Geological Quarterly, 2012, **56** (1): 107–116

Palaeoecology of the middle Miocene foraminifera of the Nowy Sącz Basin (Polish Outer Carpathians)

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Gonera M. (2012) – Palaeoecology of the middle Miocene foraminifera of the Nowy Sącz Basin (Polish Outer Carpathians). Geol. Quart., **56** (1): 107–116.

Foraminifera from newly exposed outcrop sections located in a middle Miocene piggyback basin of the Outer Carpathians Nowy Sącz Basin indicate an environment of normal saline waters on the inner shelf and a temperature not lower than 18°C. The area was ideal for the proliferation of: *Miliolina* spp., *Elphidium crispum*, *Ammonia beccarii* and *Pararotalia*. The habitat below the sediment surface was not colonised by foraminifera. Planktonic foraminifera are absent. The age of the population studied is referred based on the climate-related data, to the *Orbulina suturalis* Zone of the Miocene Climate Optimum.

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Key words: Poland, Paratethys, middle Miocene, foraminifera, palaeoecology.

INTRODUCTION

The deposits of the site studied belong to the Miocene para-autochthonous cover separated by an angular unconformity from the Carpathian Flysch of the Nowy Sącz Basin (Fig. 1). The basin profile consists of freshwater deposits up to 500 m thick and marine and brackish deposits some 50 metres thick (Bałuk, 1970; Oszczypko and Stuchlik, 1972; Oszczypko, 1973; Łańcucka-Środoniowa, 1979; Oszczypko *et al*., 1992; Oszczypko-Clowes *et al*., 2009).

The section in the Kamienica Nawojowska River was exposed due by flood erosion in 2001 (Gonera and Styczyński, 2002). The site studied (2.9 km upstream from the river inlet into the Dunajec) are exposed for some 50 m along the riverbed and its escarpment on the left side of the valley. The section displays fossil-bearing silty mudstones. The sediments are homogenous, poorly consolidated, greenish and dark grey in colour. Macrofossils, including bivalves and gastropods, are randomly dispersed and accumulated in a semi-laminar form. They disintegrate when the matrix is removed. Microfossil sampling revealed the presence of plant remains, ostracodes, bryozoans, fish otoliths, green algae, echinoids and foraminifera. Foraminifers are the most frequent, and they were examined in this study, which documents the assemblage from this site and interprets some features of its habitat.

MATERIALS AND METHODS

Rock samples have been collected from four locations of the site (Fig. 1C) and prepared using standard micropalaeontological techniques. The specimens are abundant in sample 1 and rare in the others (2, 3 and 4). Quantitative analysis was therefore performed on foraminifera from sample 1. The foraminiferal data obtained were used for palaeoenvironmental reconstruction. Methods of palaeoecological interpretation based on the principles of uniformitarianism were applied (Murray, 1991, 2001).

RESULTS

Among the total number of 1784 foraminifera, only 6 obscure planktonic specimens were found (they are omitted in further consideration). The foraminifera recognized are listed in Table 1 and shown in Figures 2–4. The assemblage is com-

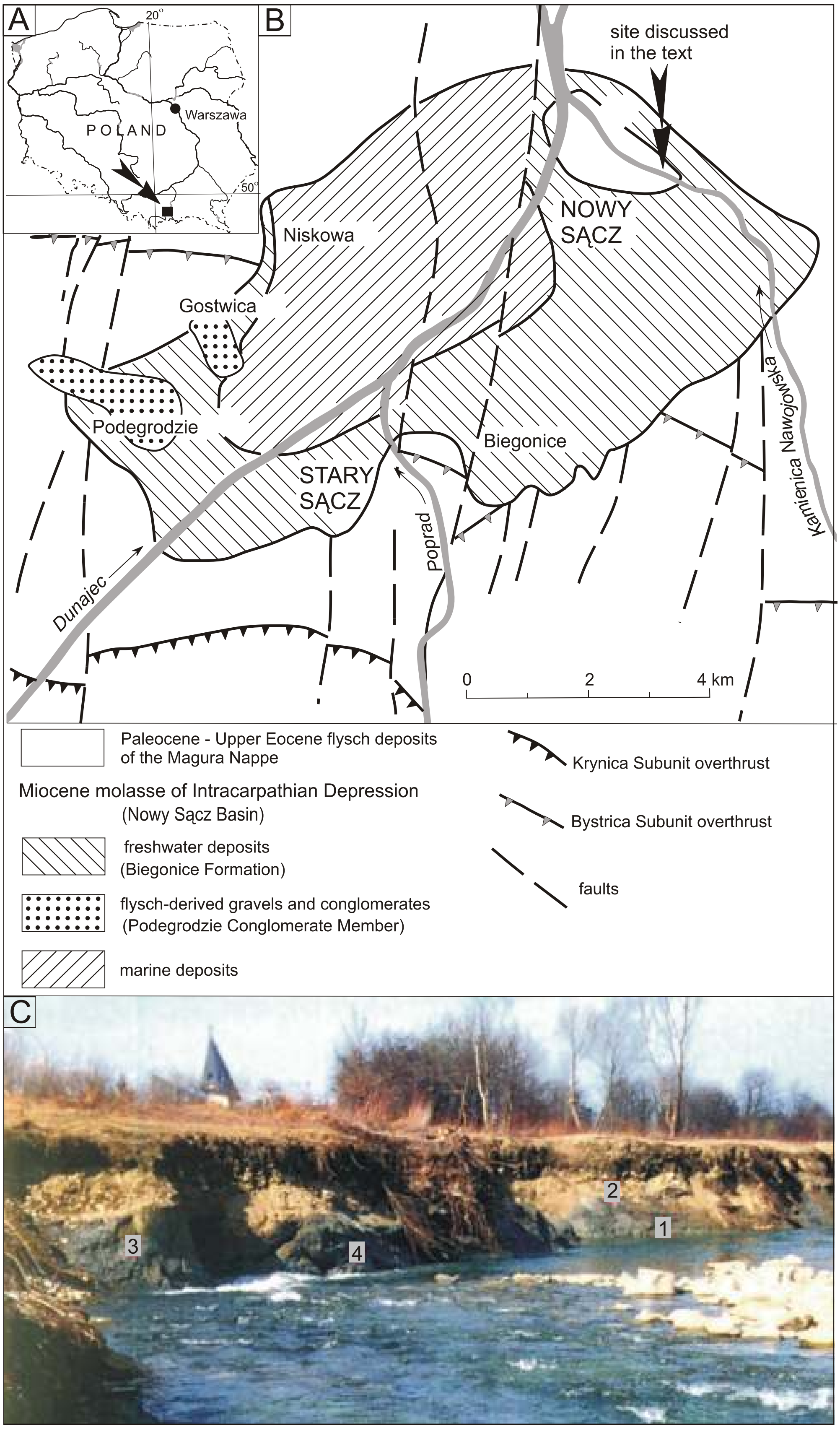

Fig. 1. The section sampled and the site location with its geological context (according to Oszczypko *et al.*, 1992, simplified)

Numbers 1–4 refer to sample location

Table 1

Miocene Foraminiferida of Nowy Sącz

Suborder*	Family	Species	Wall structure
Textulariina	Textulariidae	*Textularia laevigata* d'Orbigny, 1826	agglutinated
Miliolina	Hauerinidae	*Siphonaperta mediterranensis* Bogdanowicz, 1950	calcareous porcellaneous
		Cycloforina badenensis (d'Orbigny, 1846)	
		Cycloforina contorta (d'Orbigny, 1846)	
		Cycloforina hauerina (d'Orbigny, 1846)	
		Cycloforina lachesis (Karrer, 1868)	
		Cycloforina vermicularis (Karrer, 1868)	
		Hauerina compressa d'Orbigny, 1846	
		Hauerina tumida Serova, 1953	
		Lachlanella incrassata (Karrer, 1868)	
		Quinqueloculina akneriana d'Orbigny, 1846	
		Quinqueloculina anagallis Łuczkowska, 1974	
		Quinqueloculina buchiana d'Orbigny, 1846	
		Quinqueloculina haidingeri d'Orbigny, 1846	
		Pseudotriloculina consobrina (d'Orbigny, 1846)	
		Pyrgo lunula (d'Orbigny, 1846)	
		Triloculina inflata d'Orbigny, 1846	
		Articulina sulcata (Reuss, 1850)	
	Alveolinidae	*Borelis melo* (Fichtel et Moll, 1803)	
	Peneroplidae	*Spirolina austriaca* d'Orbigny, 1846	
Lagenina	Polymorphinidae	*Globulina gibba* d'Orbigny, 1826	calcareous hyaline
		Globulina granulosa (Egger, 1857)	
Rotaliina	Buliminidae	*Virgulopsis tuberculatus* (Egger, 1857)	
	Reusellidae	*Reusella pulchra* Cushman, 1945	
	Rosalinidae	*Neoconorbina terquemi* (Rzehak, 1888)	
	Glabratellidae	*Glabratella mira* Cushman, 1922	
	Discorbinellidae	*Biapertorbis biaperturatus* Pokorny, 1956	
	Asterigerinidae	*Asterigerinata planorbis* (d'Orbigny, 1846)	
	Planorbulinidae	*Planorbulina mediterranensis* d'Orbigny, 1826	
	Nonionidae	*Nonion commune* d'Orbigny, 1826	
	Rotaliidae	*Pararotalia aculeata* (d'Orbigny, 1846)	
		Ammonia beccarii (Linné, 1758)	
	Elphidiidae	*Elphidium rugosum* (d'Orbigny, 1846)	
		Elphidium crispum (Linné, 1758)	
		Elphidium aculeatum (d'Orbigny, 1846)	

* – the systematic concept according to Loeblich and Tappan (1988)

posed of miliolids, *Elphidium crispum*, *Pararotalia aculeata*, and *Ammonia beccarii*. Specimens of these taxa account for 89.7% of the total foraminiferal assemblage (Fig. 5).

INTERPRETATION AND DISCUSSION

The ecology of these dominanting was used as a set of basic indicators of environmental conditions. The porcellaneous forms (Miliolina) constitute a high proportion of the foraminifers in shallow water (inner shelf) of warm to temperate areas. They thrive in normal salinity but may also tolerate high salinities (Brasier, 1975; Hottinger *et al.*, 1993; Cherif *et al.*, 1997; Haunold *et al.*, 1997). Some of them are restricted to tropical areas, e.g., *Borelis*, typical of temperatures constantly higher than 18°C (compare: Hottinger *et al.*, 1993; Cimerman and Langer, 1991). Light penetration on the sea bottom can be evaluated by the abundance of symbiont-bearing foraminifera. The presence of *Elphidium* harbouring highly photic plants (green algae) suggests that the environment could not have been deeper than a few to a dozen metres (Leutenegger, 1984). Elphidiidae are shallow water (inner shelf) forms and generally easily adapted to a considerable range of salinity and temperature, an exception being taxa having a keeled periphery to their

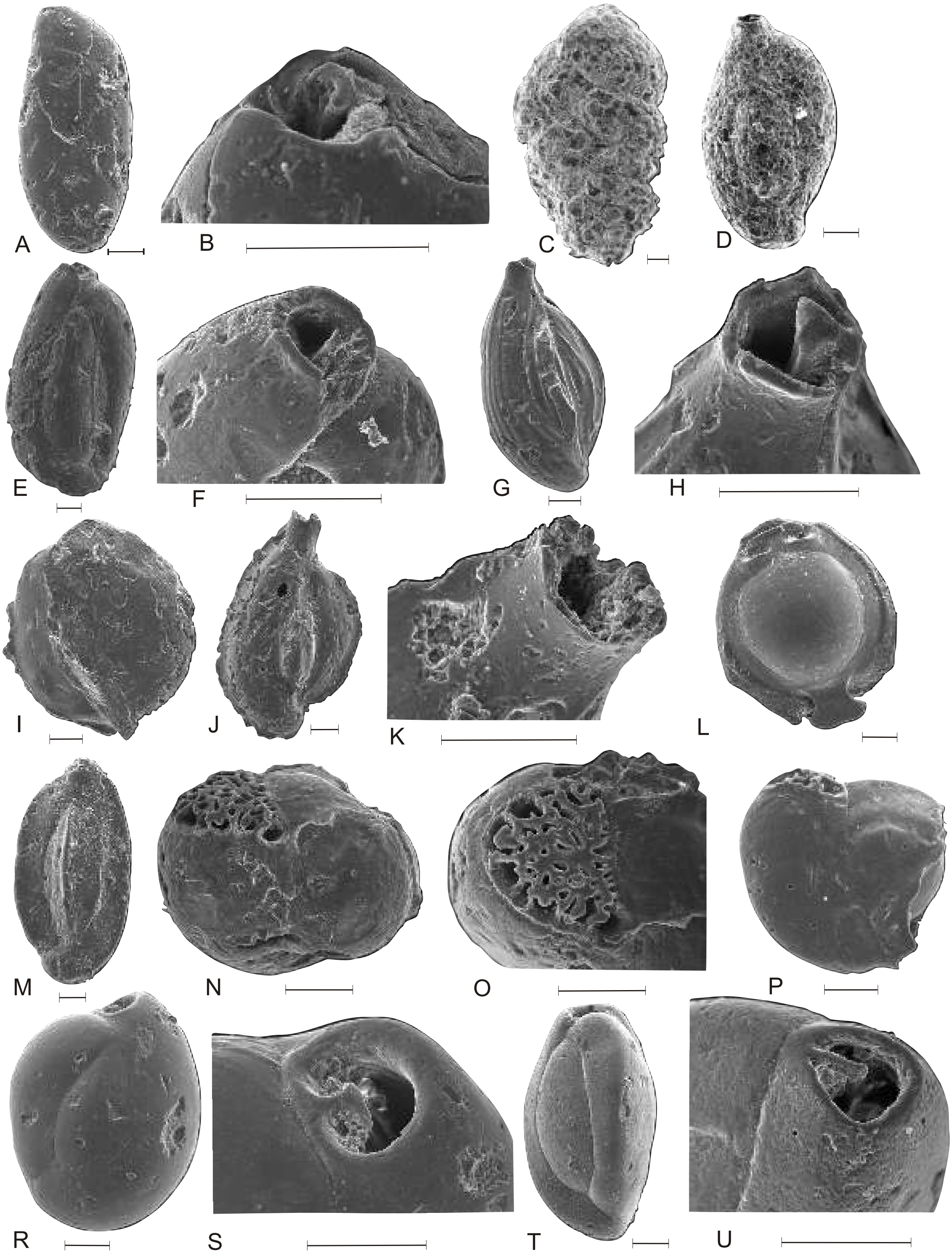

Fig. 2A, B – *Pseudotriloculina consobrina* (A – side view, B – apertural view); C – *Textularia laevigata*, side view; D – *Siphonaperta mediterranensis*, side view; E, F – *Cycloforina hauerina* (E – side view, F – apertural view); G, H – *Cycloforina vermicularis* (G – side view, H – apertural view); I – *Cycloforina badenensis*, side view; J, K – *Cycloforina lachesis* (J – side view, K – apertural view); L – *Pyrgo lunul*, side view; M – *Cycloforina contorta*, side view; N, O – *Hauerina tumida* (N – side view, O – apertural view); P – *Hauerina compressa*, side view; R, S – *Triloculina inflata* (R – side view, S – apertural view); T, U – *Quinqueloculina akneriana* (T – side view, U – apertural view)

Scale bar – 100 microns

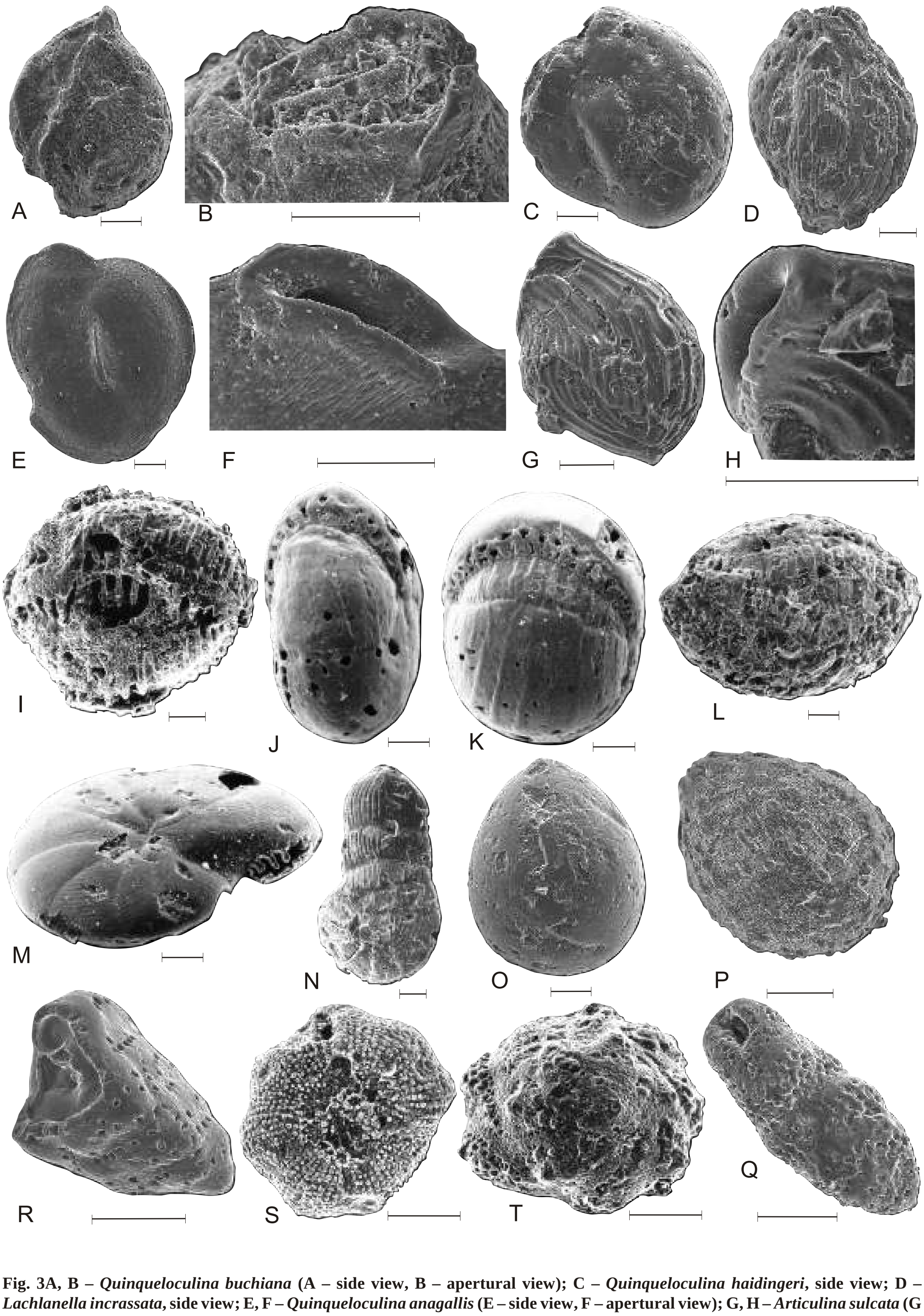

Fig. 3A, B – *Quinqueloculina buchiana* (A – side view, B – apertural view); C – *Quinqueloculina haidingeri*, side view; D – *Lachlanella incrassata*, side view; E, F – *Quinqueloculina anagallis* (E – side view, F – apertural view); G, H – *Articulina sulcata* (G – side view, H – apertural view); I, L – *Borelis melo*, apertural view; M, N – *Spirolina austriaca* (M – apertural view of spiral stage, N – side view); O – *Globulina gibba*, side view; P – *Globulina granulosa*, side view; R – *Reusella pulchra*, side view; S, T – *Glabratella mira* (S – apertural view, T – spiral side); Q – *Virgulopsis tuberculatus*, side view

Scale bar – 100 microns

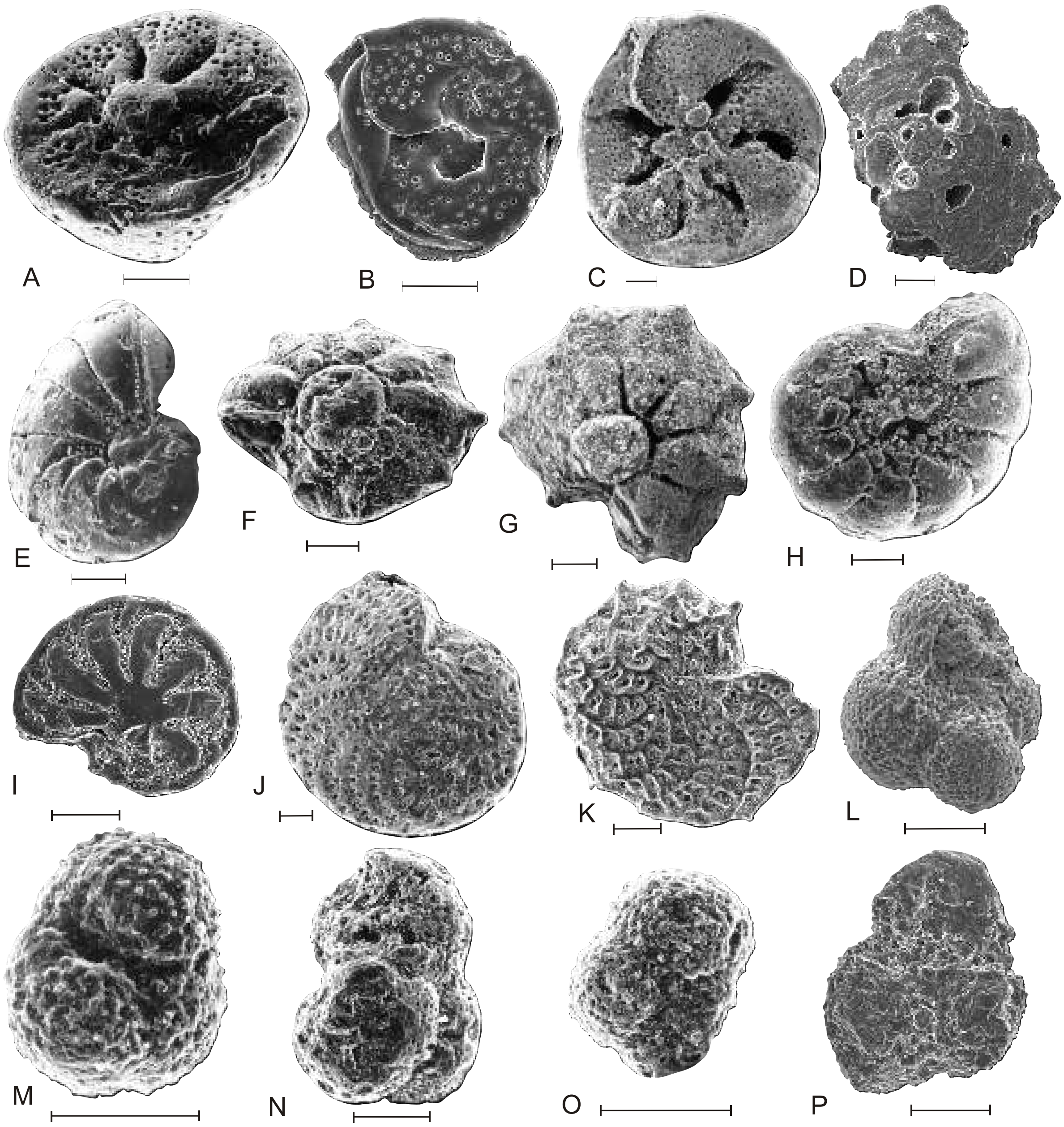

Fig. 4A – *Biapertorbis biaperturatus*, apertural view; B – *Neoconorbina terquemi*, apertural view; C – *Asterigerinata planorbis*, apertural view; D – *Planorbulina mediterranensis*, viewed from formerly attached side; E – *Nonion commune*, side view; F, G – *Pararotalia aculeata* (F – side view, G – apertural view); H – *Ammonia beccarii*, side view; I – *Elphidium rugosum*, side view; J – *Elphidium crispum*, side view; K – *Elphidium aculeatum*, side view; L – *Globigerina* cf. *bulloides*, apertural view; M, P – undetermined planktonic foraminifera due to poor preservation

Scale bar – 100 microns

test (e.g., *Elphidium crispum*), which are present only in normal saline waters and in areas not cooler than temperate (Murray, 1973). *Ammonia* is also a eurytopic species in terms of both salinity and temperature (Walton and Sloan, 1990) but it is restricted to upper sublittoral waters. Its distinct morphotypes are characteristic of local salinities and hydrodynamic conditions. Those specimens showing highly ornamented shells (plugs, fissures, pillars and pustules) as in the Nowy Sącz assemblage are typical of high-salinity and high-energy regimes. *Pararotalia aculeata* is a species of inner shelf, warm and normal saline waters.

From these ecological characters, the foraminifera studied represent an inner shelf, normal saline and warm-water environment (normal saline lagoon or open coast waters). Since salinity was normal, low bathymetry and/or a short distance to shore may account for the absence of planktonic foraminifera in the Nowy Sącz assemblage.

Elphididae, *Borelis* and *Spirolina* are symbiont-cultivating foraminifera (Leutenegger, 1984). These species account for

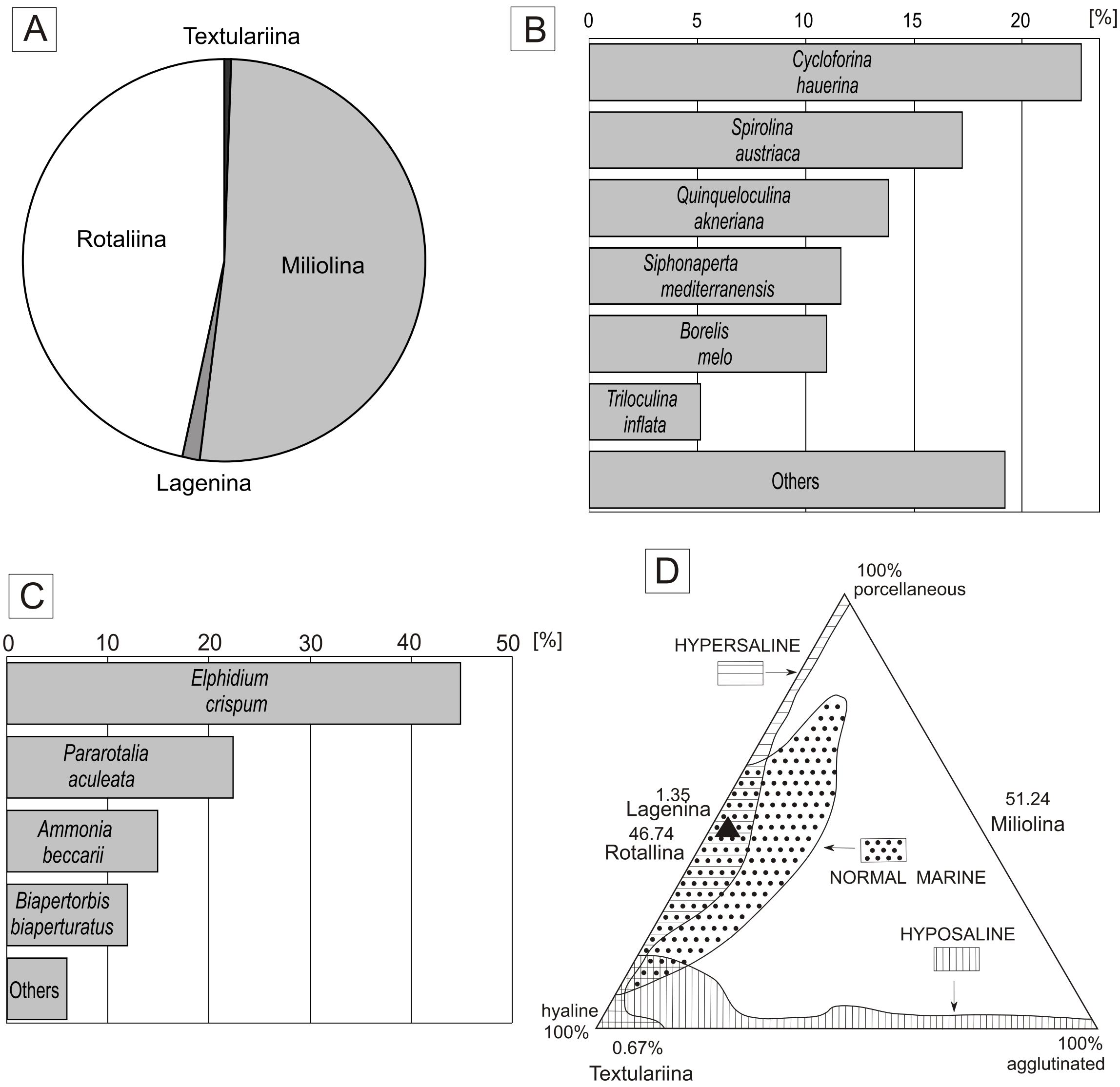

Fig. 5. Quantitative analyses of the Nowy Sącz foraminifera assemblage studied

A – percentage of suborders, B – most abundant species of Miliolina, C – most abundant species of Rotaliina, D – wall structure categories of foraminifera *versus* environments after Murray (1973); the association studied is marked by a black triangle

36.0% of the assemblage studied (Fig. 5). Green algae – plants hosted in the canal system of *Elphidium* shells – have a high light requirement. These conditions can be found only in the uppermost part of the water column, so the depth of the Nowy Sącz assemblage could not exceed this limit, effectively around a few metres.

All the foraminifera taxa present in the assemblage are adapted to high-energy waters (with currents and tidal movements). They display different adaptations to this environment. Attached forms, either cemented to the substrate (*Planorbulina*) or crawling (*Asterigerinata*, *Neoconorbina*, *Biapertorbis*, *Glabratella*), represent 7.0% of specimens. The majority of the foraminifers are mobile, free-living forms with robust tests as a survival strategy for highly agitated conditions. There is a virtual absence of thin-walled and slender morphotypes of miliolids typical of low-energy waters. All miliolids (Miliolina) and elphidids (Elphidiidae) as well as *Pararotalia*, *Ammonia*, *Nonion*, *Borelis* and *Globulina* use this life strategy. Shallow, high-energy conditions, with a low sedimentation rate habitat, is supported by the poor preservation of most specimens. The tests are broken and abraded, as if they were exposed to water action for a long period after death.

The site studied is a part of the molasse unit, i.e. the transgressive deposits extending into both the Carpathian Foredeep Basin as a continuous cover and to the flysch units by patches of piggyback basin deposits. At the base of the second area, *Orbulina suturalis* appears (Alexandrowicz, 1971; Gonera, 1994). This indicates that the marine piggyback basin deposits are not older than biostratigraphic Zone N9, i.e. late Langhian, according to Rio *et al.* (1997). That taxon is a major stratigraphic marker for the Paratethyan molasse. Although younger deposits of this area yield rich and diversified foraminifera assemblages, they do not include Globigerinina index-taxa of Tethys (Cicha *et al*., 1975; Łuczkowska, 1998). Nevertheless temporal changes in the foraminiferal associations may be regarded as biostratigraphic ecozones (Szczechura, 1982, 2000; Gonera, 2001). Mid Miocene climate changes have been proposed as the factor influencing Paratethys environments and strongly modifying the taxonomic composition of the Badenian foraminiferal assemblages (Gonera, 2001; Bicchi *et al*., 2003).

Temperature as one of the key indicators of climate can be fairly well-assessed from foraminifera: modern *Borelis* inhabit warm-water areas (see above). In the Badenian stratotype (Baden-Sooss, Austria) the warm-water foraminifera are found in its lower part (Upper Lagenid Zone) dated as the N9 Zone (Brestenska, 1978; Rögl *et al*., 2008). None of the warm-water taxa of foraminifera are present either in the younger deposits of this particular section (the Sandschaler Zone and Buliminen-Bolivinen Zone) or in the equivalent units of the adjacent areas of the Paratethys (Seneš, 1975). These data support the idea of climate deterioration in the upper part of the Badenian based on isotopic studies on Badenian foraminifera in the Polish part of the Carpathian Foredeep (Durakiewicz *et al*., 1997; Gonera *et al*., 2000).

CONCLUSIONS

1. According to the general principle that species abundance is greatest in optimal environmental conditions, the assemblage studied, represents a normal salinity, shallow- and warm-water habitat. An analogous environmental conclusion has been reached based on ostracodes and green algae from this site (Szczechura, 2006).

2. The assemblage is dominated by epifaunal taxa, mostly high energy forms, suggesting an environment swept by currents. The empty tests were transported to the deeper, muddy/siliciclastic settings as postulated also by Bitner and Kaim (2004) for brachiopods of this site.

3. Warm, subtropical conditions allowing *Borelis* to proliferate in the Polish part of the Paratethys were established only during the Miocene Climate Optimum. This feature allows placing of the stratigraphic position of the Nowy Sącz assemblage within the *Orbulina suturalis* Zone. Both the assemblage studied and freshwater deposits of the Nowy Sącz Basin (Łańcucka-Środoniowa, 1979) originated in the same climate conditions.

Acknowledgments. The author wishes to extend sincere thanks to Prof. J. Szczechura, Dr. W. Majewski, Prof. M. Narkiewicz, Prof. N. Oszczypko, Prof. T. M. Peryt and Dr. M. Rogerson for their constructive revision of this paper.

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