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CORRELATION OF LATE BADENIAN SALTS OF THE WIELICZKA, BOCHNIA AND KALUSH AREAS (POLISH AND UKRAINIAN CARPATHIAN FOREDEEP)

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Abstract: Within the Carpathian Foredeep, open marine basin evolved into restricted evaporitic basin during the Badenian (Serravallian), and along the Carpathian front chloride sub-basins developed. The studies of foraminifera and calcareous nannoplankton were conducted to obtain new biostratigraphic data which could constrain the age and correlation of the salt deposits between Wieliczka–Bochnia in Poland, and Kalush in the Ukraine. These studies proved that chloride deposits (in the Ukrainian territory also potassium salts) originated generally during the same period corresponding to the Late Badenian NN6 zone and undivided NN6–NN7 zone. The uppermost part of sub-evaporitic beds belongs to the boundary between the NN5 and NN6 zones, although locally (Bochnia Salt Mine) only the NN6 zone was found. This suggests that the lower boundary of salt deposits can be diachronous. Deposits overlying the salt (Chodenice and lowermost part of Grabowiec beds – Bogucice Sands) represent the Late Badenian NN6/NN7 zone. The similarity in age between the folded Middle Miocene strata in Poland (Zgłobice Unit) and the Ukraine (Sambir Unit) implies that they were folded during the same time and that they can represent one tectonic unit, developed in front of the advancing Carpathian orogen.

Key words: biostratigraphic dating, salt deposits, Middle Miocene, Carpathian Foredeep, Poland, Ukraine.

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INTRODUCTION

The age and position of evaporitic deposits in the Carpathian Foredeep Basin play an important role in understanding the palaeogeography and tectonics of the Outer Carpathians and their foreland. For a long time it has been believed that chloride facies in the Wieliczka–Bochnia and in Kalush areas were deposited in different time. In the Wieliczka–Bochnia area, the salt deposits (Wielician stage) were considered to be of the Middle Badenian age (Łuczkowska, 1978; Garlicki, 1979), while in the Sambir Unit they were considered to be of the Karpatian (Late Helvetian; Chlebowski, 1947; Burov *et al.*, 1978; Kruglov, 1978) or the Early Badenian age (see Dzhinoridze, 1980). However, new data imply the mid-Badenian age also for the salt from the Sambir Unit (Andreyeva-Grigorovich & Kultchytsky, 1984; Andreyeva-Grigorovich *et al.*, 1997, 1999) and from its continuation towards the Sub-Carpathian Unit (Crihan 1999; Marunteanu, 1999) and Transylvanian Basin in Romania. According to Balintoni & Petrescu (2002), the halite precipitation in the Transylvanian Basin took place in the 13.6–13.4 Ma time interval, during the lower part of the NN6 zone. This time interval corresponds to the eustatic third-order cycle 2.5 within Tejas B2 (Haq *et al.*, 1987). Salt deposits in the East Slovakian Basin (Bukowski *et al.*, 2003) are probably of similar age.

The aim of the present paper is to constrain the age of salt deposits and to present the results of a new biostratigraphic correlation based on foraminifera and calcareous nannoplankton. This project involved the Institute of Geological Sciences of the Jagiellonian University in Kraków, the Institute of Geological Sciences of National Academy of Sciences of the Ukraine in Kyiv, and the Geological Research Institute in Lviv, Ukraine, and it commenced in 2001. Preliminary results were presented at the XVII Congress of Carpathian-Balkan Geological Association in Bratislava (Andreyeva-Grigorovich *et al.*, 2003).

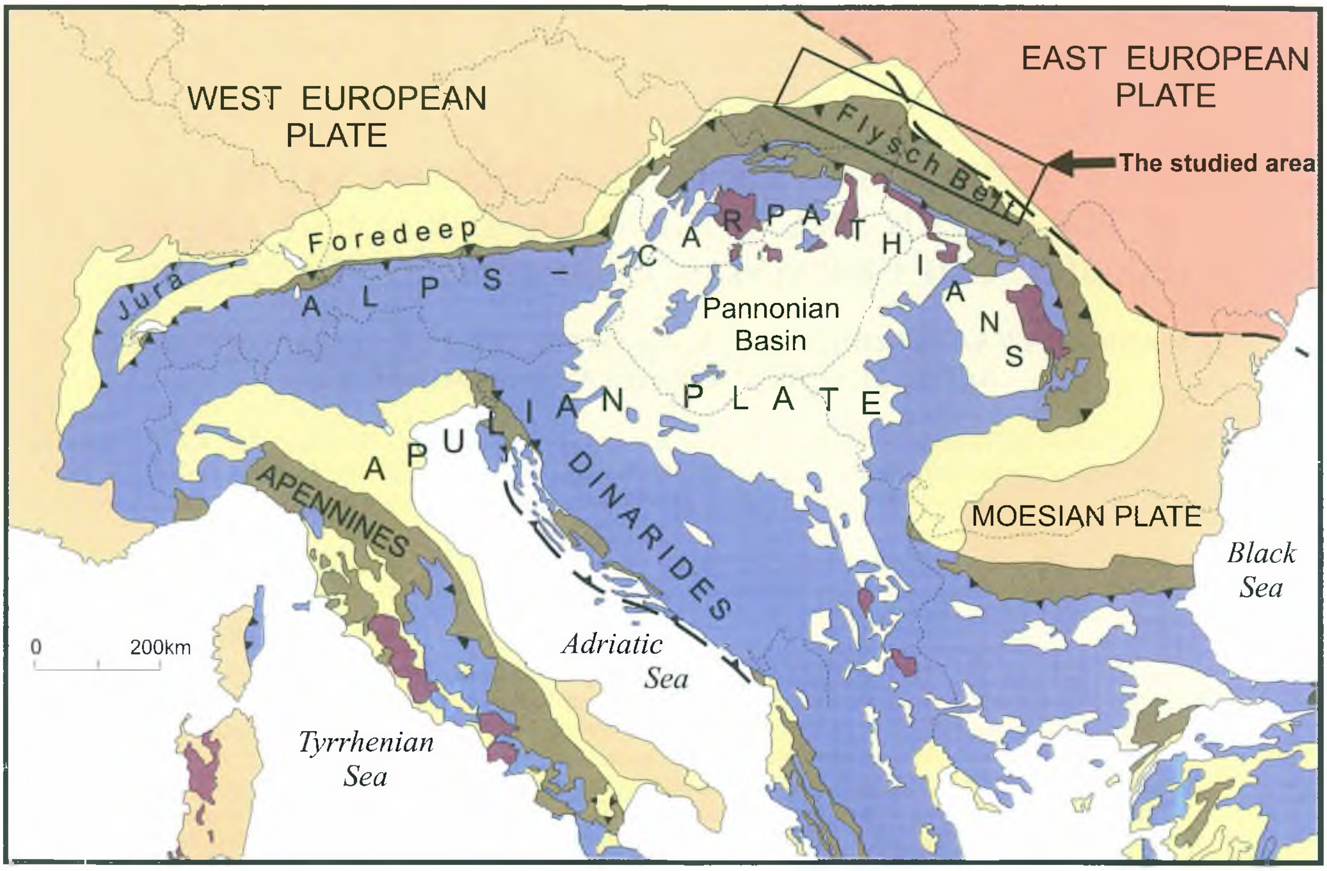


Fig. 1. Generalized map of the Carpathian and Alpine area and their foreland (after Picha, 1996; simplified)

GEOLOGICAL SETTING

The Carpathian Foredeep Basin (CFB) (Fig. 1) belongs to the Central and probably Eastern Paratethys biostratigraphic province of Central and Eastern Europe (Kovač *et al.* 1998). It was developed in front of the advancing Carpathian orogen on the southern edge of the North European Platform (Oszczypko & Ślączka, 1985; Oszczypko, 1998), and the SW edge of the East European Platform. The CFB can be subdivided into two sub-basins: the inner and outer ones. The inner sub-basin is generally composed of Lower and Middle Miocene continental, brackish and marine deposits, bearing two distinct evaporitic horizons. The outer sub-basin is filled with Middle Miocene (Badenian and Sarmatian), mainly marine strata. During the Early Miocene, older evaporitic deposits developed in the eastern part of the inner sub-basin (Boryslav-Pokutya Unit in the Ukraine, and Marginal Fold Unit in Romania), whereas during the Late Badenian younger evaporitic deposits formed an wide area spreading from Upper Silesia in Poland (Garlicki, 1994) to Doftana Valley in Romania (Crihan, 1999; Marunteanu, 1999; Marunteanu *et al.*, 1999). During that time, the evaporatic deposition took place both in the inner and outer sub-basins, as well as on marginal part of the Outer Carpathians (Skole Unit in Poland and Tarcau Unit in Romania). The Badenian evaporatic deposits also developed in the Transylvanian Basin (Balintoni & Petrescu, 2002), East-Slovakian Basin, and Trans-Carpathian Basin in the Ukraine.

As an effect of Miocene tectonic movements, a narrow zone of the folded Miocene strata composed of Badenian evaporatic deposits developed along the Carpathian thrust (Fig. 2). This zone is represented by the Zgłobice Unit in Poland (Fig. 3), Sambir Unit (Fig. 4) in the Ukraine, and Sub-Carpathian Unit in Romania. These units were overthrust on the autochthonous Miocene deposits of the more external part of the foredeep. Within the Polish part of the foredeep, the folded Miocene zone is less than 2 km wide (Fig. 4), in the Ukrainian part it is up to 24 km wide, whereas in the Kalush area three flat-lying thrust-sheets can be distinguished (Fig. 5).

Polish Carpathian Foredeep

In the Polish Carpathian Foredeep Basin (PCFB), the Badenian strata rest directly on the platform basement, except for the SE part of the inner foredeep, where they cover the Lower Miocene strata (Oszczypko, 1998; Oszczypko *et al.*, in print). According to biostratigraphic analyses (Alexandrowicz, 1958, 1961, 1963; Łuczkowska, 1958, 1978, 1995), the Skawina beds represent the Early Badenian, and the Chodenice and Grabovian beds represent the Late Badenian. Usually, the "Lower Badenian" (Ney, 1968; Ney *et al.*, 1974) begins with a thin layer of conglomerates, however, in the western part of the foredeep the Dębowiec Conglomerates are up to 100 m thick. These conglomerates pass upwards into dark, clayey-sandy sediments (Skawina For-

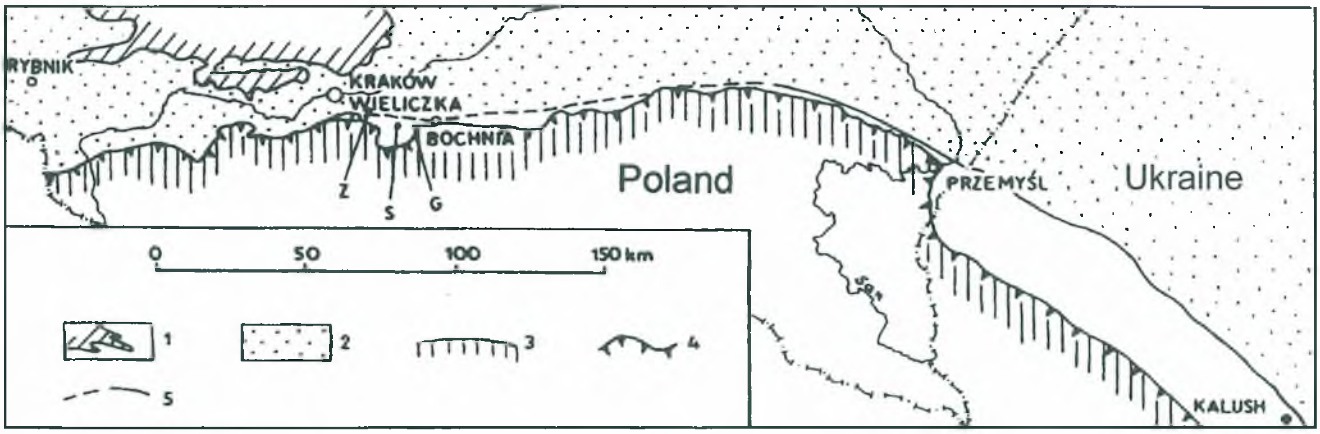


Fig. 2. Sketch-map of the Carpathian Foredeep and location of investigated places (based on Garlicki, 1979): *1* – boundary of Carpathian Foredeep deposits, *2* – autochthonous Miocene deposits in Poland, *3* – Carpathian orogen, *4* – Carpathian frontal thrust, *5* – outer boundary of the folded Miocene (Wieliczka–Zgłobice Unit in the West and Sambir Unit in the East); Z – Zabawa, S – Sułków, G – Gierczyce

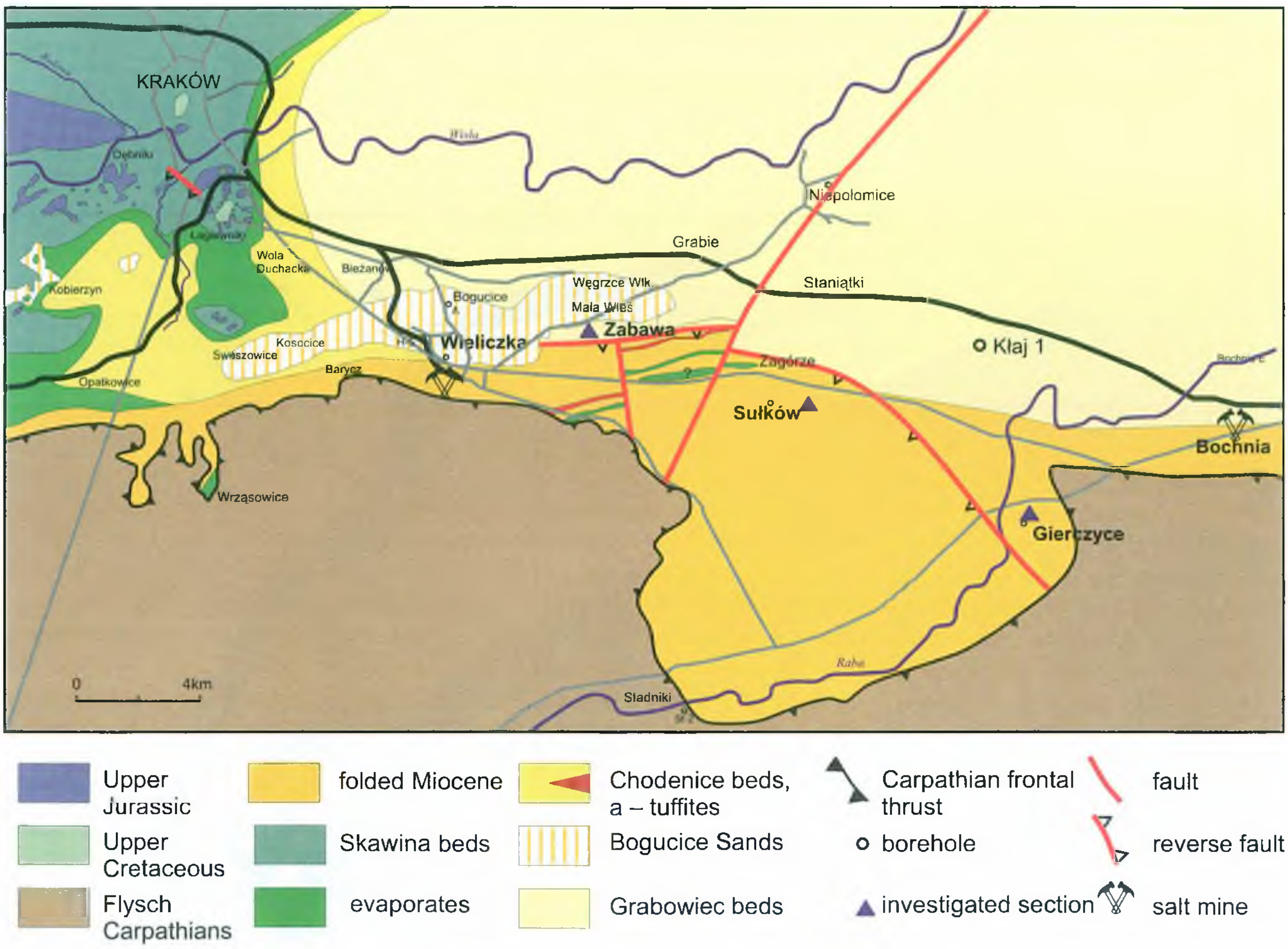


Fig. 3. Geology of the Wieliczka–Bochnia area and location of sampling sites (after Porębski & Oszczypko, 1999; simplified)

mation). The thickness of the "Lower Badenian" strata is variable, reaching up to 1,000 m in the western inner foredeep, whereas in the remaining parts of the foredeep it rarely exceeds 30–40 m (Ney *et al.*, 1974). Sedimentation of the Skawina Fm. began in the inner foredeep with *Praeorbulina glomerosa* zone (N 8), whereas in the outer one with the *Orbulina suturalis* (N 9 or N 10) zone (Garecka *et al.*, 1996; Olszewska, 1999; see also Oszczypko, 1997). According to calcareous nannoplankton studies, this formation belongs to the NN 5 zone, and in its uppermost part to the

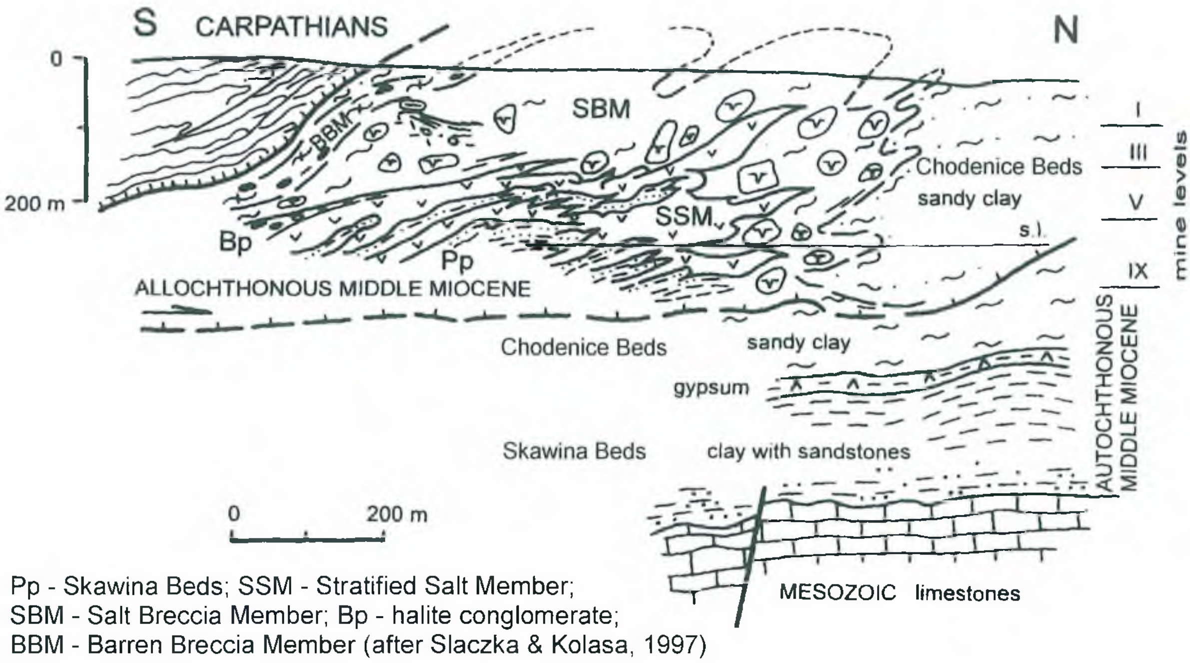


Fig. 4. Cross-section through the Wieliczka Salt Mine (after Ślączka & Kolasa, 1997)

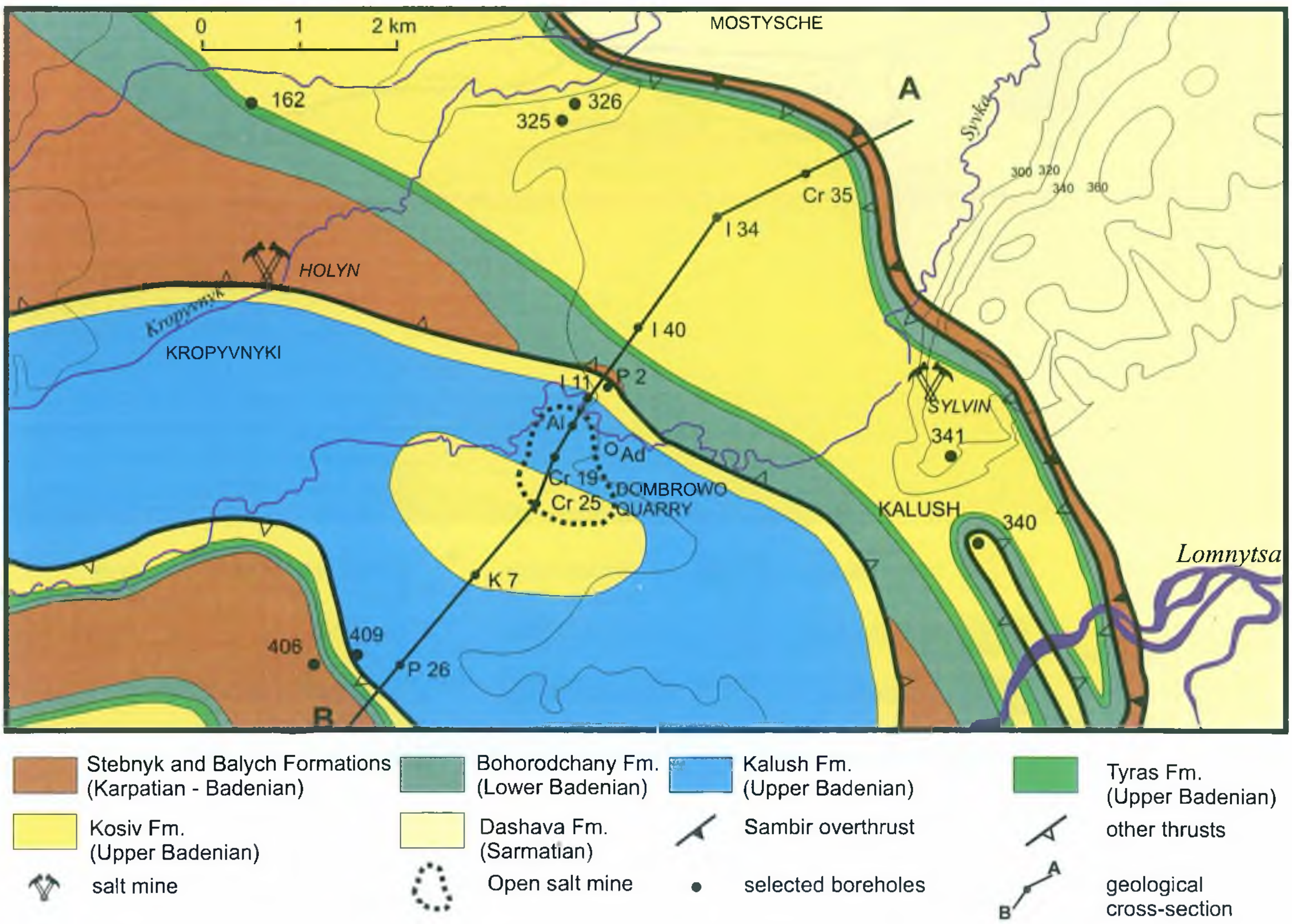


Fig. 5. Geological sketch-map of the Kalush area and location of sampling sites (partly after Glusko & Kornieyeva, 1953)

NN 6 zone (Andreyeva-Grigorovich *et al.*, 1997, 1999). The radiometric age of a tuffite layer from the uppermost part of the Skawina Fm. in the Wieliczka Salt Mine (WT-1; Bukowski, 1999) has been determined as 12.5±0.9 Ma. The Badenian evaporate horizon either overlies this formation or rests directly upon the platform basement. This horizon consists of rock salts, claystones, anhydrites, gypsum and marls. Between Wieliczka and Tarnów, the thickness of salts attains 70–110 m (Garlicki, 1968; Bukowski & Szaran, 1997), and decreases towards the east to a few dozen meters, whereas the thickness of gypsum and anhydrites commonly varies between 10 and 30 m.

The Badenian evaporite deposits in the PCFB are included into two formations: Krzyżanowice Formation (anhydrites) and Wieliczka Formation (salts) (Alexandrowicz *et al.*; 1982, Garlicki, 1994).). According to foraminiferal study, the Krzyżanowice and Wieliczka Formations belong to the Badenian assemblage of the *Uvigerina costai* zone (Łuczkowska, 1978, 1995; Łuczkowska & Rolewicz, 1990; Olszewska, 1999).

Based on the calcareous nannoplankton study, the evaporites were included into the NN6 zone (Dudziak & Łaptaś, 1991) or into the NN7 zone (Gaździcka, 1994). D. Peryt (1997) proved that the Badenian sulfates in the Gliwice region represent the lower part of the NN6 zone and, subsequently, she found that also the evaporites in the Bochnia Salt Mine and in several boreholes in southern Poland contain a calcareous nannoplankton assemblage which is characteristic for the NN6 zone (D. Peryt, 1999). Recently, Andreyeva-Grigorovich *et al.* (1999, 2003) have found that the evaporites in the Bochnia, Wieliczka and Kalush deposits belong to the NN6 zone.

The evaporate horizon passes upwards into the Upper Badenian–Sarmatian (NN6/7 to NN 8/9 zones; *cf.* Gaździcka, 1994; Andreyeva-Grigorovich *et al.*, 1999; see also Olszewska, 1999) sand-silty deposits with a thick sandstone complex at the base. Their thickness ranges from a few hundred metres in the Tarnów area up to 3,000 m near Przemyśl. In the Rzeszów area, these deposits rest directly on the platform basement. In the Kraków–Bochnia region the salt deposits are covered by clays and mudstones (Chodenice beds), passing upwards into sand-clayey complex (Grabowiec beds) bearing a sandy lithosome (Bogucice Sands) in the lower part (Porębski & Oszczypko, 1999). The Chodenice beds contain a few intercalations of tuffites. The radiometric age of these tuffites is around 12 Ma BP (Van Couvering *et al.*, 1981). In the northern, marginal part of the PCFB the Early Sarmatian littoral carbonate and clastic deposits are well preserved.

The foraminifera and calcareous nannoplankton of the Sambir (Stebnik) Unit in the PCFB have been studied by Garecka & Olszewska (1997). The foraminiferal assemblages of the Balych beds are composed of: *Globorotalia scitula*, *Globigerinoides trilobus*, and *Dentoglobigerina langhiana*, wheras nannoplakton assemblages indicate a Badenian age. The Balych beds are overlain by the Early Badenian Przemyśl beds, which are an equivalent of the Skawina Formation. The evaporate sediments of the Sambir Unit in Poland are practically devoid of fossils (Garecka & Olszewska, 1997).

Ukrainian Carpathian Foredeep

In the Ukrainian Carpathian Foredeep Basin (UCFB), the Badenian and Sarmatian strata occur both in the folded allochthonous Miocene (Sambir Unit), as well as autochthonous deposits of the Bilche-Volytsa Zone, resting on the platform basement. Locally, the Badenian strata represent a posttectonic cover overlying the folded Carpathians (Skole–Skyba Unit).

In the Sambir Unit, which is up to 24 km wide, the Early Miocene sediments underlie the Badenian sediments. They begin with conglomerates (Sloboda Formation), covered by shallow water and brackish clays, mudstones and sandstones (Dobrotiv Formation; up to 400 m thick) of Eggenburgian (Smirnov *et al.*, 2000) or Ottnangian age (Andreyeva-Grigorovich *et al.*, 1997). Subsequently, there occurs an Ottnangian sequence of variegated marls, and sandstones (Stebnyk Formation), up to 2,500 m thick, passing upwards into greenish-grey clays, mudstones, and sandstones (Balych beds; up to 2,000 m in thickness) representing the Karpatian and lowermost Badenian (zone NN4; Andreyeva-Grigorovich *et al.*, 1997). The Lower Badenian boundary between the mentioned series is probably diachronous.

The Badenian (zone NN5; Andreyeva-Grigorovich & Kulchytsky, 1985) within the Sambir Zone starts with a complex of grey clays, marls and sandstones (Bohorodchany Formation; up to 250 m in thickness), with intercalations of Lithothamnium limestones and tuff layers representing the Early Badenian.

In the Bilche-Volytsa Zone, the Miocene transgression starts with glauconitic sand and sandstones, passing into marls, mudstones and clays (Zhuriv Formation, up to 70 m in thickness) of the Early Badenian age (zone NN5; Andreyeva-Grigorovich *et al.*, 1997). Above these early Badenian sediments, a complex of evaporate deposits (Tyras Formation) is developed throughout the foredeep. They are represented by gypsum and anhydrites with clays and limestones, and locally by rock salt and potassium salt deposits. Generally, the salt was deposited in deeper (up to 100 m), southern part of the foredeep, now incorporated into the folded Sambir Unit, and gypsum – in more shallow parts, mainly in the Bilche-Volytsa Zone. There is an opinion, however, that also gypsum could have been deposited in deep basins (Smirnov *et al.* 1995). In the Bilche-Volytsa Zone, small separate salt basins are known from the vicinity of Kolomya (Korshiv Depression) and Kosiv (Glushko & Kruglov eds., 1971). The salt deposits, apart from precipitated deposits, halite and potassium salt, contain also intercalations of redeposited salt (Peryt & Kovalevich, 1997). Basinal evaporates with salt display thicknesses ranging from tens of metres up to 200 m, whereas those of gypsum are from 10 to 300 m.

The age of the evaporatic sequence has been controversial for a long time. The Early Badenian age inferred from micropalaeontological studies was proposed for salt deposits by Sierova (1950); nevertheless, several authors (*e.g.*, Burov *et al.*, 1978; Kruglov, 1978) regarded the Kalush salts as being of an Early Miocene age, and stated that the salt was older than the Tyras gypsum. Only age of the upper part of salt deposits in the Korshiv Depression was accepted as

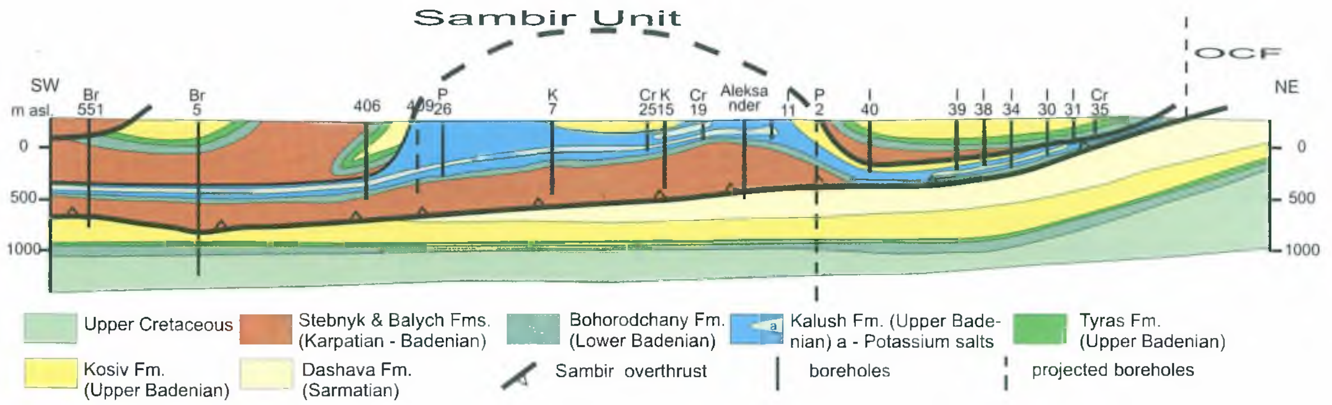


Fig. 6. Cross-section through the Kalush Salt Mine (partly after Chlebowski, 1947)

the Late Badenian (Glushko & Kruglov eds., 1971). Dzhinoridze (1980) correlated gypsum horizon (Tyras Fm.) with the salt sequence and regarded all of them as the Badenian. More recently, the evaporites and related deposits in the UCFB have been included into the Tyras Suite (Fm.) (Petryczenko *et al.*, 1994). Calcareous nannoplankton studies (Andreyeva-Grigorovich & Kulchytsky, 1985) established that salt deposits were situated between the NN5 and NN6/7 zones. Subsequent research (Andreyeva-Grigorovich *et al.*, 1997) suggested that the evaporatic sequence can also embrace the NN5 zone. However, an opinion still exists that the evaporatic sequence represents Middle Badenian (Smirnov *et al.*, 2000). Petrichenko *et al.* (1997) proposed that gypsum deposits in the marginal part of the basin correspond to the upper part of the evaporatic sequence in the basin centre. Determination of the radiometritic age of potash minerals from the Kalush mine varies from 6 to 14.5Ma, however, this age for most of the langbeinite samples varies from 13.6 to 14.6 Ma, only (Wójtowicz *et al.*, 2002), corresponding to the Late Badenian (cf. Fig. 6).

In the north-western part of the Sambir Zone, the evaporatic horizon was not found what suggests that locally in the foredeep basin there were no conditions for evaporatic sedimentation. Limestones (Ratyn Limestones) in the

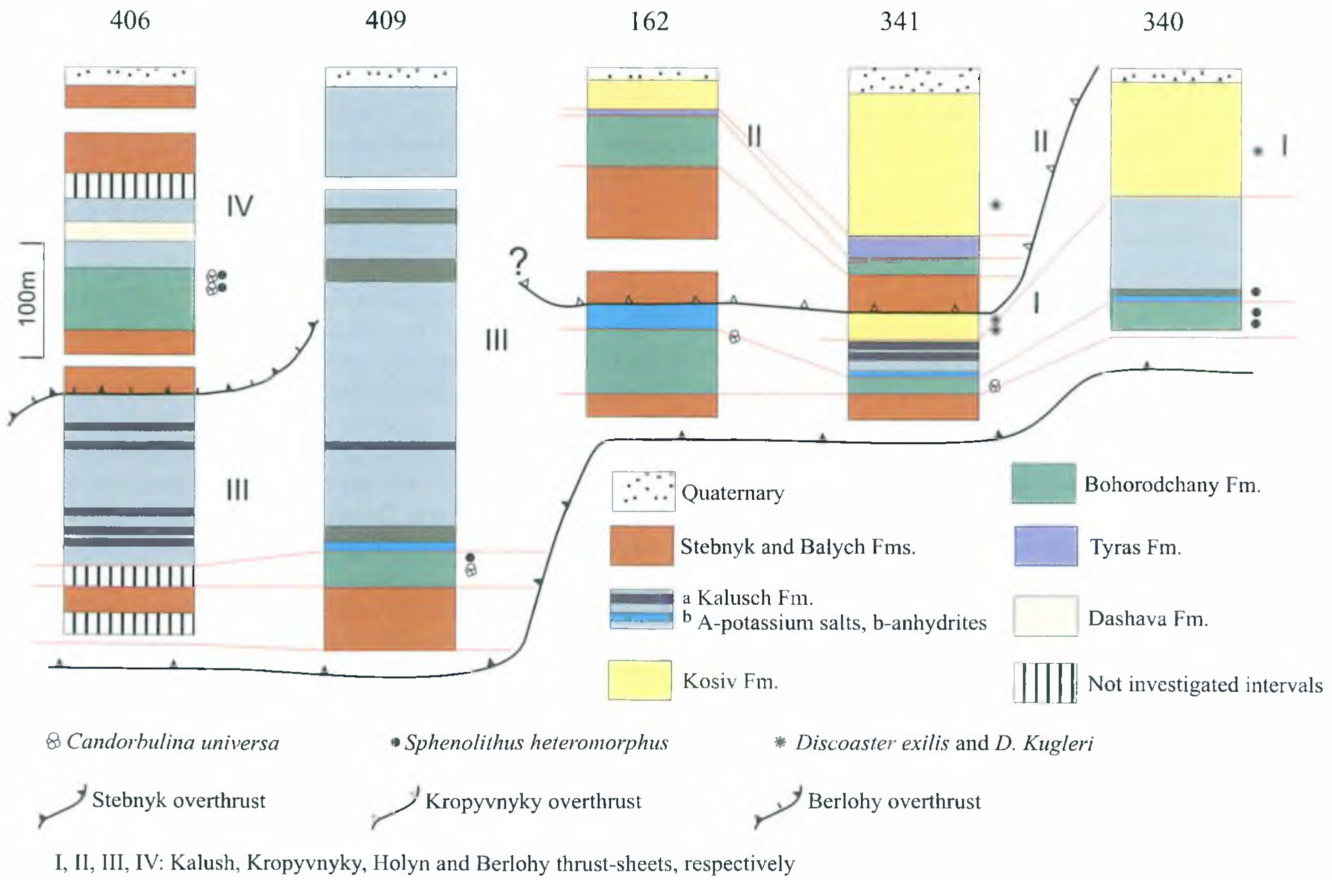


Fig. 7. Stratigraphy of Miocene deposits from selected boreholes in the Kalush area and sampling sites in borehole Kalush 340 (after Dzhinoridze, 1980; Andreyeva-Grigorovich & Kulchytsky, 1985; supplemented)

northern part of the Bilche-Volytsa Zone replaced a part of gypsum.

The evaporatic deposits are capped by grey clays and sandstones with tuff intercalations (Kosiv beds; up to 200 m) of the Late Badenian–earliest Sarmatian age (NN 6/7 zone). Nevertheless, the nannoplankton zone NN5 was noted as well (Andreyeva Grigorovich *et al.*, 1997), but it is undoubtedly redeposited. Intercalations of sandstones and conglomerates (Pistynka Conglomerates) occur locally in the Bilche-Volytsa Zone (Pistynka and Rybnytsa rivers). The Radych Conglomerates near Dobromil in the Sambir Zone are regarded as their equivalent (Andreyeva-Grigorovich *et al.*, 1997). The Sarmatian deposits occur mainly in the Bilche-Volytsa Zone and are represented by grey clays with sands and sandstones, and in higher part contain tuffite intercalations.

Another view of the lithostratigraphy of the whole sequence above the Dobrotiv beds, up to the Radych Conglomerates, was presented by Smirnov *et al.* (2000). According to them, a single litostratigraphic unit, named Kalush beds, represents deposits of the timespan extending from the Eggenburgian to the Late Badenian, and contains several intercalations of evaporates.

LOCATION OF SAMPLES

The study concentrated in the Wieliczka–Bochnia area and in the Kalush region, and focused on clay intercalations within evaporate deposits and sediments below and above the salt complex. Several sections have been investigated.

In the Polish Carpathian Foredeep, five sections were subject to detailed sampling (Fig. 3). In the Wieliczka Salt Mine, samples from sub-evaporate strata (Skawina beds) were collected along the Gerant Gallery and in the vicinity of the Szwinder Schaft. Samples from the oldest salt were taken in the August Gallery, samples from clay intercalations within the Green Salt – along the Franz Mueller Gallery (lower part of the Stratified Salt Member), and those from the Spiza Salt (upper part of the Stratified Salt Member) – along the August Gallery. The Salt Breccia Member was sampled along the August Gallery. In the Bochnia Salt Mine, samples were collected from level IV, along the Krystian Gallery (Skawina beds and upper part of the southern salt), and in the vicinity of the Campi Schaft (Skawina beds with tuffite intercalations). At Sułków, samples were picked out from the Chodenice beds that are exposed in an old quarry in the vicinity of tuffite intercalations, and at Gierczyce also from the Chodenice beds, from an old quarry situated behind the brickyard. At Zabawa, samples were taken from clay intercalations within the Bogucice Sands exposed along the creek (see Porębski & Oszczypko, 1999).

In the Ukrainian Carpathian Foredeep, two sections were examined from the Sambir Unit (Fig. 2); one from borehole Kalush 340, where a complete sequence from sub-evaporate up to post-evaporate deposits was penetrated (Fig. 7), and the second one from post-evaporate clays exposed in the SE part of the Dombrowo Quarry, in the Kalush Salt Mine.

BIOSTRATIGRAPHIC RESULTS

The biostratigraphic research was based on calcareous nannoplankton and foraminiferal assemblages.

Methods

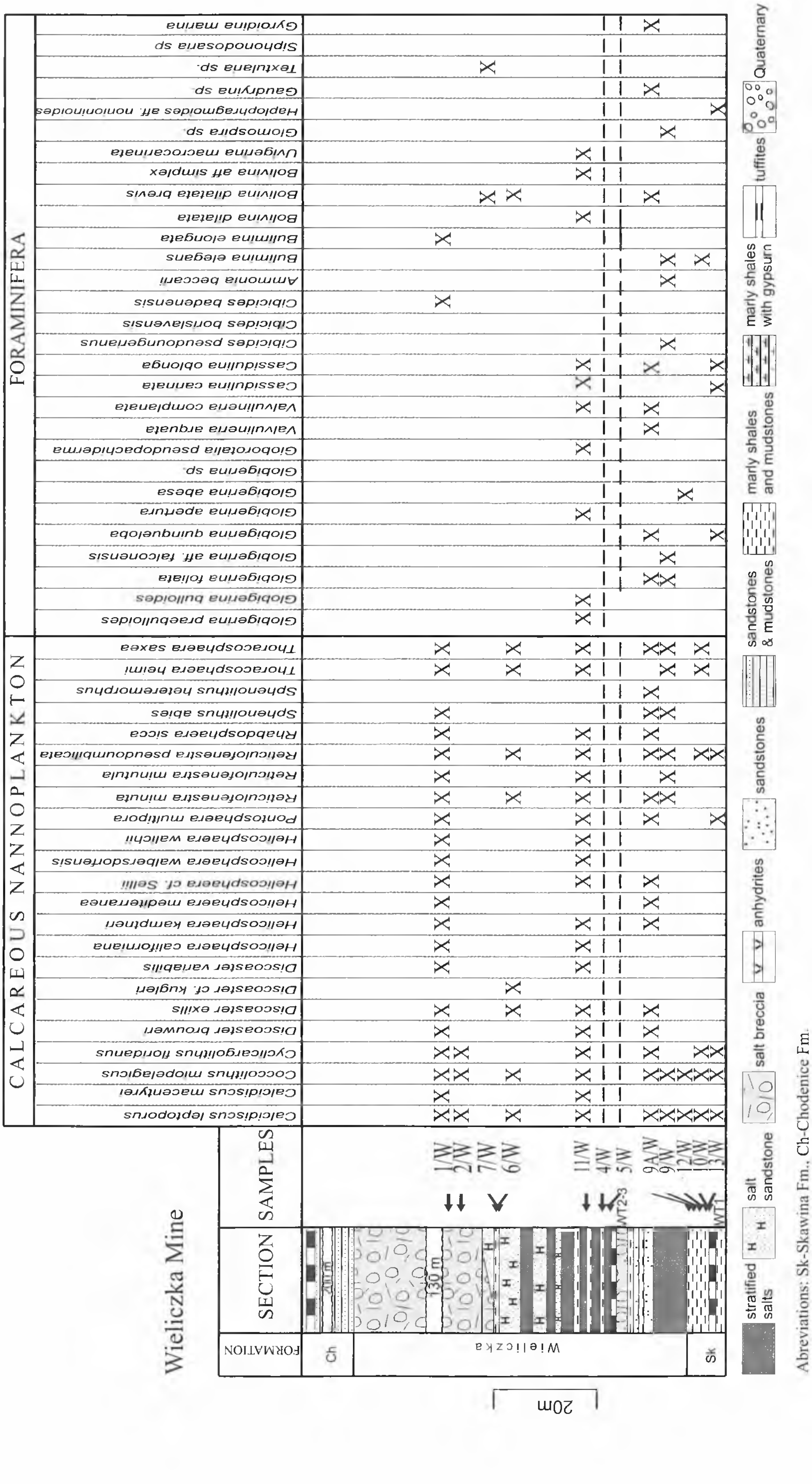
Calcareous nannofossils. Suspension slides were prepared from 62 samples using a decantation method (separated fraction 3–30 μm), in the following way: the heavy fraction was allowed to settle for 3 minutes in 45-mm water-column; the fine fraction for 45 minutes. Slides were inspected with a Axilab/ Carl Zeiss light-microscope at 1000x magnification. For the purpose of this work, the standard zonation of Martini (1971), Martini & Worsley (1970), and Sprovieri *et al.* (2002) was used.

Foraminifera. 58 samples for foraminiferal studies were disaggregated by repeated boiling and freezing using sodium carbonate solution. Then, they were washed over a 63 μm screen, and foraminifera were picked up from the >125 μm fraction. The 63–125 μm fractions were also examined, but they did not contain identifiable foraminifera. The number of specimens, the species diversity, and the state of preservation varied from sample to sample. In case of poor samples, the whole material was examined for foraminiferal content. Figures 17–20 with nannoplankton and foraminiferal contents contain only those samples which yielded more significant microfossils.

Nannoplankton data

A nannoplankton assemblage belonging to the boundary between NN 5 and NN 6 zones, and to the lower part NN 6 zone has been established in the marly clays below salt deposits (Skawina Fm.) of the Wieliczka (Fig. 8) and Bochnia (Fig. 9) sections, and also in the lower part of the salt deposits in Wieliczka. The nannoplankton association contains the most abundant species, such as: *Coccolithus pelagicus* (Wall.), *C. miopelagicus* Bukry, *Calcidiscus leptoporus* (Murray & Black.), *Cyclicargolithus floridanus* (Roth. & Hay) Bukry, and *Reticulofenestra pseudoumbilicus* (Gartner). Less common, but particularly notable, are: *Calcidiscus premacintyrei* Theodoridis, *Coronocyclus nitescens forma elliptica* (Kampt.), *Discoaster exilis* Mart. & Braml., *D. brouweri* Tan, *Helicosphaera carteri* (Wall.), *H. walbersdorfensis* Muller, *Sphenolithus abies* Defl., *Umbilicosphaera rotula* (Kampt.) Varol. *Sphenolithus heteromorphus* Defl. and *Discoaster* cf. *kugleri* Mart. & Braml. are very rare.

Grey calcareous shales (Bohorodchany beds) in the sub-evaporate deposits from the Kalush area (borehole Kalush 340, Fig. 10) contain calcareous nannoplankton representing the NN 6 zone. There occur: *Coccolithus pelagicus* (Wall.), *Cyclicargolithus floridanus* (Roth & Hay) Bukry, *Discoaster variabilis* Mart. & Braml., *D. exilis* Mart. & Braml., *Calcidiscus leptoporus* (Murray et Black.), *Helicosphaera carteri* (Wall.), *Pontosphaera multipora* (Kampt.), *Rhabdosphaera sicca* (Str.), and *Reticulofenestra pseudoumbilicus* (Gartner) (>7 μm).



Abreviations: Sk-Skawina Fm., Ch-Chodenice Fm.

Fig. 8. Distribution of calcareous nannoplankton and foraminifera in the Wieliczka Salt Mine sequence and location of samples with their numbers (lithostratigraphy partly after Bukowski, 1999)

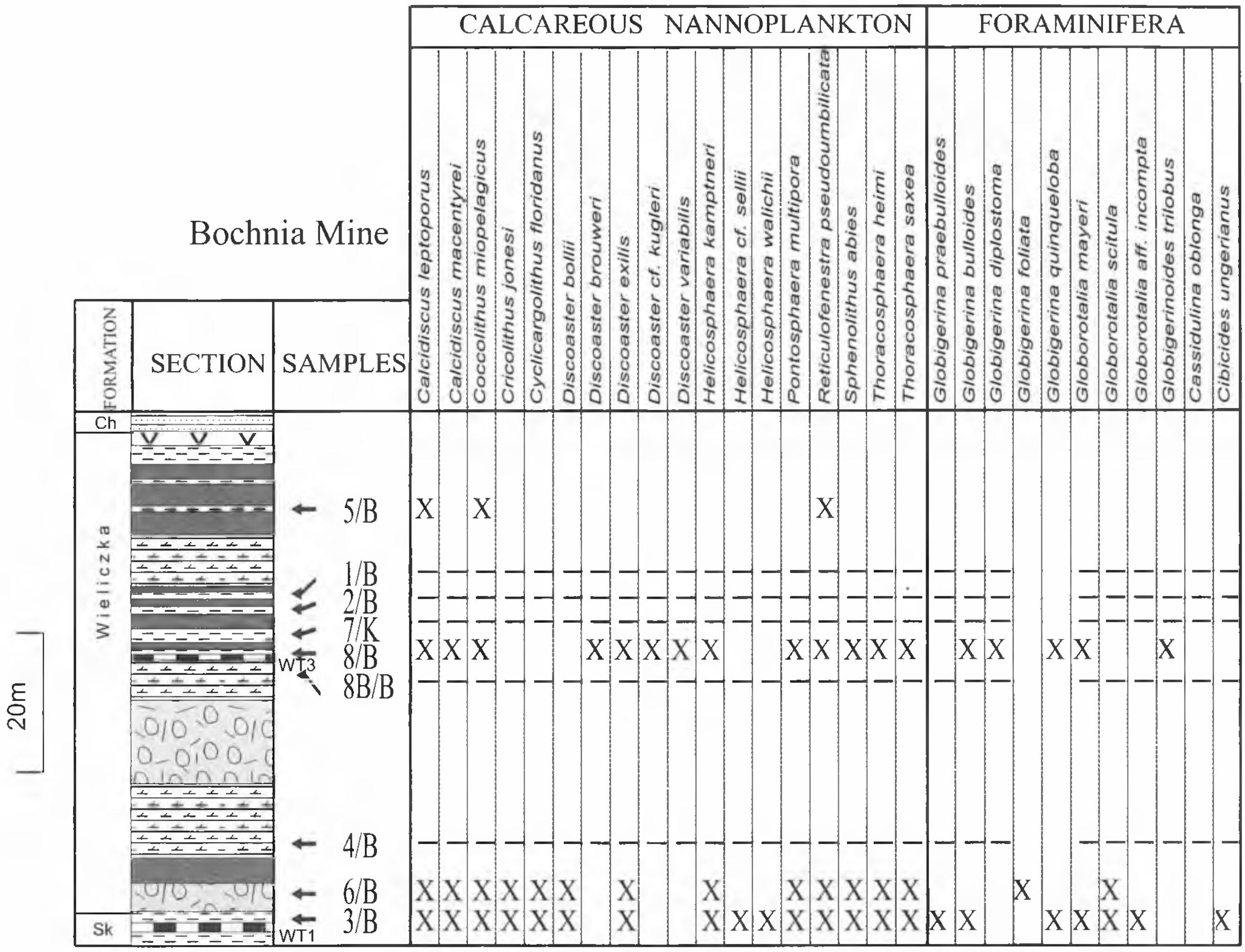
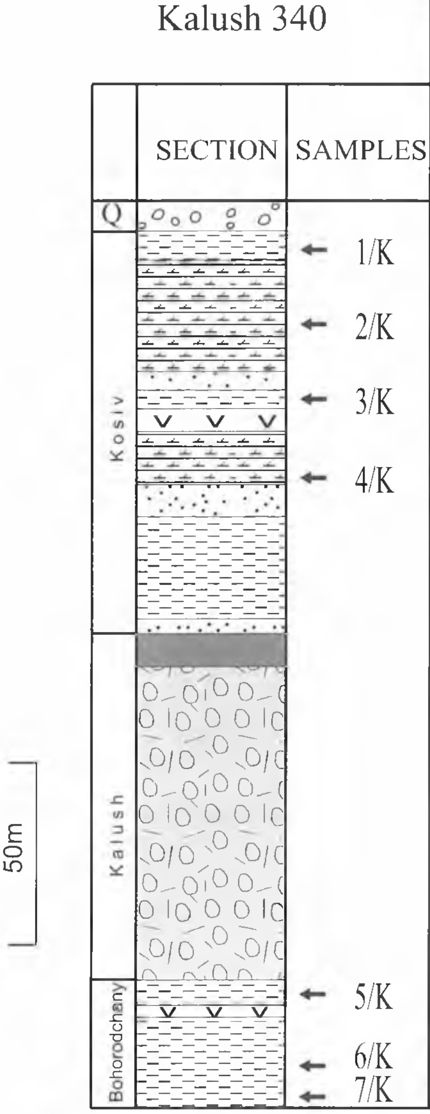


Fig. 9. Distribution of calcareous nannoplankton and foraminifera in the Bochnia Salt Mine sequence and location of samples with their numbers (lithostratigraphy after Bukowski & Szaran, 1997). For explanations – see Fig. 8

In a mudstone intercalation within the Green Salt Complex (Stratified Salt Member) above or near tuffite horizon WT 3, in the Wieliczka and Bochnia Salt Mines, nannoplankton assemblages belonging to undivided zones NN 6–NN 7 have been found (Figs. 8, 9). The most common species are: *Calcidiscus leptoporus* (Murray & Black), *Coccolithus pelagicus* (Wall.), *C. miopelagicus* Bukry, and *Reticulofenestra pseudoumbilicus* (Gartner) (7 µm); *Calcidiscus macintyrei* (Bukry & Braml.), *Discoaster exilis* Mart. & Braml., *D. variabilis* Martini & Braml., D. kugleri Mart. & Braml., *Helicosphaera carteri* (Wall.), *Sphenolithus abies* Defl., *Thoracosphaera heimii* (Lohm.) Kampt., and *Umbilicosphaera rotula* (Kampt.) Varol., being less common. A similar nannoplankton assemblage (NN 6–NN 7 zones) has been identified in the lower part of the Salt Breccia Member from the Wieliczka Mine (Fig. 8).

The nannoplankton assemblage from clays (Chodenice beds) above the evaporate horizon in the Sułków quarry, east of Wieliczka, contains: *Calcidiscus leptoporus* (Murray & Black.), *Calcidiscus macintyrei* (Bukry & Bramb.), *Helicosphaera carteri* (Wall.), *Reticulofenestra pseudoumbilicus* (Gartner), and *Sphenolithus abies* Defl. Less common or rare are: *Discoaster kugleri* Mart. & Braml., *Pontosphaera multipora* (Kampt.), *Holodiscolithus macroporus* (Defl.), *Scyphosphaera amphora* Defl., and *Braarudosphaera bigelowi* (Gran & Braar), which suggest the NN 6–NN 7 zone (Fig. 11). Similar nannoplankton assemblages that correspond to the NN 6–NN 7 zone have been found within the Bogucice Sands near Zabawa (Fig. 12). Very poor nannoplankton assemblages with *Coccolithus pelagicus* (Wall.), *C. miopelagicus* Bukry, *Calcidiscus leptoporus* (Murray & Black.), *Reticulofenestra pseudoumbilicus* (Gartner), *R.* sp. small, *Helicosphaera carteri* (Wall.), and *Umbilicosphaera rotula* (Kampt.) Varol., have been found in the Chodenice beds exposed in the Gierczyce brickyard (Fig. 13), within grey clays above the evaporatic sequence in the Kalush 340 borehole (Fig. 10), and in the Dombrowo salt quarry (Fig. 14). Although the species-markers are absent, these data suggest that the sediments belong to the zone NN 6–NN 7. The characteristic and important species from the sampled sites are presented on figures 17 and 18.



CALCAREOUS NANNOPLANKTON

Sample	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Calcidiscus macentyrei*	*Coccolithus miopelagicus*	*Cyclicargolithus floridanus*	*Discoaster brouweri*	*Discoaster exilis*	*Discoaster cf. kugleri*	*Discoaster variabilis*	*Discoaster sp.*	*Helicosphaera kamptneri*	*Helicosphaera obliqua*	*Helicosphaera perch - nielseniae*	*Helicosphaera walbersdorfensis*	*Pontosphaera multipora*	*Reticulofenestra pseudoumbilicata*	*Rhabdosphaera sicca*	*Sphenolithus abies*	*Sphenolithus heteromorphus*	*Scyphosphaera apsteinii*	*Umbilicosphaera jafari*	*reworked Cretaceous*	*reworked Eocene*
1/K		X		X	X						X					X		X				X	X
2/K		X		X	X						X					X		X				X	X
3/K		X		X	X						X					X		X				X	X
4/K	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
5/K		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6/K	X			X	X										X	X						X	X
7/K	X	X	X	X	X		X			X	X				X	X		X				X	X

Fig. 10. Distribution of calcareous nannoplankton in borehole Kalush 340 and location of samples with their numbers. For explanations – see Fig. 8

Foraminiferal data

In the sub-evaporate deposits (Skawina beds) in the Wieliczka Salt Mine (Fig. 8), the Badenian assemblage with *Globigerina foliata* Bolli, *G. cf. falconensis* Blow, *Turborotalita quinqueloba* (Natland), *Globigerinella obesa* (Bolli), *Valvulineria arcuata* (Reuss.), *V. complanata* (Orb.), *Cassidulina carinata* Cushm. et Park, *C. oblonga* Reuss, *Cibicides pseudoungerianus* Cushman., *Ammonia beccarii* (Linne), *Bolivina dilatata brevis* Cicha et Zapletal, and *Elphidium crispum* (Linne) have been found. Within the lower part of the Salt Breccia Member there exists an assemblage with *Globigerina praebulloides* Blow, *G. bulloides* Orb., *G. apertura* Cushman, *Globorotalia pseudopachyderma* Cita, Premoli-Silva et Rossi, *Valvulineria complanata* (Orb.), *Bolivina dilatata dilatata* Reuss, and *Uvigerina macrocarinata* Papp et Turnovsky, typical for the Late Badenian. Only in one sample an assemblage with *Siphonodosaria* sp., *Anomalinoides badenensis* (Orb.), *Bulimina elongata* Orb., and *Halicoryne morelleti* (Pokorny), showing an affinity to the lower part of the Early Sarmatian, is present. The assemblages from the Skawina beds and from evaporate sequence from the Bochnia Salt Mine correspond to the Late Badenian only (Fig. 9). They contain: *Globigerina praebulloides* Blow, *G. bulloides* Orb., *G. diplostoma* Reuss, *G. foliata* Bolli, *Turborotalita quinqueloba* Natl., *Globorotalia may-*

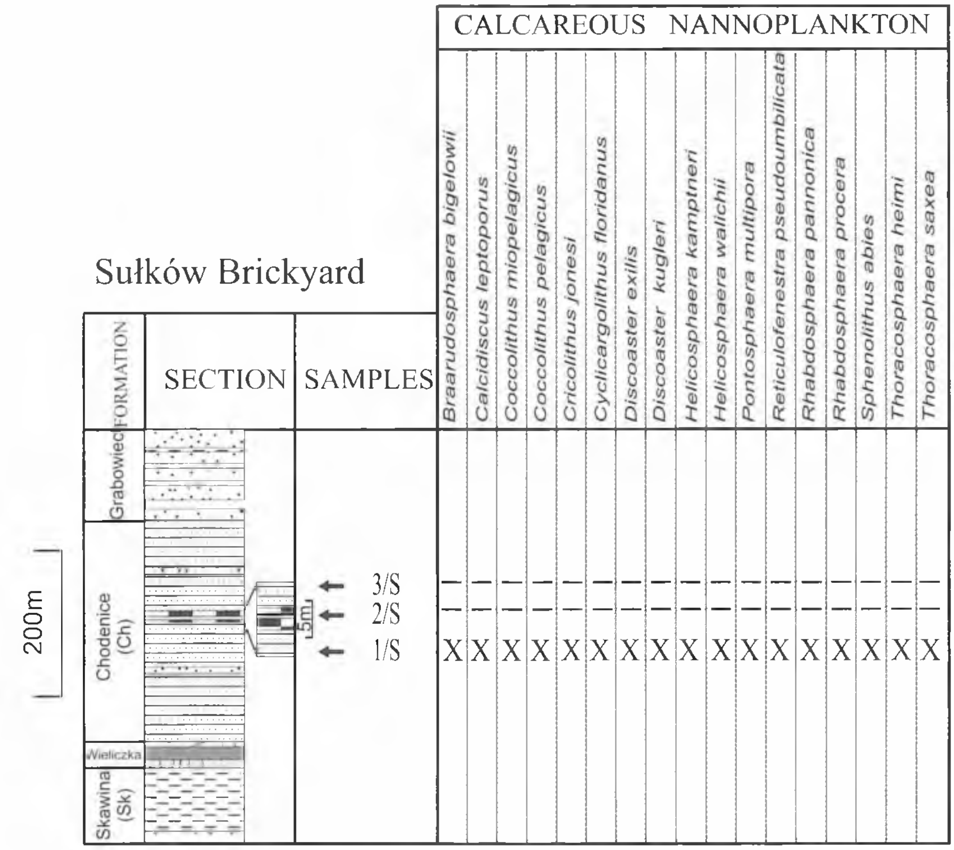


Fig. 11. Distribution of calcareous nannoplankton and foraminifera in a quarry sequence at Sułków and location of samples with their numbers. Explanations on Fig. 8

eri (Cushman et Ellis), *G. scitula* Brady, *Globigerinoides trilobus* Reuss., *Cassidulina oblonga* Reuss, and *Cibicides ungerianus* (Orb.).

The foraminiferal assemblages from the Sułków quarry are typical for the Late Badenian (Fig. 11), and contain: *Martinotiella communis* (Orb.), *Turborotalita quinqueloba* Natl., *Globorotalia mayeri* (Cushm. et Ellis.), *Bulimina elongata* Orb., *B. striata* Orb., *Bolivina dilatata* Reuss, and *B. aff. simplex* (Phleg. et Park).

In the Gierczyce brickyard, the Badenian foraminifera *Globigerina bulloides* Orb., *G. praebulloides* Blow, *G. juvenilis* Bolli, *Globorotalia aff. bykovae* (Aisen.), *Bulimina striata mexicana* Cushman, *Bitubulogenerina reticulata* Cushman, and *Elphidium macellum* (Ficht. et Moll) have been identified (Fig. 13), but they do not allow for a more precise age determinations of the host strata.

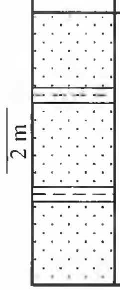
The foraminiferal assemblages from the clays situated above the evaporatic horizon in the Dombrowo quarry are similar to the Late Badenian ones (Fig 14). They contain: *Atriculina problema* (Orb.), *Quinqueloculina consobrina* Orb., *Globigerina juvenilis* Bolli, *Turborotalia quinqueloba* Natl., *Globigerinella regularis* (Orb.), *Bulimina gutsulica* (Liv.), *Angulogerina angulosa* (Will.), *Bolivina dilatata dilatata* Reuss., *Hanzawaia boueana* Orb., *Ammonia becarii* (Linne), and *Elphidium crispum* (Linne). The characteristic and important species from the sampled sites are presented on figures19 and 20.

CONCLUSIONS AND PALAEOENVIRONMENTAL IMPLICATIONS

The results of our biostratigraphic studies show that the age of salt deposits in Wieliczka and Bochnia area is a Late Badenian one, being contemporaneous with the Tyras salt in the Ukraine (Figs. 15, 16). Pelitic intercalations within salt deposits in Wieliczka, Bochnia, and Kalush areas contain calcareous nannoplankton assemblages corresponding to the NN6 zone and the undivided zone NN6–NN7, as well as foraminiferal assemblages corresponding to the Late Badenian. The sub-evaporatic beds in Wieliczka (the uppermost part of Skawina beds) belong to the transition zone between the NN 5 and NN 6 zones, and in the case of Bochnia Salt Mine and the Kalush 340 borehole section – to a lower part of the NN 6 zone. It implies that the lower boundary of salt deposits can be diachronous. Sediments overlying the salt sequence (Chodenice beds in the PCFB, and the examined lower part of the Kosiv beds in the UCFB) belong to the NN6/NN7 zone (Late Badenian/Early Sarmatian).

The occurrence of the Sarmatian-like foraminifera in the Salt Breccia Member of the Wieliczka Salt Mine sequence can be explained by redeposition of salt deposits by gravitational flow at the end of the Badenian and/or at the boundary between the Badenian and Sarmatian. However, it can be also explained by local development of brackish en-

Zabawa



		←Z2	←Z1
CALCAREOUS NANNOPLANKTON	*Coccolithus pelagicus*	x	x
	C. miopelagicus	x	x
	Calcidiscus leptoporus	x	x
	C. premacintyrei	x	x
	C. macintyrei	x	
	Cyclicargolithus floridanus	x	x
	Coronocyclus nitescens	x	x
	C. nitescens f. elliptica	x	x
	Reticulofenestra pseudoumbilicus	x	x
	R. spp. small f.	x	x
	Umbilicosphaera rotula	x	x
	Discoaster cf. kugleri	x	
	D. sp.		x
	Helicosphaera carteri	x	x
	H. walbersdorfensis	x	x
	H. intermedia		x
	Sphenolithus abies	x	x
	Pontosphaera multipora	x	x
	Syracosphaera pulchra	x	x
	Rhabdosphaera sicca	x	x
	Braarudosphaera bigelowi	x	x
	Holodiscolithus macroporus	x	x
	Calciosolenia murrayi	x	x
	Thoracosphaera spp.	x	x
	Reworked K	x	x
	Reworked P	x	x
	Reworked M	x	x
FORAMINIFERA	*Martinottiella cf communis*		x
	Stilostomella adolphina		x
	Sphaeroidina bulloides	x	
	Catapsidrax sp. (R)	x	
	Bolivina dilatata	x	
	Bulimina elongata	x	x
	B. subulata		x
	B. aff. insignis		x
	Uvigerina pudica		x
	U. cf. bononiensis		x
	Neoeponides schreibersi		x
	Cibicides ungerianus		x
	Lobatula lobatula		x
	Asterigerinata planorbis		x
	Heterolepa dutemplei	x	x
	Hansenisca soldanii	x	x
	Melonis pompilioides		x
	Porosononion granosum		x
	Ammonia beccarii	x	x
	Elphidium crispum	x	x
	E. fichtellianum	x	x
	E. flexuosum	x	

Sandstone Shale

Fig. 12. Distribution of calcareous nannoplankton and foraminifera in the Zabawa sequence and location of samples with their numbers

Gierczyce Brickyard

Group	Taxon (SAMPLE NUMBER →)	G2	G1	G3	G4	G6	G5
CALCAREOUS NANNOPLANKTON	*Coccolithus pelagicus*	x	x	x	x	x	x
	C. miopelagicus	x				x	x
	Cyclicargolithus floridanus	x	x	x	x	x	x
	Calcidiscus leptoporus						x
	C. premacintyrei				x		
	Coronocyclus nitescens						x
	Reticulofenestra pseudoumbilicus	x	x	x	x	x	x
	R. spp. small f.	x	x	x		x	x
	Umbilicosphaera rotula	x			x		
	Helicosphaera carteri	x			x		x
	H. intermedia					x	x
	H. walbersdorfensis						x
	Discoaster sp.	x			x		
	Sphenolithus cf. abies				x		
	Pontosphaera multipora	x	x	x	x	x	x
	Syracosphaera pulchra	x	x				x
	Thoracosphaera sp.	x			x		x
	Holodiscolithus macroporus				x		
	Perfocalcinella fusiformis ("calcacerous elements")	x	x	x	x	x	x
	Reworked K_2	x	x	x	x	x	x
	Reworked P	x	x	x	x	x	x
	Reworked M_1	x	x	x	x	x	x
FORAMINIFERA	*Rhizammina sp.*		x				
	Ammodiscus aff. miocenicus						x
	Repmanina charoides					x	
	Globigerina praebulloides	x					
	G. bulloides	x					
	G. juvenilis	x					
	G. sp.			x			x
	Subbotina sp. (R)	x				x	
	Globorotalia aff. bykovae						x
	Bitubulogenerina aff. reticulata	x					
	Bulimina elongata	x					
	B. aff. striata mexicana					x	
	Elphidium aff. macellum	x					
	Cibicides sp.		x	x			
	Neoeponides sp.					x	

Fig. 13. Distribution of calcareous nannoplankton and foraminifera in the Gierczyce brick yard sequence and location of samples with their numbers

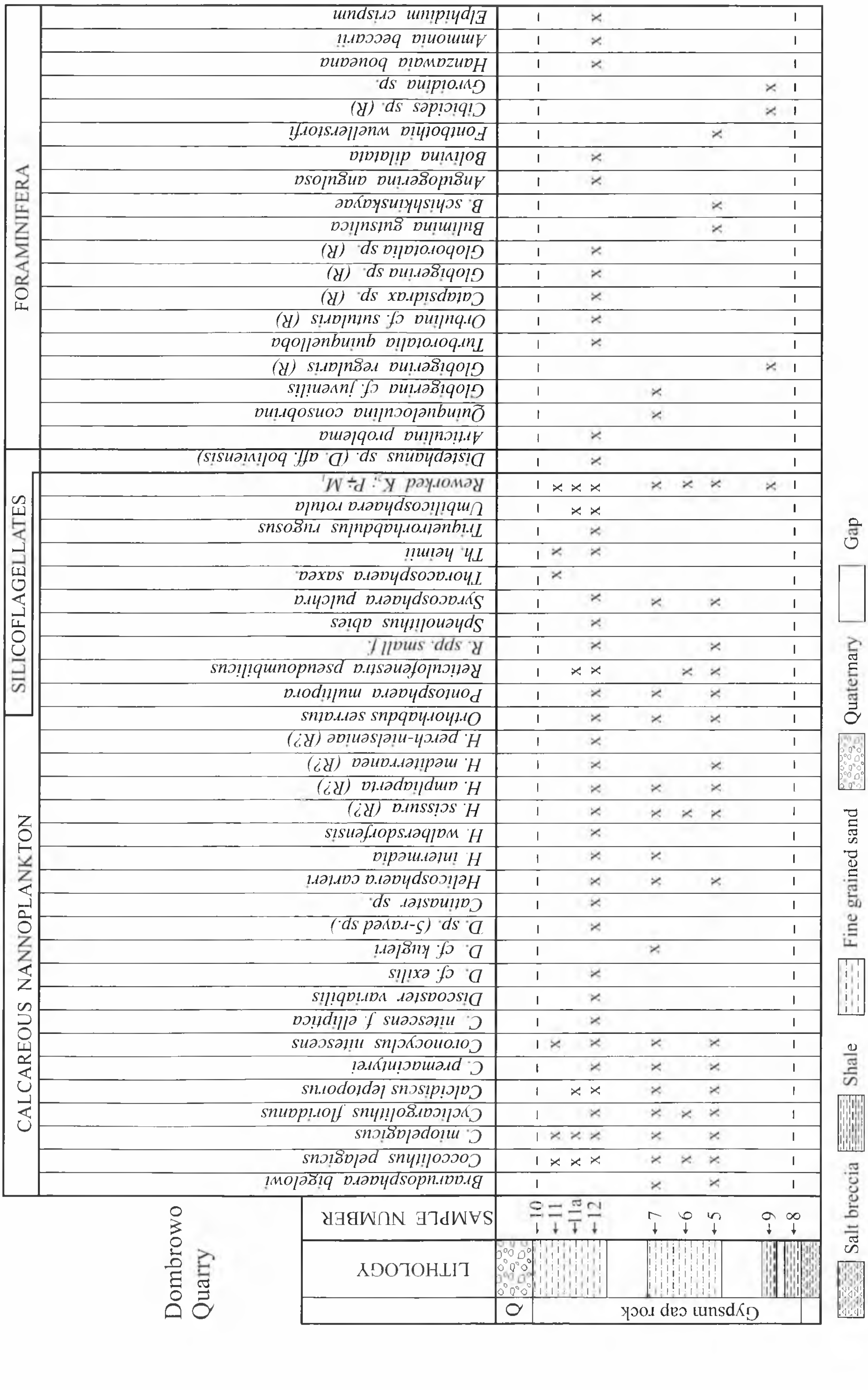


Fig. 14. Distribution of calcareous nannoplankton and foraminifera in the Dombrowo quarry sequence and location of samples with their numbers

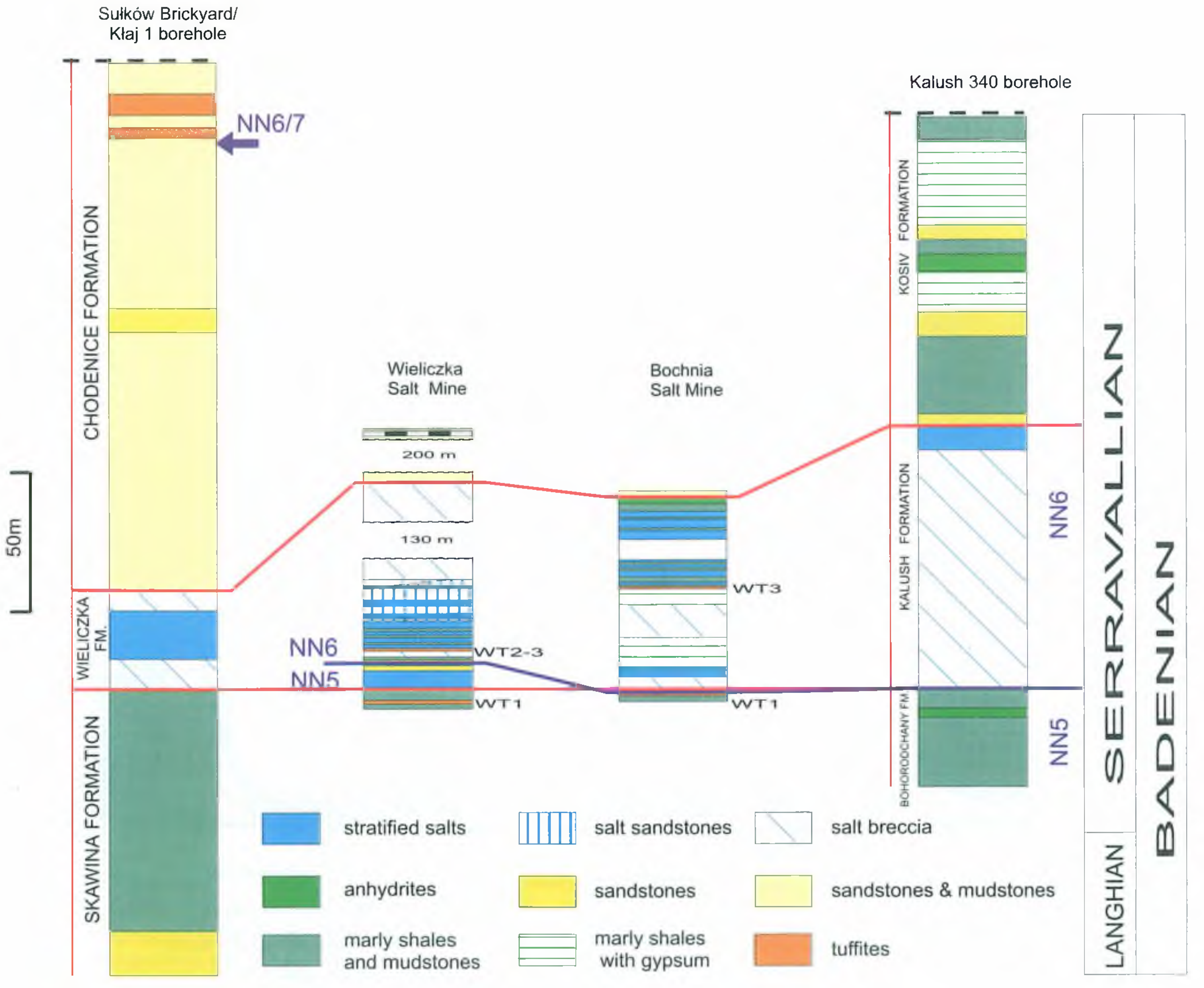


Fig. 15. Lithostratigraphic correlation of the Late Badenian salt deposits of the Wieliczka–Zgłobice and Sambir Units

vironments in the marginal part of the basin, caused by an influx of fluvial waters from the nearby Carpathian Range. The importance of inflow of fluvial waters to the salt basin has already been pointed out by Bukowski *et al.* (2001). It should be mentioned that the earlier studies (Łuczkowska & Rolewicz, 1990) demonstrated existence of foraminiferal assemblages not younger than Badenian, and that the calcareous nannoplankton is only of the Late Badenian age.

The obtained biostratigraphic data presented in this paper show clearly that although the Carpathian Foreland Basin underwent during the Badenian three main environmental stages: open marine, hypersaline and open-marine, the hitherto existing division of the Badenian into three parts (Lower, Middle and Upper) is difficult to accept. The previous Middle Badenian (Wielician; Łuczkowska, 1978) sub-stage corresponds to the NN6 and undivided NN6-NN7 zone, and in reality it is of Late Badenian age in a greater part. Moreover, foraminifera from salt complexes are typical for the Late Badenian.

The new biostratigraphic results have also tectonic implications. The similar age of the post-evaporate sediments shows that the Zgłobice and Sambir Units were folded during the similar, post-Badenian time. However, in the Zgłobice Unit, the movement embraced deposits only from the external sub-basin, while in the Sambir Unit – mainly from the internal sub-basin. It was probably caused by oblique arrangement of the Carpathian front in relation to the Foredeep structures. In the Early Badenian, the Carpathians already passed the inner sub-basin in the west, and in the east they were situated still in a more inner position. Now, the folded Miocene strata represent one continuous tectonic unit that runs in front of the Carpathians.

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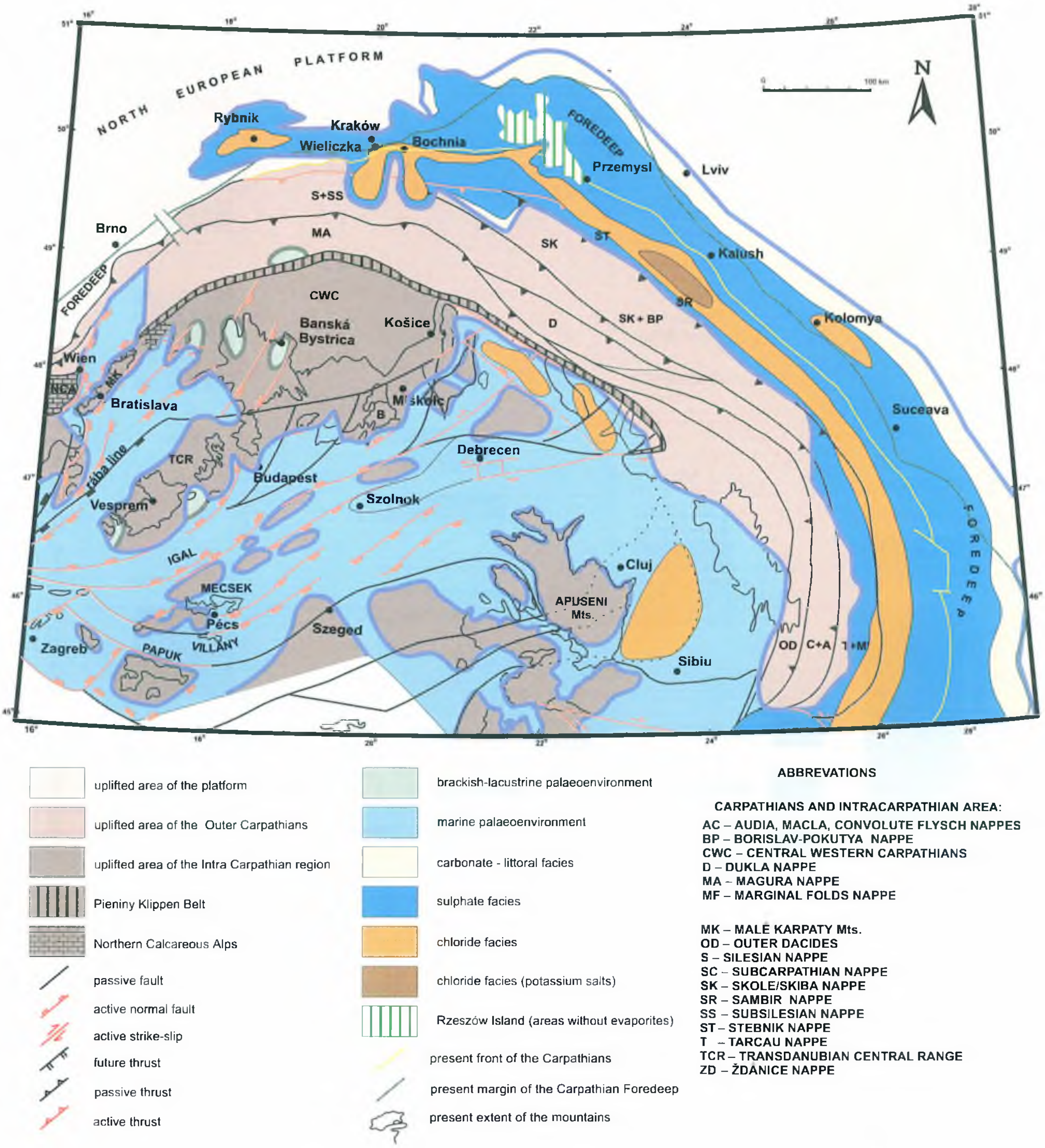

Fig. 16. Late Badenian palaeogeographic-palinspastic map of the Carpathian-Pannonian Region (after Kovač *et al.*, 1998 and Oszczypko, 1998, supplemented)

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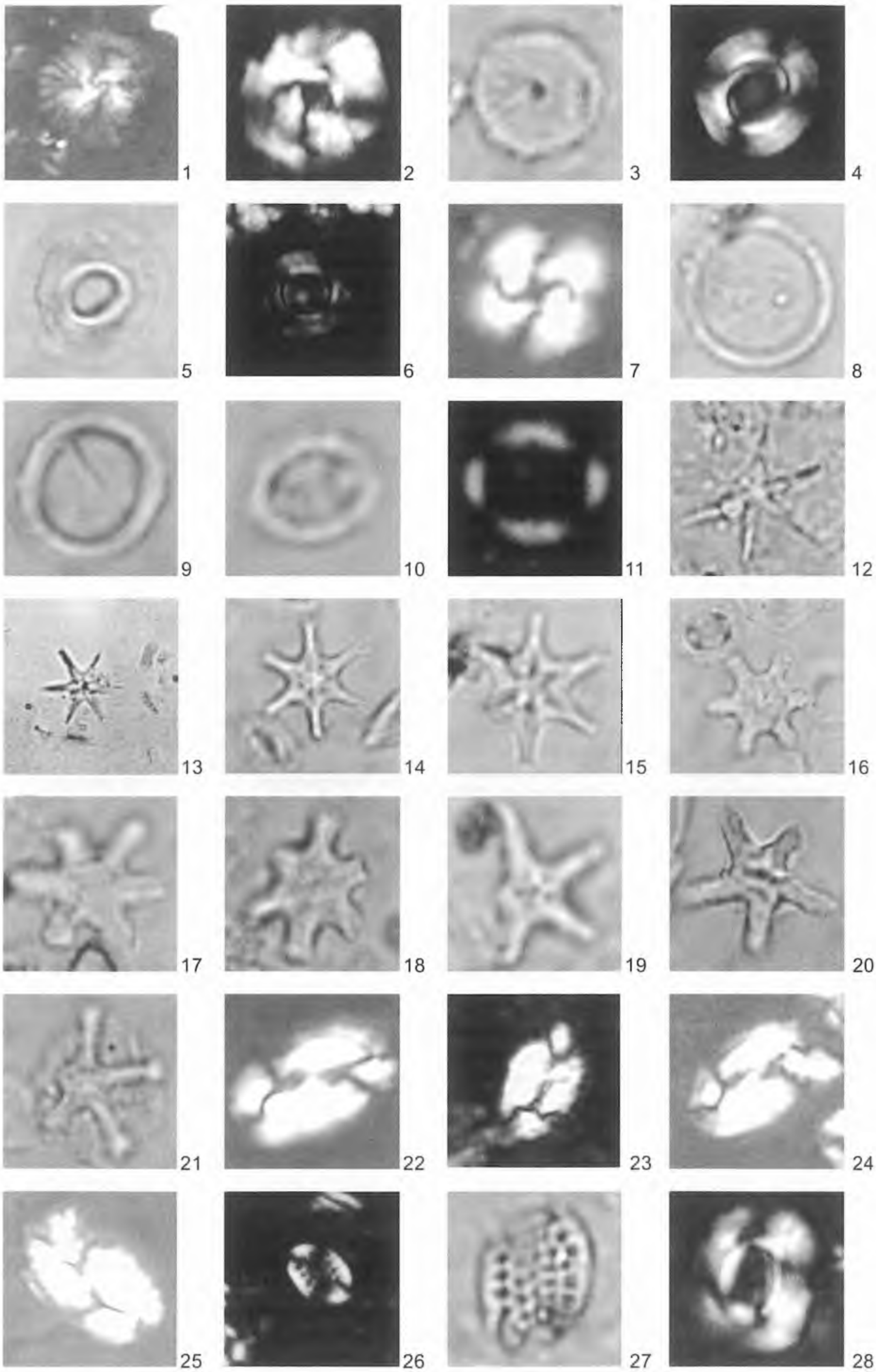
Fig. 17. Middle Miocene calcareous nannoplankton. **1, 3** – *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan: 1 – Zabawa section, ×5400; 3 – Gierczyce section, ×5400; **2** – *Calcidiscus* sp. Bochnia Mine, ×5400; **4, 5** – *Calcidiscus premacintyrei* Theodoridis. Wieliczka Mine, ×2700; **6** – *Calcidiscus macintyrei* (Bukry and Bramlette) Loeblich and Tappan. Zabawa section, ×2700; **7** – *Cyclicargolithus floridanus* (Roth and Hay) Bukry. Kalush 340 borehole, ×5400; **8, 9** – *Coronocyclus nitescens* (Kamptner) Bramlette and Wilcoxon. Bochnia Mine, ×5400; **10, 11** – *Coronocyclus nitescens* elliptical forms. Zabawa sections, ×5400; **12, 13** – *Discoaster brouweri* Tan: 12 – Kalush 340 borehole, ×2700; 13 – Kalush 340 borehole, ×1350; **14, 15** – *Discoaster exilis* Martini and Bramlette: 14 – Wieliczka Mine, ×2700; 15 – Bochnia Mine, ×5400; **16** – *Discoaster kugleri* Martini and Bramlette. Wieliczka Mine, ×2700; **17, 18** – *Discoaster* cf. *kugleri* Martini and Bramlette. Bochnia Mine, ×5400; **19–21** – *Discoaster* sp. (5-rayed discoasters): 19, 20 – Sułków section, ×5400; 21 – Zabawa section, ×2700; **22, 24** – *Helicosphaera carteri* (Wallich) Kamptner. Zabawa section, ×5400; **23, 25** – *Helicosphaera carteri* var. *wallichii* (Lohmann) Theodoridis: 23 – Kalush 340 borehole, ×2700; 25 – Sułków section, ×5400; **26, 27** – *Pontosphaera multipora* (Kamptner) Roth: 26 – Bochnia Mine, ×2700; 27 – Kalush 340 borehole, ×5400; **28** – *Reticulofenestra pseudoumbilicus* (Gartner) Gartner. >7 μm. Kalush 340 borehole, ×5400



Streszczenie

KORELACJA PÓŹNOBADEŃSKICH SOLI WIELICZKI, BOCHNI I REJONU KAŁUSZA (POLSKO-UKRAIŃSKIE ZAPADLISKO PRZEDKARPACKIE)

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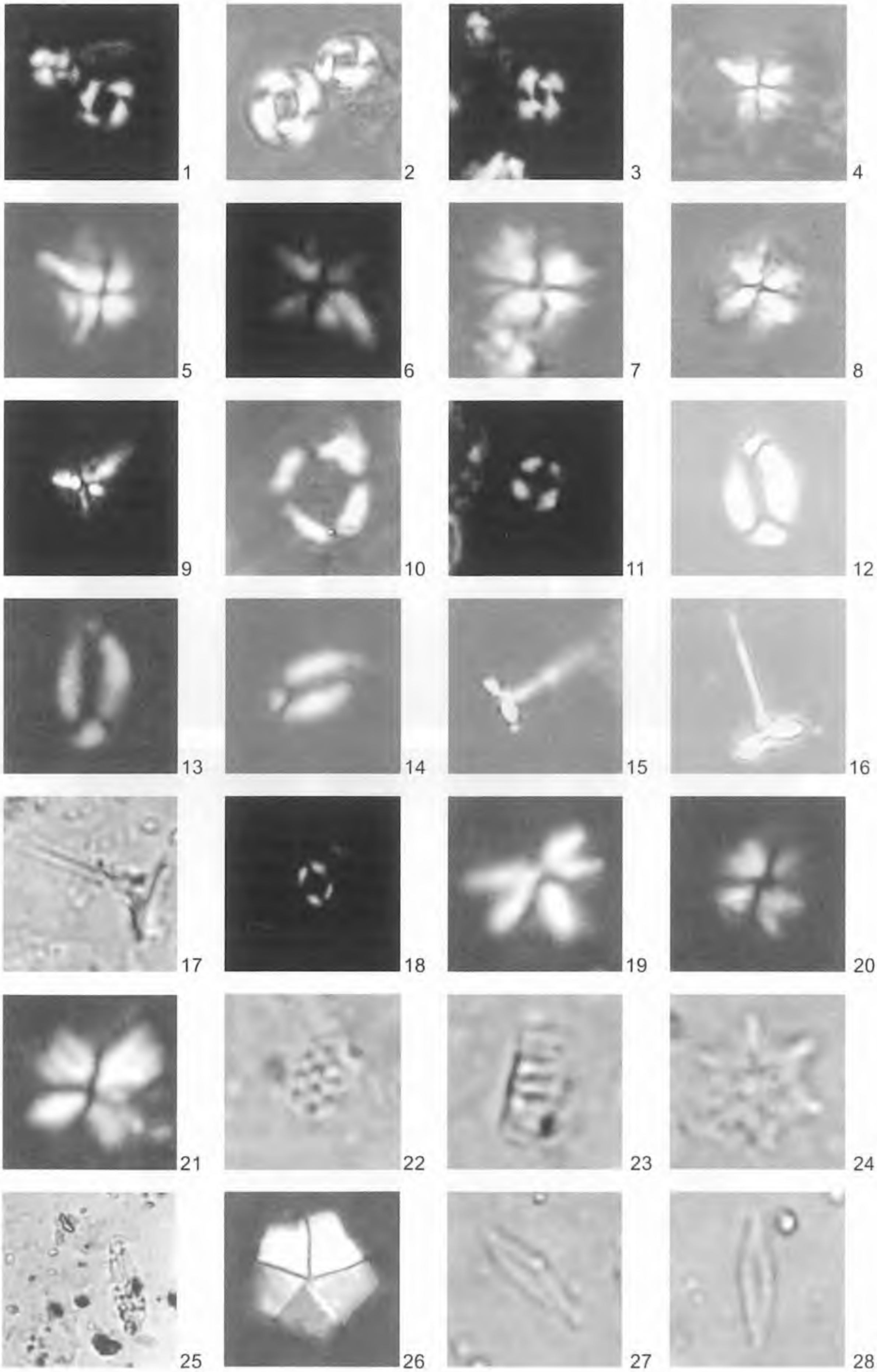
W czasie miocenu przed czołem nasuwających się Karpat wytworzył się basen przedgórski (Fig. 1), w którym można wyróżnić basen wewnętrzny, gdzie sedymentacja rozpoczęła się od wczesnego miocenu oraz zewnętrzny, który utworzył się dopiero w środkowym miocenie-badenie (Oszczypko, 1999). W czasie badenu (serrawalu) panujące początkowo warunki morza otwartego zmieniły się (Garlicki, 1979) i doszło do tworzenia się osadów ewaporatowych: facji siarcznowej głównie w części centralnej i północnej, a osadów solnych w wewnętrznej części basenu u czoła nasuwających się Karpat. W polskiej części zapadliska utwory miocenu zawierające osady solne osadziły się bezpośrednio na mezopaleozoicznych utworach platformowych, a następnie uległy częściowo sfałdowaniu w czasie mioceńskich ruchów górotwórczych (Fig. 2–4) Zaczynają się one morską formacją skawińską, reprezentujące niższą część badenu (N9 lub N 10, oraz NN5 do NN6) i przechodzącą ku górze profilu w utwory ewaporatowe. Są one przykryte przez późnobadeńsko–wczesnosarmackie utwory morskie (warstwy chodenickie i grabowieckie), a następnie w utwory brakiczne sarmatu (Oszczypko, 1998). Na przedpolu Karpat wschodnich profil miocenu środkowego z osadami solnymi zaczyna się od dolnego miocenu, a kończy się w sarmacie (Andreyeva-Grigorovich & Kulchytsky, 1985). Również i tutaj utwory zawierające sole uległy sfałdowaniu (Fig. 5, 6). Wiek i pozycja osadów solnych w basenie przedkarpackim była dyskusyjna i uważano, sole we wschodniej części tego basenu (rejon Kałusza) są wczesnomioceńskie lub wczesnobadeńskie (Burov *et al.*, 1974; Dzhinoridze, 1980; Andreyeva-Grigorovich, 1985), a w części zachodniej (rejon Wieliczki–Bochni) środkowobadeńskie (Łuczkowska, 1978). Ostatnio prowadzone badania sugerowały jednak, że mogą one być mniej więcej równowiekowe (Andreyeva-Grigorovich *et al.*, 1999).

Dla jednoznacznego ustalenia wieku tych osadów oraz ich korelacji w basenie wielicko-bocheńskim oraz kałuskim wykonane zostały badania otwornic i wapiennego nanoplanktonu. Badaniami objęto strefę sfałdowanych soli u czoła Karpat, jednostkę zgłobicką w rejonie Wieliczki i Bochni oraz jednostkę samborską w rejonie Kałusza. W rejonie Wieliczki–Bochni przebadano 5 profili (Fig. 3): w kopalni soli Wieliczka (utwory podsolne i solne; Fig. 8), w kopalni soli Bochnia (warstwy podsolne i sole; Fig. 9), w Sułkowie i Gierczycach (utwory nadsolne – warstwy chodenickie; Fig. 11 i 13) i Zabawie (piaski bogucickie, Fig. 12). W rejonie Kałusza przebadano dwa profile: z wiercenia Kałusz 340 (utwory podsolne, solne i nadsolne; fig. 12) oraz nadsolne z kopalni odkrywkowej soli Dombrowo koło Kałusza (Fig 5, 14).

Przeprowadzone badania wykazały, że łupki występujące bezpośrednio pod solami w kopalni Wieliczka i Bochnia reprezentują przejście między zonami NN5 i NN6, przy czym podobnego wieku jest również najniższa część soli Wieliczki (Fig. 8 i 9). Zespoły otwornicowe w profilu Wieliczki reprezentują niższą część badenu, a w Bochni – późny baden (Fig. 9). Utwory podścielające sole w otworze Kalusz 340 reprezentują już zonę NN6 (Fig. 10). W utworach solnych Wieliczki i Bochni stwierdzono obecność zony NN6–NN7 (Fig. 8, 9), a zespoły otwornicowe są charakterystyczne dla późnego badenu. Jedynie w jednej próbce (1W, z dolnej części złoża bryłowego) stwierdzono obecność form znanych z sarmatu. W utworach nadsolnych odsłaniających się w Sułkowie (Fig. 11) i Zabawie (Fig. 12) stwierdzono zespoły nanoplanktonu odpowiadające przejściu pomiędzy zonami NN6 i NN7. Podobne, ale uboższe zespoły stwierdzono w pozostałych profilach utworów nadsolnych (Fig. 13 i 14). Zespoły otwornicowe z utworów nadsolnych w Sułkowie są typowe dla późnego badenu (Fig. 11), podobnie jak w kopalni odkrywkowej w Dombrowo (Fig. 14). W pozostałych profilach nietypowe zespoły nie pozwalają na bliższe określenie wieku.

Powyższe rezultaty badań wskazują, że osady solne występujące w jednostkach zgłobickiej i samborskiej są podobnego wieku i mogą być korelowane ze sobą (Fig. 15, 16). Nie tworzą one jednak odrębnego, środkowobadeńskiego poziomu, ale w całości należą do późnego badenu (zona NN6 i nie rozdzielone zony NN6 i NN7) i w związku z tym stosowany trójpodział badenu na wczesny, środkowy i późny, powinien być ponownie rozpatrzony i zastąpiony podziałem na wczesny i późny. Wyniki badań wskazują również, że początek sedymentacji utworów solnych może być diachroniczny. Utwory leżące bezpośrednio nad solami (warstwy chodenickie i dolna część warstw kosowskich) reprezentują jeszcze najwyższą część badenu oraz już sarmat, jak na to wskazują wyniki badań nanoplanktonu, nie potwierdzone jednak badaniami otwornicowymi. Interesująca jest obecność w utworach złoża bryłowego otwornic znanych dopiero z sarmatu. Może to sugerować, że utwory te powstały już na pograniczu z sarmatem, względnie że pojawienie się brakicznych form sarmackich wywołane zostało okresowym lokalnym wysłodzeniem się zbiornika. Za tą ostatnią interpretacją może przemawiać brak form sarmackich w zespole nanoplanktonu. Podobieństwo wieku utworów nadsolnych w jednostkach zgłobickiej i samborskiej sugeruje, że obie te jednostki uległy sfałdowaniu w tym samym czasie i mogą stanowić jedną strukturę tektoniczną, zgłobicko-samborską, rozwiniętą u czoła nasuwających się Karpat, która kontynuuje się dalej ku południowemu wschodowi.

Fig. 18. Middle Miocene calcareous nannoplankton. **1, 2** – *Reticulofenestra pseudoumbilicus* (Gartner) Gartner: 1 – Zabawa section, ×2700; 30 – Wieliczka Mine, ×2700; **3** – *Reticulofenestra haqii* Backman. Gierczyce section, ×2700; **4–6** – *Sphenolithus abies* Deflandre: 4, 5 – Kalush 340 borehole, ×5400; 6 – Sułków section; × 5400; **7, 8** – *Sphenolithus moriformis* (Bronnimann and Stradner) Bramlette and Wilcoxon: 7 – Kalush 340 borehole, ×2700; 8 – Sułków section; ×2700; **9** – *Sphenolithus heteromorphus* Deflandre. Wieliczka Mine, ×2700; **10, 11** – *Umbilicosphaera rotula* (Kamptner) Varol: 10 – Zabawa section, ×5400; 11 – Bochnia Mine, ×2700; **12–14** – *Helicosphaera walbersdorfensis* Muller: 12, 13 – Sułków section; ×5400; 14 – Zabawa section, ×2700; **15–17** – *Rhabdosphaera sicca* (Stradner): 15, 16 – Sułków section; ×6000; 17 – Kalush 340 borehole, ×5400; **18** – *Syracosphaera pulchra* Lohmann. Gierczyce section, ×2700; **19–21** – *Perforocalcinella fusiformis* Bona. Sułków section; ×5400; **22, 23** – *Holodiscolithus macroporus* (Deflandre) Roth. Sułów section; ×5400; **24** – *Catinaster* sp.? Dombrowo quarry; ×5400; **25** – *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon. Dombrowo quarry; ×1350; **26** – *Braarudosphaera bigelowi* (Gran and Braarud) Deflandre. Zabawa section, ×2700; **27, 28** – *Calciosolenia murrayi* Gran. Zabawa section, ×5400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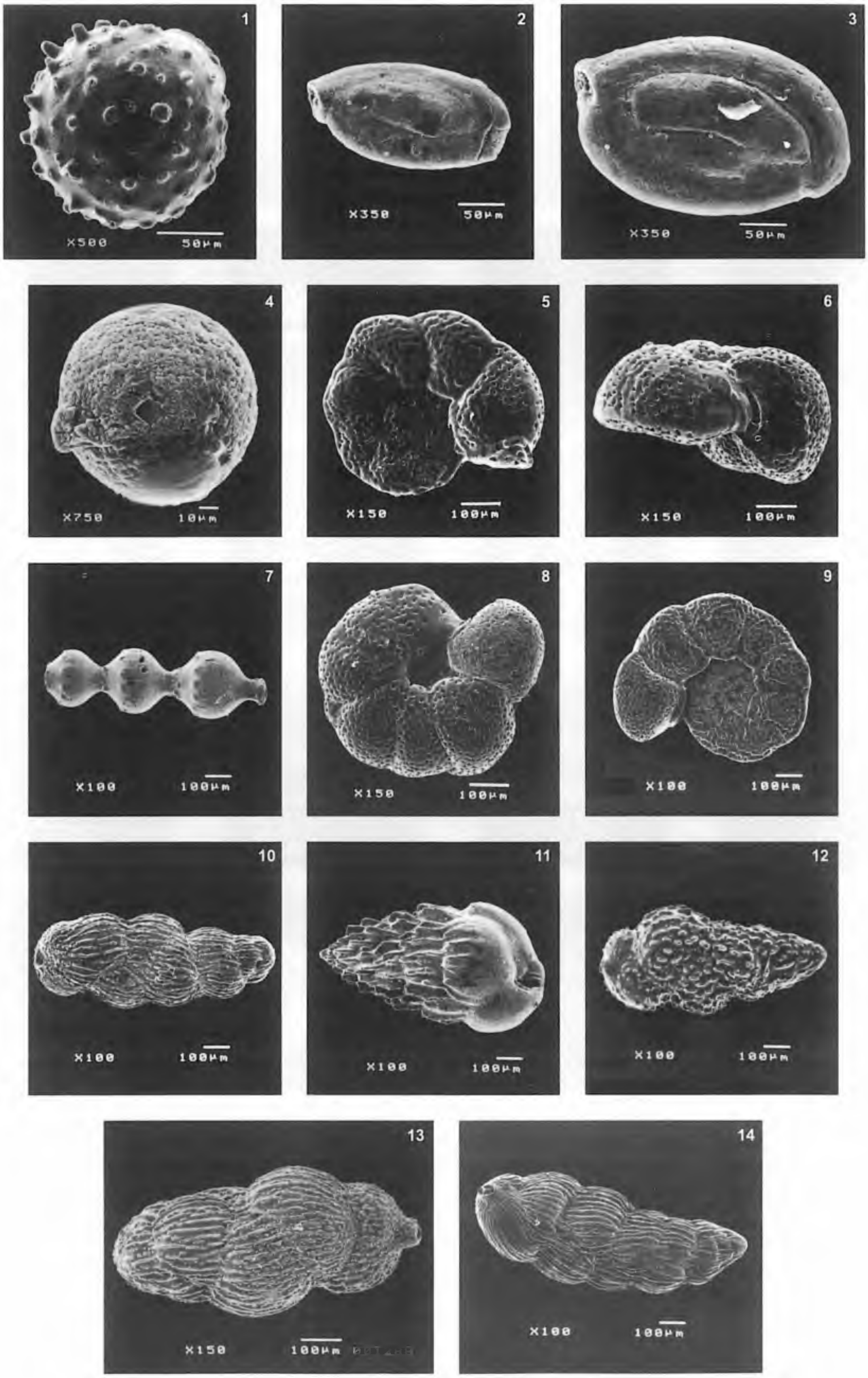

Fig. 19. Middle Miocene foraminifera and incerte sedis. **1** – *Bolboforma badenensis* Szczechura, Wieliczka Mine; **2** – *Quinqueloculina consobrina* d'Orbigny, Dombrowo quarry; **3** – *Quinqueloculina akneriana* d'Orbigny var. *elongata* Gerke, Dombrowo quarry; **4** – *Halicoryna* (?) sp., Wieliczka Mine; **5, 6** – *Anomalinoides badenensis* d'Orbigny, Wieliczka Mine; **7** – *Stilostomella adolphina* (d'Orbigny), Zabawa section; **8, 9** – *Lobatula lobatula* (Walker et Jacob), Zabawa section; **10** – *Uvigerina* aff. *graciliformis* Papp et Turnovsky, Wieliczka Mine; **11** – *Bulimina striata striata* d'Orbigny, Sułków brickyard; **12** – *Uvigerina aculeata* d'Orbigny, Dombrowo quarry; **13** – *Uvigerina pudica* Luczkowska, Zabawa section; **14** – *Uvigerina* cf. *bononiensis* Fornasini, Zabawa section

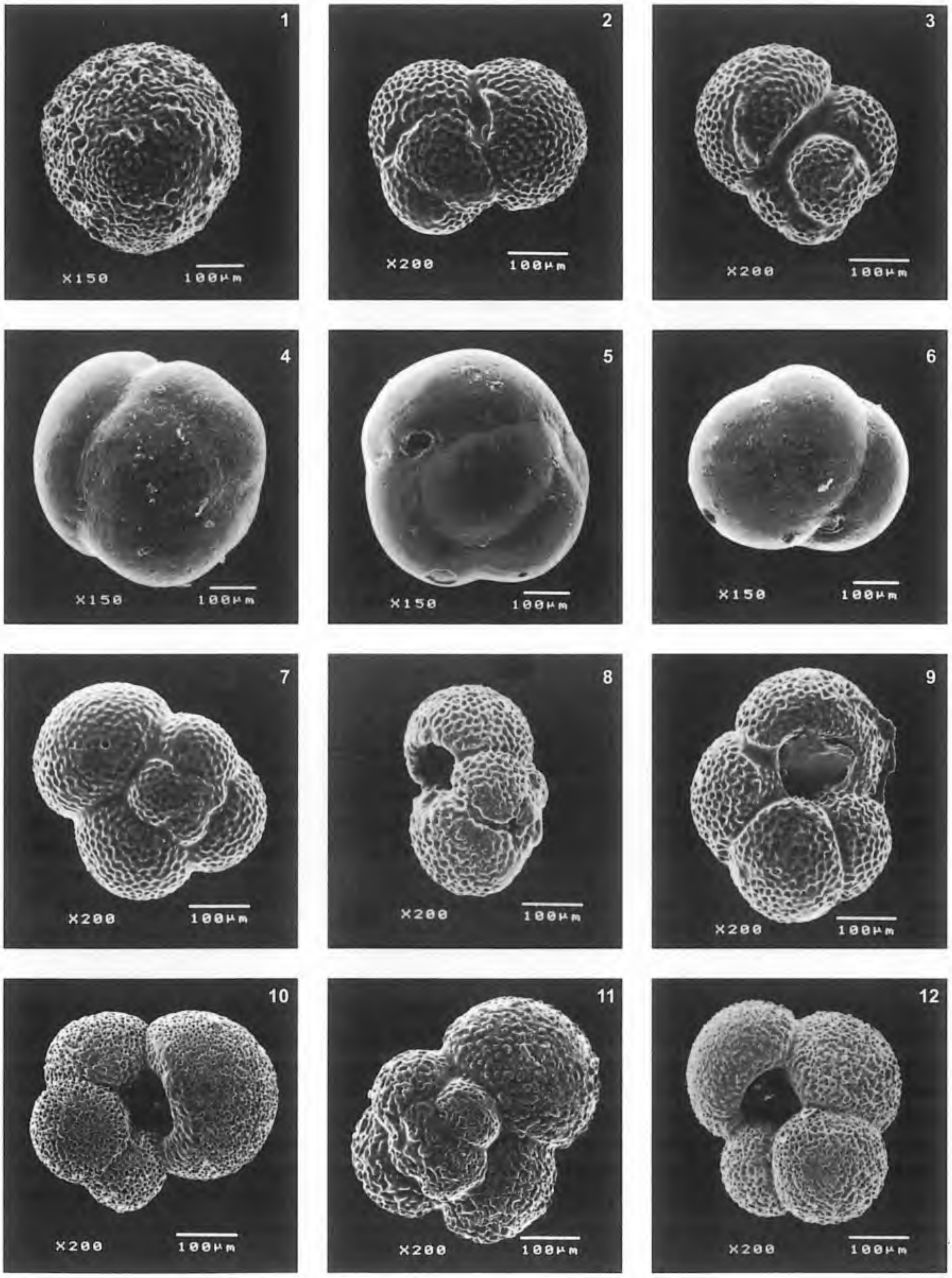

Fig. 20. Middle Miocene foraminifera. **1** – *Orbulina suturalis* Bronniman, Dombrowo quarry; **2**, **3** – *Globigerinoides trilobus* Reuss, Bochnia Mine; **4–6** – *Sphaeroidina bulloides* d'Orbigny, Zabawa section; **7–9** – *Globoturborotalita* cf. *decoraperta* (Takayanagi et Saito), Wieliczka Mine; **10–12** – *Globigerina bulloides* d'Orbigny, Wieliczka Mine