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Benthic foraminiferal associations in the Miocene of Southern Poland

ABSTRACT: Distributional patterns of more than 50 most common benthic foraminiferal genera of the Polish Badenian to Sarmatian (Miocene) are studied semi-quantitatively by factor analysis of correspondences. They appear independent one of another and do not permit recognition of any consistent ecological communities. The multi-species (or better, multi-genus) method appears therefore as the only valid benthic-foraminifer-based paleoecological approach to paleoenvironmental reconstruction. Six distinct associations are recognized among the Polish Miocene foraminifers, and called after their most typical genera; these are the *Asterigerina*, *Quinqueloculina*, *Valvulineria*, *Robulus*, *Florilus*, and *Sphaeroidina* associations. The former three associations prevail under shallow-water conditions, while the others are indicative of deeper-water environments. The *Asterigerina* association is recognized for typical of seagrass or kelp beds. The *Quinqueloculina* association typical of the Sarmatian deposits appears indicative of very high availability of the calcium carbonate.

INTRODUCTION

Benthic foraminifers are well known to be among the most common marine fossils in the Miocene deposits of Southern Poland. Their taxonomy and distributional patterns have for long been studied for purposes of both stratigraphical correlation and, to some extent, of paleoenvironmental reconstruction. The present paper is intended to consider the latter point in some detail.

It was clearly shown by Lawrence (1968) that all paleoecological approaches to the problem in paleoenvironmental reconstruction rely heavily upon the transfer of informations on biology of modern organisms into the geological past, which undermines largely their validity. One may, however, claim that the Neogene marine benthic biota do so strongly resemble the Recent ones that it would be unreasonable to reject any paleoecological inference just because of its necessary dependence upon an uniformitarian background.

The most common paleoecological approach to paleoenvironmental analysis consists in recognition of the limiting ecospace dimensions for the best known

species of a fossil assemblage. This involves usually a strictly actualistic argument. The trouble is, however, in that in each particular case one can hardly know whether the basic assumption of constancy in ecological requirements of the species through time is valid or not. The constraints of possible evolutionary changes in species biology and ecology upon the single-species approach are overcome with use of the multi-species approach. When applying the latter, overlapping portions of the present-day ecological ranges of all co-occurring species are regarded as indicative of a paleoenvironment. The weak point of the single-species method can also be overcome with use of the community approach assuming that benthic-community composition and structure do always reflect environmental conditions. Following this assumption, the biota are then categorized into some more or less broadly meant community types considered as indicative each one of a specific set of ecological parameters.

Actually, the difference between the multi-species and community approaches to paleoenvironmental reconstruction arises from their contrasting basic assumptions on the controls of distributional patterns of benthic species. Either it is assumed that these patterns are independent one of another, and the species do co-occur only because of their similar responses to environmental parameters or factors; then, the multi-species approach appears as the only valid one. Or one assumes that the benthic species form some recurrent assemblages or associations controlled mainly by various biological interrelationships. In order to recognize the most adequate and reliable benthic-foraminifer-based approach to paleoenvironmental analysis, one has therefore to study distributional patterns of foraminifers over a considerable range of facies, and to estimate their interdependence.

In the present paper, distributional patterns of some 50 most common benthic foraminiferal genera of the Polish Badenian to Sarmatian (Miocene) are studied semiquantitatively by factor analysis of correspondences (cf. Benzécri 1973, David & *al.* 1974). The multivariate analysis groups variables displaying similar statistical characteristics and hence, permits a recognition of recurrent clusters of the investigated taxa and estimation of their mutual interdependence. The associated sediments are also analysed to give insight into the nature of foraminifer-lithofacies relationships in the Miocene of Poland.

MATERIALS AND METHODS

To be able to study distributional patterns of benthic foraminifers, one needs a large set of samples, each one with foraminiferal relative abundances described at least in semiquantitative terms and with a brief characteristics of the associated sediment. Unexpectedly, even so vague informations can hardly be derived from most studies on the Polish Miocene microfauna. Sample locations are usually so imprecise that the samples cannot be referred to their geological settings (*see for example*

the recent monograph by Łuczowska, 1974, where singular faunal lists represent whole localities, each one with several exposures, long geological sections, and variable lithologies). Moreover, faunal lists do often not contain any information on relative abundances of particular taxa.

Therefore, despite the diverse investigations of the Polish Miocene benthic foraminifers, all the data analysed in the present paper (210 samples) derived from but a few sources, namely the reports by Alexandrowicz (1960, 1961, 1963*a, b*), Alexandrowicz & Odrzywolska-Bieńkowska (1960), Łuczowska (1955, 1964, 1967), and Odrzywolska-Bieńkowska (1964). The original investigations cover nearshore to offshore areas of the Miocene facies developed in the Fore-Carpathian Depression. Stratigraphically, the samples range from Lower Badenian to Lower Sarmatian. The associated sediments comprise clays, sands, marls, and various limestones.

In order to minimize the bias introduced to the analysis by the uniformitarian assumptions, the investigated foraminifers (Table 1) were considered at the generic level. This approach was also required to overcome the possible effects of species evolution upon the foraminiferal distributional patterns in the investigated stratigraphical interval. The relative abundances of foraminiferal genera in the samples were determined in semiquantitative terms (absent = 0, present = 1, rare = 2, common = 3, abundant = 4). The lithofacies were coded arbitrarily as expressed by proportions (0 to 3) of the three lithological endmember components, *viz.* clay, sand, and calcium carbonate.

Table 1

Foraminiferal genera discussed in the present study; indicated are the abbreviations used in the R-mode factor scattergrams (Fig. 2)

AMPH	— <i>Amphistegina</i>	MELO	— <i>Melonis</i>
ANOA	— <i>Anomalina</i>	NODO	— <i>Nodosaria</i>
ANOS	— <i>Anomalinoidea</i>	NOGE	— <i>Nodogenerina</i>
ARTI	— <i>Articulina</i>	NONI	— <i>Nonion</i>
ASTR	— <i>Asterigerina</i>	PLAN	— <i>Planulina</i>
BIGE	— <i>Bigenerina</i>	PSGL	— <i>Pseudoglandulina</i>
BOLI	— <i>Bolivina</i>	PULL	— <i>Pullenia</i>
BORE	— <i>Borelis</i>	PYRG	— <i>Pyrgo</i>
BULI	— <i>Bulimina</i>	QUIN	— <i>Quinqueloculina</i>
CASS	— <i>Cassidulina</i>	REUS	— <i>Reussella</i>
CIBI	— <i>Cibicides</i>	ROBU	— <i>Robulus</i>
DENT	— <i>Dentalina</i>	ROTA	— <i>Rotalia</i>
DIMO	— <i>Dimorphina</i>	SIGM	— <i>Sigmoilina</i>
DISC	— <i>Discorbis</i>	SINO	— <i>Siphonodosaria</i>
ELPH	— <i>Elphidium</i>	SITE	— <i>Siphotextularia</i>
EPIS	— <i>Epistomina</i>	SPHA	— <i>Sphaeroidina</i>
EPON	— <i>Eponides</i>	SPIR	— <i>Spiroplectammina</i>
FLOR	— <i>Florilus</i>	STIL	— <i>Stilostomella</i>
GLOB	— <i>Globulina</i>	STRE	— <i>Streblus</i>
GUTT	— <i>Guttulina</i>	TEXT	— <i>Textularia</i>
GYPS	— <i>Gypsina</i>	TRIL	— <i>Triloculina</i>
GYRO	— <i>Gyroldina</i>	UVIG	— <i>Uvigerina</i>
KARR	— <i>Karreriella</i>	VAGI	— <i>Vaginulina</i>
LAGE	— <i>Lagena</i>	VALV	— <i>Valvulineria</i>
LENT	— <i>Lenticulina</i>	VIRG	— <i>Virgulina</i>
LOXO	— <i>Loxostomum</i>	MART	— <i>Martinotiella</i>
MARG	— <i>Marginulina</i>		

The data matrix was studied by both R- and Q-mode factor analyses of correspondences intended to permit an estimation of foraminiferal interdependence and relationship to the sediment type, a recognition of foraminiferal associations, and a subsequent assignment of the investigated samples to foraminiferal biofacies.

RESULTS

As indicated by the gently sloping diagram of the eigenvalues of the *R*-mode interrelationship matrix (Fig. 1), most investigated foraminiferal genera display their own, unique distributional patterns. The foraminifers are so independent one of another that the first seven *R*-mode factor axes account jointly for merely 40% of the total variability of the data matrix. This demonstrates clearly that the Miocene foraminifers of Poland do not form any biologically controlled communities. In contrast, their associations arise incidentally due to a partial overlap of their ecological ranges controlled and delimited mostly (if not entirely) by physical-chemical factors.

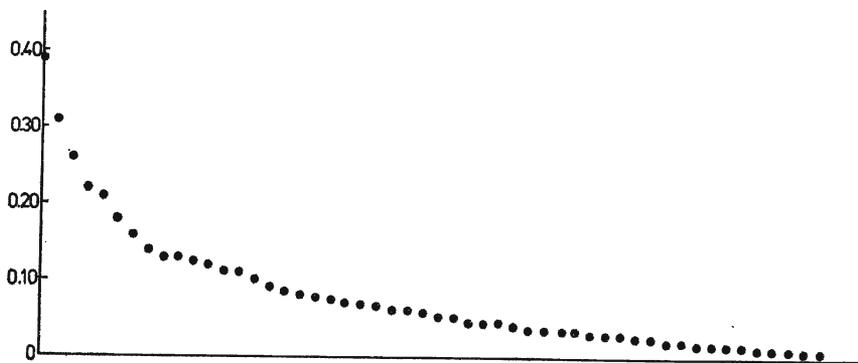


Fig. 1. Eigenvalues of the *R*-mode interrelationship matrix

Despite the low amounts of the total variability accounted for by the extracted factors, ten foraminiferal genera are perfectly represented by the *R*-mode analysis; over twenty genera are moderately represented, while twenty genera are clearly underrepresented. When those genera perfectly or moderately represented by the analysis are plotted versus the first four factor axes (Fig. 2), a few more or less distinct foraminiferal associations can be recognized (marked with distinctive graphic symbols in the scattergrams).

The associations differ in their distinctness and homogeneity. The most distinct and homogeneous are the *Quinqueloculina* and *Florilus* associations (marked with black squares and white triangles, respectively). However, the genus *Quinqueloculina* itself along with another miliolid genus *Triloculina* appear intermediate between the *Quinqueloculina*, *Asterigerina* (marked with white circles), and *Valvulineria* (marked with black circles) associations. The latter two associations do considerably overlap one with the other. The *Robulus* and *Sphaeroidina* associations (marked with crosses and black triangles, respectively) do

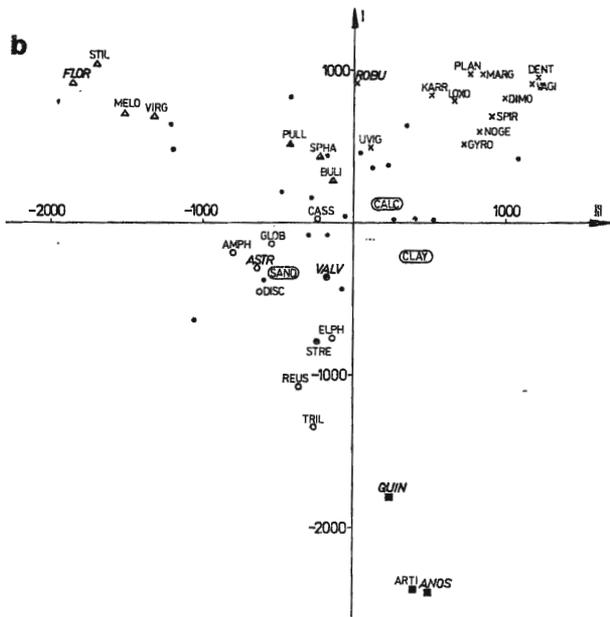
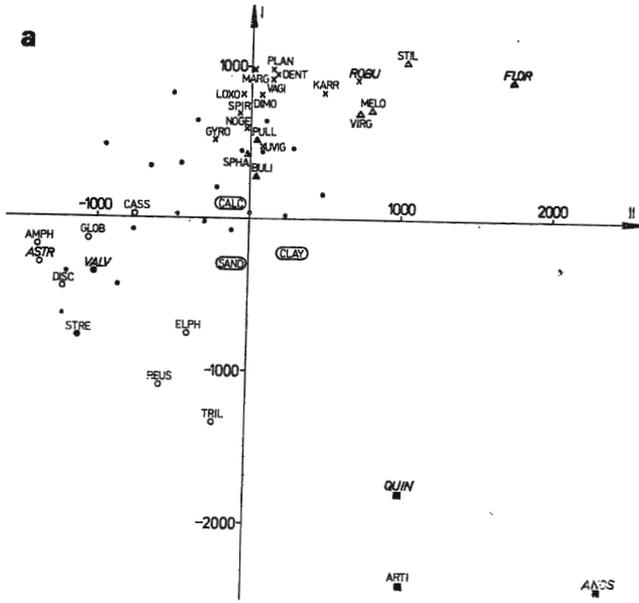
also appear quite homogeneous but their distinctness is low due to their close relationship to many underrepresented genera.

The lithological endmember components are also plotted versus the *R*-mode factor axes. They do not appear related significantly to any of the distinguished foraminiferal associations, even though the representation of clay by the analysis is perfect and that of the calcium carbonate is good; the sand is very poorly represented. This demonstrates that distributional patterns of most Miocene foraminiferal genera of Poland do not depend upon the sediment type. Possibly, however, such a dependence does exist at the specific level. Some genera underrepresented by the analysis may also be controlled by the substrate.

More than a hundred samples are perfectly or well represented by the *Q*-mode factor analysis. They are plotted versus the first three factor axes (Fig. 3) and assigned (cf. Table 2) to particular biofacies (marked in the scattergrams with the same graphic symbols as the respective associations in the *R*-mode graphs). The biofacies do partly overlap one with another which demonstrates that they are defined each by a dominant rather than specific association for a given biofacies. Nevertheless, the *Quinqueloculina* and *Robulus* biofacies are indeed quite distinctive and homogeneous. The *Asterigerina* and *Valvulineria* biofacies grade more or less continuously one into the other due to the common co-occurrence of the respective associations in a single sample. This is also the case with the *Florilus* and *Sphaeroidina* biofacies. The *Quinqueloculina* biofacies overlaps in part with the *Asterigerina* and *Valvulineria* ones, which results mainly from the common occurrence of the miliolids in samples dominated by any of the three associations.

DISCUSSION

The results of the present study show that because of their mutual independence, distributional patterns of the Miocene foraminiferal genera of Poland do not permit recognition of any consistent ecological communities. The apparent recurrence of foraminiferal associations demonstrated by the factor analysis appears merely as a by-product of the similar responses of various taxa to the environmental conditions. This is indeed consistent with the very nature of present-day benthic foraminiferal associations recorded by Walton (1964) in the Gulf of Mexico. Furthermore, in a recent study of foraminiferal assemblages associated with modern *Thalassia* beds, Buzas & al. (1977) did not find any significant habitat partitioning among the species all of which were clearly opportunistic, regulated mainly through cropping by nondiscriminant predators. Then, the multi-species method appears as the only valid benthic-foraminifer-based paleoecological approach to paleoenvironmental reconstruction. The multi-genus method may actually be



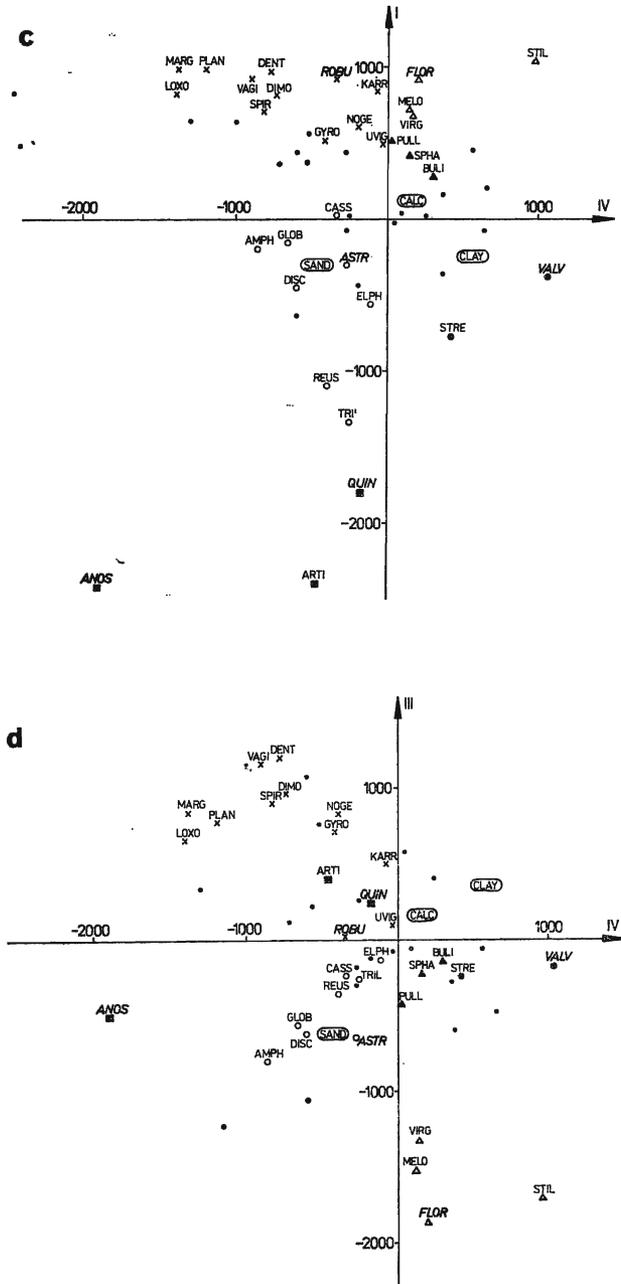


Fig. 2. R-mode factor scattergrams (symbols explained in the text)

Foraminiferal associations are marked with distinctive graphic symbols (abbreviations of the generic names are given in Table 1); perfectly represented genera are marked with italicized abbreviations; unnamed dots refer to underrepresented genera

Factor-spatial position of the lithological endmember components are also shown

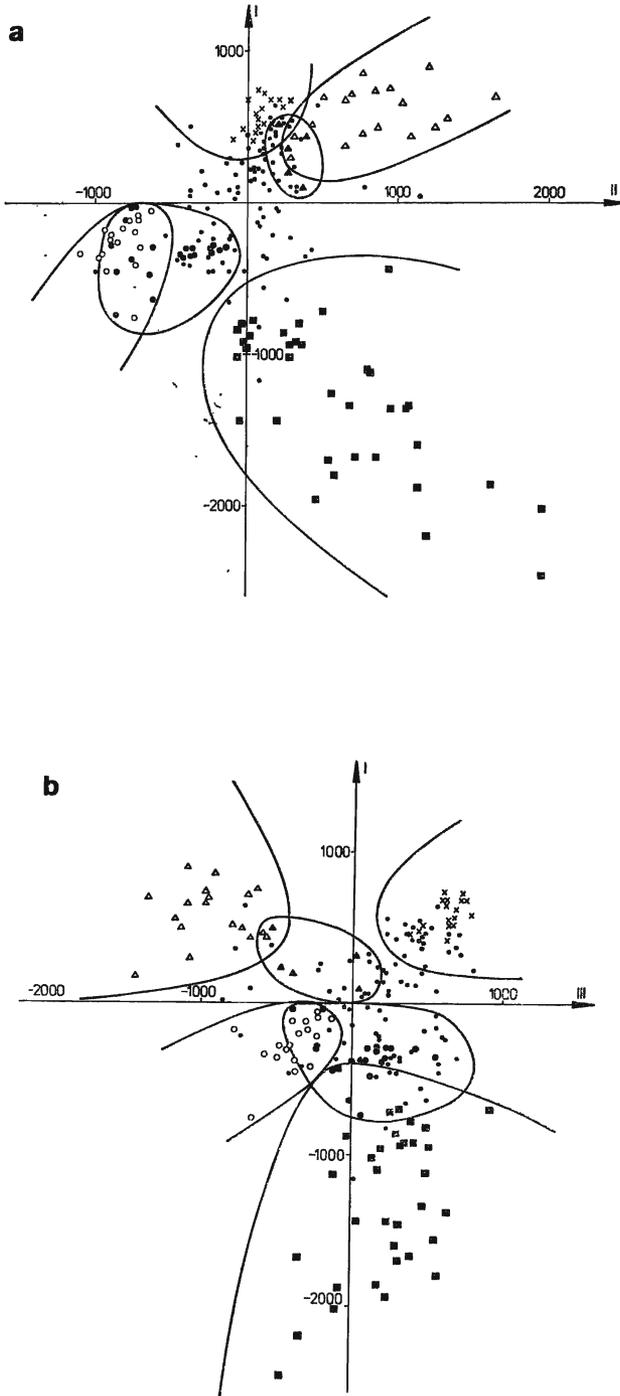


Fig. 3. Q-mode factor scattergrams

Foraminiferal biofacies are marked with distinctive graphic symbols (the same as for the respective associations in Text-fig. 2); dots refer to underrepresented samples

even more reliable (but at the same time less precise), as the probability of a change in ecological requirements of a taxon decreases obviously from lower to higher taxonomic units.

Any paleoenvironmental inference from the *R*-mode factor-spatial relationships among the foraminiferal associations recognized in this study must be made with great caution, as the parsimony of the factor-analytic solution appears very low. Nevertheless, one may claim that the first factor axis reflects a gradient in water depth. It clusters separately the genera well known to prefer either deep-water, or shallow-water habitats. This is documented by the positive loadings shown by the following mainly deep-water genera: *Robulus*, *Karreriella*, *Uvigerina*, *Gyroidina*, *Loxostomum*, *Marginulina*, *Planulina*, *Dentalina*, *Pullenia*, *Sphaeroidina*; any by the negative loadings of the following mainly shallow-water genera: *Quinqueloculina*, *Amphistegina*, *Asterigerina*, *Elphidium*, *Globulina*, *Streblus*, and *Discorbis* (cf. Parker 1948, 1954; Walton 1955, 1964; Bandy 1956, 1961, 1964; Phleger 1956, 1960; Bandy & Arnal 1957; Smith 1964; Gevirtz & al. 1971; Larsen 1976). Then, it is to be concluded that the *Quinqueloculina*, *Asterigerina*, and *Valvulineria* associations are indicative of relatively shallow-water environments, while the *Robulus*, *Florilus*, and *Sphaeroidina* associations are typical of deeper waters.

Interpretation of the *Florilus* association as a deep-water one may appear surprising, since the genus *Florilus* itself has been reported from both Miocene and Recent shallow-water habitats (Brasier 1975, Walkiewicz 1975). The factor-spatial position of the association is, however, consistent with some actualistic ecological data pointing clearly to deep-water habitat preferences of the genera *Melonis* (cf. Montcharmont-Zei 1962) and *Virgulina* (cf. Walton 1955, Phleger 1960, Smith 1964) related closely in their distribution in the Polish Miocene to *Florilus* and *Stilostomella*.

The genus *Valvulineria* has insofar been recorded mostly in deep-water environments (Parker 1948, 1954; Walton 1955; Bandy & Arnal 1957; Smith 1964), which might make doubtful the above presented bathymetrical interpretation of the *Valvulineria* association. In the Miocene deposits of southern Poland, *Valvulineria* co-occurs, however, most commonly with the species *Streblus beccarii* (L.) restricted certainly to nearshore habitats (cf. Phleger 1960). Furthermore, Brasier (1975) reported the occurrence of present-day *Valvulineria* from extremely shallow-water environments off Jamaica.

Assignment of the genus *Cassidulina* to the typical shallow-water *Asterigerina* association may also seem doubtful, as most of its species are clearly deep-water forms (Phleger 1960, Walton 1964). However, several non-carinate species of *Cassidulina* occur preferably if not exclusively in shallow-water habitats (Walton 1955, Phleger 1956, Smith 1964).

Interpretation of the *Quinqueloculina* association as a shallow-water one is supported notasmuch by the ecological range of *Quinqueloculina* itself which is actually a fairly ubiquitous genus with its peak of abundance attained in moderately shallow waters, as by the high preference of *Articulina* for shallow-water environments (cf. Weis & Steinker 1977).

Table 2
Key to the samples analysed in the present study

Sample	Locality	Bed	Biofacies	Sample	Locality	Bed	Biofacies	
1		3		72		21	<i>Sphaeroidina</i>	
2		5	<i>Valvulineria</i>	73		22		
3	Brzozówka	13		74	Łędziny	23	?	
4		15	?	75		24		
5		1 Grab.	<i>Valvulineria</i>	76		1	?	
6		2 Grab.		77		2	<i>Sphaeroidina</i>	
7	Chełm n. Rabą	1 Chod.	?	78		3	?	
8		4 Chod.		79	Grzybów	4		
9		1		80		5	<i>Sphaeroidina</i>	
10		2		81		additional	?	
11		3	<i>Asterigerina</i>	82		depth 31.5 m		
12		4	?	83	Radruż	depth 39.8 m	<i>Quinqueloculina</i>	
13		6	<i>Valvulineria</i>	84			depth 52.0 m	?
14		7	<i>Asterigerina</i>	85		depth 15.6 m		
15	Bochnia	8		86	Łowcza	depth 20.2 m		
16		9		87		depth 31.1 m	<i>Quinqueloculina</i>	
17		10	<i>Valvulineria</i>	88		depth 116.4 m		
18		11		89		depth 127.0 m		
19		12		90		depth 48.2 m	?	
20		13		91		depth 59.0 m		
21		14	<i>Asterigerina</i>	92		depth 97.0 m	<i>Quinqueloculina</i>	
22		16		93		depth 102.3 m		
23		17	<i>Valvulineria</i>	94	Józefów	depth 136.7 m		
24		18		95			depth 140.5 m	?
25		19	?	96			depth 156.3 m	
26		1		97		depth 184.4 m	<i>Quinqueloculina</i>	
27		2		98		depth 207.6 m		
28		3		99		depth 214.5 m	?	
29		4	<i>Robulus</i>	100		1		
30		5		101		2		
31		6		102		3	<i>Quinqueloculina</i>	
32		7		103		4		
33		8		104	Zrecze	6		
34		9		105			7	
35		10	?	106		8		
36	Czechowice	11		107		9		
37			12		108		10	?
38		13		109		5		
39		14		110		1		
40		15	<i>Asterigerina</i>	111		2		
41		16		112		3		
42		17		113		4	<i>Quinqueloculina</i>	
43		18		114	Rytwiany	5		
44		19		115			6	
45		20		116			7	
46		21	?	117			8	
47		22		118			9	
48		23		119		10	?	
49		24		120		1		
50		25	<i>Valvulineria</i>	121		2	?	
51		26		122		3		
52		27	<i>Asterigerina</i>	123	Miechocin	4		
53		1		124			5	
54		2	<i>Robulus</i>	125			6	<i>Quinqueloculina</i>
55		3		126			7	
56		4		127			8	
57		5		128		1		
58		6	?	129		2		
59		7		130		3	<i>Quinqueloculina</i>	
60		8		131		4		
61		9		132		5		
62	Łędziny	10	<i>Valvulineria</i>	133		6		
63			11		134	Budy	7	?
64		12		135			8	
65		13		136		9	<i>Sphaeroidina</i>	
66		14		137		10		
67		15	?	138		11	?	
68		16		139		12	<i>Florilus</i>	
69		17		140		13	?	
70		18		141		1		
71		19		142	Młyny	2	<i>Florilus</i>	

Sample	Locality	Bed	Biofacies	Sample	Locality	Bed	Biofacies
143		3	<i>Florilus</i>	176		3	
144		4	?	177	Krzyżanowice	3	<i>Valvulineria</i>
145	Młyny	5		178		3	
146		6		179		3	
147		7		180		1	
148		8	<i>Florilus</i>	181	2	?	
149		9		182	2		
150		10		183	3		
151		11		184	2		
152		1		185	Golejów	3	
153		2		186		4	
154	Grabki Duże	3	<i>Florilus</i>	187		5	?
155		4		188		6	
156		5		189		7	
157		6		190		8	
158		7	?	191	2	<i>Robulus</i>	
159		8		192	4		
160		9	<i>Florilus</i>	193	5	?	
161		10	?	194	Żory	5	
162		10		195		6	<i>Sphaeroidina</i>
163		12	<i>Robulus</i>	196		7	
164	Chełm Wlk.	13		197	9	?	
165		14	?	198	2		
166		14		199	3	?	
167		1		200	Wilcza	5	<i>Sphaeroidina</i>
168	Poręba	1	?	201		7	?
169		2		202		7	<i>Valvulineria</i>
170		2		203		8	?
171		2	<i>Valvulineria</i>	204		3	<i>Valvulineria</i>
172		2		205	5	<i>Robulus</i>	
173			2	?	206	6	
174		Krzyżanowice	2		207	Kłodnice	7
175	3		<i>Valvulineria</i>	208	8		
				209	9		?
				210	10		

Sources of data:

- Samples 1—4 — Alexandrowicz (1963a)
 Samples 5—8 — Alexandrowicz (1961)
 Samples 9—25 — Łuczowska (1955)
 Samples 26—52 — Alexandrowicz (1960)
 Samples 53—75 — Alexandrowicz & Odrzywolska-Bieńkowska (1960)
 Samples 76—81 — Łuczowska (1967)
 Samples 82—99 — Odrzywolska-Bieńkowska (1964)
 Samples 100—160 — Łuczowska (1964)
 Samples 161—210 — Alexandrowicz (1963b)

One may thus conclude that those samples well represented by the present analysis and assigned more or less unequivocally to particular foraminiferal biofacies can also be interpreted in paleobathymetrical terms (eventhough very vague ones). In turn, underrepresentation of a sample indicates that at least two benthic foraminiferal associations contrasting in their bathymetrical requirements co-occur within a single faunule. This phenomenon reflects probably the commonness of post-mortem transportation of benthic foraminiferal tests in the Polish Miocene.

Water depth is commonly considered as the most important environmental factor limiting benthic foraminiferal distributional patterns. Actually, few other ecospace parameters have been convincingly demonstrated to control benthic foraminifers. One might claim that despite

the low parsimony of the factor-analytic solution, this is reflected by the present study, as neither the second, nor the next five *R*-mode factor axes can be interpreted in environmental terms. Water temperature is among the exceptions but it is neglected in the present study because it can be expected to be insignificant within a single province. Seagrass or kelp cover makes surely another exception and indeed, the association of genera *Asterigerina*, *Amphistegina*, *Discorbis*, *Elphidium*, and the miliolids may be regarded as indicative of large benthic plants (cf. Brasier 1975, Buzas & *al.* 1977).

Calcium-carbonate availability (dependent mostly upon water temperature, salinity, and depth) for foraminifers extracting or precipitating it from the surrounding water appears as the main environmental factor controlling distribution of hyaline versus porcelaneous foraminifers. Porcelaneous foraminifers prevail under supersaturation conditions, whereas hyaline foraminifers attain their peak of abundance under normal marine conditions. This is indicated by the empirical patterns recorded in the Gulf of Mexico and the adjacent estuaries and lagoons as well as by the theoretical considerations of the foraminiferal calcite-wall construction (Greiner 1974*a, b*). Then, the *Quinqueloculina* association is to be interpreted as indicative of very high availability of the calcium carbonate. Interestingly, some samples assigned to the *Quinqueloculina* biofacies comprise also the species *Anomalinoides dividens* Łucz. which documents that they are of Sarmatian age. The other benthic foraminiferal faunules dominated by the *Quinqueloculina* association resemble closely the Polish Sarmatian in biofacies but may be of Late Badenian age as well.

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MIOCEŃSKIE ZESPOŁY OTWORNIC BENTONICZNYCH

(Streszczenie)

Przedmiotem pracy jest analiza czynnikowa rozmieszczenia kilkudziesięciu najpospolitszych rodzajów otwornic bentonicznych w osadach badenu i sarmatu Zapadliska Przedkarpackiego (por. Tab. 1—2). Okazało się, że rodzaje te występują zupełnie od siebie niezależnie (por. Fig. 1), nie tworzą zatem żadnych biocenoz. Wszelkie rekonstrukcje środowiska kopalnego oparte na otwornicach bentonicznych odwoływać się więc muszą do najprostszej, ale i najbardziej ogólnikowej metody paleoekologicznej zakładającej, że warunki życia rozważanego zespołu odpowiadały wspólnej części zakresów tolerancji ekologicznej poszczególnych taksonów.

Na podstawie analizy czynnikowej typu R wyodrębnić można wśród otwornic bentonicznych miocenu Zapadliska Przedkarpackiego sześć zespołów (Fig. 2), którym nadano nazwy pochodzące od ich najbardziej typowych składników. Przy pomocy analizy czynnikowej typu Q wyodrębnić można odpowiadające tym zespołom biofacje otwornicowe (Fig. 3). Zespoły *Asterigerina*, *Quinqueloculina* i *Valvulineria* dominują w warunkach płytkowodnych, natomiast zespoły *Robulus*, *Florilus* i *Sphaeroidina* typowe są dla środowisk wód głębszych. Występowanie zespołu *Asterigerina* wskazuje na obecność roślinności morskiej. Typowy dla utworów sarmackich zespół *Quinqueloculina* świadczy o wielkiej obfitości węglanu wapnia w wodzie morskiej.
