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New data on the late Badenian–Sarmatian deposits of the Nowy Sącz Basin (Magura Nappe, Polish Outer Carpathians) and their palaeogeographical implications

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In the Nowy Sącz Basin, newly exposed Middle Miocene deposits have been studied and sampled in the Kamienica Nawojowska, Poprad and Dunajec rivers. The calcareous nannoplankton of the freshwater to marine deposits was examined. Pale grey and brown clayey shales with plant remains and thin seams of lignite represent the freshwater deposits of the Biegonice Formation. These deposits pass upwards into *ca*. 50 m thick packet of brackish and marine deposits, represented mainly by dark marly shales with bivalves and gastropods of the Iwkowa and Niskowa formations. These deposits contain relatively rich late Badenian to Sarmatian calcareous nannoplakton (NN6/7 Zone).

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Key words: Middle Miocene, freshwater and marine deposits, lithostratigraphy, calcareous nannoplakton.

INRODUCTION

The Nowy Sącz Basin is the only intramontane basin in the Polish Outer Carpathians that is filled with both freshwater and marine Miocene deposits (Fig. 1). The Miocene deposits rest unconformably upon folded and eroded deposits of several facial-tectonic subunits of the Magura Nappe (Oszczypko, 1973; Oszczypko *et al*., 1992). Pleistocene and Holocene alluvial deposits up to 12 m thick overlap the Miocene deposits. None of the exposures of the Miocene strata are located on the western (Niskowa), eastern (Falkowa) and SE (Biegonice) periphery of the basin (Fig. 2).

During the course of hydrogeological (1963–1966) mapping the Nowy Sącz I borehole (Fig. 2), which is 704 m deep, was drilled by the Polish Geological Institute (PGI). This borehole pierced the flysch basement at a depth of 540 m (Oszczypko and Stuchlik, 1972; Oszczypko, 1973). New boreholes were drilled in 1984–1985 for the PGI near the villages of Niskowa and Podegrodzie on the western periphery of the basin. The core material was studied and palynological, foraminifer and calcareous nanoplankton determinations were carried out (see Oszczypko *et al*., 1991, 1992). These studies enabled the revision of previous opinions concerning the litho- and biostratigraphy of the freshwater and marine deposits in the Nowy Sącz Basin, and established new litho- and biostratigraphic standards for this basin.

During the flooding of 2001 and the later intensive erosion in the Kamienica Nowojowska River rock-bed, both Miocene freshwater as well as marine deposits were discovered. From this, Middle Miocene marine foraminifera (Gonera and Styczyński, 2002; Gonera and Gedl, 2005), brachiopods (Bitner and Kaim, 2004), ostracodes and green algae (Szczechura, 2006) were determined. As a result of recent flooding new exposures of Miocene strata have also appeared in the Poprad and Dunajec rivers (Fig. 2).

The authors, over the period 2003 to 2008, visited the Kamienica Nawojowska valley several times, beneath the inflow of the Kamienna Stream, as well as the Poprad and Dunajec rivers. The authors observed further erosion and documented new exposures. Between 2006–2007 the studied exposures progressively disappeared and new constructions against erosion were established. These new exposures supplemented knowledge on the Middle Miocene deposits in the Nowy Sącz

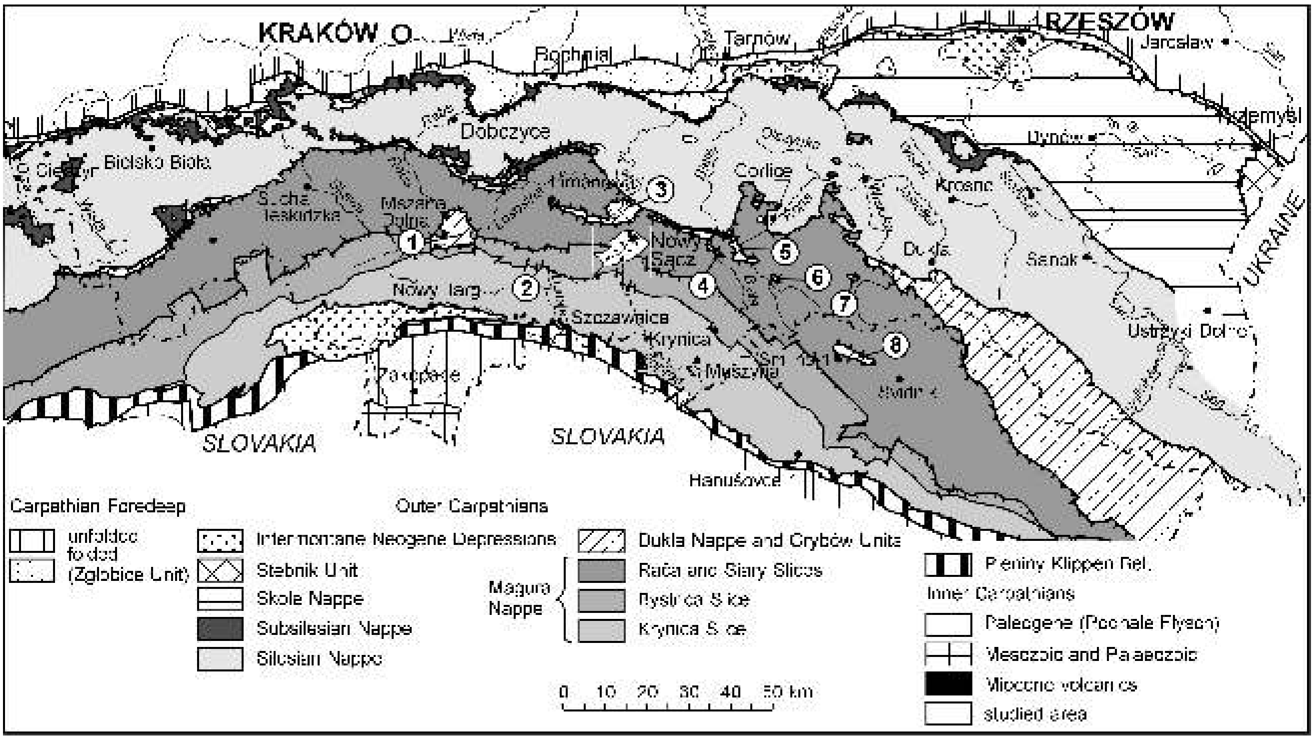


Fig. 1. Geological map of the Polish Outer Carpathians (based on Żytko *et al*., 1989) with location of the area studied

1 — Mszana Dolna, 2 — Szczawa, 3 — Klęczany, 4 — Grybów, 5 — Ropa, 6 — Uście Gorlickie, 7 — Świątkowa, 8 — Smilno Tectonic Window

Basin. The aim of this paper is to present the results of field observations and, of new calcareous nannoplankton age determinations and to discuss their tectonic and palaeogeographical implications. Reconstruction of the tectonic regime of the Nowy Sącz Basin based on quantitative subsidence analysis and, sedimentation rate, by 1D backstripping and forward modelling, has been made.

PREVIOUS WORKS

The Miocene deposits of the Nowy Sącz Basin were discovered by Uhlig (1888) and further described by Szajnocha (1903), Doliński *et al*. (1921) and Skoczylasówna (1930). Skoczylasówna subdivided these deposits into:

1. Grey clays with lignitic seams;
2. Yellow thick-bedded sands;
3. Grey-yellowish thin-bedded sands.

All deposits from Niskowa were described as upper Tortonian-Grabovian (upper Badenian according to present standards). On the basis of foraminifera studies by Alexandrowicz (1962), these deposits were assigned to the lower Badenian. Detailed macro-faunistic studies were carried out by Bałuk (1966, 1970). According to this author, the deposits from Niskowa represent the lowermost part of the lower Badenian, whereas the freshwater deposits of the Nowy Sącz Basin were considered to be Mio-Pliocene. A few years later Oszczypko and Stuchlik (1972) and Oszczypko (1973) considered the freshwater deposits as older than the marine strata at Niskowa. Based on the results of palynological studies, the lignite-bearing clays were assigned to the Karpatian–lower Badenian. Łańcucka-Środoniowa (1979), on the basis of the macroscopic plant remains from the Nowy Sącz II borehole (Fig. 2), related the latter deposits to the Badenian. Twenty years later, Oszczypko *et al.* (1991) established the freshwater deposits in the Nowy Sącz Basin as the Biegonice Formation. Within this formation the Podegrodzie Conglomerate Member was locally distinguished. Based on palynological analysis, an uppermost Badenian–lower Sarmatian age for the Biegonice Formation was determined. The freshwater deposits of the Biegonice Formation are overlain by marine deposits which Oszczypko *et al*. (1992) divided into the Iwkowa and Niskowa formations. Based on foraminiferal and calcareous nannoplankton studies the Iwkowa Formation (lagoonal deposits of reduced salinity) was assigned to the late Badenian (Kosovian), while the age of the Niskowa Formation (sandy-silty marine deposits) was determined as the late Badenian and/or early Sarmatian.

FIELD WORKS

Over the period 2003 to 2008 Middle Miocene deposits were studied and sampled in exposures located along the Kamienica Nawojowska, Poprad and Dunajec rivers.

Kamienica Nawojowska River section (A). In this section, which is more than 1.5 km long, the Middle Miocene deposits are exposed as a shallow synform with two small antiforms (Figs. 3 and 4). The basement of these deposits is the Late Eocene to Early Oligocene Magura Formation

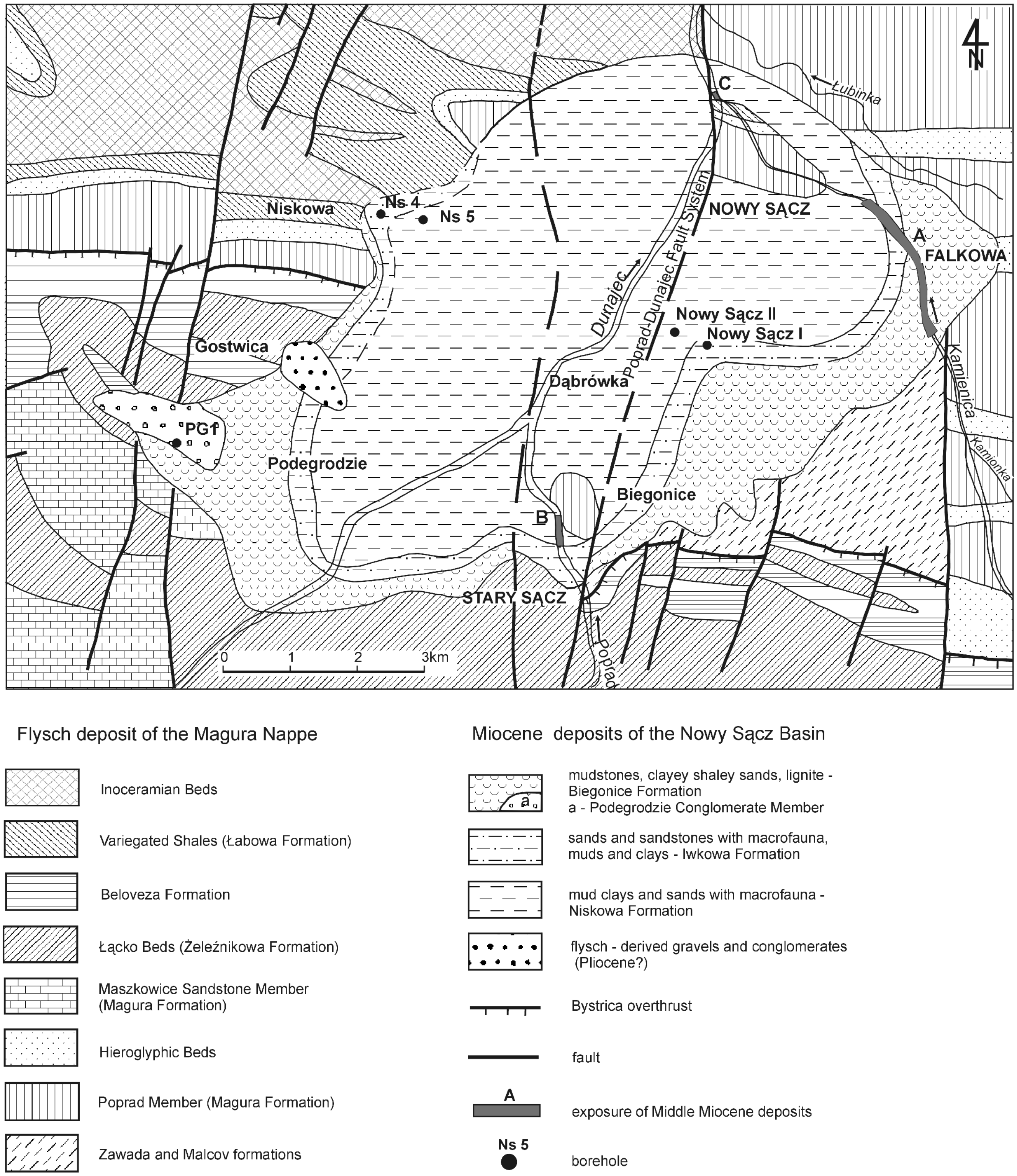


Fig. 2. Geological map of the Nowy Sącz Basin (after Oszczypko and Wójcik, 1991, supplemented)

(Oszczypko-Clowes, 2001). This formation, exposed on the both sides of the section studied, comprises south-dipping, poorly cemented very thick-bedded sandstones (Fig. 5A, B). The contacts of these sandstones with the Middle Miocene claystones are covered by alluvial gravels. The first exposures of the Miocene strata are located *ca*. 500 m south from the small bridge on the Kamienica Nawojowska River (Fig. 3). Going down the river, northwards dipping (20–25°), bluish and dark brown, non-calcareous claystones with grey and dark grey laminated mudstones at the top are exposed (Fig. 5D). These strata

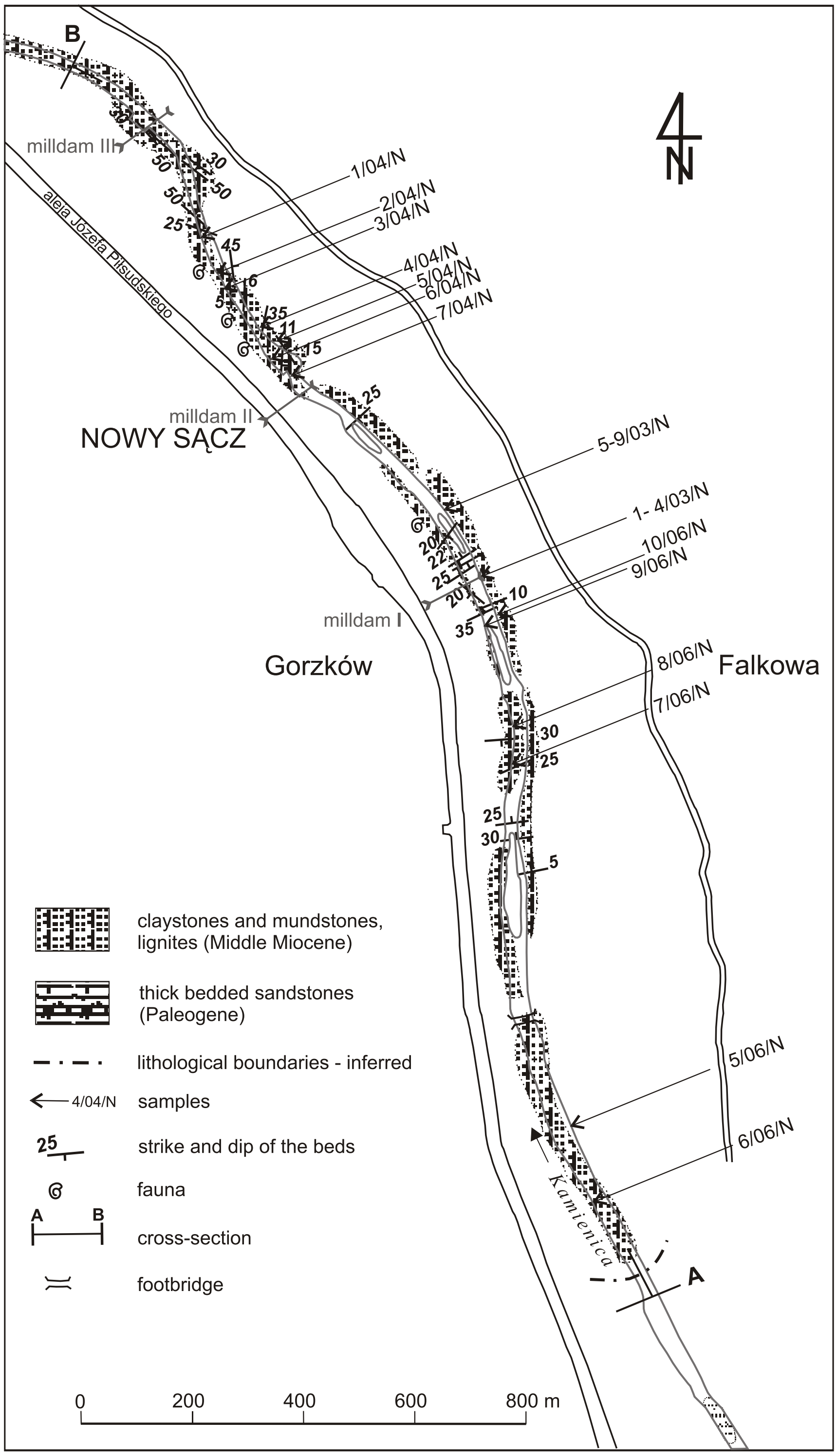


Fig. 3. Locations of sections studied in the Kamienica Nawojowska River

pass upwards into green-bluish claystones with intercalations of brown-rusty fine-grained sands with sideritic concretions (Fig. 5C). The uppermost part of this sequence is composed of north-dipping, brown-rusty thick-bedded and fine-grained massive sandstones intercalated with bluish-greenish, lumpy mudstones (Fig. 6). Locally at the top of the mudstones, 5–7 cm-thick layers of rusty weathering siderite are visible. These strata pass upwards into dark grey claystones with 10–50 cm-thick lignite intercalations (upper part of the Biegonice Formation). Going down the stream up to the first milldam (GPS N 49°,60, 744'; E 20°,72, 9473') there is a shallow syncline, which displays bluish/greenish claystones and thin-bedded, fine-grained sands, with intercalations of dark claystone and lignite (10–25 cm thick). In this place the authors

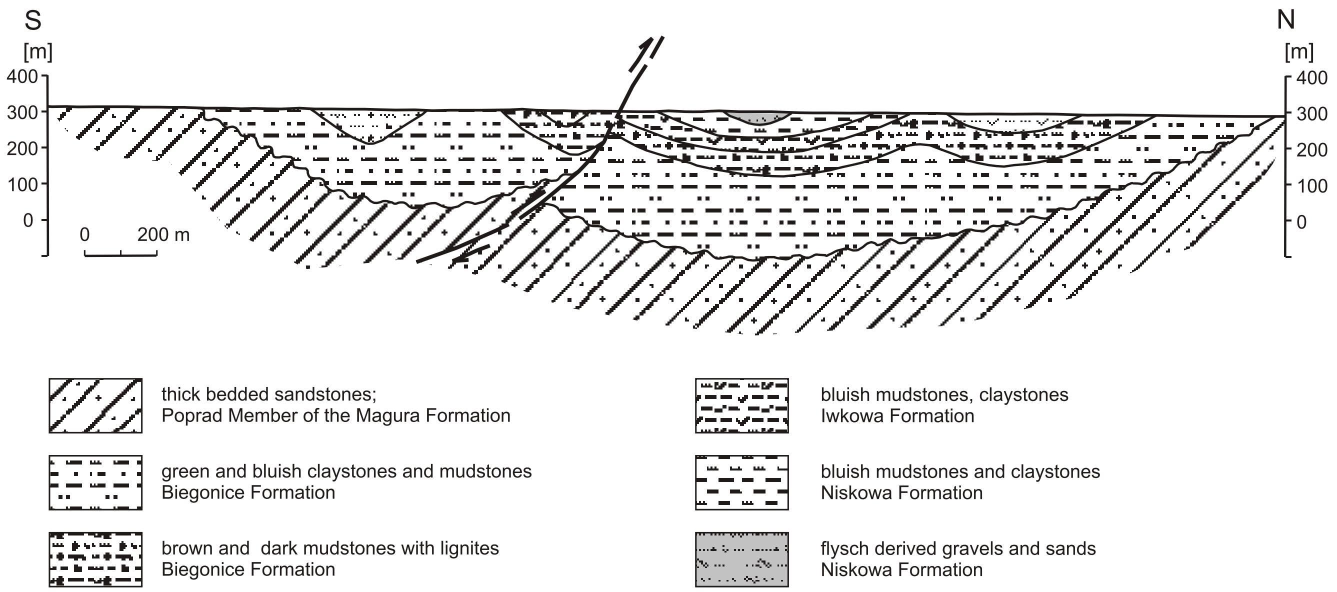


Fig. 4. Simplified geological cross-section along the Kamienica Nawojowska River

found coalified wood roots buried in an upright growth position (Fig. 7A, B). Around 120 m downstream of this milldam, in the right bank of the river, bluish calcareous claystones (Iwkowa Formation) with crushed shells of molluscs were found.

The youngest part of the sequence studied is exposed between the milldams (Fig. 3): III (GPS N 49°61, 70’N, E 20°72, 173’; alt. 299 m a.s.l.) and II (GPS N 49°61, 304’, E 20°72, 512’, alt. 300 m a.s.l.). This section reveals east-dipping (NE, E, SE) strata, up to 50 m thick, which display a coarsening and thickening upwards sequence. These deposits begin with green mudstones with a 15 cm thick lignite layer (Fig. 7C), of the uppermost part of the Biegonice Formation, and pass upwards into dark grey calcareous claystones (Fig. 7D) and mudstones with crushed mollusc shells (Iwkowa Formation). Occasionally dark grey claystones are intercalated with yellow weathered claystones with sideritic concretions. The grey claystones are up to 20 m thick. Higher up in the section the dark grey marly claystones of the Niskowa Formation with mollusc shells (Fig. 7E, F) are intercalated with 2 m of dark, poorly cemented fine-grained sandstone. Progressively grey claystones are replaced by green mudstones with intercalations of fine to coarse-grained sands with sporadic lignite clasts. The mudstones with intercalations of lignite pass upwards into a 3 m-thick sequence composed of laminated fossiliferous sands, mudstones with coalified plants, and very coarse to medium-grained sands, with parallel and low-angle cross-lamination at the top. These sands pass up into a 30 cm layer of gravel with flysch-derived cobbles (Fig. 8). The gravels pass upwards into 1.5 m of coarse to fine-grained sands, with cross-lamination (palaeotransport from 210° SWS) and then into 1 m of clay with a coalified flora, thin sand layers and into coquina beds. The coquinas are overlapped by a 2 m layer of very coarse to medium-grained sand with cross-laminated lenses (Fig. 8C). The top of the exposures is located at the base of milldam II (Fig. 3).

Biegonice section (B). A small exposure of Miocene deposits is located in the right bank of the Poprad River, *ca.* 50 m beneath the bridge (Fig. 2). In this part, at the water level of the river, dark grey marly claystones were sampled. These claystones are cut by a sub-Holocene erosion surface and overlapped by cobbles and boulders of a 3 m high terrace.

Nowy Sącz section (C). New exposures of Miocene claystones were found in December 2006 beneath the inflow of the Kamienica River into the Dunajec River (Fig. 2). These exposures, which are of dark bluish marly claystones with crushed snail shells, are in the right bank of the Dunajec River at a distance of *ca*. 250 m. These SW dipping (235/30) claystones are exposed on the sub-Holocene erosion surface. 100 m downstream there occur thick-bedded, coarse-grained sandstones (190/48) of the Poprad Sandstone Member of the Magura Formation (Fig. 2; see also Oszczypko, 1973; Oszczypko and Wójcik, 1991).

CHARACTERISTICS OF THE NANNOFOSSIL ASSEMBLAGES

METHODS

All samples used in nannofossil analyses were collected during the fieldwork between 2003–2007 (Fig. 3 and Table 1). Altogether 26 samples were collected, of which 12 were barren (7/04/N, 3–4/03/N, 6/03/N, 9/03/N, 4–10/06/N). All samples were prepared using the standard smear slide technique for light microscope (LM) observations. The investigation was carried out under LM — *Nikon–Eclipse E 600 POL*, at a magnification of 1000× using parallel and crossed nicols. The majority of the samples examined yielded poor and badly preserved nannofossil assemblages. The distribution pattern of nannofossils is illustrated in Table 1. Several of the specimens photographed in LM are illustrated in Figures 9 and 10.

Fig. 5. Kamienica Nawojowska section (southern part)

A — Kamienica Nawojowska River section (southern part). South-dipping thick-bedded sandstones of the Poprad Member of the Magura Formation (Late Eocene–Oligocene); **B** — thick-bedded sandstones of the Poprad Member; **C** — north-dipping bluish mudstones and yellow-rusty siltstones of the lower part of the Biegonice Formation; **D** — laminated grey and dark grey mudstones (Biegonice Formation)

Fig. 6. Middle part of the Kamienica Nawojowska section (Biegonice Formation)

A — north-dipping (30°) massive dark grey pebbly mudstones with intercalations of yellowish poorly cemented sandstones with muddy clast; **B** — mudstones with small angular clasts passing upwards into lenticular stratified fine-grained sandstone with muddy clasts; **C** — thick-bedded yellowish siltstones with lenticular beds of dark greenish mudstones with rusty weathering sideritic layer at the top

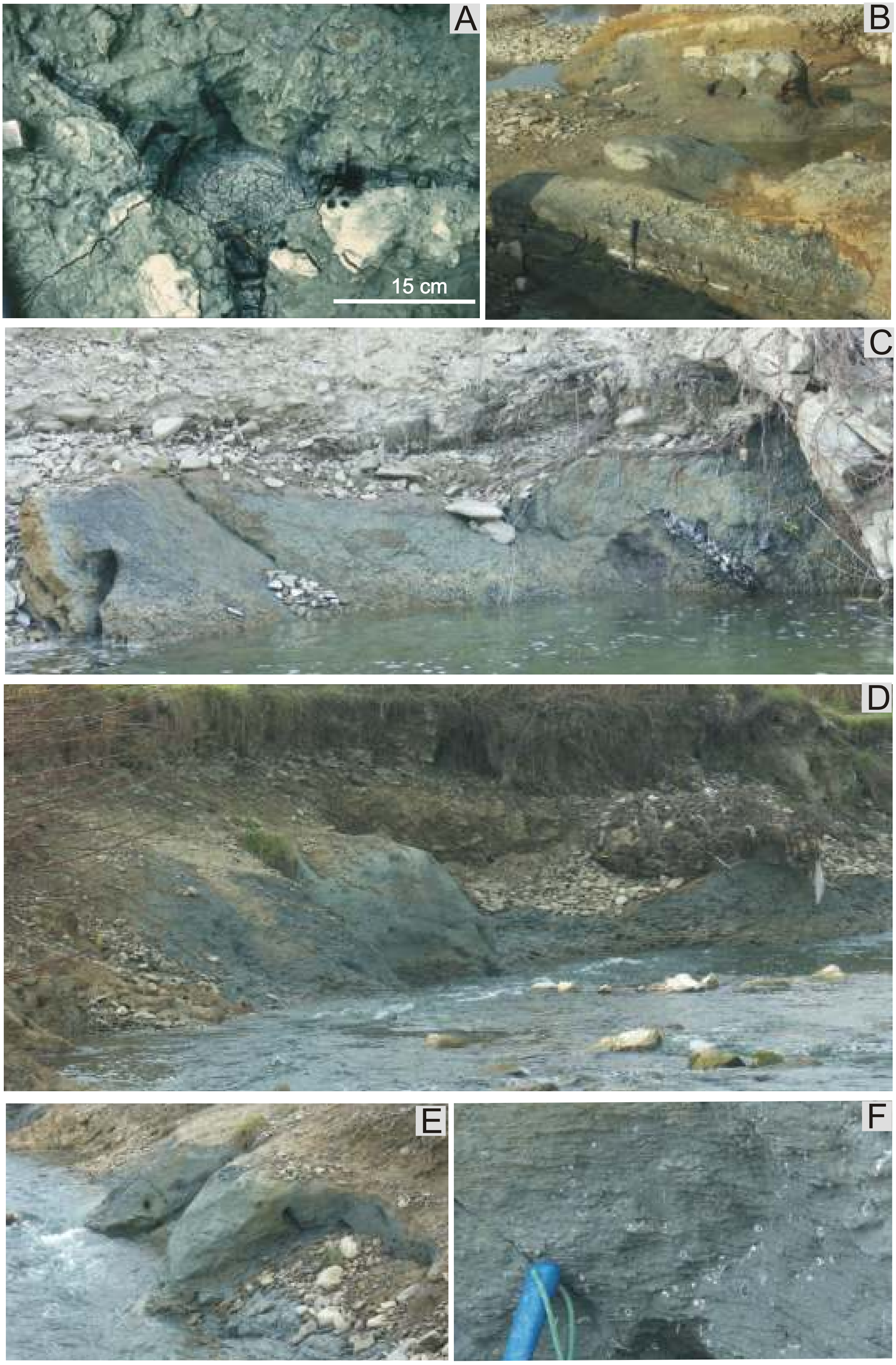


Fig. 7. Lower part of the Kamienica Nowojowska section (Biegonice and Iwkowa formations)

A — green-grey mudstones with coalified wood roots buried in upright growth position, upper part of Biegonice Formation on the right bank of river (near milldam I, Fig.3); **B** — dark grey and bluish mudstones with lenses of NE dipping layer of lignite and yellow-rusty fine-grained sandstones; upper part of Biegonice Formation on the left bank of the river; **C** — dark greenish mudstones with rusty spots and layer of lignite; upper part of Biegonice Formation; **D** — bluish mudstones and claystones of the Iwkowa Formation, right bank of the river; **E** — bluish mudstones and claystones of the Niskowa Formation, left bank of the river; **F** — bluish mudstones with gastropod-bivalve shell bed (see Bitner and Kaim, 2004; Szczechura, 2006), left bank of the river

Fig. 8. The south-dipping strata (*ca*. 35°) of the upper part of Niskowa Formation on the left bank of the river

A — flysch-derived gravels with laminated coarse-grained sands at the top; **B** — flysch-derived cobbles; **C** — medium to fine grained, parallel-laminated sands and mudstone sequence

Table 1

Calcareous nannofossil distribution in the Kamienica Nawojowska, Biegonice and Nowy Sącz sections

	Iwkowa Fm.							Niskowa Fm.						
	1/04/N	2/04/N	1/03/N	2/03/N	5/03/N	7/03/N	8/03/N	3/04/N	4/04/N	5/04/N	6/04/N	1/06/N	2/06/N	3/06/N
Braarudosphaera bigelowii									X	X				
Calcidiscus leptoporus	X									X		X	X	X
Calcidiscus premacintyrei	X		X			X		X		X		X	X	X
Calcidiscus tropicus	X							X					X	X
Chiasmolithus danicus	X	X						X	X	X				
Chiasmolithus expansus	X	X						X	X	X				
Chiasmolithus gigas				X				X	X					
Chiasmolithus grandis	X	X		X				X	X	X				
Chiasmolithus solitus				X				X	X					
Coccolithus miopelagicus large				X									X	X
Coccolithus miopelagicus	X	X	X	X	X			X		X	X	X	X	X
Coccolithus pelagicus	X	X	X	X	X	X	X	X	X		X	X	X	X
Coronocyclus nitescens	X	X	X	X	X			X	X		X	X	X	X
Cribocentrum reticulatum					X									
Cyclicargolithus abisectus	X		X	X	X	X		X	X	X	X	X	X	X
Cyclicargolithus floridanus	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dictyococcites bisectus	X	X	X	X	X	X	X	X	X	X	X		X	X
Discoaster barbadiensis	X								X					
Discoaster brouweri									X					
Discoaster cf. *kuglerii*				X										
Discoaster saipanensis	X								X					
Discoaster deflandrei				X			X		X	X	X			
Discoaster exilis				X				X	X			X	X	X
Discoaster variabilis				X				X	X					
Ericsonia fenestrata					X	X		X	X			X	X	X
Ericsonia formosa	X	X			X	X		X	X	X		X	X	X
Helicosphaera bramlettei				X	X				X					
Helicosphaera carteri	X	X			X	X	X	X	X	X	X	X	X	X
Helicosphaera compacta				X					X	X				
Helicosphaera euphratis	X		X						X	X	X	X		
Helicosphaera intermedia		X		X					X	X				
Helicosphaera mediterranea				X					X	X				
Helicosphaera recta				X	X				X	X		X	X	
Helicosphaera seminullum														X
Helicosphaera stalis								X						
Helicosphaera valbersdorfensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Holodiscolithus macroporus	X				X		X	X		X		X	X	X
Isthmolithus recurvus	X							X		X			X	X
Lanternithus minutus								X		X			X	
Neococcolithes dubius										X				
Pontosphaera discopora					X					X		X	X	
Pontosphaera enormis										X				
Pontosphaera latelliptica					X			X	X	X	X	X	X	X
Pontosphaera multipora	X	X	X		X			X	X	X	X	X	X	X
Pontosphaera plana				X	X	X		X	X	X		X	X	X
Pontosphaera rothi								X	X	X				

Table 1 cont.

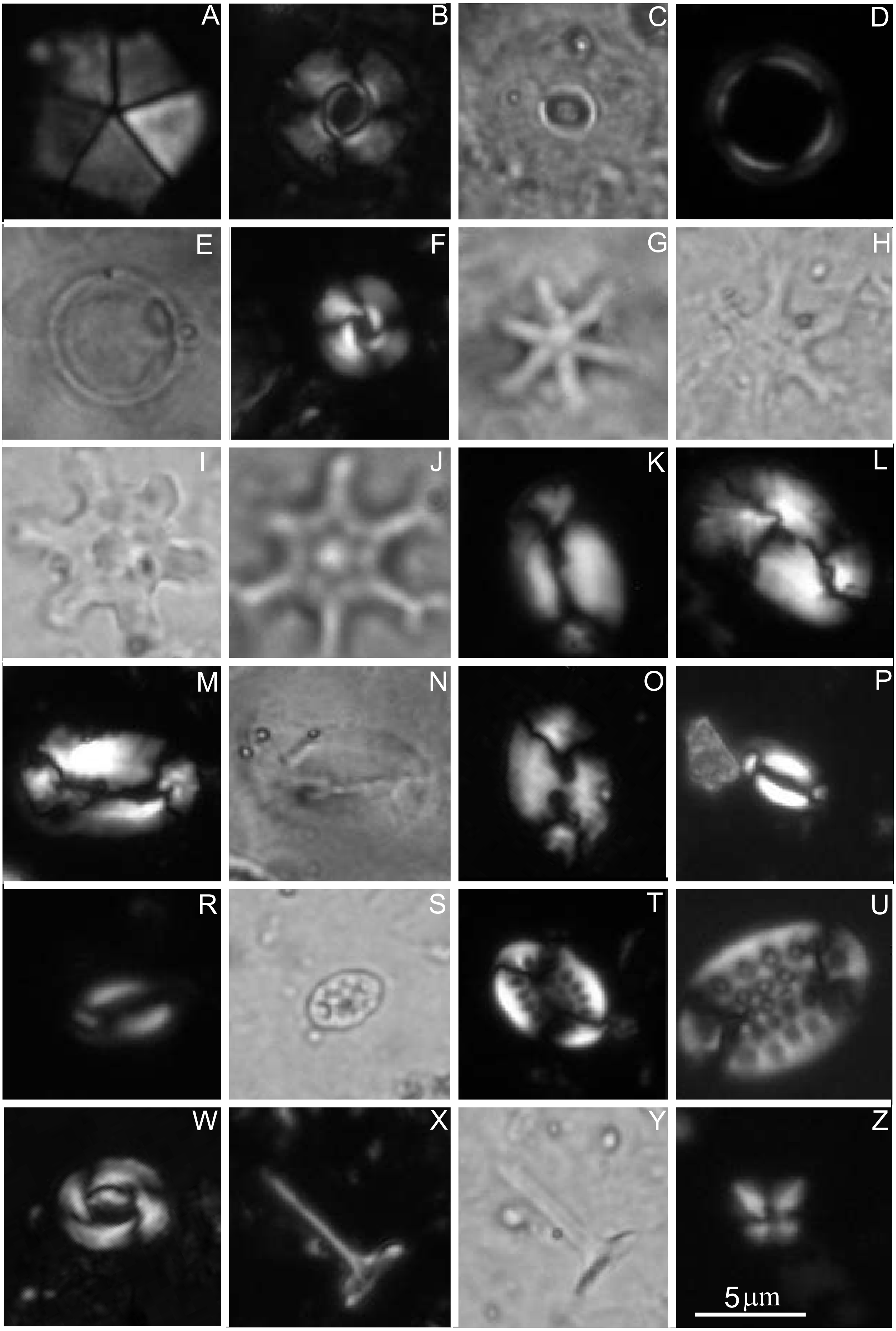
	Iwkowa Fm.							Niskowa Fm.						
	1/04/N	2/04/N	1/03/N	2/03/N	5/03/N	7/03/N	8/03/N	3/04/N	4/04/N	5/04/N	6/04/N	1/06/N	2/06/N	3/06/N
Rhabdosphaera sicca		X						X	X	X		X	X	X
Reticulofenestra spp. small	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reticulofenestra daviesii												X	X	X
Reticulofenestra dictyoda		X			X	X		X	X	X		X	X	X
Reticulofenestra lockeri		X	X	X	X			X	X	X		X	X	X
Reticulofenestra pseudoumbilica	X	X		X	X			X	X	X	X	X	X	X
Reticulofenestra umbilica				X	X			X		X				
Reticulofenestra ornata				X				X	X					
Sphenolithus abies				X				X	X	X	X	X	X	X
Sphenolithus capricornutus				X										
Sphenolithus conicus					X	X								
Sphenolithus disbelemnos			X	X		X			X					
Sphenolithus dissimilis		X			X		X		X		X	X	X	X
Sphenolithus moriformis					X			X	X	X	X	X	X	X
Sphenolithus pseudoradians								X						
Transversopontis fibula			X	X					X					
Transversopontis obliquipons				X					X				X	
Transversopontis pulcher					X				X			X	X	X
Transversopontis pulcheroides				X				X	X			X	X	X
Transversopontis pygmaea				X	X				X					
Transversopontis sigmoidalis				X				X						
Umbilicosphaera rotula	X	X	X	X	X			X	X	X	X			
Zygrhablithus bijugatus			X	X	X	X	X	X	X	X	X	X	X	X

Iwkowa Formation. The nannofossils are poorly preserved and the assemblages reveal a rather low diversity as well as a low number of specimens. The only sample containing a relatively rich assemblage (9–10 specimens per observation field) is 2/03/N. The auchtonous assemblage is characterized by the presence of: *Calcidiscus leptoporus* (Murray and Blackman), *Coccolithus miopelagicus* Bukry, *Coccolithus pelagicus* (Wallich), *Coronocyclus nitescens* (Kamptner), *Cyclicargolithus floridanus* (Roth and Hay), *Discoaster deflandrei* Bramlette and Riedel, *Helicosphaera carteri* (Wallich), *Helicosphaera compacta* Bramlette and Wilcoxon, *Helicosphaera euphratis* Haq, *Helicosphaera intermedia* Martini, *Helicosphaera mediterranea*, *Helicosphaera valbersdorfensis*, *Helicosphaera stalis* Theodoridis, *Pontosphaera multipora* (Kamptner), *Pontosphaera plana* (Bramlette and Sullivan), *Reticulofenestra minuta* Roth, *Reticulofenestra pseudoumbilica* (Gartner), *Sphenolithus abies*, *Sphenolithus moriformis* (Bronnimann and Stradner) and *Umbilicosphaera rotula*. The associations are formed by relatively common *Coccolithus pelagicus*, small *reticulofenestrids* and *Umbilicosphaera rotula*. The assemblage is accompanied by the rare and irregular presence of *Discoaster variabilis*, *Calcidiscus premacintyrei* and *Discoaster kuglerii*.

Niskowa Formation. The abundance pattern is different for certain samples. It varies from more than 20 specimens (per observation field) in samples 3–4/04/N, 1–3/06/N down to less than 10 specimens (per observation field) in samples 6/04/N. A semi-quantitative study of the autochthonous nannoplankton assemblage indicates the dominance of placoliths over asteroliths, sphenoliths and helicoliths.

The Miocene assemblage is characterized by common to abundant *Cyclicargolithus floridanus* and *Coccolithus pelagicus* (more than 1 specimen per observation field), whereas *Helicosphaera carteri*, *Reticulofenestra pseudoumbilica* are abundant, but to a lesser extent. The species belonging to the *Discoasteraceae* are rare and represented only by two species: *Discoaster variabilis* and *Discoaster exilis* Martini and Bramlette.

Almost all samples investigated are dominated by reworked species, especially those of Late Eocene and Oligocene age. The level of reworking is highest in samples such as Falkowa 1/04/N, 2/04/N, and 2/03/N, where reworked taxa represent more than 50% of all determined species, whereas in samples 3–5/04/N, 1/03/N, 7 and 8 it decreases considerably, reaching a value not higher than approximately 20–30%. The remaining samples contain less than 20% of reworked species. The allochthonous assemblage consists mostly of Late Eocene species such as *Chiasmolithus oamaruensis* (Deflandre), *Isthmolithus recurvus* Deflandre, *Discoaster saipanensis*, *Reticulofenestra reticulata* (Gartner and Smith) and *Reticulofenestra umbilica* (Levin). The Oligocene association is represented by *Cyclicargolithus abisectus* (Müller), *Helicosphaera perch-nielseniae*, *Helicosphaera recta* Haq, *Pontosphaera latelliptica* Baldi-Beke and Baldi, *Pontosphaera rothi* Haq, *Reticulofenestra lockeri* Müller, *Reticulofenestra ornata* Müller, *Transversopontis obliquipons* (Deflandre).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BIOSTRATIGRAPHIC INTERPRETATION

For the purpose of this work the standard zonation of Martini (1970) and Martini and Worsley (1971) was used. In the cases where index species were not observed, it was necessary to use secondary index species from the following authors: Baldi-Beke (1971), Perch-Nielsen, (1985), Bukry (1973, 1975), Raffi and Rio (1979), Okada and Bukry (1980), Theodoridis (1984), Martini and Müller (1986), Fornaciari and Rio (1996), Fornaciari *et al*. (1996), Marunteanu (1999).

The Miocene nannoplankton zonation is mainly based on the last (LO) or first occurrence (FO) of discoasters and thus is easily accomplished at low latitudes where discoasters are common in open ocean assemblages. However, these typically warm water and open ocean species are rare or absent at higher latitudes and also in assemblages from marginal seas. All other marker species belong to genera that are more common or even restricted to low latitudes. Therefore the zonation is most reliable and correlatable over a wider distance at low latitudes only. This explains why the Miocene zonation of Martini and Worsley (1971) as well as that of Okada and Bukry (1980) is reliable only at lower latitudes. Owing to the Miocene palaeoecological and palaeobiogeographical differentiation which affected the nannofossil distribution, it was necessary to construct several regional schemes which modified previous zonations (Müller, 1986; Raffi and Rio, 1979; Theodoridis, 1984; Fornaciari and Rio, 1996; Fornaciari *et al*., 1996; De Kaenel and Villa, 1996; Young, 1998).

According to the standard zonation (Martini, 1970) the last occurrence of *Sphenolithus heteromorphus* takes place at the top of NN5 whereas the first occurrence of *Discoaster kuglerii* defines the bottom of zone NN7. However, the occurrence of *Discoaster kuglerii* is extremely rare, which renders it as inadequate as a datum event. In this case zones NN6 and NN7 are frequently joined together as the combined zone NN6–7 (see Young, 1998). The last common occurrence of *Calcidiscus premacintyrei* is usually found slightly below the first occurrence of *Discoaster kuglerii* and thus can be used to approximate the NN6 and NN7 boundary (Fornaciari *et al*., 1996; Young, 1998). Important also is the stratigraphic range of *Helicosphaera valbersdorfensis*, whose first appearance occurs within the upper part of NN5 and whose last appearance marks the boundary between NN7/NN8 (Fornaciari *et al*., 1996; Young, 1998). Additionally, autochtonous assemblages are complemented by *Sphenolithus abies* and *Helicosphaera stalis* which are characteristic species for zone NN6 and younger (see Young, 1998). Taking into account the presence of *Helicosphaera valbersdorfensis*, *Cyclicargolithus floridanus*, *Sphenolithus abies*, *Helicosphaera stalis* and also rare *Calcidiscus premacintyrei* and *Discoaster kuglerii* as well as the absence of *Sphenolithus heteromorphus*, it is possible to assume that all samples belong to zone NN6–7. According to Coric and Svabenicka (2004), Coric *et al*. (2004) and Kováč *et al*. (2006) the boundary between Badenian and Sarmatian is located in the upper part of NN6 zone.

LITHOSTRATIGRAPHY

The deposits exposed in the Kamienica Nowojowska, Poprad and Dunajec sections show similarities to the Biegonice, Iwkowa and Niskowa formations established by Oszczypko *et al.* (1991, 1992).

BIEGONICE FORMATION

This formation unconformably overlies folded flysch deposits (Figs. 2–4). Small exposures of the formation occur in the Dąbrówka and Biegonice area, while the best exposure was located in the Biegonice brickyard. A few exposures are known from the western slopes of the River Dunajec (Podegrodzie, Gostwica and Niskowa).

The oldest deposits of the formation, conglomerates and poorly cemented sandstones, were recognized in the Nowy Sącz I borehole (Figs. 2 and 11) and in the unnamed stream above the Biegonice brickyard (Oszczypko, 1973). The flysch-derived conglomerates are composed of flat, well-rounded pebbles of fine-grained, muscovitic or glauconitic sandstones, and clasts of the Łącko type marls. The thickness of the basal conglomerates and sandstones is at least 4 m. These deposits are overlain by laminated, blue-greyish sandy mudstones, which pass upwards into a 18.5 m thick succession of thick-bedded, variably-grained, sometimes conglomeratic sandstones and pale grey mudstones with thin intercalations of poorly cemented fine- and very fine-grained sandstone. Higher in the profile there is a 60 m-thick olistostrome, with flysch-derived blocks of sandstone and marl up to 10 m in diameter

Fig. 9. LM microphotographs of autochtonous calcareous nannofossils

A — *Braarudosphaera bigelowii*, Niskowa Fm.: sample 5/04/N (cross-polarised light — XPL); **B** — *Calcidiscus premacintyrei*, Iwkowa Fm.: sample 1/04/N (XPL); **C** — *Calcidiscus premacintyrei*, Iwkowa Fm.: sample 1/04/N (plane-polarised light — PPL); **D** — *Coronocyclus nitescens*, Iwkowa Fm.: sample 5/03/N (XPL); **E** — *Coronocyclus nitescens*, Iwkowa Fm.: sample 5/03/N (PPL); **F** — *Cyclicargolithus floridanus* Iwkowa Fm.: sample 5/03/N (XPL); **G** — *Discoaster* sp., Niskowa Fm.: sample 4/04/N (PPL); **H** — *Discoaster exilis*, Iwkowa Fm.: sample 2/03/N (PPL); **I** — *Discoaster* cf. *kuglerii*, Iwkowa Fm.: sample 2/03/N (PPL); **J** — *Discoaster variabilis*, Niskowa Fm.: sample 3/04/N (PPL); **K** — *Helicosphaera carteri*, Iwkowa Fm.: sample 1/04/N (XPL); **L** — *Helicosphaera carteri* var. *burkei*, Niskowa Fm.: sample 2/06/N (XPL); **M** — *Helicosphaera carteri* var. *wallichii*, Niskowa Fm.: sample 3/06/N (XPL); **N** — *Helicosphaera carteri* var. *wallichii*, Niskowa Fm.: sample 3/06/N (XPL); **O** — *Helicosphaera mediterranea*, Iwkowa Fm.: sample 2/03/N (XPL); **P** — *Helicosphaera valbersdorfensis*, Iwkowa Fm.: sample 1/04/N (XPL); **R** — *Helicosphaera valbersdorfensis*, Niskowa Fm.: sample 3/06/N (XPL); **S** — *Holodiscolihus macroporus*, Iwkowa Fm.: sample 8/03/N (PPL); **T** — *Pontosphaera multipora*, Niskowa Fm.: sample 3/06/N (XPL); **U** — *Pontosphaera multipora*, Iwkowa Fm.: sample 1/04/N (XPL); **W** — *Reticulofenestra pseudoumbilica* >7 µm, Niskowa Fm.: sample 3/06/N (XPL); **X** — *Rhabdosphaera sicca*, Iwkowa Fm.: sample 2/04/N (XPL); **Y** — *Rhabdosphaera sicca*, Iwkowa Fm.: sample 2/04/N (PPL); **Z** — *Sphenolithus abies*, Iwkowa Fm.: sample 2/03/N (XPL)

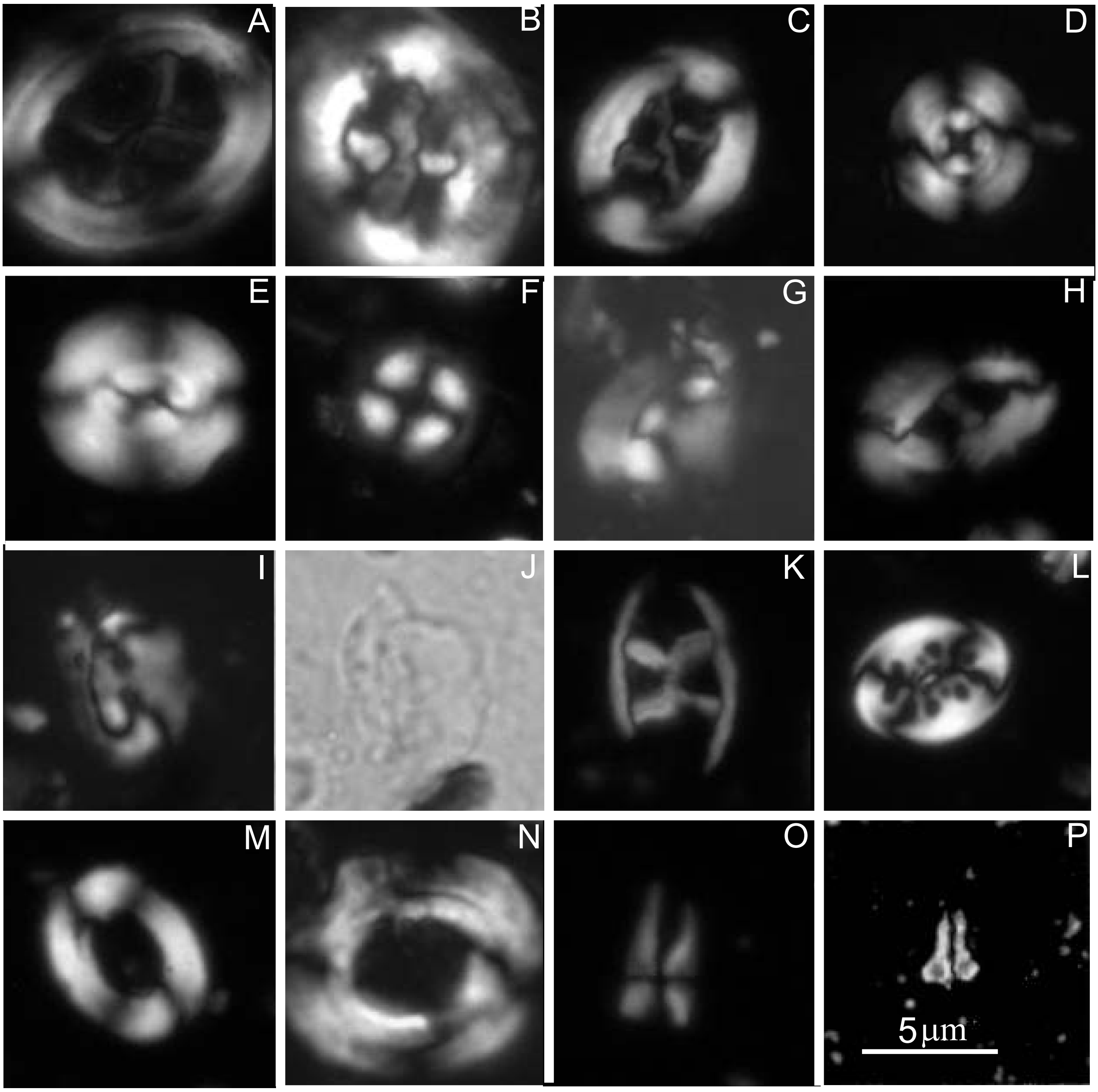

Fig. 10. LM microphotographs of reworked calcareous nannofossils

A — *Chiasmolithus expansus*, Iwkowa Fm.: sample 1/04/N (XPL), **B** — *Chiasmolithus gigas*, Iwkowa Fm.: sample 2/03/N (XPL), **C** — *Chiasmolithus solitus*, Iwkowa Fm.: sample 2/03/N (XPL), **D** — *Cyclicargolithus abisectus*, Iwkowa Fm.: sample 2/03/N (XPL), **E** — *Dictyococcites bisectus*, Niskowa Fm.: sample 3/06/N (XPL), **F** — *Ericsonia formosa*, Iwkowa Fm.: sample 2/04/N (XPL), **G** — *Helicosphaera compacta*, Niskowa Fm.: sample 5/04/N (XPL), **H** — *Helicosphaera compacta*, Niskowa Fm.: sample 4/04/N (XPL), **I** — *Helicosphaera recta*, Niskowa Fm.: sample 4/04/N (PPL), **J** — *Helicosphaera recta*, Niskowa Fm.: sample 4/04/N (XPL), **K** — *Neococcolithes dubius*, Niskowa Fm.: sample 5/04/N (XPL), **L** — *Pontosphaera enormis*, Niskowa Fm.: sample 5/04/N (XPL), **M** — *Pontosphaera latelliptica*, Iwkowa Fm.: sample 5/03/N (XPL), **N** — *Reticulofenestra umbilica*, Iwkowa Fm.: sample 2/03/N, **O** — *Sphenolithus capricornutus*, Iwkowa Fm.: sample 2/03/N (XPL), **P** — *Zygrhablithus bijugatus*, Niskowa Fm.: sample 3/06/N (XPL)

(Fig. 11). The total thickness of the lowest part of the Biegonice Formation is about 220 m.

The upper part of the formation is known from surficial outcrops and from numerous shallow boreholes. Its characteristic feature is the presence of lignitic beds and numerous horizons with plant remains (Oszczypko, 1973; Oszczypko *et al*., 1991). This part of formation is dominated by pale grey clayey shales, and marly mudstones, while brown and/or black shales and mudstones occur more rarely. The shales and mudstones are intercalated with sands and/or poorly cemented sandstones several cm to 1 m-thick. The mudstones show a parallel lamination, while the sandstones mainly reveal low-angle cross-lamination. Carbonate, partly sideritic concretions occur locally in clayey shales and mudstones. There also occur numerous brown coal laminae, while brown coal seams up to 2 m thick are less frequent. This bed contains numerous tree trunks up to 25–30 cm in diameter. Plant rootlets and regoliths occur frequently in the deposits discussed. In the Nowy Sącz I (Oszczypko, 1973) and the

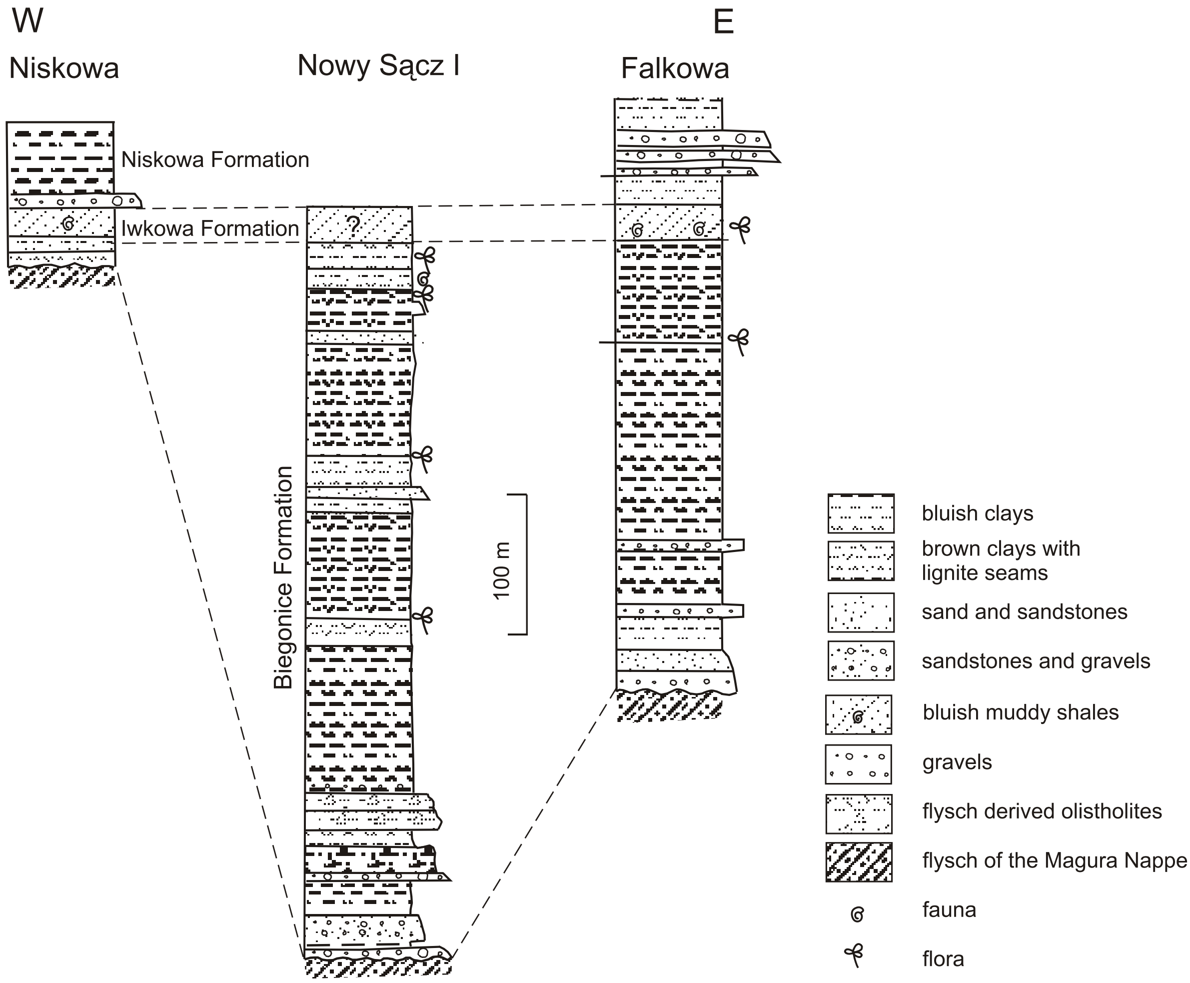

Fig. 11. Correlation of the Middle Miocene deposits of the Nowy Sącz Basin

PG 1 (Oszczypko *et al*., 1991) boreholes, freshwater gastropods of the genus *Planorbis* have been encountered. The thickness of lignite-bearing deposits varies from 8–17 m in the Niskowa area up to at least 300 m (Oszczypko, 1973) in the Nowy Sącz I borehole. In the Niskowa area the upper boundary is transitional to blue marly clays with numerous *Cerithium shells*, belonging to the Iwkowa Formation (Oszczypko *et al*., 1992).

Taking into account the lithological development, the bipartite lower part of the Kamienica Nawojowska section, probably up to 300 thick, can be correlated with the Biegonice Formation.

IWKOWA FORMATION

In the Nowy Sącz Basin, this formation was found at the Pruska Stream in Niskowa and drilled at Niskowa by the Ns 4 and Ns 5 boreholes (Figs. 2 and 11). In the Niskowa area the Iwkowa Formation up to 15 thick is represented by bluish marly clays 3–6 m thick with *Cerithium* coquinas (see Bałuk, 1970). Higher up in the section, clays pass into fine-grained sands with thin intercalations of silt with small clasts of flysch-derived sandstone. In the section studied similarities to the Iwkowa Formation include dark grey calcareous claystones with crushed snail shells up 20 m thick.

NISKOWA FORMATION

In the stratotype area the Niskowa Formation is bipartite (Oszczypko *et al*., 1992). The lower part of formation is represented by a 8 to 25 m-thick sandy succession with thin intercalations of greyish silt. In the Ns 5 borehole, the thick-bedded sands are replaced by thin-bedded sandy layers with frequent intercalations of silt (*op. cit*). This sandy complex is rich in macrofauna. The upper part of the Niskowa Formation was recognized in the Ns 4, Ns 5 boreholes (Oszczypko *et al*., 1992). This part of the formation is dominated by laminated greyish marly silts with intercalations of fine to medium-grained sand, locally with flysch-derived clasts up to 1.5 cm in diameter. The deposits are rich in coalified plants and mollusc shells. In the stratotype area, the Niskowa Formation is at least 60 m thick (*op. cit*).

In the Kamienica Nawojowska section the thickness of the Niskowa Formation is more or less the same but the sequence of deposits is different. The presence of gravel and coarse-grained sands suggests the nearshore, high-energy marine environmental deposition (Fig. 12).

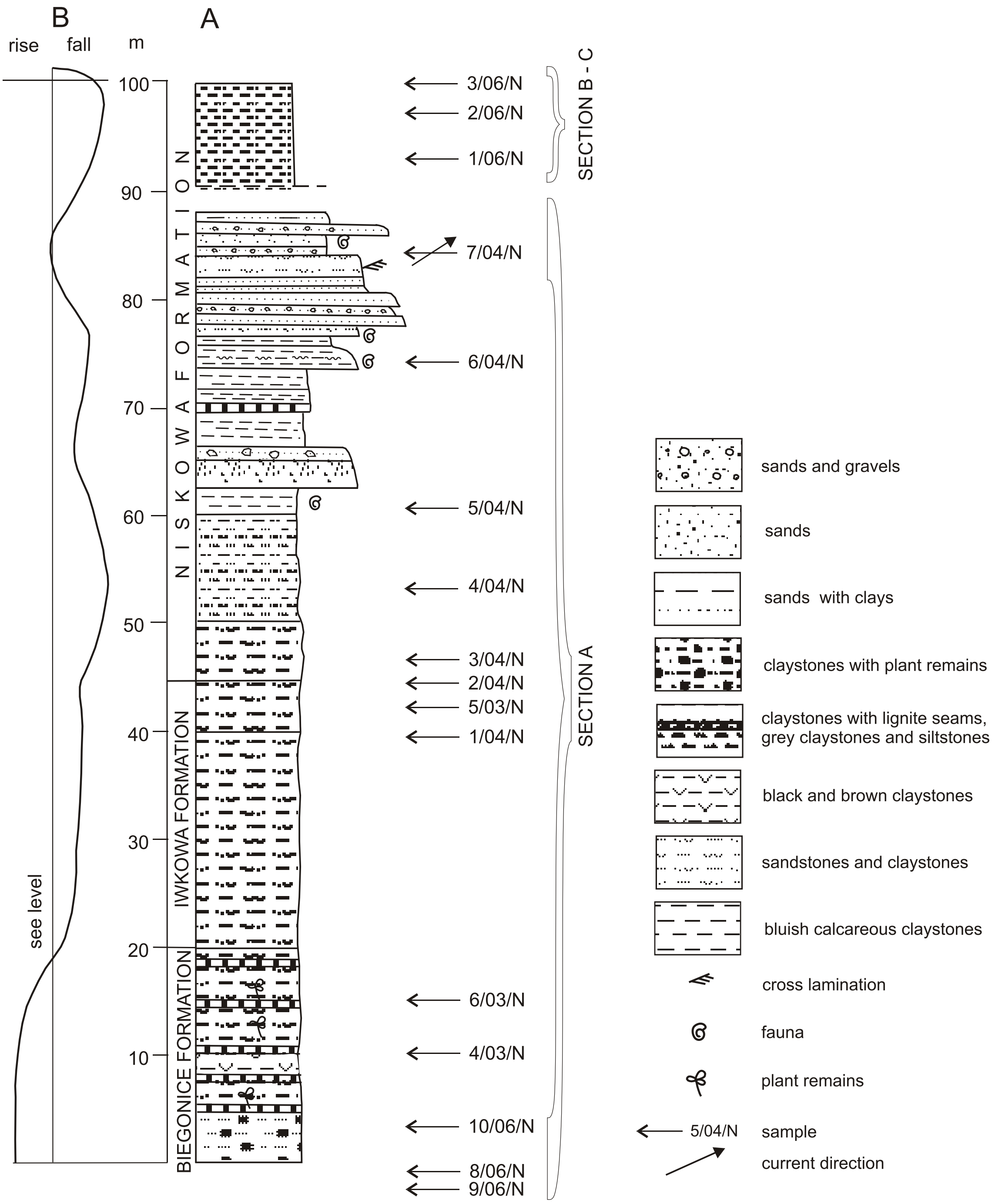

Fig. 12. Sedimentological log of the Kamienica Nawojowska section (A) *versus* oscillation of relative late Badenian/early Sarmatian sea level (B)

PALAEOGEOGRAPHICAL AND PALAEOTECTONIC IMPLICATIONS

Reconstruction of the sedimentary and tectonic evolution of the Nowy Sącz Basin (a synorogenic, intramontane basin with diversified deposition) is important for the understanding the middle Miocene evolution of the Western Outer Carpathians.

The Middle Miocene deposits of Nowy Sącz rest uncomfortably upon folded and eroded flysch deposits of the Magura Nappe, belonging to the Rača and Bystrica facies-tectonic zones. Geoelectric measurements (Oszczypko, 1973; Fig. 6) suggest the existence of transverse faults, which are several hundred metres in throw. These faults are grouped in the central part of the basin, and are likely connected with the Dunajec–Poprad valley fault zone, as revealed by analysis of geological mapping (Oszczypko, 1973; Oszczypko and Wójcik, 1991). According to mesostructrural analysis these mostly NE-trending faults include both sinistral and dextral strike-slip faults (Oszczypko and Zuchiewicz, 2004). Of special importance is the Poprad–Dunajec Fault System (Fig. 2), which was active at the time of the deposition of the late Badenian–Sarmatian infill of the Nowy Sącz Basin (Oszczypko, 1973). Synsedimentary folding is recorded by the appearance of flysch olistolith blocks inside the Biegonice Formation (Fig. 11).

The freshwater deposits of the Biegonice Formation were accumulated in a swampy environment (Fig. 12). At the western margin of the basin, paludal deposits interfinger with conglomerates and sandstones of alluvial fans (Podegrodzie Conglomerate Member). During the late Badenian transgression, the Nowy Sącz depression was covered with swamps developed on a peri-marine plain, which were surrounded by lagoons.

The Iwkowa Formation in the Niskowa and Kamienica Nowojowska sections is characterized by the presence of claystones with coquina beds. The dominance of clayey-mudstone deposits with coquina beds is typical of lagoon environments of reduced salinity (15–20‰, see Bałuk, 1970). Analysis of planktonic taxa from this formation shows the predominance of species known from the central and eastern Paratethys over those characteristic of the Mediterranean or Indo-Pacific Miocene (Oszczypko *et al.*, 1992). During the sedimentation of the Niskowa Formation the bathymetry of the Nowy Sącz Basin ranged from a few metres during the deposition of sandy sediments, to 30 m or more during the sedimentation of the silty deposits while the salinity of the water oscillated from 16.5 to 28‰ during the sandy sedimentation, and from 25–28‰ to normal during the silty sedimentation (see Bałuk, 1970). In the Kamienica Nawojowska section, marine claystones of the Niskowa Formation pass upwards into claystones and mudstones with intercalations of sand and conglomerate with local flysch derived material (Fig. 12). This part of the section reveals a coarsening and thickening sequence that is typical for shallowing (regression) of the basin. The Kamienica Nawojowska section records late Badenian to Sarmatian oscillation of sea level and sea- and landward shifts of the shoreline (Fig. 12).

The mid-Miocene infill of the Nowy Sącz Basin reflects the tectonic history of the middle part of the Magura Nappe in Poland. The opening of this basin was preceded by the late Burdigalian (Karpatian) folding and overthrusting of the Outer Carpathian nappes over the Early Miocene deposits of the inner part of the Carpathian Foredeep Basin (Oszczypko *et al.*, 2006). As a result of these movements the Carpathian orogen was uplifted and eroded. During the Langhian, the marginal part of the Carpathians was flooded by the sea. After mid-Badenian salinity crises, the Carpathians nappes were shifted towards the north (Oszczypko *et al.*, 2006). Probably this was followed by an episode of relaxation of the strain and extensional fault tectonics in the present-day Dunajec valley and opening of the Nowy Sącz Basin. The extensional charac-

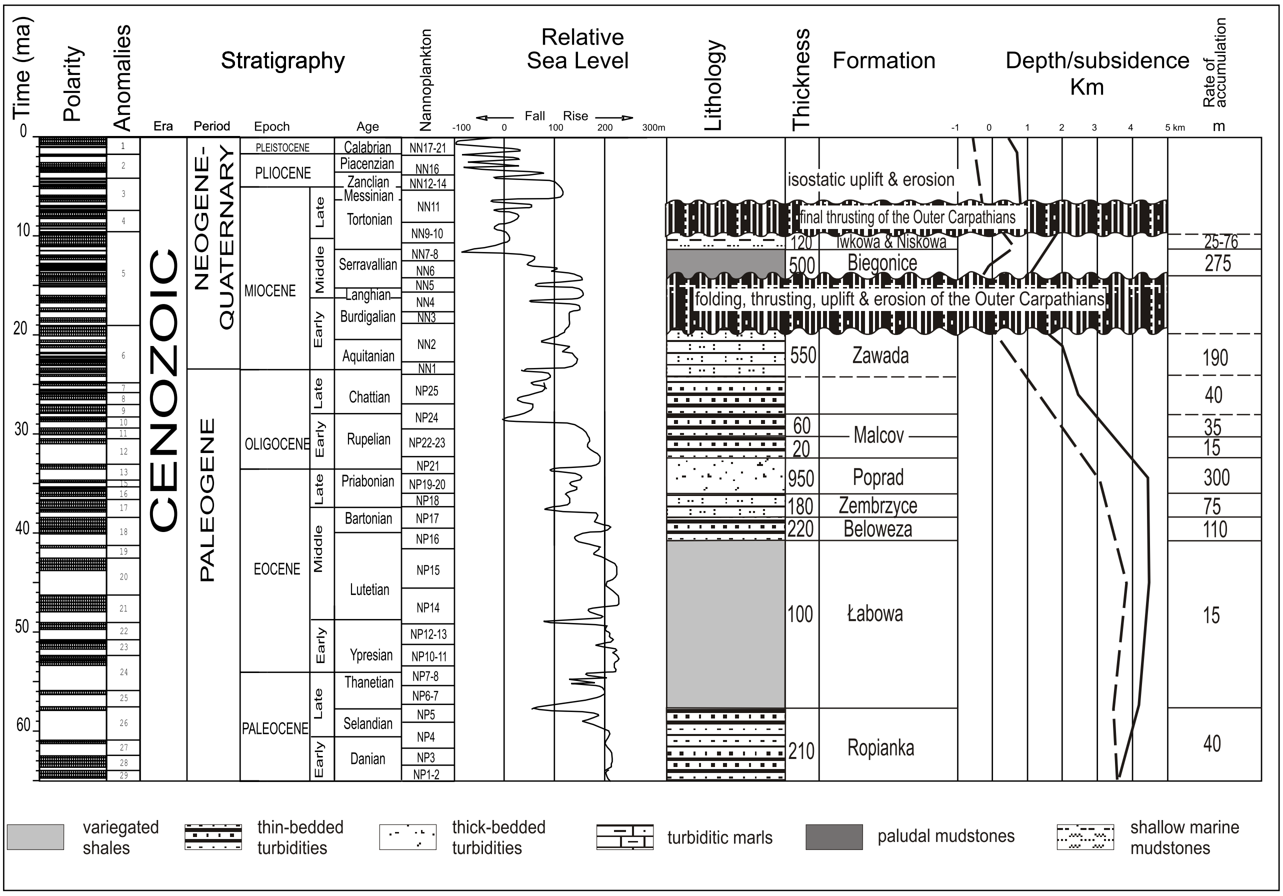

Fig. 13. Paleogene and Neogene history of the Nowy Sącz Basin

ter of the basin is deduced from geoelectric sounding. It would be important to prove this hypothesis by seismic survey, which is a more precise tool for the recognition of basin architecture and tectonics. As a result of post-nappe collapse of the northern Carpathians, the sea invaded the already-eroded Carpathians. The subsidence and sedimentation rate diagrams reveal tectonic control of deposition of the mid-Miocene deposits of the Nowy Sącz Basin (Fig. 13). During the deposition of the Biegonice Formation the tectonic subsidence reached *ca*. 600 m, with the rate of sedimentation up to 275 m/my. This high rate of subsidence enabled marine transgression. During brackish deposition (Iwkowa Formation) the rate of sedimentation decreased to few dozen m/my while during the open marine deposition it increased to 270 m/my. At that time the basin was supplied with material derived from erosion of the flysch deposits, mainly of Eocene and Oligocene age (see Fig. 10). The closing of the basin was probably induced by a compressional tectonic regime connected with final, post-Sarmatian, thrusting of the Outer Carpathian nappes to their present-day position. This is manifested by strike-slip movements along the Dunajec–Poprad Fault System, by uplift of the flysch basement documented by Nowy Sącz and Biegonice "inlands", as well as by the partial refolding of Miocene strata (see also Oszczypko, 1973).

CONCLUSIONS

1. The Middle Miocene sedimentary infill of the Nowy Sącz Basin (*ca*. 70 km^2) is represented both by freshwater silty-sandy deposits of the Biegonice Formation as well as by clayey brackish (Iwkowa Formation) and marine deposits of the Niskowa Formation. The thickness of these deposits reached at least 540 m.

2. In the Kamienica Nawojowska section, the upper part of the Niskowa Formation reveals a coarsening and thickening upwards sequence, typical of shallowing (regression) in the basin.

3. The Iwkowa and Niskowa formations contain relatively rich late Badenian to Sarmatian calcareous nannoplankton (NN6/7 Zone).

4. The freshwater, brackish and marine deposits of the Nowy Sącz Basin are age-equivalents of the Machów Formation in the outer part of the Carpathian Foredeep Basin in Poland.

5. The opening and subsidence of the Nowy Sącz Basin were probably controlled by activity of NE–SW trending transverse faults, though piggy-back basin mechanisms cannot be excluded.

6. During the post-Sarmatian thrust movements of the Outer Carpathians, the Mid-Miocene deposits of the Nowy Sącz Basin were moderately folded.

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