao, J., and Jiang, S. 1981. Corals from the Shaodong Formation (Etroeungt) of South China. *Acta Palaeontologica Sinica* 20: 1–14.

Wulff, R. 1922. Das Famennien des Aachener gegend. *Jahrbuch der Preussischen Geologischen Landesanstalt zu Berlin* 43: 1–70.

Yü, C.C. 1931. The correlation of the Fengninian System, the Lower Carboniferous as based on corals zones. *Bulletin of the Geological Society of China* 10: 1–4.

Yü, C.C. 1933. Lower Carboniferous corals of China. *Palaeontologia Sinica* 12 (3): 1–211.

Yü, C.C. 1963. Discussion on relationship between *Cystophrentis* and Hexacoralla, and establish Order Mesocorallia (ord. nov.) and Family Cystophrentidae (fam. nov.). *Acta Palaeontologica Sinica* 11: 307–316.

Zhavoronkova, R.A. [Žavoronkova, R.A.] 1972. Description of corals [in Russian]. *In*: A.P. Tyaževa and R.A. Žavoronkova (eds.), *Korally i brahiopody pograničnyh otloženji silura i nižnego devona zapadnogo sklona ûžnogo Urala*, 17–55. Akademiâ Nauk SSSR, Baškirskoj filial, Institut Geologii, Moskva.