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Reworked Eocene–Oligocene dinoflagellate cysts in the Miocene of the Carpathian Foredeep Basin: implications for Paleogene palaeogeography in SE Poland

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Miocene strata of the Carpathian Foredeep Basin in Poland contain reworked Eocene and Oligocene dinoflagellate cysts, which come from two sources: the Flysch Carpathians and the epicontinental basin. The occurrence of the latter is almost the only trace of the epicontinental Eocene–Oligocene sedimentary cover, which extended across southwestern Poland, and is today nearly completely eroded. The distribution of epicontinental Eocene and Oligocene taxa in the Miocene strata of the northeastern part of the Carpathian Foredeep is uneven, clearly pointing to a limited extent of the host deposits and their variable erosion intensity. Erosion of the Eocene and Oligocene platform cover took place prior the Miocene transgression and took place also during the Badenian; its intensity increased during Late Badenian–Sarmatian tectonic movements, resulting in an increased frequency of reworked specimens in strata postdating the mid-Badenian deposits.

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INTRODUCTION

Marine Eocene and Oligocene deposits of the NW and central European epicontinental sea are well recognized in northern Poland and the extent of these marine basins has been precisely reconstructed (Fig. 1). Rich micropalaeontological assemblages allow the distinction of several transgression events and their links with neighbouring basins. However, southeastwards the documentation of Eocene and Oligocene marine deposits becomes scarce (see Krzowski, 1993). This is due to non-continuous cover of these strata, which south of the northern margin of the Lublin Upland they occur as isolated occurrences only (e.g., Piwocki, 2004; Fig. 1). Additionally, a scarcity of microfossil did not allow for their precise dating and correlation.

Dinoflagellate cysts are commonly present in the fragmentarily preserved Eocene–Oligocene deposits of SE Poland (Gedl, 2000a). Following the erosion of these, reworked dinoflagellate cysts in the Miocene deposits of the Carpathian Foredeep are often the only traces of the Eocene and Oligocene marine deposits of SE Poland.

Earlier palynological studies of the Miocene of the Polish Carpathian Foredeep Basin revealed the presence of dinoflagellate cysts (Macko, 1957; Kita, 1963). However, these studies focused mainly on pollen, while dinoflagellate cysts were described superficially. Moreover, no precise taxonomical studies were conducted, commonly referring these assemblages to the Hystrichosphaeridae only. This meant that no difference between *in situ* and reworked forms was noted in these earlier papers. Hence, palaeoenvironmental reconstructions made on the basis of such dinoflagellate cyst assemblages might have been erroneous since they very likely also included reworked taxa (see e.g., Kita, 1963, p. 520). More recent studies of dinoflagellate cysts from the Miocene of the Polish Carpathian Foredeep Basin (e.g., Gedl, 1995, 1996a, 1997a, 2005a; Peryt and Gedl, 2010) distinguished between Miocene forms and the ones reworked from pre-Miocene strata. Moreover, various stages of preservation of the reworked specimens made it possible to distinguish their source of origin: less well-preserved, commonly darker-coloured specimens were derived from Carpathian strata, whereas the pale-coloured ones came from epicontinental deposits. However, many Paleogene species, especially the Oligocene ones, are also known from Miocene. This pertains to several species representing genera such as: *Spiniferites*, *Operculodinium*, *Systematophora*, *Reticulatosphaera*, *Selenopemphix*, *Hystrichokolpoma*, etc., which commonly occur in the Miocene strata of

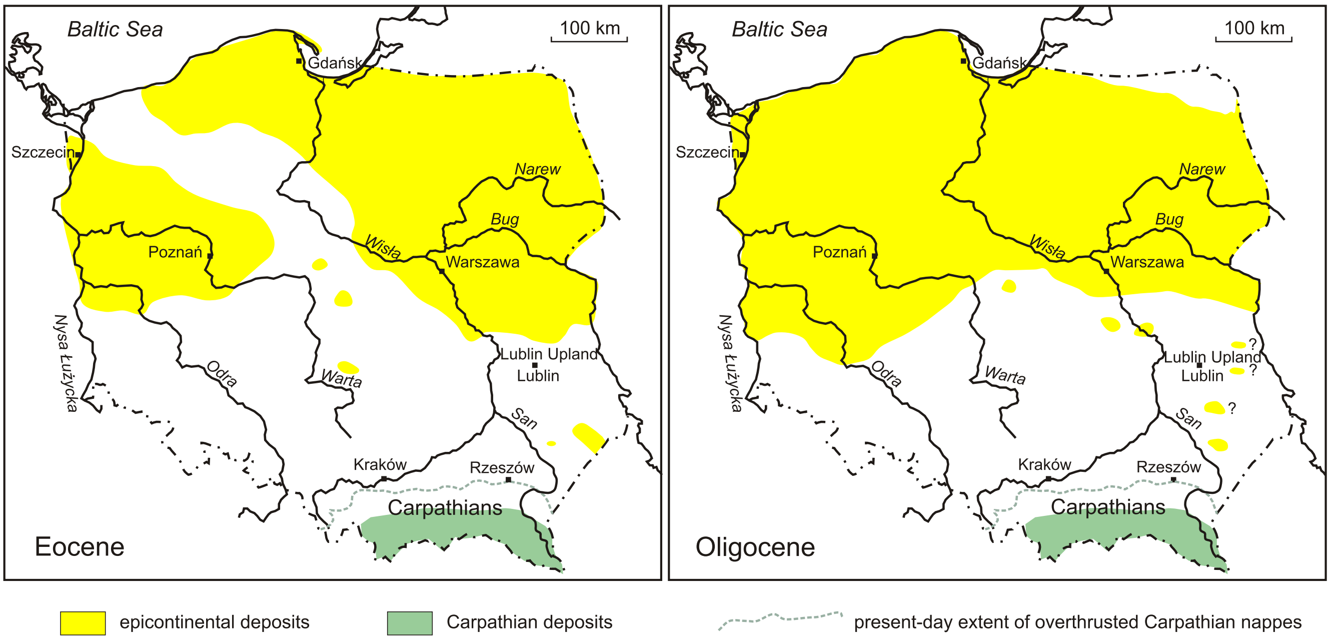

Fig. 1. Present-day extent of Eocene and Oligocene deposits in Poland (based on Piwocki, 2004; supplemented by data from Odrzywolska-Bieńkowa et al., 1978; Grabowska and Słodkowska, 1993; Gedl, 2000a; Słodkowska, 2004; Myśliwiec and Śmist, 2006)

Dotted line indicates extent of Carpathian nappes, which due to overthrusting were moved up to 50 km northwards (see Kotlarczyk, 1985)

the Carpathian Foredeep Basin. Since their similar state of preservation does not allow for the distinction reworked forms from those *in situ*, only these species which have known stratigraphical ranges limited to the Paleogene will be considered as "reworked" (e.g., Wetzelielloideae). In this paper new data on reworked Eocene and Oligocene dinoflagellate cysts from Miocene deposits in the Polish Carpathian Foredeep Basin are presented. They are compared with previously published data. Although the distribution of reworked dinoflagellate cysts in Miocene strata is related to several factors (e.g., sedimentation mode, erosion intensity, drainage system pattern) it may also provide significant evidence towards the palaeogeographical reconstruction of the varying extent of the Paleogene seas in SE Poland.

GEOLOGICAL SETTING

During the Paleogene, the northwestern and central European epicontinental sea extended from the North Sea through northern Germany and Poland to Belarus and Ukraine (e.g., Ziegler, 1978). In Poland, the most complete Eocene and Oligocene succession is known from northern Poland (Fig. 1). But there also, it contains frequent hiatuses, and particular lithostratigraphic units are of small thickness and commonly of local occurrence (e.g., Piwocki, 2004). Lower Eocene deposits are known from northwestern Poland only. Bartonian–Priabonian deposits have a broader distribution: they occur in north and northeastern Poland. Rupelian deposits consist of continental and marine strata. The youngest is the Chattian Leszno Formation known from western Poland only (Piwocki, 2004).

The southeastern boundary of palaeontologically well-documented Eocene deposits runs approximately along the northern peripheries of the Lublin Upland. In this area the Bartonian–Priabonian Siemień Formation has been documented (e.g., Woźny, 1966; Pożaryska and Locker, 1971; Uberna and Odrzywolska-Bieńkowa, 1977; Uberna, 1981; Kosmowska-Ceranowicz and Pożaryska, 1984; Kasiński and Tołkanowicz, 1999). Słodkowska (2004) documented Mid–Late Eocene phytoplankton from the Wisła River valley at a similar latitude. Sandy-glauconitic deposits known from isolated sites on the Lublin Upland are palaeontologically barren. These have been traditionally regarded as Oligocene in age but Krzowski (1993), on the basis of radiometric K-Ar dating of glauconite, suggested their Mid–Late Eocene age. Marine Eocene deposits with micropalaeontologically documented ages have been recently documented from Roztocze (the so-called Sołokija Graben Eocene: e.g., Cieśliński and Rzechowski, 1993; Buraczyński and Krzowski, 1994; Gaździcka, 1994) and the Carpathian Foredeep (Łukowa 4 borehole: Myśliwiec and Śmist, 2006; Fig. 1). These two isolated sites with Eocene deposits occur in the area which, according to Piwocki (2004), was a land barrier (Bohemian–Małopolska–Ukrainian massifs) separating Carpathian basins from the epicontinental sea.

The situation is similar with the Oligocene deposits, which are widely distributed north of the Lublin Upland (Piwocki, 2004); south of this region, only isolated sites with marine Rupelian deposits are known from the Carpathian Foredeep (Tarnogród area: e.g., Gedl, 2000a; Myśliwiec and Śmist, 2006; Fig. 1). The position of these deposits is enigmatic: in the light of palaeogeographic reconstructions, the Oligocene epicontinental deposits of Poland are linked with transgressions from the west (Piwocki, 2004).

MATERIAL

Material for the present study comes from several sites within the Carpathian Foredeep (Fig. 2), which include both boreholes and exposures. Below, a brief description is provided.

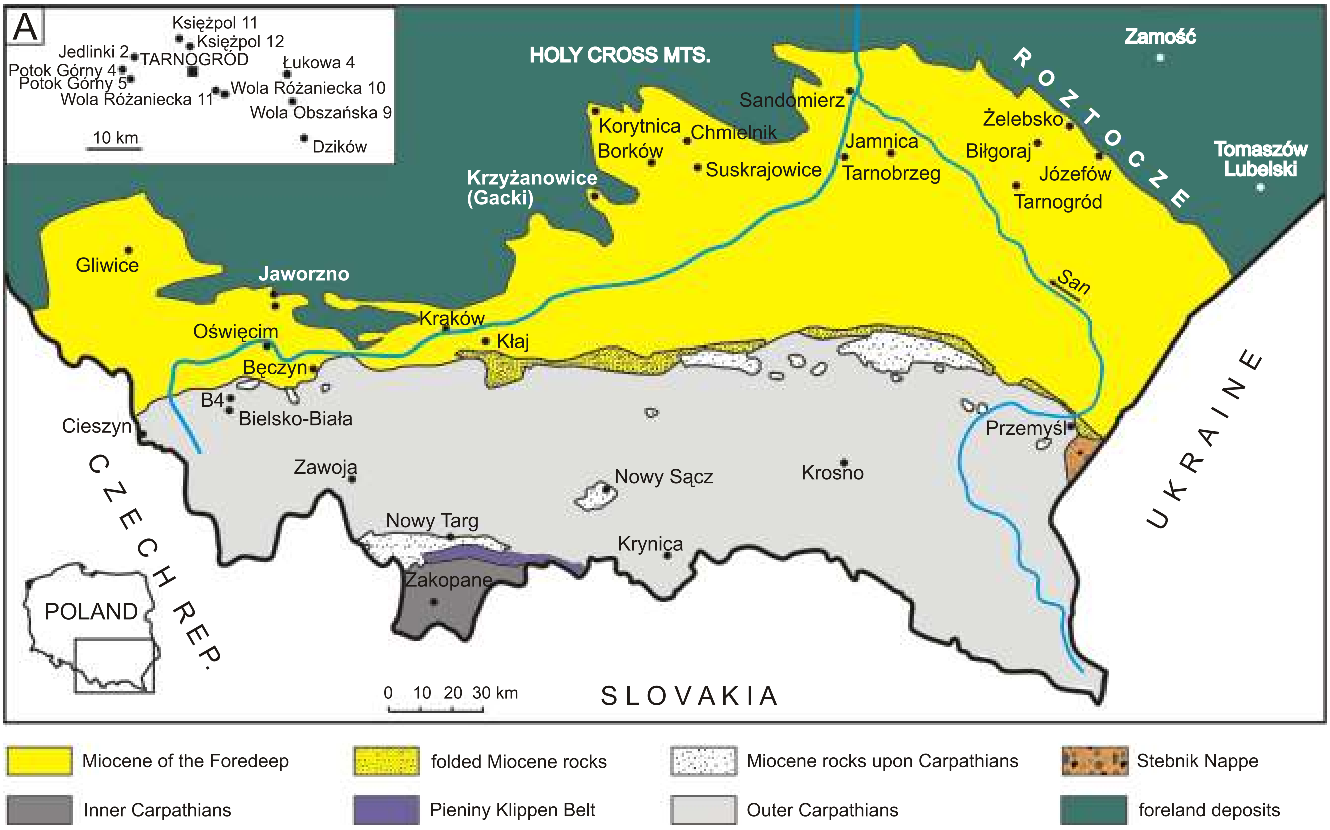

Fig. 2. Geological sketch of the Miocene Carpathian Foredeep with locations of sites studied

A – location of boreholes in the Tarnogród vicinity (after Myśliwiec and Śmist, 2006)

Since the lithostratigraphical division of the Miocene of the Carpathian Foredeep is still not uniform, local names for particular lithostratigraphic units are followed (for discussion of their correlation see Olszewska, 1999 and Jasionowski et al., 2004).

SOUTHWESTERN PART OF THE POLISH FOREDEEP BASIN, BELOW THE CARPATHIAN OVERTHRUST

Konior and Krach (1964) described from the B4 borehole (ca. 5 km north of Bielsko-Biała; Fig. 2) the basal interval of the Miocene succession, which occurs there below the Dębowiec conglomerate (depth 1549.65 m). The lowermost part of this succession consists of brownish-grey sandstones, which pass upwards into whitish sandstones (1679–1721 m). Higher up, Konior and Krach (1964) distinguished dark non-calcareous mudstone with abundant macrofauna and brown coal layers; these two lithological units were included by Kuciński et al. (1975) in the Hałcnów Formation. Samples for dinoflagellate cysts were taken from the 1661.8–1668.2 m interval developed as dark mudstone with brown coal intercalations passing upwards into a richly fossiliferous non-calcareous mudstone.

KRAKÓW–OŚWIĘCIM AREA

The Miocene between Kraków and Oświęcim consists of the Lower–Middle Badenian Skawina Beds, the Middle Miocene Wieliczka Formation and the Upper Badenian Chodenice and Grabowiec Beds (e.g., Książkiewicz, 1951; Alexandrowicz, 1958, 1961, 1963; Ney, 1968; Łuczkowska, 1995). Several boreholes in this area have been studied as regards dinoflagellate cysts (see Pilarz, 2012; Appendix 1).

A complete sequence of Miocene near the margin of the Carpathian overthrust was drilled by the Kłaj 1 borehole (Fig. 2). It penetrated almost 800 m of Miocene, which rests there on Upper Cretaceous marls (Stemulak, 1955 *fide* Kita, 1963; see also Kirchner, 1956; Olewicz, 1973; Łuczkowska, 1978). Palynology from this succession was studied by Kita (1963). 57 samples were studied for dinoflagellate cysts: 18 samples from the Skawina Beds (interval 733–842 m) and 39 samples from the upper part of the Chodenice Beds and basal part of the Grabowiec Beds (374–632 m).

Additional material was collected by the author from artificial exposures of the Skawina Beds and mid-Badenian evaporites exposed during construction work in Kraków.

NORTHERN MARGIN OF THE FOREDEEP BASIN (SOUTH OF THE HOLY CROSS MTS.)

The Middle Miocene succession south of the Holy Cross Mts. starts with Badenian marine strata (e.g., Radwański, 1969), which locally rest on the continental Trzydnik Formation *sensu* Alexandrowicz et al. (1982; clastic deposits with lignite seams) or directly on eroded Cretaceous and Jurassic rocks. It includes the Lower Badenian Pińczów Formation, which consists of various, commonly locally developed, informal lithostratigraphic units (e.g., the Korytnica Clays and the Baranów Beds;

Kowalewski, 1930; Bałuk and Radwański, 1977, 1979, 1984; Jasionowski, 1997; Czapowski, 2004), the Middle Badenian Krzyżanowice Formation (evaporites), the Upper Badenian marls and marly clays with intercalations of sands and limestones, and the youngest Chmielnik Formation (Alexandrowicz et al., 1982), which includes the so-called "detrital Sarmatian". The age of the Chmielnik Formation is Lower Sarmatian (e.g., Czapowski and Studencka, 1990, 1996). The following sites from this area were studied for dinoflagellate cysts:

- the Korytnica Clays are locally underlain by continental strata developed as green non-calcareous clay and dark-coloured organic-rich non-calcareous clay (see e.g., Bałuk and Radwański, 1977; Szymanko and Wójcik, 1982). The thickness of these strata is variable; it reaches a maximum of 70 m (Szymanko and Wójcik, 1982). Material from these strata obtained from shallow boreholes at Niziny was studied for palynology;
- an abandoned quarry at Krzyżanowice near Pińczów (also known as the Gacki Quarry) exposed a complete Badenian succession composed of Lower Badenian fine-grained marly deposits underlying the Middle Miocene Krzyżanowice Formation and overlying clays (Alexandrowicz and Parachoniak, 1956; Łuczkowska, 1974). Seven samples come from clays overlying the evaporitic horizon, and a single sample from clays underlying the gypsum;
- several outcrops of the "detrital Sarmatian" are known from the Chmielnik vicinity (see Rutkowski, 1976; Czapowski and Studencka, 1990). These generally coarse-grained deposits contain occasional thin intercalations of fine-grained material, sampled for dinoflagellate cysts at an exposure at Suskrajowice.

NORTHEASTERN MARGIN OF THE POLISH FOREDEEP BASIN

The northeastern part of the Carpathian Foredeep Basin was characterized by bimodal facies development, especially during the post-evaporitic period. This was due to the diverse tectonic history of this part of the basin: the marginal zone was then mainly uplifted (the present-day Roztocze area; see below) whereas the basinal part was predominantly downwarped (Oszczypko, 1996; Krzywiec, 2001; Wysocka, 2002, 2006a). As a consequence, the latter area is characterized by a thick (up to 2000 m) sequence of fine-grained, loamy-silty deposits.

Several boreholes examined for dinoflagellate cysts in the Biłgoraj–Tarnogród area penetrated the Miocene sequence that is over 1 km thick in this region (see Myśliwiec and Śmist, 2006; Fig. 2A; Appendix 1). It rests upon Mesozoic–Paleozoic to pre-Paleozoic rocks, and consists of the Lower Badenian Baranów Beds (2–3 m, maximum 10 m thick), evaporitic deposits (about 20 m – Peryt et al., 1998) and approximately 1000 m of post-evaporitic heterolithic deposits. In a few boreholes, packages several metres thick of marine Paleogene deposoits have been found (Gedl, 2000a). Fourteen boreholes have been analyzed for reworked Paleogene dinoflagellate cysts (Appendix 1).

ROZTOCZE

The Miocene of the Roztocze area represents a marginal facies of the Carpathian Foreland basin. During the Badenian marine transgression, which entered this region, it represented an uplifted area in relation to the central part of the basin (e.g., Ney et al., 1974). A different sedimentary setting in this marginal zone resulted in a much thinner Miocene sequence (several to a few tens of metres compared to almost 2000 m in the basinal part) consisting generally of shallow-marine sands, marls and organodetrital limestones (see e.g., Buraczyński, 1997). Three sites in Roztocze area were studied, located in two quarries at Józefów and in a quarry at Żelebsko. The Upper Badenian exposed in these sites consists chiefly of sandy organodetrital limestone (calcarenite to calcirudite; see Wysocka, 2002, 2006b; Wysocka et al., 2006; Jasionowski et al., 2006). Within these coarse-grained deposits rare fine-grained layers occur; these were sampled for dinoflagellate cysts.

PREVIOUS STUDIES

Previously published data on reworked Eocene and Oligocene dinoflagellate cysts include studies from: the western part of the Foredeep Basin (Gliwice area: Gedl, 1997a); the southwestern part of the Foredeep Basin, below the Carpathian overthrust (Zawoja 1 borehole: Gedl, 1997b, Gedl in Oszczypko et al., 2000); Kraków–Oświęcim area (Bęczyn: Gedl, 2005a; boreholes at Trzebinia: Gedl, 1995); the southern surrounds of the Holy Cross Mts. (Korytnica: Gedl, 1996a; quarry at Borków: Peryt and Gedl, 2010); and the northeastern margin of the Foredeep Basin (Jamnica S119 borehole: Gedl, 1999).

Individual specimens of very well-preserved pale-coloured specimens (*Areosphaeridium diktyoplokum*, *Chiropteridium* sp., *Charlesdowniea* sp., *Deflandrea heterophlycta*, *Wetzeliella* sp.) were found in Lower Badenian clays of the Baranów Beds that underlie the Krzyżanowice Formation in the Borków Quarry (Fig. 2; Peryt and Gedl, 2010).

Reworked Paleogene taxa, characterized by pale colours and a good state of preservation, occur throughout the whole sequence of the over 250 metres deep Jamnica S119 borehole (Fig. 2; Gedl, 1999). *Areoligera coronata*, *Enneadocysta pectiniformis*, *Homotryblium pallidum* occur in the Baranów Beds (sample 274.5–276.5 m). The lower part of the *Pecten* Beds yielded rather infrequent reworked specimens (sample 257–258 m: *Charlesdowniea clathrata*, *Fibrocysta* sp., *Wetzeliella symmetrica*; samples 250.5 and 253 m: *Charlesdowniea clathrata*, *Enneadocysta pectiniformis*, *Homotryblium* sp.). These are also rare in the lowermost part of the Krakowiec Clays (sample 236.03–236.06 m: *Deflandrea heterophlycta*, *Enneadocysta pectiniformis*; sample 234.09–234.1 m: *Deflandrea phosphoritica*). The higher part of this lithostratigraphic unit contains reworked specimens (including Cretaceous species), which appear to be more common than the Miocene ones (interval 208.5–228.17 m: *Areosphaeridium diktyoplokum*, *Deflandrea phosphoritica*, *Glaphyrocysta* sp., *Homotryblium* sp., *Rhombodinium longimanum*, *Wetzeliella* sp.). In the upper part of the Krakowiec Clays (interval 36–120 m), Paleogene forms are almost the only dinoflagellate cysts (*Areosphaeridium diktyoplokum*, *Enneadocysta pectiniformis*, *Deflandrea phosphoritica*, *Glaphyrocysta* sp., *Homotryblium plectilum*, *Homotryblium* sp., *Thalassiphora pelagica*, *Wetzeliella gochtii*, *W. symmetrica* subsp. *incisa*). In this interval, much less well-preserved, dark-coloured specimens of Carpathian origin occur; they appear together with pale-coloured epicontinental ones.

METHODS

The samples were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. The standard palynological procedure applied included 38% hydrochloric-acid (HCl) treatment, 40% hydrofluoric-acid (HF) treatment, heavy-liquid ($ZnCl_2$ + HCl; density 2.0 g·cm^{-3}) separation, ultrasound for 10–15 s and sieving at 10 µm on a nylon mesh. No nitric-acid (HNO_3) treatment was applied.

The quantity of rock processed was 20 g for each sample. Thin sections were made from each sample using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

RESULTS

Samples from the Lower?–lower Middle? Miocene of the B4 borehole near Bielsko-Biała contain no reworked Paleogene dinoflagellate cysts (Fig. 3); samples of mudstone with coal intercalations appeared to be barren, whereas samples of fossiliferous mudstone contain assemblage of the latest Early to earliest Middle Miocene.

Similarly, samples collected from the Trzebinia borehole as well as from the man-made exposures in Kraków (sub-evaporitic deposits and evaporites) yielded no reworked Paleogene specimens. The Skawina Beds contain typical offshore dinoflagellate cyst assemblages (see Gedl, 1995) with various admixtures of terrestrial organic particles, whereas anhydrites from Kurdwanów (southern suburbs of Kraków) yielded a palynofacies consisting of dominant pollen grains and aquatic algae *Leiosphaeridia*.

Among 15 samples from 6 boreholes from the Kraków–Oświęcim area only a single sample from borehole Chełm 7 yielded reworked Paleogene dinoflagellate cysts (Fig. 3). A sample from depth 33 m (Chodenice Beds) contains poorly preserved, dark-coloured specimens (*Wetzeliella* sp., *Homotryblium tenuispinosum*, *Deflandrea* sp., associated with a Cretaceous *Oligosphaeridium* sp.); their preservation suggests that they derive from the Carpathians.

The Miocene sequence from the Kłaj 1 borehole yielded frequent reworked Paleogene dinoflagellate cysts (Fig. 3). Generally, only the basal part of the Skawina Beds (823–842 m) contains no reworked forms; higher up, these forms occur in various amounts. They consist of predominantly Paleogene taxa (e.g., *Homotryblium*, *Lanternosphaeridium*, *Deflandrea* and *Wetzeliella*) and subordinate Cretaceous ones (e.g., *Cribroperidinium*, *Oligosphaeridium* and *Odontochitina*). The highest ratio of reworked specimens occurs in the sub-evaporitic interval (374–632 m) where they commonly occur more frequently than do the *in situ* specimens. All reworked specimens from the Kłaj 1 borehole are dark-coloured and moderately to poorly preserved. These preservational features suggest that they derive from eroded Carpathian nappes.

Miocene sites south of the Holy Cross Mts. yielded various amounts of reworked Eocene–Oligocene dinoflagellate cysts. Presumed continental deposits at Niziny contain no dinoflagellate cysts. A single sample from fine-grained deposits that underlie the chemical deposits at Gacki yielded a typical taxonomically diverse assemblage of Badenian dinoflagellate cysts; only very rare reworked Paleogene specimens were found (*Deflandrea* spp., *Dracodinium*? sp.). More frequent Paleogene taxa, although subordinate to the *in situ* ones, occur in clays above the evaporitic succession. They are represented by *Deflandrea* (co-occurring with reworked Cretaceous taxa). All reworked specimens are pale-coloured and have intact wall structure showing their origin from the epicontinental basin.

Much more common are Paleogene dinoflagellate cysts, which occur in clay laminae from “detrital Sarmatian” deposits exposed at Suskrajowice. These are pale-coloured, but commonly mechanically damaged specimens of *Wetzeliella*, *Deflandrea* and incomplete gonyaulacoids; Paleogene taxa represent 100% of the determinable forms.

A Miocene sequence over 1 km thick in the Biłgoraj–Tarnogród area locally rests on marine Oligocene strata (Gedl, 2000a; see also Myśliwiec and Śmist, 2006). The basal part of the Miocene succession below the anhydrite horizon (Baranów Beds, locally including the *Lithothamnium* marl) usually contains no Paleogene dinoflagellate cysts (Potok Górny 4, Dzików 15, 17, Wola Obszańska 9, Jedlinki 2, Wola Różaniecka 11, Księżpol 10, 11 – for boreholes location see Fig. 2A). The Baranów Beds from Potok Górny 4, Jedlinki 2, and Księżpol 11 rest directly on Oligocene strata. Individual reworked specimens have been found in the sub-anhydrite strata in the boreholes Wola Różaniecka 7 (*Deflandrea phosphoritica*) and 10 (*Areosphaeridium diktyoplokum*) only. In some wells, anhydrite yielded infrequent Paleogene specimens, which represent the only dinoflagellate cysts from chemical deposits (Potok Górny 5: *Homotryblium* sp.; Sucha Wola 1: *Deflandrea* sp., *Operculodinium microtriainum*; Dzików 12: *Areosphaeridium diktyoplokum*; Jedlinki 2: *Homotryblium pallidum*).

The frequency of reworked Eocene–Oligocene dinoflagellate cysts increases in the supra-evaporitic heterolithic deposits. Although its basal part, i.e., strata just above the anhydrite horizon (*Spirialis* Clays), yielded rather rare reworked specimens (Jedlinki 2, Wola Różaniecka 7, 10 boreholes) but higher parts contain much frequent Paleogene specimens, which commonly represent most of the dinoflagellate cyst assemblages (Table 1).

Fine-grained intercalations of generally coarse-grained organodetrital (mainly coralline algae) limestones of the Upper Badenian of Roztocze yielded common Eocene dinoflagellate cysts. This refers to samples collected from the Józefów quarries – the sample from the Żelebsko Quarry contains no reworked forms. The Eocene dinoflagellate cyst assemblage there consists of chorate gonyaulacoids: *Adnatosphaeridium multispinosum*,

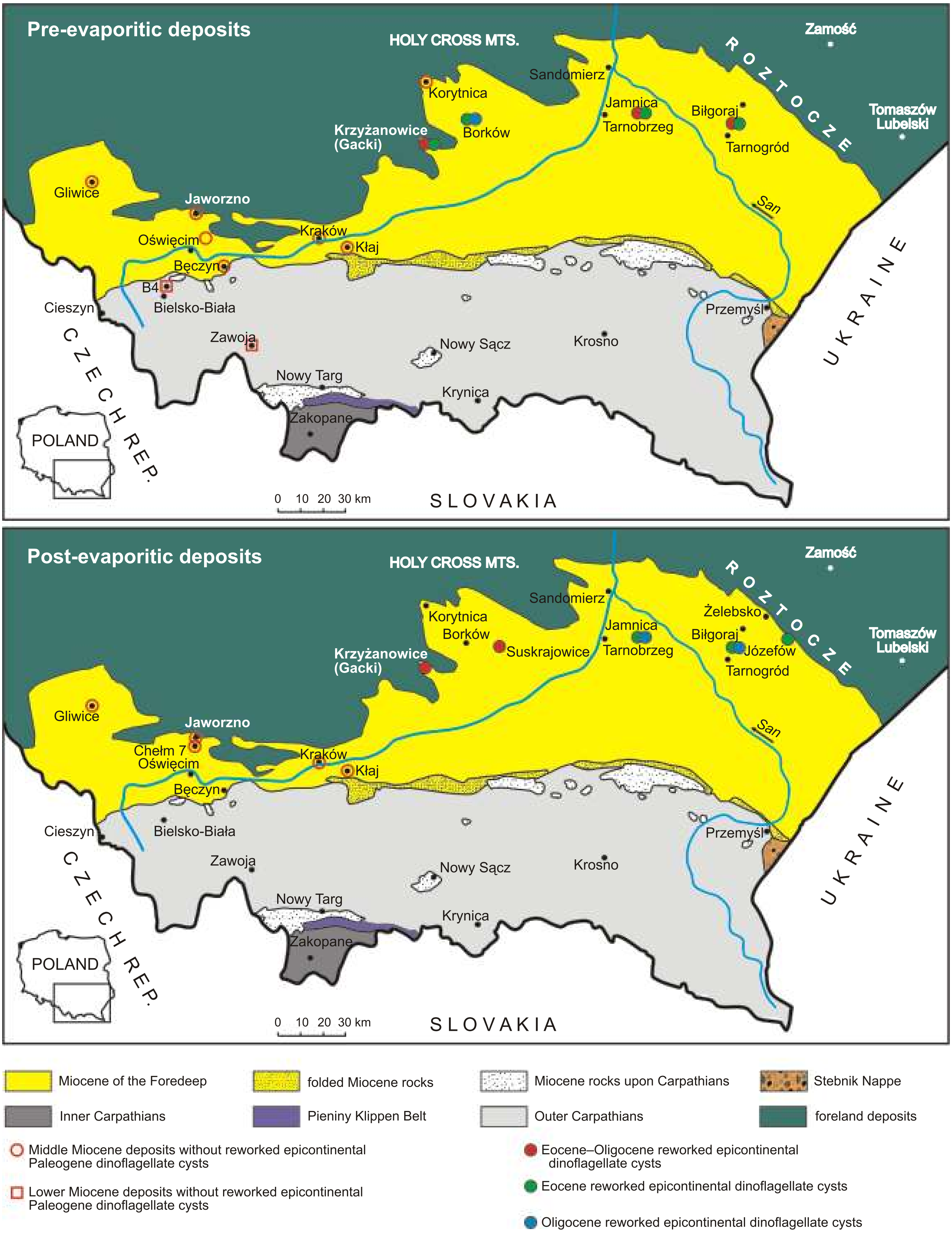

Fig. 3. Occurrence of reworked epicontinental Eocene–Oligocene dinoflagellate cyst specimens in the Miocene of the Carpathian Foredeep

Table 1

Occurrence of reworked Eocene–Oligocene dinoflagellate cysts in the supra-evaporitic deposits of the Tarnogród area

Number	Species	Borehole													
		Dzików 12	Dzików 15	Dzików 17	Jedlinki 2	Księżpol 10	Księżpol 11	Księżpol 12	Potok Górny 4	Potok Górny 5	Sucha Wola 1	Wola Obszańska 9	Wola Różaniecka 7	Wola Różaniecka 10	Wola Różaniecka 11
1	*Apectodinium homomorphum*		x												
2	*Areoligera* sp.													x	
3	*Areoligera*/*Glaphyrocysta* sp.											x			
4	*Areosphaeridium diktyoplokum*		x												
5	*Charlesdowniea* sp.									x			x		
6	*Cordosphaeridium cantharellum*		x							x		x			
7	*Cordosphaeridium inodes*	x												x	
8	*Cordosphaeridium* sp.						x								
9	*Deflandrea heterophlycta*	x													
10	*Deflandrea phosphoritica*			x	x				x	x					
11	*Deflandrea* sp.	x				x	x	x	x	x	x	x	x		
12	*Enneadocysta multicornuta*		x						x						
13	*Glaphyrocysta pastielsii*										x				
14	*Glaphyrocysta* sp.					x						x			
15	*Homotryblium pallidum*								x	x	x				
16	*Homotryblium plectilum*				x				x		x				
17	*Homotryblium tenuispinosum*										x				
18	*Homotryblium* sp.	x	x	x	x	x	x	x	x	x		x	x	x	x
19	*Hystrichokolpoma cinctum*											x			
20	*Membranophoridium aspinatum*								x			x			
21	*Operculodinium microtriainum*								x						
22	*Rhombodinium draco*			x					x	x					
23	*Wetzeliella articulata*								x						
24	*Wetzeliella gochtii*										x				
25	*Wetzeliella symmetrica*								x		x				
26	*Wetzeliella* sp.				x			x				x		x	

Areoligera sp., ?*Areosphaeridium michoudii*, *Areosphaeridium diktyoplokum*, *Cordosphaeridium gracile*, *Enneadocysta* sp., ?*Enneadocysta arcuata*, *Glaphyrocysta* spp., *Homotryblium tenuispinosum*, *Membranophoridium aspinatum*.

INTERPRETATION

AGES OF REWORKED EPICONTINENTAL ASSEMBLAGES

Most of the taxa treated here as reworked (i.e., having their last appearances pre-Miocene) are rather long-lived, typical of both the Eocene and Oligocene. Some other taxa such as *Homotryblium* and *Deflandrea* are also known from Lower Miocene strata (e.g., Dybkjær, 2004). The occurrence of *Homotryblium* in the Middle Miocene of the Foredeep was treated by Gedl (2005a) as reworked despite some other authors reporting its occurrence from Middle or even Upper Miocene strata (e.g., Köthe and Piesker, 2007; for discussion see de Verteuil and Norris, 1996).

The westernmost assemblages of reworked epicontinental Paleogene dinoflagellate cysts, in Borków and Gacki quarries, include species which represent both Eocene and Oligocene taxa. The occurrence of *Areosphaeridium diktyoplokum* in samples from Borków suggests erosion of Middle–Upper Eocene deposits since the stratigraphic range of this species is Middle–Late Eocene (e.g., Stover *et al.*, 1996). However, the presence of *Chiropteridium* sp. in material from Borków points also at a younger, Oligocene source. This genus is known to appear for the first time during the Early Oligocene. Remaining taxa from Borków (*Charlesdowniea* sp., *Deflandrea heterophlycta*, *Wetzeliella* sp.), as well as those from Gacki (*Deflandrea* spp., *Dracodinium*? sp.) may represent both Eocene and Oligocene, although the latter genus is more typical of the Eocene.

Common reworked peridinioids that occur in Sarmatian deposits at Suskrajowice (*Deflandrea phosphoritica* and broken specimens of the *Wetzeliella articulata-symmetrica* complex) cannot date this assemblage more precisely than Eocene–Oligocene.

A similar, Eocene–Oligocene date can be applied to the majority of the samples studied from the Jamnica S119 borehole.

A reworked assemblage from the Baranów Beds includes *Enneadocysta pectiniformis* (Priabonian–Rupelian; Stover and Williams, 1995) and *Areoligera coronata* (Senonian–Middle Eocene; Eaton, 1976). Another assemblage, containing *Charlesdowniea clathrata*, was found in strata directly above the evaporitic horizon (the *Pecten* Beds: 244–258 m). This species, known to have appeared during the latest Ypresian–early Rupelian (Stover et al., 1996), co-occurs in a sample from 257–258 m depth with *Wetzeliella symmetrica* (Bartonian–Chattian; Stover et al., 1996), and with *Enneadocysta pectiniformis* in a sample at 250.5 m. The Priabonian-Rupelian age of the reworked dinoflagellate cyst assemblages from the basal part of the Krakowiec Clays can be established on the basis of the presence at *Enneadocysta pectiniformis* presence. Eocene species (*Areosphaeridium diktyoplokum*, *Rhombodinium longimanum*; Powell, 1992) occur in the higher part of the Krakowiec Clays in the Jamnica S119 borehole, indicating erosion of Eocene strata. The upper part of the Krakowiec Clays yielded, in turn, typical Oligocene species (*Wetzeliella gochtii*: Rupelian – Powell, 1992; *W. symmetrica* subsp. *incisa*: Oligocene – Gerlach, 1961) and the Eocene species (*Areosphaeridium diktyoplokum*).

"Paleogene-bearing" samples from the Biłgoraj–Tarnogród area contain assemblages, which do not allow precise dating. Most of the reworked specimens are of Eocene–Oligocene species. Only in a few samples do *Areosphaeridium diktyoplokum* (Dzików 15), typical of the Eocene, and *Wetzeliella gochtii* (a Rupelian species; Sucha Wola 1) occur.

An outstanding assemblage of reworked Paleogene dinoflagellate cysts was found in Józefów. It consists of gonyaulacoid chorate specimens only; the presence of *Areosphaeridium michoudii* suggests Middle–Late Eocene age for this assemblage (Bujak and Mudge, 1994).

SPATIAL AND TEMPORAL DISTRIBUTION OF REWORKED EPICONTINENTAL FORMS

The data presented above show a varied distribution of reworked Eocene–Oligocene dinoflagellate cysts in the Miocene of the Carpathian Foredeep (Fig. 3). The most common specimens are dark-colourated and are believed to represent forms, which originate from the overthrusted Carpathians (Fig. 4G–J; e.g., Gedl, 1996b, 1997b, 2004, 2005b) and reflect thermal maturity acquired during folding – this feature allows distinction them from epicontinental specimens, which although commonly mechanically damaged, show no increased thermal maturity. This interpretation is supported by their spatial occurrence: Carpathian specimens occur most frequently in the southern part of the Polish Carpathian Foredeep, where they appear in olistoliths (e.g., Zawoja 1 borehole; Gedl, 1997b, Gedl in Oszczypko et al., 2000) or in Miocene clays (e.g., Kłaj 1, Bęczyn; Gedl, 2005a) near the Carpathian overthrust (Fig. 3). The distribution of Carpathian specimens in the Miocene of the Foredeep is also controlled by palaeogeographic conditions and the timing of Carpathian overthrusting, but this problem is beyond the scope of the present paper.

Pale-coloured, thermally unaltered specimens of Eocene-Oligocene dinoflagellate cysts (Fig. 4A–F), treated here as derived from epicontinental deposits, occur exclusively in the northeastern part of the Foredeep, in both sub- and supra-evaporitic strata (Fig. 3). No reworked Paleogene dinoflagellate cysts have been found in Miocene strata from the western part of the Polish Foredeep Basin (Gliwice area; Gedl, 1997a), whereas exclusively Carpathian-derived reworked forms occur in the southwestern part of the Polish Foredeep Basin (Gedl, 1997b; Gedl in Oszczypko et al., 2000; Gedl, 2005a). The western boundary of their occurrence runs approximately along the Pińczów meridian: the westernmost occurrence of reworked epicontinental Paleogene specimens is recorded from Gacki (Krzyżanowice) and Borków, although the Lower Badenian Korytnica Clays (as well as the underlying fossil-barren clays with lignite), contain no Paleogene taxa; only two specimens of *Surculosphaeridium* (Gedl, 1996a, fig. 7h), presumably reworked from the Cretaceous, were found (see Gedl, 1996a, p. 213 for discussion).

There is a significant difference between the frequency of reworked specimens from sub-evaporitic and supra-evaporitic strata of the northwestern part of the Carpathian Foredeep. The ones from the sub-evaporitic part of the Miocene sequence are infrequent, commonly they occur as isolated specimens, especially when compared to the rich assemblages of *in situ* specimens. This contrasts with much more frequent occurrence of reworked Paleogene specimens in supra-evaporitic strata of the northwestern Miocene succession of the Foredeep. The latter occur both in basinal fine detrital deposits (the Upper Badenian–Sarmatian Krakowiec Clays) as well as in the coarse-grained organodetrital rocks of the Roztocze area (Upper Badenian) and the Sarmatian of the southern surrounds of the Holy Cross Mts. This phenomenon may be associated with increased erosion of the Paleogene cover after the mid-Badenian salinity crisis (cf. Oszczypko et al., 2006). But the frequent occurrence of reworked specimens also may be related to a change in the prevailing sedimentary mode, from generally hemipelagic before the salinity crisis to commonly deltaic during the Late Badenian and Sarmatian. This is clearly visible in the Jamnica S119 borehole: samples with an increased ratio of terrestrial elements contain more frequent Paleogene forms (i.e., the upper part of the Krakowiec Clays), whereas samples with "pelagic" palynofacies (middle and upper parts of the *Pecten* Beds: 244.1–254 m; lowermost part of the Krakowiec Clays: 229.02–242.9 m) contain rare reworked specimens, or none (Gedl, 1999).

Most of the samples studied contain assemblages that can be imprecisely dated as "Eocene–Oligocene" only. However, in a few samples well-dated assemblages have been found, which may be correlated with known marine strata (Fig. 3).

The oldest reworked assemblages represent Middle Eocene (presumably Bartonian) forms found at Roztocze (Józefów quarries). The age of these assemblages allow their correlation with Middle Eocene deposits from the basal part of the Sołokija Graben Eocene, and from the Łukowa 4 borehole. According to Gaździcka (1994), the Sołokija Graben Eocene represents the Bartonian. There are no more precise Middle Eocene age indicators among reworked specimens. This means that the known distribution of marine strata of this age in southeastern Poland is limited to the Sołokija Graben and the vicinity of Łukowa (Fig. 5) whereas reworked species of this age occur in the Miocene of the neighbouring Roztocze area only. This suggests a limited extent of the Middle Eocene (Bartonian) transgression in this area. However, several reworked dinoflagellate cyst species found in the Foredeep farther west may also represent specimens

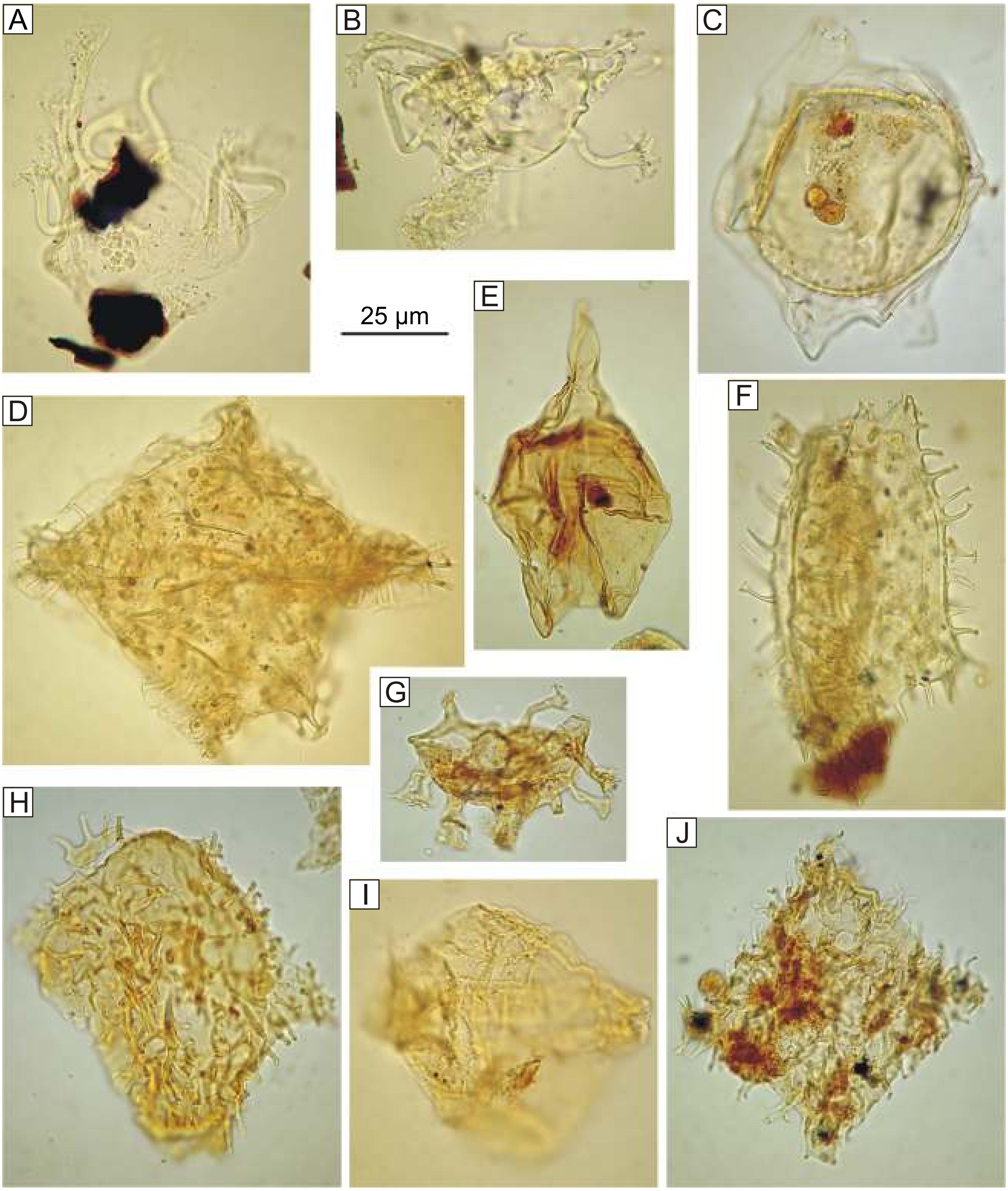

Fig. 4. Reworked dinoflagellate cysts from the Miocene of the Carpathian Foredeep
(A–F – specimens from epicontinental deposits; G–J – Carpathians Flysch specimens)

A – *Areosphaeridium michoudii* (Pardysówka); **B** – *Areosphaeridium michoudii* (Pardysówka); **C** – *Deflandrea heterophlycta* (Borków); **D** – *Charlesdowniea* sp. (Borków); **E** – *Deflandrea* sp. (Gacki); **F** – *Wetzeliella* sp. (Borków); **G** – *Homotryblium tenuispinosum* (Chełm); **H** – *Wetzeliella* sp. (Chełm); **I** – *Rhombodinium perforatum* (Bęczyn); **J** – *Wetzeliella* sp. (Bęczyn)

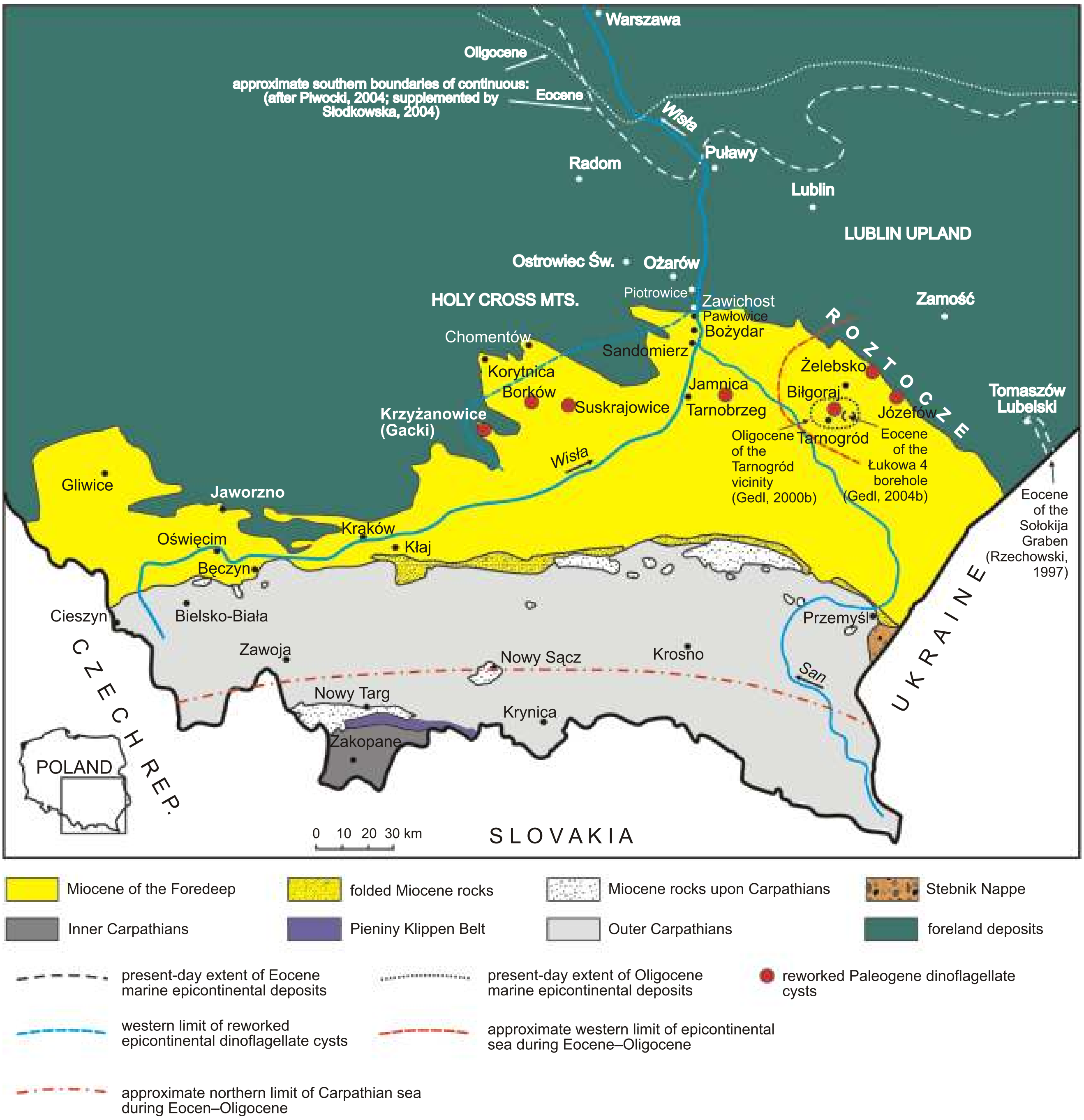

Fig. 5. An attempt at the Eocene–Oligocene palaeogeographical reconstruction of SE Poland on the basis of the extents of palaeontologically documented Paleogene marine epicontinental deposits and the occurrence of reworked epicontinental Eocene–Oligocene dinoflagellate cyst specimens in the Miocene of the Carpathian Foredeep

Approximate northern limit of the Carpathian sea during the Eocene–Oligocene after Kotlarczyk (1985)

derived from Middle Eocene strata (e.g., *Areosphaeridium diktyoplokum*, *Dracodinium* sp., *Areoligera* sp.). Moreover, the topmost part of the Sołokija Graben succession yielded poorly age-diagnostic specimens of *Deflandrea*, which when found in the Miocene, can be dated as Eocene–Oligocene taxa only.

A similar question refers to the distinction of younger, Priabonian dinoflagellate cysts: most of the reworked Paleogene specimens are also known from Late Eocene. No species restricted to the Priabonian were found in the Miocene deposits. This means that the delineation of the Priabonian transgression in southeastern Poland remains difficult. Marine strata of this age were recognized in the upper part of the Sołokija Graben succession.

Among reworked specimens, the most precisely identifiable Oligocene specimens, represented by species with post-Eocene first appearances such as *Chiropteridium* sp. or *Wetzeliella gochtii*. Oligocene specimens were found in the upper part of the Krakowiec Clays of the Jamnica S119 borehole, and in the Biłgoraj–Tarnogród area (Sucha Wola 1 borehole); a single specimen was found in Borków.

Most of the reworked Oligocene specimens were thus found in proximity to the *in situ* epicontinental Oligocene deposits, which occur below the Miocene sequence in the Biłgoraj–Tarnogród area (Gedl, 2000a). This suggests a relatively limited extent of the Oligocene transgression in southeastern Poland. However, a single specimen of *Chiropteridium* sp. found in Borków, may indicate that the Oligocene marine transgression was much more extensive and reached the Holy Cross Mts area (note: as in the case of reworked Eocene dinoflagellate cysts, distinction of Oligocene specimens in the case of long-ranging species is impossible).

DISCUSSION

The limitation of reworked specimens to the northeastern part of the Polish Carpathian Foredeep clearly points to a limited range of marine Eocene and Oligocene cover in epicontinental basins in southeastern Poland. The distribution of reworked specimens reflects the stratigraphic extent of source deposits, and also subsequent factors such as sedimentary transport directions. However, sedimentological data suggest a predominantly southwards direction of clastic input into the Foredeep Basin along its northern boundary (e.g., Czapowski and Studencka, 1990, 1996; Jasionowski, 1997, p. 53; Wysocka, 2002).

Reworked Eocene and Oligocene dinoflagellate cysts, which occur in the basal parts of the Miocene sequences in the westernmost part of the Polish Carpathian Foredeep (Zawoja 1 borehole) are of Carpathian origin only. This agrees with the interpretations of several authors (e.g., Moryc, 1989) who point at the Carpathians as the main source area for Miocene sediments in this part of the Carpathian Foredeep. The ages of basal intervals of the Carpathian Foredeep succession in this area seems to be not older than Early Miocene. Oszczypko and Oszczypko-Clowes (2003) documented marine deposits representing the NN1 Calcareous Nannoplankton Zone in the lower part (depth 2324–2333 m) of the "Zebrzydowice Formation" in the Andrychów 6 borehole. According to these authors, underlying conglomerates (the "Andrychów Formation") may also represent the Oligocene although no micropalaeontological evidence for this age was given (Oszczypko and Oszczypko-Clowes, 2003, fig. 9).

A lack of reworked epicontinental Eocene and Oligocene dinoflagellate cysts in the Kraków–Silesia area suggests that this area was not covered by coeval marine transgressions. This conclusion is supported by the results of earlier studies, which indicated no traces of marine conditions in the Kraków–Silesia area. Indeed, geological and geomorphological studies show that this area was then land. The assumption of prevailing continental conditions here is based on the occurrence of regolith and karst, and also sandy deposits typical of a terrestrial environment (e.g., Gradziński, 1962, 1977; Rutkowski, 1965, 1989; Alexandrowicz, 1969; Błaszak, 1970; Felisiak, 1992; see also Bosák et al., 1979). The lack of palaeontological evidence from these deposits makes their precise dating impossible – their deposition must have taken place between the Senonian (the age of the youngest levels) and the Miocene.

Similarly, no traces of Eocene–Oligocene marine transgression across the Holy Cross Mts. have been noted (Fig. 5). The oldest Cenozoic strata in the southeastern surrounds of the Holy Cross Mts. are represented by continental loamy and phytogenic deposits known from the Chomentów vicinity (Kowalewski, 1927, 1930), and from Ostrowiec and Ożarów (e.g., Samsonowicz, 1934). In the latter area, Paleogene deposits are preserved locally, mainly as continental deposits, commonly associated with karst (Kosmowska-Suffczyńska, 1966). Also the northern surrounds of the Holy Cross Mts. show no traces of marine deposits of Eocene–Oligocene age. Karaszewski (1966) described, from a few localities south of Radom, locally occurring quartzose and glauconitic deposits. Due to a lack of fossils Karaszewski (1966) questionably interpreted these as traces of marine transgression of Oligocene age. However, his descriptions of these deposits point to their, at least partly, karst origin, and should be thus related to a continental environment. Similar glauconitic deposits with characteristic large quartz pebbles (locally termed "quartz beans") are known from the Puławy area where they rest on Danian gaizes.

The situation in the central part of the foreland between the Holy Cross Mts. and the Roztocze area is in some ways different. Although the Cenozoic succession generally starts there with Miocene strata (e.g., Brzezińska, 1961; Areń, 1971) glauconitic clastic deposits have been discovered in a few places which were arbitrary attributed to the marine Oligocene. An example is "Oligocene" deposits that locally occur on the pre-Cenozoic basement at Trzydnik (Kasiński and Piwocki, 1994, fig. 5). Several other sites of "marine Oligocene" are reported from the Opatówka River valley. Kowalewski (1957) described there an 11 m thick succession of green to brownish loamy quartz sands from the Bożydar (also known as Boży Dar) borehole. These pass into phytogenic deposits dated by Kowalewski (1957) as Lower–lowermost Middle Miocene. Samsonowicz (1933, 1934) reported, from the Opatówka River valley and neighbouring Zawichost area the green glauconitic loamy sands known as the Zawichost sands ("piaski zawichojskie" or "piaski zawichoskie"; see Pożaryski in Bielecka, 1964). These are also known from nearby Pawłowice (e.g., Kubica, 1965) and Piotrowice where they were exploited in the second half of the 20th century. Similar "green sands" occur also on both sides of the Wisła River where they rest on Upper Cretaceous rocks (e.g., Pożaryski, 1951). Czapowski and Peryt (2004) correlated these deposits with the marine Oligocene described by Gedl (2000a) from the Biłgoraj–Tarnogród area. However, in the author's opinion, this correlation is questionable, as the former deposits contain no fossils, whereas the ones from around Tarnogród contain abundant marine phytoplankton fossils. Moreover, they also differ lithologically: marine deposits from Biłgoraj are dark-brown to grey and whitish in the uppermost part, and they contain subordinate amounts of glauconite. The Zawichost sands, in turn, are green, and they contain large amounts of glauconite. The only lithological similarity can be seen between the Biłgoraj sands and the upper part of the sands in the Bożydar borehole, which are also brownish and contain small amount of glauconite (Kowalewski, 1957).

The northern surrounds of the Polish Carpathian Foredeep, the area of the Holy Cross Mts. and the Sandomierz Upland, have been generally subjected to subaerial erosion at least since the Late Cretaceous, when this region was uplifted by the Laramian movements (e.g., Pożaryski, 1962). The Danian transgression covered only the northern part of this region. There are no palaeontologically documented Eocene and Oligocene deposits in this area. The only post-Danian deposits are of continental origin, and their age is uncertain due to lack of fossils; they span the Danian–Early Miocene.

It is also difficult to precisely date the erosion of marine Eocene–Oligocene deposits in the eastern part of the Polish Carpathian Foredeep and in Roztocze. Their erosion presumably took place during several phases. There is little known about the pre-Oligocene erosion of older Eocene deposits: Oligocene deposits contain no reworked Eocene fossils which suggests no erosion during the Oligocene transgression. However, the scarcity of *in situ* Oligocene deposits makes this interpretation highly uncertain. The general preservation of epicontinental Eocene–Oligocene deposits in the Polish Carpathian Foredeep as isolated outcrops suggests that the main phase of erosion took place before the deposition of the oldest Miocene strata (i.e., Lower? or Middle Miocene), i.e., during the Late Oligocene–Early Miocene. The age of this event might be correlated with the time of deposition of the conglomerates and coarse-grained clastic deposits that fill erosional channels in the basement of the western (Moryc, 1989; Oszczypko et al., 2000; Oszczypko and Oszczypko-Clowes, 2003) and eastern (Moryc, 1995) parts of the Carpathian Foredeep, questionably dated as Oligocene–earliest Miocene.

Erosion of Eocene–Oligocene epicontinental deposits on areas not covered by the Miocene sea of the Foredeep Basin continued throughout the whole period of its existence, i.e., during the Badenian and Sarmatian. This presumably increased after general tectonic rebuilding of the Foredeep architecture and subsidence of its basinal part, which took place just after deposition of the evaporitic succession (i.e., during the latest Badenian–earliest Sarmatian; e.g., Krzywiec, 2001). The latter phase of erosion led to almost complete removal of the Eocene–Oligocene cover from the foreland area, leaving only small locally preserved outcrops, mainly in depressions (such as the Sołokija Graben).

CONCLUSIONS

The occurrence of reworked epicontinental dinoflagellate cysts of Eocene–Oligocene age is limited to the northeastern part of the Miocene of the Polish Carpathian Foredeep. They occur in both sub- and post-evaporitic deposits in this area. Such a distribution likely reflects the extent of marine transgression during the Eocene and Oligocene in SE Poland. Marine strata deposited down during these transgressions were later eroded: according to several authors they served as the source for clastic deposits of the Miocene succession, especially its basal part (e.g., Kowalewski, 1957; Brzezińska, 1961). Deposits of the older, Eocene transgression were possibly at least partly removed by the Oligocene transgression, or during denudation between the Late Eocene and earliest Oligocene. Therefore Eocene forms could be reworked twice, first during the Oligocene transgression, and secondly, from Oligocene sands into the Miocene. This makes precise delimitation of a particular transgression difficult.

The westernmost occurrence of reworked epicontinental Paleogene dinoflagellate cysts shows that marine transgression did not enter the area of the Holy Cross Mts. which, during the Eocene–Oligocene, was land (Fig. 5). This interpretation agrees with the lack of coeval marine deposits across this territory. The only post-Mesozoic–pre-Miocene deposits, regarded by earlier authors as traces of “Oligocene” transgression (e.g., Samsonowicz, 1934), are generally continental deposits associated with karst; there no age indicators of these deposits, which may well be of Paleocene age. However, the occurrence of reworked forms cannot serve as a direct indication of a transgression extent. The latter is documented by *in situ* deposits found at Roztocze and in the Tarnogród vicinity (Fig. 5).

So far, fossil-documented epicontinental marine deposits in the Carpathian Foredeep and foreland represent at least three transgressive pulses: Middle Eocene, Late Eocene and Early Oligocene (Gaździcka, 1994; Gedl, 2000a; Słodkowska, 2004; Myśliwiec and Śmist, 2006). Their correlation with particular reworked specimens is difficult because most documented reworked forms have long stratigraphic ranges, being known from the Eocene and Oligocene. Nevertheless, the oldest reworked specimens represent Mid–earliest Late Eocene forms, and they occur at Roztocze (Upper Badenian of the Józefów quarries). They may be correlated with Eocene deposits known from the Łukowa 4 borehole and from the lower part of the Eocene succession in the Sołokija Graben.

The youngest reworked assemblages, in turn, are grouped mainly in the northeastern part of the Carpathian Foredeep; they can be linked with the marine *in situ* Oligocene deposits of the Biłgoraj–Tarnogród area. Rare Oligocene specimens south of the Holy Cross Mts. indicate the extent of the Early Oligocene transgression that reached the eastern parts of this region, but did not cover it.

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APPENDIX 1

BOREHOLES FROM THE KRAKÓW–OŚWIĘCIM AREA

Dąb 4 (Chodenice Beds: sample 22.3–24.3 m; Skawina Beds: samples 60.3–63.3 and 101.9–102.5 m), Chełm Wielki (Skawina Beds: samples 27 and 69 m), Libiąż 139 (Skawina Beds: samples 21 m and 38.7 m), Jaworzno 5902 (samples 32.6–34.6 m, 26.6–28.6 m, 19.6–21.6 m), Chełm 7 (Skawina Beds: samples 127 m, 67 m; Chodenice Beds: 33 m).

BOREHOLES FROM THE TARNOGRÓD AREA

Dzików 12 (eight samples: 1048 m, 1047 m, 1045 m, 946 m, 909 m, 817 m, 737 m, 471 m), Dzików 15 (nine samples: 1091 m, 1088 m, 1086 m, 1071 m, 920 m, 835 m, 732 m, 462 m, 224 m), Dzików 17 (six samples: 1013 m, 1011 m, 1008 m, 952 m, 745 m, 496 m), Jedlinki 2 (ten samples: 1035 m, 1033 m, 1032 m, 1027 m, 1018 m, 1001 m, 865 m, 847 m, 806 m, 741 m), Księżpol 10 (ten samples: 942 m, 865 m, 825 m, 786 m, 752 m, 711 m, 677 m, 607 m, 502 m, 405 m), Księżpol 11 (five samples: 915 m, 894 m, 737 m, 540 m, 331 m), Księżpol 12 (samples: 905 m, 748 m, 545 m, 335 m), Potok Górny 4 (six samples: 1099 m, 1096 m, 830 m, 810 m, 740 m, 732 m), Potok Górny 5 (six samples: 1131 m, 1124 m, 1102 m, 1004 m, 912 m, 864 m), Sucha Wola 1 (four samples: 1165 m, 755 m, 709 m, 413 m), Wola Obszańska 9 (six samples: 918 m, 822 m, 663 m, 508 m, 352 m, 206 m), Wola Różaniecka 7 (eleven samples: 1121 m, 1120 m, 1107 m, 1078 m, 974 m, 870 m, 765 m, 662 m, 558 m, 455 m, 349 m), Wola Różaniecka 10 (eight samples: 1057 m, 1052 m, 1031 m, 1030 m, 1028 m, 988 m, 937 m, 501 m), Wola Różaniecka 11 (nine samples: 1067 m, 1066 m, 1052 m, 1051 m, 1049 m, 947 m, 940 m, 819 m, 557 m).