Offshore to onshore transition in the Upper Viséan paleontological record from the Paprotnia section (Bardo Mts., West Sudetes)

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Abstract   This report provides detailed information on the taphocenosis succession from the Paprotnia series exposed in the western part of the Bardo Mts. (West Sudetes) and regarded as a temporal equivalent of the pelagic *crenistria* Limestone (cd III α, Upper Viséan). Five taphocoenoses have been recognised in the investigated section, which is composed of claystone and mudstone shales, greywackes and subordinately by carbonates. They differ mainly in terms of the relative frequency, size and state of preservation of specimens, and less in terms of their taxonomical composition. Changes in their vertical succession are coincidental with changes in the lithological record. Analyses of their taxonomical composition and various parameters of their paleontological record, reviewed herein, were used to estimate the paleoenvironment. Taphocoenosis I was deposited under low-energy conditions, probably in oxygen-deficient waters below the wave base. Taphocoenosis II was most likely accumulated in the environment located between the storm wave and fair weather wave bases, in oxygenated water. The fossils of assemblage III developed in a turbulent environment of well-oxygenated and relatively high-temperature shallow water. The organisms of taphocoenosis IV reflect renewed settling of the shallow seafloor during a short period of low energy conditions interrupted by the rapid delivery of a large quantity of terrigenic deposits. The uppermost part of the section, composed mainly of greywackes, which contain only the remains of terrestrial plants (taphocoenosis V) may suggest proximity to land. Both the paleontological and lithological features of the Paprotnia series indicate gradual environmental changes from offshore to onshore conditions. Consequently, the Paprotnia series represents the shallower facies equivalent of the pelagic *crenistria* Limestone, which is widespread in the Kulm facies of Variscan Europe.

INTRODUCTION

The complicated evolution of the early Carboniferous sedimentary environment in the Bardo Mts. unit is documented by the unit's great lithological diversity. The Lower Carboniferous is mainly composed of wildflysch and flysch. Locally, the flysch overlaid the Famennian–Lower Carboniferous deposits of the platform succession (Wajsprych, 1995). According to Wajsprych (1995), the uppermost part of the platform sequence, represented by the Paprotnia series, was accumulated during the "crenistria transgression". It is regarded by the author as a temporal equivalent of the *crenistria* Limestone (cdIII α, Upper Viséan).

The *crenistria* Limestone is widespreaded in the Kulm facies of Variscan Europe and forms a distinct set of three beds (see Jackson, 1990; Warnke, 1997). These limestone beds above all contain a pelagic fauna, mainly represented by planktonic, pseudoplanktonic and nektonic organisms; fossils of benthonic organisms are usually rare (Wranke, 1997). The origin of the limestone is interpreted in different ways. Jackson (1990) suggests that it is the result of inorganic precipitation in peculiar oceanographic conditions (an oxygenated seaflor with temporarily increased salinity). Herbig (1994, see Wranke, 1997) considers that it was deposited in conditions of sea-level highstand, whereas Wranke (1997) concluded that the carbonate forming the beds originated from microbial calcite precipitation, and fit them into a paleo-oceanographic model. According to him, the process was induced by the decomposition of the soft tissue of radiolarians and siliceous sponges in oxic bottom waters. The oxic conditions are well-documented by the high content of Mn and the presence of benthic organisms (sponges and bioturba-
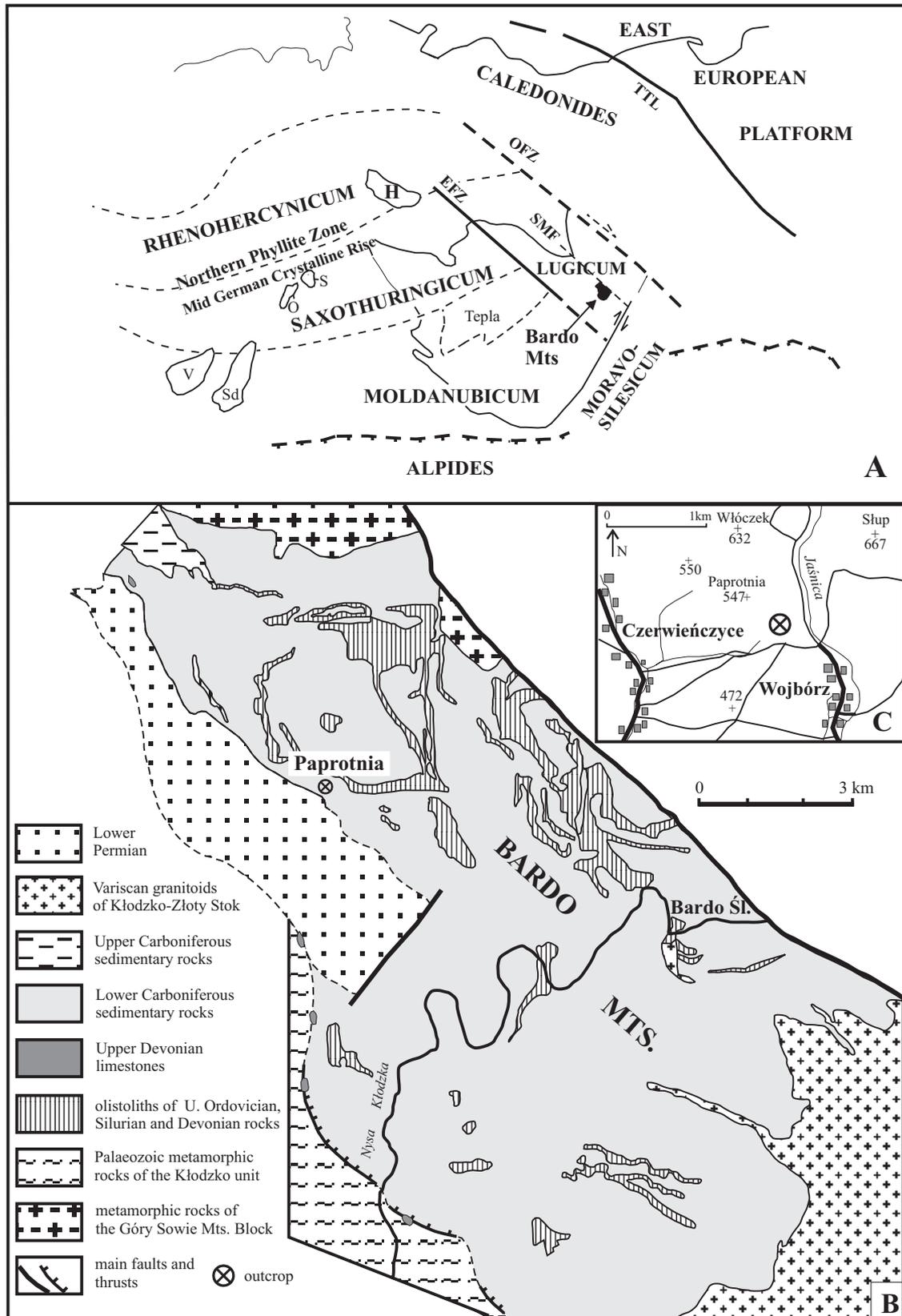
Fig. 1. Geological position of the Bardo Mt. unit (map B) in central Europe (map A). Inset map C shows location of the studied outcrop. Map A: EFZ – Elbe Fault Zone; H – Harz; O – Odenwald; OFZ – Odra Fault Zone; S – Spessart; Sd – Schwarzwald; SMF – Sudetic Marginal Fault; TTL – Teisseyre-Tornquist Line; V – Vosges.

tions) throughout the limestone beds. On the other hand, Wajsprych (1995) postulated a different concept of origin for their temporal eqivalent, which occurs in the Bardo unit and is distiguished as the Paprotnia series. In his opinion, both the fauna and carbonates of this series were developed in chemogenic vent-related conditions, with methane supplying the animals with energy and food, and the authigenic carbonates with carbon.

In the Bardo region, the best outcrop of the Paprotnia series is located on southern slope of Paprotnia hill, about 1.5 km east of the village of Czerwieńczyce (Fig. 1). The exposed beds contain a very rich paleontological record, which has been studied by many geologists and paleontologists (see Schmidt, 1925; Paeckelmann, 1930, 1931; Kühne, 1930; Górecka, 1958; Żakowa, 1963; Górecka & Mamet, 1970; Fedorowski, 1971). In most cases, these investigations have been restricted to determining the species composition of selected systematic groups, and to defining the chronostratigraphical affiliation of their host sediments. Only Górecka (1958) and Fedorowski (1971)

described the vertical distribution of the certain groups (flora and corals) and the most abundant other fossils occurring in this section. According to Fedorowski (1971), the coral communities, distinguished on the basis of the frequency composition of their composite taxa, display differences resulting from the influence of facial changes. In his opinion, it is not unlikely that the periodically exuberant development of corals took place in a bay connected with the open sea.

This conclusion and another interpretation of the environmental conditions under which the Paprotnia series was accumulated, presented by Wajsprych (1995), inspired us to provide a detailed study of its paleontological record as an environmental indicator. Analysis of fossil distribution in the lihological record, the character of their accumulation, their state of preservation and their taxonomical composition were used to reconstruct the environmental conditions under which the organisms might have existed.

GEOLOGICAL AND STRATIGRAPHICAL FRAMEWORK

The Bardo Mts. form a separate structural unit within the West Sudetes (Fig. 1). This complex structure consists in general of sedimentary and a minority of slightly metamorphosed rocks representing a vast time span from at least Late Ordovician to earliest Late Carboniferous. Its lithological column does not represent any single nor continuous stratigraphic sequence.

Recently, two main successions were distinguished by Wajsprych (1986, 1995) within the Upper Ordovician–Lower Carboniferous rocks:

1. An allochthonous, completely exotic succession assigned to the Upper Ordovician–Devonian. According to Wajsprych (1995), this succession is composed of no less than three different flysches, which can be regarded as active continental margin deposits.

2. An autochthonous (parautochthonous) Famennian–Lower Carboniferous platform-to-foreland succession, composed of carbonates and several facially differentiated series. The upper part of this succession is represented by flysch and wildflysch sediments with olistoliths of Ordovician to Devonian rocks, which indicate the foreland-type deposition regulated by an invaiding orogenic front (Wajsprych, 1995, see also Fig. 11).

According to Wajsprych (1995, see also Fig. 18), the sediments of the allochthonous succession were thrust over the platform deposits in the late stages of platform de-

velopment, probably after the *crenistria* Chron.

Several lithostratigraphical units have been distinguished among the Lower Carboniferous deposits. Their stratigraphical succession has been corrected taking into account new paleontological data (Oberc, 1957, 1980; Żakowa, 1963; Wajsprych, 1978, 1995; Haydukiewicz, 1990). Reconstruction of their primary stratigraphical succession is still difficult because of the complicated tectonic framework of the Bardo unit (Oberc, 1957, 1972, 1987, 1991).

In the model of tectono-stratigraphic framework of the Bardo unit proposed by Wajsprych (1995), the sediments under investigation belong to an autochthonous/parautochthonous platform-to-foreland succession. Their Late Viséan age was determined based on the occurrence of brachiopods, goniatites, corals and foraminifers (Schmidt, 1925; Paeckelmann, 1930, 1931; Górecka, 1958; Górecka & Mamet, 1970; Fedorowski, 1971). In older literature, these sediments were described as the shale-greystone series (Finckh *et al.*, 1942), while Oberc (1957) distinguished them as an "upper horizon of Carboniferous Limestone" and Żakowa (1963) described them as "the Czerwieńczyce beds". In the recently-created lithostratigraphic scheme for the Bardo unit, they are designated as the "Paprotnia series" (Wajsprych, 1995) (Fig. 2).

THE LITHOLOGY OF THE PAPROTNIA SERIES SECTION

The section under investigation is situated in the road-escarpment of the path to Wojbórz from the eastern end of Czerwieńczyce village, about 500 m SE of Paprot-

nia hill (547.3 m) (Fig. 1). The lithology, fauna and flora have been already described on more than one occasion (Oberc, 1957; Górecka, 1958; Fedorowski, 1971; Wajs-

Standard division			after Oberc, 1957 generalized	after Żakowa, 1963	after Wajsprych, 1995
		γ granosus		NW probably stratigraphic gap SE	WŁÓCZEK SEQUENCE
	Goniatites - Go				ORZECH SQ. ?
		β striatus	Wilcza conglomerates	Wilcza conglomerates shale-greystone serie	SREBRNA GÓRA FM WILCZA SERIES
VISEAN		α crenistria	upper horizon of Carboniferous Limestone	Czerwieńczyce beds	PAPROTNIA SERIES WINNA GÓRA SQ.
		δ	shale	greywackes	
			and		NOWA WOJBÓRZ
	Ammonellipsites (Pericyclus) - Pe		greywacke	Ostróg beds	
			series	Carboniferous from Widałek and Chełmik	WIEŚ SEQUENCE
		γ	lower horizon of the Carboniferous Limestone (Kohlenkalk)	Limnic deposits	FM
			gneissic conglomerates greywackes		
TOURNAISIAN		β		stratigraphical gap	
		α	?		GOŁOGŁOWY FM.
					WAPNICA FM.
	Gattendorfia	crassa	Gattendorfia limestone	Wapnica beds	
		subinvoluta			

Fig. 2. Proposed different lithostratigraphical divisions of the Lower Carboniferous of the Bardo Mt. unit.

prych, 1995 b). The descriptions of the lithological record presented by the mentioned authors differ in their details, and the frequency relationships of the different faunal groups were only elaborated on very generally (Górecka, 1958; Fedorowski, 1971).

The Paprotnia series as excavated in this locality is mainly represented by claystone and mudstone shales and greywackes, and subordinately by carbonates, which are about 13.7m thick (Fig. 3). The deposits predominantly contain fossils of benthonic fauna. Pelagic organisms are less frequent (Fig. 4, 5). Intercalations of thin, light yellow bentonite layers were also observed in several horizons. They are the objects of separate studies. The strata dip 50–60° to the north. In the topmost part of the section, the Paprotnia series passes gradually to the polymictic Wilcza conglomerate (Oberc, 1957; Żakowa, 1963).

The lowermost part of the section comprises greenish-grey and grey claystone and mudstone shales (Fig. 6A, B). Their individual layers are several centimetres thick. Some of them are thinly laminated. Laminae consist of quartz grains or contain a greater accumulation of floral debris. A few intercalations of thin dark-grey micritic limestone beds (up to 3.0 cm thick) occur within the shales. The 1.5m thick deposits are overlain by dark-grey and dark-olive mudstone shales (Fig. 6C, D). They are successively upwards-intercalated with thin layers (2–4 cm thick) of grey claystones and greywackes. Also, six bentonite layers (from 1 cm to 10 cm thickness) and irregularly distributed small mudstone nodules can be found within the 5.3m thick shale package. The middle part of the section comprises sandy-mudstone shales (Fig. 7B, D) and greywackes with lenses and nodules of dark-grey organo-detrital limestones, which usually form distinct horizons. The abundance of the carbonate lenses distinctly decreases upwards (Fig. 3). In most cases, the lower part of a given lens is composed of bioclastic packstone (Fig. 6E, F; Fig. 7A, C), whereas its upper part consists of poorly-fossiliferous fine-grained wackestone. The maximum thickness of the lenses ranges up to 40 cm. The sediments of the middle part of the section (about 4m thick) are overlain by greywackes containing rare sandy and mudstone shale intercalations. These greywackes terminate the Paprotnia series, passing gradually to the polimictic Wilcza conglomerates with sandstone and mudstone intercalations.
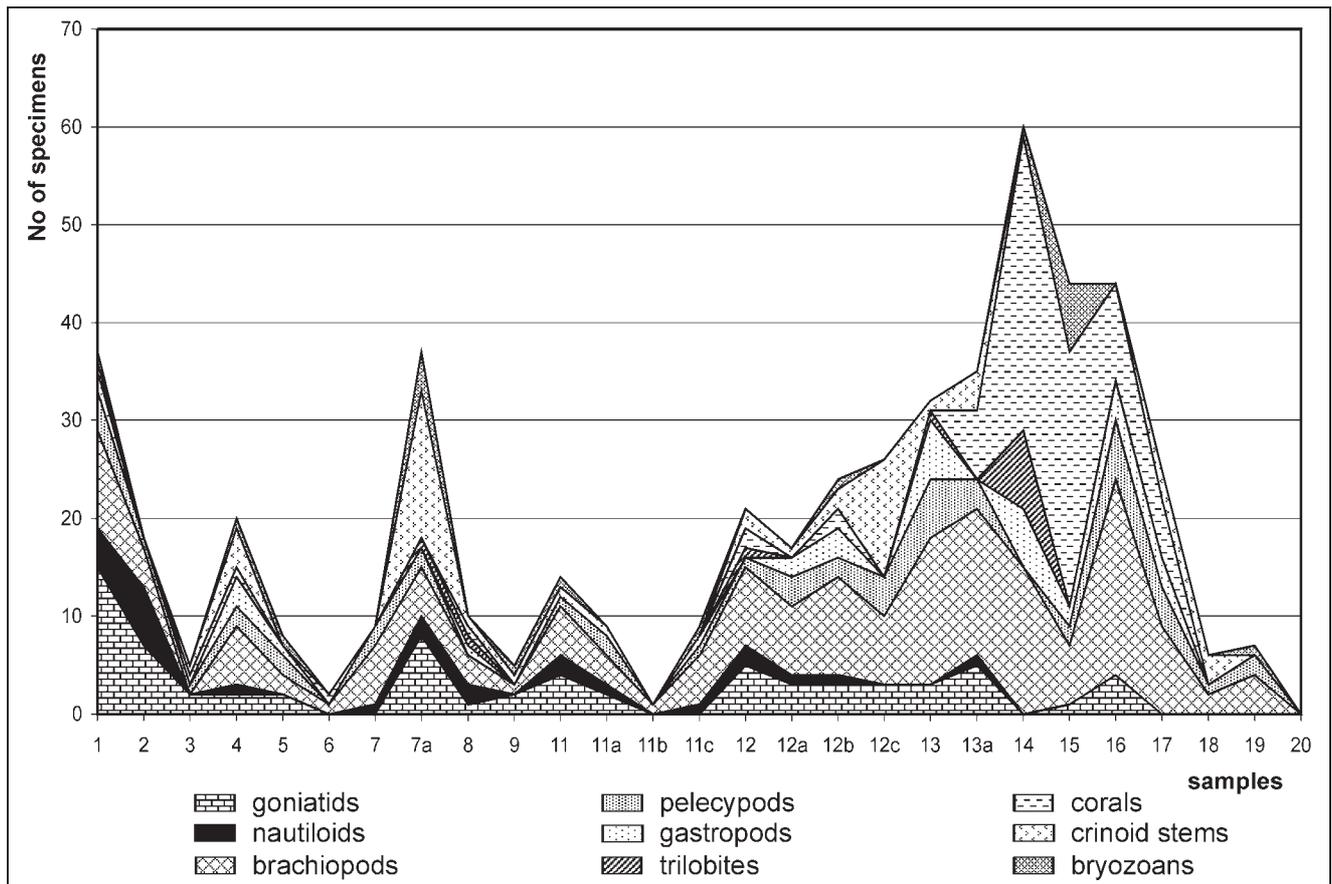
Fig. 3. The lithology and taphocoenosis succession in the Paprotnia section.

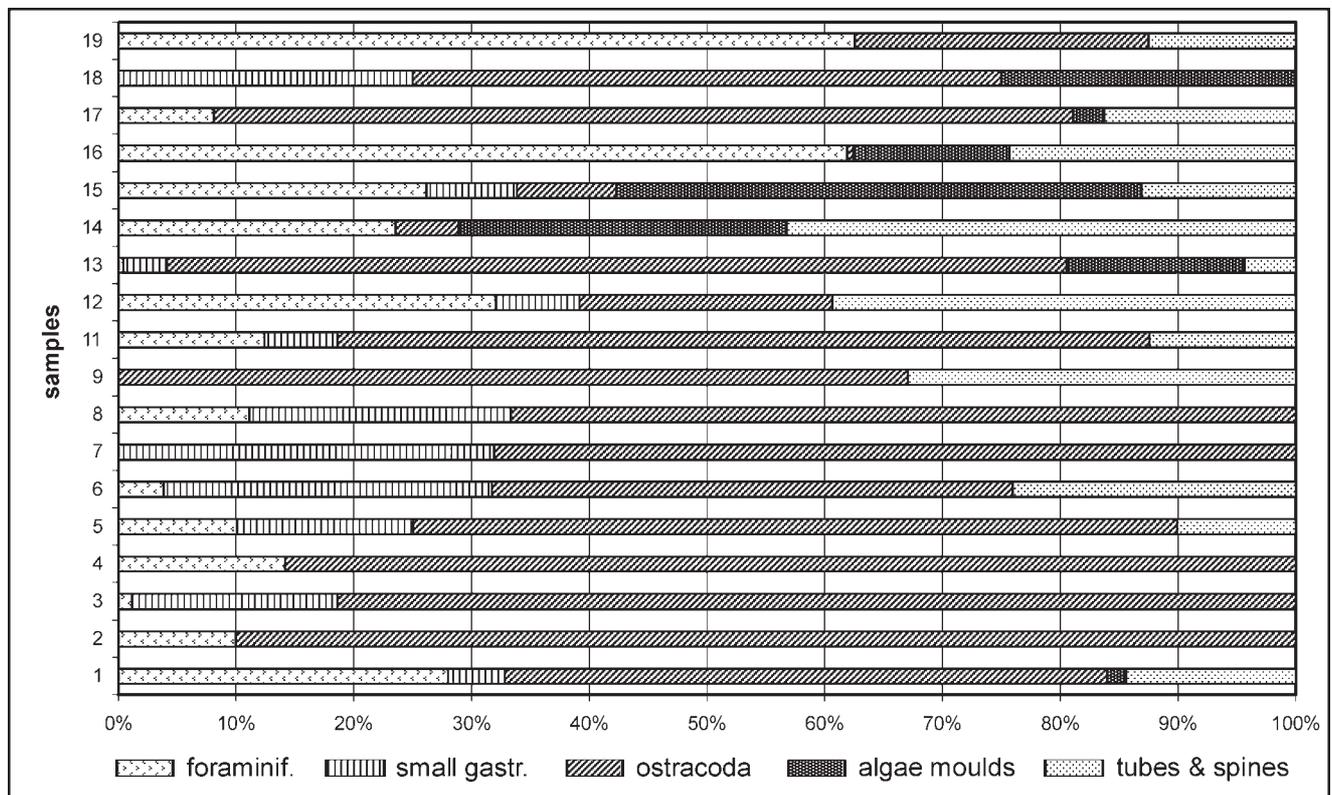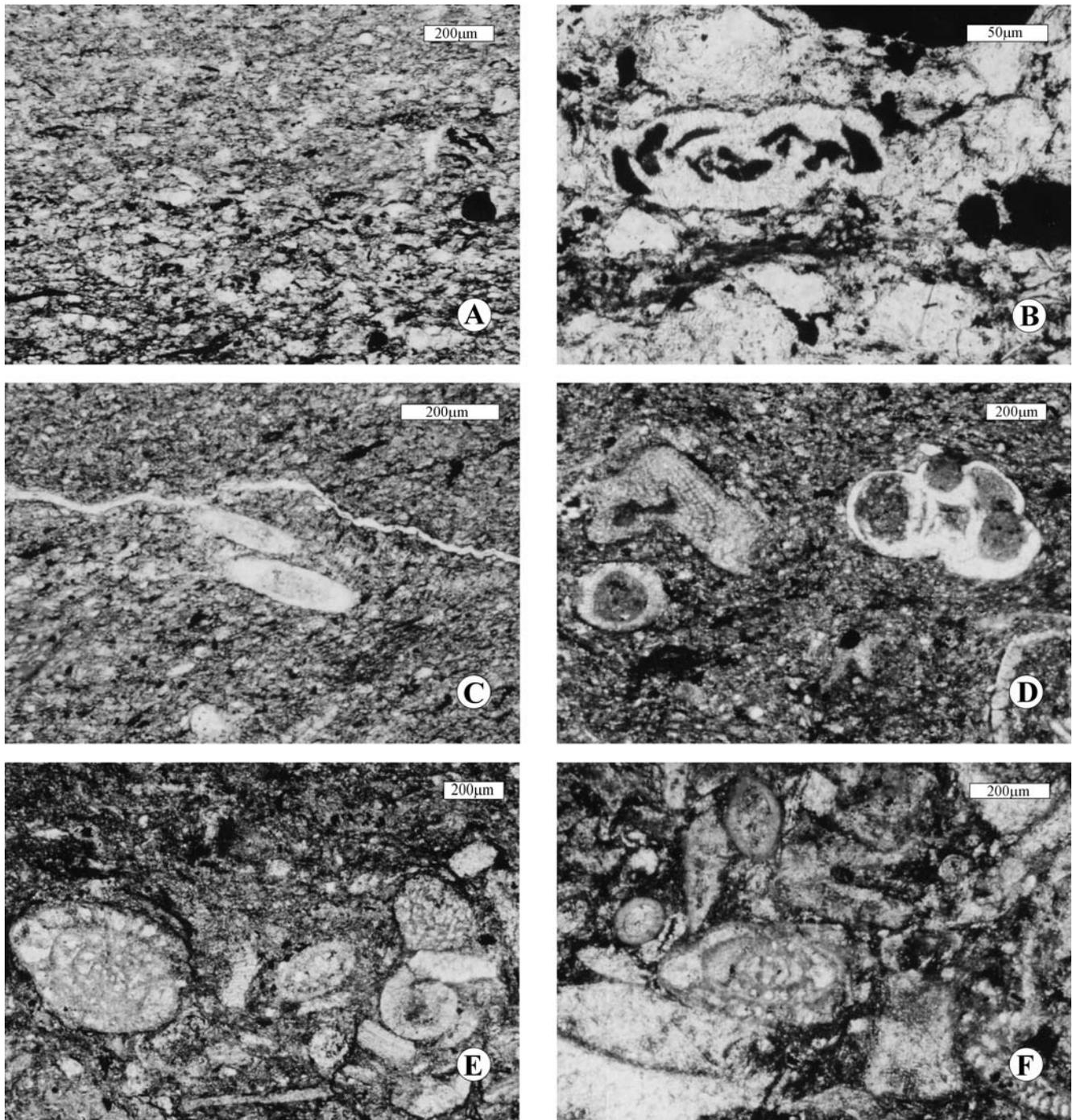**Fig. 4.** The relative frequency of macrofossils in the Paprotnia section.

Fig. 5. The relative frequency of the most common microfossils and organic micro-remains in the Paprotnia section.

Fig. 6. A, B – Clayey mudstone shale with sclerotioid grains and rare foraminifers (*Archaeodiscus* sp.), thin section, sample Pa1. **C** – Clayey mudstone with bioclasts, thin section, sample Pa11. **D** – Clayey mudstone with bioclasts of algae (*Stacheia* sp., *Nanopora* sp.) and molluscs, thin section, sample Pa12b. **E, F** – Bioclastic packstone with abundant fragments of dasycladacean alga and foraminifers, thin section, sample Pa17.

METHODS

The fossil content from the various types of sediment of the Paprotnia series were examined in detail to interpret depositional environment. Analysis of the character of macrofossil accumulations was the main point of the investigation. 32 samples of about 2 kg each were taken from individual layers along their accessible strike. Macrofossils of each taxonomical group obtained from each sample were separately counted. The data were plotted on a diagram to illustrate the vertical distribution of their relative frequency in the section.
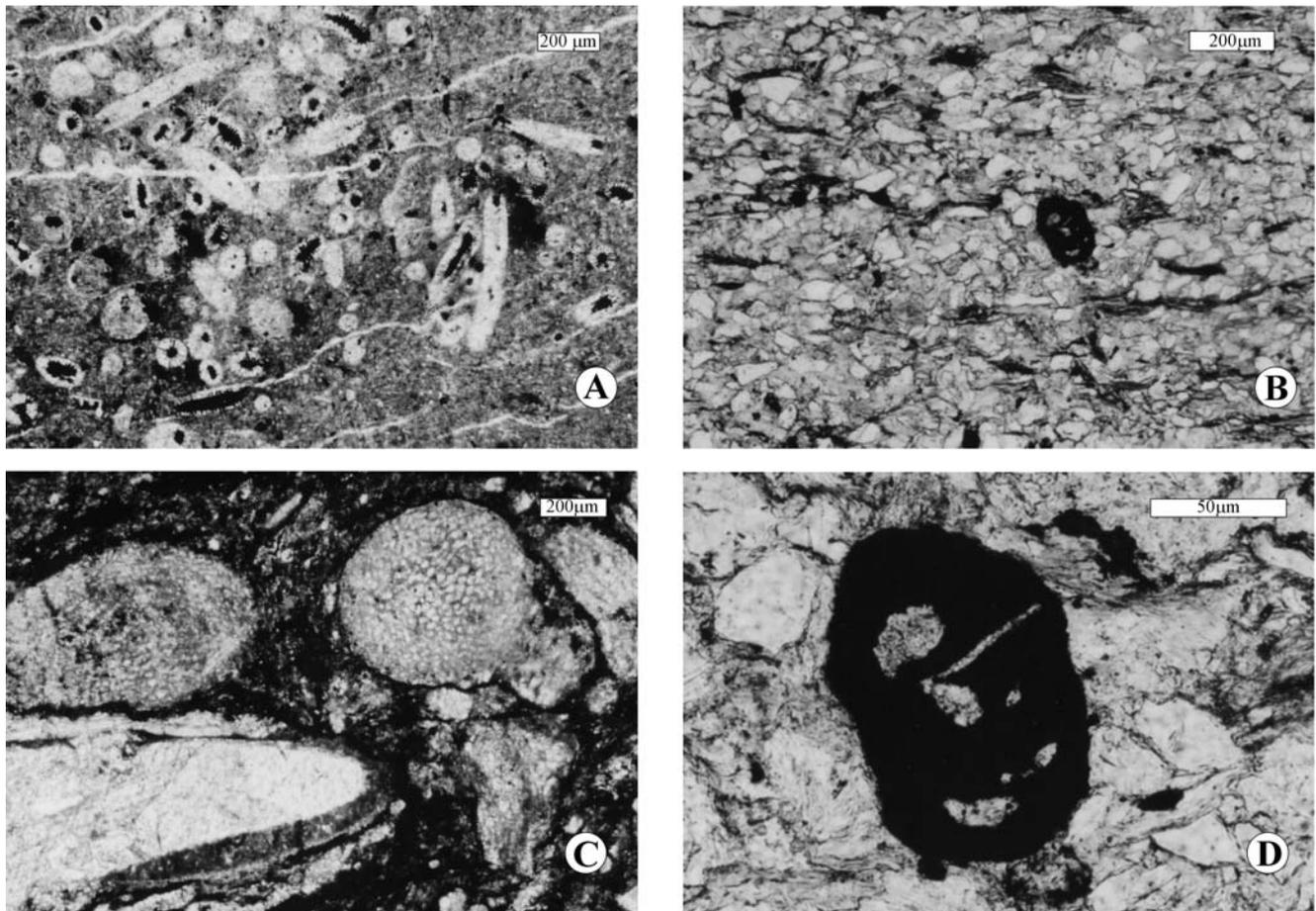
Fig. 7. **A** – Accumulations of *Nanopora* sp. in micrite matrix, thin section, sample Pa14. **B, D** – Mudstone surrounding calcareous lenses with foraminifera impregnated by iron oxide, thin section, sample Pa16. **C** – Bioclastic packstone with Stacheiinae (?), thin section, sample Pa17.

In the case of brachiopods, pelecypods and gastropods, specimens were counted if at least 2/3 of their shell or its impression was preserved. In the case of nautiloids, only specimens considered big enough, containing at least 5 chambers, were taken into account. In the case of ammonoids, only specimens with at least 3 whorls (individuals of small size) or half a whorl of at least 1.5 cm high were analysed. Coralites had to be at least 1 cm long, and crinoid stem fragments at least 0.4 cm in diameter, for them to be included in the count. We only counted whole pygidias of trilobite, and all visible fragments of bryozoan colonies were included.

In the next stage, 0.5 kg of each sample was used for microfaunal investigations. The microfaunistic samples were disaggregated with Na_2SO_4, and washed with water. The 0.125 mm sieve fraction was collected. The specimens of the different microfossil groups were counted to plot a bar chart of their relative frequency (Fig. 5).

Photos of microfossils and algae were taken using a JSM 5800LV Jeol electron scanning microscope.

PALEONTOLOGICAL MATERIAL

The macrofossils from the Paprotnia section represent taxonomically differentiated benthic and nektonic assemblages. The rich benthonic fauna is clearly dominated by brachiopods and corals (mainly colonial rugosa). Pelecypods, gastropods, fragments of crinoids, bryozoa colonies and trilobites are less numerous (Fig. 4). Fossils of nektonic organisms (goniatids and nautiloids) are common. The sediments of this section also contain ostracods, foraminifers, numerous fragments of calcareous algae and different kinds of calcareous tubes and spines (some of them are probably of polychaetid and brachiopod origin) (Fig. 5). The macrofloral elements, diminutive plant debris and sclerotioid grains are distributed in nearly all the lithologies.

Brief descriptions of the state of preservation, size variations and shell concentrations of the most common fossils are presented below.

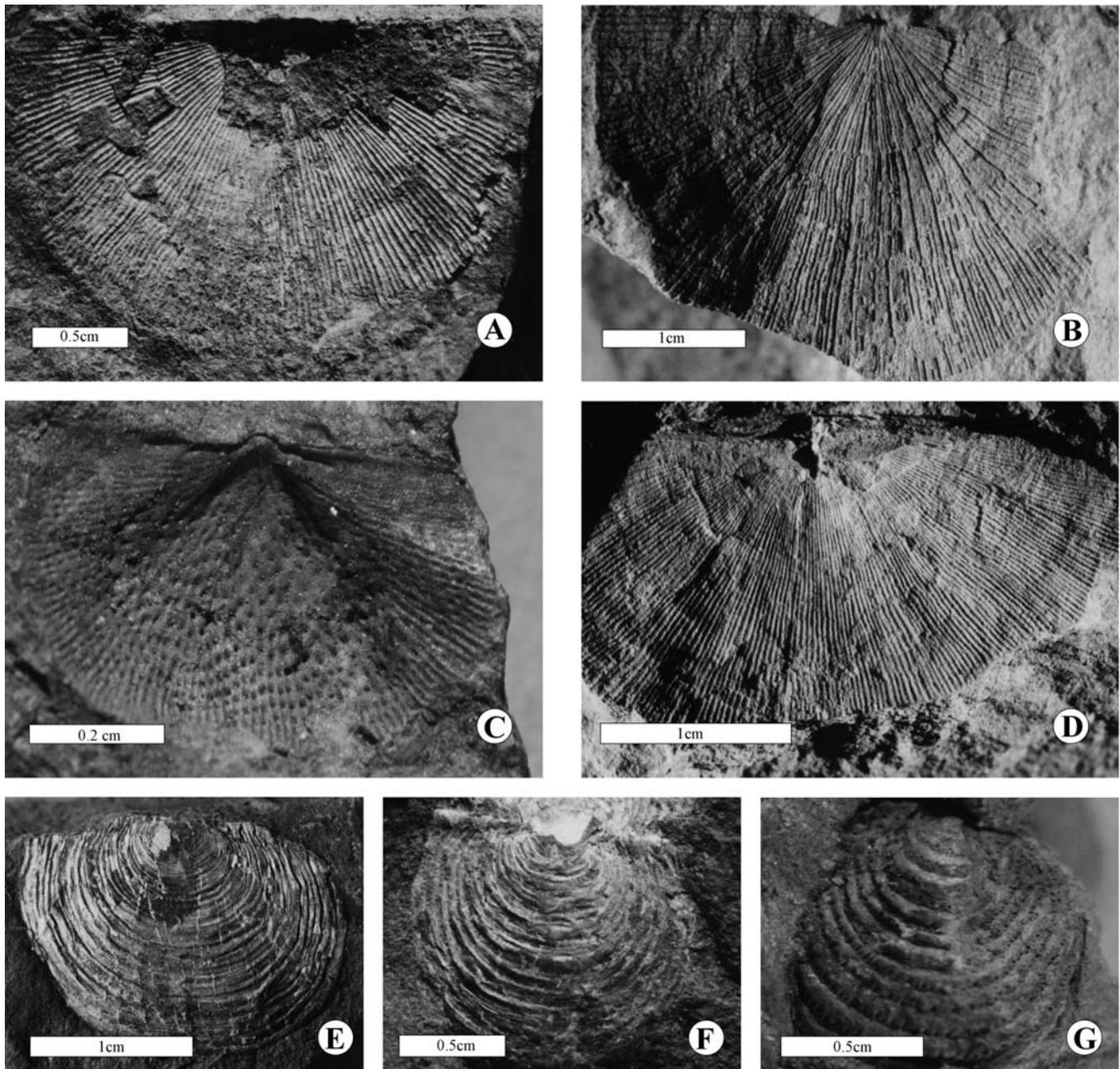Brachiopods are mainly represented by specimens of

Fig. 8. Brachiopods: **A** – *Schellwienella crenistria* (Phill.), sample Pa16a; **B** – *Schuchertella portlockiana* (v.Sem.), sample Pa14; **C** – *Rugosochonetes laguessianus* (de Kon.), sample Pa13; **D** – *Megachonetes zimmermanni* (Paeck.), sample Pa 14; **E, F** – *Chonetipustula carringtoniana* (Dav.), sample Pa1; **G** – *Echinoconchus punctatus* (Sow.), sample Pa14.

Productacea, Chonetacea, Spiriferacea and probably Orthida (Tab. 1; Fig. 8A–G; Fig. 9A–F). Paeckelmann (1930, 1931) made the first description of some of their species. Valves or their fragments and impressions are present in nearly all the samples of the section, excluding samples Pa3 and Pa20. The impressions of valves and their rare fragments usually occur in shales or sandy sediments. In these sediments, the specimens of particular taxa of strophomenids usually do not reach considerable size; exceptionally, some of them reach a maximum width of about 4–5 cm. Only in the case of gigantoproductids does the valve width reach 7–12 cm. Concentrations of their almost complete valves were found in the lower parts of calcareous nodules and lenses together with accumulations of corals. Within the sandy mudstones surrounding the lenses, their large valves are usually strongly cracked. Spiriferid specimens are usually of modest size, with the valves of their biggest specimens of a maximum width of 3.0 cm. In the upper part of the section (samples Pa18, Pa19), above the calcareous lenses, the brachiopods are distinctly smaller (the width of productid valves is below 3 cm), and less frequent (Fig. 4). Neither valves nor impressions of brachiopods form distinct concentrations (excluding calcareous lumps). They are evenly distributed in the sediment.
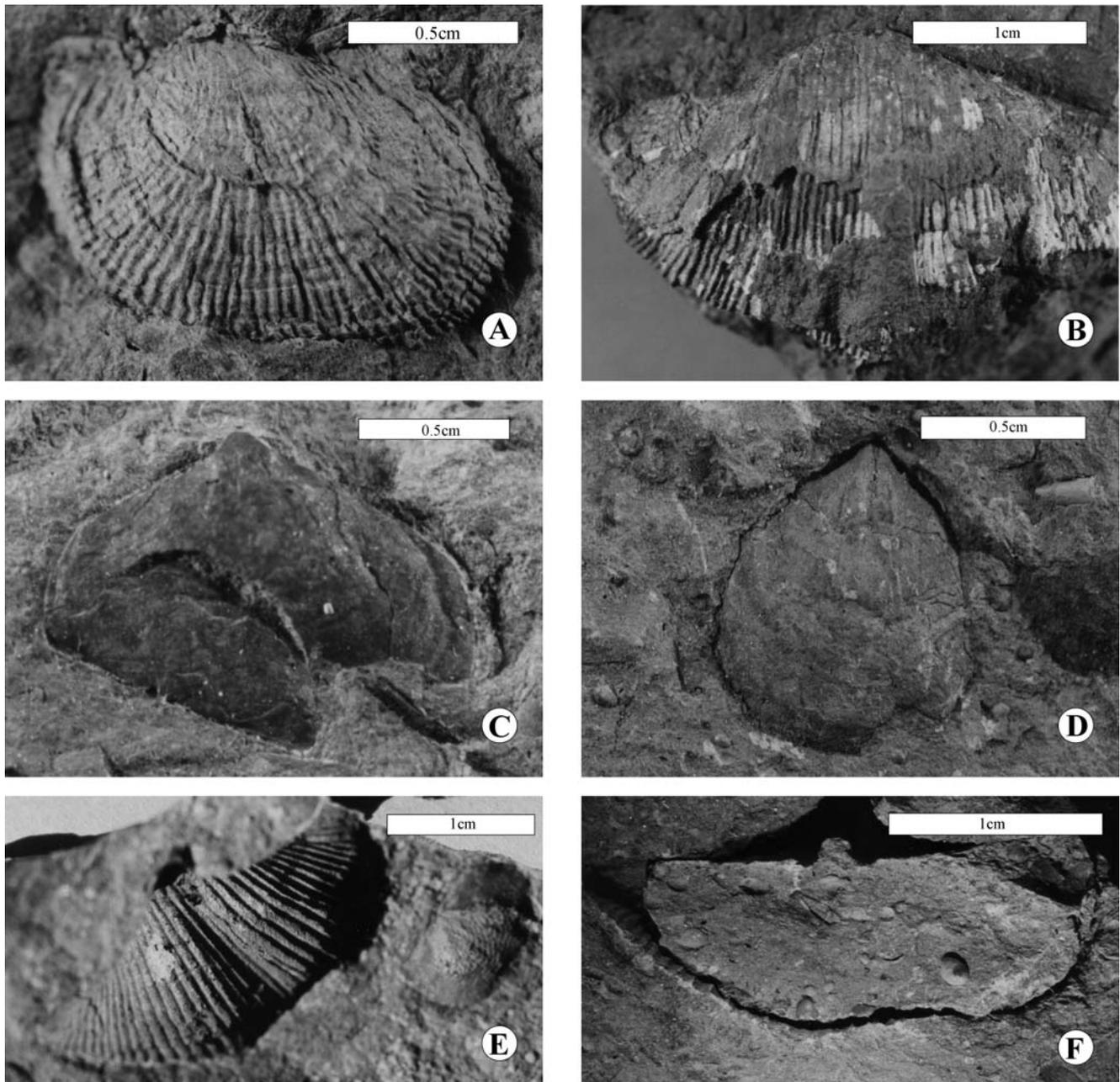
Fig. 9. Brachiopods: **A** – *Eomarginifera* sp., sample Pa14; **B** – *Gigantoproductus latissimus* (Sow.), sample Pa15; **C** – *Athyris expansa* (Phill.), sample Pa1; **D** – *Dielasma hastata* Sow., sample Pa13; **E** – *Spirifer trigonalis* Mart., *Rugosochonetes laguessianus* (de Kon.), sample Pa13; **F** – *Spirifer trigonalis* Mart. – part of mould with numerous ostracods, sample Pa13.

List 1
The list of Rugosa taxa from the Paprotnia section, as determined by Fedorowski (1971)
Cyathaxonidae Milne-Edwards & Haime
Fasciculophyllum bowerbanki (Milne-Edwards & Haime)
F.omaliusi (Milne-Edwards & Haime)
Rotiphyllum rushianum (Vaughan)
Cryptophyllum hibernicum de Konick
Polycoeliidae Roemer
Hapsiphyllidae Grabau
Caninophyllum archiaci Milne-Edwards & Haime
Clisiophyllum keyserlingi McCoy
Dibunophyllum bipartitum bipartitum (McCoy)

D. bipartitum konicki (Milne-Edwards & Haime)
Lithostrotion junceum (Fleming)
L. pauciradiale McCoy
L. caespitosum (Martin)
L. volkovae Dobrolubova
L. mccoyanum Milne-Edwards & Haime
Diphyphyllum lateseptatum McCoy
Slimoniphyllum slimonianum (Thomson)
Aulophyllum fungites (Fleming)
Konickophyllum magnificum Thomson & Nicholson
Heterophyllia grandis McCoy
Hexaphyllia marginata (Fleming)
    Corals are mainly represented by colonial rugosa;
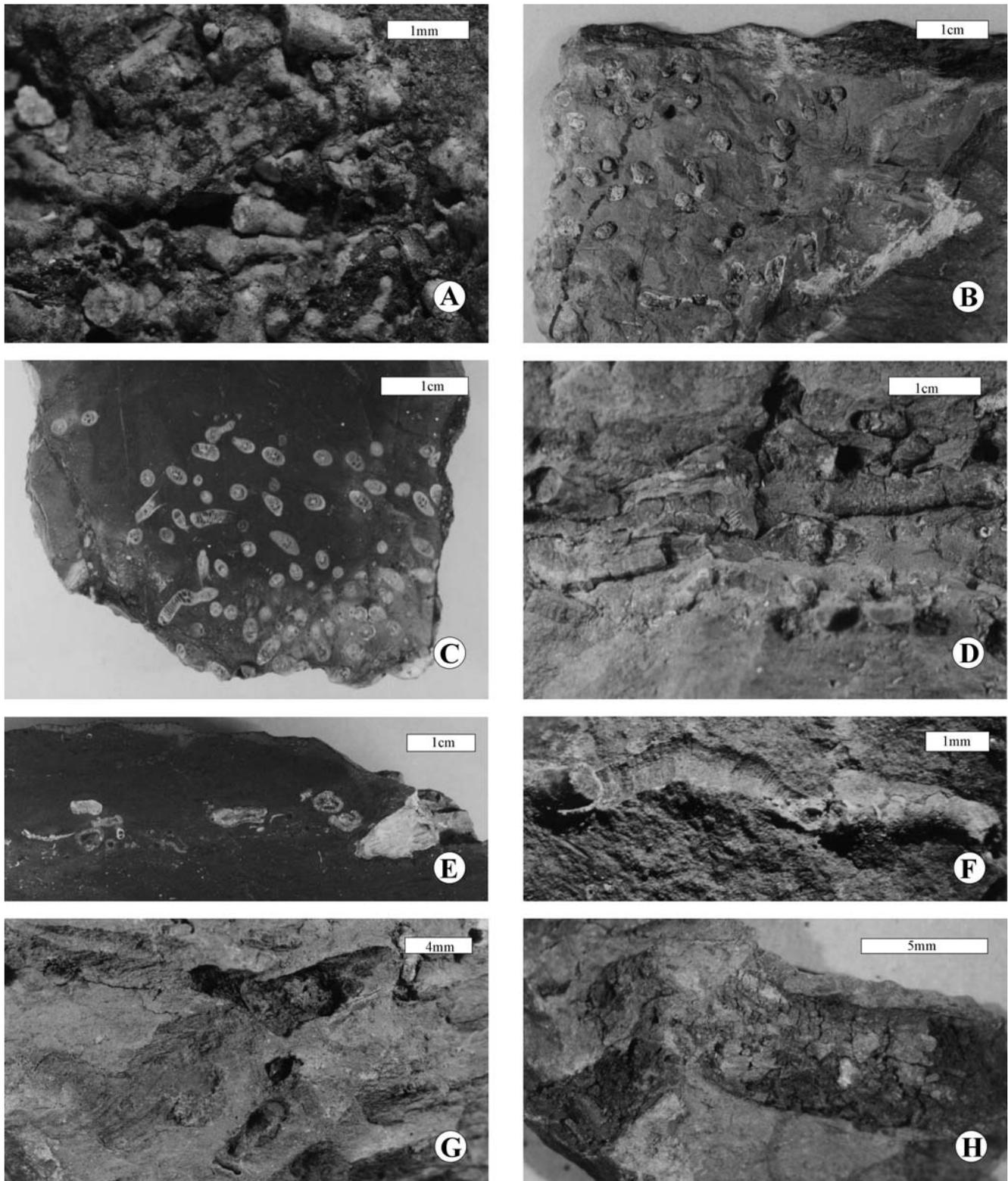
Fig. 10. **A** – accumulation of calcareous alga, sample Pa16; **B–E** – concentrations of corals in the calcareous lenses, sample Pa14; **C, E** – polished slabs; **F** – fragment of polychaetid tube, sample Pa13a; **G, H** – trace fossils, partly-preserved spongy lining is visible in the channels, sample Pa14.
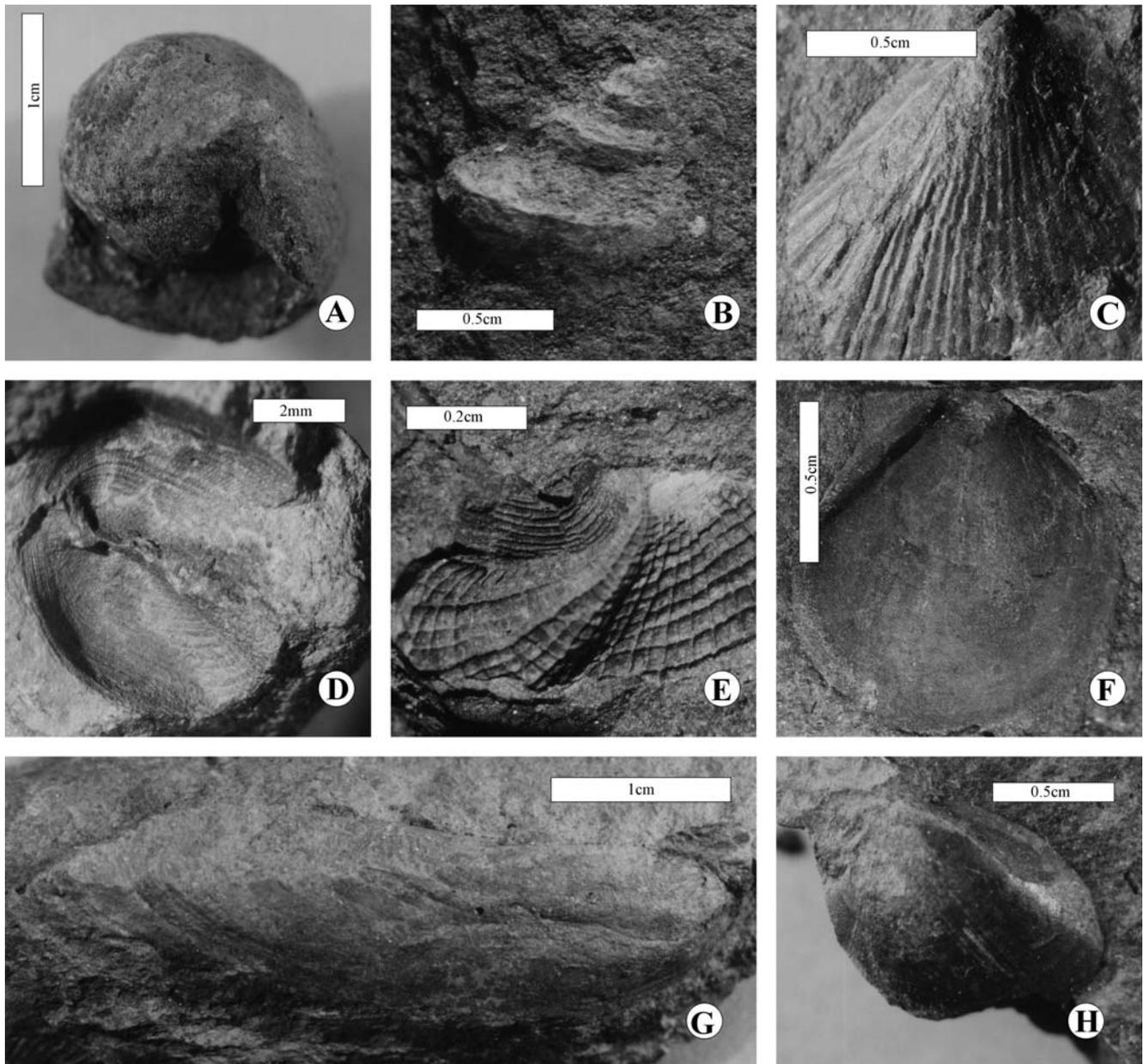
Fig. 11. Gastropods: **A** – *Bellerophon* sp., sample Pa11; **B** – *Ptychomphalus intermedius* de Kon., sample Pa1. Pelecypods: **C** – *Paleolima simplex* Phill., sample Pa17; **D** – *Parallelodon semicostatus* McCoy, sample Pa15; **E** – *Parallelodon reticulatus* McCoy, sample Pa5; **F** – *Streblochondria elliptica* (Phill.), sample Pa11a; **G** – *Sanguinolites* sp., sample Pa17; **H** – *Protoschizodus* sp., sample Pa1.

solitary species are rare. The species identified by Fedorowski (1971) are mentioned in List 1. We found some small fragments of tabulates. Colonial rugosa are predominant in calcareous lumps and lenses, mostly forming nests in the life position. According to Fedorowski (1971), various species of *Lithostrotion*, forming bushlike (phaceloid) colonies are the most frequent representatives of this fauna. Their maximum length is about 10–12 cm; their diameter varies from 0.3 to 0.6 cm (samples Pa13–Pa17). They also form concentrations of crushed corallities in the lower part of calcareous lenses (Fig. 4; Fig. 10B–E). The distance of their redeposition was rather short. In the limestone lenses and in the sandy mudstones surrounding them, solitary tetracorals are also dispersed. The largest in-

dividuals reach 5 cm in length and have diameters of about 1–3 cm. Scarce specimens of solitary rugosa of considerably smaller size (maximum 3 cm long) occur in the mudstones of the lower part of the section (below sample Pa13). Some of them are in the life position and some are overturned but without traces of transportation. Fedorowski (1971), analysing the frequency of various rugosa species, recognised a few coral assemblages. In his opinion, all of them are typical for the D_2 coral zone of the British nomenclature.

Scarce pelecypod moulds, impressions and shell fragments occur in nearly all the beds of the section, excluding the greywackes (Fig. 4). They are mainly represented by infaunal and some epifaunal species (Tab. 1). The infaunal

The composition and occurrence of macrofossils in the Paprotnia section

Taxa	samples					Taxa	samples				
	1-2	3-13	13a-17a	18-19	20-20c		1-2	3-13	13a-17a	18-19	20-20c
	taphocoenoses*						taphocoenoses*				
	I	II	III	IV	V		I	II	III	IV	V
Ammonoidea/Goniatitida						**Anthozoa**					
Goniatites crenistria Phill.			+			Rugosa		++**	+++*		
Goniatites sp.	+++	++	+			Favositidae indet.		+			
Nomismoceras sp.	+++	+				**Pelecypoda**					
Nautiloidea						Protoschizodus axiniformis Portl.			+		
Dolorthoceras sp.	+	+				Protoschizodus	+				
orthocone	+	+				Nuculavus cf. gibbosa Flem.		+			
Brachiopoda						Nuculavus sp.		+	+		
Leptaenella analoga (Phill.)			+			Palaeoneilo sp		+			
Schellwienella crenistria (Phill.)			+			Parallelodon reticulatus McCoy		+	+		
Schuchertella portlockiana (v. Sem)			+			P. semicostatus McCoy			+		
Schuchertella sp.			+			Edmondia sp.		+	+	+	
Chonetes sp.		+				Sanguinolites sp.			+		
Rugosochonetes laguessianus (de Kon.)	+	+	++			Paleolima simolex Phill.			+		
Plicochonetes sp.			+			Streblochondria elliptica (Phill.)		+			
Paeckelmannia konickiana (v. Sem)	+					Streblochondria sp.	+	+	++		
Megachonetes zimmermanni (Paeck.)			+			Aviculopecten semicostatus Portl.	+				
Chonetipustula carringtoniana (Dav.)	++					**Gastropoda**					
Chonetipustula sp.		+				Bellerophon sp.		+			
Pustula pyxidiformis (de Kon.)		+				Ptychomphalus intermedius de Kon.	+				
Pustula sp.		+	+			Ptychomphalus sp.		+			
Eomarginifera sp.		+	+			Euphemites urei (Flem.)		+			
Antiquatonia sp.		+				Euphemites sp.		+			
Echinoconchus punctatus (Sow.)		+	+			Soleniscus sp.			+		
Gigantoproductus latissimus (Sow.)			++			Murchisonia archiaciana de Kon.		+			
Gigantoproductus gigantheus (Paeck.)			++			Loxonema cf. sulcatum de Kon.			+		
Gigantoproductus sp.		+	+			Loxonema sulcatula McCoy			+		
Productidina indet.				+		Loxonema sp.		+	+		
Athyris expansa (Phill.)	+	+				**Trylobita**					
Athyris sp.	+	+	+			Bollandia claviceps (Burm.)		+			
Crurithyris sp.		+				Bollandia sp.		+			
Dielasma hastata Sow.			+			Phillipsia sp.			+		
Dielasma sp.		+				Linguaphillipsia sp.			+		
Spirifer trigonalis Mart.		++	+			**Bryozoa**					
Spirifer sp.		+				Fenestella plebeja McCoy		+	+	+	
Martinia glabra (Sow.)		+	+	+		Fenestella sp.		+	+		
Spiriferida indet.		+				**Plant remains*****	++	+	+	+	+++

* + – <5 specimens; + + – 5-1- specimens; + + + – >10 specimens
** see List 1
*** see List 2

pelecypods, chiefly represented by the genera *Nuculavus*, *Parallelodon* and *Edmondia*, are commonly dispersed in nearly all the deposits of the section (Fig. 11C–H). In the upper part of the section, some specimens are in the life position. Their maximum length varies from 1.5 cm (specimens from the claystone shales of the lower part of the section) to 4.0 cm (specimens from the sandy mudstones of the upper part of the section). The impressions and fragmentary preserved thin shells of epifaunal pelecypods (mainly Pectinacea) are dispersed through nearly all the rocks of the outcrop, excluding the sandy mudstones of its upper part. Their maximum height and length are about 2.0 cm.

Gastropods are mainly represented by moulds and shells of Bellerophontacea, Pleurotomariacea, Murchisoniacea and Loxonematacea (Tab. 1; Fig. 11A, B). Kühne
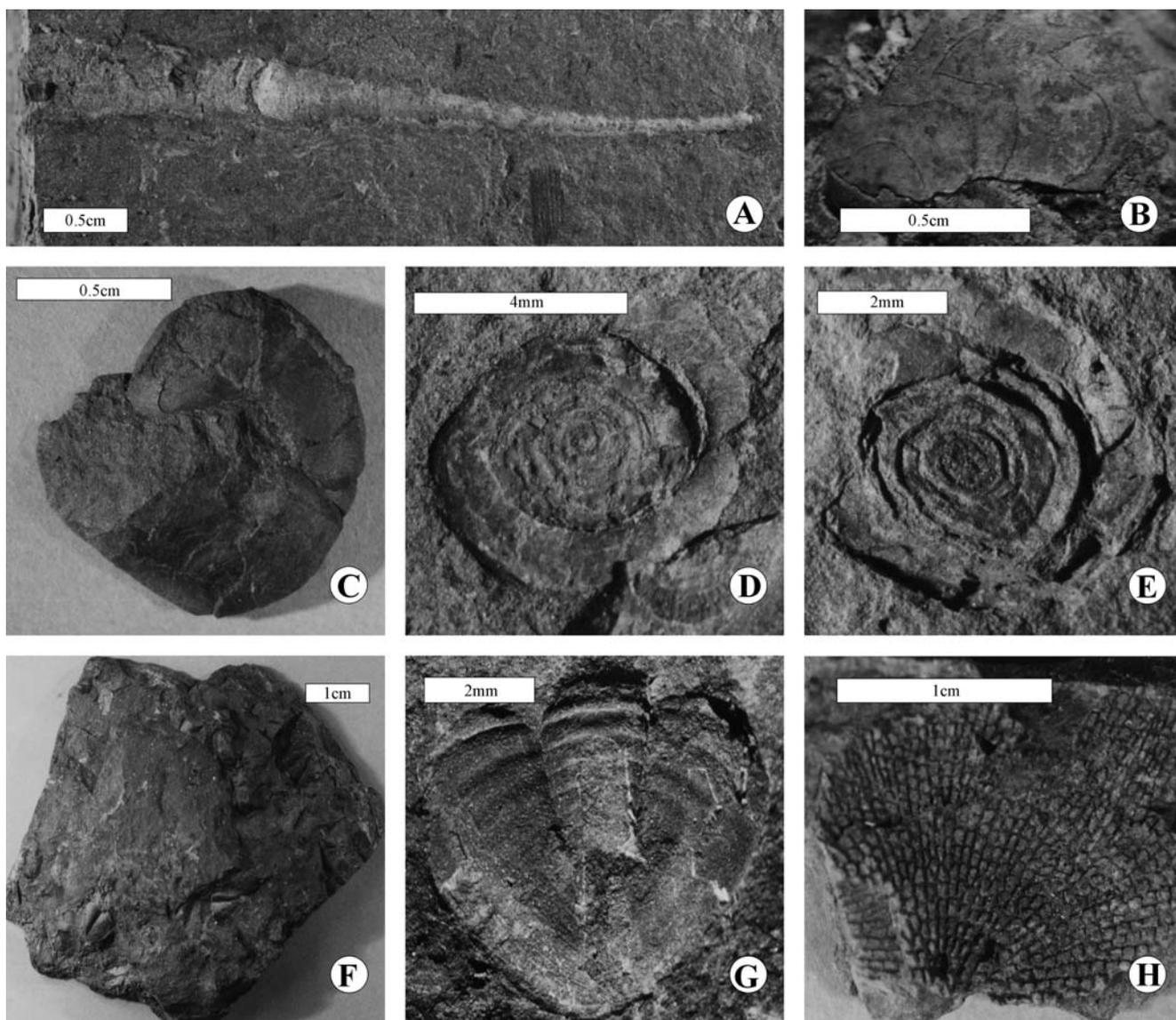
Fig. 12. Cephalopods: **A** – *Dolorthoceras* sp., sample Pa1; **B** – *Goniatites crenistria* Phill., sample Pa13a ; **C** – *Goniatites* sp., sample Pa12; **D, E** – *Nomismoceras* sp., sample Pa1. Trilobites: **F** – accumulation of trilobite remains (*Bollandia* sp.), sample Pa14; **G** – *Bollandia claviceps* (Burm.), sample Pa7a. Bryozoa: **H** – *Fenestella plebeja* McCoy, sample Pa19.

(1930) made the first detailed descriptions of some of their species. The maximum diameter of specimens is about 2.0 cm, and the height of shells is usually less than 1.0 cm. Their scarce fossils were found in nearly all the lithologies; only in the calcareous lumps and mudstones surrounding them was their relative frequency higher (Fig. 4; samples Pa13, 14). Very small specimens were also obtained from the sieve fraction of 0.125–0.325 mm. They are abundant in most of the samples (Fig. 5; Fig. 13G, H).

Goniatites are poorly preserved; the impressions of their whorl fragments are usually flattened, in some cases with relief and suture line. The majority of the specimens are very small; only a few are larger than 3.0 cm in diameter. 2.0 cm fragments of their whorls indicate the existence of bigger specimens. Most of them definitely represent the *Goniatites* and *Nomismoceras* genera (Tab. 1; Fig. 12B–E). They are most numerous in the claystone shales and in

the thin limestone beds of the lowest part of the section, whereas they are absent from its upper part (Fig. 4).

Nautiloids are mostly preserved as fragments of straight orthoconic shells, some of them representing *Dolorthoceras* (Tab. 1; Fig. 12A). Their maximum length is about 7.0 cm. They only occur in small quantities, and only in samples from the lower part of the section (Fig. 4). Their disappearance is coincidental with the first appearance of the coral limestone lenses.

There are only scarce, poorly-preserved trilobite fossils present (*Bollandia* and *Phillipsia*) (Tab. 1; Fig. 12F, G). Small pygidia and occasional thorax fragments were mainly found in the mudstones surrounding the calcareous lenses; some specimens were also found in the similar sediment of the lower part of the section (Fig. 4; samples Pa8, 13a–Pa15).

Small amounts of fenestrated bryozoans (Fenestelli-
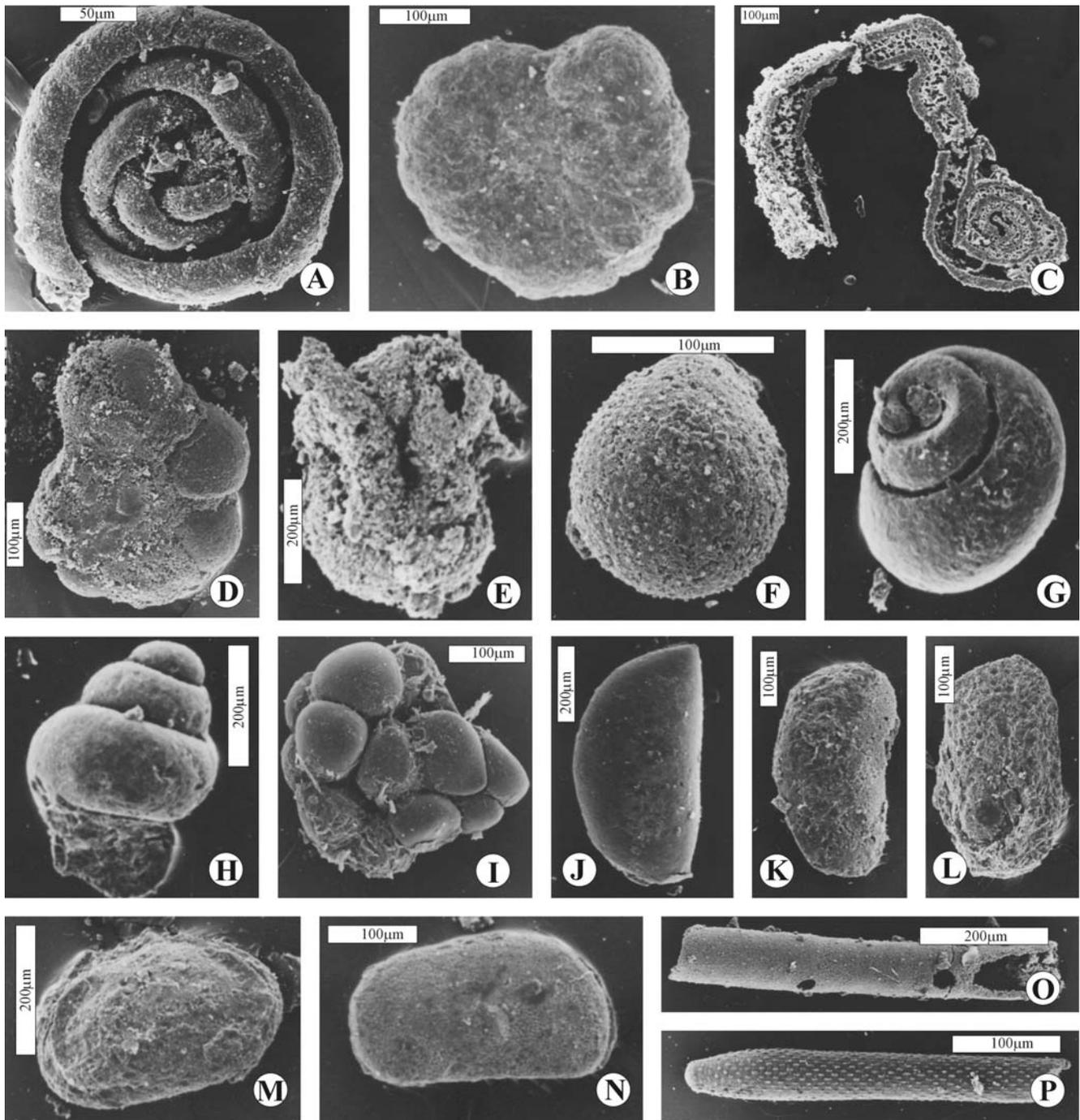
Fig. 13. Foraminifers: **A** – *Archaediscus* sp., sample Pa14; **B** – *Endothyra* cf. *media*, sample Pa14; **C** – Tolypammininae?, sample Pa12; **D** – *Endothyra* cf. *excentralis*, sample Pa1; **E** – ?*Ammovertellina* sp., sample Pa14. Gastropods: examples of small specimens; **G** – ?*Straparollus* sp., sample Pa13; **H** – ?*Macrochilina* sp., sample Pa14. Ostracods: **J 13** – ?*Acratia* sp., sample Pa11; **K 15** – *Bairdiocypris* sp., sample Pa16; **L 17** – *Amphissella* sp., sample Pa6; **M 14** – *Healdianella* sp., sample Pa11; **N 16** – ?*Healdia* sp., sample Pa12. Incertae sedis: **F** – ?*Saccamminopsis*, specimen with fine ornamentated and perforated wall, sample Pa16; **I** – cluster of micritic "mini-lumps", sample Pa1; **O** – example of bored calcareous tube, sample Pa12; **P** – spine with micro-ornamentation, sample Pa14.

dae) occur in the claystone and mudstone shales of the lower part of the section (Fig. 4; samples Pa4–6). Their remains are most abundant in the calcareous lumps and lenses (Fig. 4; samples Pa14, Pa15; Fig.12H). The length of the biggest fragments of colonies is about 5 cm.

Coarse crinoidal debris is dispersed within nearly all the beds, excluding the claystone shales from the lowest

part of the section (Fig. 4). Their longer stem fragments (maximum length about 5.0 cm, maximum diameter about 1.0 cm) are most often embedded in the sandy mudstones surrounding the limestone lenses.

All the types of microfossil obtained from the sieve fraction (of not less than 0.125 mm) were counted to define their average relative frequency. The vertical distribu-
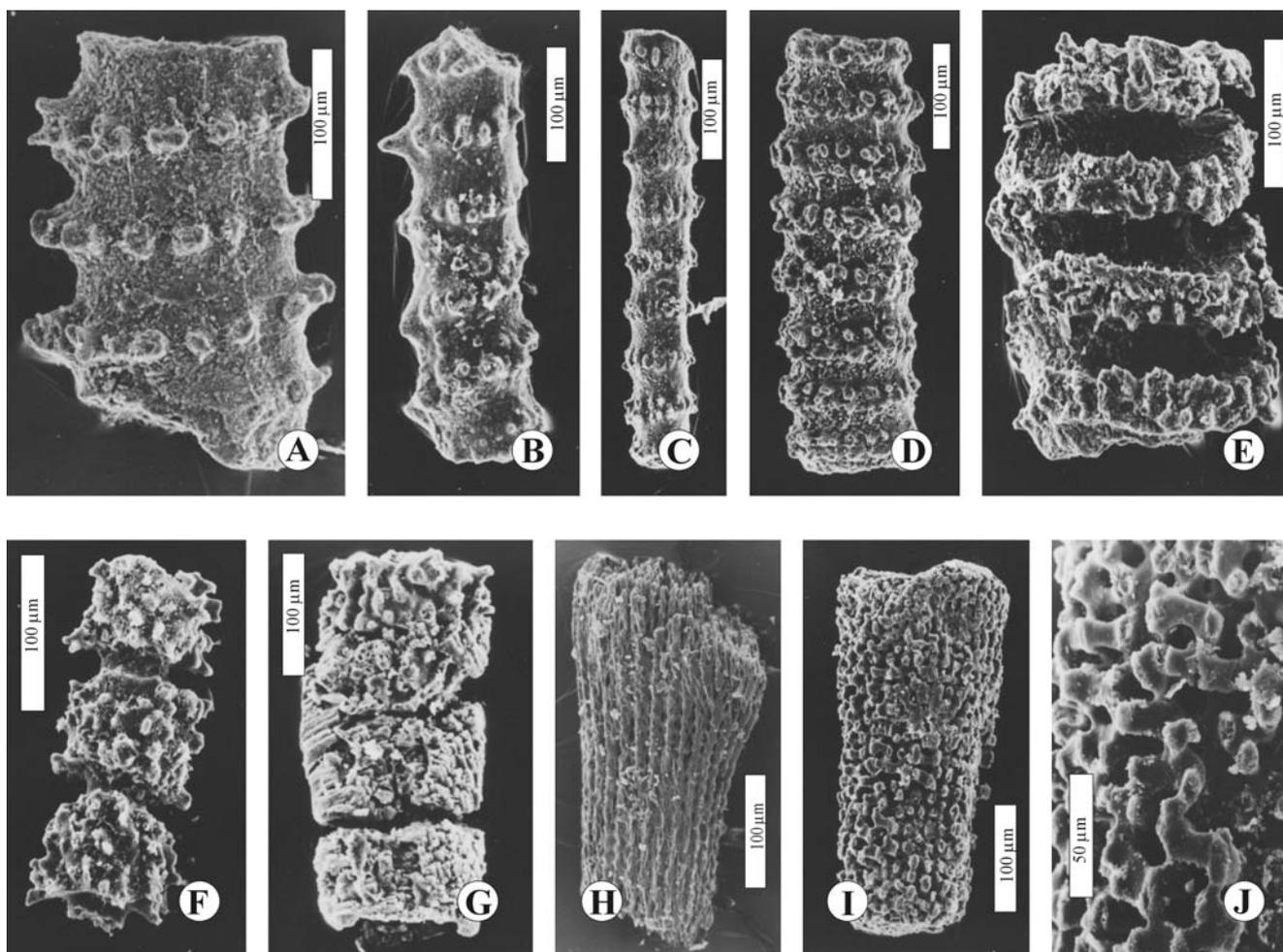
Fig. 14.   Different moulds of calcareous algae: **A–G** – Moulds of paleoberresellid algae represented by *Kamaena*; **A, B** – with single-row verticils of branches (sample Pa13); **C–E** – with double-row verticils of branches (sample Pa13); **F, G** – with composite verticils, specimen 8 possesses partly-preserved calcareous wall (sample Pa15); **H** – Unidentified mould of calcareous alga with a net-like surface of calcareous sleeve (sample Pa14); **I** – Unidentified mould of calcareous alga with irregularly distributed "branches" (sample Pa13); **J** – magnification of "branches" (sample Pa13).

tion of different microfossils in the section is shown in Fig. 5.

Most of the ostracods are preserved as internal moulds and impressions of separate valves; only rare specimens kept their calcareous carapaces. They are distributed in variable quantities through nearly all the beds of the section, with distinct concentrations found in the mudstone shales directly underlying the first horizon of calcareous lenses and nodules (Fig. 5; sample Pa13). A rough examination of the ostracod assemblage revealed that it mainly consists of specimens of Bairdiacea (Fig. 13J–N).

Foraminifers occur with different frequency in nearly all the samples (Fig. 5; Fig. 6A, B, E, F; Fig. 7C, D; Fig. 13A–E). According to Górecka & Mamet (1970), the species which occur in this locality are characteristic for the *Archaediscus karreri-Howchinia gibba-Valvulinella youngi* zone coinciding with the *crenistria IIIá* zone.

The remains of calcareous algae are present in all the limestone lens samples. Their scarce fragments were also found in the mudstones surrounding the calcareous lumps and lenses (Fig. 5; samples Pa13–Pa18; Fig. 10A). Sometimes they are preserved as internal moulds, especially in samples Pa13 and Pa15. Representatives of the Dascycladales group are particularly abundant; among them, the remains of *Kamaena* and *Nanopora* are dominant (Fig. 7A; Fig. 14A–G). Some remains similar to Stacheiinae (? Rhodophyta) and other unindenfied taxa were also found (Fig. 6D; Fig. 7C; Fig. 14H–J). The algal remains disappear somewhere above the last occurrence of the calcareous lenses.

Sclerotioid grains were found in all the samples. The grains are black and have a maximum length of about 0.5 mm. Their shape varies from spherical to irregularly elongate. The grain surfaces are smooth or have a coarse ornament (Fig. 15B–G). These black grains are very similar to the grains which were precisely described by Bless *et al.* (1976) from the Dinantian of the northern and northeastern part of the Rheinish Massif and the Attendorn-Elsper Syncline. Those authors deduced (from the results of their own and other investigators' chemical analyses) that these
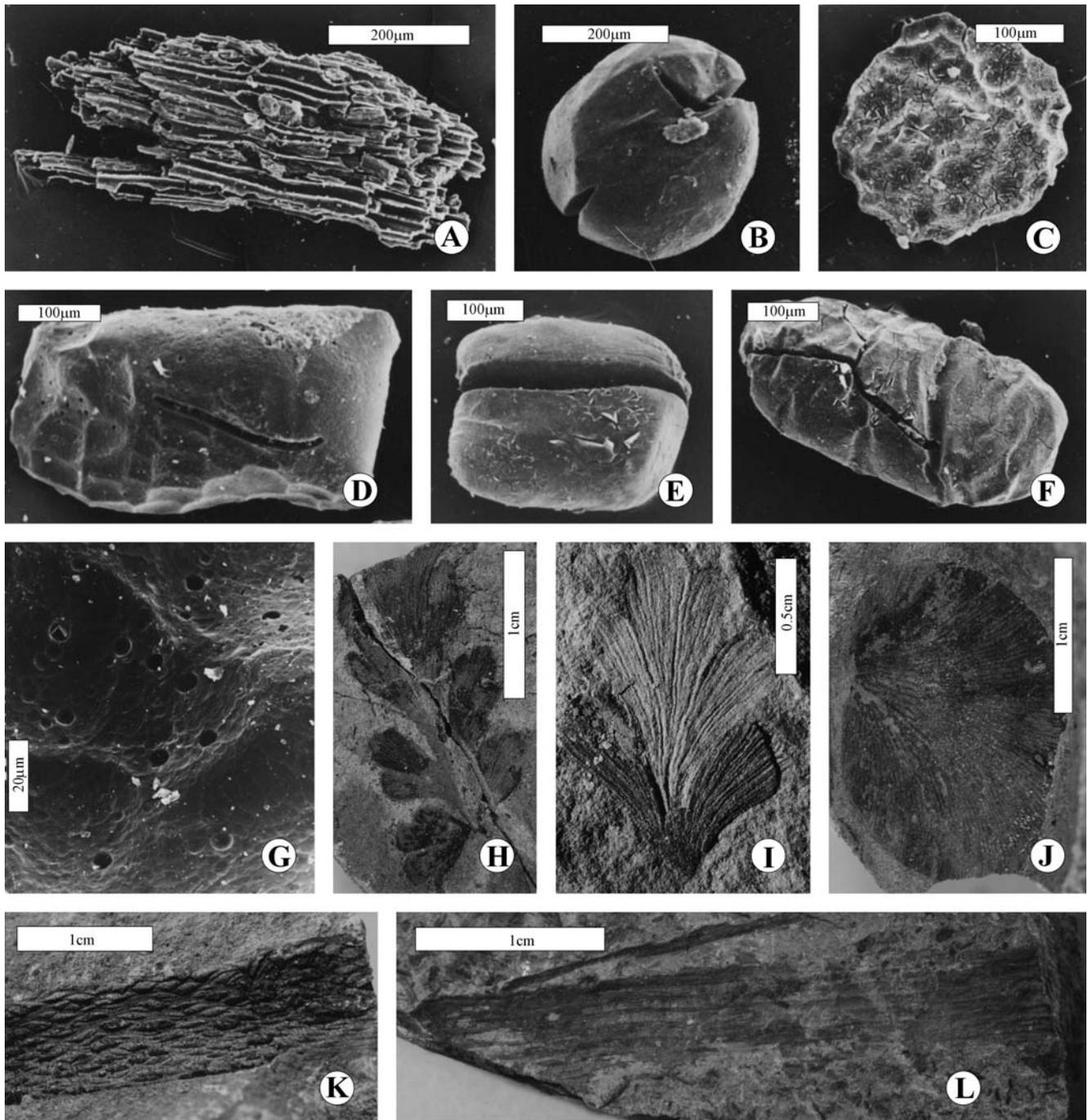
Fig. 15. A – Example of fossil charcoal; such examples are very numerous in the clayey mudstones and greywackes; sample Pa1. **B–F** – Examples of differently-shaped sclerotioid grains: **B** – specimen with isolated fissures and a smooth surface, sample Pa14; **C** – specimen with a more or less polygonal net and small irregular fissures, sample Pa12; **D, F** – specimens with a more or less ornamented surface, sample Pa14; **E** – specimen with a deep open fissure, surface smooth, sample Pa14; **G** – magnification of specimen D, the surface is covered with crater-like pits, sample Pa14. **H–L** – Macrofloral remains: **H** – *Sphenopteridium dissectum* (Goeppert) Schimper, sample Pa1; **I** – *Sphenopteridium dissectum* (Goeppert) Schimper, sample Pa7a; **J** – *Cardiopteris frondosa* (Goeppert) Schimper, sample Pa7a; **K** – *Lepidodendron* sp., sample Pa3; **L** – *Archaeocalamites* sp., sample Pa7a.

may be either resinite or corpovitrinite grains, and are certainly not sclerotia. They also believed that the sclerotioid grains might have been produced by some gymnosperm(s). The sclerotioid grains were never previously found in deposits older than Upper Viséan (Bless *et al.*, 1976).

Small fragments of fossil charcoal are also dispersed through nearly all the lithologies of this section (Fig. 15A).

Unidentified calcareous tubes and spines are present in various amounts in the majority of the samples (Fig. 5; Fig. 13O, P). Most of the tubes are circular in cross-section

and ornamented with delicate concentric rings. They are twisted to various degrees. Some of them are probably serpulid remains (Fig. 10F). Some smooth spines, usually narrow at one end, are probably of brachiopod origin.

List 2
The list of macrofloral taxa from the Paprotnia section, as determined by Górecka (1953) and the authoress
Lepidodendron Veltheimi Sterb.
Lepidodendron cf. *volkmannianum* Sternb.
Lepidodendron sp.
Stigmaria ficoides Brongn.
Archaeocalamites radiatus (Brongn.) Stur
Cardiopteris frondosa (Goepp.) Schimp.
Sphenopteridium Schimperi Goepp.

Sphenopteridium dissectum (Goepp.) Schimp.
Alloiopteris quercifolia (Goepp.) Pot.
Rhodea Feistmanteli Kidst.
Trigonocarpus ellipsoideum Goepp.
Trigonocarpus sp.

Terrestial plant debris is present in all the sediments of the Paprotnia section. Scarce larger fragments of fern leaves, and lycopsid and sphenopsid stems occur in the claystones and mudstones of its lower part, whereas in the greywackes of its upper part, larger relicts (e.g. some horsetail stems reaching several dozen centimetres in length) are very common (Fig. 15H–L). The floral species identified by Górecka (1958) are quoted in List 2.

The fossil collection is housed at the Institute of Geological Science of the University of Wrocław.

TAPHOCOENOSIS VERTICAL SUCCESSION

Five taphocoenoses, differing in the relative abundance of particular taxonomical groups, the size and state of preservation of specimens, can be recognised in the vertical sequence of the Paprotnia section (Figs. 3–5; Tab. 1).

Taphocoenosis I – Its main components are goniatites (mostly of juvenile size) and orthoconic nautiloids, small spiriferids, thin-shelled chonetids, productoids, gastropods (*Ptychomphalus*) and scarce pelecypods (mainly *Aviculopecten*, *Streblochondria*, *Protoschizodus*). Nautiloid longicones (up to about 7 cm long max) mainly represented by *Dolorthoceras*, are well preserved. The majority of goniatite individuals are of juvenile size, though there are scarce larger fragmented shells. The maximum width of brachiopod valves does not exceed 3.0 cm. The maximum length of pelecypod shells varies from 2.0 to 2.5 cm, and the height of gastropod shells does not reach 1.5 cm. Some ostracods (mainly their moulds), foraminifers and poorly-defined fine calcareous spines occur in this assemblage. Some of the last are probably of brachiopod origin. Small amounts of calcareous algal detritus (probably of Dasycladales) are also present. Terrestrial plant detritus with some distinguishable fragments of horsetail stems and fern leaves are also abundant.

This taphocoenosis occurs in the claystone and mudstone shales of the lower part of the section (Fig. 3). The thin intercalations of dark-grey micritic limestone contain only scarce small goniatite fragments and calcareous spines.

The fossils of this taphocoenosis are dispersed in the sediment. Distinct accumulations of shells were not found. The trace fossils were not found. The benthonic community is mainly represented by epifaunal suspension and deposit feeders, which inhabited a clayey-muddy soft ground. The small shell sizes of the benthonic organisms may indicate their affiliation to low-level suspension-feeders (Branchley & Harper, 1998).

Taphocoenosis II – Compared to the previous one, this fossil assemblage is enriched in solitary rugosa, frag-

ments of crinoidal columnals, trilobites and bryozoan colonies (Fig. 4; Tab. 1). Shells and different skeletal fragments of benthonic fauna are dominant. Among the brachiopods, spiriferids and productoids are the most abundant, and some well-preserved chonetid valves were also found. The dimensions of the brachiopod valves are similar to those from taphocoenosis I, with only productoids reaching a valve width of 4–6 cm. Locally (mostly in the upper part of the sediment package hosting this community), distinct planar accumulations of their large valves can be observed. In many cases, the large productoids occur in the life-position, with the massive pedicle valve undermost. Small, scarce epifaunal and infaunal pelecypod shells (the greatest length of their valves varying from 1 to 2 cm) are mainly well preserved and not separated. Trilobites are not present in large numbers, only isolated pygidia (mainly of *Bollandia*) or parts of cephala were found. Bryozoans are represented by rare fragments of fenestrate forms (e.g. Fenestellids). A gradual increase in the frequency of crinoid debris, small body size gastropods (probably specimens of *Straparollus* and *Soleniscus*) and diminutive solitary rugosa (according to Fedorowski, 1971, represented by specimens of Cyathaxoniidae, Polycoeliidae, Metriophyllidae and Hapsiphyllidae) were noted within this taphocoenosis, whereas the relative abundance of cephalopods distinctly decreases. The abundance of foraminifers and ostracods is variable – in general, samples rich in ostracods are poor in foraminifers (Fig. 5). The deposits with this taphocoenosis also contain calcareous algal remains (most of them are paleoberesellids), which first appear in the mudstone shales of its topmost part (Fig. 5; sample 13). Numerous ichnofossils are also present; their richness rises vertically. They are mostly represented by burrows, which are partly filled with a ferruginous substance of a porous structure. Trace fossils are usually well preserved in layers underlying horizons with productoid accumulations.

The fossils of this community are usually irregularly

dispersed in a package of mudstone shales containing grey-wacke intercalations and thin bentonite layers (Fig. 3). The relative frequency of the particular taxonomical groups is not stable, but varies depending on lithology. Locally, accumulations of large productoid shells form distinctly marked horizons. A distinct deacrease in the amount of benthonic fauna is noticeable within the grey-stone intercalatoins (containing only scarce shell debris and plant remains) and in the interval of mudstone shales with thin bentonite layers (A–D), and just below the thickest one (E). However, above this last layer, a progressive increase is documented (Figs. 3, 4).

Most of the organisms of this taphocoenosis are components of the low benthos level, while the large productoids are elements of the second high level (5–25 cm) (Branchley & Harper, 1998). Most of them are representatives of sessile epifauna (brachiopods, corals, bryozoans). Free-burrowing bivalves (e.g. *Nuculavus*, *Paleoneilo*) and probable shallow burrowers (e,g, *Parallelodon*, *Edmondia*) are also present (Wilson, 1989). Other epifaunal and nectonic forms are less common (crinoids, trilobites, gastropods, cephalopods).

Taphocoenosis III – The fossils of this assemblage occur in sandy mudstone shales containing lumps and lenses of organodetrital limestones forming several distinct horizons in the succession (Fig. 3). The relatively high fossil frequency of particular benthonic organisms, the distinct decrease in amount of goniatites and the gradual disappearance of nautiloids (Fig. 4, Tab. 1) is characteristic for this taphocoenosis. The coral associations mainly contain various species of *Lithostrotion* and *Diphyphyllum* (Fedorowski, 1971), which formed bush-like and subceroid or ceroid colonies. Some individual corralites reached a height of about 10–12 cm. The colonies are mainly restricted to the lower part of the above-mentioned limestone lenses, where they are often preserved in growth positions, whereas layers of its disarticulated corralites are common in the mudstone shales surrounding these lenses. In some cases, concentrations of colonial corals occur close above large productoid valves. This may suggest that the corals preferred to settle the hard elements of the substrate. Among the brachiopods, large specimens of *Gigantoproductus* are dominant; their largest valves are about 12 cm wide. Chonetids (width about 5–6 cm) are also common in this taphocoenosis, but the abundance of spiriferids decreases. Almost well-preserved productoid valves occur in coral-rich calcareous lenses. Similar rich assemblages of brachiopods and corals were described by Żakowa (1966) from the Upper Viséan sections of the

Sowie Mts. In her opinion, brachiopods settled in a mass in the peripheral parts of the coral colonies or directly on them. Some of the organodetrital limestone lenses contain rich algal debris, ostracods, foraminifers and various imprecisely-identified calcareous tubes and spines. The distribution of the relative frequency of the microfossils in the calcareous and mudstone samples is variable, but the increase in the amount of ostracods is distinctly correlated with a decrease in the amount of foraminifers and algal remains (Fig. 5). Benson (1998) mentioned associations in which ostracods occur, and noted that "in sediments where calcareous foraminifers are abundant, ostracods are not". On the other hand, Skompski (1986), studying the microfacies of Upper Viséan limestones from the Lublin area, ascertained that the quantitative increase in algal material is connected with a decrease in foraminifer quantity.

The shells of benthonic organisms dispersed in the sandy mudstones surrounding the calcareous lenses are in general fragmentally preserved. In this sediment, numerous local accumulations of trilobite remains occur. The relative frequency of microfossils and algal material also decreases. The various kinds of trace fossils are of common occurrence, especially inclined and horizontal burrows with spongy lining (Fig. 10G, H).

The organisms of this assemblage grew above the bottom to the heights of the second tiering level (5–25 cm)[1] in oxygenated water.

Taphocoenosis IV – This fossil community is restricted to the narrow interval of sandy mudstone shales of about 80 cm thick, occurring in the upper part of the section (Fig. 3). It is composed of scarce, diminutive brachiopods (maximum width of spireferid shells – ca. 1.5 cm; productids – 3.0 cm), infaunal pelecypods *Edmondia* (maximum height of shells – 2.0 cm), fragments of bryozoans colonies and crinoidal stems (Fig. 4, Tab. 1). The shells of this taphocoenosis are usually fragmentally preserved. The macrofaunal fossils are associated with foraminifers, ostracods, small gastropods and calcareous algae detritus, which is only distributed in the lower part of the mentioned sedimentary package (Fig. 5). Scarce trace fossils (mostly burrowings) are also present.

Taphocoenosis V – This group is only represented by plant fossils; faunal remains are totally absent. Among them, the most numerous are asterocalamite stems, some of them reaching several dozen centimetres in length. Lepidodendron remains and fern leaves (mainly of *Sphenopteridium* and *Cardiopteris*) and seeds are less abundant. This plant assemblage occurs in the greywackes and mudstone shales of the topmost part of the Paprotnia section.

DISCUSSION AND CONCLUSIONS

The composition, specimen size, state of preservation, differences in the relative frequency of particular fossils in the recognised taphocoenoses and lithological features of their host rocks were used to characterize the paleoenvi-

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1   Layering in marine communities according to their height above the substrate or their depth within the substrate has been termed tiering (Branchley & Harper 1998)

ronment. The examined paleontological and lithological record indicates gradual environmental changes from off-shore to near-shore conditions.

The claystone and mudstone shales with rare intercalations of thin micritic beds of the lower part the section containing taphocoenosis I might have been deposited in mid- or outer shelf conditions. The low taxonomical diversity of this community (Tab. 1), the small size of benthonic taxa, the thin shells and lack of bioturbation may indicate oxygen-deficient bottom waters (see Kammer *et al.*, 1986). The thin laminated sediment and lack of signs of transport on the benthic skeletal material suggests a quiet water environment below the wave base. The longicone specimens of *Dolorthoceras* with intact thin septa which are common in this taphocoenosis can be a tool for assignating the depth range in which the organinisms of this community lived. Westermann (1973, 1985) calculated the implosion depths for different Paleozoic nautiloids, and thus their maximum depth range. According to him, the longicone nautiloids with thin, densely-spaced septa probably lived in depths of 100–200 m. The fragments of larger goniatite shells, abundant in this taphocoenosis, are probably the consumption remnants of larger sea carnivores, such as fish or eurypterids, and not the result of their implosion. The juvenile-size ammonoids may have had their growth stunted by the oxygen-deficient conditions (Kammer *et al.*, 1986).

The well-preserved nautiloid shells may indicate shallower depths than 100–200 m. The presence of an insignificant amount of calcareous algal detritus (probably of dasycladaceans) in the clayey-mudstone shales does not exclude such depths. The record depth for living dasycladacean algae is 90 m. (Brett *et al.*, 1993). On the other hand, it cannot be excluded that the scarce algal remains were delivered from a shallower part of sea floor and were deposited only after a long period of floating.

Taphocoenosis II, recognised within the mudstone shales containing greywacke intercalations and bentonite layers, indicates oscillations in the environmental conditions.

The progressive increase in species richness in this taphocoenosis compared to the previous one (Tab. 1), the dominance of epifaunal suspension feeders, and the presence of bioturbations in the host sediment may be regarded as evidence of aerobic conditions. It is known that contemporaneous aerobic communities have more than twice the number of preserved species than dysaerobic communities have (Kammer *et al.*, 1986) and, according to Theede *et al.* (1969), suspension feeders are not known to tolerate low-oxygen conditions.

The benthonic organisms of this taphocoenosis could have existed in an environment with a gradually increasing influx of terrigenic material and bottom water turbulence. The state of preservation of their fossils, which occur in muddy deposits, suggests that they were not moved far from their habitat. Intercalations of greywackes containing only shell debris and floral remains (horsetail stems, fern leaves) may indicate short episodes of rapid clastic delivery from the inshore part of the sedimentary basin. Storm events cannot be excluded in this case, and possibly during the current action, the water could have been well oxygenated. Rapid terrigenic influx caused short-term regresses of benthos development, as indicated by decreases in the relative frequency of its different individuals close above the greywacke beds. The same faunal reaction must have occurred upon the delivery of greater amounts of volcanic ash. On the other hand, the progressive increase of fossils, recorded above the thickest bentonite layer, could indicate water fertilization, which could lead to intensification of phytoplankton and zooplankton development, which in turn could induce intensive development of suspension-feeders.

The diverse benthonic biota, the remnant of which is represented by the fossils of taphocoenosis III (Tab. 1; List 2; Fig. 4, 5), occuring in the middle part of the section, is one which colonized the shallow subtidal sea floor with moderate to periodically higher energy conditions. The larger productoids with their pedicle valve buried in sediment and anchored with spines may have rested on the bottom in a high-energy regime probably affected by tidal currents (Wilson, 1989), and could have formed nest concentrations stabilising the mud-sand sediment. Fragmentated smaller brachiopod valves and other fossils were surely displaced many times before their final burial. The lenses and nodules of bioclastic packstones, which appear in several horizons within the mud-sand deposits, indicate a periodic development of small, isolated patch structures. They may start to grow on the nest accumulations of dead or still-living brachiopods, on and around which bush coral colonies settled. Their growth probably took place during short intervals of moderate energy environment and in relatively clear water, but the periodic intensive clastic influxes hampered their vertical and lateral rise. The abundance of calcareous alga remains (mainly *Kamaena*) in the limestone lenses also suggest a relatively shallow water sedimentary environment of moderate energy. Recent dasycladales are light sensitive, and their thalli are not particularly strong or wave resistant. They are found exclusively in warm waters, usually at low latitudes (Beadle, 1988). According to Flügel (1985, see also Brett *et al.*, 1993, Fig. 1), recent dasycladales occur in masses not deeper than 30 m and only sporadically exist to 90 m. Their abundant remains are known from different Devonian and Carboniferous shallow-water biofacies (Dressen *et al.*, 1985; Skompski, 1986, 1987, 1996; Adams *et al.*, 1992).

Consequently, it can be assumed that the organisms of this community lived in turbulent conditions in shallow well-oxygenated waters, and that the abundance of corals and dasycladales may indicate a relatively warm-water environment. The calculated seawater temperature, based on the oxygen isotope composition of Dinantian brachiopod shells from a variety of western European locations, may suggest a temperature oscillating between 38° and 23°C (Bruckschen & Veizer, 1997). The epifaunal heavy individuals, e. g. *Gigantoproductus* and *Lithostrotion* colonies, were able to withstand the most violent wave action. It is probable that small patches in which corals and algae were abundant were formed during short periods of low clastic inflow. We agree with Fedorowski (1971), who

suggests that the conditions were favourable for easy precipitation of calcium carbonate around the accumulation of organic remains or still-living organisms, but the intensive terrigenic delivery buried the patch structures and interrupted their development several times.

On the other hand, Wajsprych (1995) advocated a hypothetical concept of chemogenic vent-related origin for both the fauna and the carbonates. In his opinion, the terrigenous sediment hosting the carbonate lenses is practically devoid of $CaCO_3$ (about 2–3%), which could indicate that the physico-chemical conditions of the seawater did not allow the generation of carbonates. The spatial distribution of the carbonates and faunal concentrations isolated within terrigenous sediment, according to the author, could also be the next argument for this concept, and can be interpreted as the result of submarine methane seepage supplying organisms with energy and food, and the authigenic carbonates with carbon. However, such an interpretation still requires backup in the form of geochemical and isotopic documentation (Wajsprych, 1995).

The drastically reduced next fossil assemblage (taphocoenosis IV), occuring only in the thin mudstone shales intercalating the greywackes overlying the host deposits of taphocoenosis III (Fig. 3–5; Tab. 1), reflects renewed settling of only the eurytopic organisms. The low state of preservation of shells, and the scarce preserved trace fossils point to a high-energy environment of near-shore conditions. The repeatedly changing conditions generated by sediment-laden currents could have made the nesting of the benthonic organisms impossible. One of the probable reasons for their disappearance was the dense suspended matter which clogged the feeding apparatus of the suspension-feeders and filtrators.

The floral remains of taphocoenosis V, especially rich in longer fragments of horsetail stems, embedded in the greywackes of the topmost part the Paprotnia section, may suggest a proximity to land and a short transportation distance. On the other hand, it is well known that large wood fragments may float for several years. However, long flotation of hollow horsetail stems was rather impossible, because they would fill with water, and sink faster than floating leaves or larger wood fragments.

Wajsprych (1995), analysing the geographical range of the Paprotnia series and its probable temporal equivalents in the Bardo region and in the neighbouring areas (Intra-Sudetic depression and the Sowie Mts.), considers that it was deposited in transitional conditions from a shallow- to deep-water environment during the large scale "crenistria transgression". Regarding the Paprotnia series as a temporal equivalent of the *crenistria Limestone*, he considers it to be the result of a sea-level highstand, as does Herbig (1994, see Warnke, 1997).

In our opinion, the lithology and the succession of biotic components in the excavated part of the Paprotnia series reflect a gradual change from deeper to shallower water sedimentation. Its lower part, composed of clayey mudstone shales containing several layers of micritic limestones and a well-preserved thin-shelled benthonic assemblage, could point to an open pelagic environment. The upwardly-increasing terrigenic content suggests frequent delivery of clastic material, which could have led to a gradual shallowing of the sedimentary basin, assuming that the subsidence was relatively low. The horizons of limestone lenses, containing numerous corals, brachiopods, bryozoans and algal remains, were deposited in a shallow-water environment during the relatively short periods when the terrigenic influx was not so intensive. Consequently, the middle and upper part of the Paprotnia series represents the shallow-water, littoral equivalent of the pelagic *crenistria* Limestone. It is not unlikely that it could have been deposited during a sea-level highstand, with periodic incoming clastic material from an adjacent near-shore area gradually filling at least the western part of the late Viséan Bardo reservoir. As yet, the occurence of the Paprotnia series has been not documented for the eastern and southern part of the Bardo unit, so it may be that it was buried there by the allochtonous sequences (see Wajsprych, 1995, Fig. 13).

The similarity of the Late Viséan lithological and paleontological records of the Bardo unit to the adjacent Intra-Sudetic Basin and the Góry Sowie Massif (Żakowa, 1966; 1968) may suggest a shallow-water environment in the Sudetic part of the wide mid-European Variscan basin at that time.

Acknowledgements

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