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The youngest deposits infilling the Gdów "embayment" (Carpathian orogenic front, south Poland) are not older than late Sarmatian-Pannonian

Antoni WÓJCIK[1, *], Małgorzata GARECKA[1], Tomasz MALATA[1] and Monika PILARZ[2]

[1] Polish Geological Institute – National Research Institute, Carpathian Branch, Skrzatów 1, 31-560 Kraków, Poland

[2] AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Al. A. Mickiewicza 30, 30-099 Kraków, Poland

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The Gdów "embayment" is the most pronounced deflection along the northern boundary of the Carpathians. It is filled by the sandy clay deposits which used to be named the Skawina Formation or Chodenice beds or, locally, conglomerates (of Sypka Góra). Their stratigraphic position according to studies of foraminifers had been determined as Badenian. New results obtained from micropalaeontological material sampled at three exposures near Wiatowice, Jawczyce (Giewont) and Gdów (Sypka Góra), and based on boreholes, indicate a much younger age of for the deposits infilling the Gdów "embayment". These studies show that the surface deposits are not older than Late Sarmatian/Pannonian (Serravalian/Tortonian). They also suggest a much later time for the last stages of the thrusting of the Carpathian Mountains over the Carpathian Foredeep.

Key words: Carpathian orogenic front, Carpathian Foredeep, Neogene basin, Miocene, Sarmatian, Pannonian, Gdów "embayment".

INTRODUCTION

Variations in the Western Carpathians overthrust led to the identification of the "embayments" (of Gdów, Wojnicz, Pilzno, Rzeszów), which are clearly marked on the tectonic map of the Carpathians (Żytko et al., 1989). The "embayment" of Gdów appears most clearly along the northern border of the Carpathians and covers the area between Wieliczka and Bochnia, where the margin of the Carpathians turns to the south (Fig. 1), and was first noticed by Niedźwiedzki (1883, 1884). At the fringe of the Gdów "embayment" there are salt mines at Wieliczka and Bochnia, while in the centre there is a non-operating mine at Łężkowice-Siedlec (Garlicki, 1960, 1994). The southern border of the "embayment" is marked by the overthrust of the Carpathian Flysch (Subsilesian Nappe) and the northern border by the overthrust of the Zgłobice Nappe on the autochthonous Miocene succession of the Carpathian Foredeep (Poborski and Jawor, 1987; Fig. 2). The age of the deposits filling the "embayment" has until now been poorly constrained, and their stratigraphic classification has been debatable. According to earlier views, the "embayment" is infilled with tectonically disturbed Miocene strata referred to the Skawina Formation (Burtan, 1956; Alexandrowicz, 1964; Doktor, 1983; Bukowski et al., 2010), based on a lack of evaporite deposits in boreholes and on tectonic models, e.g. of Połtowicz (1962, 2004) or Poborski and Jawor (1987). Their age, determined on the basis of microfauna, was stated to be Lower Badenian (Łuczkowska, 1955, 1978; Alexandrowicz, 1964), or as late as the Middle and Upper Badenian (Połtowicz, 2004), which led to distinguishing the Chodenice and Grabowiec beds.

REVIEW OF CURRENT STUDIES

The region of the Gdów "embayment" has aroused interest because of the possibility of salt and bitumen deposits in the area. In prospecting for these, several deep boreholes have been drilled (Fig. 2; Połtowicz, 1962, 1991, 2004; Moryc, 1979a, b, 1976; Poborski and Jawor, 1987). Up to 1200 m of thick Neogene deposits comprising clays and claystones, with intercalations of sands and sandstones, were penetrated by these boreholes (Moryc, 1970a, b, 1976). No evaporite deposits were found in the boreholes located south of the Łężkowice-Siedlec salt deposit up to the margin of the Carpathian overthrust. This sedimentary pattern was the reason for the age of sediments

* Corresponding author, e-mail: awojc@pgi.gov.pl

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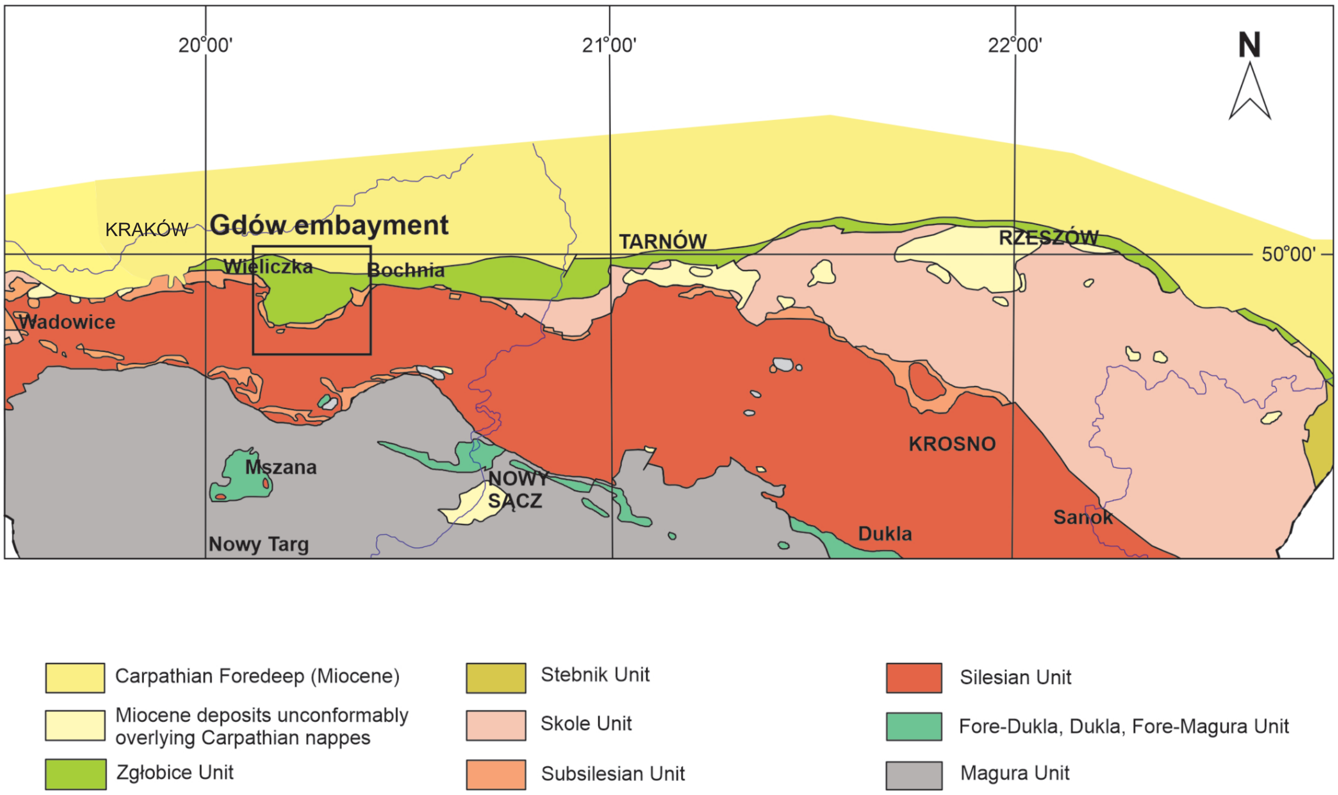

Fig. 1. Setting of the "embayment" within the tectonic scheme of the Carpathians (after Żytko et al., 1989, modified)

filling the Gdów "embayment" being interpreted as older than the evaporite succession (Garlicki, 1960; Olewicz, 1968; Poborski and Jawor, 1987; Połtowicz, 2004). The results of micropalaeontological studies also indicated such an age (Łuczkowska, 1955, 1958; Kirchner, 1956; Alexandrowicz, 1961). Kirchner (1956), based on microfaunal analyses, stated that the strata drilled were Lower Badenian in age. These were overlain by Middle and Upper Badenian strata containing derived from Lower Badenian fossils. In his later works, Połtowicz (2004) noted that the Lower Badenian deposits are thin, with the overlying strata that represent the Chodenice and Grabowiec beds containing the redeposited Early Badenian microfauna. Olewicz (1968, 1973) included the entire succession of the Gdów "embayment" within the autochthonous strata of the Carpathian Foredeep. Połtowicz (1962) initially considered that these were wholly autochthonous deposits, of Lower Badenian age. According to Olewicz (1973) and Połtowicz (1991), in the southern part of the Gdów "embayment", autochthonous Lower Badenian deposits have been uplifted to the surface in the form of a tectonic window. Poborski and Jawor (1987) and Połtowicz (1991), based on boreholes and on geophysical data, found that in the basement of the Miocene of the Gdów "embayment" there are reverse faults that continue into the Miocene deposits. Łańcucka-Środoniowa (1963, 1966) described plant remains from boreholes in the area of the Gdów "embayment" and in its vicinity (Fig. 2). Palynological studies were also carried out on borehole material from Suchoraba and Kłaj. Łańcucka-Środoniowa (1966) stated that the flora of the "embayment" has more in common with the Sarmatian flora of Stare Gliwice than with the floras studied in the vicinity of Wieliczka, which she thought were older. However, she recognized (Łańcucka-Środoniowa, 1966) that the micropalaeontological determinations made by Łuczkowska (1955, 1958), Kirchner (1956) and Alexandrowicz (1961) were more reliable and supported an Early Badenian age for these deposits.

Palynological analysis of clays from Stare Gliwice made by Oszast (1960) indicated great similarity to the pollen spectra of deposits from the Kłaj 1 borehole (located north of the study area) and their age was determined as Late Miocene. The deposits from the Kłaj 1 borehole were studied micropalaeontologically by Kirchner (1956, 1962), and a spore-pollen analysis was made by Kita (1963), who found that the pollen spectrum indicates a Late Miocene age.

Studies of the salt deposits have been concentrated along the northern part of the Gdów "embayment", comprising those of "Wieliczka and Łężkowice-Siedlec", where Garlicki (1960, 1961) and others examined the evaporite succession and distinguished the Upper Badenian Wieliczka Formation (Garlicki, 1979). Based on micropalaeontological studies, the salt deposits at Wieliczka have been referred to the lower part of the NN6 Zone (Upper Badenian). The overlying Chodenice beds in Sułków Quarry (in the northern part of the Gdów "embayment"), based on the occurrence of *Calcidiscus leptoporus*, *C. macintyrei*, *Helicosphaera carteri*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus abies*, *Discoaster kugleri*, *Scyphosphaera amphora* and *Braarudosphaera bigelowii*, have been assigned into the Upper Badenian NN6-NN7 zone (Andreyeva-Grigorovich et al., 2003). Very poor nannoplankton assemblages with *Coccolithus pelagicus*, *Coccolithus miopelagicus*, *Calcidiscus leptoporus*, *Reticulofenestra pseudoumbilicus*, *Reticulofenestra* spp. (small forms), *Helicosphaera carteri* and *Umbilicosphaera rotula* have been found in the Chodenice beds in Gierczyce brickyard (in the eastern part of Gdów "embayment"). The foraminifer assemblage from the Chodenice beds in

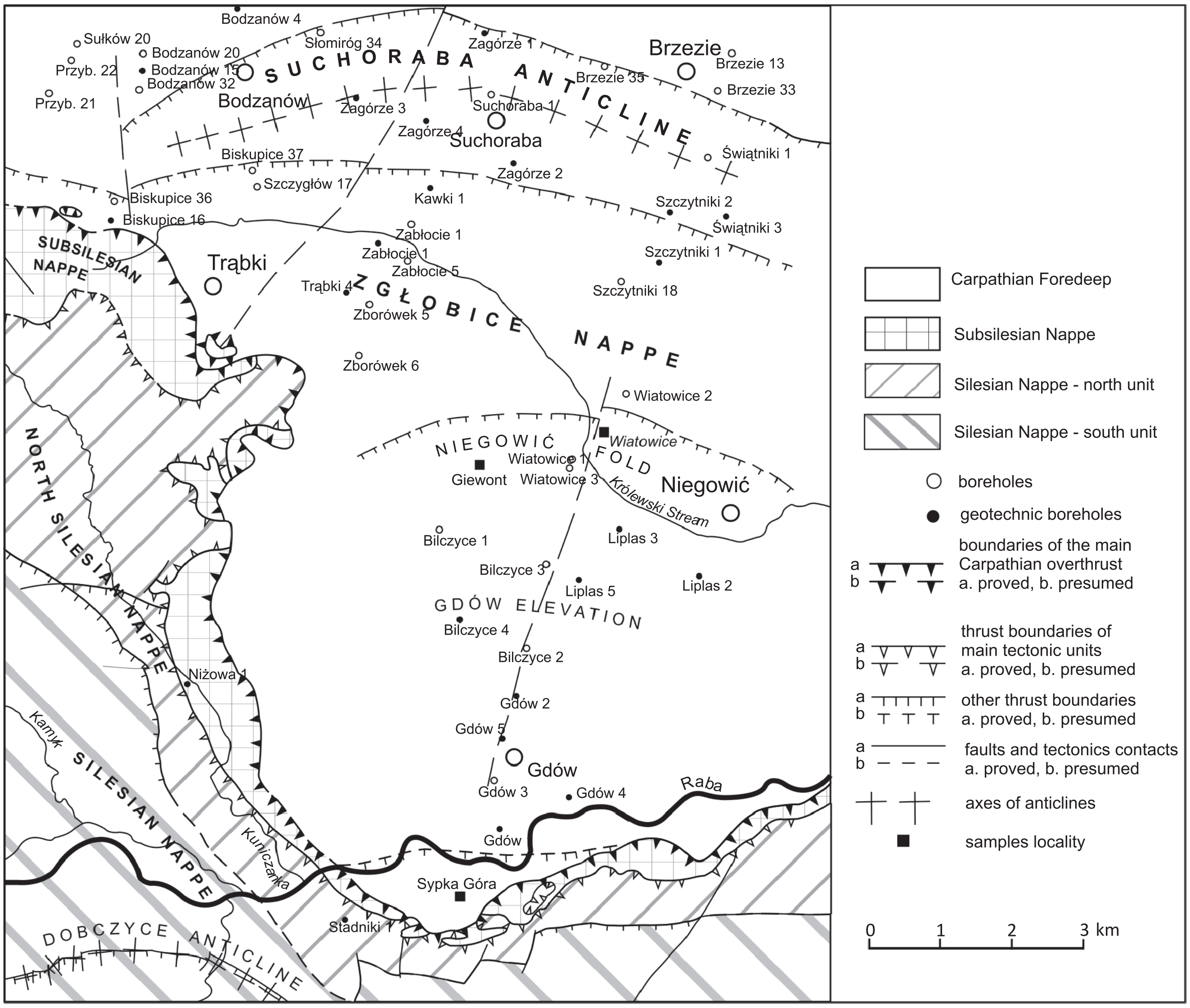

Fig. 2. Location of the boreholes and selected exposures in the western part of the Gdów "embayment"

Sułków Quarry contains species characteristic of the Upper Badenian, but in the case of the Gierczyce brickyard it is not possible to precisely determine the age (Andreyeva-Grigorovich et al., 2003). Geophysical studies (magnetic and seismic) have also been carried out. Considering seismic data from the area of the Carpathian Foredeep, Krzywiec and Verges (2007) and Krzywiec et al. (2012) hypothesised that disturbances in the zone of the overthrust of the Zgłobice Nappe may be associated with a hypothesized tectonic wedge. In the Miocene succession of the Gdów "embayment", tuffites have been recorded (Burtan, 1956; Garlicki, 1960; Połtowicz, 1962), which suggested that the "embayment" was infilled with sediments that were related to the Chodenice and Grabowiec beds, in which occurrences of tuffite are relatively frequent. Bukowski et al. (2010) dated tuffites in the vicinity of Wiatowice at 13.76 Ma, associating them with tuffites in the Skawina beds.

In the area of Stadniki near Gdów the coarse clastic deposits known as the Gdów beds (Burtan and Wójcik, 2017) or as the Sypka Góra conglomerates (Doktor, 1987) occur. These were studied earlier by Burtan (1956, 1964), Alexandrowicz (1964) and Doktor (1983, 1987). They were interpreted as fan delta sediments deposited in the coastal zone. Drilling in Stadniki has shown that they extend southwards, beneath the Carpathian overthrust (Połtowicz, 2004), and are of considerable thickness, reaching ~500 m.

In the light of this data, the question arises as to why the strata of the Gdów "embayment" are included into the Lower Badenian Skawina Formation? The lack of an evaporite unit can be explained by invoking a local elevation or by a lack of sedimentation during the Early and Middle Badenian, as is assumed for the Rzeszów area (Komorowska-Błaszczyńska, 1965).

MATERIALS AND METHODS

The material for our paper was collected during fieldwork for a Detailed Geological Map of Poland and during field observations of dry flood-control reservoirs in the Raba catchment of the Wiatowice-Niegowić region (Fig. 2). We found that the strata previously included within the Skawina Formation differ from this formation lithologically because they contain coarse clastic material. To clarify their position and age, samples were taken for micropalaeontological examination (calcareous nannoplankton and foraminifera). As part of the geological studies, sedimentological observations and detailed logging of the boreholes were performed. Earlier logs of deep boreholes and of geotechnical boreholes have been also used in the current work.

Material for examination was sampled from: surface exposures near Wiatowice, Jawczyce (Giewont) and Gdów (Sypka Góra), and from shallow boreholes in the area of Niegowić (Fig. 2). The material collected were subject to micropalaeontological analyses of calcareous nannoplankton and foraminifer assemblages. All samples were collected from the uppermost part of the Miocene succession of the Zgłobice Nappe infilling the Gdów "embayment".

Smear slides for the nannoplankton studies were prepared according to the method described by Báldi-Beke (1984). For light microscope examination, a fine aqueous suspension of the rock was spread out on a glass slide. After stirring, a short period of settling and drying, the microscope slide was covered with Canada balsam and a cover glass. The slides were inspected with a *Nikon Eclipse LV100POL* light microscope at 1000x magnification. Photographs were taken under the light microscope using a *Nikon DS-Fi1* camera. Foraminifera studies were performed on samples treated with water, washed and dried in an oven. Photographs of selected species were taken by SEM.

RESULTS AND DISCUSSION

WIATOWICE-NIEGOWIĆ AREA

In the region of Wiatowice (the middle part of the Gdów "embayment"; Fig. 2), Miocene deposits show up in two exposures (Figs. 2 and 3) on the west side of the Łysa Góra, along the Królewski Potok Stream. One of these, located farther south, on the left side of the Królewski Potok Valley, was studied by Alexandrowicz (1964). Here there are exposed mainly sands, with locally sandy gravels containing mollusc shell detritus, in places strongly cemented as different sized lenses. The sands are interlayered with sandy and clayey silts. The gravel material is dominated by sandstone clasts of Carpathian origin (Alexandrowicz, 1964). These layers dip to the north at an angle of 20°. The sands have been locally exploited, and lithologically they are similar to the Bogucice and Rajsko sands.

North of the exposure described by Alexandrowicz (1964) and Doktor (1987) and west of the tuffite exposure described by Bukowski et al. (2010), on the lower part of the Łysa Góra slope, there is a small exposure made during the construction of a henhouse (Fig. 3, Wiatowice N). There are three sedimentary units in the exposure: the upper one consists of interlayered clays and sandy silts (a); the middle one contains gravels and sands (b); and the lower one consists of stratified sands (c). The exposure profile in Wiatowice (near the henhouse) in detail is as follows (from the top) (Figs. 3 and 4):

- 0.0–1.5 m – interlayered fine sands and sandy silts with grey calcareous clays, as layers mostly 1–3 cm, and up to 15 cm, thick; the whole unit is characterized by horizontal layering and suggests sedimentation on the gently inclined slope of a delta;
- 1.5–2.1 m – gravels and sands of various grain sizes, poorly sorted with scattered grain skeleton; the lower surface is uneven, characterized by shallow chutes due to washing-out associated with erosion of the underlying sands; in the troughs there are clusters of medium-sized pebbles (Figs. 3 and 4). The gravel composition is dominated by sandstone clasts (up to 20 cm across) originating from the erosion of the Carpathians with a large proportion of light-coloured tuffite pebbles, originating probably from erosion of Miocene strata of the Skawina beds;

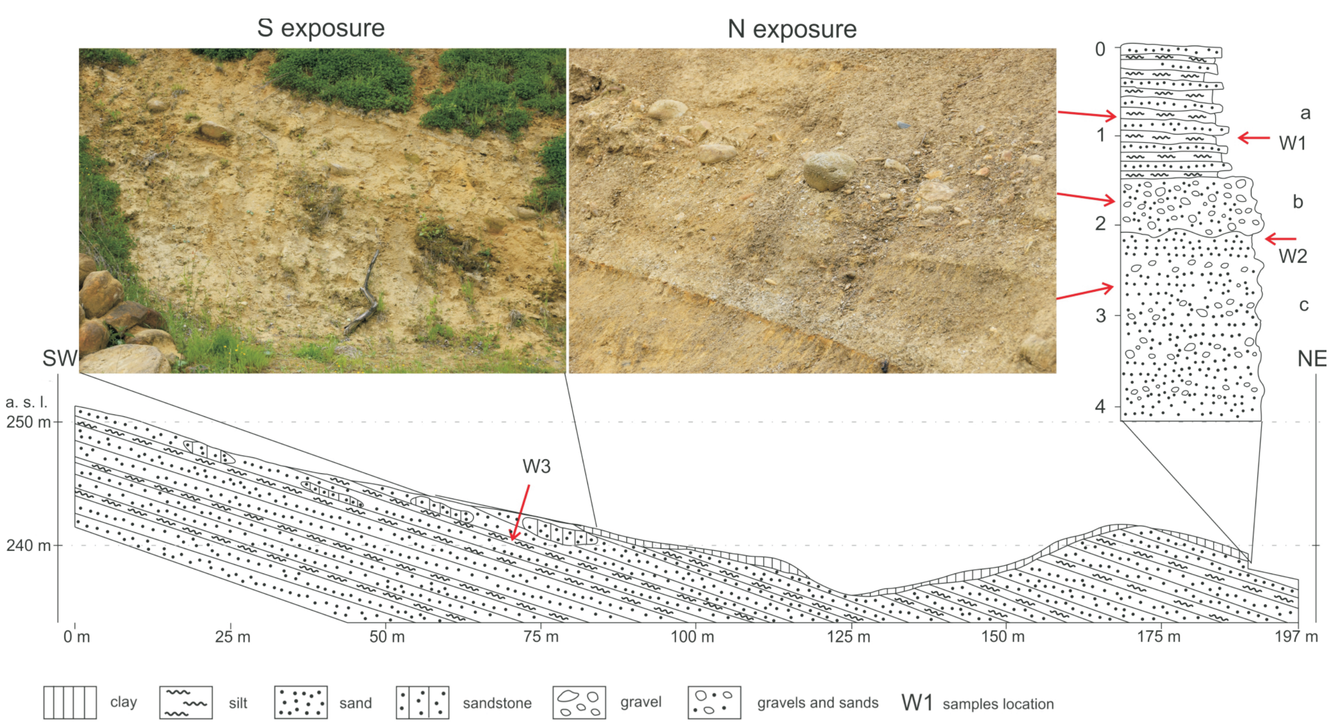

Fig. 3. Schematic profile along the western slopes of Łysa Góra in Wiatowice, and part of the profile with sampling sites for palaeontological examination

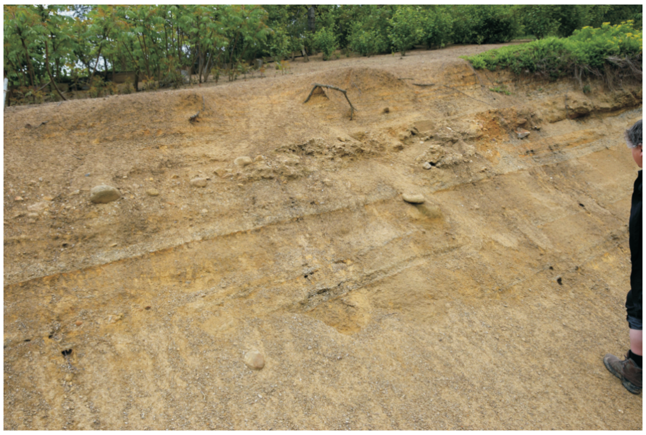

Fig. 4. Exposure of Miocene deposits in Wiatowice

– 2.1–4.6 m – horizontally bedded sands of varying grain size, with irregular gravel layers and shell remains on the lower surface and at the top (Fig. 3); it also includes interbeds of claystone.

In the Wiatowice area, south of the exposures described, Burtan (1956) observed tuffite exposures, which are currently not visible. The tuffites described by Bukowski et al. (2010) lie at a similar topographic elevation to that of we described in this section. It is unclear whether the dated tuffites are of *in situ* origin or were redeposited.

In the site described by us, located ~0.1 km to the west from dated tuffites, we have clear evidence that the tuffite boulders are redeposited.

The samples taken for micropalaeontological analysis revealed a rich and diverse calcareous nannofossil assemblage dominated by redeposited species from the Paleogene and less commonly from the Late Cretaceous. A large proportion of redeposited species, the presence of numerous coccolith fragments, the poor preservation (in principle it is not possible to distinguish redeposited species from autochthonous ones, especially in the case of forms with a long stratigraphic range) indicate transportation and re-working of the sediment, perhaps repeatedly. The autochthonous Miocene species are an insignificant element of the assemblage due to the shallow conditions and freshwater influx as well as to the reworking of older Miocene species. In the sample taken from the youngest levels of the northern exposure (layer a, sample W1; Fig. 3), the assemblage consists mainly of long-ranging species, such as: *Braarudosphaera bigelowii* (Gran et Braarud) Deflandre, *Coccolithus pelagicus* (Wallich) Schiller, *Cyclicargolithus floridanus* (Roth et Hay) Bukry, *Discoaster deflandrei* Bramlette et Wilcoxon, *Helicosphaera carteri* (Wallich) Kamptner, *H. intermedia* Martini, *H. walbersdorfensis* Müller, *Pontosphaera multipora* (Kamptner) Roth, *Reticulofenestra pseudoumbilicus* Gartner, *Sphenolithus moriformis* (Brőnnimann et Stradner) Bramlette et Wilcoxon, *S. abies* Deflandre and *S. heteromorphus* Deflandre and *Umbilicosphaera rotula* (Kamptner) Varol. The co-occurrence of *Helicosphaera walbersdorfensis* and *S. heteromorphus* suggest the Lower Badenian NN5b Subzone (Andreyeva-Grigorovich et al., 2001) and MNN5b Subzone in the Mediterranean region (Fornaciari and Rio, 1996). In a sand sample (layer c, sample W2; Fig. 3), the Miocene assemblage is even more depleted. Besides *C. pelagicus*, *Cy. floridanus*, *H. carteri*, *P. multipora*, *R. pseudoumbilicus, S. heteromorphus* and *U. rotula* the *Rhabdosphaera* species [*Rhabdosphaera procera* Martini and *Rh. siccus* (Stradner) Fuchs et Stradner] were recorded. The occurrence of *S. heteromorphus* suggests that this sample is not older than the Lower Badenian. The NN5 Zone is defined as the interval between the last occurrence (LO) of *Helicosphaera ampliaperta* Bramlette et Wilcoxon (the bottom part of the Zone) and the LO of *S. heteromorphus* (the top part) in Martini's scheme (1971). It was recorded in the Skawina beds which underlie the evaporate horizon in the Polish part of the Carpathian Foredeep (e.g., Martini, 1977; Dudziak and Łaptaś, 1991; Peryt, 1997; Garecka and Jugowiec, 1999; Andreyeva-Grigorovich et al., 2003; Garecka, 2014; Gaździcka, 2015; Wójcik et al., 2015; Nosowska et al., 2019; Pilarz, 2019) and in boreholes in the Carpathians between the Cieszyn and Sucha areas (Garecka et al., 1996). The uppermost part of these beds belongs in the NN6 zone (e.g., Andreyeva-Grigorovich et al., 1997, 2003; Garecka, 2014). In the Gdów "embayment" area no calcareous nannoplankton assemblages corresponding to the NN5 Zone have been found so far. The samples investigated from the Wiatowice-Niegowić area (samples W1 and W2) consist of many damaged, indistinguishable elements of coccoliths, with scarce (or even absent) diagnostic Middle Miocene species, and a large abundance of redeposited, mainly Paleogene, species and much terrigenous material. Characteristic Middle Miocene *Discoaster* species, such as *D. variabilis*, *D. exilis*, *D. deflandrei* and *D. musicus* did not occur or occur very rarely, mainly as fragments of arms. The abundant redeposited coccoliths and their damaged state, together with terrigenous material with organic fragments, indicate unfavourable conditions for the development of coccolithophores, such as changes in eustatic sea level, tectonic activity of the Carpathian orogen, a shallow environment with low water clarity, and mixing and destruction during transport. In a sample taken from the southern exposure (sample W3; Fig. 3), rare Miocene species (one Miocene species in every 10 or more fields of view) were found. In addition to the species found in the samples from the northern exposure, the following species were present: *Calcidiscus macintyrei, Coronocyclus nitescens, D. kugleri, D. musicus*, *D. cf. variabilis* and *Umbilicosphaera jafarii.* These are very poorly and poorly preserved, but the occurrence of the index taxon *Discoaster kugleri* suggests the NN7 Zone. The usefulness of the first occurrence of this species as a zonal marker is problematic. In badly preserved material it is difficult to distinguish *D. kugleri* from other similar discoasters. *Discoaster* species, including *Discoaster kugleri*, are never numerous in the Polish segment of Paratethys (Gaździcka, 1994; Wójcik and Jugowiec, 1998; Andreyeva-Grigorovich et al., 2003; Garecka and Olszewska, 2011). Usually one specimen, rarely two or more, were found in a sample (Garecka in Studencka et al., 2017). The single specimen of *D. kugleri* in the Pecten Beds at Machów suggests redeposition, according to Gaździcka (1994). De Kaenel et al. (2017) devised the *Discoaster kugleri* group to which taxa with a large, mostly featureless central area and rays with simple terminations were assigned. Based on ray length and morphology, and stratigraphic range, three taxa are included within this group (see de Kaenel et al., 2017). One of these is *D. kugleri* with very short tapered rays and slightly notched tips. The second is *D. hexapleuros* with a hexagonal central area, the presence or absence of a distal knob (a stellate central knob with its points directed towards the arms; Theodoridis, 1984) and parallel-sided rays. The third is *D. cuspidatus* with long tapered rays. The species shown in Figure 5H resembles forms identified in samples from Przecław brickyard (Studencka et al., 2017) which was included into the *Discoaster kugleri* group according to de Kaenel et al. (2017). According to Vass (1999) the extreme rarity of *D. kugleri* indicates conditions under which marine nannoflora could not thrive.

The identification of discoasters is problematic or even difficult because of the ease with which they are damaged during transport and because calcite overgrowths are common on the tests (Peryt and Peryt, 1994; Báldi, 2006). In the samples analysed significant disintegration of the specimens was observed. Many fragments of coccoliths (plates) of indeterminate taxonomic affiliation were found as background for the few, mechanically damaged, deformed, orange-brown stained coccoliths with crystal overgrowths that represent Miocene species. With such material, it is difficult to reach an unequivocal stratigraphic interpretation. The presence of *Discoaster kugleri*, characteristic of the NN7 Zone (e.g., Garecka and Olszewska, 2011; Studencka et al., 2017), in the sample from the southern exposure (Fig. 3) suggests a younger age for these deposits. Discoasters are typical of warm open oceanic environments in tropical and subtropical areas. Among them are forms such as *Discoaster deflandrei*, *D. exilis* and *D. variabilis* which are more tolerant and also occur in temperate waters (Chira and Mărunteanu, 1999). The scarce occurrence of latitudinally-controlled discoaster species suggests not only temperate waters but also a coastal environment (Ćorić and Hohenegger, 2008). They are more common in the Mediterranean than in the more isolated Paratethys. The very rare occurrence of *D. kugleri* was noted by Mărunteanu (1999) in the lower part of the Sipotel Formation of the Subcarpathian Inner Zone (Romania) within a poor calcareous nannoplankton assemblage of the NN7 Zone. The CNM10 (*D. kugleri* Total Range Zone) of Backman et al. (2012) is characterized by the occurrence of *D. kugleri.* The interval of common and continuous presence of *D. kugleri* has been observed in the tropical Pacific, mid-latitude northern and tropical Atlantic and the Mediterranean (Raffi et al., 1995; Backman and Raffi, 1997). Theodoridis (1984) noted that *D. kugleri* is absent in the Mediterranean sections studied. According to Švábenická (2002), epicontinental marine sediments contain smaller and less numerous specimens than oceanic sediments. Martini (1977) also drew attention to the small size of some species while studying the Middle Miocene deposits of the Korytnica Basin (Holy Cross Mountains). The high proportion of redeposited nannofossil species and of damaged coccoliths, the scarcity (or absence) of some Miocene index species and the mainly poorly state of preservation suggest terrigenous supply into the basin and an unstable shallow environment (Garecka and Olszewska, 2011).

These deposits can be interpreted as representing the distal part of the delta in a relatively shallow basin subject to subsidence. Bukowski et al. (2010) obtained the date of 13.76 Ma for the tuffite from Wiatowice and assumed that the strata in this area correspond to the Skawina beds. From the presence of tuffite pebbles in the newly exposed profile, it can be inferred that the tuffites may be redeposited. Therefore, not only the strata of which the Carpathians are built, but also the younger Miocene deposits located south of the Gdów “embayment” have been subject to erosion. Near the exposures in Wiatowice described, three deep boreholes have been drilled: Wiatowice 1, 2 and 3, located on different tectonic elements (Fig. 2). In the Wiatowice 1 drilling, the Miocene deposits were 514.5 m thick. Olewicz (1952) described these deposits as the middle part of the “2nd sandy-clay series” (one of the sedimentary units below the salt level distinguished by him), within which he indicated the presence of lignites at depths of 259, 265, 327 and 402 m. The bottom part of this unit is more sandy. These strata therefore seem to have been deposited in a relatively shallow basin subject to constant subsidence that filled rather quickly. In the nearby Wiatowice 3 borehole, Miocene deposits were drilled to a depth of 824.0 m. They were described as steel-grey clays and clayey shales with sand and sandstone interlayers (Górka and Dulniawka, 1971). Such variation in thickness over a short distance can be explained by syn-sedimentary and post-sedimentary tectonic movements.

South of the exposures in Wiatowice, three geotechnical holes were drilled in Niegowić (Fig. 2; Kos et al., 2016) into clays interbedded with sands at the valley bottom. Preliminary results of micropalaeontological studies (calcareous nannoplankton) from the Niegowić W-1, W-2 and W-3 boreholes show similarities to the assemblages from Wiatowice. Redeposited species from the Paleogene and Cretaceous (forms characteristic of Carpathian flysch deposits) predominate in the samples, with abundant fragmentary undetermined coccoliths (even at the genus level). These coccoliths are broken, with visible signs of corrosion, secondary crystallization and changes in colour. Miocene species are very rare. The assemblage is poor, with single specimens found every ten or few tens of observation fields. The numbers of *Coccolithus pelagicus* and *Cyclicargolithus floridanus* are higher in samples from the Niegowić W-3 borehole at depths of 14.3 and 14.8 m. In samples from the Niegowić W-2 (depth of 12.5 m) and Niegowić W-1 (12.2 m) boreholes there are many *C. pelagicus* and *R. pseudoumbilicus* (Fig. 5). There was a single occurrence of *Discoaster kugleri* (Fig. 5H), which suggests the NN7 Zone. In specimens with larger plate sizes, secondary crystallization was noted (especially of *Discoaster*) the plate edges were crushed or dissolved. Paleogene and less numerous Cretaceous taxa predominate in the assemblage while Miocene species are few. The state of preservation of redeposited species from the Paleogene and Cretaceous can be described as very good (even delicate forms are preserved, which are usually the first to disintegrate) to very poor (fragments of placoliths), and colour change in the coccoliths was commonly observed (including of Miocene forms). This shows that even Miocene species, the youngest elements of the assemblage, can be redeposited. The most numerous group comprises long-ranging opportunistic species (mainly *C. pelagicus, Cy. floridanus, R. pseudoumbilicus*). *Braarudosphaera* and *Pontosphaera*, characteristic of shallow, almost brackish zones (mainly *Braarudosphaera*) (Bukry, 1974; Báldi-Beke, 1984; Siesser et al., 1992; Chira, 2000; Bartol et al., 2008), are usually very well preserved (effects of mechanical damage are visible, but the plates are unchanged). The absence of *S. heteromorphus* from the assemblage suggests a younger age than the NN5 Zone. The lack of certain forms can be explained by their true disappearance or unfavourable (i.a. salinity, temperature, shallowing, terrigenous supply) environmental conditions eliminating some, mainly more sensitive, species.

According to Gonera (Bukowski et al., 2010) the foraminifera assemblage from Wiatowice has been interpreted as of the Badenian biozone IIC/IIγ, characteristic of the upper part of the Skawina beds (Alexandrowicz, 1963).

GIEWONT AREA NEAR JAWCZYCE

To the west of Wiatowice, in the region of the local hill called “Giewont” (Fig. 2), to the south of Jawczyce, there are exposures of generally poorly (though locally strongly) lithified bedded yellow sands, with bed thickness of 0.1–0.7 m, interlayered with light grey sandy silt beds 0.03 to 0.2 m thick (Fig. 6).

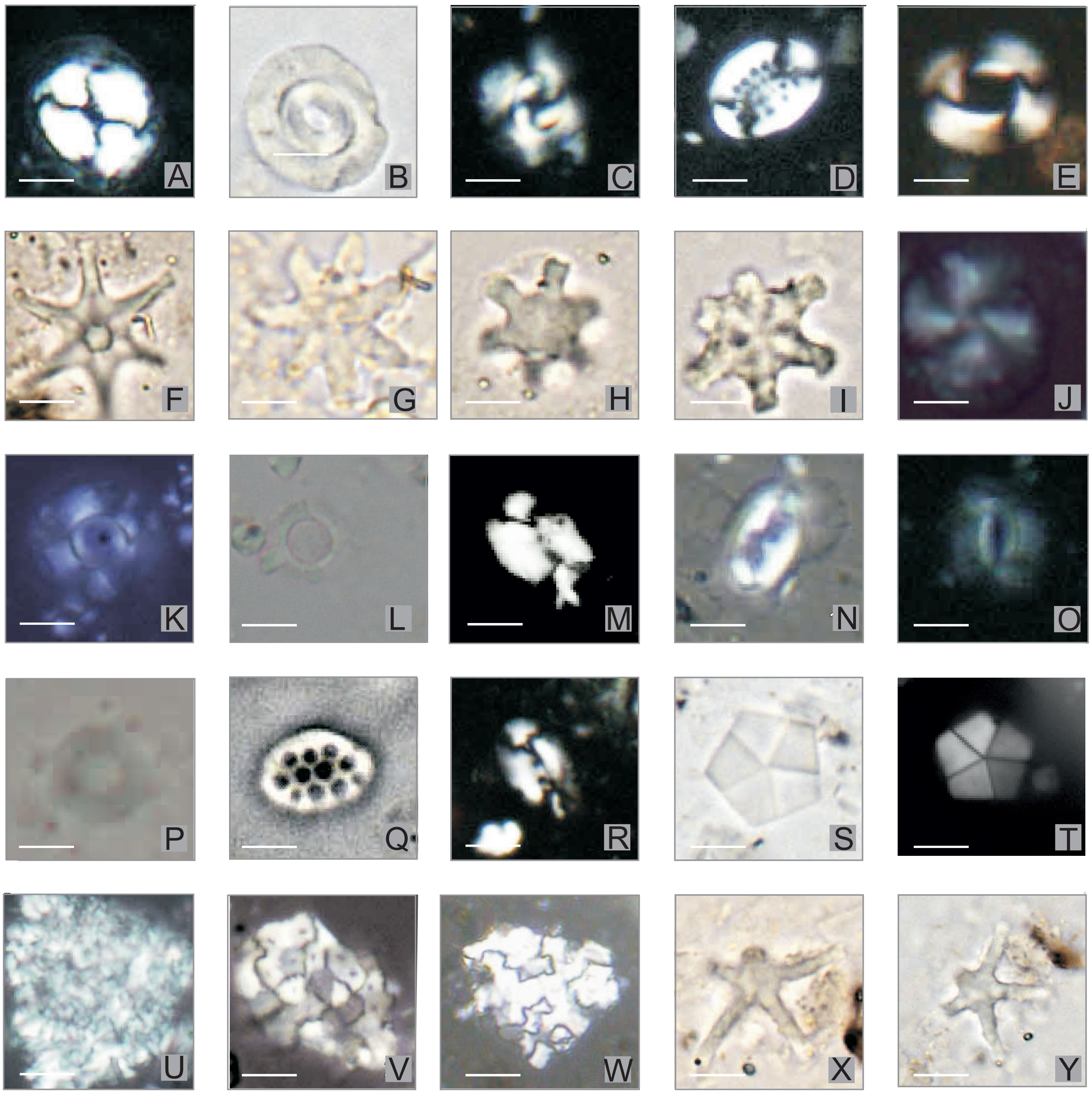

Fig. 5. Microphotographs of calcareous nannofossils from the Sypka Góra, Giewont and Wiatowice exposures

A, B – *Coccolithus pelagicus* (Wallich) Schiller; **C** – *Cyclicargolithus floridanus* (Roth et Hay) Bukry; **D** – *Pontosphaera multipora* (Kamptner) Roth; **E** – *Reticulofenestra pseudoumbilicus* Gartner; **F** – *Discoaster exilis* Martini et Bramlette; **G** – *Discoaster formosus* Martini et Worsley; **H** – *Discoaster kugleri* Martini et Bramlette; **I** – *Discoaster musicus* Stradner; **J** – *Calcidiscus leptoporus* (Murray et Blackman) Loeblich et Tappan; **K** – *Calcidiscus macintyrei* (Bukry et Bramlette) Loeblich et Tappan; **L** – *Umbilicosphaera rotula* (Kamptner) Varol; **M** – *Helicosphaera carteri* (Wallich) Kamptner; **N** – *Helicosphaera walbersdorfensis* Müller; **O** – *Calcidiscus pataecus* (Gartner) de Kaenel et Villa; **P** – *Umbilicosphaera jafarii* Müller; **Q** – *Holodiscolithus macroporus* (Deflandre) Roth; **R** – *Helicosphaera carteri* var. *burkei* (Black) Theodoridis; **S**, **T** – *Braarudosphaera bigelowii* (Gran et Braarud) Deflandre; **U** – *Thoracosphaera fossata* Jafar; **V** – *Thoracosphaera heimii* (Lohmann) Kamptner; **W** – *Thoracosphaera saxea* Stradner; **X**, **Y** – *Discoaster* sp; the scale bar is 5 µm

Lithologically, they are similar to the deposits cropping out in the vicinity of Wiatowice. Samples for micropalaeontological studies were taken from the silts in two exposures located on both sides of the road cutting. One sample yielded numerous redeposited Paleogene taxa, which predominate over Upper Cretaceous forms (as in the samples from the Wiatowice area). However, sixteen Miocene species were identified, usually as single occurrences among the poorly preserved material. Most common are *Reticulofenestra pseudoumbilicus*, small-sized *Reticulofenestra* species and *Coccolithus pelagicus*. Other species, such as *Braarudosphaera bigelowii, Calcidiscus leptoporus, Calcidiscus pataecus, Coronocyclus nitescens, Cy. floridanus, Discoaster deflandrei, D. exilis, Helicosphaera carteri, Pontosphaera multipora, Rhabdosphaera siccus* and *Umbilicosphaera jafarii* occur rarely (Fig. 5). *Reticulofenestra pseudoumbilicus* was more abundant than *Cyclicargolithus floridanus* indicating the Badenian/Sarmatian boundary (Galović, 2020), whereas *Calcidiscus pataecus* could suggest rather the Upper

Fig. 6. Exposures of Miocene deposits in the region of Giewont Hill in Jawczyce

Badenian NN6c Subzone (Mărunteanu, 1999), recently revised by Galović (2020) as Subzone PNN6c of the Paratethys, where the boundary was distinct. In the Paratethys this form is found only in the Middle Miocene (Galović and Young, 2012). The Miocene taxa are poorly to very poorly preserved, mechanically disintegrated, and also with secondary changes: recrystallization, plate deformation, corrosion, colour changes to orange--brown. Glauconitic grains, a few organic clasts and reddish-brown clasts were also found in the preparations. The second sample yielded only single isolated plates of *Braarudosphaera*. Specimens of this genus quickly disintegrate during transport and are sensitive to dissolution (Bukry, 1981; Bartol, 2006). Sharp-edged quartz grains, pyroclastic quartz, sandstone clasts stained with iron oxides and a few gypsum crystals were found in the residue.

The foraminifers from Giewont near Jawczyce are rare, though show very diverse preservation. Some tests are crushed, deformed or fragmentary, showing mechanical damage. Many tests are filled with white or transparent calcium carbonate, while some large tests of planktonic foraminifers are filled with iron compounds or with fine-grained sediment. Some test surfaces are coloured with iron compounds, while others are unnaturally snow-white. The tests of some benthonic foraminifers are very thin and transparent. All foraminifers have been grouped according to their size and state of preservation. The most numerous group – sub-assemblage A – are species with typically sized tests. *Globigerina bulloides* d"Orbigny, *Valvulineria complanata* (d"Orbigny) and *Bulimina elongata* d"Orbigny predominate in this group (Fig. 7). They are accompanied by single specimens of *Ammonia beccari* (Linné), *Neobulimina longa* Venglinski, *Quinqueloculina regularis* Reuss and other taxa (Fig. 7). Sub-assemblage B comprises dwarf foraminifera: *Bolivina dilatata* Reuss (dominant) with *Elphidium advenum* (Cushman), ?*Fursenkoina* sp., *Haynesina depressula* (Walker et Jacob) (= *Nonion depressulum*), *Nonion tumidulus* Pishvanova, *Nonion* sp. and *Porosononion* sp. (Fig. 7). Sub-assemblage C consists of broken and poorly or fragmentarily preserved specimens. Among them, there are Lower Badenian microfossils, such as fragments of *Dentalina* sp., damaged fragments of *Bolboforma reticulata* Daniels et Spiegler. The species composition of the foraminifera from the Giewont exposure has some similarity to the microfauna occurring in the area studied, both beneath and above the evaporites (Łuczkowska, 1955; Alexandrowicz, 1961; Olewicz, 1968; Łuczkowska and Odrzywolska-Bieńkowa in Olewicz, 1973). Species of sub-assemblage, A, *Globigerina bulloides, Bulimina elongata, B. gibba* Fornasini, *Ammonia beccari*, were found in large numbers in the Grabowiec beds in Chełm on the Raba River (Alexandrowicz, 1961), but they can also occur beneath the evaporites (Łuczkowska, 1978). The same is true for *Valvulineria complanata*, which is usually more numerous below the gypsum beds (Gonera et al., 2014). However, the presence of the index species *Neobulimina longa* indicates a Late Badenian age (Łuczkowska, 1964; Cicha et al., 1975). Sub-assemblage B contains small representatives of species that do not specify age. This sub-assemblage consists of *Elphidium advenum*, *Fursenkoina* sp., *Haynesina depressula*, *Nonion tumidulus*, *Nonion* sp. and *Porosononion* sp. All species included into this sub-assemblage have been found in the Upper Badenian Grabowiec and Chodenice beds (Łuczkowska, 1955; Alexandrowicz, 1961; Olewicz, 1968; Łuczkowska and Odrzywolska-Bieńkowa in Olewicz, 1973). Dwarf assemblages, yet of different species composition, have also been found in the Chodenice beds (Gonera et al., 2011). All species of sub-assemblage B also occur in the Sarmatian deposits in which many dwarf assemblages of foraminifera have been found (Łuczkowska, 1964; Czepiec, 1996). However, in those cases they usually occur together with typical Sarmatian species. The foraminifers in this pseudo-association from Giewont thus are not older than Late Badenian but, due to the state of preservation, presumably younger.

SYPKA GÓRA AREA NEAR GDÓW

In the zone of the Carpathian overthrust, south of Gdów, the outcropping (Fig. 2) gravels and sands are known as Sypka Góra conglomerates (Doktor, 1983) or Gdów beds (Burtan and Wójcik, 2017). These were correlated with coarse clastic deposits drilled in the Stadniki 1 borehole (Alexandrowicz, 1964; Doktor, 1983). In clasts and clay balls sampled from the gravels, Alexandrowicz (1964) found foraminifer assemblages characteristic of the Skawina Formation, which he associated with the lower part of the Badenian. Doktor (1983, 1987) inferred that the deposits at Sypka Góra represent polymictic gravels originating from the erosion of the Western Carpathians, and that the deposition of the gravels took place in "marine, gravel, fan delta" conditions, in an area subject to significant subsidence. The Sypka Góra succession is seen in along the Raba Valley between Stadniki and Zręczyce. Exposures of gravels and of sands with gravels can be observed for a distance of about 500 m along a distinct scarp along the right side of the Raba Valley, at a variable height, from 20 to 50 m, above the Raba Holocene terrace which lies at a height of 225 m above sea level. In many places, the scarp is affected by present-day landslides. There are considerable variations in the lithological composition of the deposits in individual exposures, where moderately rounded pebbles of various diameters, associated with gravels and coarse sands, can be observed. Within these deposits Doktor (1987) distinguished 3 units:

- massive conglomerates (A),
- fractional conglomerates (B),
- complex conglomerates (C).

During the fieldwork, intercalations of fine-grained sand with thin and discontinuous silt laminae, likely trough-fills, were found at a height of 237 m a.s.l. (Fig. 8). The exposed succession (49°33'28.3" N and 20°10'49.9" E), above the massive coarse gravels and smaller diameter gravels with sands, comprised (profile from below; Fig. 8):

- 1.2 m – sands with gravel;
- 0.65 m – sands with scattered pebbles, with parallel lamination at the top;

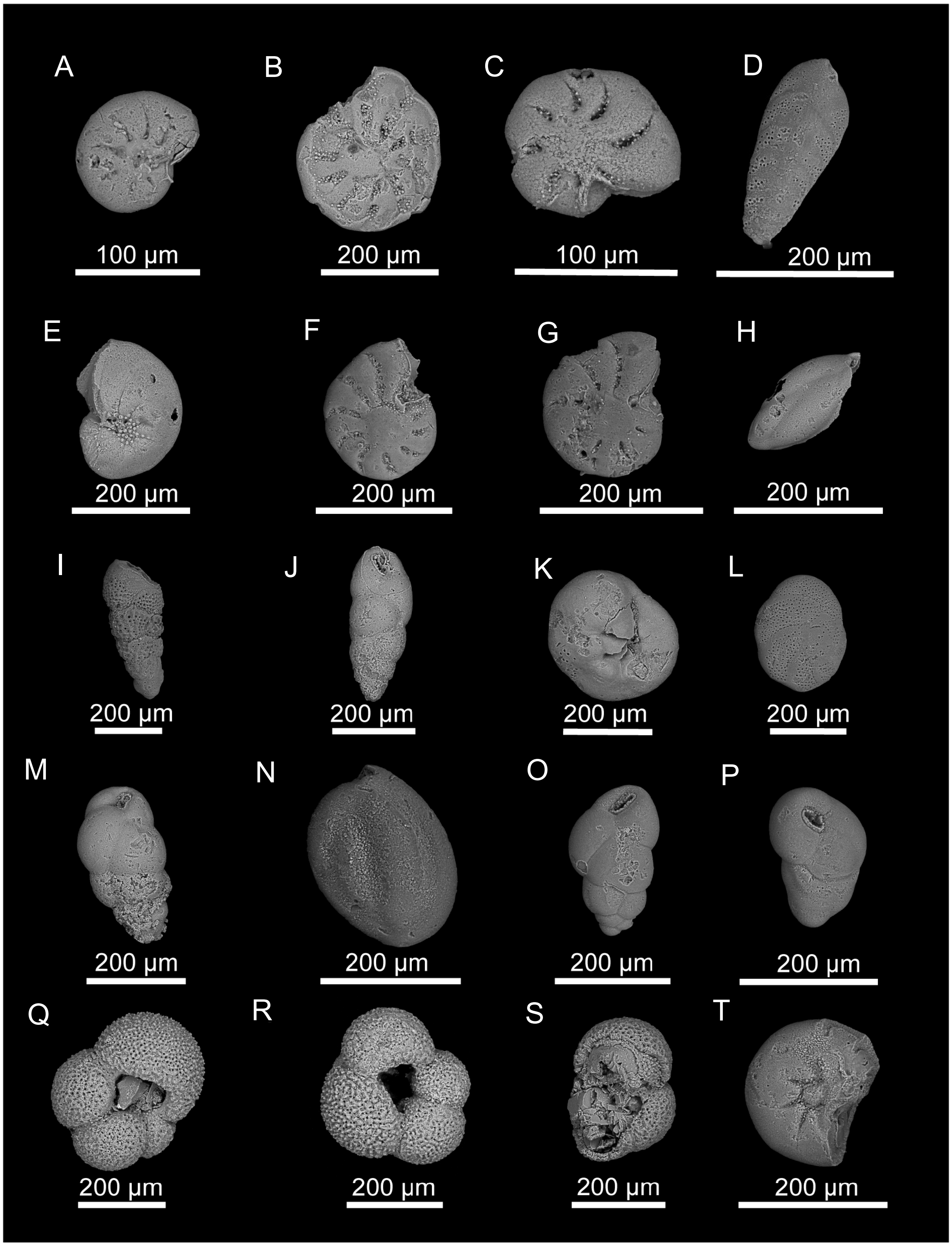

Fig. 7. SEM images of foraminifers from the Giewont and Sypka Góra outcrops

A – *Haynesina depressula* (Walker et Jacob); **B** – *Elphidium flexuosum* var. *reussi* Marks; **C** – *Nonion tumidulus* Pishvanova; **D** – *Bolivina dilatata* Reuss; **E** – *Nonion commune* (d'Orbigny); **F** – *Elphidium advenum* (Cushman); **G** – *Elphidium advenum* (Cushman); **H** – ? *Fursenkoina* sp.; **I** – *Bolivina* sp.; **J** – *Bulimina elongata* d'Orbigny; **K** – *Valvulineria complanata* (d'Orbigny); **L** – *Valvulineria complanata* (d'Orbigny); **M** – *Bulimina gibba*? Fornasini; **N** – *Quinqueloculina regularis* Reuss; **O, P** – *Bulimina elongata* d'Orbigny; **Q** – *Globigerina bulloides* d'Orbigny; **R** – *Globigerina* aff. *diplostoma* Reuss; **S** – *Globigerina* sp. test filled inside with $CaCO_3$; **T** – *Ammonia beccari* (Linné); A–F, H, J–T – Giewont exposure; G, L – Sypka Góra exposure

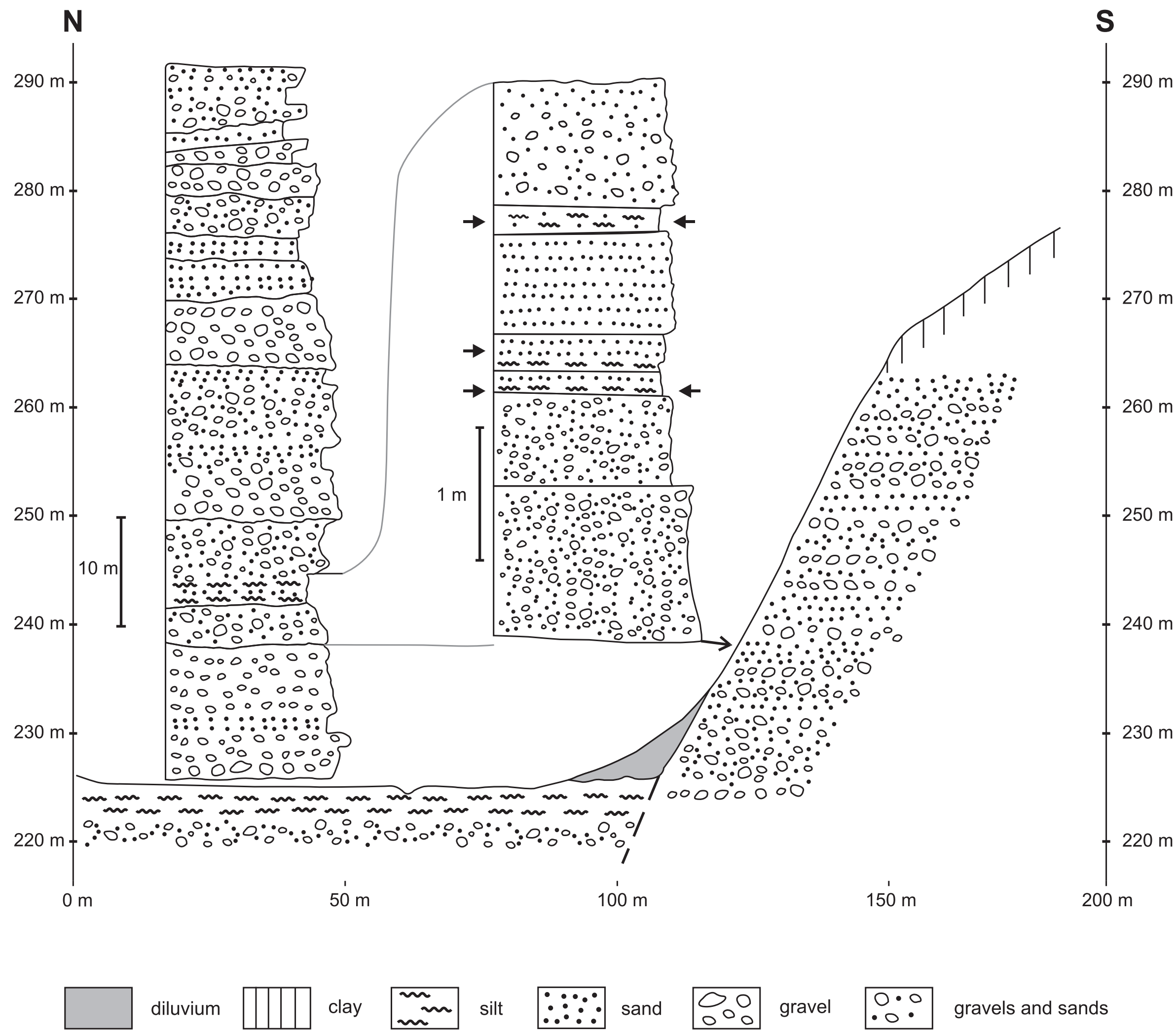

Fig. 8. Profile of gravel-sandy deposits in Sypka Góra near Gdów

– 0.01–0.04 m – grey silt (sample at 239 m a.s.l.);
– 0.12 m – medium-grained sands;
– 0.03 m – lower sandy silts (sample at 240.1 m a.s.l.);
– 0.25 m – medium-grained sands with numerous silt clasts;
– 0.70 m – medium-grained sands;
– 0.15 m – grey sandy silts;
– 0.50 m – sands and gravels.

Above there are sands and gravels of various grain sizes. With reference to the profile described by Doktor (1983), the deposits discussed represent the bottom part of the profile of the coarse clastic deposits, ~12.5 m from the exposure base (Fig. 9).

Samples for microfossils were taken from heights of ~239.0 and 240.1 m a.s.l. from thin (1–4 cm) layers of pale grey silt. These yielded a large and species-diverse assemblage of calcareous nannoplankton. The assemblage was dominated by redeposited taxa from the Paleogene and less commonly from the Upper Cretaceous. Miocene species are almost absent from the assemblage. The followings coccoliths were identified: *B. bigelowii, C. pelagicus, D. exilis, D. kugleri, D. musicus, D. variabilis, H. carteri, P. multipora, R. pseudoumbilicus*, small *Reticulofenestra* species and *Umbilicosphaera jafarii*. Five-rayed specimens of *Discoaster* were also found, though their poor preservation prevented their identification at species level. The forms identified more resemble *Discoaster bellus* than *D. hamatus*. According to some authors (Perch-Nielsen, 1985; Backman et al., 2012) the first five-rayed species of *Discoaster,* as well as *Discoaster hamatus* Martini et Bramlette, *D. bellus* Bukry et Percival and *D. prepentaradiatus* Bukry et Percival appear in the NN8 Zone (D. hamatus Zone, *sensu* Martini, 1971; interval E: NN8-10a *sensu* Young, 1998; Zone CNM12 – Catinaster coalitus Base Zone, *sensu* Backman et al., 2012; Eu-discoaster bellus Subzone, Theodoridis, 1984). No characteristic species of *Catinaster* were found in the material analysed. Gaździcka (1994) identified, in the top part of the Krakowiec clays (in the region of Stalowa Wola) five-rayed forms belonging to *Discoaster bellus*, *D. neohamatus* Bukry et Bramlette, *D. intercalaris* Bukry and *D. brouweri* Tan Sin Hok which are characteristic of zones NN9-10. According to Gaździcka (1994), the deposits above the evaporites (in boreholes in the Tarnobrzeg region) represent the NN8 (Catinaster coalitus Zone) or even the NN9 Zone (Discoaster hamatus Zone), while in the calcareous nannoplankton assemblage of the Machów Formation *Discoaster exilis* was not recorded (last occurrence in NN9 Zone; Young, 1998), while individual occurrence of *D. kugleri* in the *Pecten* beds suggest redeposition. Instead, *D. calcaris* Gartner, the first occurrence of which indicates the NN8 Zone (Perch-Nielsen, 1985; Martini and Müller, 1986; Young, 1998) is dated at 11.3 Ma in the Paratethys (Vass, 1999). This

Fig. 9. Exposures of sands with silt layer in Sypka Góra

is in accordance with our findings as regards the last occurrence of *D. kugleri* group, dated according to de Kaenel et al. (2017) at 11.037 Ma, which is close to the top of NN8 at low latitudes. Five-rayed *Discoaster* species such as *D. hamatus* in the Paratethys characterize the Pannonian NN9 (Mărunteanu, 1999), with the first occurrence of small forms at the base of NN8 based on the recent discovery of Browning et al. (2017). Nevertheless, from the Andrychów region, Jugowiec (Wójcik and Jugowiec, 1998) described a calcareous nannoplankton assemblage indicating the NN9a/8 boundary (Lower Pannonian; Piller, 1996; Sarmatian, Gaździcka, 1994; Mărunteanu, 1999; Andreyeva-Grigorovich et al., 2008). The occurrence of *Catinaster coalitus* and *C.* cf. *calyculus*, the sporadic occurrence of the *Discoaster kugleri* group and the lack of *D. hamatus* marks PNN8a, and therefore the Sarmatian PNN8 Zone (Galović, 2020). Fragmentary material of *Discoaster*, a genus characteristic of more open marine environments (e.g., *D. exilis),* and of placoliths (*Coccolithus*, *Reticulofenestra*), which are the most resistant to dissolution (Bukry, 1981; Beaufort and Aubry, 1992; Bartol, 2006; Palcu et al., 2015), and the large number of reworked and damaged specimens, support the observations regarding the displacement, reworking, and mixing of sediments (Gaździcka, 2015). In addition to coccoliths, fragments of silicified foraminifer, organic particles, glauconite grains and numerous (almost bulk) fragments of indefinite generic and specific affiliation were found. These deposits are referred to the Late Miocene, while the abundance and state of preservation suggest that their age is perhaps even younger, with all the microfossils being reworked. Single, damaged foraminifer specimens, sponge, fish remains and irregular tubular forms with plants remains inside were found. This pseudo-association consists of dwarf specimens of *Bolivina dilatata* (dominant), *Nonion tumidulus*, *N. commune*, *N.* sp., *Elphidium advenum* with typically sized *Ammonia beccari*, *Bulimina elongata*, *Heterolepa dutemplei* (d'Orbigny), *Valvulineria complanata* and others. All these species are also present in the sample from the Giewont exposure, in sub-assemblage A and B. The foraminifer species found are common in the Badenian, but both their small number and state of preservation suggest that they are reworked. The foraminifer assemblages from both the Sypka Górka and Giewont exposures are pseudo-associations, having been redeposited. Based on the species composition and state of preservation, the Giewont and Sypka Góra deposits are not older than Upper Badenian and presumably are younger.

CONCLUSIONS

Our study revises the geological interpretation of the deposits in the Gdów "embayment", micropalaeontological data unequivocally documenting a younger age of sedimentation than previously thought. They show that the southern part of the Gdów "embayment" in the Badenian was not occupied by sea and was a land, perhaps an island, with no evaporite sedimentation. Most likely there was a shallow basin here during the Sarmatian, as shown by the presence of organic deposits in borehole material and by the recognition of plant remains (trees, shrubs, small herbaceous plants, mosses, fungi, algae) and spores and pollen by Łańcucka-Środoniowa (1966). Organic sedimentation was interrupted by supply of terrigenous material from the south. Fans and deltas formed in front of the Carpathian Mountains overthrust. The deposits exposed in the Wiatowice area have features of a delta slope or prodelta, while, in the region of Gdów and Stadniki, these are proximal parts of a fan delta. Drilling in Stadniki shows these deposits to be >500 m thick and overlain by rocks of the Subsilesian Nappe. To the south of current overthrust, sedimentation of the Chodenice beds took place in the Badenian, as documented by petroleum exploration boreholes (Oszczypko and Oszczypko-Clowes, 2012), and Miocene deposits may have also been located in the area where the Carpathian Mountains were overthrusting. An example of this may be the Miocene deposits in Żegocina (Skoczylas-Ciszewska, 1960). In the Sarmatian and younger stages of the Miocene, both the Miocene units and Carpathian rocks were eroded and deposited in the shallow Sarmatian Sea. This is shown by the composition of gravels in the region of Gdów and Wiatowice as well as the presence of tuffite pebbles in the gravel. Tuffites, as low-density rocks, could have been transported far north of where they originated. The exposures in Gdów and Wiatowice are further points where young Miocene deposits were present in the area of folded Miocene strata in front of the Carpathian overthrust. Their age is even younger than assumed for the deposits of the autochthonous Miocene in the western part of the Carpathian Foredeep (Żytko et al., 1989). This is documented by the Carpathian thrusting over the Carpathian Foredeep in the western and central sections of the Carpathian arc being very young and falling into the Pannonian or being younger than the Pannonian. We are inclined to accept the hypothesis that the entire Carpathian Mountains were thrusting over their foreland at one time and this took place (at least the last stages of this process) even later than suggested by Kotlarczyk (1988). According to previous views and regional stratigraphic schemes, the Sypka Góra conglomerates (Gdów beds) were assigned to the Lower Badenian and placed below the Skawina Formation (Oszczypko and Oszczypko-Clowes, 2012). According to the data from the Gdów region, these are much younger deposits and in the stratigraphic profiles they occur above the Grabowiec beds (Fig. 10) and may correspond to the age of the youngest deposits found near Tarnobrzeg (Gaździcka, 1994). The hitherto accepted stratigraphic divisions, based on foraminifers, suggested a much older age. This may be due to high redeposition rates or the presence of microfauna in secondary deposits. Similarly, the results of our studies contradict earlier views about the diachronous timing (becoming younger from west to east) inferred for when the Carpathians were thrusting over the Carpathian Foredeep and are closer to the view that the overthrusting in the entire segment of the northern Carpathians took place simultaneously "en block" (Kotlarczyk, 1988). Kotlarczyk (1988) considered that the folded Miocene unit in the region of Przemyśl was involved in thrusting at the end of the Sarmatian in the

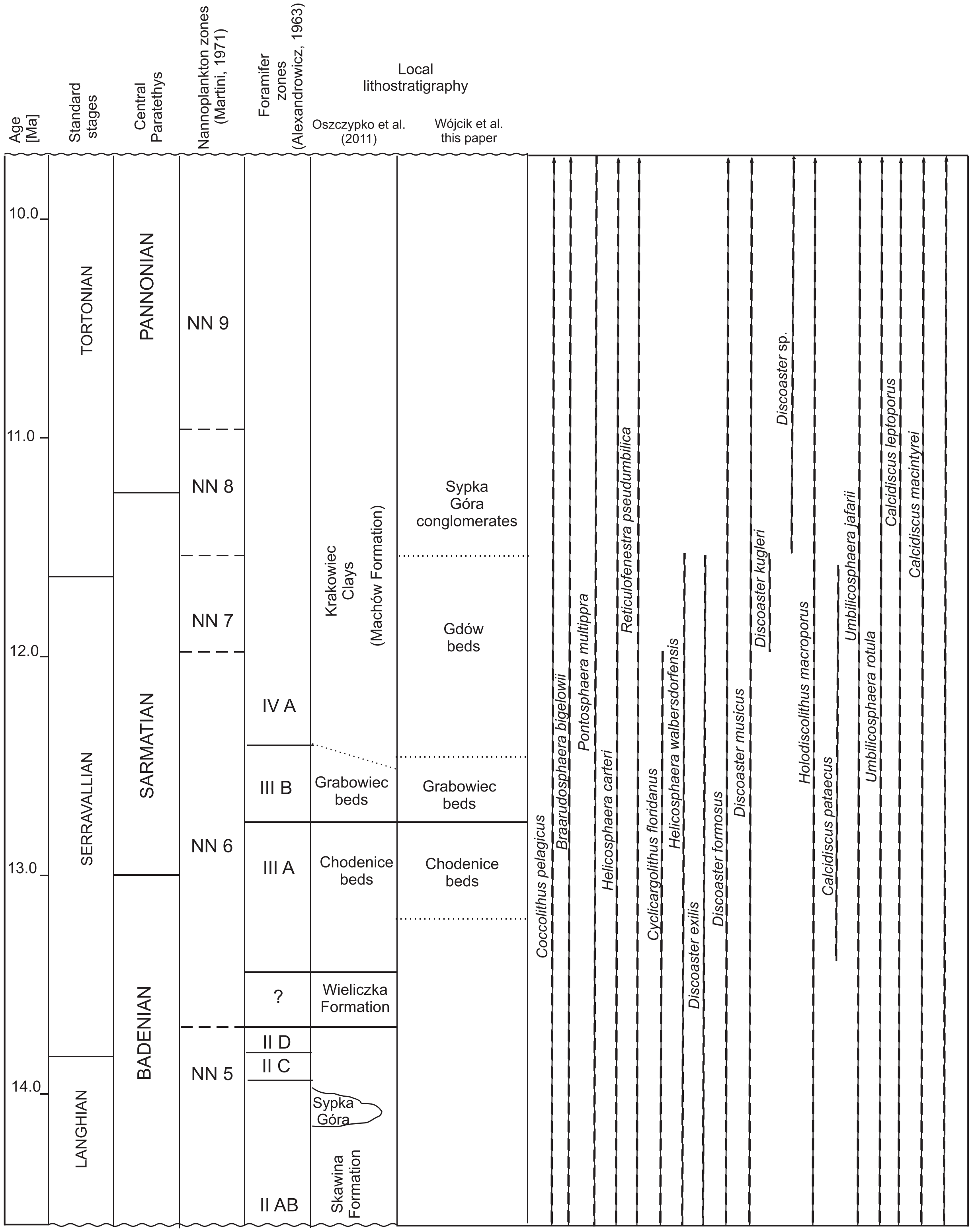

Fig. 10. The local Middle and Upper Miocene stratigraphy of the Carpathian Foredeep in comparison with the standard global chronostratigraphy

Moldavian Phase, when the folding, detachment and thrusting of the Zgłobice Nappe over the autochthonous Miocene deposits took place. Currently, data from the Andrychów and Gdów regions show that sedimentation was still ongoing in the Late Miocene (Pannonian), but the sediments were preserved only in some places whereas in a significant part of the area they had been eroded. The tectonically deformed (folded) Upper Miocene deposits indicate the post-Sarmatian age of the last stages of thrusting of both the Carpathians and the Zgłobice Nappe over the autochthonous deposits of the Carpathian Foredeep.

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