

Multivariate discrimination of *Buryella* species from the Lower Eocene of the Outer Flysch Carpathians, Poland

MARTA BAK¹ & WANDA BARWICZ-PISKORZ²

¹Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, PL-30-063, Kraków, Poland (e-mail: mbak@ing.uj.edu.pl)

²Department of Stratigraphy and Regional Geology, University of Science and Technology, Mickiewicza 30, PL-30-059, Kraków, Poland

ABSTRACT – Variegated shales in the Lower Eocene hemipelagic deposits of the Subsilesian Series, Polish part of the Western Carpathians, have yielded rich radiolarians with common representatives of the genus *Buryella*. Two new radiolarian species, *Buryella spina* sp. nov. and *Buryella hanna* sp. nov., are described, and two other species have been recognized: *Buryella tetradica* Foreman and *Buryella clinata* Foreman. Specimens have been measured, grouped and interpreted using cluster analysis, principal component analysis (PCA) and canonical variates analysis (CVA). Species attributed to *Buryella* have three or four segments, a fusiform or lobate outline, and a constricted, rather than flared, aperture. The cephalis always possesses an apical horn of varying length with a distinct vertical pore at the collar stricture. All specimens possess a pronounced vertical tube, rounded or elongate, that might extend to the base of apical horn. Near the base of the cephalis the parallel ridges observed on the external wall of the cephalis are ridges from the horn that diverge and extend to the collar stricture except ventrally, where two ridges rejoin to enclose the vertical pore and form an upwardly directed tube. These structure might be evidence of the presence of arches (A-Vbl, A-Vbr) and bars (Vbl, Vbr), which form the vertical tube. *J. Micropalaeontol.* 25(1): 45–54, April 2006.

KEYWORDS: *Radiolaria*, *Buryella*, multivariate analysis, Lower Eocene, Carpathians

INTRODUCTION

The genus *Buryella* was first erected by Foreman (1973) and included in the family Theoperidae based on material from the Gulf of Mexico (DSDP, Leg 10). Foreman described three new species of *Buryella* and proposed a new *Buryella clinata* Zone, the base of which is defined by the earliest evolutionary appearance of *B. clinata*.

Buryella has been found in tropical and subtropical localities (e.g. Indian Ocean DSDP Site 237, North Pacific DSDP Site 313, equatorial Pacific ODP Leg 199, Site 1220; South Pacific DSDP Site 208, and Site 1121; Gulf of Mexico DSDP Sites 86, 94 and 96, Caribbean DSDP Leg 15, North Atlantic ODP Leg 171B), in Subantarctic sediments from the Pacific (ODP Site 700) and, to the north, it is known as far as 40° N (DSDP Site 384) in the western North Atlantic (e.g. DSDP Site 603) (Dumitrica, 1973; Foreman, 1973; Riedel & Sanfilippo, 1973; Nishimura, 1987; Nigrini & Sanfilippo, 2001; O'Connor, 2001; Sanfilippo & Blome, 2001).

Species belonging to the genus *Buryella* are important in the southern high-latitude radiolarian biostratigraphy of the Paleocene (Hollis, 1993, 1997, 2002; O'Connor, 2001). In addition, in the Boreal Realm, *Buryella longa* and *Buryella tetradica* are used as a biostratigraphical zone markers (Kozlova, 1983a, b, 1984, 1993, 1999). *Buryella* also occurs in the Outer Carpathians, where the *B. clinata* Zone is well defined in many localities (Bak *et al.*, 1997; Rajchel *et al.*, 1999; Rajchel & Barwicz-Piskorz, in press; Bak & Barwicz-Piskorz, 2005).

The present paper evaluates diversification of *Buryella* in the Carpathians in comparison with representatives described from low latitude localities. Two new radiolarian species, *Buryella spina* sp. nov. and *Buryella hanna* sp. nov., are also described. The taxa discussed herein occur in a rich and diverse Lower Eocene radiolarian assemblage within the Subsilesian Series of the Outer Carpathians. All the original siliceous skeletons are

replaced by pyrite framboids, resulting in exceptional preservation of external, morphological features (for explanation of the pyritization processes, see Bak & Sawlowicz, 2000).

A qualitative approach to buryellid systematics has been used, using detailed measurements and statistics. Additionally, recent studies of the genus *Buryella* (O'Connor, 1997, 2001) have been referred to, which include a new genus diagnosis, as well as the inclusion of *Buryella* into the family Artostrobiidae. The complexities of the phylogenetics of the Lower Eocene members of the genus from the Carpathians are also discussed.

MATERIAL AND METHODS

Location of samples investigated

Samples were collected from the Lower Eocene deposits of the Subsilesian Nappe, from the Polish Carpathians, the northern part of the Carpathian Mountains, which are a part of the European Alpides (Fig. 1). The Carpathians have been subdivided into two principal tectonic zones: the Inner and the Outer Carpathians. The boundary between them is marked by a narrow, tectonically complex zone – the Pieniny Klippen Belt. The Outer Carpathians consist of several tectonic units, the deposits of which were laid down in separate basins. These basins comprised several longitudinal troughs and ridges, developed on the thinned continental crust of the southern margin of the North European Platform (Fig. 2). The sediments mainly comprise turbidites of Late Jurassic to Miocene age.

Variegated shales are the main type of Lower Eocene sediments in the Subsilesian Unit. Deposition occurred from the Cenomanian through the Late Eocene (e.g. Książkiewicz, 1962; Bieda *et al.*, 1963; Geroch & Gradziński, 1965; Golonka *et al.*, 2000). Similar deposits occur also in other parts of the Carpathians, as well as in the Alps, Apennines, North Atlantic

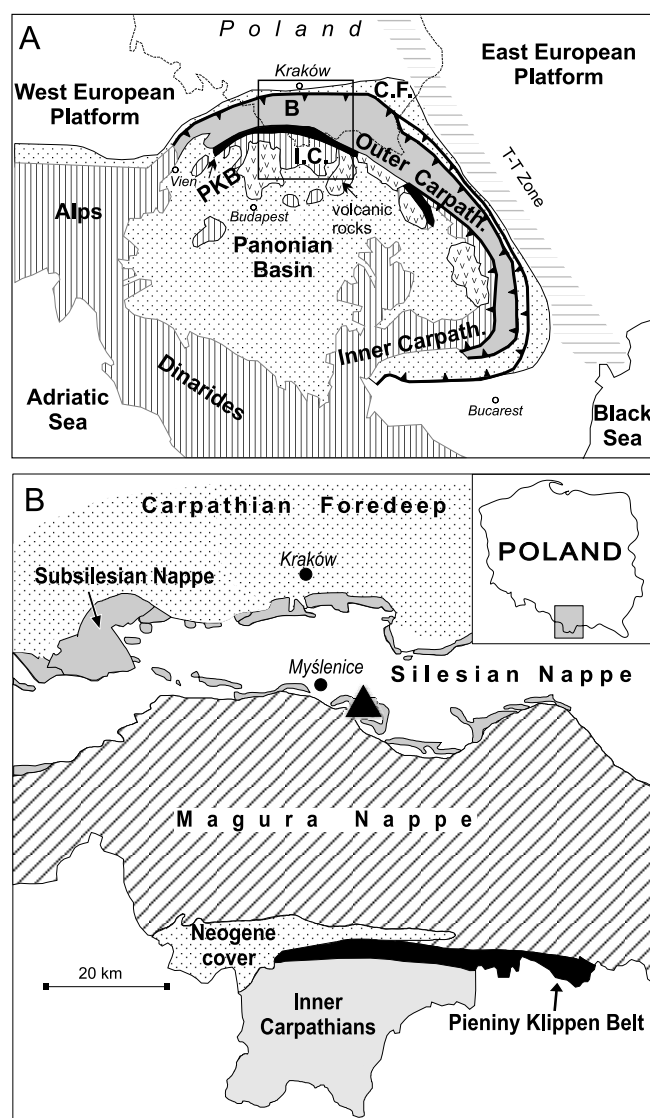


Fig. 1. Position of the studied sections in relation to the main geological units. (A) Outer Carpathians against the background of a simplified geological map of the Alpine orogens and their foreland. C.F., Carpathian Foredeep; I.C., Inner Carpathians; PKB, Pieniny Klippen Belt; T-T Zone, Teisseyre-Tornquist Zone. (B) Subsilesian Nappe against the background of the western part of the Outer Carpathians (geology after Żytka *et al.*, 1988 – simplified). Black triangle indicates location of the outcrop.

and Pacific (e.g., Andrusov, 1959; Winkler, 1983; Stefanescu & Micu, 1987; Moullade *et al.*, 1988; Kuhnt & Kaminski, 1990; Bak, 2000).

The Subsilesian unit crops out in the Polish part of the Western Carpathians in two parallel zones. The northern zone is located to the north of the Silesian Nappe, while the southern zone crops out in a few tectonic windows (Fig. 1).

The study area is one of a series of exposures in the axial zone of the Wisniowa tectonic window east of Myslenice. These Subsilesian deposits were folded and form two tectonic slices. Though they crop out in isolated exposures, Late Cretaceous through Palaeogene deposits have been mapped.

Lithostratigraphic units have been defined following Burtan (1974, 1978) and Cieszkowski *et al.* (2001): the 'Węglówka-type marls' are Senonian in age, whilst the Czerwin Sandstone, the Green Shales and the Variegated Shales are Palaeogene in age.

Radiolarian assemblage

The material used in this study was collected for foraminifera originally by Waskowska-Oliwa (University of Science and Technology, Kraków, Poland). Radiolarians were extracted by washing fine residue left over from that previous study through a 63 µm sieve.

Type specimens are currently housed in the author's collection (Institute of Geological Sciences, Jagiellonian University), collection reference is ING-EE-II. Scanning electron micrographs were prepared using a HITACHI S-4700 SEM.

Generally, radiolarians are present throughout the Variegated Shales, but common, well-preserved specimens occur rarely. These well-preserved radiolarian skeletons have occurred due to pyritization, which can result in exceptional replacement of original siliceous skeletons by pyrite framboids. Although this process has preserved the external skeletal features, inner structures remain obscured or damaged by the pyritization process.

The radiolarian assemblage contains common *Buryella*, especially *B. clinata* Foreman and *B. tetradica* Foreman s.s., which together make up 9% of the total assemblage. Other common species include *Calocyclus ampulla* (Ehrenberg), *Podocyrus papalis* Ehrenberg, *Phormocyrtis striata striata* Brandt, *Lychnocanoma auxilla* Foreman, *L. babylonis* (Clark & Campbell), *Lamptonium fabaeforme chaunothorax* Riedel & Sanfilippo, *Lychnocanium bellum* Clark & Campbell, *L. conicum* Clark & Campbell, *L. tripodium* Ehrenberg, *Amphisphaera coronata* (Ehrenberg), *Carpocanobium* sp., *Clathrocyclas universa amplaspina* Clark & Campbell, *Theocotylissa ficus* (Ehrenberg), *Dorcadospyrus confluens* Ehrenberg, *Dorcadospyrus pentas* Ehrenberg and *Tessarospyrus* (?) *bicaudalis* Clark & Campbell. Most of these specimens are typical of low latitudes; however, some taxa present in the Subsilesian Series have been reported previously from the areas of mixing of Tethyan and Boreal influences by Popova *et al.* (2002) (e.g. *Heliodiscus heliasteriscus* Clark & Campbell, *H. perplexus* Clark & Campbell, *Gorgospyrus hemisphaerica* Clark & Campbell) and from the Boreal Province by Kozlova & Gorbovetz (1966) (e.g. *Phacodiscus duplus* Kozlova).

Biostratigraphy and age

The biostratigraphic age determination is based on the presence of radiolarian taxa widely distributed in the low-latitude Lower Eocene, such as *Phormocyrtis striata striata* Brandt, *Lychnocanium bellum* Clark & Campbell, *Thyrsoyrus rhizodon* Ehrenberg, *Theocotylissa ficus* (Ehrenberg) and other representatives of the *Phormocyrtis striata striata* Interval Zone (RP9) (Foreman, 1973; emend. Riedel & Sanfilippo, 1978). However, this radiolarian zonation which is defined for the tropics was found to be not fully applicable for dating and correlating the Carpathian material. Some species whose first and last occurrences define this zone in the tropics were either missing or have different ranges in the Subsilesian Series. For example, *Lychnocanoma auxilla* Foreman has its last occurrence

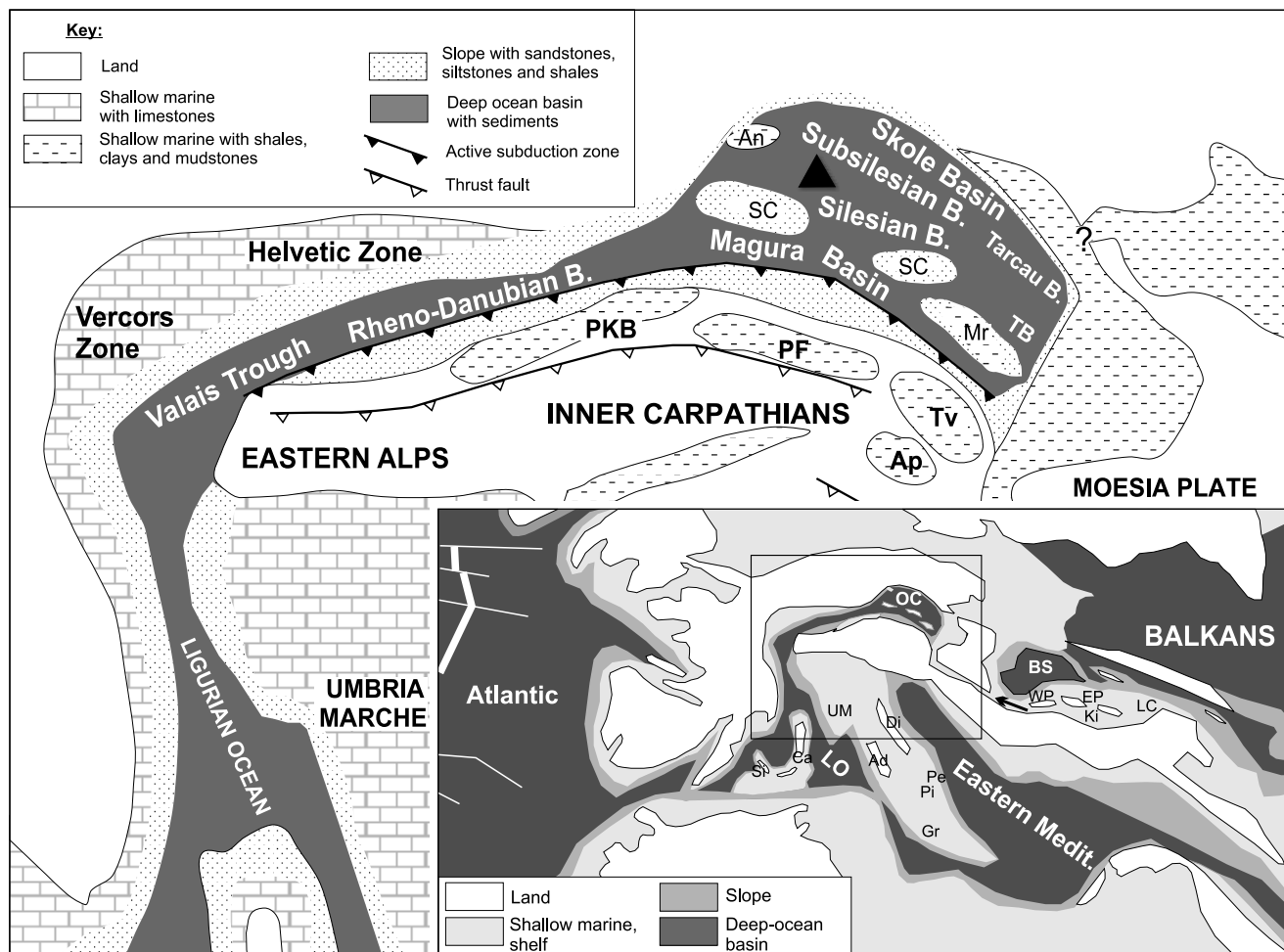


Fig. 2. Palaeoenvironment and lithofacies of the circum-Carpathian area during the Lutetian; plate position at 45 Ma (after Golonka *et al.*, 2000 – simplified). Ad, Adria (Apulia); An, Andrychov ridge; Ap, Apuseni Mts; BS, Black Sea; Ca, Calabria–Campania terranes; Di, Dinarides; EP, Eastern Pontides; Gr, Greece; Ki, Kirsehir plate; LC, Lesser Caucasus terrane; LO, Ligurian (Piemont) Ocean; Mr, Marmarosh massif and klippe; OC, Outer Carpathians; Pe, Pelagonian plate; PF, Podhale Flysch basin; Pi, Pindos Ocean; PKB, Pieniny Klippen Belt basin; SC, Silesian Cordillera; Si, Sicily plate; TB, Teleajen basin; Tv, Transilvanian basin; UM, Umbria Marche; WP, Western Pontides.

in the Subsilesian Series later than in the tropics; *Thecotyle venezuelensis* Riedel & Sanfilippo is present in the Subsilesian deposits, although its first appearance in the tropics is noted in the *Thecotyle cryptocephala* Zone (RP10). *Buryella tetradica* Foreman, has its last occurrence later in the Subsilesian Series. Species missing in the Subsilesian Series by comparison with the tropical faunas are: *Thecotrys anaclasta* Riedel & Sanfilippo, the lowest occurrence of which defines the lower limit of the *Phormocyrtis striata striata* radiolarian Zone and *Lamptonium fabaeforme constrictum* Riedel & Sanfilippo and *Podocyrtis (Lampterium) acalles* Sanfilippo & Riedel, the first occurrences of which are approximately synchronous with the lower limit of the RP9 zone. The *Lithocyclus ocellus* group Ehrenberg is also missing here, although it is common to abundant in the Skole Series of the Western Polish Carpathians (Bak *et al.*, 1997). Diachronous first and last occurrences, or the absence of some species in the Lower Eocene deposits of the Subsilesian Series result from many factors, including preservation, reworking, geographical distribution of species, and their dependence on oceanic water masses and currents.

Agglutinated foraminifera were also present in this material, enabling correlation of radiolarian and foraminiferal zonal schemes. The foraminiferal assemblage consists of well-preserved and diversified taxa (Waskowska-Oliwa *et al.*, 2001), particularly numerous specimens of *Saccamminoides carpathicus* Geroch, *Gerochammina conversa* (Grzybowski), *Glomospira gordialis* (Jones & Parker), *G. charoides* (Jones & Parker), *Haplophragmoides walteri* Grzybowski, *H. kirki* Wickenden, *Paratrochamminoides* div. sp., *Recurvoides* div. sp. and *Rhabdammina* sp. This foraminiferal assemblage indicates the presence of the *Saccamminoides carpathicus* Zone of Geroch & Nowak (1984) and, therefore, the Lower Eocene in the flysch series of the Outer Carpathians (Geroch & Nowak, 1984).

Statistical analysis

From 120 specimens of *Buryella*, 40 of the best preserved complete skeletons were selected for scanning electron microscope investigation. Of these specimens, 28 were measured and grouped by statistical methods. The specimens illustrated and described by Foreman (1973, 1975) as *Buryella clinata* and

Species	Specimen	Total length including horn	Maximum width	Length of apical horn	Length of cephalis	Maximum width of cephalis	Length of thorax	Maximum width of thorax	Ceph+Th. length	Length of abdomen	Maximum width of abdomen	Number of transverse pore rows of thorax	Number of pores on half equator of thorax	Number of transverse pore rows on abdomen	Number of pores on half equator of abdomen	Number of segments
<i>Buryella clinata</i> (Subsilesian series)	250513	133	80	22	22	41	26	57	48	61	80	3	8	6	9	4
	250806	138	85	12	21	28	27	58	48	66	85	4	7	7	9	4
	250901	144	85	13	24	31	30	57	54	64	85	4	7	7	8	4
	251002	134	79	7	18	31	27	59	45	54	79	4	7	5	9	4
	251401	127	80	14	22	33	26	63	48	58	80	3	7	5	8	4
	250709	139	88	19	23	31	29	67	52	57	88	4	8	5	9	4
	250013	146	80	20	23	35	29	61	52	54	80	3	7	5	9	4
	250022	137	76	12	22	30	32	55	54	68	76	3	7	7	8	4
	250814	156	86	23	23	39	17	63	40	73	86	3	7	6	7	4
	250812	146	90	26	19	38	19	65	38	77	90	3	8	7	9	4
	250807	141	99	19	19	42	23	69	42	65	99	3	9	6	10	4
	250810	136	76	26	20	30	20	51	40	54	76	4	8	7	8	4
	250001	140	79	24	29	36	27	63	56	61	79	3	10	7	9	4
	250028	139	82	22	30	37	21	61	51	63	82	4	9	8	10	4
	Min.	127	76	7	18	28	17	51	38	54	76					
	Max.	156	99	26	30	42	32	69	56	77	99					
	Mean	118	83	18	22	34	25	61	48	62	83					
<i>B. clinata</i> (Foreman's specimens)	FM3	180	62	18	17	36	28	55	45	78	62	4	8	7	8	4
	FM2	180	78	19	26	43	28	59	54	67	78	3	8	8	9	4
	FM19	165	75	14	28	36	24	58	52	58	75	3	7	7	8	4
	FM1	145	76	16	26	34	26	59	52	52	75	3	7	6	9	4
<i>Buryella spina</i>	250056	160	104	19	30	34	42	73	72	69	104	5	7	6	10	3
	250307	172	97	25	34	42	31	73	65	67	97	4	9	6	8	3
	251104	164	92	28	25	38	32	65	57	64	92	4	7	8	9	3
	251403	164	92	38	24	24	31	63	54	63	92	4	8	6	9	3
	Min.	160	92	25	24	24	31	63	54	63	92					
	Max.	172	104	38	34	42	42	73	72	69	104					
	Mean	165	96	28	28	35	34	69	62	66	96					
<i>Buryella hanna</i>	250608	110	80	14	20	31	22	55	42	43	80	3	8	4	8	3
	250204	114	74	7	20	29	23	54	43	54	74	3	8	6	9	3
	250057	105	76	14	27	35	21	57	48	56	76	3	7	6	8	3
	250504	119	80	8	19	32	20	55	39	61	80	4	8	6	9	3
	250403	115	87	10	23	36	20	61	43	57	87	3	6	5	8	3
	251115	117	83	8	13	33	24	58	37	55	83	4	7	6	9	3
	250710	117	80	10	15	30	28	60	43	49	80	3	8	4	9	3
	250516	102	77	7	19	30	22	56	41	48	77	4	8	7	10	3
	250017	104	77	8	21	32	19	52	40	57	77	3	7	5	8	3
	250010	113	76	10	18	29	20	50	38	73	76	3	6	7	9	3
	Min.	102	74	7	13	29	19	52	37	43	74					
	Max.	119	83	14	27	36	28	61	48	73	83					
	Mean	112	79	10	20	32	22	56	41	55	79					
<i>Pterocodon</i> (?) <i>anteclinata</i> (Foreman's specimens)	219377	146	59	42	15	23	40	52	55	49	59	5	8	7	8	3
	219376	146	66	38	14	28	24	52	38	66	66	5	8	7	8	3
	219375	120	71	38	19	28	24	52	43	61	71	4	8	8	8	3

Table 1. Dimensions of specimens used for statistical analysis (μm).

Pterocodon (?) *anteclinata* were also measured and included into the dataset. The specimen parameters used in the calculations are presented in Table 1. A combination of cluster analysis, principal component analysis (PCA) and canonical variates analysis (CVA) was used for calculations. Statistical analyses were carried out on the original specimen dimensions (Table 1) using the software package PAST-Palaeontological Statistics, ver. 0.97, written by Ryan *et al.* (1995). Explanations of statistical techniques implemented there are presented in Harper (1999) and Hammer *et al.* (2001).

Cluster analysis was employed to find hierarchical groupings in the multivariate dataset. The dendrograms derived from Ward's method (with Euclidean distance) and the unweighted pair-group average (computed separately with Chord distance and Morisita's index) were compared. As the groupings were effectively the same after using these methods, only one dendrogram, constructed using Ward's method, is presented (Fig. 3). The hierarchical clustering routine (R-mode) produced a cluster diagram showing five major groups of specimens: 'Group one' assembled specimens of *B. clinata* previously distinguished in the

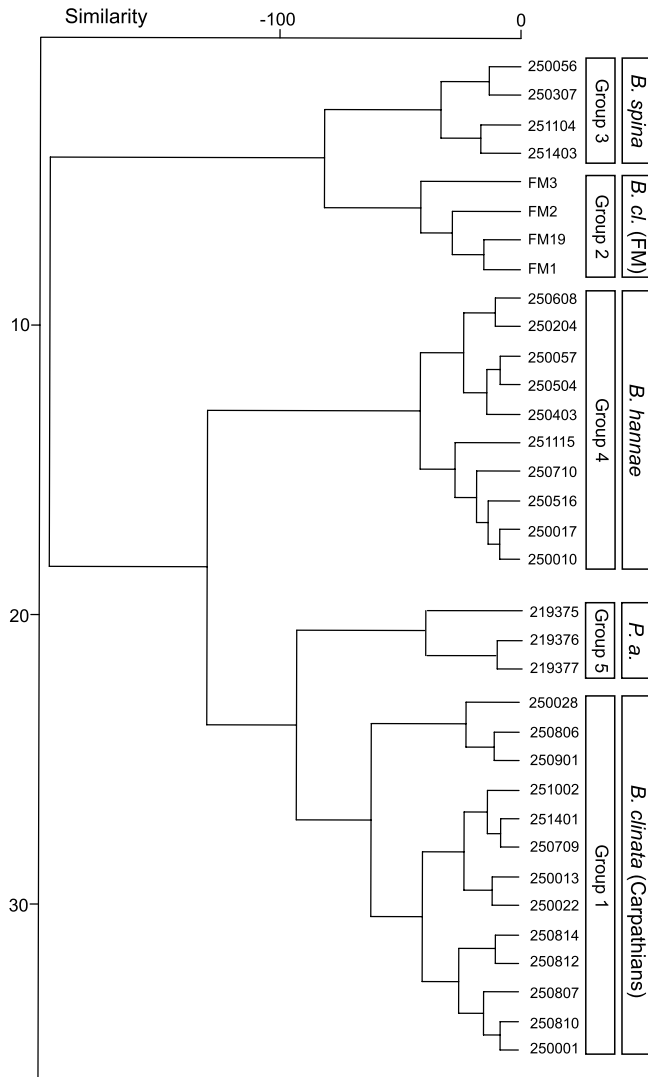


Fig. 3. Cluster diagram for *Buryella* specimens (excluding *B. tetradica*) and *Pterocodon* ? *anteclinata* Foreman, based on Euclidean similarity; distance measure: Ward's method (Ryan *et al.*, 1995). Specimens are classified into five major groups identified in the right-hand column. Horizontal scale indicates the unstandardized similarity coefficient. Specimens of *Buryella clinata* described and illustrated by Foreman (1973) taken into calculation: FM19 – Holotype, 94-29 (CC), USNM 178884, J43/0; FM1 – USNM 178917, P47/1; FM2 – USNM 178873, T11/0; FM3 – USNM 178839, C34/1. Numbers of specimens of *Pterocodon* ? *anteclinata* taken into calculation after Foreman (1973); *B. cl.* (FM), *Buryella clinata* described and illustrated by Foreman (1973); *P.a.*, *Pterocodon* ? *anteclinata*.

material studied; 'Group two' combined specimens of *B. clinata* derived from Foreman's study (1973, 1975); whilst 'Group five' pooled Foreman's specimens of *Pterocodon* (?) *anteclinata*. Groups three and four agglomerated Carpathian specimens, which have been subsequently nominated as two new species – *Buryella spina* ('Group three') and *Buryella hanna* ('Group four'). Cluster analysis also showed a degree of similarity between distinguished groups of specimens. The Carpathian specimens of *B. clinata* ('Group one') showed close similarity with *P. (?) anteclinata*. Subsequently, *B. hanna* is combined further with the *P. (?) anteclinata*–*B. clinata* 'supercluster'.

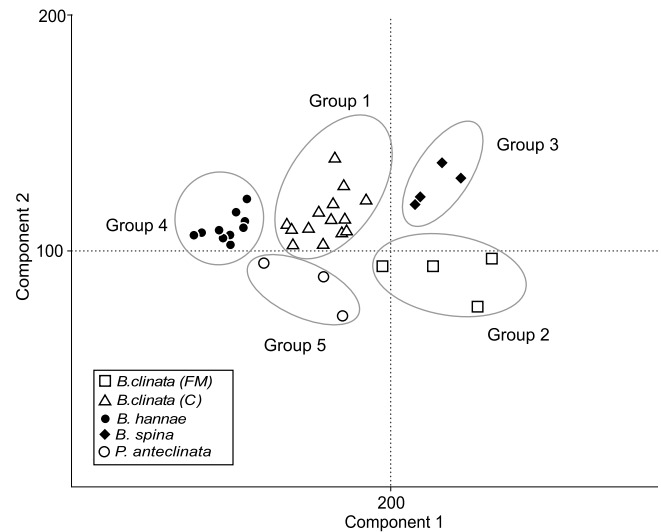


Fig. 4. Principal components analysis. Plot of coordinates given by the two most important components. The percentages of variance accounted are given in the text.

Foreman's specimens of *B. clinata* are morphologically much closer to newly distinguished *Buryella spina* from the Carpathians assemblage. Both species consist of separate branches of the dendrogram.

PCA was carried on the whole dataset (Table 1), with all specimens included in one PCA analysis, identifying major axes of morphological variation. The PCA routine distinguished the eigenvalues and eigenvectors of the variance–covariance matrix. The eigenvalues gave a measure of the variance accounted for by the corresponding components. The percentage of variance accounted for by the first four most important components are: (1) 58.1; (2) 18.9; (3) 10.9; (4) 5.5. The PCA results score each species along a series of abstract mathematical axes of decreasing statistical importance. Axis-1 and axis-2, with highest values, were plotted against one another to show grouping trends in the dataset (Fig. 4). The first principal component is the most important, explaining 58.1% of the variation. All calculated distances increase almost equally fast, which indicates that the first axis captures general size. Loadings on the second component showed that, axially, all measurements represent parameters of length (e.g. length of whole specimens, apical horn, thorax, etc.) which rapidly decrease with width values. The second component can therefore describe a length: width ratio axis. The use of the first two components reduces the original multi-dimensional dataset to two dimensions. Constructed scatter plots (Fig. 4) showed that five groups of specimens, previously distinguished in cluster analysis, occupy five different regions of morphospace. Clear separation between the groups on the PCA scatter plot has been corroborated additionally using CVA (Fig. 5).

SYSTEMATIC PALAEOONTOLOGY

Order *Nassellaria* Ehrenberg, 1875

Suborder *Cyrtida* Haeckel, 1862, emend. Petrushevskaya, 1971

Family *Artostrobiidae* Riedel, 1967, emend. O'Connor, 1997, emend. O'Connor, 2001

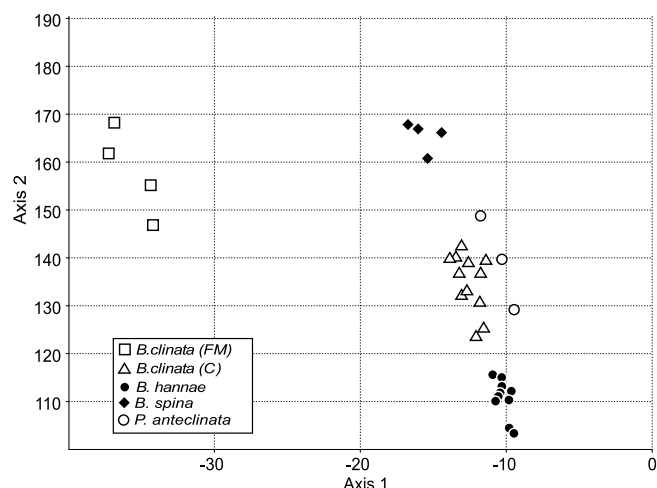


Fig. 5. Scatter plot of five groups in canonical variates analysis (CVA). mh;0

Remarks. The diagnosis emended by O'Connor (1997, 2001) is used herein to include the genus *Buryella* in the Family.

Genus *Buryella* Foreman, 1973, emend. O'Connor, 2001

Type species. *Buryella tetradica* Foreman, 1973.

Remarks. O'Connor (2001) emended the genus and stated that species included in *Buryella* should possess the following internal cephalic features unique to the family Artostrobiidae: (1) arches joining apical spine and branches extend laterally from vertical spine at either side of base of vertical tube (A-Vbl and A-Vbr) in all the members of the genus; and (2) multiple axobat (Ax) in some of them. This second feature may be ancestral and lost in most descendant species. O'Connor (2001) derived the ancestry of *Buryella* from *B. granulata*, which possibly evolved from *Lithostrobilus wero* in the Lower Paleocene (RP3 Zone). All *Buryella* species described by O'Connor (2001) from the South Pacific Paleocene (Radiolarian zones RP3–RP5) possess arches A-Vbl and A-Vbr. *B. granulata* and *B. foremanae* – the oldest members of the genus also possess multiple axobat (Ax).

Species from the Lower Eocene of the Subsilesian Series attributed to *Buryella* have three or four segments, are fusiform or lobate in outline and have a constricted rather than flared aperture. The cephalis always possesses an apical horn of varying length with a distinct vertical pore at the collar stricture. Internal structures of cephalis are invisible because of pyritization. However, all specimens possess a pronounced vertical tube (e.g. Pl. 1, fig. 2), rounded or elongate, which may extend to the base of apical horn. Near the base of the cephalis are external longitudinal ridges that diverge from the horn and extend to the collar stricture. Ventrally, two of these ridges rejoin to enclose the vertical pore and form an upwardly directed tube. These structures might be evidence of the presence of arches (A-Vbl, A-Vbr) and bars (Vbl, Vbr), which form the vertical tube. Based on this feature, the species described herein is included in the genus *Buryella*, although the internal structures of the cephalis need further investigation to confirm the placement of these species in *Buryella*.

Buryella tetradica Foreman, 1973
(Pl. 1, figs 1–3)

1973 *Buryella tetradica* Foreman: 433, pl. 8, figs 4, 5; pl. 9, figs 13, 14.

2001 *Buryella tetradica* Foreman; O'Connor: 11, pl. 1, figs 14–18; pl. 3, figs 16–21.

Description. See Foreman (1973), Hollis (1997) and O'Connor (2001).

Dimensions of the Carpathian specimens. Based on three specimens. Length of test including horn is 138–161 µm (mean 150 µm). Width of abdomen is 79–84 µm (mean 81 µm).

Stratigraphic range. This taxon is known from the Lower Eocene of the Carpathians, present within the *Phormocyrtis striata striata* Radiolarian Zone and *Saccamminoides carpathicus* Foraminiferal Zone. The first and the last occurrences of *B. tetradica* differ globally. Its first occurrence is known from the Upper Paleocene of the Gulf of Mexico, from the lower part of an unzoned interval (Foreman, 1973); from the Upper Paleocene of the Caspian and the middle Volga areas (Kozlova, 1983b, 1993). It ranges from an unzoned interval to the *Buryella clinata* Radiolarian Zone in the Caribbean region (Riedel & Sanfilippo, 1973); from RP5b to RP10 zones in the Southwest Pacific (Hollis, 1997; O'Connor, 2001; Hollis *et al.*, 2005). *B. tetradica* s.l. (Sanfilippo & Blome, 2001) is also known from RP6–RP10 zones in the western North Atlantic.

Remarks. Four-segmented, subovate test, with well-developed strict longitudinal and transverse alignment of abdominal pores and pronounced longitudinal ridges separate each row of pores observed on the specimens are features appearing in later members of this species. Another feature is the orientation of the vertical tube. As mentioned and illustrated by O'Connor (2001), the vertical tube is directed upwards at an angle in the early evolutionary members, whilst in Foreman's specimens and those herein the vertical tube is directed horizontally or almost horizontally.

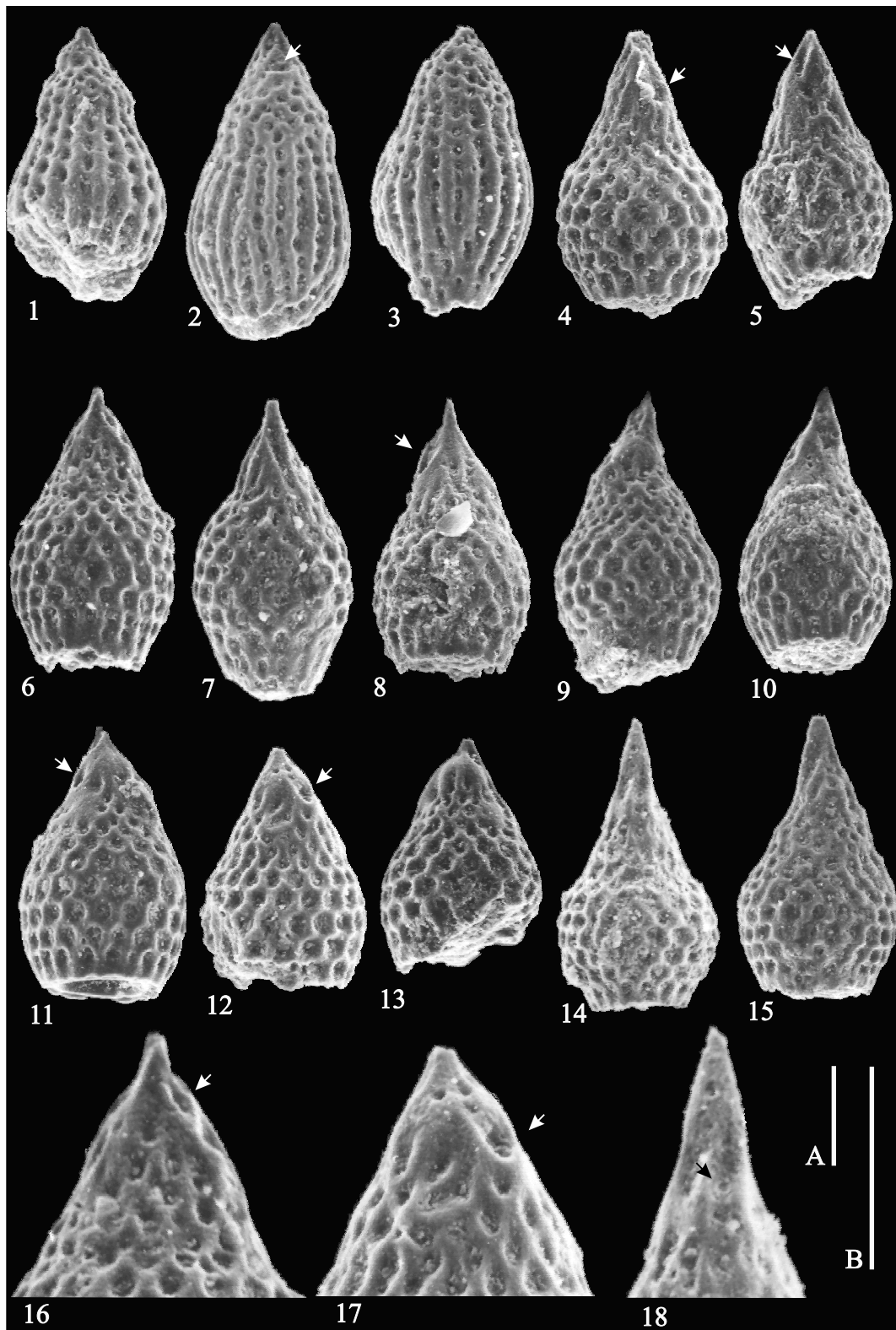
Specimens found in the Subsilesian Series match the original description of Foreman (1973). In comparison with the specimens of Sanfilippo & Blome (2001), they correspond to *B. tetradica* s.s. rather than to *B. tetradica* var. A, which also appeared stratigraphically earlier. It differs from *B. tetradica tetradica*, *B. tetradica tridicaas* presented by Hollis (2002) and *B. tetradica* described by O'Connor (2001) and Hollis (1997) in having a much more elongated and oval post-thoracic test.

Buryella clinata Foreman, 1973
(Pl. 1, figs 4–10, 16)

1973 *Buryella clinata* Foreman: 433, pl. 8, figs 1–3; pl. 9, fig. 19.

Dimensions of the Carpathian specimens. Based on 14 specimens. Length of test including horn is 127–156 µm (mean 139 µm). Width of abdomen is 76–85 µm (mean 83 µm).

Stratigraphic range. This species has been hitherto recorded in the Carpathians from the Lower Eocene. It is present in the



Explanation of Plate 1.

Species of *Buryella* from Subsilesian Unit. **figs 1–3.** *Buryella tetradica* Foreman: **1**, CZRW 250910; **2**, CZRW 251201; **3**, CZRW 250815. **figs 4–10.** *Buryella clinata* Foreman: **4**, CZRW 250901; **5**, CZRW 250013; **6**, CZRW 250806; **7**, CZRW 250814; **8**, CZRW 250513; **9**, CZRW 250709; **10**, CZRW 250022. **figs 11–13.** *Buryella hanna* sp. nov.: **11**, holotype, CZRW 250504; **12**, paratype, CZRW 250710; **13**, CZRW 250017; **figs 14, 15.** *Buryella spina* sp. nov.: **14**, holotype, CZRW 251403; **15**, paratype, CZRW 251104. **fig. 16.** Close up of the vertical pore area for *Buryella clinata* Foreman illustrated in figure 6. **fig. 17.** Close up of the vertical pore area for *Buryella hanna* sp. nov. illustrated in figure 12. **fig. 18.** Close up of the vertical pore area for *Buryella spina* sp. nov. illustrated in figure 14. Arrows indicate vertical pore area. Scale bars 50 µm: (A) specimens in figures 1–15; (B) specimens in figures 16–18.

Buryella clinata through the *Phormocyrtis striata striata* Radiolarian Zones (Bak *et al.*, 1997; Rajchel *et al.*, 1999; Rajchel & Barwicz-Piskorz, 2005; Bak & Barwicz-Piskorz, 2005). *B. clinata* is found in the Lower to lowest Middle Eocene from tropical localities. Its evolutionary transition from *Pterocodon* (?) *anteclinata* marks the base of the *B. clinata* Zone. It becomes extinct at approximately the lower limit of the *Theocotyle cryptocephala* Zone (Foreman, 1973; Sanfilippo & Nigrini, 1998, 2001).

Remarks. The problem of placing *B. clinata* into the Family Artostrobiidae remains open because O'Connor (2001), during his examination of the genus *Buryella*, excluded *B. clinata* from the genus, as it needs more elucidation of the internal structures. Although *B. clinata* is commonly present in the Carpathians there is no sufficiently well-preserved specimens for internal investigation.

Specimens measured herein as *B. clinata* represent groups 1 and 2 on the dendrogram (Fig. 3) and the PCA and CVA graphs (Figs 4, 5). The Carpathian specimens (Group 1) are slightly different from the forms described by Foreman (1975) (Group 2). Both groups include forms having four-segmented tests, a bladed apical horn with bases as wide as the cephalis. However, Foreman's specimens are more elongated in the thorax and the abdominal width, while the Carpathian specimens are more inflated and the arrangement of pores on the thorax is disrupted in some places by areas of non-porous wall. This may be a consequence of very strongly developed ridges extending from the apical horn. The fourth segment is inversely truncated being conical, but very short in the specimens herein, having only one or two transverse rows of pores. This taxon is included in the genus *Buryella* on the presence of the external skeletal features, especially the pronounced vertical tube directed proximally at an angle (as discussed above).

Buryella hanna sp. nov.
(Pl. 1, figs 11–13, 17)

Derivation of name. In honour of Prof. Hanna Górka for her significant contributions to radiolarian studies in Poland.

Holotype. CZ-250504 (Pl. 1, fig. 11).

Paratype. CZ-250710 (Pl. 1, figs 12, 17).

Locality and horizon. Czerwin Creek, greenish shales of the Variegates Shales, *Saccamminoides carpathicus* Foraminiferal Zone, *Phormocyrtis striata striata* Radiolarian Zone.

Description. Test of three segments. Cephalis spheroidal, with very few, small circular pores, distributed irregularly. Cephalis bearing a thin, short, weakly bladed, conical apical horn; slight ridges at the base of apical horn continue downward, vague in the uppermost part of cephalis, pronounced toward the thorax. Vertical tube directed upwards towards the posterior base of cephalis, expressed externally by two rejoined ridges. Collar stricture is, in most cases, externally barely visible as a slight change in contour. Thorax truncate-conical; pores circular to droplike or oval, generally quincuncially arranged to irregular, in three to four transverse rows. On some specimens this

arrangement may be disrupted by areas of non-porous wall material. Abdomen inflated, cylindrical; pores circular to ovate, quincuncially arranged in seven to eight rows; termination smooth.

Dimensions. Based on ten specimens. Length of test including horn is 102–119 µm (mean 112 µm). Width of abdomen is 76–83 µm (mean 79 µm).

Stratigraphic range. Lower Eocene in the Carpathians, present in the *Phormocyrtis striata striata* Radiolarian Zone and *Saccamminoides carpathicus* Foraminiferal Zone.

Remarks. *B. hanna* differs from most members of *Buryella* by having only three segments. It differs from *B. clinata* Foreman in having a much shorter and less bladed apical horn, and a clearly visible spherical cephalis with extended ridges from apical horn. It differs from *B. helenae* O'Connor by having a not so bulging, shorter thorax and an elongated abdomen. It differs from *B. petrushevskayae* O'Connor and *B. tridica* O'Connor primarily in having quincuncially, rather than rectilinearly, arranged pores on the abdomen. It differs from *B. longa* Kozlova in having only three segments, which are longer, not so rounded, an inflated abdomen, and is conical rather than hemispherical in the cephalo-thoracic part of the skeleton.

Buryella spina sp. nov.
(Pl. 1, figs 14, 15, 18)

Derivation of name. Named for its long apical horn.

Holotype. CZ-251403 (Pl. 1, figs 14, 18).

Paratype. CZ-251104 (Pl. 1, fig. 15).

Locality and horizon. Czerwin Creek, greenish shales of the Variegates Shales, *Saccamminoides carpathicus* Foraminiferal Zone, *Phormocyrtis striata striata* Radiolarian Zone.

Description. Tri-segmented test. Cephalis hemispheroidal, with very few circular pores, bearing a thick, bladed apical horn, almost equal to the length of the thorax. Weak cephalic ridges, starting distally and continuing on the external wall of the cephalis. Vertical tube at posterior base of cephalis, expressed as a low, truncated cone. Thorax truncate-conical, with circular to sub-circular pores, quincuncial to randomly arranged in three to four transverse rows. Abdomen inflated cylindrical, slightly longer than the thorax. Stricture between the thorax and abdomen is externally visible as a change of outline. Abdominal pores circular, quincuncially arranged in five to six rows, termination ragged.

Dimensions. Based on four specimens. Length of test including horn is 164–172 µm (mean 165 µm). Width of abdomen 92–104 µm (mean 96 µm).

Stratigraphic range. Lower Eocene in the Carpathians, present within the *Phormocyrtis striata striata* Radiolarian Zone and *Saccamminoides carpathicus* Foraminiferal Zone.

Remarks. *B. spina* differs from most members of *Buryella* by having only three segments. It differs from *B. clinata* Foreman by having a conspicuously massive, elongated and less bladed apical horn and a significantly inflated and not so elongated abdomen. It differs from *B. petrushevskayae* O'Connor and *B. tridica* O'Connor primarily in having quincuncially, rather than rectilinearly, arranged abdominal pores; from *B. helenae* O'Connor in possessing a smaller and less inflated thorax. It is distinguished from *B. hanna* in having a more massive apical horn, and a shorter, more inflated abdomen with a ragged termination. It differs from *B. longa* Kozlova having only three segments, a shorter test, and a strongly conical, rather than hemispherical cephalo-thoracic skeleton. *B. kaikoura* Hollis and *Buryella* sp. C, as described by Dumitrica (1973), differ from *B. spina* which has a long, and more massive, bladed apical horn, and a truncated-conical rather than an inflated thorax.

CONCLUSIONS

Well-preserved, pyritized radiolarian assemblages from the Lower Eocene deposits of the Subsilesian Series (Polish part of the Outer Flysch Carpathians) have yielded common specimens of the genus *Buryella*. The pyritization process, preserved the external radiolarian skeletons exceptionally well; however, subsequent pyrite framboid crystallization has destroyed any internal structures.

Two new species of the genus *Buryella* have been described based on the material investigated. However, it should be stressed that their description is based on external skeletal morphology, with only the tracing of external cephalic features to indicate the presence of internal arches and bars. It was not possible to observe any internal structures due to pyritization. Additionally, the problem of placing *Buryella clinata* into the Family Artostrobiidae remains open, as stated by O'Connor (2001), subsequent to further studies of internal skeletal structures.

Despite the absence of *Pterocodon* (?) *anteclinata* or any ancestral material of *B. clinata*, and the unclear position of the internal skeletal structures, some phylogenetic connections have been inferred, based on specimen morphology and external measurements. The newly described species are probably local Carpathian variants of low-latitude representatives of the genus *Buryella*, which has been useful in the southern high-latitude radiolarian biostratigraphy of the Palaeogene (Hollis, 1993, 1997, 2002; O'Connor, 2001), as well in the Boreal realm (Kozlova, 1983a, b, 1984, 1993, 1999). *B. hanna* appears to be an offshoot of *B. clinata* Foreman developed by the loss of the distal segment, with a weaker grid of ridges on the external abdomen wall. However, the non-porous areas on the thorax wall may be the distal remnants of strongly developed apical horn ridges. *B. spina* appears to be an offshoot of *B. clinata* through a similar loss of the distal segment.

The phylogenetic relationships of the Carpathian species with the forms of *B. clinata*, as described by Foreman, and its ancestor *Pterocodon* (?) *anteclinata*, as suggested by Foreman (1975), cannot be discussed here without reference to the internal cephalic structure. The application of simple statistical methods has shown close similarity between the Carpathian *B. clinata* and *Pterocodon* (?) *anteclinata* and suggests that the

Carpathian specimens probably represent local variants of early evolutionary forms of *B. clinata*.

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