

MICROFOSSIL ASSEMBLAGES AS BATHYMETRIC INDICATORS OF THE TOARCIAN/AALENIAN “FLECKENMERGEL”-FACIES IN THE CARPATHIAN PIENINY KLIPPEN BELT

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Abstract: Cluster and principal component analyses of Toarcian-Aalenian microfossils from a uniform Fleckenmergel facies, found in two different parts of the Pieniny Klippen Basin have been undertaken on the basis of the percentage abundance of benthic foraminifers and the standardized number of all microfossils per 100-grams of sediment. The latter type of input data appeared to separate two paleobathymetric settings much better than relative benthic foraminiferal data alone. Comparison of the foraminiferal assemblages with fossil and recent analogues suggests not so strong paleodepth differences within the basin ranging from the middle/outer neritic for the Czorsztyn and the outer neritic and/or upper bathyal for the Branisko Zone. The shallower part of the basin is dominated by *Spirillina* associated with other epibenthic foraminifers, enhanced abundance of ostracods, crinoid and other echinoderm fragments. Higher abundance of crinoid fragments and sponge spicules within the shallower (Czorsztyn) zone suggests a slightly higher energetic environment with very weak bottom currents. Predominance of nodosariids associated with tubular agglutinated foraminifers (astrohizids), as well as lower abundance of benthic foraminifers and ostracods linked to a higher abundance of radiolaria are supposed to indicate deeper basinal settings. These distributional trends are most likely related to trophic conditions, and only indirectly to the paleobathymetry of the basin.

Key words: Jurassic, paleoecology, benthic foraminifers, multivariate statistics, Krempachy Marl Fm.

Introduction

For a number of years, geologists have applied various marine paleodepth (e.g. sedimentologic, ichnologic, paleontologic, and geochemical) proxies. However, they never give precise depths because they usually do not directly depend on them. Benthic foraminifers serve as an example of such a proxy, related to water depth and water masses (e.g. Schnitker 1974; Lutze & Coulborn 1983). Their distribution is most strongly influenced by surface water productivity and organic carbon flux to the sea bed (e.g. Altenbach & Sarnthein 1989). Depth in itself does not affect the distribution of marine organisms. It seems that especially light, nutrients or food, oxygenation, temperature, CO₂ saturation, substrate type and current activity are closely linked to certain paleodepths, but vary from basin to basin and within a basin. A paleobathymetric proxy should therefore be used mainly through covariation between depth and other factors, especially oxygen and organic flux (Van der Zwaan et al. 1999). It is clear that paleobathymetric reconstructions should never be based on individual marker species, but preferably on quantitative assemblage characteristics (Van der Zwaan et al. 1999). The best way to achieve that in the fossil record, is to have insight into a multidimensional distributional pattern of fossils, applying multivariate analytical methods.

The Toarcian-Aalenian Krempachy Marl Formation (Fig. 1) is used to test applicability of multivariate methods and potential paleobathymetric proxies. The formation is an example of a Fleckenmergel-type facies, which lacks any clear macroscopic paleodepth indications. This facies, developed in almost the whole Pieniny Klippen Basin during that time (Birkenmajer 1977), was widespread in the Early and Middle

Jurassic Tethys. It is interpreted as basinal deposits sedimented in poorly ventilated, semi-enclosed troughs developed under extensional tectonic regime (Bernoulli & Jenkyns 1974). During the Callovian, the Pieniny Klippen Basin was already very deep with high paleodepth contrasts (Fig. 1b) (after Birkenmajer 1977). The question is whether the studied Toarcian-Aalenian basin was already as deep as later, and whether its architecture was so differentiated. I will concentrate only on two different parts of the basin, the Czorsztyn and Branisko successions/paleobathymetric zones, because these successions have been studied in more detail. There are several possible paleobathymetric interpretations (Fig. 2A–E): model A considers very shallow depths in both zones; model B shows comparable shallow depths with a slightly deeper Branisko Zone; model C highly differentiates both zones and resembles the Callovian reconstruction (Fig. 1b); model D considers comparable although very deep depths (e.g. bathyal); and model E suggests that the Czorsztyn Zone was distinctly deeper than the Branisko Zone. These models cannot be tested using sedimentological and ichnological characteristics, thus, the microfossil quantitative analysis is used here.

The aim of this study is to extract paleoecological, especially paleobathymetric signals from a relatively uniform facies (Fleckenmergel), to test paleodepth models, and to evaluate the applicability of selected multivariate methods.

Geological setting

The Pieniny Klippen Belt (PKB) represents the axial, heterogeneous, highly deformed tectonic zone of the Western Car-

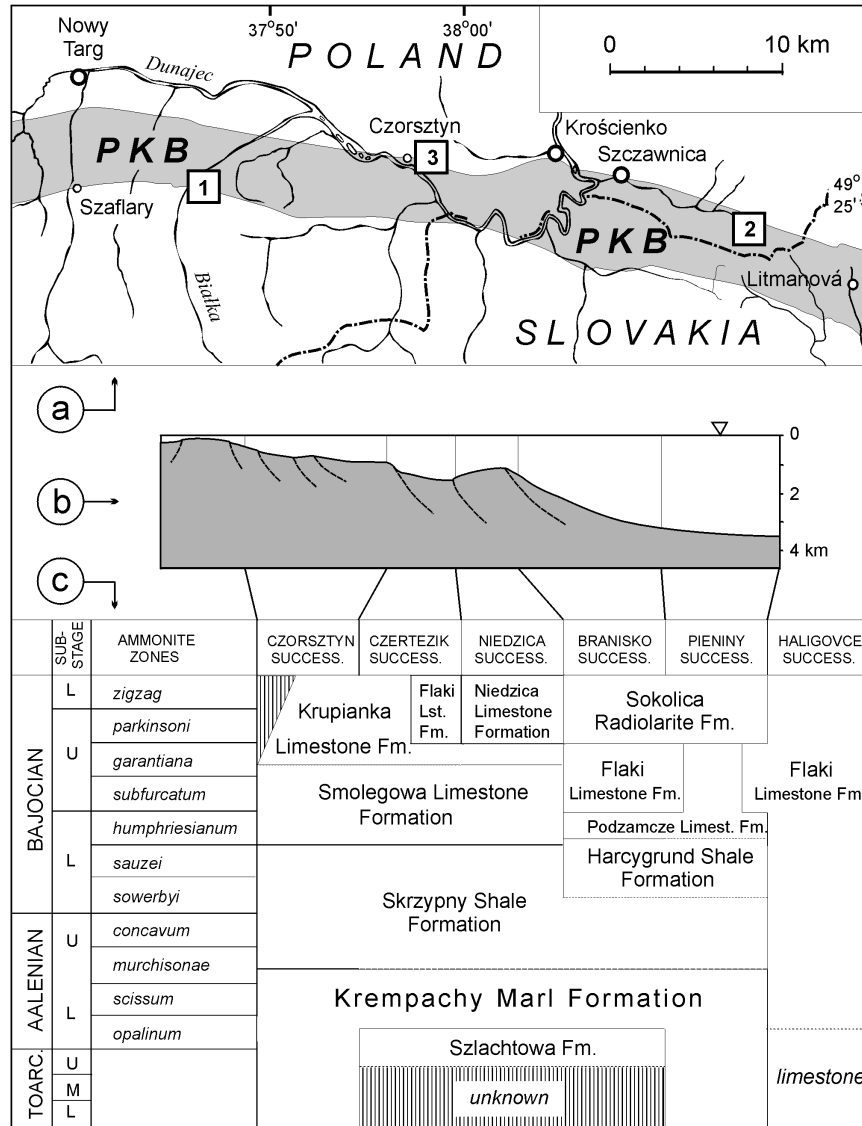


Fig. 1. a — Location map with sampled localities (1-3) cropping out the Krempachy Marl Formation. **1** — Krempachy; **2** — Biała Woda; **3** — Podubocze. The grey zone schematically depicts the Pieniny Klippen Belt (PKB). **b** — Palinspastic reconstruction of the Pieniny Klippen Basin during the Callovian with positions of stratigraphic/facial successions representing different paleobathymetric zones (Birkenmajer 1977, modified and simplified). **c** — Lithostratigraphy of Early-Middle Jurassic rocks in the Pieniny Klippen Belt (adapted from Birkenmajer 1977; modified).

pathians (Fig. 1) separating the Outer Carpathian (Magura), and the Central Carpathian units (Birkenmajer 1977). Several successions of facies depict different paleobathymetric zones within the PKB from the 'north' to the 'south' (Fig. 1b,c) (Birkenmajer 1988). Uppermost Early Jurassic (Pliensbachian, ?Toarcian) is poorly recorded in the PKB (Horwitz 1936; Birkenmajer & Myczyński 1994). Aalenian and Bajocian sediments are better preserved and represent the Fleckenmergel and Fleckenkalk facies formed by grey spotty marls and limestones (Krempachy Marl Formation and Podzámecze Limestone Formation) interrupted by dark-grey to black claystones, mudstones and marls (Skrzypny Shale Formation and Harcygrund Shale Formation). These "black shale" facies developed at the Aalenian/Bajocian transition record a regional anoxic event (Tyszka 1994b) (Fig. 1c).

The Krempachy Marl Formation is characterized by thin-bedded grey to grey-bluish spotted marlstones and limestones.

The thickness of this unit usually varies between 10 and 30 m (Birkenmajer 1963, 1977). An about 100 m thick sequence from the Krempachy type locality is probably tectonically repeated (Birkenmajer pers. commun.). It occurs in the Czorsztyn, Czertezik, Niedzica, Branisko, and probably Pieniny successions (Fig. 1b,c). The Czorsztyn and Branisko successions have been studied here. In the Czorsztyn Succession the age of the formation, was indicated by ammonites, as the latest Pliensbachian to early Aalenian (Birkenmajer 1977; Myczyński 1973). In the Branisko Succession, the formation ranges from the Lower Aalenian to the lowermost Upper Aalenian (*Leioceras opalinum* to *Ludwigia murchisonae* zones) only (Myczyński 1973). Benthic foraminifers at least support Late Toarcian to earliest Early Aalenian age documented by the *Falsopalmula tenuistriata* Subzone as the lower unit of the *Lenticulina d'orbignyi* Zone (Tyszka 1999). Spotty structures are interpreted as trace fossils dominated by *Planolites*, and

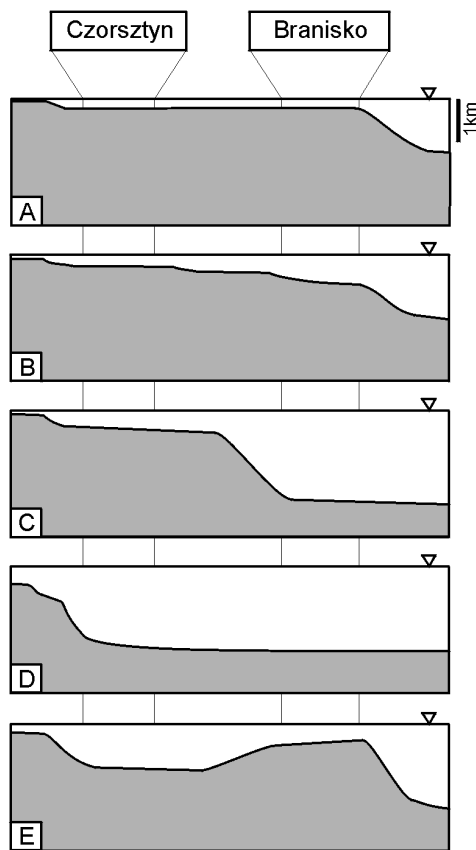


Fig. 2. Possible hypothetical paleodepth models A-E of the studied paleobathymetric zones within the Pieniny Klippen Basin during the Toarcian–Aalenian (discussed in this paper).

Chondrites associated with *Thalassinoides* and very rare *Zoophycos* and *Teichichnus*. Maximum burrow diameters (MBD) vary from 5–12 mm, usually 6–8 mm, in the Czorsztyn Succession, and 4–8 mm in the Branisko Succession. The rock consists of abundant filaments of the bivalve *Bositra buchi*.

Our knowledge of the microfaunal composition of this formation is limited. Birkenmajer & Pazdro (1963) discovered numerous ostracods and foraminifers dominated by lenticulinids and associated with *Eoguttulina liasica* Strickland and two species of *Reinholdella* within the "Opalinus Beds" (=The Krempachy Marl Formation of Birkenmajer 1977) of the Niedzica Succession. Scheibnerová (1968) figured fifteen foraminiferal taxa and four ostracod taxa from a single locality of the Czorsztyn Succession in the Orava valley (Slovakia).

Material and methods

Eighteen samples have been collected from three localities: Krempachy (Czorsztyn Succession), Biała Woda (Czorsztyn Succession), and Podubocze (Branisko Succession), (Fig. 1; App. 1; for exact sample locations see Tyszka 1995, Figs. 6, 7). They represent the best accessible outcrops of the Krempachy Marl Formation in Poland (recently Podubocze was flooded by an artificial lake). The samples collected were dried, weighed out (250 g), and then disintegrated in a sodium solution. Disin-

tegrated samples were sieved through a 105 µm mesh sieve. The MVSP Version 3.0" (Kovach 1998) was used for the cluster analysis (CLA) and principal component analysis (PCA) of quantitative microfossil data.

Data sets. Two types of quantitative data sets were used in both analyses: (1) percentages of all benthic foraminiferal taxa, and (2) abundance of all benthic microfossils per 100 g sediment, including the number of foraminifers per 100 g sediment and an ostracod valves/carapaces ratio. In order to avoid overestimation of ostracod tests, ostracod number (N) has been recalculated using a formula, where C represents the carapaces number, and V the valves number: $N = C + V/2$.

PCA recommends an equal or lower amount of variables than cases. In order to fulfil this requirement, the number of variables has been reduced to eighteen. Most common microfossils are kept separately and directly transferred to input files (see App. 2 and 3). Rare taxa or groups, which show taxonomic or morphological affinity, have been added together according to codes presented within the data tables (see App. 2 and 3).

Cluster analysis. CLA offers a set of numerical techniques, which divide the object of study into discrete groups usually presented as dendrograms. Here, the clustering, based on the cosine theta distance, also known as the normalized Euclidean distance, links every pair of cases/clusters with the lowest distance.

$$C = \sqrt{\sum_{k=1}^n \left(\frac{x_{ik} - x_{jk}}{SS_i - SS_j} \right)^2} \quad \text{where} \quad SS_i = \sqrt{\sum_{k=1}^n x_{ik}^2}$$

In these two formulae, C represents cosine theta distance, n gives the total number of variables, i and j represent two rows (cases) of the data matrix, k represents the column (variable), and therefore x_{ik} would be the datum in the k_{th} column of row i . The cluster formed by two cases is considered a single object, which is compared and linked to other objects (subclusters). The Unweighted Pair Group Average method (UPGMA) is used, which employs the average linkage technique. In this method, the average point (centroid) is closer to the group with more points (Kovach 1998). Q- and R-mode analyses have been conducted.

Principal component analyses. PCA remains one of the most widely used ordination techniques in paleoecology (Spicer & Hill 1979). The aim of PCA is to find meaningful axes in the multidimensional space defined by the variable (taxon abundance). The result of an analysis is to plot the PC-loadings against usually the first two or three principal axes in the form of a scatter plot. By performing either an R-mode or a Q-mode PCA both variable and sample scores can be obtained, which creates a dual ordination of the original data matrix. PCA was invented to present a continuum that may sometimes be assigned to an environmental gradient. Nevertheless, it also detects discontinuities, and thereby groups the data. The clustering on scatter plots (biplots) may then be used as a basis for dividing the sampled fossils into assemblages, each exhibiting a more homogeneous structure (Spicer & Hill 1979). It means that variable points in close proximity will show the correlation between variables, which may be interpreted as a result of the same paleoecological, sedimentary,

and/or taphonomic process. The variables may not all be directly comparable, so it would seem necessary to convert all of them to standardized form (Davis 1986). In order to avoid species abundance and sedimentation rate problems standardized data are used here.

Results

Biofacies/Microfossils. Quantitative microfossil data are presented in App. 2 and 3. Preservation of microfossils is similar in both studied successions. The biofacies of the formation within the Czorsztyn Succession is characterized by abundant benthic foraminifers and ostracods, common echinoderm fragments, including frequent crinoid remains and echinoid spines, and sponge sclerites (triactines, monactines, hexactines, and more complex ones) (Fig. 3). Besides benthics, relatively abundant radiolaria (1000–10000 specimens per 250 g-sample) have also been found. In general, benthic foraminifers from the Czorsztyn Succession are more abundant than in Branisko. They are dominated by calcareous foraminifers, especially *Spirillina* (25.4–52.2 %; mean 42.5 %), *Laevidentalina* (12–24 %) and *Lenticulina* (9–22 %). *Patellina* and *Rheinholdella* are rare (up to 5 %) but quite characteristic. Elongated morphogroups depict various species of *Laevidentalina*, *Pseudonodosaria*, and *Eoguttulina*. *Lenticulina* constitutes 9 to 22 %. Other nodosariids are rare and compose no more than 4 %. *Hyperammia*, *Ammobaculites*, *Trochammina*, *Reophax* and adherent *Tolypammia* represent scarce agglutinated foraminifers. Smooth-carapace ostracods are quite abundant (200–350 individuals per 100 g sediment).

Laevidentalina (22–56 %), *Lenticulina* (9–47 %), and *Spirillina* (1–46 %, 21.4 % on average) predominate in the Branisko Succession. Samples enhanced in *Lenticulina* exhibit the lowest number of *Spirillina*. Elongated nodosariids are relatively more frequent than in the Czorsztyn Succession. *Patellina* and *Rheinholdella* do not occur at all. Agglutinated foraminifers show a slightly higher number of tubular forms, such as *Hyperammia*, *Rhabdammina*. Ostracods are less abundant (100–200 valves and carapaces per 100 g sediment) than in the Czorsztyn Succession. Scarce sponge spicules and echinoderm fragments exhibit the same pattern. In contrast, radiolaria (preserved as calcitic casts) are more abundant in the Branisko than in the Czorsztyn Succession.

Microfaunal association described by Scheibnerová (1968) from the same 'formation' (so-called "Opalinus Beds") of the Czorsztyn Succession in the Orava valley shows 70 % of foraminifers and 30 % of smooth-walled ostracods that is similar to our results. Nodosariids are also very abundant with a domination of elongated forms, such as *Frondicularia sulcata* Bornemann, *Nodosaria fontinensis* Terquem, *Dentalina vetustissima* d'Orbigny. The lack of spirillinids and high proportion of agglutinated foraminifers (up to 40 %) dominated by *Ammodiscus incertus* (d'Orbigny) and *Trochammina inflata* (Montagu) are surprising. Especially *Ammodiscus* "forms the essential part of the association" (Scheibnerová 1968). Actually, agglutinated tubular and planispiral *Ammodiscus* is morphologically analogous to calcareous *Spirillina*. Our forms are calcareous and do not comprise agglutinated tests (Fig. 3). There are several possible explanations of such differences,

but they cannot be tested without comparative studies of the Orava valley microfauna.

Cluster analysis. The analysis of percentage foraminiferal data separates variables (benthic foraminiferal taxa) into two clusters, which represent different assemblages (Fig. 4a). *Patellina*, *Rheinholdella*, *Spirillina*, *Eoguttulina*, ophthalmidiids, and *Pseudonodosaria* are most closely linked within the first cluster. All of them represent calcareous foraminifers and, except for *Pseudonodosaria*, do not belong to the nodosariids. However, nodosariids clearly predominate in the second, very wide cluster, which links some agglutinated foraminifers, such as tubular astrophorids, *Trochammina*, *Ammobaculites*, and *Subreophax*. Sample clustering reveals two main clusters surprisingly linking all the Czorsztyn Succession samples with selected Branisko Succession samples (Fig. 4b). The Czorsztyn Succession samples representing the same locality (Biała Woda: BK-1, -2, -3, -11) are most closely associated within a single subcluster, which is associated with a Branisko Succession sample (PDK-17).

The cluster analysis of standardized abundance data, including all benthic microfossils per 100 g sediment and an ostracod valves/carapaces ratio, shows a different pattern. Variables have revealed two main loosely linked clusters (Fig. 5a). One of them is separated into two subclusters, where *Patellina*, *Rheinholdella*, *Spirillina* (including rare ophthalmidiids), *Eoguttulina* are closely associated with abundant foraminifers, ostracods, crinoid and other echinoid fragments. These closely linked variables represent well-separated microfossil assemblage pronounced within samples from the Czorsztyn Succession. Other subclusters are not so distinct, loosely linking astrophorids with nearly all elongated nodosariids, and other agglutinated foraminifers with *Nodosaria regularis* and *Ramulina*, holothurian sclerites, and valves/carapaces ratios. These variables characterize the microfossil assemblage fitting into samples from the Branisko Succession. Clustering of samples clearly separates the Czorsztyn Succession samples from the Branisko Succession ones (Fig. 5b).

Principal component analyses. The same procedure with the input data has been applied. In this case, non-standardized percentage values bring about domination of most common taxa, such as *Spirillina*, *Laevidentalina*, and *Lenticulina*, and to some extent *Pseudonodosaria* and *Eoguttulina* (Fig. 6a). The distribution of these taxa is responsible for most of the variability within the data set. The first axis accounts for about 66 % of the variance, and the first three axes for 95 % of the variance. The first vs. the second axis plot separates four clusters of samples representing either mixed Czorsztyn with Branisko successions or just the Branisko Succession alone. Samples from the Biała Woda Valley (BK) are most closely linked due to similar proportions of *Spirillina*, *Laevidentalina*, and *Lenticulina*. These samples have shown the highest loadings on the first axis and medium values on the second axis. They also link a single Branisko Succession sample, with a high proportion of *Spirillina* (Fig. 6a). In fact, the high and stable relative abundance of *Spirillina* is mostly responsible for such variability along the first axis. The second cluster, which contains some Czorsztyn Succession (from the Krempachy locality) and Branisko Succession samples, shows medium values on both axes. Another two clusters spread along the second axis. The highest second axis loadings are characteristic

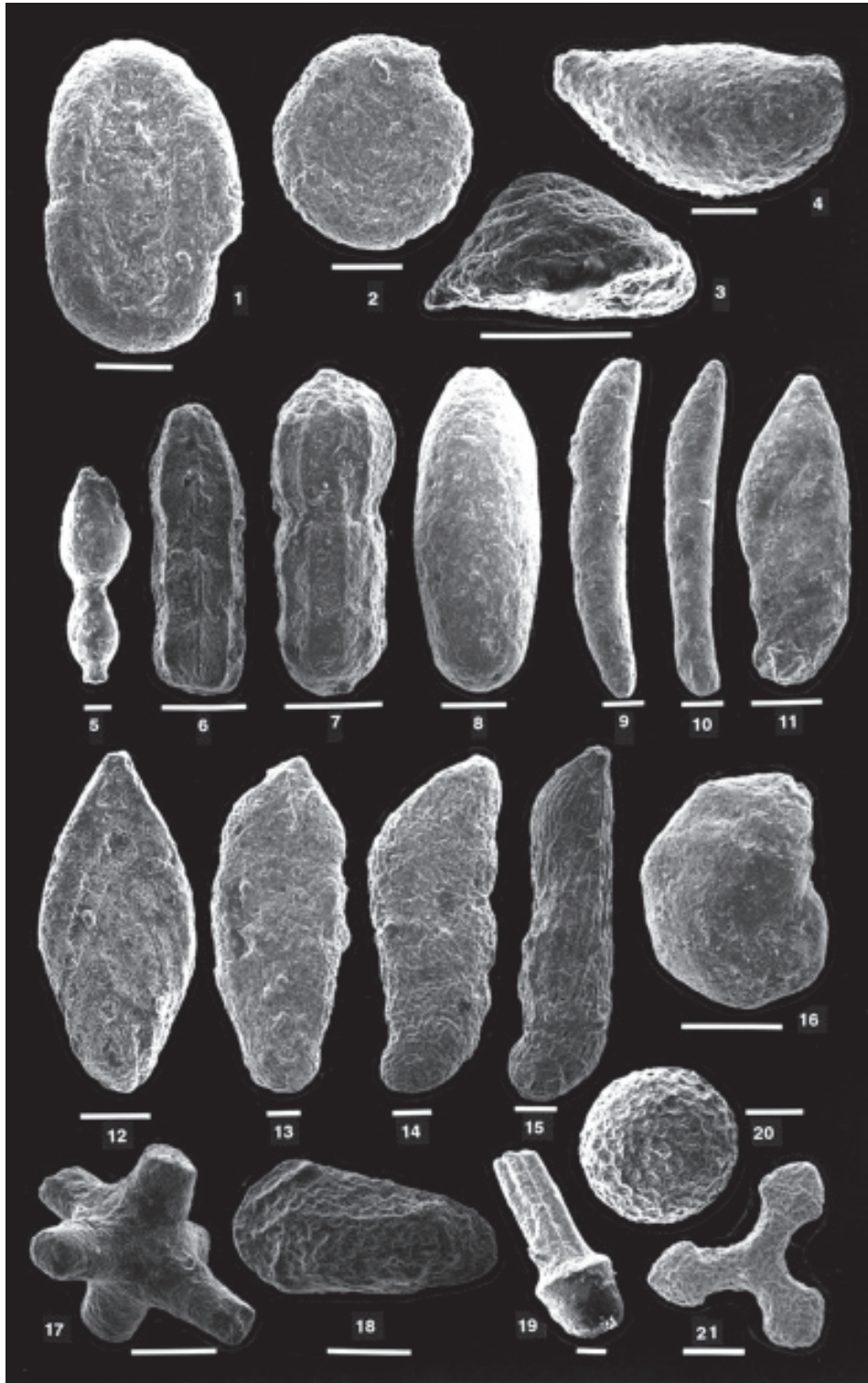


Fig. 3. Benthic foraminifera (1-16) and selected microfossils (17-21) from the Krempachy Marl Formation. Scale bar = 100 μm . 1 — *Spirillina elongata* Bielecka & Pożaryski, spiral view, sample PDK-17. 2 — *Spirillina infima* Strickland, spiral view, sample PDK-15. 3 — *Patellina* sp., peripheral view; sample BK-4. 4 — Morphogroup C-2, *Ramulina spandeli* Paalzow, sample PDK-18. 5 — *Nodosaria regularis*, sample PDK-2. 6 — *Pyramidulina columnaris* (Franke), sample PDK-10. 7 — *Pyramidulina dispar* (Franke), sample PDK-1. 8 — *Pseudonodosaria bajociana* (Terquem), sample PDK-1. 9 — *Laevidentalina subplana* Franke, sample PDK-18. 10 — *Laevidentalina* sp., sample PDK-11. 11 — *Astacolus anceps* (Terquem), sample PDK-18. 12 — *Falsopalmula deslongchampsii* (Terquem), sample PDK-10. 13 — *Falsopalmula tenuistriata* (Franke), sample PDK-10. 14 — *Marginulinopsis dictyodes dictyodes* (Deecke), sample PDK-10. 15 — Uncoiled *Lenticulina d'orbigny* (Roemer) sample PDK-10. 16 — *Lenticulina polygonata* (Franke), sample PDK-18. 17 — Sponge macroscler; sample PDK-2. 18 — Ornamented ostracod, ? *Lophocythere* sp., left valve, sample PDK-2. 19 — Echinoid spine, KSK-6. 20-21 — Radiolaria, (20) sample PDK-2; (21) sample PDK-18.

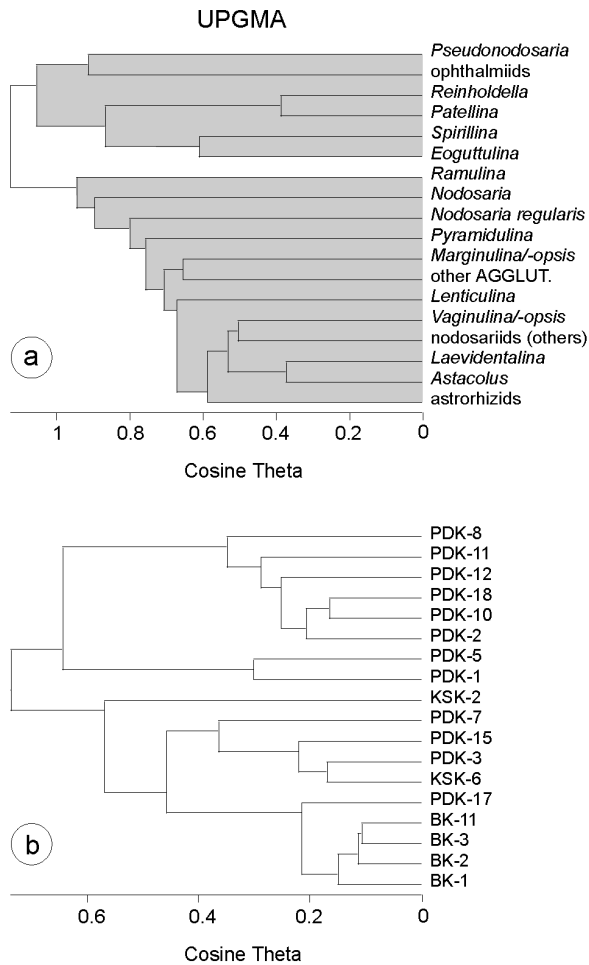


Fig. 4. Dendrogram from cluster analysis based on percentage abundance of benthic foraminifers from the Krempachy Marl Formation. Distance is measured by the cosine theta coefficient. Unweighted method of average linkage (UPGMA) is used. **a** — Clustering by variable (taxon/groups). **b** — Clustering by sample.

for *Laevidentalina* dominated samples, the lowest of which are associated with high proportions of *Lenticulina* (samples PDK-1, PDK-5). The third axis does not reveal any distinct pattern (App. 4).

Analysis of standardized abundance of all microfossils clearly separates two microfossil assemblages deriving from both successions (Fig. 6b,c). Five factors (axes) are significant and explain 85.1 % of the variance within the data set. The foraminiferal abundance, *Eoguttulina*, *Spirillina*, ostracod, and crinoid fragment abundance (including other echinoderm remains) show the highest (> 0.3) loadings for Axis 1, which accounts for 41.5 % of the variance. Axis 2 depicts the highest loadings (0.3–0.5) for all agglutinated foraminifers, calcareous *Nodosaria regularis* + *Ramulina*, and *Laevidentalina*. This axis explains only 16.1 % of the variance. Axis 3 shows the highest loadings for *Patellina* and *Reinholdella* and the most negative for sponge spicules and echinoid spines (App. 5).

Interpretation and discussion

Comparison of multivariate analytical results. Analyses of standardized abundance data better separate samples from two

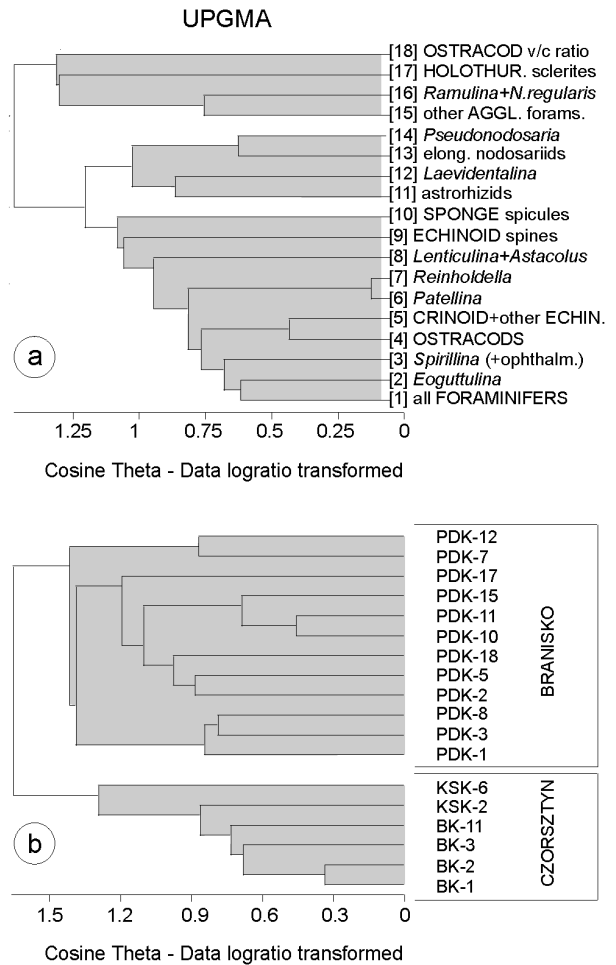


Fig. 5. Dendrogram from cluster analysis based on abundance of all microfossils (per 100 g sediment) from the Krempachy Marl Formation (for other notes see Fig. 5). **a** — Clustering by variable (taxon/groups) with a key for variables from Fig. 6b. **b** — Clustering by sample.

different successions than relative foraminiferal data, which depict higher variability within successions than variability between the two successions (Figs. 4–6). It suggests that foraminiferal assemblages reveal close affinities in both successions and points to not too strong paleoenvironmental differences. On the other hand, percentage values always close the data, changing their structure. Any highly fluctuating variable causes fluctuations of other, more stable components. For instance, analyses of percentage data indicate closer affinity of relatively abundant *Lenticulina* to agglutinated foraminifers and most of the nodosariids (Figs. 4, 6a). The results based on abundance data show an opposite trend, that is closer association with *Patellina*, *Spirillina* and other microfossils (Figs. 5, 6b). Comparison of *Spirillina* vs. *Lenticulina* distribution presented in percentages and abundances (per 100 g sediment) explains this contradiction (App. 2 and 3). Percentage data reveal distinctly higher proportions of *Lenticulina* within some Branisko samples (see Appendix 2; e.g. PDK-1, -2, -3, -5). Abundance data give a comparable number of *Lenticulina* specimens in both successions with slightly higher values for the Czorsztyń Succession samples (App. 2). This distributional pattern becomes clear when comparing values for *Spirillina*, which are on average much higher in the Czorsztyń Succes-

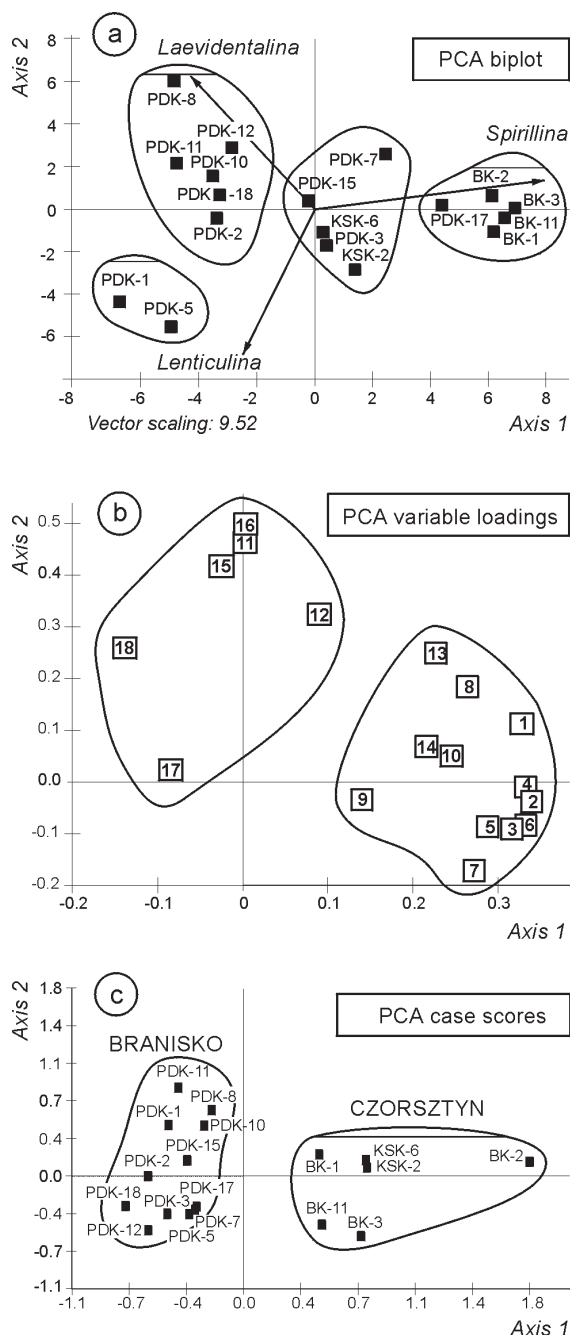


Fig. 6. a — Principal Component Analysis biplot for axes 1 and 2 based on percentage abundance of benthic foraminifera from the Krempachy Marl Formation. b — PCA plots for axes 1 and 2 based on abundance of all microfossils (per 100 g sediment) from the Krempachy Marl Formation (key for variables can be found on Fig. 5a). c — plot of samples revealing two clusters separating Czorsztyń and Branisko successions.

sion creating an artefact of a relatively lower proportions of *Lenticulina*. Thus, *Lenticulina* distribution is stable in both successions and does not distinctly associate with any succession.

Paleobathymetry. The formation studied reveals benthic foraminiferal assemblages dominated by calcareous foraminifera, which suggest paleodepths fairly above the CCD (calcite compensation depth) and exclude deep bathyal or abyssal depths for both the Czorsztyń and Branisko paleobathymetric

zones. This rules out hypothetical paleobathymetric models C and D (Fig. 2). Nevertheless, the studied zones somewhat differ in the composition of their microfauna, which probably indicates paleoenvironmental and also paleobathymetric differences. All these biofacies differences are compiled in Table 1. High abundance of planispiral *Spirillina* is the most characteristic feature of the whole formation. This epibenthic foraminifer is clearly dominant in the Czorsztyń Succession deposits, but also relatively common in those of the Branisko Succession. Multivariate analyses indicate that *Spirillina* is closely associated with other epibenthic forms, such as *Patellina* and some epistominids (*Reinholdella*), as well as with some elongated, probably endobenthic forms, like *Eoguttulina* (see Figs. 4–6). The distribution of these taxa also shows close affinity to other variables, that is to the total benthic foraminiferal abundance, mostly contributed by much higher abundance of *Spirillina*, as well as, to the abundance of ostracods, crinoid fragments, other echinoderm remains, and sponge spicules.

Gordon (1970) interpreted floods of Jurassic *Spirillina* as indicative of shallowing. Abundant *Spirillina infima* was reported by Morris (1982) from shallow water coralliferous marls and bioturbated limestones associated with Middle Jurassic oolitic facies of Wales. He considered this taxon to form a "primary weed fauna" associated with the filamentous algae. Nagy (1992) reported spirillinids from the Yons Nab Beds (Bajocian, North Sea deltas) reflecting "a shallow marine environment, presumably within the photic zone". Samson (1997) summarized Jurassic Spirillinidae as a characteristic group for the infralittoral super-biotope within the photic zone (down to a. 100 m). Johnson (1977) described *Spirillina infi-*

Table 1: Summary of selected sedimentologic and micropaleontologic features of the Krempachy Marl Formation between both Czorsztyń and Branisko successions.

	CZORSZTYN SUCCESION	BRANISKO SUCCESION
<i>similarities</i>		
lithology	spotty marlstones and marly limestones	
coloration	grey to bluish grey	
trace fossils	extensive bioturbation, medium to large maximum diameters, common <i>Planolites</i> & <i>Chondrites</i> , frequent <i>Thalassinoides</i>	
<i>differences</i>		
dominating foram. morphogroups	epibenthic forms	endobenthic forms
benthic foraminifers:	very abundant	abundant
<i>Patellina</i>	frequent	absent
<i>Rheinholdella</i>	frequent	absent
<i>Spirillina</i>	very abundant	common to abundant
<i>Eoguttulina</i>	common	single to frequent
nodosariids	frequent to common	very abundant
astrohizids	single	single to frequent
ostracods	abundant	common
crinoid fragments	frequent	single
other echinoderm remains	abundant	frequent
sponge spicules	abundant	frequent
radiolaria	abundant	very abundant
<i>interpretation</i>		
paleodepth	middle/outer neritic	outer neritic to upper bathyal
oxygenation	dysoxic	dysoxic
trophic regime	mesotrophic	mesotrophic
food supply	vertical (?seasonal fluxes) and lateral (weak currents)	vertical

ma and *Reinholdella* from the inner to the outer neritic (Toarcian-Domerian of Wales). Herrero (1993) reported Toarcian outer neritic assemblages from the Cordillera Iberica dominated by the Lagenina (Vaginulinidae family) subordinately associated with *Spirillina*. Monaco et al. (1994) described the Aalenian *Spirillina* Unit (up to 50 % of spirillinids associated with nodosariids) from Central Italy and interpreted as middle shelf with regressive trends. Spirillinids also dominate within Oxfordian neritic biohermal sponge facies from southern Poland and the French Jura (Barwicz-Piskorz 1989; Gaillard 1984 cited by Barwicz-Piskorz 1989), as well as, within the shallow water Kimmeridgian marlstones of central Poland (Barwicz-Piskorz & Tarkowski 1984). *Patellina* and *Reinholdella* have usually been reported from shallow neritic depths (Gordon 1970; Gradstein 1983; Stam 1986; Copestake & Johnson 1989; Riegraf & Luterbacher 1989). Jurassic *Eoguttulina* may also indicate a relatively shallow marine environment (Brouwer 1969; Birkenmajer & Tyszka 1996). On the other hand, Gradstein (1983) reported Jurassic assemblages dominated by nodosariids and some small agglutinated foraminifers associated (but not dominated!) with rare to common *Spirillina* and *Epistomina* from abyssal depths of the Blake-Bahama Basin. Similar deep oceanic (abyssal) occurrences of Upper Jurassic *Spirillina* were described from DSDP sites by Luterbacher (1972), Bartenstein (1974), and Kuznietsova (1974). According to Riegraf & Luterbacher (1989), the Upper Jurassic "deep water fauna" in the DSDP boreholes contains mostly nodosariids and small agglutinated forms associated with variable amount of epistominids, *Ophthalmidium*, and *Spirillina*.

Recent analogues are given by Davies (1970) and Brasier (1975) who described *Spirillina* on algae in modern lagoons. Berthold (1976), as well as Kitazato (1988) included *Spirillina vivipara* Ehrenberg and *Patellina corrugata* Williamson to vagrant phytal forms mainly living on seaweeds. Seaweeds require light that may govern distribution of these epiphytal foraminifers (Kitazato 1988; Murray 1991).

In conclusion, *Spirillina* and related taxa were reported from nearly all depths, but assemblages dominated by these taxa tend to indicate shallow settings, usually the inner to middle neritic. Thus, all above references suggest that the *Patellina*, *Spirillina* and associated microfossils, deriving from the Czorsztyn Succession, indicate relatively shallow, open sea paleoenvironment, which may be placed around the middle neritic zone. This is also supported by their association with abundant, poorly sorted, and morphologically diverse echinoderm (mainly crinoidal) remains which were probably not transported from other distant areas. Gluchowski (1987) interpreted optimum conditions for Middle Jurassic crinoid communities as comparatively shallow, below the wave base, but still within the photic zone.

Relatively low differences in the faunal composition between two zones point out quite low paleobathymetric differences. Slightly enhanced proportions of astrorhizids, domination of nodosariids, a lower number of crinoidal fragments, and a higher abundance of radiolaria suggest deeper location of the Branisko Zone and exclude a further two tested paleobathymetric models, that is models A and E (Fig. 4). Nodosariids from the Oxford Clay of England have already been mentioned as indicators of deeper (epicontinental) water, even if

they are not restricted to it (Barnard et al. 1981). Foraminiferal assemblages of the comparable "Fleckenmergel" facies from the Branisko Succession have already been analysed (Tyszka 1994a). Those assemblages are dominated either by agglutinated tubular foraminifers (astrorhizids) or nodosariids associated with astrorhizids. They indicate much deeper settings, however above the CCD, identified as the upper to lower bathyal. Furthermore, it seems that *Lenticulina* alone is probably not a good paleodepth proxy. Jurassic assemblages dominated by *Lenticulina* have been identified from all depths above the CCD (see Morris 1982; Gradstein 1983; Tyszka 1994a,b).

All above references and comments do not suggest any strong paleobathymetric variability. The Czorsztyn paleobathymetric zone can be estimated within the inner to middle neritic. The Branisko Zone was probably slightly deeper and ranged around the outer neritic or the uppermost bathyal. Thus, model B is the most probable reconstruction of the Toarcian-Aalenian Klippen Basin (Fig. 2B).

Trophic and oxic regime. Dense bioturbations, a high proportion of endobenthic foraminifers, and common radiolaria do not indicate any strong shortage of nutrients and food. All studied sections have revealed quite monotonous trace fossil assemblages with *Thalassinoides*, *Planolites*, and *Chondrites*. Such ichnofossil assemblages are typical of low oxygenated environments (Bromley & Ekdale 1984; Savrda & Bottjer 1986; Tyszka 1994a). Relatively high maximum burrow sizes, ranging between 6 and 12 mm, a common occurrence of *Thalassinoides*, and appearance of skeletal fossils such as echinoderm and holothurian remains indicate moderate dysoxic conditions of bottom water and surficial part of the substratum. Long-term temporal and spatial changes in bottom water oxygenation are not recorded by trace fossils and macrofaunal skeletal fragments. Actually, foraminiferal morphogroups show a spatial variability pattern, that is the Czorsztyn Zone is dominated by epibenthic forms (mostly spirillinids), and the Branisko Zone by endobenthic forms (elongated nodosariids). The TROX of Jorissen et al. (1995) and TROX-2 of Van der Zwaan et al. (1999) models and some earlier references imply either control by elevated redox boundary or shortage of nutrients as controlling factors of epibenthic dominance (see Van der Zwaan et al. 1999 for refs.). Such a more elevated position of the redox boundary in a shallower setting would be the easiest explanation, because organic flux is usually higher at shallower depths, and a higher organic matter content causes oxygen utilization and rising of the redox boundary (e.g. Van der Zwaan et al. 1999). Deep and complex tierings of burrows throughout all successions do not support such an explanation.

Stam (1986) assumed that the distribution and abundance of spirillinids might depend not so much on the amount of food but more on the quality of food. It can be speculated that epibenthic spirillinids preferred mesotrophic conditions with episodic, probably seasonal fluxes of food related to phytoplankton blooms. Spirillinids as surface dwellers were probably best suited for fast response and reproduction after seasonal organic matter influxes. This seasonal scenario seems to be supported by the high dominance of *Spirillina* associated with the enhanced abundance (per 100 gram sediment) of all benthic foraminifers. Such averaged fossil assemblage may represent a very dynamic community with a highly fluctuating

population size. The community may have been highly over-dominated by spirillinids during high organic fluxes. Periods with a lower organic matter influx were probably favoured by endobenthic forms and specialized epibenthos with very low proportions of spirillinids. On average in the fossil record, these communities show averaged proportions oscillating around 50 % in the Czorsztyn and 20 % in the Branisko zones. This lower proportion of *Spirillina* in the Branisko Zone probably reflects a lower seasonal organic matter influx due to recycling of organic matter during sinking through the deeper water column and/or due to lower primary productivity.

Abundance of ostracods follows trends in abundance of benthic foraminifers. Their higher abundance in the Czorsztyn Succession may indicate either a higher productivity or a lower sedimentation rate, which caused condensation of microfossils. Considering discussion presented below, strong differences in the sedimentation rate between the two successions are doubtful. The ostracods/foraminifers ratio reaches on average 0.45, but varies between 0.23 and 0.92 that is comparable to the highest values recorded in the moderately to weakly dysaerobic biofacies of the Podzamcze Limestone Formation, but much higher than the lowest values (0.01–0.05) characteristic for strongly dysaerobic biofacies (Tysza 1994a). It means that, in general, ostracods were less resistant to suboxic conditions than benthic foraminifers. Their valves/carapaces ratio shows high variability and seems to be enhanced in the Branisko Succession, but, actually, this pattern is caused by two unusually high values (App. 2).

The Czorsztyn Succession preserved an enhanced abundance of crinoid fragments and sponge spicules (especially at the Krempachy locality), therefore, skeletal fragments of suspension feeders. It indicates weak bottom currents carrying nutrients, essential for their survival. On the other hand, conditions were far from optimal for densely populated crinoidal meadows, which developed in the shallower part of the basin later, that is during the Bajocian and Bathonian (see Birkenmajer 1963; Głuchowski 1987). It is likely that stagnation of the basin and bottom water oxygen-depletion did not favour crinoidal meadows.

Sedimentation rate. It is important to be aware of susceptibility to species abundance when abundances of fossils within unit volumes of rock are ordinated in PCA. In this case, any variation in abundance arising from varying rates of sedimentation will be introduced into the final pattern (Spicer & Hill 1979). If variability of sedimentation rate was the only reason for changes in microfossil abundance, one could expect stable (constant) proportions of microfossils. The negative correlation of radiolaria vs. foraminifera abundance in the Czorsztyn and Branisko successions suggests that sedimentation rate during deposition of the Krempachy Marl Formation was not so different in the two successions. It also means that the enhanced abundance of foraminifers associated with shallow water indicators is not just an artefact of a lower sedimentation rate in the Czorsztyn Succession. The foraminiferal productivity was most likely higher in the shallower part of the basin, possibly due to higher (?seasonal) food fluxes. Unfortunately, absolute sedimentation rates cannot be calculated due to poor time control and tectonically obscured stratigraphic boundaries. On the basis of the duration of ammonite zones and reported thickness of the formation, it can be roughly estimated

that the sedimentation rate in both successions ranged between several up to a dozen or so millimetres per ka.

Conclusions

The results of multivariate analyses based on percentage abundance of benthic foraminifers and standardized number of all microfossils per 100 gram sediment have revealed that the latter data appear to separate paleobathymetric settings much better than the percentage of benthic foraminiferal data alone (Figs. 4–6). It is therefore worthwhile to extend quantitative study to all microfossils and include them into multivariate statistics.

Comparison of the foraminiferal assemblages with fossil and recent analogues suggests relatively small paleodepth differences within the basin estimated at the middle/outer neritic for the Czorsztyn and the outer neritic and/or upper bathyal for the Branisko paleobathymetric zone. *Spirillina* is the most dominant constituent of the foraminiferal assemblage in the shallower part of the basin being still frequent or even common in the Branisko Zone. Association of abundant *Spirillina* with *Patellina* and *Reiholdella* indicates shallow neritic depths. The predominance of nodosariids associated with tubular agglutinated foraminifers (astrorhizids) suggests deeper basinal settings. Enhanced abundance of ostracods, crinoid, and other echinoderm fragments appears to be a shallow water indicator. On the other hand, higher abundance of crinoid fragments and sponge spicules within the shallower (Czorsztyn) zone points to a higher energetic environment with very weak lateral currents.

All these proxies depend on organic matter flux. The benthic association suggests mesotrophic conditions with moderate organic matter influx. Moderate primary productivity is also indicated by relatively abundant radiolaria, which are very sensitive paleoproductivity proxies. The possibility of seasonal fluctuations on primary productivity and their effect on a foraminiferal distributional pattern is also speculated.

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Appendices

Appendix 1. Locations: Krempachy (Czorsztyn Succession). This Krempachy Marl Formation type locality is poorly outcropped on the right bank of the Bialka River, south of the Kramnica Klippe (Birkenmajer 1963) (Fig. 1a). According to Birkenmajer (1963, 1977), about 100 m thick sequence was accessible before. At present, just a small, one meter thick, ditch dug provided access to a few samples (KSK-2, KSK-6). Outcropped deposits represent grey to grey-bluish spotty marly limestones intercalated by similar grey spotted shaly marlstones.

Biala Woda (Czorsztyn Succession). The formation crops out in the stream-bed (left bank) of the Biala Woda Valley, to the east of the Smolegowa Skala klippe (Fig. 1a). The locality exposes about 1.5 m thick profile of the bluish grey marly limestones (10–15 cm thick beds) intercalated with grey marlstones (5–10 cm thick). Beds dip in 194/64. Four samples (BK-1, BK-2, BK-3, BK-11) have been analysed.

Podubocze (Branisko Succession). The outcrop was exposed to the east of the Czorsztyn Castle (Fig. 1a), in a small ENE-WSW valley (recently flooded by an artificial lake). A 6–8 m thick section was outcropped along the valley, on a distance approximately 40 m. Thin (8–15 cm) layers of grey and grey-bluish spotted limestones are intercalated with thin bands of spotted marly limestones and marlstones. Beds dip in 180/19, 161/22, and 157/34 and are most likely tectonically overturned as is indicated by trace-fossil structures. Twelve samples (PDK-) have been analysed (App. 2 and 3).

Appendix 2. Abundance of all identified microfossils per 100 g sediment. The second column depicts the ‘code’ which is applied into row input data to reduce the number of variables for multivariate statistical analyses: (*) rows used directly as input data; (a–f) sum of variables from selected rows, including as follow: (a) other agglutinated foraminifers (except for astrorhizids); (b) *Lenticulina* with *Astacolus*; (c) other nodosariids; (d) *Ramulina* with *Nodosaria regularis*; (e) *Spirillina* with ophthalmiids (planispiral, with tubular chambers); (f) crinoid and other echinoderm remains (excluding echinoid spines).

Succession	CZORSZTYN						BRANISKO												
	code	BK-1	BK-2	BK-3	BK-11	KSK-2	KSK-6	PDK-1	PDK-2	PDK-3	PDK-5	PDK-7	PDK-8	PDK-10	PDK-11	PDK-12	PDK-15	PDK-17	PDK-18
foram.abund./100g	*	750	1240	742	637	485	624	289	187	258	213	346	672	438	418	198	392	426	160
<i>Ammobaculites</i>	a	6.4	1.6	-	-	-	-	9.6	3.2	-	3.2	-	-	4.8	1.6	-	1.6	-	0.8
astrorhizids:	*	11.2	19.2	9.6	3.2	3.2	22.4	17.6	14.4	3.2	-	22.4	30.4	22.4	38.4	4.8	22.4	4.8	4
<i>Conotrochammina</i>	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	-	-
<i>Evolutinella</i>	a	-	-	3.2	-	-	-	-	-	-	-	-	-	-	1.6	-	1.6	-	-
<i>Reophax</i>	a	-	-	-	-	9.6	-	-	1.6	-	-	-	-	-	-	-	-	-	3.2
<i>Subreophax</i>	a	-	-	-	-	-	-	1.6	-	-	-	-	4.8	-	1.6	-	4.8	-	-
<i>Textularia</i>	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	-
<i>Tolypammina</i>	a	4.8	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	-
<i>Trochammina</i>	a	6.4	3.2	-	-	3.2	3.2	6.4	3.2	1.6	1.6	-	3.2	4.8	9.6	-	4.8	-	2.4
<i>Verneulinoides</i>	a	-	-	-	-	-	-	2.4	-	-	-	-	-	-	-	-	-	-	3.2
<i>Astacolus</i>	b	35.2	28.8	22.4	9.6	16	19.2	10.4	8	6.4	6.4	3.2	32	14.4	25.6	14.4	12.8	11.2	8
<i>Citharina</i>	c	-	3.2	-	-	3.2	3.2	0.8	6.4	-	-	3.2	-	1.6	1.6	-	3.2	1.6	1.6
<i>Eoguttulina</i>	*	20.8	67.2	19.2	41.6	41.6	32	0.8	1.6	1.6	3.2	12.8	4.8	4.8	4.8	-	1.6	16	0.8
<i>Falsopalmula</i>	*	-	-	3.2	-	6.4	6.4	4	-	1.6	3.2	-	-	11.2	4.8	6.4	8	6.4	-
<i>Fronducularia</i>	c	4.8	3.2	-	3.2	3.2	3.2	-	-	1.6	-	3.2	3.2	6.4	12.8	1.6	-	1.6	0.8
<i>Laevidentalina</i>	*	99.2	213	112	96	59.2	147	76	59.2	65.6	57.6	106	378	166	160	83.2	115	94.4	56
<i>Lenticulina</i>	b	118	114	86.4	86.4	89.6	134	107	43.2	70.4	99.2	32	57.6	76.8	56	28.8	73.6	68.8	31.2
<i>Lingulina</i>	c	-	-	-	1.6	1.6	6.4	-	-	-	-	-	-	-	1.6	-	-	-	-
<i>Marginulina</i>	c	-	-	-	-	-	-	2.4	-	-	-	-	-	-	-	-	-	-	-
<i>Marginulinopsis</i>	c	4.8	-	3.2	3.2	1.6	9.6	3.2	3.2	1.6	-	3.2	1.6	8	-	-	3.2	-	2.4
<i>Nodosaria</i>	c	3.2	16	-	3.2	4.8	19.2	-	-	4.8	-	6.4	4.8	-	8	3.2	3.2	-	2.4
<i>Nodosaria regularis</i>	d	4.8	12.8	-	3.2	1.6	3.2	16	6.4	4.8	4.8	-	1.6	8	22.4	-	4.8	-	-
ophthalmiids	e	4.8	3.2	3.2	3.2	6.4	-	-	-	3.2	3.2	-	-	1.6	1.6	-	-	-	-
<i>Patellina</i>	*	12.8	57.6	38.4	12.8	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Planularia</i>	c	-	-	-	-	-	-	5.6	-	-	-	6.4	1.6	1.6	-	-	-	-	-
<i>Pseudonodosaria</i>	*	12.8	38.4	6.4	9.6	83.2	6.4	6.4	-	3.2	-	9.6	14.4	3.2	3.2	4.8	1.6	1.6	0.8
<i>Pyramidulina</i>	c	6.4	9.6	-	3.2	8	6.4	3.2	-	3.2	-	3.2	8	9.6	6.4	1.6	-	4.8	0.8
<i>Ramulina</i>	d	3.2	1.6	-	-	6.4	3.2	-	1.6	1.6	3.2	-	9.6	6.4	-	-	1.6	8	5.6
<i>Reinholdella</i>	*	9.6	38.4	41.6	28.8	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Saracenaria</i>	c	-	-	-	-	-	-	-	-	-	-	-	-	-	0.61	1.29	-	-	0.8
<i>Spirillina</i>	e	373	602	387	323	123	176	4	30.4	81.6	25.6	134	112	73.6	43.2	41.6	114	195	27.2
<i>Vaginulina</i>	c	-	-	-	1.6	3.2	-	-	4.8	1.6	1.6	-	1.6	-	1.6	-	4.8	1.6	0.8
<i>Vaginulinopsis</i>	c	8	6.4	6.4	3.2	4.8	22.4	11.2	-	-	-	-	3.2	12.8	11.2	4.8	8	6.4	6.4
ostracod carapaces		194	314	195	173	258	259	119	114	150	179	147	130	123	80	106	120	104	62.4
ostracod valves		92.8	43.2	44.8	70.4	28.8	48	49.6	81.6	36.8	33.6	35.2	54.4	75.2	38.4	27.2	30.4	17.6	18.4
OSTRACOD SUM	*	240	335	218	208	272	283	144	154	169	196	165	157	161	99.2	119	135	113	71.6
valves/carapaces ratio	*	0.48	0.14	0.23	0.41	0.11	0.19	0.42	0.72	0.24	0.19	0.24	0.42	0.61	0.48	0.26	0.25	0.17	0.29
SPONGE spicules	*	14.4	35.2	12.8	36.8	57.6	89.6	4.8	4.8	6.4	4.8	3.2	-	14.4	12.8	4.8	9.6	-	4
CRINOID fragments	f	12.8	19.2	25.6	12.8	4.8	12.8	0.8	-	1.6	-	-	-	-	-	-	-	3.2	-
other ECHINODERM frag.	f	65.6	123	112	35.2	56	70.4	0.8	11.2	28.8	6.4	11.2	16	8	3.2	1.6	8	-	-
ECHINOID spines	*	8	6.4	6.4	12.8	14.4	19.2	0.8	12.8	1.6	14.4	9.6	1.6	12.8	4.8	1.6	4.8	6.4	0.8
ECHINODERMS SUM	*	86.4	149	144	60.8	75.2	102	2.4	24	32	20.8	20.8	17.6	20.8	8	3.2	12.8	9.6	0.8
HOLOTHURIAN sclerites	*	-	-	-	-	-	-	2.4	-	9.6	-	-	4.8	-	-	-	-	-	-
juvenile BIVALVES		1.6	-	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BIVALVE fragments		-	1.6	-	-	-	-	-	-	-	3.2	6.4	4.8	-	3.2	-	-	-	-
FISH teeth		-	-	-	-	-	-	-	-	-	-	-	3.2	-	-	-	-	-	-
RHYNHOLITHS		-	-	-	-	-	-	-	-	1.6	-	-	-	-	1.6	-	-	-	-

Appendix 3. Relative proportions of all foraminifers (in percent). The second column depicts the 'code' which is applied into row input data: (*) rows used directly as input data; (a-d) sum of variables from selected rows, including as follow: (a) other agglutinated foraminifers (except for astrorhizids); (b) other nodosariids; (c) *Marginulina* with *Marginulinopsis*; (d) *Vaginulina* with *Vaginulinopsis*.

Succession	CZORSZTYN							BRANISKO											
	code	BK-1	BK-2	BK-3	BK-11	KSK-2	KSK-6	PDK-1	PDK-2	PDK-3	PDK-5	PDK-7	PDK-8	PDK-10	PDK-11	PDK-12	PDK-15	PDK-17	PDK-18
<i>Ammobaculites</i>	a	0.9	0.1	-	-	-	-	3.3	1.7	-	1.5	-	-	1.1	0.4	-	0.4	-	0.5
astrorhizids	*	1.5	1.5	1.3	0.5	0.7	3.6	6.1	7.7	1.2	-	6.5	4.5	5.1	9.2	2.4	5.7	1.1	2.5
<i>Conotrochammina</i>	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-
<i>Evolutinella</i>	a	-	-	0.4	-	-	-	-	-	-	-	-	-	-	0.4	-	0.4	-	-
<i>Reophax</i>	a	-	-	-	-	2.0	-	-	0.9	-	-	-	-	-	-	-	-	-	2.0
<i>Subreophax</i>	a	-	-	-	-	-	-	0.6	-	-	-	-	0.7	-	0.4	-	1.2	-	-
<i>Textularia</i>	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Tolypammina</i>	a	0.6	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Trochammina</i>	a	0.9	0.3	-	-	0.7	0.5	2.2	1.7	0.6	0.8	-	0.5	1.1	2.3	-	1.2	-	1.5
<i>Verneulinoides</i>	a	-	-	-	-	-	-	0.8	-	-	-	-	-	-	-	-	-	-	2.0
<i>Astacolus</i>	b	4.7	2.3	3.0	1.5	3.3	3.1	3.6	4.3	2.5	3.0	0.9	4.8	3.3	6.1	7.3	3.3	2.6	5.0
<i>Citharina</i>	b	-	0.3	-	-	0.7	0.5	0.3	3.4	-	-	0.9	-	0.4	0.4	-	0.8	0.4	1.0
<i>Eoguttulina</i>	*	2.8	5.4	2.6	6.5	8.6	5.1	0.3	0.9	0.6	1.5	3.7	0.7	1.1	1.1	-	0.4	3.8	0.5
<i>Falsopalmula</i>	b	-	-	0.4	-	1.3	1.0	1.4	-	0.6	1.5	-	-	2.6	1.1	3.2	2.0	1.5	-
<i>Fronicularia</i>	b	0.6	0.3	-	0.5	0.7	0.5	-	-	0.6	-	0.9	0.5	1.5	3.1	0.8	-	0.4	0.5
<i>Laevidentalina</i>	*	13.2	17.2	15.1	15.1	12.2	23.6	26.3	31.6	25.5	27.1	30.6	56.2	38.0	38.3	41.9	29.4	22.2	35.0
<i>Lenticulina</i>	*	15.8	9.2	11.6	13.6	18.5	21.5	37.1	23.1	27.3	46.6	9.3	8.6	17.5	13.4	14.5	18.8	16.2	19.5
<i>Lingulina</i>	b	-	-	-	0.3	0.3	1.0	-	-	-	-	-	-	-	-	0.8	-	-	-
<i>Marginulina</i>	c	-	-	-	-	-	-	0.8	-	-	-	-	-	-	-	-	-	-	-
<i>Marginulinopsis</i>	c	0.6	-	0.4	0.5	0.3	1.5	1.1	1.7	0.6	-	0.9	0.2	1.8	-	-	0.8	-	1.5
<i>Nodosaria</i>	*	0.4	1.3	-	0.5	1.0	3.1	-	-	1.9	-	1.9	0.7	-	1.9	1.6	0.8	-	1.5
<i>Nodosaria regularis</i>	*	0.6	1.0	-	0.5	0.3	0.5	5.5	3.4	1.9	2.3	-	0.2	1.8	5.4	-	1.2	-	-
ophthalmidiids	*	0.6	0.3	0.4	0.5	1.3	-	-	-	1.2	1.5	-	-	0.4	0.4	-	-	-	-
<i>Patellina</i>	*	1.7	4.6	5.2	2.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Planularia</i>	b	-	-	-	-	-	-	1.9	-	-	-	1.9	0.2	0.4	-	-	-	-	-
<i>Pseudonodosaria</i>	*	1.7	3.1	0.9	1.5	17.2	1.0	2.2	-	1.2	-	2.8	2.1	0.7	0.8	2.4	0.4	0.4	0.5
<i>Pyramidulina</i>	*	0.9	0.8	-	0.5	1.7	1.0	1.1	-	1.2	-	0.9	1.2	2.2	1.5	0.8	-	1.1	0.5
<i>Ramulina</i>	*	0.4	0.1	-	-	1.3	0.5	-	0.9	0.6	1.5	-	1.4	1.5	-	-	0.4	1.9	3.5
<i>Reinholdella</i>	b	1.3	3.1	5.6	4.5	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Saracenaria</i>	b	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.8	-	-	1.0
<i>Spirillina</i>	*	49.7	48.5	52.2	50.8	25.4	28.2	1.4	16.2	31.7	12.0	38.9	16.7	16.8	10.3	21.0	29.0	45.9	17.0
<i>Vaginulina</i>	d	-	-	-	0.3	0.7	-	-	2.6	0.6	0.8	-	0.2	-	0.4	-	1.2	0.4	0.5
<i>Vaginulinopsis</i>	d	1.1	0.5	0.9	0.5	1.0	3.6	3.9	-	-	-	-	0.5	2.9	2.7	2.4	2.0	1.5	4.0
SUM		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix 4. Principal components structure matrix for the benthic foraminiferal percentage data. The table presents the correlations of the taxa to the components (axis).

	Axis 1	Axis 2	Axis 3
Eigenvalues	352.657	124.015	30.304
Percentage	66.264	23.303	5.694
Cum. Percentage	66.264	89.567	95.261
PCA variable loadings			
	Axis 1	Axis 2	Axis 3
ASTRORHIZIDS	-0.078	0.089	-0.097
other AGGLUT. FORAM.	-0.065	-0.062	-0.089
<i>Astacolus</i>	-0.042	0.042	-0.037
<i>Eoguttulina</i>	0.085	-0.045	-0.233
<i>Laevidentalina</i>	-0.451	0.662	0.407
<i>Lenticulina</i>	-0.26	-0.719	0.508
<i>Marginulina/-opsis</i>	-0.012	-0.011	-0.01
<i>Nodosaria</i>	-0.001	0.02	-0.031
<i>Nodosaria regularis</i>	-0.054	-0.052	-0.034
NODOSARIIDS (others)	-0.05	0.024	-0.099
OPHTHALMIDIIDS	0.002	-0.026	-0.004
<i>Patellina</i>	0.061	0	-0.001
<i>Pseudonodosaria</i>	0.026	-0.061	-0.576
<i>Pyramidulina</i>	-0.006	0.012	-0.051
<i>Ramulina</i>	-0.014	-0.001	0.011
<i>Reinholdella</i>	0.066	-0.005	0
<i>Spirillina</i>	0.833	0.144	0.392
<i>Vaginulina/-opsis</i>	-0.039	-0.01	-0.056

Appendix 5. Principal components matrix for all microfossil abundance (per 100 g) data.

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	7.475	2.901	2.419	1.351	1.171
Percentage	41.526	16.114	13.438	7.508	6.504
Cum. Percentage	41.526	57.64	71.077	78.585	85.089
PCA variable loadings					
Microfossils	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
FORAM. Abundance	0.33	0.112	0.222	0	0.079
astrorhizids	0.001	0.468	0.144	0.094	0.353
other AGGL. forams.	-0.026	0.42	-0.041	0.063	-0.585
<i>Eoguttulina</i>	0.343	-0.039	-0.068	-0.021	0.006
<i>Laevidentalina</i>	0.09	0.327	0.279	-0.183	0.49
<i>Lenticulina</i> + <i>Astacolus</i>	0.267	0.187	-0.036	0.056	-0.139
elong. nodosariids	0.229	0.252	-0.342	-0.204	0.019
<i>Ramulina</i> + <i>N.regularis</i>	0.002	0.504	0.047	0.005	-0.192
<i>Patellina</i>	0.29	-0.089	0.324	0.066	-0.15
<i>Pseudonodosaria</i>	0.217	0.069	-0.278	-0.35	-0.227
<i>Reinholdella</i>	0.274	-0.173	0.302	0.149	-0.105
<i>Spirillina</i> (+ophthalm.)	0.319	-0.092	0.246	0.085	-0.046
OSTRACODS (valves/2)	0.336	-0.011	-0.12	-0.026	0.046
Valves/Carapaces ratio	-0.141	0.262	0.125	0.459	0.016
SPONGE spicules	0.246	0.051	-0.379	0.011	0.21
ECHINOID spines	0.141	-0.035	-0.418	0.404	0.287
CRINOID+other ECHINOD.	0.336	-0.084	0.122	0.021	-0.041
HOLOTHURIAN sclerites	-0.085	0.024	0.169	-0.614	0.11