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Palaeozoic (Silurian and Devonian) radiolarians and conodonts from chert olistoliths of the Volissos Turbidites, Chios island, Greece

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Key words: Radiolarians, conodonts, Silurian, Devonian, Volissos Turbidites, Chios Mélange

ABSTRACT

The Volissos Turbidites (also known as Chios Mélange) are a thick Palaeozoic wildflysch sequence that crops out on the Greek island of Chios. It consists of chert, limestone and volcanic olistholits floating in a siliciclastic turbiditic matrix. During the Early Carboniferous (Mississippian), these turbidites were severely deformed and structurally thickened probably at the toe of an accretionary wedge. Whereas there are many studies on the fossiliferous content of the limestone olistoliths, scant attention was given to the cherts. We report here for the first time some radiolarian and conodont assemblages from the chert olistholiths (ribbon radiolarites) embedded in the siliciclastic sequence of the Volissos Turbidites.

The radiolarites sampled near Kardamila and Marmaro (northeastern Chios), where the Volissos Turbidites are not affected by metamorphism, have given identifiable radiolarians and conodonts. The different samples document different ages. Some radiolarians document Silurian, possible Pridolian age, whereas the conodonts indicate a distinct Famennian (late Late Devonian). The radiolarians of other samples delineate a more general range (Devonian-?Early Carboniferous).

Introduction and Geological Setting

Chios, one of the largest Greek islands, is located in the eastern Aegean Sea a few kilometers from the Turkish Karaburun Peninsula (Fig. 1). According to previous authors (Besenecker et al. 1968, 1971), two main thrust sheets with different successions crop out in the island.

The Lower Unit (“*autochthonous*” of Besenecker et al. 1968, 1971) includes siliciclastic turbidites and embedded olistoliths (also up to 100 m in diameter) of Silurian to Carboniferous rocks, named *Volissos turbidites* by Zanchi et al. (2003) or *Chios Mélange* by Robertson & Pickett (2000) and Groves et al. (2003), overlain by a Mesozoic mixed terrigenous-carbonate succession. The Upper Unit (“*allochthonous*” of Besenecker et al. 1968, 1971) occurs in isolated klippen and consists, in ascending order, of an Upper Carboniferous to Upper Permian sequence, sporadic reports of Middle Triassic limestones and a Liassic shallow-water carbonate platform (Kauffmann 1969; Besenecker et al. 1968).

The Volissos Turbidites consist of a thick flysch-type succession composed of limestone, chert and volcanic blocks floating in a siliciclastic turbiditic matrix with partially preserved original stratigraphic contacts. Shales, sandstones and conglomerates form the terrigenous matrix, that exhibits common turbiditic sedimentary structures as normal grading, cross-lamination, flute casts, grooves, often organised in the typical Bouma sequences.

Tectonic repetitions and intensive deformation of the entire succession hamper the evaluation of its original thickness (several kilometres at least) and relationships.

The Volissos Turbidites are also affected in the lowermost part of the unit (north western Chios) by metamorphism associated with deformation that does not exceed very-low grade conditions, as suggested by sparse chlorite and sericite beards along cleavage planes (Zanchi et al. 2003).

An eastward decrease in thermal alteration is suggested by the Conodont Alteration Index (CAI, Epstein et al. 1977; Re-

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Fig. 1. Map of the Aegean Sea and location of Chios Island.

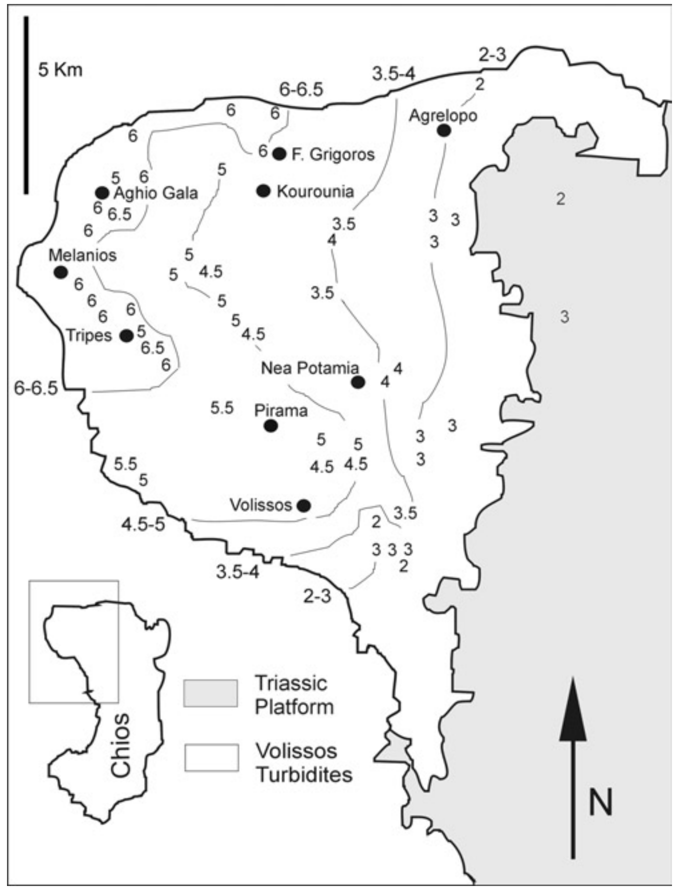

Fig. 2. Map of CAI (Colour Alteration Index) of NW part of Chios Island

jeban et al. 1987) of the carbonate Palaeozoic olistoliths. Based on the evaluation of conodonts sampled by Herget and Roth in the '60 and housed in Marburg (Germany), we have defined different alteration zones oriented N-S following the main structural trends which also correspond to the distribution of the major olistostrome layers (Fig. 2). CAI values decrease from 6/6.5 in the Melanios area to 2.5 in the Spartounta-Siderounta area close to the boundary with the Mesozoic cover.

According to Zanchi et al. (2003) the turbidites were most likely deposited in a Paleotethyan remnant ocean basin and later were severely deformed and structurally thickened probably at the toe of an accretionary wedge.

Radiolarites

Blocks (olistholiths) of sheared and ribbon cherts (Figs. 3a, b) up to many metres across (3–4 m) are randomly distributed in the matrix of the Volissos Turbidites, but are particularly common in northeastern Chios (near Kardamila) where the blocks reach the greatest size (several decametres). Colours of the cherts are variable but black and dark red are prevailing.

The olistoliths are poorly sorted and reach very large sizes (many tens of metres), they are more or less folded; the largest ones are almost concordant with stratification and commonly consist of silicified mudstones similar to the distal facies of a turbidite fan.

In spite of these similarities the cherts within the complex have been generally deformed more readily and at a smaller wavelength if compared with the turbiditic matrix, many of these folds have a sedimentary origin, easily distinguishable by a true tectonic origin; nevertheless the cherts frequently have a second set of folds that overprints earlier folds and in some areas the contact between the chert and the turbiditic sandstone and shale is defined by a high strain zone. Sometimes the bedded cherts are boudinaged, chevron folded and highly sheared.

Blocks of lesser size, metrical or decametrical, often show the typical "pod-like" shape, frequently described in the mélange of the accretionary complexes (Miller & Gray 1996).

The authors have frequently used the term "lydite" ("Lydit" of the German Authors) to indicate the fine levels with silicatic or fillosilicatic prevalent composition cropping out at Chios (Herget & Roth 1968; Neubauer & Statteger 1995), nevertheless this term does not distinguish the exotic chert olistoliths, with evident traces of radiolarians, from the finely laminated levels of the matrix.

Fig. 3. **a**: outcrop of ribbon cherts near Volissos, **b**: detail.

Sampling

During the summer 2001, all the cherty blocks with visible traces of radiolarians have been sampled in the Volissos Turbidites. Forty-five samples have been collected from 15 olistoliths in the different part of the unit and from a conglomeratic level with chert clasts (Mesorachi section, Papanikolaou & Sideris 1992).

The specimens from the olistholits in the lower parts of the Volissos Turbidites are affected by recrystallisation related to very low-grade metamorphism and have not provided identifiable radiolarians. Only the specimens collected near Kardamila and Marmaro (samples CL192, 223, 224, 230, 231; Fig. 4), in the uppermost part of the unit, have yielded identifiable specimens. Sample CL273 from Afrodisia (central-north Chios) and CL283 from Melanios (north-west Chios) have yielded Late Palaeozoic possible Entactiniidae, recrystallised and indeterminable.

Kauffmann (1965) reported, from the Kardamila and Marmaro areas, several outcrops of limestones and shales with more ancient Silurian and Devonian conodonts and Silurian graptolites.

Preparation and processing of samples

The rock samples were dissolved in 5% HF solution for about 24 hours. Radiolarians and conodonts remains were picked from the residue under a binocular microscope.

All the taxa described in this paper are illustrated using scanning electron micrographs, and all the specimens described are deposited in the Dipartimento di Scienze della Terra, Università degli Studi di Milano, via Mangiagalli 34, Milano.

Radiolaria and Conodonta Occurrences

The recovered radiolarian and conodont fauna allow to establish a quite precise age for two samples, one Late Silurian and one Late Devonian, whereas for a few others only a generical "Devonian-?Early Carboniferous" age can be proposed (Fig. 5).

Tab. 1. Distribution of radiolarians and conodonts identified in the radiolarites.

Samples → **Recovered taxa**	**CL** 192	**CL** 230	**CL** 231
Pseudospongoprunum sagittatum		**X**	
Pseudospongoprunum tazukawaensis		**X**	
Pseudospongoprunum cf. *P. prototypum*		**X**	
?*Helioentactinia* (?) *prismspinosa*		**X**	
?*Devoniglansus* sp.		**X**	
?*Zadrappolus*			
Stigmosphaerostylus cf. *S. herculeus*	**X**		
Stigmosphaerostylus cf. *S. variospina*	**X**		
Entactiniidae indet.	**X**		**X**
Polygnathus vogesi			**X**
Palmatolepis gracilis gracilis			**X**
Palmatolepis gracilis sigmoidalis			**X**

Sample CL230 – Late Silurian

The oldest datable cherts in the study area (sample CL230 from Kardamila) can be probably assigned to the Pridolian (late Silurian), on the basis of radiolarians of the *Pseudospongoprunum sagittatum* Assemblage. The fauna includes some species of Genus *Pseudospongoprunum* Wakamatsu, Sugiyama & Furutani 1990: beside the assemblage index, *P. sagittatum* Wakamatsu, Sugiyama & Furutani 1990, and *P.* cf. *P. prototypum* Umeda 1998, only one specimen of *P. tazukawaensis* Wakamatsu, Sugiyama & Furutani 1990 has been recovered. The latter is generally considered as a Wenlockian and Ludlowian form (Wakamatsu et al. 1990), nevertheless the reports of this species in other Silurian successions are rare and its range uncertain (see remarks in the systematic description). Furthermore, not well preserved forms of uncertain identification as ?*Helioentactinia* (?) *prismspinosa* Waka-

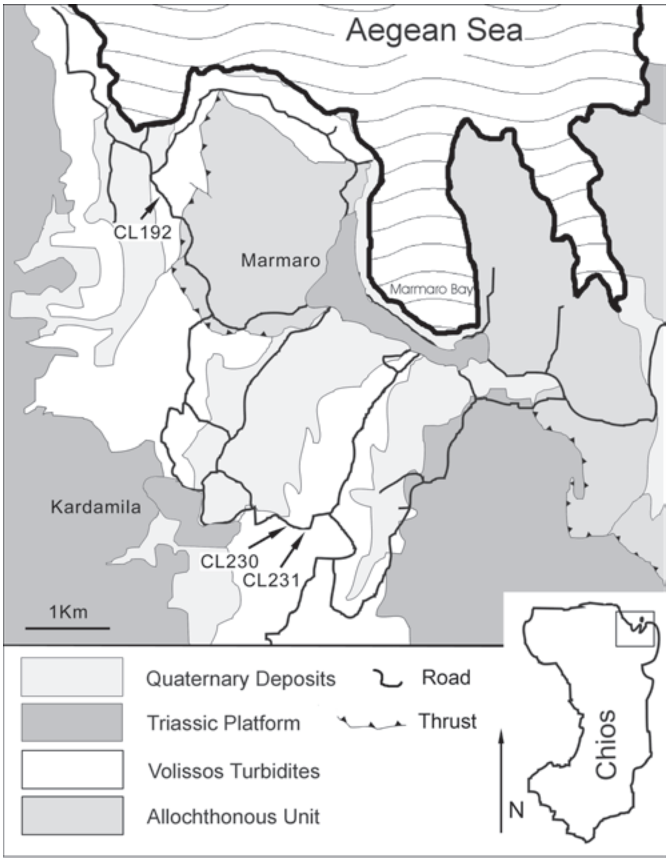

Fig. 4. Geological map of NE corner of Chios Island and position of studied samples.

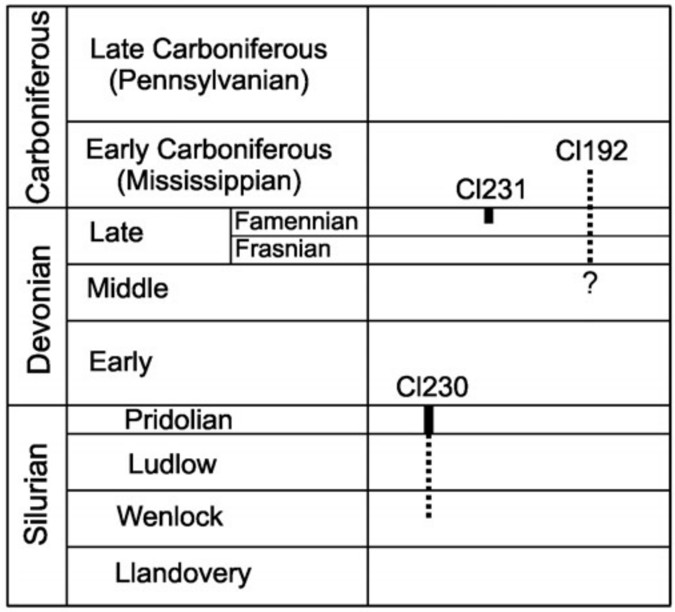

Fig. 5. Age of studied samples. Solid bars indicate precise age ranges (well-established for CL231, only probable for CL230). Dashed lines indicate maximum age range.

MATSU, SUGIYAMA & FURUTANI 1990, ?*Devoniglansus* sp., ?*Zadrappolus* sp. and others not identifiable Silurian morphotypes (Spumellaria gen. et sp. indet. Pl. 1, Figs. 11, 12) are also present.

According to Noble (1994), Umeda (1998) and Kurihara & Sashida (2000), the *P. sagittatum* assemblage is Pridolian (Late Silurian).

Sample CL231 – Late Devonian

Sample CL 231, collected near Agrelia, yielded a poorly preserved fauna with a few Late Devonian conodonts of genera *Palmatolepis* ULRICH & BASSLER 1926 and *Polygnathus* HINDE 1879 and Entactiniidae radiolarians.

Among conodonts, *Palmatolepis gracilis gracilis* BRANSON & MEHL 1934, *P. gracilis sigmoidalis* ZIEGLER 1962 and *Polygnathus vogesi* ZIEGLER 1962 have been collected, as well as a large fragment of *Polygnathus* sp. A similar, but more abundant conodont assemblage (including also *Po. communis*, *Pseudopolygnathus marburgensis* and *Bispathodus stabilis*) was reported by Herget & Roth (1968) in one sample (459/2) from a limestone olistolith cropping out 1.75 km southeast of Kampia (northern Chios).

The conodont fauna suggests an age interval included within the Lower *expansa* and the Middle *praesulcata* Zones (late Famennian). In fact, *Po. vogesi* is known from this interval (Ji Qiang & Ziegler 1993), whereas *Pa. gr. gracilis* and *Pa. gr. sigmoidalis* have a wider range.

The radiolarians found in this sample are indeterminate Entactiniidae, and are not biostratigraphically useful.

Other samples – Devonian-?Early Carboniferous

The radiolarians recovered from other samples are in general poorly preserved or long-range morphotypes and do not allow a precise age statement, suggesting only a Devonian-?Early Carboniferous age.

A few Entactiniidae have been collected from samples CL273 (near Afrodisia, northcentral Chios) and CL283 (near Melanios, northwestern Chios); however these specimens are recrystallised and indeterminable, due to the low-grade metamorphism which affected these areas.

A not well defined Devonian-Early Carboniferous age is indicated by specimens from samples CL223 and CL224. Here some morphotypes are close to those illustrated as Entactiniidae gen. et sp. ind. sp. by Stratford & Aitchison (1997) from the Lower Carboniferous of Australia. However, this taxonomic indetermination reflects an uncertain age.

Finally, Sample CL192 yielded a better preserved association, with *Stigmosphaerostylus* cf. *S. herculeus* and *Stigmosphaerostylus* cf. *S. variospina*. The latter species is often reported from the Lower Carboniferous but its range probably includes also the Late Devonian (see remarks in Systematic Paleontology section).

The presence of Lower Carboniferous in the radiolarites of the Volissos Turbidites is thus not sure.

Comparison with the Karaburun area.

The northwestern Karaburun peninsula (Turkey) is dominated by a highly sheared mélange with Silurian-Carboniferous blocks, compared by Kozur (1997a, b, 1998), Robertson & Pickett (2000) and Zanchi et al. (2003) to the Volissos Turbidites (=Autochthonous or Chios Mélange of the former authors).

Caridroit et al. (1997) reported radiolarians and conodonts together with ostracods, foraminifers, and others vertebrate remains from a single uppermost lower Tournaisian limestone block from the "Karareis Formation", which is part of the Palaeozoic siliciclastic series of the northwestern Karaburun.

Also Kozur (1997b) reported a Palaeozoic radiolarian fauna with Albailellaria associated with Muellerisphaerida (*incertae sedis*); a Silurian to Early Devonian age of a part of the clastic series was proven by Muellerisphaerida, later confirmed by conodonts and radiolarians. Kozur (1998) also reported Late Devonian conodonts from the Karareis Formation.

In the Chios samples Albailellaria and Muellerispharedida have not been found and the late Famennian conodonts of Chios reported in this paper (Lower *expansa* – Middle *praesulcata* interval) have not been found by Kozur (1998) in the limestone blocks of Karaburun; nevertheless as reminded by Kozur (1998) the late Famennian was a period of widespread basinal deposits (shale and lydites) in the circumediterranean region. A deep water basinal origin of the cherts from the Volissos Turbidites is suggested both by the lithofacies and by the conodont biofacies of the sample CL231 (late Famennian), *Palmatolepis* and *Polygnatus* in fact predominate in the pelagic sedimentary environment of the Late Devonian (Sandberg 1976).

Systematic Paleontology

Phylum Protista
Subclass Radiolaria MÜLLER 1858
Order Polycystida EHRENBERG 1838
Suborder Spumellaria EHRENBERG 1875
Family Sponguridae HAEKEL, emend. PESSAGNO 1973

Genus *Pseudospongoprunum* WAKAMATSU, SUGYAMA & FURUTANI 1990

Type species: *P. tazukawaensis* WAKAMATSU, SUGYAMA & FURUTANI 1990

***Pseudospongoprunum tazukawaensis* WAKAMATSU, SUGIYAMA & FURUTANI 1990**
Plate I, Fig. 1.

1990 *Pseudospongoprunum tazukawaensis* WAKAMATSU, SUGIYAMA & FURUTANI 1990, p.173, pl.2, figs.1–4.

Remarks. – Compared with many specimens of *P. sagittatum*, only one specimen of *P. tazukawensis* has been discovered in the sample CL230. This species is similar to *P. sagittatum* but differs from it essentially in the more subspherical shell.
Range. – According to Wakamatsu et al. (1990), *P. tazukawaensis* defines an assemblage ranging from the middle Wenlockian to the middle Ludlovian, nevertheless Kurihara & Sashida (2000) reported *Pseudospongoprunum* cfr. *P. tazukawaensis* from the *P. sagittatum* assemblage (Pridolian) from the clastic rock sequences in the Kuzuryu Lake district of the Hida Gaien Belt, Fukui Prefecture, central Japan.

***Pseudospongoprunum sagittatum* WAKAMATSU, SUGYAMA & FURUTANI 1990**
Plate I, Figs. 5, 6, 8.

1990 *Pseudospongoprunum sagittatum* WAKAMATSU, SUGIYAMA & FURUTANI 1990, p.173, pl.3, figs.1–4.
1998 *Pseudospongoprunum sagittatum* WAKAMATSU, SUGIYAMA & FURUTANI, – *Umeda,* p.38, pl.5, figs. 1–4 and mentioned synonymy.
2000 *Pseudospongoprunum sagittatum* WAKAMATSU, SUGIYAMA & FURUTANI – *Kurihara, Sashida,* p.58–59, pl.1, figs. 8–9.

Remarks. – This species exhibits a typical elliptical shaped shell and two polar spines with distinct heteropolarity.
Range. – According to Wakamatsu et al. (1990), *P. sagittatum* defines a Pridolian (Late Silurian) assemblage, an opinion later confirmed by Umeda (1998) and Kurihara & Sashida (2000).

***Pseudospongoprunum* cf. *P. prototipum* UMEDA 1998**
Plate I, Fig. 7

Remarks. – The specimen exhibits a large elongate shell with a trapezoidal profile, although the bad state of preservation does not permit to appreciate the most diagnostic character of this species, i. e. the conical and deeply grooved short apical spine.
Range. – According to Umeda (1998) *P. prototipum* is possibly Pridolian (late Silurian).

Genus *Devoniglansus* WAKAMATSU, SUGIYAMA & FURUTANI *1990*

Type species: *D. unicus* WAKAMATSU, SUGYAMA & FURUTANI 1990

***?Devoniglansus* WAKAMATSU, SUGIYAMA & FURUTANI 1990**
Plate I, Fig. 2

Remarks. – Only one specimen could be attributed dubitatively to *Devoniglansus*, genus frequently reported in the Pridolian (Late Silurian) assemblages, although the bad state of preservation does not permit a certain attribution.
Range. – Noble (1994) used this genus as a key taxon for the zonation of the late Silurian of the Marathon uplift, West Texas. According to Noble, the range of this genus is presumably restricted to the Silurian. The species attributed up to now

to *Devoniglansus* are reported only in the late Silurian (Wakamatsu et al. 1990; Noble 1994; Umeda 1998).

Family Inaniguttidae NAZAROV & ORMISTON 1985

The Silurian genera of this family have been revised by Noble (1994) and we have referred to her emended diagnosis.

Genus *Zadrappolus* FURUTANI 1990

***? Zadrappolus* sp.**
Plate I, Fig. 9

Remarks. – From the rod-shaped spines and the possible absence of a delicate outer cortical shell, this specimen can tentatively be attributed to *Zadrappolus* FURUTANI 1990, although given the bad state of preservation of the shell and the inaccessibility to the internal characters, it is not possible to make a certain attribution.
Range. – This genus is typically Silurian.

Family Entactiniidae RIEDEL 1967; emend. NAZAROVA & ORMISTOV

Genus *Helioentactinia* NAZAROV 1975

***?Helioentactinia (?) prismspinosa* WAKAMATSU, SUGIYAMA & FURUTANI 1990.**
Plate I, Fig. 3

Remarks. – The specimen resembles in the number and shape of the spines to paratype ESN 146012 (Wakamatsu et al. 1990; pl. 5, fig. 7) of *Helioentactinia* (?) *prismspinosa*. Given the poor state of preservation of the shell it is not possible to make a precise attribution.
Range. – Wakamatsu et al. (1990) included *Helioentactinia* (?) *prismspinosa* in the *Devoniglansus unicus* assemblage. According to these authors the *D. unicus* assemblage was late Silurian but they did not know the relationship between this assemblage and the *Pseudospongoprunum sagittatum* assemblage. According to Umeda (1998), the *P. sagittatum* assemblage can be compared to the radiolarians from the upper part of the *Devoniglansus unicus- Pseudospongoprunum* (?) *tauversi* Zone whose age is regarded as Pridolian.

Genus *Stigmosphaerostylus* RÜST 1892

Type species: *S. notabilis* RÜST 1892

As suggested by Aitchinson & Stratford (1997) and later confirmed by Aitchinson et al. (1999), Luo et al. (2002) and Sashida et al. (2002), *Entactinia* FOREMAN 1963 is a junior synonym of *Stigmosphaerostylus* RÜST 1892. We accepted this opinion and use herein the genus name of *Stigmosphaerostylus* instead of *Entactinia*.

***Stigmosphaerostylus* cf. S. *variospina* (WON 1983)**
Plate I, Figs. 4, 10, 14, 17.

Remarks. – Internal shell features of these specimens are not observed, nevertheless the shell exhibits external characters similar to those of *S. variospina* (WON 1983).
Range. – *S. variospina* was reported in the Lower Carboniferous (Mississippian) of Thailand. According to Sashida et al. (1998) and Sashida et al. (2002) *S. variospina* ranges from the Late Devonian to the Early Carboniferous. Sashida et al. (1998) use this species as an index of a Famennian-Tournaisian assemblage.

***Stigmosphaerostylus* cf. S. *herculeus* (FOREMAN 1963)**
Plate I, Figs. 16, 18

Remarks. – Internal shell features of these specimens are not observed, nevertheless the shell exhibits external characters similar to those of *S. herculeus* (FOREMAN 1963).
Range. – Reported for the first time (Foreman 1963) in the Upper Devonian of the Huron Member of the Ohio Shale (USA) it was later reported in other Upper Devonian successions (Braun 1990; Braun et al. 1992).

Phylum Chordata BATESON 1886
Class Conodonta PANDER 1856
Order Ozarkodinida DZIK 1976
Family Palmatolepidae SWEET 1988

Genus *Palmatolepis* ULRICH & BASSLER 1926

Type species: *P. perlobata* ULRICH & BASSLER 1926

***Palmatolepis gracilis gracilis* BRANSON & MEHL 1934**
Plate I, Figs. 19, 22a–b

1934 *Palmatolepis gracilis* BRANSON & MEHL, p.238, pl.18, fig. 8 (*only*).

Remarks. – *Pa. g. gracilis* is characterised by a narrow platform and, in the lower surface, by a twisted keel around the basal cavity. The studied material consists of two almost complete specimens, and a couple of more fragmentary elements.
Range. – *Pa. g. gracilis* is known from middle and upper Famennian (Upper *rhomboidea* Zone – Upper *praesulcata* Zone, Ji & Ziegler 1993). However, a few authors (i.e.: Sandberg & Ziegler 1979, fig.1) dubitatively suggested the possibility to found representatives of the species in the lowermost Carboniferous, but no recent data seem to support this hypothesis.

Studied material: 4 elements.

***Palmatolepis gracilis sigmoidalis* ZIEGLER 1962**
Plate I, Figs. 21

1962 *Palmatolepis deflectens sigmoidalis* ZIEGLER, p.56, pl.3, figs.24–28.
1977 *Palmatolepis gracilis sigmoidalis* Ziegler – ZIEGLER in Ziegler (ed.), p.325, pl. *Palmatolepis*-7, figs.13–16 (*cum syn*).

Remarks. – *Pa. gracilis* characterised by a strongly sigmoidal twisting of the blade-carina and by a small, triangular platform. The studied element is incomplete, since the posterior part of the platform is missing.
Range. – Middle and upper Famennian (Upper *trachytera* Zone – Upper *praesulcata* Zone, Ji & Ziegler 1993).
Studied material: 1 element.

Family Polygnathidae BASSLER 1925

Genus *Polygnathus* HINDE 1879

Type species: *P. dubius* Hinde 1879

***Polygnathus vogesi* ZIEGLER 1962**
Plate I, Fig. 23

1962 *Polygnathus vogesi* ZIEGLER, p.94–95, pl.11, figs.5–7.

Remarks. – The single element studied is largely incomplete, since the posterior and the right anterior parts of the platform, as well as the blade, are missing. An evident ridge, diverging on acute angle from the carina is present on the left-anterior sector of the platform; posteriorly a very weak ornamentation is observable. These two features are diagnostic of the present species.
Range. – *Polygnathus vogesi* is reported from upper Famennian (Lower *expansa* Zone – Middle *praesulcata* Zone, Ji & Ziegler 1993).
Studied material: 1 element.

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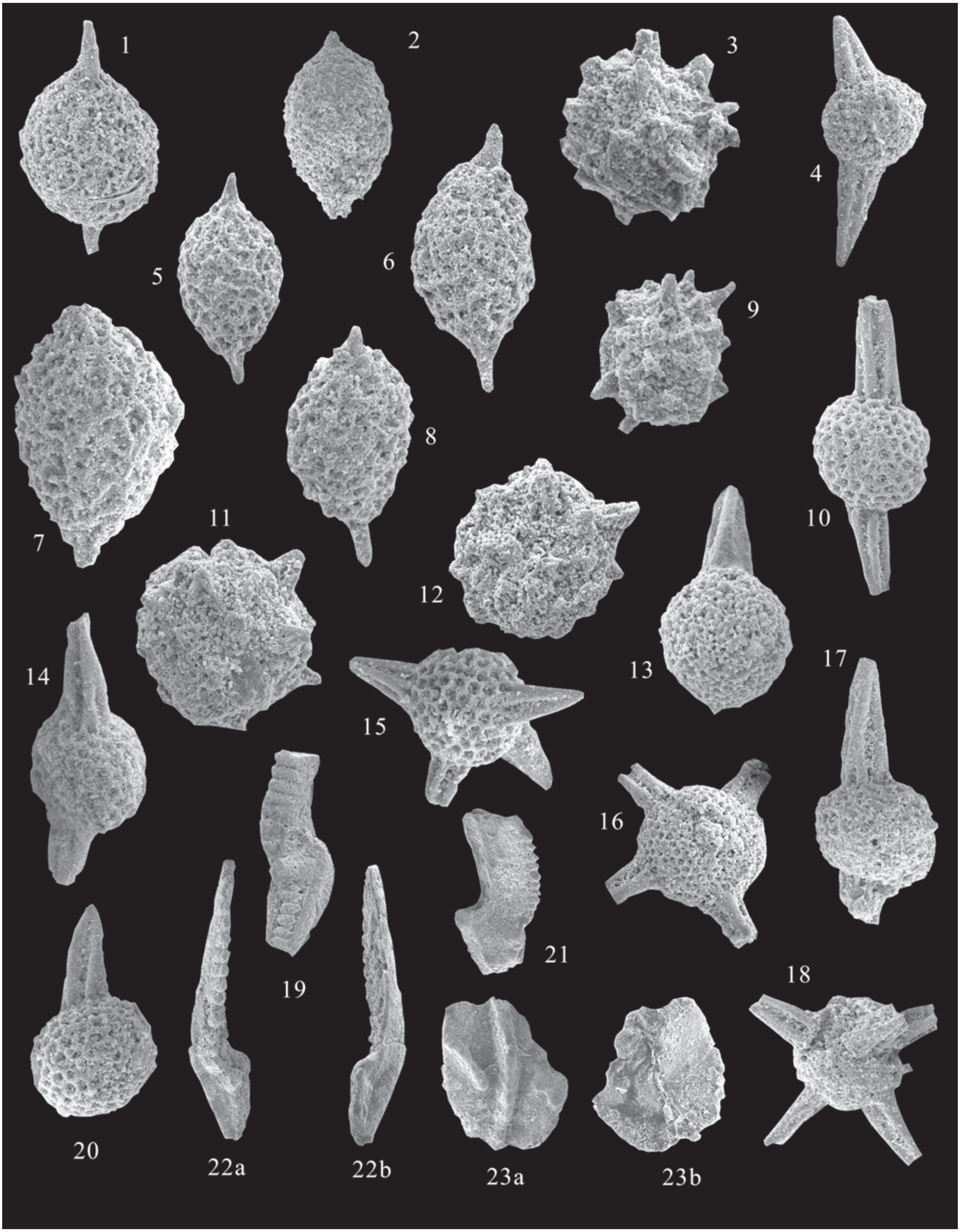
Plate 1

1–3, 5–9, 11, 12: sample CL230; 4, 10, 13–18, 20: sample 192; 19, 21–23: sample 231; *1 (X220): Pseudospongoprunum tazukawaensis* Wakamatsu, Sugyama and Furutani *1990*; 5 (X190), 6 (X190), 8 (X190): *Pseudospongoprunum sagittatum* Wakamatsu, Sugyama and Furutani 1990; 7 (X260): *Pseudospongoprunum* cf. *P. prototypum*; 2 (X160): ?*Devoniglansus* sp.; 3 (X230), 9 (X220): ?*Fusalfanus* sp.; 11 (X220), 12 (X 210): Spumellaria gen. et sp. indet.; 16 (X190), 18 (X180): *Stigmosphaerostylus* cf. *S. herculeus*; 4 (X150), 10 (X200), 14 (X200), 17 (X190): *Stigmosphaerostylus* cf. *S. variospina;* 13 (X200), 15 (X200), 20 (X200): Entactiniidae indet.; 19 (X95), 22 (X95): *Palmatolepis gracilis gracilis* Branson & Mehl 1934; 21 (X95): *Palmatolepis gracilis sigmoidalis* Ziegler 1962; 23 (X95): *Polygnathus vogesi* Ziegler 1962.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