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SEDIMENTARY CONDITIONS IN THE SIARY ZONE OF THE MAGURA BASIN (CARPATHIANS) IN THE LATE EOCENE–EARLY OLIGOCENE

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Abstract: The sediments of the upper Eocene (Priabonian)–lower Oligocene (Rupelian) of the Siary zone in the Magura nappe (basically Magura Beds in glauconitic facies) display features indicating their origination in sedimentary conditions quite different from those in which coeval sediments from the other parts of the Carpathians were deposited. This paper aims at interpreting the sedimentary conditions on the basis of lithofacies, their vertical and lateral distribution, foraminifera assemblages, $CaCO_3$ and organic matter content determined in six transects through the entire Siary zone, the contents of main and trace elements determined in 11 samples from one section and different published data.

Lithofacies and the present day shape of the Siary zone suggest sedimentation of the entire succession in a strongly elongated confined basin. Facies distribution indicates deposition on a submarine ramp that gradually expanded to NE and E along the slopes of the outer basin margin. Assemblages of foraminifera suggest location of the basin bottom below the foraminiferal lysocline. Moreover, foraminifera together with bioturbation structures and sediment geochemistry indicate sedimentation mainly in weakly oxic, close to dysoxic bottom waters.

The differences in facies in relation to the coeval deposits of the other parts of the Carpathians are interpreted as resulting mainly from intense resedimentation in the Siary zone during the Priabonian–Rupelian, and in part from the relatively low calcium carbonate supply. Gradual expansion of resedimentation towards NE, followed by a decrease in the supply of coarse-grained material is regarded as due to lithosphere rollback beneath the evolving Carpathians. This process is interpreted as of superior significance in controlling sedimentation during the Priabonian–Rupelian not only in the Siary zone but also in the entire Magura basin. This was the factor responsible for forcing the subsidence of the Magura basin, accretionary wedge development in its inner part, and fore-bulging of the area at some distance in front of the zone of the rolling back lithosphere, i.e. in the source area of the sedimentary succession in question. Finally, this process also caused drowning and burying of the source area.

Key words: Flysch, Carpathians, Magura nappe, Siary zone, Priabonian, Rupelian, sedimentation.

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INTRODUCTION

Sediments of the upper Eocene (Priabonian)–lower Oligocene (Rupelian) display a very characteristic facies pattern in vast areas of the Carpathians (see Bieda *et al.*, 1963; Leszczyński, 1997). Green shales are characteristic of the lower and middle Priabonian. Cream-yellow to yellowish-green globigerina marls represent upper Priabonian and lowermost Rupelian, whereas predominantly dark-coloured shales and marls with a chert horizon and different proportion of sandstones are representative of the remaining part of the Rupelian (Menilite Beds). The entire succession is in many sections only several tens-of-metres thick. However, such a facies pattern is common only in the outer flysch nappes (menilitic-krosno group of nappes), i.e. in all the nappes of the Outer Carpathians except for the Magura nappe. To some extent it is recorded along the entire northern margin of the Alpine orogenic belt in Europe. It denotes sedimentation in a poorly oxygenated to anoxic basin with significant influence of organogenic material that varied with time in both type and amount (see Książkiewicz, ed., 1962; S. Leszczyński, 1997). Additionally, wide distribution of calcareous background sediments (globigerina marls, mainly hemipelagites and muddy turbidites), indicates that large parts of the sedimentary basins were at that time located above CCD (for the first time at this scale in the Upper Cretaceous–Paleogene part of the flysch succession of the Carpathians). Milankovich cyclicity was suggested by Leszczyński (1996, 1997) to be responsible for the vertical fluctuation of calcium-carbonate content in the package of concentrated occurrence of the globigerina marls (the Sub-Menilite Globigerina Marl Sequence, SMGMS) and to some extent for the distribution of coarse-grained sediments. Intense resedimentation of organic and siliciclastic material recorded in the Rupelian part of the succession, and oceanographic changes that lowered carbonate production, were suggested by Leszczyński (1997) to be the main factors responsible for the retreat of the SMGM facies and the onset of the Menilite Beds sedimentation.

In the Magura nappe and the Inner Carpathians, the named facies pattern is less distinctive or is absent. However, one has to note that except for the outer part of the Magura nappe (the Rača and Siary zones, see Koszarski *et al.*, 1974), the Rupelian sediments are known only from several isolated places (see Książkiewicz & Leško, 1959). More than a thousand metre thick succession, dominated by sandstones with different proportion of fine-grained sediments (shales) represents the Priabonian–Rupelian sediments in the Rača and Siary zones (see Bromowicz, 1992; Oszczypko-Clowes, 2001). This succession represents either the whole or only the upper part of a lithostratigraphic unit known in the older literature as the Magura Beds (Świdziński, 1934). Absence of red mudstones (variegated shales), characteristic of the pre-Priabonian flysch of all nappes, and predominance of green colour in mudstones of the Priabonian of the Magura and the outer nappes are the most distinctictive common features of the succession in question of the entire Outer Carpathians.

Of the entire Magura nappe, the Priabonian–Rupelian sediments display the most extensive distribution and greatest thickness in the Siary zone (see Bromowicz, 1992), i.e. the outermost part of the nappe (see Koszarski *et al.*, 1974). Except for the eastern part of the zone, the entire succession is built up basically of sediments which differ from the coeval sediments of the southern part of the nappe primarily in the occurrence of glauconite-rich sandstones (Magura Beds in glauconitic facies *sensu* Książkiewicz, 1974; MB). East of the Nowy Sącz meridian, the entire Priabonian part of the succession or at least the lower Priabonian part was described as being built up of nearly exclusively fine-grained sediments (Blaicher & Sikora, 1963; Sikora, 1970; Kopciowski, 1996). Foraminiferal assemblages similar to those recorded in the SMGMS of the outer flysch nappes were discovered there. Nevertheless, sedimentary origin of these sediments has not been interpreted so far.

The Priabonian–Rupelian sediments of the Siary zone, according to the descriptions in the previous literature (e.g., Książkiewicz, 1956, Książkiewicz, ed., 1962; Bromowicz, 1992), appear to be entirely different in origin from the coeval sediments of the other parts of the Carpathians. Actual relationships of their origin in the whole Carpathians as well as the range of and reasons for the differences have not been satisfactorily recognised yet. This is in fact a question of crucial significance as far as the evolution of the Carpathians is concerned. This paper aims to improve the hitherto limited understanding of sedimentary conditions in the Siary zone during Priabonian–Rupelian. It focuses on interpreting (1) the sedimentary origin of the fine-grained facies, (2) the nature of their calcareous material, (3) the spectrum of background and episodic sediments as well as their distribution in the succession. Furthermore, bathymetry and oxygenation regime at the basin-floor, and chief sedimentation controls are explained. The interpretations are based on complex investigations of the succession in six transcets through the Siary zone.

GEOLOGICAL SETTING AND PREVIOUS WORK

The study area is located in the central part of the Polish Outer Carpathians (Fig. 1). It embraces marginal part of the Magura nappe, generally corresponding to the Siary zone after Koszarski *et al.* (1974) or the Northern Gorlice zone after Węcławik (1969). It is a zone where, according to the Detailed Geological Map of Poland, 1:50,000, edited by Geological Survey in 1966 and 1967, the MB are immediately underlain by the sediments of the Variegated Shale unit or a unit of undivided Variegated Shale and Hieroglyphic Beds. It embraces the entire area occupied by the MB in the east whereas in the middle and western segments only part of this area is included. The Siary zone is bounded by the margin of the Magura nappe in the north and in the south by the more internal part of the Magura nappe, called the Rača zone after Koszarski *et al.* (1974), Southern Gorlice zone after Węcławik (1969), and Rača zone in this paper. Together with the two more internal ones (Sącz or Bystrica and Krynica zones), all these zones were originally distinguished as different facies zones because of different stratigraphy (Fig. 2). According to Koszarski *et al.* (1974), this differentiation results from the dividing of the Magura basin into sub-basins, due to Laramian orogeny. In the Slovakian and Czech Carpathians, and partly in Poland, these facies zones are also considered as representing distinct tectonic units (e.g., Koszarski *et al.*, 1974). In fact, the facies zones are more distinctive than the tectonic ones, e.g. the Siary and Rača units as shown on the tectonic map of Poland (Znosko, ed., 1998) in the western segment of the Polish Carpathians. Moreover, structural distinction of these units is disputable.

The Outer Carpathians represent an accretionary wedge consisting of several thrust sheets comprising the fill of several basins whose tectonic affiliation changed with time (see Nemčok *et al.*, 2000). The rock succession of the Eocene–Oligocene of the Western Carpathians, including the area under study, displays features indicative of sedimentation in a foreland basin (cf. Oszczypko, 1992, 1999) dominated by deep-marine realms (the Carpathian flysch-sea) whose paleogeography, however, is still controversial. According to Książkiewicz (1956), the Magura basin was separated from the more outer parts of the flysch-sea, particularly those represented by the present day Silesian nappe, by an elevation called the Silesian cordillera. This elevation formed the outer margin of the Siary zone and was the source area for the Paleogene clastic sediments of this zone (v. Książkiewicz, ed., 1962). At the same time, in the inner zones, particularly in the Krynica and Sącz zones, sediment supply is presumed to be generally from areas located on southern side of the basin. Recently, Nemčok *et al.* (2000) have suggested that the Magura basin was located to

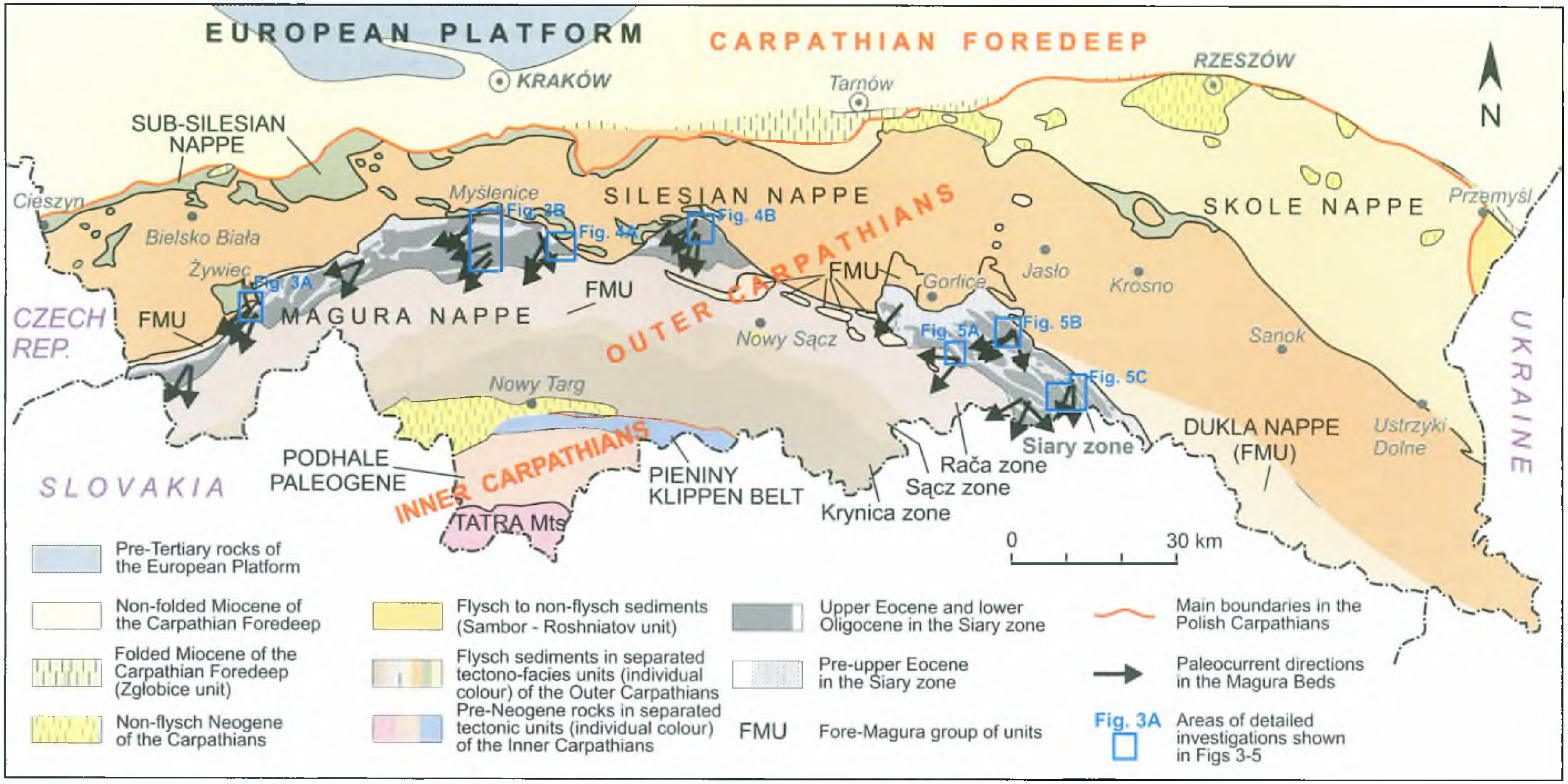
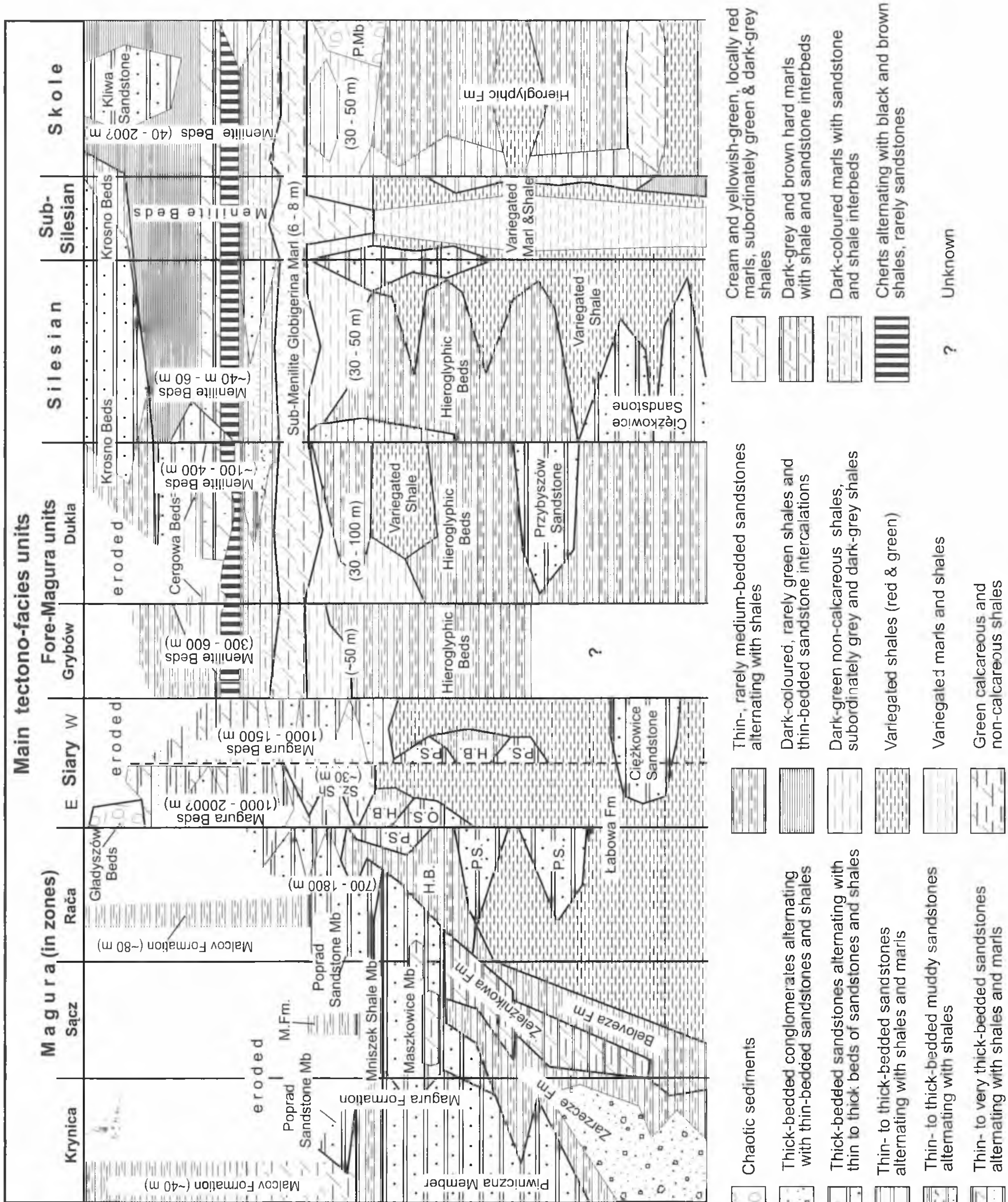


Fig. 1. Regional and structural context of the study area according to the Tectonic Map of Poland (Znosko, ed., 1998) with Leszczyński's modifications for the southern boundary of the Siary zone



Main tectono-facies units
Age
Oligocene
Eocene
pars
M a g u r a (in zones)
Krynica
Sącz
Rača
Siary
Fore-Magura units
Grybów
Dukla
S i l e s i a n
Sub-Silesian
S k o l e
Malcov Formation (~40 m)
Malcov Formation (~80 m)
Magura Formation
Poprad Sandstone Mb
Mniszek Shale Mb
Maszkowice Mb
Piwniczna Member
Zarzecze Fm
Żeleźnikowa Fm
Beloveza Fm
Magura Beds (1000 - 2000? m)
Magura Beds (1000 - 1500 m)
Gładyszów Beds
Łabowa Fm
Ciężkowice Sandstone
Menilite Beds (300 - 600 m)
Menilite Beds (~100 - 400 m)
Menilite Beds (~40 m - 60 m)
Menilite Beds (40 - 200? m)
Cergowa Beds
Krosno Beds
Kliwa Sandstone
Sub-Menilite Globigerina Marl (6 - 8 m)
Hieroglyphic Beds
Hieroglyphic Fm
Variegated Shale
Variegated Marl & Shale
Przybyszów Sandstone
e r o d e d
Chaotic sediments
Thick-bedded conglomerates alternating with thin-bedded sandstones and shales
Thick-bedded sandstones alternating with thin to thick beds of sandstones and shales
Thin- to thick-bedded sandstones alternating with shales and marls
Thin- to thick-bedded muddy sandstones alternating with shales
Thin- to very thick-bedded sandstones alternating with shales and marls
Thin-, rarely medium-bedded sandstones alternating with shales
Dark-coloured, rarely green shales and thin-bedded sandstone intercalations
Dark-green non-calcareous shales, subordinately grey and dark-grey shales
Variegated shales (red & green)
Variegated marls and shales
Green calcareous and non-calcareous shales
Cream and yellowish-green, locally red marls, subordinately green & dark-grey shales
Dark-grey and brown hard marls with shale and sandstone interbeds
Dark-coloured marls with sandstone and shale interbeds
Cherts alternating with black and brown shales, rarely sandstones
Unknown

Fig. 2. Lithostratigraphic scheme and facies of the lower Eocene–lower Oligocene of the Polish Outer Carpathians. More important lithostratigraphic units are named and their boundaries are marked with heavy lines. Note differences in facies of the coeval sediments and diachronous distribution of the chief masses of coarse-grained sediments in the Magura nappe. Numbers within lithostratigraphic units of the upper Eocene–lower Oligocene denote their thickness range. H.B. – Hieroglyphic Beds, O.S. – Owczary Sandstone, P.Mb – Popiele Member, P.S. – Pasierbiec Sandstone, Sz. Sh. – Szymbark Shale. Compiled by S. Leszczyński based on various sources: Krynica and Sącz zones based on Oszczypko-Clowes (2001); Rača and Siary zones based on Sikora (1970), Książkiewicz (1974), Bogacz *et al.* (1979), Van Couvering *et al.* (1981), Malata (1981, 2001), Bromowicz (1992), Kopciowski & Garecka (1996), Oszczypko-Clowes (2001) and personal data of S. Leszczyński; other units based on Koszarski (1985), Kotlarczyk (1988), Rajchel (1990) and Leszczyński (1997)

the south of the Bohemian Massif, whereas the Silesian basin was located to the east of it. Furthermore, in their opinion, the Magura succession attained its present position mainly due to early-middle Miocene oblique thrusting with a distinctive strike-parallel sinistral strike-slip component.

According to recent interpretations (see Morley, 1993; Kováč *et al.*, 2000), the Tertiary evolution of the Carpathians resulted from: (1) gravity driven subduction of the oceanic or suboceanic lithosphere underlying the flysch basins, (2) back-arc extension associated with diapiric uprise of asthenospheric mantle and (3) lateral extrusion of lithosphere fragments from the Alpine collision between the converging European and Apulian plates.

Stratigraphic framework

The Siary zone is comprised of a continuous succession of Late Cretaceous–early Oligocene deep-marine sediments. The pre-Priabonian part of the succession is as much as several hundred metres thick. The lower and middle Eocene is represented by variegated shales (Łabowa Shale Formation, see Oszczypko *et al.*, 1999) locally with up to several hundred metres thick complexes of thick-bedded coarse-grained sandstones (Ciężkowice Sandstone, and in some places Pasierbiec Sandstone and Owczary Sandstone; see Książkiewicz, 1974; Żgiet, 1976; Bogacz *et al.*, 1979; Fig. 2), several tens metres thick complexes of thin-bedded flysch (Beloveža Beds acc. Bogacz *et al.*, 1979), and rarely other sediments. In the western part of the Siary zone, according to foraminifera and tuffite dating (Sikora & Żytko, 1960; Malata, 1981; Van Couvering *et al.*, 1981), the top part of the pre-Priabonian sediments includes the lower part of the MB.

The Priabonian–Rupelian part of the succession constitutes its dominant division in respect of thickness and areal distribution. The succession is as much as nearly 2000 m thick (see Bromowicz, 1992). Its upper boundary is erosional. The youngest dated sediments represent the calcareous nannoplankton zone NP22 (i.e. lower Rupelian) in the western part of the Siary zone and the NP24 (i.e. upper Rupelian–lower Chattian) in the east (Oszczypko-Clowes, 1999, 2000, 2001). Chronostratigraphic location of the top part of the succession in the western part of the Siary zone has not been recognised yet. The basic section of the succession, in respect of thickness, seems to represent Priabonian in the western part of the zone whereas Rupelian in the east (see Oszczypko-Clowes, 1999, 2000, 2001). The entire preserved section of Priabonian–Rupelian in the major part of the Siary zone appears to be represented basically by the MB (see Sikora & Żytko, 1960; Jednorowska, 1966; Książkiewicz, 1966, 1974; Malata, 1981, 2001; Oszczypko *et al.*, 1999). However, precise chronostratigraphic data are scanty. Moreover, lithostratigraphy of these sediments is still inconsistent (e.g., Książkiewicz, 1974; Oszczypko-Clowes, 1999, 2000, 2001).

In some sections of the eastern part of the Siary zone, entire Priabonian or its lower part is represented by green shales, subordinately dark-coloured shales and rare intercalations of thin-bedded sandstones (see Blaicher & Sikora, 1963; Sikora, 1970; Kopciowski, 1996). This unit is only several metres to some tens metres thick (see Sikora, 1970; Kopciowski, 1996). According to Kopciowski (1996), the lack of this unit or its reduced thickness in some areas result from erosion at the beginning of MB sedimentation. Fission-track age determinations on zircons from a tuffite layer, recorded in the upper part of this unit in Folusz, showed 32.8±1.3 Ma (Van Couvering *et al.*, 1981), i.e. early Rupelian, according to Berggren *et al.* (1995). The lower part of this unit was included by Sikora (1970) to the Variegated Shale unit whereas the upper part to the Globigerina Marl unit. Kopciowski (1996) called the entire unit the Szymbark Shale. The overlying sediments were included to the MB by Blaicher & Sikora (1963), Sikora (1970), and Kopciowski (1996). Recently, Oszczypko-Clowes (1999, 2000, 2001) has marked this package as belonging to the Zembrzyce Beds. According to Bogacz *et al.* (1979), the upper part of thin-bedded flysch, called by them the Beloveža Beds, might represent the lower part of Priabonian near Owczary village, south of Gorlice. According to Oszczypko-Clowes (1999, 2000, 2001), the sediments regarded here as MB start in the calcareous nannoplankton zone NP19-20 in some areas of the eastern part of the Siary zone (sections in Małastów and Ropica Górna). Kopciowski & Garecka (1996) recognised a unit of chaotic sediments (the Gładyszów Beds) above the MB in a small area south of Gorlice. Calcareous nannoplankton representing zone NP24 was there identified.

According to Cieszkowski (1992), in the middle segment of the Siary zone, a unit of thick-bedded sandstones, called by him the Wojakowa Sandstone, constitutes the lower part of Priabonian. The interpretation of chronostratigraphic location of this unit is, however, not convincing as this unit is overlain by the variegated shales (cf. Burtan & Skoczylas- Ciszewska, 1966; see Fig. 4), commonly known in the Outer Carpathians as not younger than the Middle Eocene.

The MB represent a unit characterized by massive, usually olive-green and grey-green calcareous shales (mudstones and marls) and thin to thick-bedded, frequently glauconite-rich sandstones (Książkiewicz, 1974). A tripartite structure of the MB was suggested by Książkiewicz (1974) in the western Polish part of the Magura nappe. Two units dominated by shales separated by a sandstone unit were included to the MB. These units were distinguished earlier as the separate lithostratigraphic units called respectively: the Sub-Magura Beds (Książkiewicz, 1935), the Magura Sandstone (Paul, 1868) or Magura Beds (Książkiewicz, 1935) and the Supra-Magura Beds (Książkiewicz, 1966). Książkiewicz (1974) included all these units to the MB and proposed to change the name Sub-Magura Beds into Zembrzyce Shale, whereas Supra-Magura Beds to Budzów Shale. Noteworthy, in the eastern part of the Siary zone, all these sediments were distinguished until that time as the Magura Beds (see Fig. 5). Koszarski & Koszarski (1985) applied the name Wątkowa Sandstone for the Magura Sandstone in the eastern part of the Siary zone. Bromowicz (1992) called the shaly upper part of the MB in the eastern part of the Siary zone the Małastów Shales. Recently, Oszczypko *et al.*, (1992, 1999), Oszczypko-Clowes (1999, 2000, 2001) and Malata (2001) mentioned the units included by Książkiewicz (1974) to the MB as the Zembrzyce Beds, the Wątkowa Sandstone and the Budzów Beds respectively. However, the sediments shown by Oszczypko-Clowes (1999, 2000, 2001) in particular units do not entirely fit to those indicated in the original definition of these units. Isochronous lower boundary of the Zembrzyce Beds was suggested by Oszczypko *et al.* (1999), Oszczypko-Clowes (2000, 2001) and Malata (2001) in the stratigraphic schemes of the Siary zone irrespective of the published data indicating its diachronism (see Sikora & Żytko, 1960; Sikora, 1970; Van Couvering *et al.*, 1981; Malata, 1981, 2001).

The MB generally correspond to the Zlin Formation in the Czech and Slovakian Carpathians. The lower part of the MB is coeval and intermingles with the Poprad Sandstone Member of the Magura Formation (MF; Birkenmajer & Oszczypko, 1989). Intermingling of MB and MF is particularly characteristic of the western part of the Rača zone in Poland (see Sikora & Żytko, 1960). Burtan (1978) recognised a growing upward proportion of glauconitic sandstones in the Magura Beds of the middle segment of the Rača zone in Poland. The uppermost Priabonian–Rupelian part of the MB is coeval with the Malcov Formation distinguished in the Krynica zone (see Blaicher & Sikora, 1967; Oszczypko *et al.*, 1999, Oszczypko-Clowes, 2000, 2001).

The sandstones of the entire MB reveal paleotransport directions generally from NE (e.g., Książkiewicz, ed., 1962). The coarse-grained sediments (sandstones, subordinately conglomerates) of the MB were interpreted as deposited by different gravity mass-flows, mainly turbidity currents. Turbiditic origin was also implied for the associated massive, fine-grained sediments (see Bromowicz, 1992). Książkiewicz (1966) and Sikora (1970) suggested that green and black pelitic shales represent the background sediments. Oszczypko *et al.* (1999), Oszczypko-Clowes (2000, 2001) and Malata (2001) mentioned the sediments of the Zembrzyce Beds as thick-bedded carbonate turbidites, the Wątkowa Sandstone as channel fan turbidites whereas the Budzów Beds as thick-bedded carbonate turbidites and channel fan turbidites.

Bromowicz (1992) interpreted the MB as deep-sea fan deposits. In his opinion, the Budzów and Małastów Shales were deposited during decreasing activity of their source areas. This author connected the sedimentation of the MB with westward migration of their source areas. Książkiewicz (1975) interpreted sedimentation of the upper Eocene–Oligocene deposits of the northern part of the Magura nappe in general at upper mesobathyal depths whereas those of the southern part at slightly shallower depths.

It is worth noting that the MB represent in facies immediate continuation of the MF that starts in the lower part of the Middle Eocene in the Krynica zone and expands gradually to the north (Fig. 2). The coarse-grained sediments are concentrated in the upper Priabonian and lower Rupelian in the Siary zone whereas in the remaining part of the nappe their greatest concentration occurs in the lower, middle or entire Priabonian and partly in the Rupelian. In Leluchów, i.e. in the southernmost part of the Krynica zone, the facies sequence of the Priabonian–Rupelian corresponds well to that of the outer flysch nappes (see Blaicher & Sikora, 1963). The coarse-grained sediments are concentrated here in the upper Ypresian–Bartonian (see Oszczypko *et al.*, 1999). Facies and stratigraphic distribution of the MF and MB indicate their sedimentation under primarily tectonic control. On the basis of these features, sedimentation of the entire upper Ypresian–Rupelian of the Magura nappe is inferred to have resulted from the development, and gradual, northward migration of an accretionary wedge in the Magura basin (see Oszczypko, 1999). In contrast, the coeval sediments of the outer flysch nappes appear to be deposited under significant influence of eustasy (Leszczyński, 1999).

DATA SET AND METHODOLOGY

The MB and the immediately underlying rocks, starting from the top of the Łabowa Shale Formation, were measured in field, in six transects through the Siary zone (Figs 1, 3–5), for the determination of lithofacies and vertical, and to some extent lateral differentiation of the succession. Spacing between the transects ranges from several to tens of kilometres. Facies of unexposed section segments were estimated from composition of scree and local topography. Sedimentary processes were interpreted from facies, whereas vertical and lateral differentiation of the succession was used for interpretation of its development.

The content and composition of coarse-grained material (quartz, glaucony, microfossils – especially foraminifers) determined in shales (100 samples), together with observations of the vertical facies relationships and bioturbation distribution, were used to differentiate the event and background sediments. These data together with the content of calcareous material and total organic carbon (TOC) content (80 samples), kerogen type (57 samples), carbonate type (20 samples) and major and trace elements concentration determined in shales (11 samples), were used adequately to interpret bathymetry of the sedimentary basin, oxygenation regime, origin of organic matter and geochemical control on sedimentation development. Calcareous nannoplankton content and composition were analysed in 40 samples to recognise the origin of calcareous material and reasons for its variable content in the succession. Moreover, calcareous nannoplankton and foraminifera investigations were used for stratigraphic correlations of the sections. Major and trace elements were analysed in six samples from the Szymbark Shale and five from the lower part of the MB exposed in the bed of the Kłopotnica stream in Folusz (Fig. 5).

This project was conducted by S. Leszczyński who also executed the field investigations, some laboratory works, and with the help of E. Malata prepared the text of this paper. Foraminifera were investigated by E. Malata; nannoplankton by M. Oszczypko-Clowes (Institute of Geological Sciences, Jagiellonian University), carbonate type was determined by E. Koszowska (Institute of Geological Sciences, Jagiellonian University); TOC, inorganic carbon contents and kerogen were determined at the Faculty of Geology, Geophysics and Environmental Protection of the Mining and Metallurgy Academy in Kraków; major and trace elements by Activation Laboratories LTD in Canada.

Fieldwork

Depending on the tectonic structure of the Siary zone and quality of exposures, the succession was measured in one or several sections in the transects (Figs 3–5). Main mesoscopic features of rocks, i.e. rock type, bed thickness, texture, major constituents in coarse-grained rocks, colour, structures (including bioturbation, reaction with dilute hydrochloric acid, character of bed boundaries, and paleocurrent directions) were recorded in each section with accuracy dependent on outcrop quality and facies type. The sections were measured and described bed-by-bed, except for packages of fine-grained sediments (shales *sensu lato*) and alternating thin-bedded sandstones and shales, which were usually described only generally. Rocks which effervesce with HCl were called calcareous. Each rock type was sampled for microscopic analysis. Moreover, fine-grained sediments were sampled in selected segments of the sections for the analysis of coarse fraction content, its composition and geochemical features. The fine-grained sediments, i.e. those dominated by the silt and clay fractions, irrespective of their reaction with dilute HCl, were generally called shales.

Analysis of coarse in fine

Samples of 200 g dry, fine-grained rock were disaggregated through repeated crystallisation and dissolution of the Glauber's salt with which the samples were impregnated. Disintegrated rock was washed through a 63 μm sieve and the coarse fraction was dried. The quantity of detrital grains (basically quartz) and glaucony was estimated in the washed material in percentage per 100 g of dry rock, whereas fossils (primarily foraminifers) were counted and calculated in number of specimens per 100 g of dry rock in each sample. Four groups of foraminifera (agglutinating tubular, agglutinating non-tubular, calcareous benthic, and planktonic) were differentiated in all samples. Moreover, detailed studies of foraminiferal assemblages have been carried out in 31 samples from the sections in Krzczonów, Kobielnik–Węglówka and Folusz.

Analysis of nannoplankton

Calcareous nannoplankton was analysed in smear slides prepared with standard technique for light microscope observations. The analysis was carried out under light microscope at magnification of 1000x using parallel and crossed nicols. Taxonomic composition and number of specimens per one observation field was determined in each sample. Moreover, surfaces of broken fragments of calcareous fine-grained rocks of seclected samples were analysed in scanning electron microscope to recognize how frequent are the coccolithes and what is their preservation state.

Geochemical analyses

Carbonate and TOC

An aliquot of dry sediment sample was ground to a fine powder and halved. One half was ignited at 450°C for 24 hours for organic carbon (C_{org}) removal. Afterwards, total

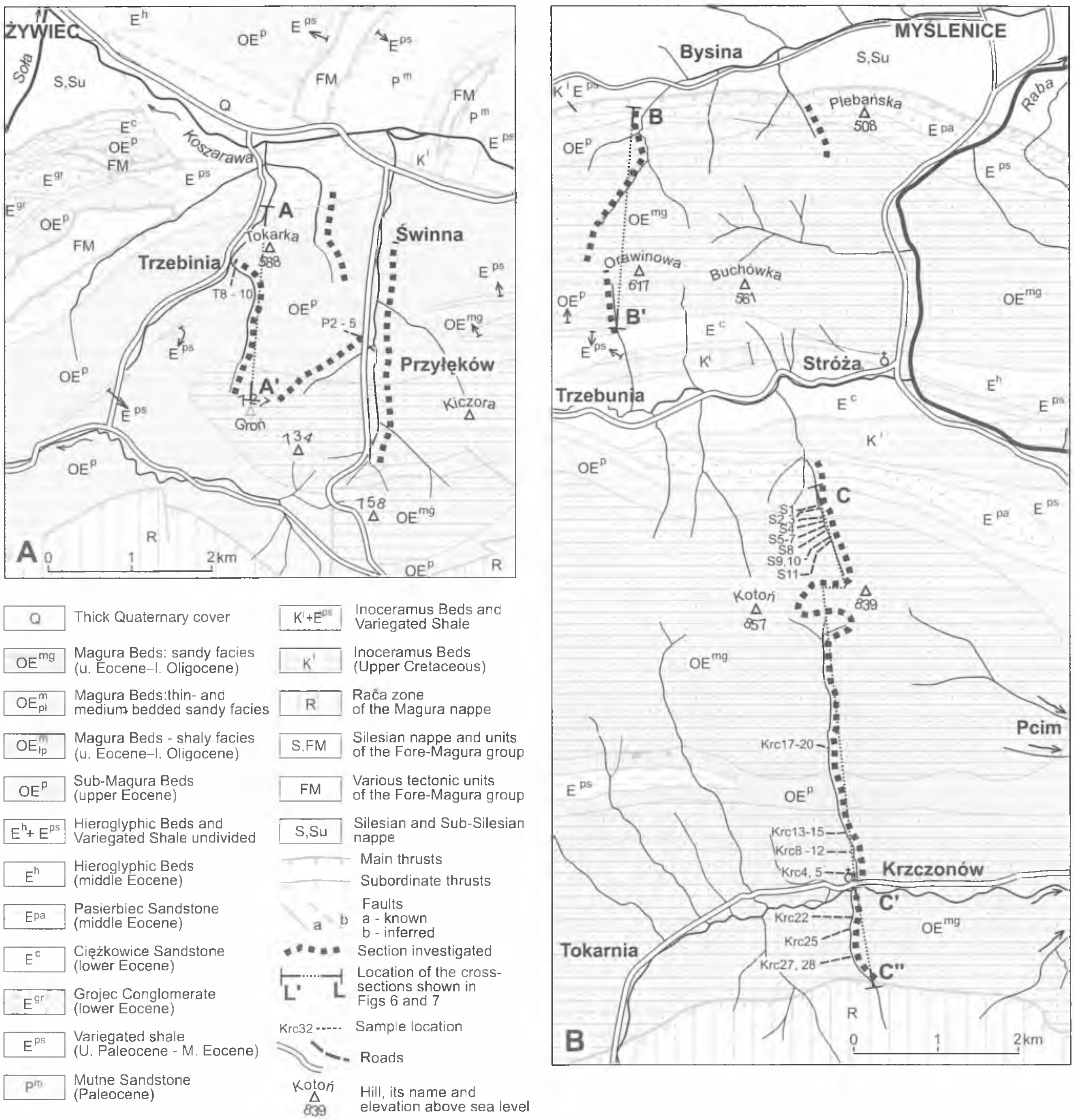


Fig. 3. Location of the sections measured in the western part of the Siary zone; location of samples mentioned in the paper and lines of cross-sections illustrated in Fig. 6. Geology of the area in **A** – according to Nowak (1966a, b), Sikora (1966) and Żytko (1966), in **B** – according to Burtan & Szymakowska (1966), slightly modified by S. Leszczyński. Note differences in stratigraphy of the sections indicated by these maps and author's data shown in Fig. 6

carbon content (C_{tot}) was determined by the use of the LECO analyser where the samples were ignited at 1350°C and the amount of emitted CO_2 was measured with an IR detector. Carbonate carbon (C_{carb}) was measured directly, whereas C_{org} was determined by subtracting C_{carb} from C_{tot}. Total C_{carb} was recalculated into $CaCO_3$. The real composition of the carbonate minerals in the investigated fine-grained sediments was determined in 20 samples by conventional X-ray diffraction (XRD).

Kerogen type

The type of kerogen was determined from selected pyrolysis-derived parameters (hydrogen index – HI, maximum temperature index – T_{max}, amount of hydrocarbon evolved from thermal alteration of kerogen, normalised to sample weight S_2 and weight % of Total Organic Carbon – TOC). Pyrolysis was executed with the instrument Rock-Eval II. The type of kerogen dominant in samples was shown in diagrams of HI *versus* T_{max} and S_2 *versus* TOC.

Major elements

Major elements were determined from whole rock analysis with the inductively coupled plasma emission spectrometry (ICP). Samples were prepared and analysed in a batch system. The samples were run for major oxides and selected trace elements on a combination simultaneous/sequential Thermo Jarrell-Ash ENVIRO II ICP. Calibration was performed using 7 prepared USGS and Canmet certified reference materials. One of the 7 standards was used during the analysis for every group of ten samples.

Trace elements

Trace elements were determined with the neutron activation analysis (INAA). An approximately 30 gram aliquot was encapsulated and weighed in a polyethylene vial and irradiated with flux wires and an internal standard (1 for 11 samples) at a thermal neutron flux of 7×10^{11} $n.cm^{-2}s^{-1}$. After a 7 day decay allowing Na-24 to decay, the samples were counted on a high purity Ge detector with a resolution of better than 1.7 KeV for the 1332 KeV C0-60. Using the flux wires, the decay-corrected activities were compared to a calibration developed from multiple certified international reference materials. Ten to thirty per cent of samples were rechecked (see Hoffman, 1992 for other details of the method).

MEASURED SECTIONS

General aspects

The sedimentary succession of the inferred Priabonian–Rupelian in the measured sections is some 800 metres to nearly 1700 metres thick (Figs 6–8). The differences in thickness result in part from variable erosion of the succession. Moreover, significant tectonic deformation and lack of sufficiently precise chronostratigraphy limit exact determination of its thickness. Seven facies types were distinguished for general description of the sections (Figs 6–8). The facies differ in the character of fine-grained sediments (shales), sandstone/shale ratio in the section and in features of the coarse grained sediments (Fig. 9). Facies bodies more than 20 m thick are indicated in Figs 6 and 7, whereas bodies thicker than 10 m are shown in the vertical sections (Fig. 8).

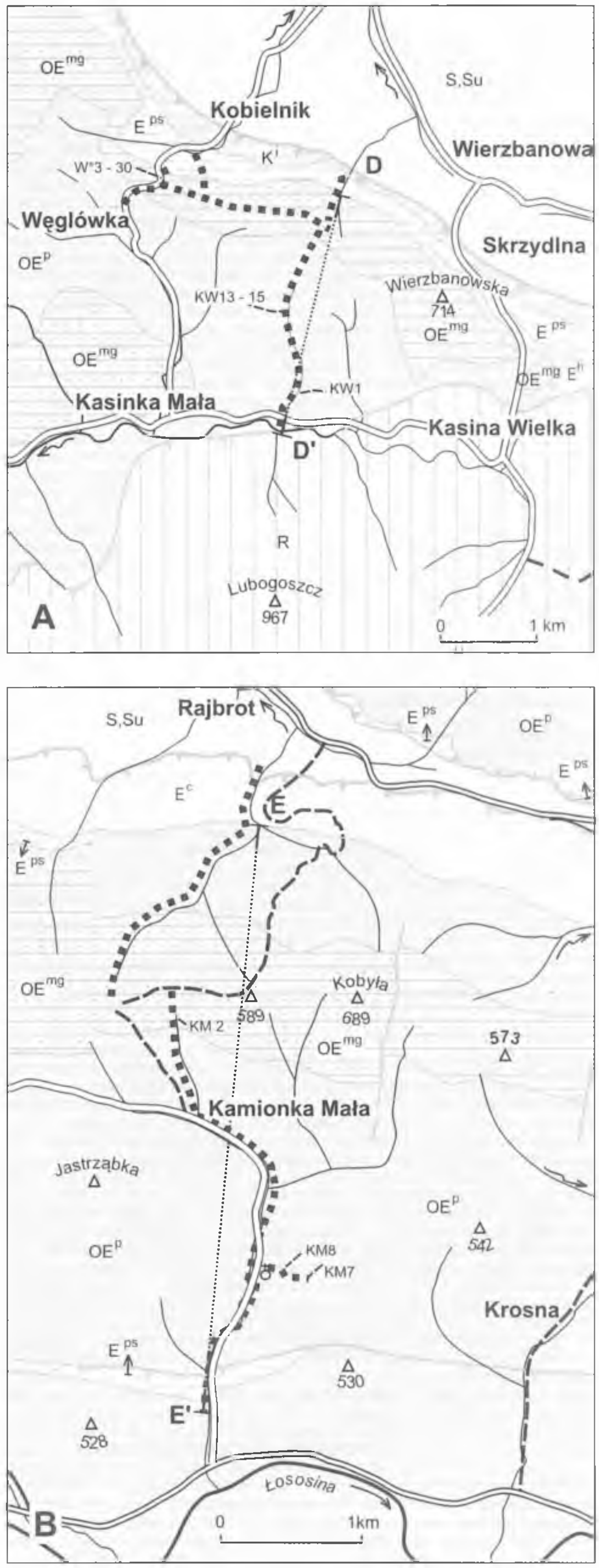


Fig. 4. Location of the sections measured in the central part of the Siary zone; location of samples mentioned in the paper and lines of cross-sections illustrated in Fig 6. Geology of the area in **A** – according to Burtan (1966), in **B** – according to Burtan & Skoczylas-Ciszewska (1966a, b) and Cieszkowski (1992), slightly modified by S. Leszczyński. The sandstone unit marked E^c was named Ciężkowice Sandstone by Burtan & Skoczylas-Ciszewska (1966a, b) whereas Cieszkowski (1992) distinguished it as Wojakowa Sandstone. Note differences in stratigraphy of the sections indicated by these maps and author's data shown in Fig. 6. Symbols and abbreviations as in Fig. 3

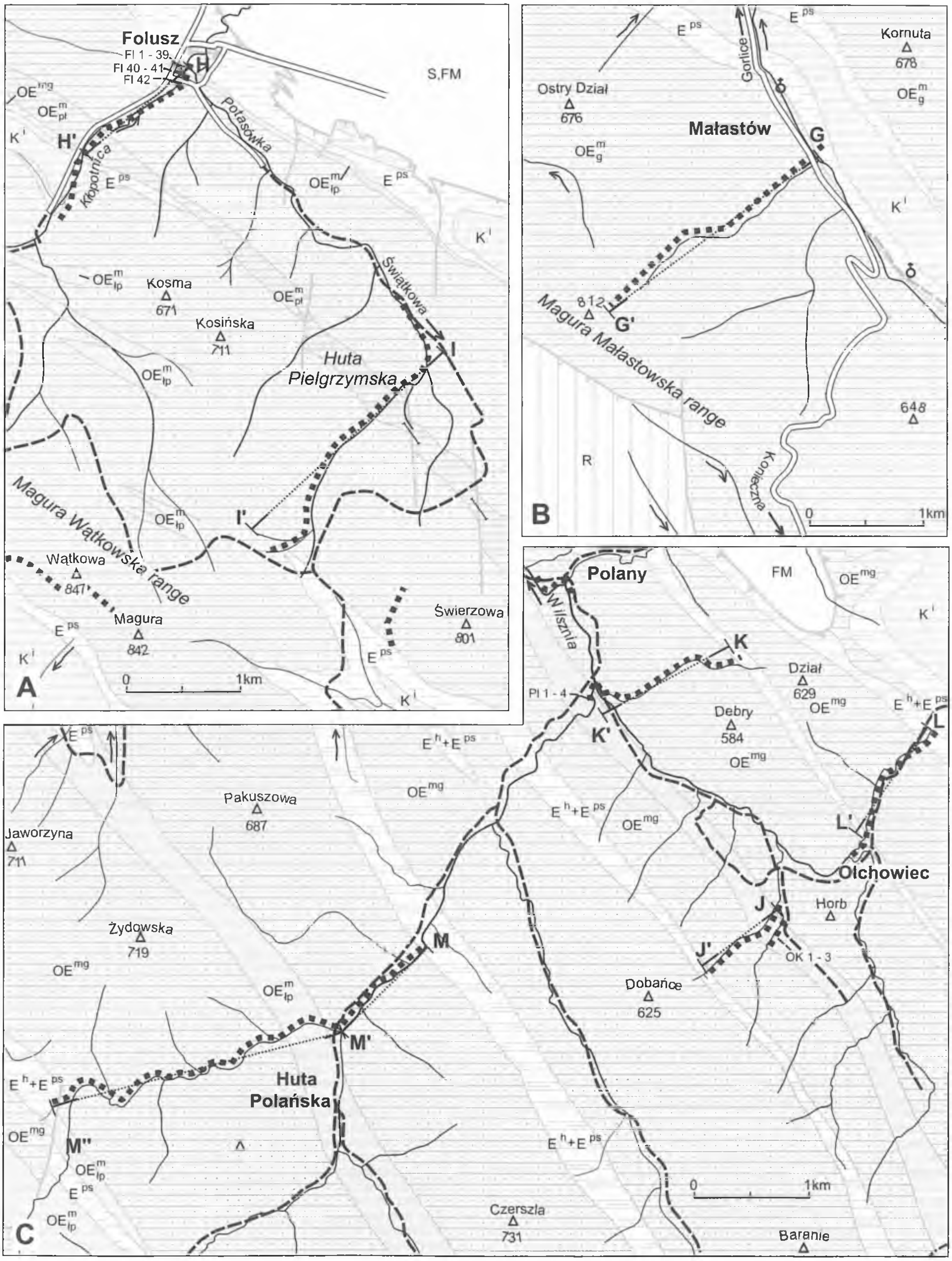


Fig. 5. Location of the sections measured in the eastern part of the Siary zone; location of samples mentioned in the paper and lines of cross-sections illustrated in Fig. 7. Geology of the area in **A** – according to Koszarski & Tokarski (1967), in **B** – according to Sikora (1967), in **C** – according to Ślączka (1967), slighthly modified by S. Leszczyński. Note differences in stratigraphy of the sections indicated by the maps and author's data shown in Fig. 7. Symbols and abbreviations as in Fig. 3

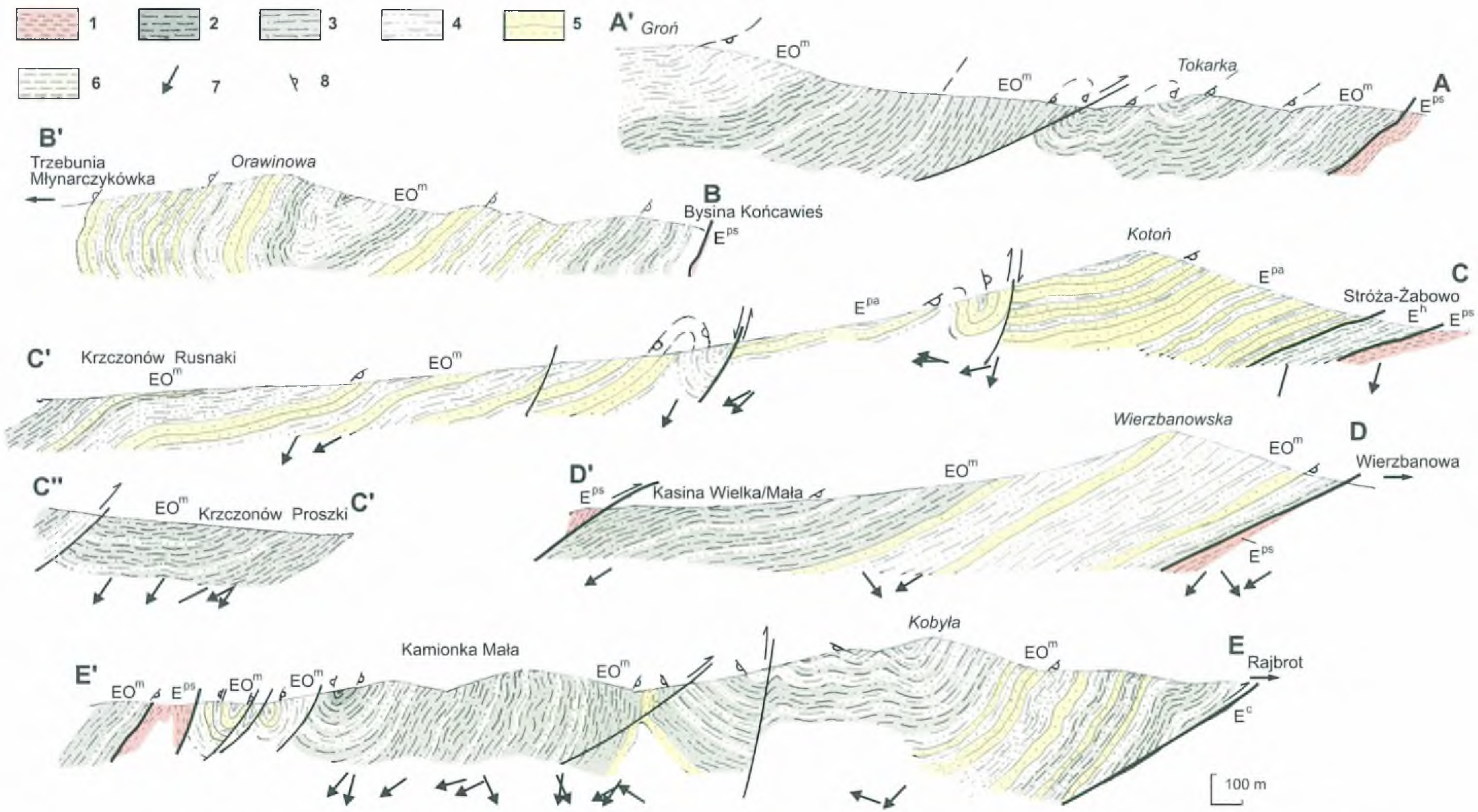


Fig. 6. Cross-sections along the lines shown in Figs 3 and 4. *1* – variegated shales (red and subordinately green shales with rare sandstone intercalations), *2* – basically thick-bedded greenish-grey, khaki and dark-grey to black shales with intercalations of thin to thick beds of sandstones (sandstone to shale ratio, sd/sh < 0.3), *3* – alternating thin to very thick beds of sandstones and thick to thin-bedded usually calcareous, greenish-grey and khaki coloured shales (sd/sh 0.3 to 1.0), *4* – alternating thin to very thick beds of sandstones and thick to thin-bedded usually calcareous, greenish-grey and khaki coloured shales (sd/sh 1.0 to 3.0), *5* – very thick to thin beds of sandstones and thin to thick beds of usually calcareous greenish-grey and khaki coloured shale intercalations (sd/sh >3.0), *6* – mainly thin-bedded calcareous and non-calcareous green shales, *7* – palaeotransport direction, *8* – orientation of bed soles; E^c – Ciężkowice (Wojakowa) Sandstone, E^h – Hieroglyphic Beds, E^o – Owczary Sandstone, E^{pa} – Pasierbiec Sandstone, E^{ps} – Łabowa Formation, E^s – Szymbark Shale, OE^m – Magura Beds

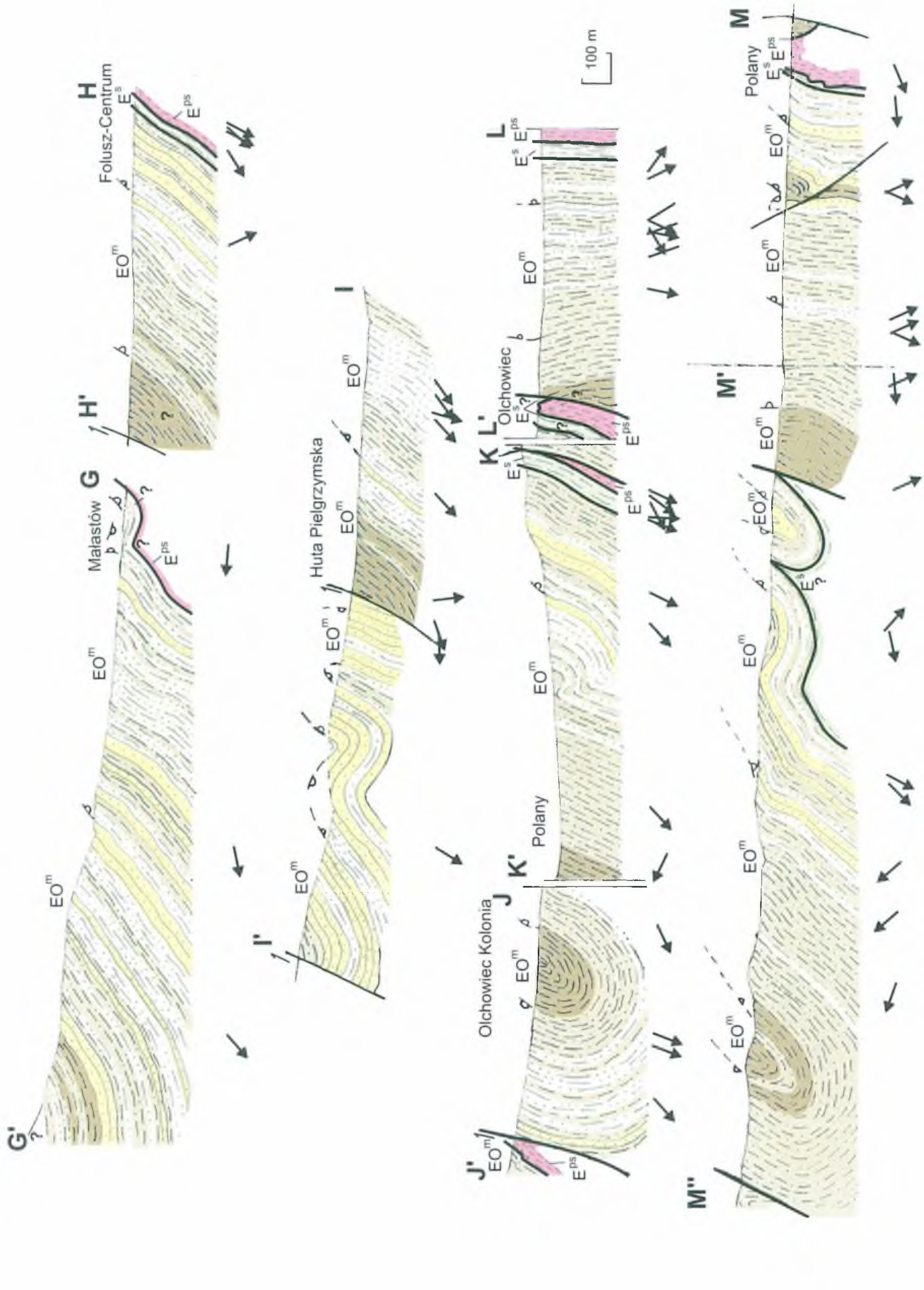


Fig. 7. Cross-sections along the lines shown in Fig 5. Symbols and abbreviations as in Fig. 6

The succession and its structure appeared different in some sections with regard to that suggested in the literature (cf. Figs 3–8). The entire preserved part of Priabonian–Rupelian in the four western transects is considered in the literature to be enclosed in the MB (see Sikora & Żytko, 1960; Malata, 1981; Jednorowska, 1966; Książkiewicz, 1974; Cieszkowski, 1992; Oszczypko-Clowes, 1999, 2000, 2001). However, in the section between Stróża and Krzczonów (Figs 4, 6C, 8), its lower *ca.* 600 m thick part, included by Burtan & Szymakowska (1966) to the MB, does not fully fit to this unit. It differs from typical MB in containing basically non-calcareous fine-grained sediments (grey-green mudstones and muddy shales). A 50 m thick lowermost part of the unit resembles in facies the Hieroglyphic Beds in the shaly facies (Książkiewicz, 1974). In the overlying *ca.* 50 m thick portion of the unit, sandstones, inclusive thick-bedded and pebbly ones, occur in increased proportion. The succeeding 500 m thick part of the unit is built up mainly of thick-bedded to very thick-bedded sandstones. The sandstones occur in simple and composite beds separated by usually thin and medium shale layers. Shales occur in higher proportion in the top part of the unit. This part of the unit passes upwards into a succession of typical MB, i.e. where the fine-grained sediments become predominantly calcareous. According to the named features and lithostratigraphic position, the entire unit enclosed between typical MB and the Hieroglyphic Beds corresponds to the Pasierbiec Sandstone. The age of this part of the section is poorly documented. Long ranged species of foraminifera were recorded in its lower portion (samples S1–S10, see Fig. 3B), whereas calcareous nannoplankton recorded *ca.* 300 m above the inferred bottom of the MB (samples Krc 13–Krc 15, Tab. 1, see Figs 3, 8) indicate NP19-20 (i.e. middle Priabonian). Considering that the above described Hieroglyphic Beds and the Pasierbiec Sandstone represent the lower Priabonian, the succession of the Priabonian–Rupelian in the sections measured in four transects in the western part of the Siary zone starts with a several tens to several hundred metre thick unit in which fine-grained sediments predominate. This unit represents the Zembrzyce Shale in sections where the succession begins with the MB. The Zembrzyce Shale is thickest in the westernmost section in Przyłęków and Trzebinia (Figs 3A, 6A, 8) and thinnest in Wierzbanowa-Kasinka Mała (Figs 4A, 6D, 8). The boundary with the underlying Łabowa Shale Formation is covered in all these sections. Character of scree and features of the sediments exposed close to the boundary indicate a rapid disappearance of red shales and gradual increase in sandstone proportion up the sequence.

In three sections located in the eastern part of the Siary zone, the succession starts with some 30 m thick package of generally green shales showing a growing upward proportion of their calcareous variety (Szymbark Shale). The package is best exposed in the section in Folusz (Figs 5A, 7H, 8) and Olchowiec (Fig. 5C, section L–L'). In the first mentioned section, Blaicher & Sikora (1963) recognised that the MB start close to the Eocene/Oligocene boundary. Similar interpretations also result from nannoplankton investigations carried out in the frame of this project (Tab. 1). In the section in Olchowiec, located similarly to that in Folusz, in the marginal part of the Siary zone, the package is similar in thickness and facies to that in Folusz. However, several thick sandstone beds appear to occur in the middle of this unit in Olchowiec (Fig. 8). In the remaining sections, the lower part of the succession is either unexposed or tectonically cut (sections I–I', J–J', M–M'–M'' in Fig. 7). Noteworthy, Oszczypko-Clowes (1999, 200, 2001) recognised that in the section in Małastów, located some 400 m to SE of the section investigated in the frame of this project (section G–G' in Fig. 7), variegated shales of the Łabowa Formation are overlain by a succession of thin to thick-bedded sandstones alternated by thin to thick layers of grey-green shale. She evidenced here the calcareous nannoplankton zone NP19-20 and included this succession to the Zembrzyce Beds.

The overlying part of the succession is in all the sections similar in the variable distribution of sandstones and shales, predominance of calcareous shales, and the fluctuating content of calcareous material. Moreover, an increased amount of dark-coloured shales occurs in its top. Except for the westernmost section, sandstones are generally concentrated in the lower and middle part of the succession, somewhere close to the Eocene/Oligocene boundary. In the investigated sections, one to two mapable units where sandstones prevail (Wątkowa Sandstone) occur in the MB, with the exception of the section in Małastów (Figs 5B, 7G–G', 8). The thickest homogeneous sandstone unit occurs in the lower part of the succession in the section Huta Pielgrzymska (Fig. 5A). There are also sections where mapable sandstone complexes (at least 50 m thick) appear to be lacking. Such case seems to occur between Kobielnik and Węglówka (Fig. 4A) and in the section along the Droździna stream in Budzów (west of Myślenice) however, the unit of Magura Sandstone was marked here before (Burtan, 1966; Książkiewicz, 1974; Oszczypko-Clowes, 1999, 2000, 2001). In the section in Olchowiec (Fig. 5C), the unit indicated in the map as having prevalence of sandstones, displays sandstone/shale ratio close to 1 : 1. Subdivision of the sections without mapable sandstone unit into Zembrzyce and Budzów Shale is highly disputable. The proportion of sandstones in the succession appears to decrease generally both to the west and east of the Siary zone. Massive shales differing in reaction with HCl, frequently dark-grey and black, predominate in the upper part of the succession, particularly in the eastern part of the Siary zone. The sandstones in the entire succession consist predominantly of quartz. Glaucony grains, feldspar and muscovite represent the minor constituents (see Bromowicz, 1992). Some beds are distinctively enriched in glaucony or in feldspar and muscovite. The sandstones rich in glaucony display characteristic green colouration whereas these enriched in feldspar and muscovite are whitish-grey.

Bed-scale facies

Normally graded granule sandstones and conglomerate-sandstone couplets

This facies consists of beds of granule sandstone (i.e. sandstone with dispersed granules, rarely pebbles) in which

Table 1

Calcareous nannoplankton assemblages recorded in the investigated samples and inferred biostratigraphic location of the samples. Samples FI13–FI22 represent the Szymbark Shale, other samples are from the Magura Beds. Other data concerning samples location see Figs 3–5

Samples	FI13	FI18	FI20	FI21	FI22	FI24	FI32	FI35	KM2	KM7	KM8	Krc13	Krc14	Krc15	Krc28	KW1	KW14	KW15	OK2	OK3	PI1	PI2	PI3	PI4	W*8	W*9	W*15	W*17	W28
Nannoplankton zones	?	NP19-20	NP21	NP21	NP21	?	?	NP21	?	NP24?	NP24?	NP19-20	NP19-20	NP19-20	NP21	NP21	NP19-20	NP19-20	NP24	NP24	NP24	NP24	NP24	NP24	NP19-20	NP19-20	NP19-20	NP21	NP21
Blackites spinosus												x						x	x	x		x	x	x		x			
Braarudosphaera bigelowii				x															x			x	x	x	x				
Chiasmolithus expansus							R																						
Chiasmolithus grandis												R															R		
Chiasmolithus medius																													R
Chiasmolithus modestus																										R			
Chiasmolithus oamaruensis		x										x			x													x	
Clathrolithus spinosus												x																	
Coccolithus eopelagicus			x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Coccolithus pelagicus	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Corannulus germanicus		x	x	x	x							x	x	x	x	x	x	x							x	x	x		
Coronocyclus nitescens		x											x															x	
Cyclicargolithus abisectus										x	x								x	x	x	x	x	x					
Cyclicargolithus floridanus		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cyclicargolithus luminis										x		x								x									
Dictyococcites bisectus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Discoaster barbadiensis		x										x	x	x				x							x	x	x		
Discoaster deflandrei					x							x			x			x							x	x			
Discoaster distinctus												R																	
Discoaster saipanensis		x										x	x	x				x							x	x	x	x	
Discoaster tanii		x	x	x	x							x	x		x			x							x	x			
Discoaster tanii nodifer		x	x	x				x				x	x		x										x	x			
Ericsonia fenestrata		x		x	x																		x		x				
Ericsonia formosa		x	x	x	x	x		x				x	x	x	x	x	x	x							x	x	x	x	x
Ericsonia subdisticha		x											x																
Helicosphaera bramlettei																									x		x		
Helicosphaera compacta		x		x	x			x		x					x		x	x		x	x	x	x	x					
Helicosphaera euphratis		x																			x	x	x					x	
Helicosphaera recta					x															x			x						
Helicosphaera seminullum																												x	
Holodiscolithus solidus															x														
Isthmohlithus recurvus		x	x	x	x			x		R		x	x	x	x	x	x	x		R	R		R	R	x	x		x	x
Lanternithus minutus			x	x	x			x		R		x	x	x	x			x			R				x		x	x	
Neococcolithes dubius		x	x	x								x	x	x	x			x							x		x		
Orthozygus aureus														x														x	
Pemma basquensis												x			x		x	x							x				
Pontosphaera multipora		x	x	x								x		x			x			x			x	x	x				
Pontosphaera plana											x									x			x	x					
Reticulofenestra callida												x	x	x	x			x							x	x	x		
Reticulofenestra daviesi																													
Reticulofenestra dictyoda			x		x			x				x	x	x	x	x	x	x				x			x	x	x	x	x
Reticulofenestra hillae												x	x	x	x											x	x	x	x
Reticulofenestra lockeri										x	x									x	x	x		x					
Reticulofenestra minuta																				x	x	x	x	x					
Reticulofenestra ornata																				x	x	x	x	x					
Reticulofenestra reticulata	x	x	x	x	x			x				x	x	x		x	x	x							x	x	x	x	x
Reticulofenestra umbilica		x	x	x	x		x	x		R		x	x	x	x	x	x	x		R	R	R	R	R	x	x	x	x	x
Sphenolithus dissimilis																				x	x	x	x	x					
Sphenolithus moriformis		x	x		x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Sphenolithus pseudoradians		x																								x	x		
Sphenolithus radians		x																									x		
Transversopontis obliquipons			x	x																									
Transversopontis pulcher			x									x		x								x	x	x	x	x			
Transversopontis pulcheroides		x										x	x	x			x			x		x	x	x	x			x	x
Transversopontis pygmaea																							x						
Zygrhablithus bijugatus		x		x	x			x		x		x	x	x	x		x		x	x		x	x	x	x	x	x		

x – determined species, R – reworked species the basal part contains increased amount of pebbles, and of beds in which the lower part consists of a clast-supported conglomerate that passes upwards to granule sandstone. The conglomerate division is up to 30 cm thick whereas the overlying sandstone attains one to several metres. Gravelly material consists of granules and pebbles of quartz, subangular granules of feldspar, subangular clasts of epimetamorphic rocks and siltstone-mudstone chips or larger clasts. One bed with clasts of pelitic limestone has also been recorded. Maximum size of extraclasts is 4.5 cm, and on average about 1 cm. Clasts show polymodal grain-size distribution and variable concentration in the beds. Grading of a coarse-tail type occurs in such beds. The elongated and disc-shaped clasts exhibit a poorly defined alignment parallel with bedding or a slight imbrication. Beds are flat based or scoured usually with an irregular upper surface. Sediments of this facies occur in amalgamated beds. Beds with a conglomerate division are rare in the investigated sections. Such beds were recorded in the unit included to the Pasierbiec Sandstone and locally in the Wątkowa Sandstone. To some extent this facies corresponds to the facies A2.7 of Pickering *et al.* (1986).

Massive sandstones and granule conglomerates

This facies consists of thick- and very thick beds of coarse-grained sandstone, sometimes with frequent granules, granule conglomerate, and medium or fine-grained sandstone lacking distinctive grading and typically showing sharp and flat bounding surfaces (Fig. 10). The medium and fine-grained massive sandstone sometimes displays water-escape structures. Outsized clasts of mudstone and sandstone occur in some beds (see Fig. 9A). The beds are laterally continuous, parallel to irregularly-sided and have a character of simple and amalgameted beds. This facies is quite frequently met both in the MB and the Pasierbiec Sandstone. The sandstone in some simple beds displays rapid passage to horizontally laminated mudstone (T_d). Some beds are very rich in coarse grains of glaucony. Beds underlain by shale show sometimes loaded bases. This facies corresponds to the facies B1.1 of Pickering *et al.* (1986).

Parallel stratified sandstones and granule conglomerates

This facies is composed of thick- to very thick beds of sandstone, typically medium to coarse-grained, subordinately of granule conglomerate with faint horizontal to near-horizontal stratification throughout (Fig. 11). Stratification is defined by cm–dm thick bands of massive sandstone or conglomerate separated by 1 to 2 cm thick laminae of finer sandstone that passes gradually both to the underlying and overlying massive sandstone (band). Some beds of this facies are very rich in glaucony, which additionally accentuates the stratification. These sandstones were recorded only within the Wątkowa Sandstone in the Magura Wątkowska range (south of Folusz) where the sandstones occur in tors, having clean, slightly weathered surfaces. Such sandstones frequently show deformation bands, which obliquely cut the original stratification. This facies corresponds to the facies B2.1 of Pickering *et al.* (1986).

Cross-stratified sandstones and granule conglomerates

This facies consists of very coarse-grained sandstone and granule conglomerate showing large-scale cross stratification. Only in two beds this stratification is visible in full (Figs. 10, 12). Beside this place, it is recorded fragmentarily in three other sites in the Wątkowa Sandstone (Fig. 9A). Like the previous stratification, this one is also disturbed by obliquely oriented deformation bands. This facies corresponds to the facies B2.2 of Pickering *et al.* (1986).

Disorganised muddy sandstones (slurry sediment)

Poorly sorted mud-rich sandstone is included in this facies (Fig. 9A). The sandy material is of coarse to fine sand-grade. The sediment is ungraded or displays faint coarse-tail grading. The lower part of the beds consists of muddy sandstone, whereas in the top part, some beds show passage to a mudstone. Mudstone chips and clasts as much as 5 cm in size occur frequently in such sediment, and are usually irregularly dispersed. Some beds show the character of a mud-clast breccia. The beds of this facies occur with varying frequency throughout the whole succession, in all sections of the MB. This facies corresponds to the facies C1.1 of Pickering *et al.* (1986).

Mottled muddy sandstones

Beds of entirely bioturbated sandstone are included in this facies. Except for two, these beds are less than 20 cm thick. The thickest one being 47 cm. Only several beds of this facies were recorded, all in the sections in the eastern part of the Siary zone. This facies corresponds to the facies C1.2 of Pickering *et al.* (1986).

Very thick-bedded sandstone-shale couplets

Coupled beds of thick to very thick sandstone and thin to very thick mudstone or marl (shale) are included to this facies (Fig. 9A–C). Sandstone passes gradually to shale. This is the most characteristic facies of the MB and the Pasierbiec Sandstone. Beds consisting of a thick to very thick predominantly massive or normally graded sandstone division, and mainly a medium to thick non-calcareous shale division, are typical of the latter mentioned unit. In the MB, beds of this facies, except for these parts of the unit where sandstones predominate, are typified by a shale division at least 50 cm thick, attaining 10 to 15 m in some beds (Fig. 9B', C). A variant of this facies with a thin to thick shale division occurs in the succession parts where sandstones predominate (Fig. 9A).

The sandstones are coarse to fine-grained, usually glauconitic, and sometimes rich in muscovite, well to poorly normally graded, dominated either by non-laminated (Lowe division S_3, Bouma division T_a) or laminated sandstone (T_{bc}). Thick beds of entirely laminated sandstone of this facies are frequent in the MB. Horizontal lamination usually occurs in the lower part of such beds whereas large-scale convolute lamination occurs in their upper part (Fig. 9A, B', C). Some beds are laminated horizontally to slightly wavy throughout (T_b; Fig. 13). The convoluted division is as much as 1 m thick. There are beds in which the entire sandstone is convoluted. Division of non-deformed to slightly deformed ripple lamination occurs in the top part of some

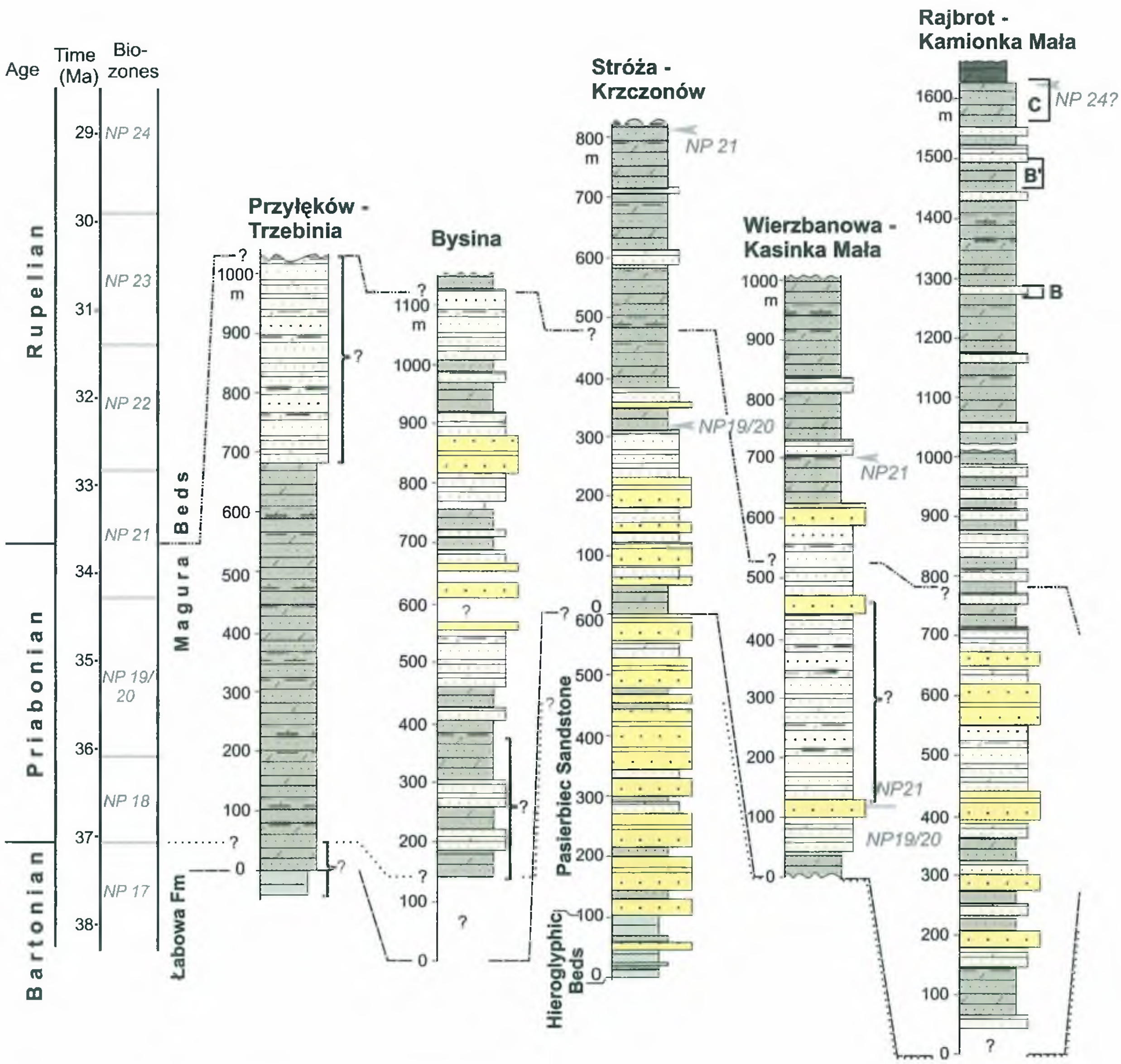


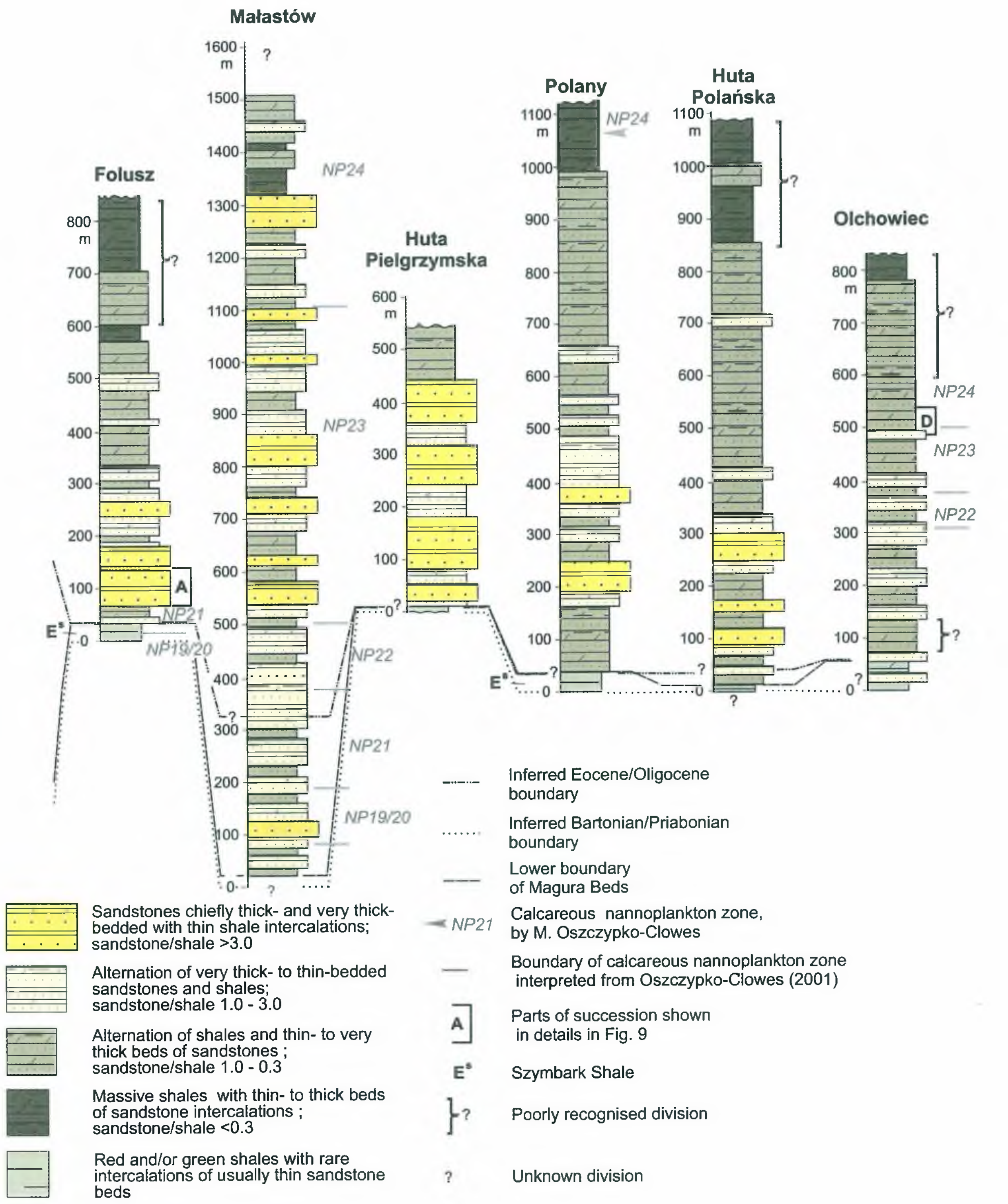
Fig. 8. Generalised logs of the Priabonian–Rupelian of the Siary zone and their correlation (see Figs 3–5 for sections location). Facies as these shown in Fig. 6. Chronostratigraphy based on Sikora & Żytko (1960), Blaicher & Sikora (1963), Sikora (1970), Malata (1981, 2001), Jednorowska (1966), biostratigraphy based on Oszczypko-Clowes (1999, 2000, 2001) and datations done by Oszczypko-Clowes in the frame of this project (see Tab. 1). Biozones according to Martini (1971) correlated with chronostratigraphic and time scales by Berggren *et al.* (1995). Note that the Magura Beds in the logs from the western part of the Siary zone are basically of Priabonian age whereas these from the eastern part are mainly Rupelian. The top of this unit is erosional and seems to not stride lower Rupelian in the western part of the Siary zone, while in the east it reaches the top of Rupelian

beds. In some beds, massive sandstone passes upward to a thin horizontally laminated division (T_b) that passes to parallel laminated mudstone (T_d). Soles of sandstone beds are flat to irregular, covered with flute and drag casts, or are loaded. Some beds are channelised (Fig. 9B, B').

The fine-grained division, here generally called shale, consists of a variety of greyish-green, dark-grey, khaki, rarely black, massive, calcareous, and rarely non-calcareous sediment. Analysis of carbonate content in fifteen beds has shown that in only three beds it was higher than 30%. In seven beds it was higher than 25%. This suggests that the massive shale divisions consist mainly of calcareous shales. These disintegrate into irregular fragments with conchoidal surfaces. Their lower part consists of silty mudstone, sometimes with larger particles of plant detritus. This shale usually displays parallel lamination or splitting surfaces characteristic of the T_d division. In the top part, the massive shale displays a gradual decrease of effervescence with HCl, becomes greener and passes to non-calcareous green shale (Fig. 14). This facies generally corresponds to the facies C2.1 of Pickering *et al.* (1986).

Thick/medium-bedded sandstone-shale couplets

Coupled beds of 10–30 cm thick sandstone and similarly thick shale are included in this facies (Fig. 15). The sandstones are medium to fine-grained, similar in composi-



tion to those of the former facies, which show T_{bc} (Fig. 16) or T_c, rarely T_{abc} divisions. Entire beds or their upper parts are frequently convoluted. The soles of sandstone beds are covered with either different current marks, bioturbation structures (Fig. 17) or load casts. The overlying shale is analogous to that in the very thick sandstone-shale couplets. It usually starts with the T_d division. The average sandstone to shale ratio is of the order of 2 : 1 to 1 : 2. Beds of this facies occur alternating with other facies. In some segments of the MB, there are thick packages built up predominantly of this facies and facies of thin-bedded sandstone-shale couplets (Fig. 9D). This facies roughly corresponds to the facies C2.2 of Pickering *et al.* (1986).

Thin-bedded sandstone-shale couplets

Coupled beds consisting of sandstone and fine-grained divisions less than 10 cm thick are included in this facies (Fig. 18). The sandstones are mainly fine and very fine-

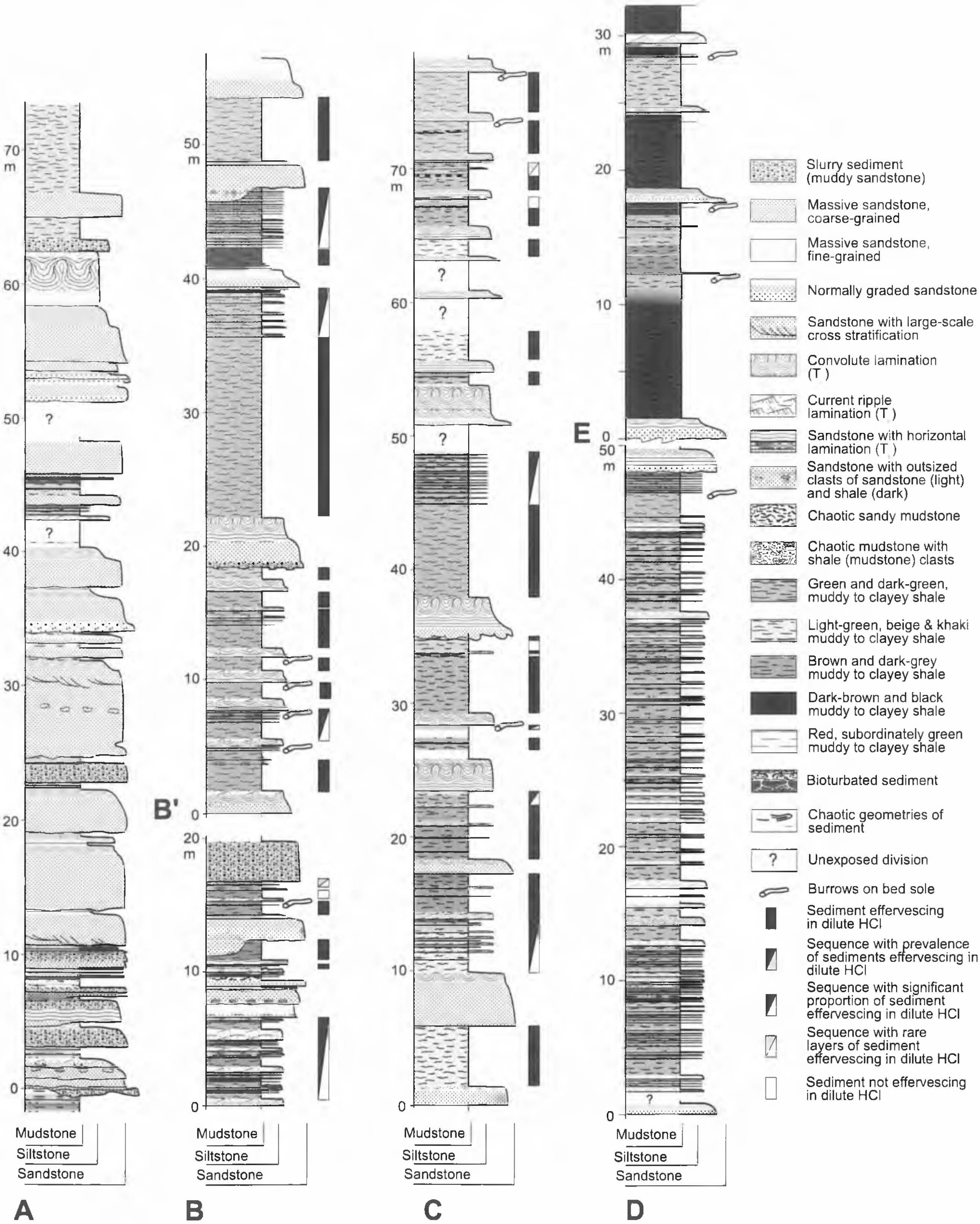


Fig. 9. Characteristic facies patterns (cf. general facies types in Figs. 7 and 8) and reaction of fine-grained sediments with diluted HCl in the Magura Beds. Sediment structures of siltstones and sandstones are shown in thick beds only. Thin and medium sandstone and siltstone beds (shown as lines) display structures of the divisions $T_{(ab)c}$ and $T_{(c)d}$ of the Bouma sequence respectively. Logs **A–D** represent succession segments shown in Fig. 8. Log **E** shows section of the upper part of Magura Beds in the bed of Wisłoka river between villages Czarne and Nieznajowa (between areas E and G in Fig. 1). Note vertical variation of carbonate content in fine-grained sediments

Fig. 10. Massive granule conglomerate on the left side of photo (1) overlain by *ca.* 80 cm thick bed of faintly cross-bedded granule conglomerate (2). Lower part of Magura Beds (Wątkowa Sandstone), Magura Wątkowska range

Fig. 11. Sandstone showing faint parallel-stratification. The stratification is cut obliquely by deformation bands dipping gently to the left. Some 8 m high part of the tor is here shown. Lower part of Magura Beds (Wątkowa Sandstone), Magura Wątkowska range

grained, similar in composition to those of the other facies of the sandstone-shale couplets. The beds usually show T_{cd} divisions; however, some very thin sandstone beds are non-laminated except for several parallel laminae in the top part. The entirely laminated sandstone beds are frequently convoluted. Bed soles are flat, covered with small current marks, bioturbation structures or show load structures. The shale is similar to that found in other facies of the sandstone-shale couplets. However, it is frequently less cal-

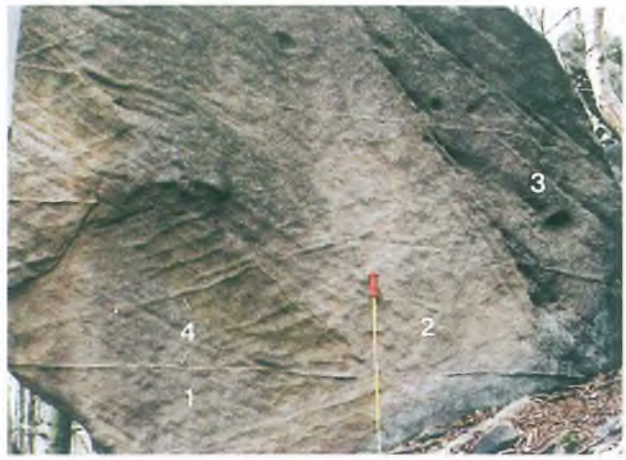


Fig. 12. Sandstone steeply dipping to the right, with three sets of large-scale cross-bedding (1, 2, 3). Cross-bedding dips to left in relation to bounding surfaces and is cut by two sets of deformation bands (4). One set of deformation bands is manifested by thick ribs dipping to left, the other is represented by three horizontal laminae. Ski-stick (1.1 m-long) as a scale. Lower part of Magura Beds (Wątkowa Sandstone), Magura Wątkowska range

Fig. 13. Sandstone with 1.3 m thick parallel to wavy-laminated division (T_b). Pocketknife (9 cm long) in the middle of photo as a scale. Lower part of Magura Beds (Wątkowa Sandstone) in Krzczonów

Fig. 14. Top part of massive calcareous shale overlain by 2 cm thick non-calcareous shale (light, arrowed). The latter is overlain by a sandstone of a sandstone-shale couplet. Pocketknife (9 cm long) as a scale. Upper part of Magura Beds (Budzów *vel* Małastów Shale?), Polany

Fig. 15. Thick/medium bedded sandstone-shale couplets. Top part of a thick mudstone (shale) layer visible in the lower part of photo. Tops of the beds to the right. Hammer (encircled, 35 cm long) as a scale, in the middle of photo. Upper part of Magura Beds (Budzów Shale *vel* Małastów Shale), Folusz

Fig. 17. Sandstone sole covered with a *Thalassinoides*-like post-depositional trace fossil. Coin (17 mm in diameter) as a scale. Upper part of Magura Beds (Budzów Shale *vel* Małastów Shale), Polany

Fig. 16. Sandstone of the facies medium-bedded sandstone-shale couplets showing T_{bc} divisions, underlain by a shale of an older couplet of similar type. Coin (17 mm in diameter) as a scale. Upper part of Magura Beds (Budzów Shale *vel* Małastów Shale), Polany

Fig. 18. Package of thin/medium bedded sandstone-shale couplets. Top of the beds up the photo. Hammer (30 cm long, in the lower corner) as a scale. Lower part of Magura Beds (Zembrzyce Shale), Krępna (between Folusz and Polany)

careous in this facies than in those thicker bedded. This facies corresponds to the facies C2.3 of Pickering *et al.* (1986).

Very thick/thick bedded shale dominated sandstone-shale couplets

Coupled beds consisting of thin to thick sandstone and a much thicker shale division are included in this facies (Fig. 9B', C, E). The sandstone shows $T_{(b)c}$ divisions, with rather flat soles covered with current marks and small bioturbation structures. The shale is at least several dm thick (Fig. 19), frequently between 1 and 2 m. Isolated, mm-thick laminae of massive siltstone with loaded soles and subtly laminated siltstone are recorded in the upper part of the shale. This facies is common in the MB and it is particularly characteristic of the upper part of this unit in the eastern part of the Siary zone. Bromowicz (1992) distinguished the part of the MB built up predominantly of such sediments as the Małastów Shale. Sandstones occur here in thin to thick beds whereas the overlying shales are at least several dm thick (Fig. 20). Moreover, couplets with grey shale alternate here with those with black shale. This facies corresponds to the facies C2.4 of Pickering *et al.* (1986).

Disorganised sandy mudstones

Beds of disorganised, usually greenish-grey mudstone with a distinctive admixture of sand to granule-grade terrigenous material, mainly quartz grains, are included in this facies. The beds are cm–dm thick and are not very distinctive, being underlain by massive shale.

Fig. 19. Package of thick/very thick-bedded, mudstone dominated sandstone-shale couplets. Top of the beds to the upper right. Hammer (35 cm long) in the lower centre (encircled), as a scale. Upper part of Magura Beds (Budzów Shale *vel* Małastów Shale), Folusz

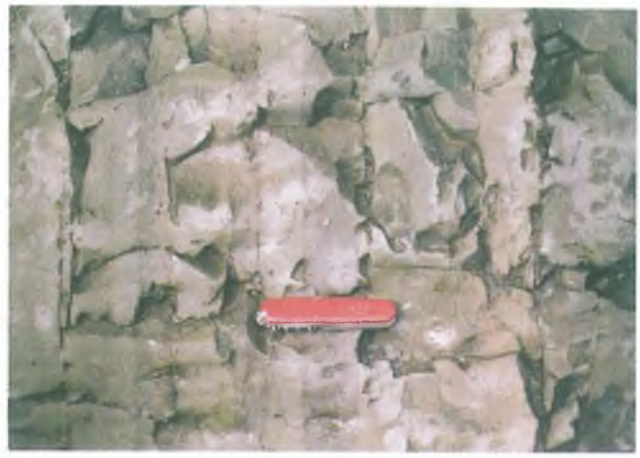


Fig. 21. Graded siltstone-shale couplets. Tops of the beds to the right. The shale in the lower part of rhythms displays a slightly lighter colour, and is usually more calcareous than that in the upper part. Pocketknife (9 cm long) as a scale. Szymbark Shale, Olchowiec

Fig. 20. Package of thick/very thick-bedded, mudstone dominated sandstone-shale couplets. Couplets with grey shale alternate here with ones with black shale. Tops of the beds to the upper right. Upper part of Magura Beds (Budzów Shale *vel* Małastów Shale), Polany

Fig. 22. Package of varicoloured shale. Note regular stratification. The dark colour is mainly due to a hue of manganese oxyhydroxides covering surfaces of fractures. Pocketknife (9 cm long) as a scale. Szymbark Shale, Folusz

Graded siltstone-shale couplets

Centimetre to decimetre thick beds starting with a mm–cm thick division of laminated siltstone that passes upward to a massive, grey-green or brownish-black shale, are included in this facies (Fig. 21). The beds show sharp contact with the underlying sediment. This facies occurs both in the MB and the Szymbark Shale. This facies corresponds to the facies D2 of Pickering *et al.* (1986).

Graded shales

Shales showing sharp contacts with the underlying sediment were arbitrarily included in this facies. The shales are grey-green and particularly khaki coloured, dark-brown and brownish-black. The khaki coloured shales, similar to those in the sandstone-shale couplets, occur in dm thick beds, whereas cm thick layers are characteristic of the other shale types. This facies corresponds to the facies E2.1 of Pickering *et al.* (1986).

Varicoloured shales

Shales consisting of interlaminated mm to cm thick laminae of green, grey-green, beige, brown to brownish-black shale showing passages between laminae are included to this facies (Fig. 22). Green and grey-green colours prevail. Fractured surfaces are usually covered with Mn oxyhydroxides suggesting a dark-grey to black colour of the shale. This facies is characteristic of the Szymbark Shale but it is also a subordinate constituent of the remaining part of the succession. It occurs in the MB and the Pasierbiec Sand-

Fig. 23. Chaotic sandy mudstone with rounded clasts of sandstone (balled mudstone). Scale 17 mm long in the lower centre. Upper part of Magura Beds (Budzów Shale), Krzczonów

Fig. 24. Concretionary ankerite layer, tectonically doubled, underlain by a greenish-grey shale and overlain by a sandstone. Hammer (30 cm long) as a scale. Upper part of Magura Beds (Budzów Shale), Polany

stone, basically in a mm–cm thick laminae of non-calcareous dark-green or black shales underlying sandstone beds. This facies corresponds to facies E1.2 of Pickering *et al.* (1986).

Chaotic, brecciated and balled sediments

Sediments consisting of a muddy matrix and disordered usually angular intraclasts, subordinately pebbles of extraclasts typify this facies (Fig. 23). It occurs in beds ranging from about 0.5 m to a metre in thickness. The beds usually occur in separated strata throughout the entire MB. In the investigated sections, the highest concentration of such beds occurs in the bottom part of the MB in Folusz. This facies corresponds to facies F2.2 of Pickering *et al.* (1986).

Concretionary rocks

Layered and lenticular bodies of ankerite, siderite and chalcedony are included in this facies (Fig. 24). The carbonate concretionary bodies are sometimes silicified. These

Fig. 25. Tuffite layer (light, 5 cm thick, behind hammer-head) in the upper part of Magura Beds (Budzów Shale), Krzczonów

rocks represent an accessory constituent of the MB. This facies corresponds to facies G3 of Pickering *et al.* (1986).

Tuffites

Laminae a few millimetre to centimetre thick of bentonized tuff with a different admixture of detrital material occur in several horizons in the succession in question (Fig. 25). The tuffites show a light-grey colour and are usually distinctively enriched in biotite.

Bioturbation structures

Bioturbation structures occur with differing frequency throughout the entire succession. They are most frequently recorded on soles of thin and medium sandstone beds underlain by green non-calcareous shale. Simple structures (Książkiewicz, 1977) with *Ophiomorpha* isp., *Palaeophycus* isp., *Arthrophycus tenuis*, *Planolites* isp. and *Thalassinoides isp.* are the most common (Fig. 17). *Taphrhelminthopsis* isp. occurs less frequently. Moreover, *Rhizocorallium* isp. and *Spirophycus* isp. were recorded in several beds. *Chondrites* isp. and *Planolites* isp. are the most frequent burrow types in the fine-grained sediments. They occur in as much as a 10 cm thick top part of the shale layers, which end with green non-calcareous shale. Characteristically, except for small *Chondrites*, bioturbation structures are absent in the beds of black and brownish-black shales and the neighbouring sediment.

Sand-grade particles in fine-grained sediments

Sand-grade particles were recorded in different amounts in the majority of samples (Appendix 1). The smallest amount up to a complete absence of such particles was recorded in the samples from the middle or upper parts of the thick shale layers. In contrast, the usually non-calcareous shale in the top part of the shale layers show nearly always distinctive admixture of such material. It amounts from single grains to 0.5%. Detrital quartz predominates. Feldspars, muscovite, sometimes biotite flakes, microfossils, heavy minerals and, in some samples (e.g., Fl

13, 14, 17, 19–21, 29, 34) characteristic fresh shards of transparent quartz constitute a subordinate admixture. The quartz shards together with biotite flakes are the most common in tuffite layers. Moreover, glaucony grains occur in some samples. Glaucony is most common in the layers showing sharp contact with the underlying sediment, and in those of disorganised sandy-mudstone. Lobate, mammilated and ovoidal grains are characteristic of the coarse fraction (>0.2 mm), whereas the finer grains are more irregular (Koszowska & Leszczyński, 2001). Microfossils are represented mainly by foraminifera. Fish teeth, sponge spicules, diatoms and radiolarians rarely occur, always in several to tens of specimens.

Foraminifera

Foraminiferal content in the investigated samples fluctuates between 0 and 10,000 specimens per 100 g of dry rock (Appendix 1; Figs 26, 27). Agglutinated species are more frequent than the calcareous ones. Of the one hundred investigated samples, agglutinated species have been absent in thirteen. In eleven samples only 1 to 2 specimens have occurred. In other samples, agglutinated species usually occur in tens to hundreds of specimens per 100 g of dry rock. The calcareous species have been recorded in forty-eight samples, mainly in several to 20 specimens per 100 g of dry rock. Calcareous benthic species have been found in forty-two samples, whereas planktonic species have been found in twenty-two samples. The richest assemblages, with agglutinated and calcareous benthic species, as well as planktonic, occur in sandy mudstones and chaotic brecciated fine-grained sediment (e.g., sample Fl 30 in Fig. 26). The calcareous benthic species are either absent or occur as single specimens in the samples of silty mudstone and shale where 0.2–0.01% admixture of sand-grade quartz occurs. In contrast, the agglutinated species are quite frequent in such sediment. This is typical for the green non-calcareous shale that occurs in thin layers in the top part of the massive calcareous shale and immediately beneath sandstone beds. In beds of graded shale, foraminifera are recorded exclusively in their lower part (cf. samples Fl7 and Fl8, Fig. 26). The massive calcareous shales characteristic of the MB are devoid of foraminifera or contain only single specimens.

Detailed foraminifera examinations were focused on the sections that displayed either more characteristic assemblages or stratigraphically important species. The Węglówka and Folusz sections were more frequently sampled than others in order to recognise the composition of foraminiferal assemblages in the background and event deposits, and along with the Krzczonów section were carefully studied in search of an equivalent of the globigerina marl assemblages, characteristic of the outer flysch nappes.

The samples of the lower part of the MB in the section along the road between Kobielnik and Węglówka (Fig. 4A; 27) have shown that the assemblages consist almost exclusively of agglutinated taxa with siliceous cement (Tab. 2). In the lowest and the highest samples (W*4 and 29), single specimens of very poorly preserved calcareous benthic species have also been found. The foraminiferal assemblages display very low species diversity (5–6) with slightly higher numbers of species in the two uppermost samples (W* 25, 29). The most abundant species in all examined material is *Haplophragmoides parvulus* Blaicher that makes up to 40–80% of the total microfauna. Among tubular forms *Nothia excelsa* (Grzybowski) and *Rhabdammina cylindrica* Glaessner are also frequent as well as *Haplophragmoides* sp. and *Paratrochamminoides* spp. In the samples W*25 and 29, *Glomospira glomerata* (Grzybowski) is relatively numerous. In the Magura Nappe the *Haplophragmoides parvulus* assemblage was considered as an indicator of the late Eocene (Małata, 2001). This is in accordance with the nannoplankton studies carried out in the Węglówka section which revelead the presence of NP19-20 and NP21 zones (see Tab. 1). This microfauna represents a slightly impoverished deep-water agglutinated foraminifera (DWAF) assemblage and can be regarded as the autochthonous due to its distribution in the sequence (see Appendix 1).

In the Krzczonów–Stróża section, six samples more abundant in foraminifera than others have been examined in details. The foraminiferal assemblages display low to moderate species diversity and relatively low abundance of specimens as well as low variety in taxonomical composition, depending on the position in the section and sediment origin. The sample Krc 17 of the dark-grey shale (Fig. 3B; Appendix 1) has yielded a monoassociation of pyritized representatives of *Chilostomella* (Tab. 2). This taxon belongs to the finely perforate calcareous benthic foraminifera which appear to be one of the more susceptible to pyritization (Sliter, 1975). In the Magura nappe deposits, this genus usually occurs in the form of pyritized moulds. Stráník and Hanzlíková (1968) regarded the occurrence of pyritized *Chilostomella* and other benthic foraminifera in the middle and upper Eocene deposits of the Bystrica zone as an indicator of an oxygen deficient environment. However, pyritization may occur in buried sediment in anaerobic microenvironments of the foraminiferal test (Sliter, 1975, Branchley & Harper, 1998).

Sample Krc 18, picked from grey shale, has yielded an assemblage with less numerous specimens of pyritized *Chilostomella chilostomelloides* Vasicek and a few agglutinated taxa with *Haplophragmoides* sp. relatively the most abundant. The assemblage found in green shale of the sample Krc 14 contains mainly agglutinated foraminifera with *Paratrochamminoides* spp., *Glomospira glomerata* (Grzybowski), *Haplophragmoides* sp. and a small admixture of badly preserved calcareous species such as *Dentalina* sp. and *Lagena* sp.

In the upper part of the Krzczonów section the green shale (Krc 27) consists of abundant pieces of tube-like morphotypes as well as 11 agglutinated species of which *Paratrochamminoides* div. sp., *Haplophragmoides* sp. and *Glomospira glomerata* (Grzybowski) are relatively numerous. Some badly preserved calcareous benthic forms have also been found. Two samples of the dark-brown shale (Krc 28, 28') consist of mixed assemblages with the agglutinated species represented by taxa similar to those occurring in the sample Krc 27, though less numerous (Tab. 2). There are some calcareous benthic species with *Cibicides lopjanicus* Mjatliuk, *Nuttallides truempyi* (Nuttall) and pyritized *Chilostomella* spp. amongst calcareous foraminifera. Planktonic foraminifera are rather rare, represented mainly by

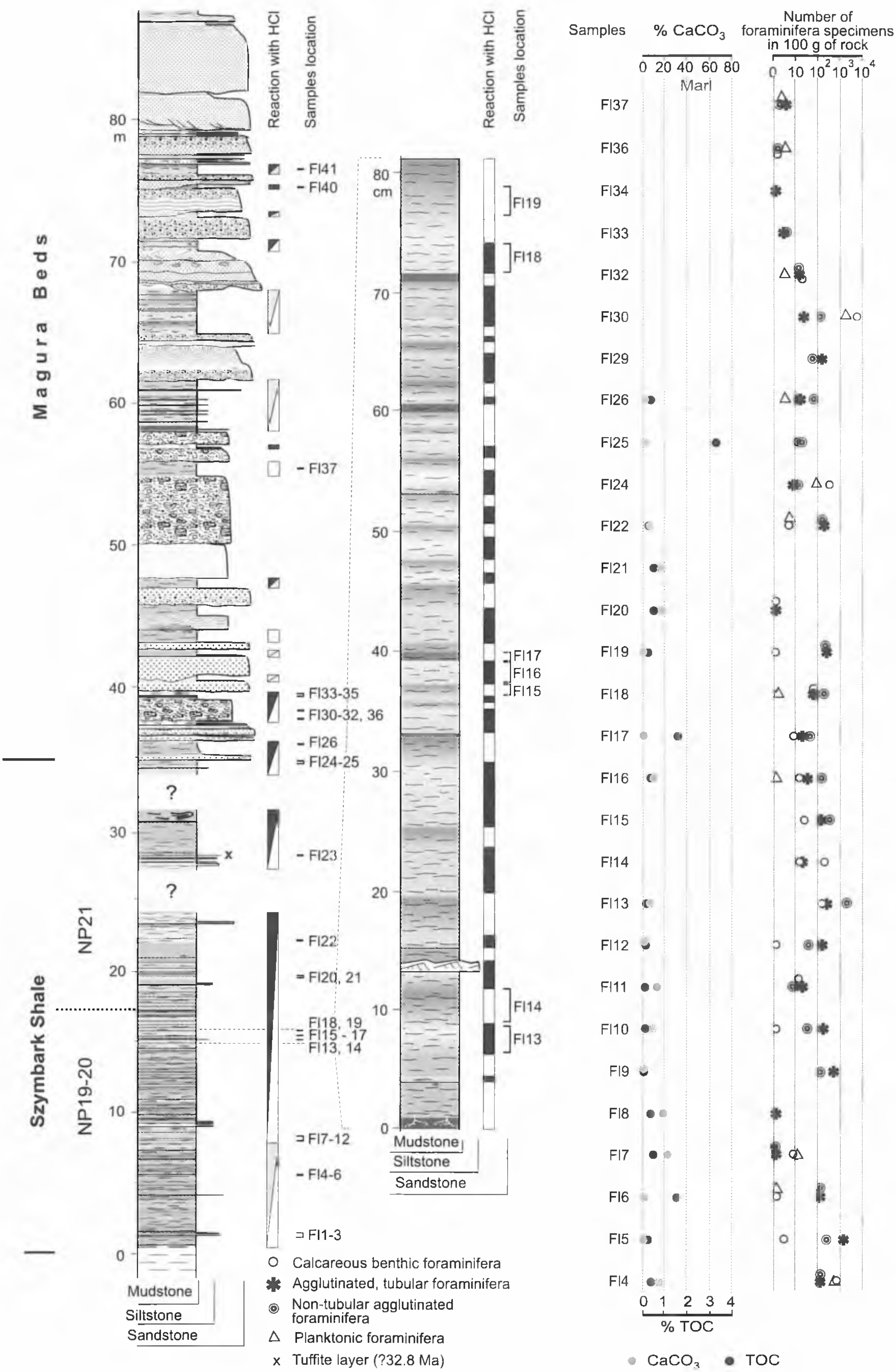


Fig. 26. Graphic log of the Szymbark Shale and the lower part of Magura Beds outcropped in the bed of Kłopotnica stream in Folusz (see Fig. 5A for section location), reaction with diluted HCl, TOC, $CaCO_3$ and foraminifera contents in the fine-grained sediments. Calcareous nannoplankton zones cf. Tab. 1 and Oszczypko-Clowes (2000, 2001). For other symbols, see Fig. 9

Tenuitella/Tenuitellinata genera. Co-occurrence of such species as *Tenuitella munda* (Jenkins), *T. liverovskae* (Bykova) and *Parasubbotina karpatica* (Mjatliuk) points to the early Oligocene (Rupelian) age of this part of the section (Olszewska *et al.*, 1996; Malata, 2001).

In the Folusz section, taxonomic compositions of foraminifera have been examined in eighteen samples from the Szymbark Shale. In the lower part of the unit, agglutinated assemblages have been found almost exclusively in three samples (Fl 5, 9, 12; Fig. 26; Tab. 2; Appendix 1). The assemblages display low diversity of up to 8 species with the constant presence of *Ammosphaeroidina pseudopauciloculata* (Mjatliuk) (Tab. 2). The representatives of the *Paratrochamminoides* genus are also a common element. In the other samples (Fl. 4, 6, 10, 11), the agglutinated taxa are accompanied by calcareous benthics and planktonic displaying low species diversity and rather low abundance. Among the calcareous benthics, *Nuttallides truempyi* (Nuttall) has been recognised as well as some specimens of the genera *Bolivina*, *Brizalina*, *Cibicidoides* and *Cibicides*. Planktonic foraminifera are represented by very small and poorly preserved specimens belonging to the genera *Testacarinata*, *Pretenuitella* and *Tenuitella*. Almost exclusively calcareous assemblage with small quantity of benthic and planktonic taxa have been found in the sample Fl 7. *Bolivina/Brizallina* and *Tenuitella/Tenuitellinata* genera are relatively more frequent.

Mixed assemblages have been recorded in the samples from the upper part of the Szymbark Shale. The agglutinated foraminifera are represented by taxa similar to those recorded in the lower part of the section. However, the most common form *A. pseudopauciloculata* is much more numerous here (Tab. 2). Among the calcareous benthic foraminifera, apart from the above mentioned, *Stilostomella longiscata* (d'Orbigny) are relatively abundant in the samples Fl. 13, 14, 18. Pyritized specimens of *Chilostomella* have also been noticed (samples Fl. 15, 16, 17, 18). Very rare and poorly preserved planktonic foraminifera have been found in the samples Fl 18, Fl 22 and Fl 24. The presence of such planktonic species as *Tenuitella* cf. *munda* (Jenkins), *Globigerina leroy* Blow et Banner, *Parasubbotina karpatica* (Mjatliuk) along with *Cibicides lopjanicus* Mjatliuk suggests the age of these sediments to be close to the Priabonian/Rupelian boundary.

The richest foraminiferal microfauna has been found in the Folusz section, in the bottom part of the MB. The sample Fl 30 (Fig. 26) of brecciated, highly calcareous sandy mudstone has yielded a calcareous assemblage with prevailing benthic taxa. The foraminifera are mixed depending on their environment and age. Such forms as *Pararotalia*, *Asterigerina* and *Discorbis* occurring in this assemblage are

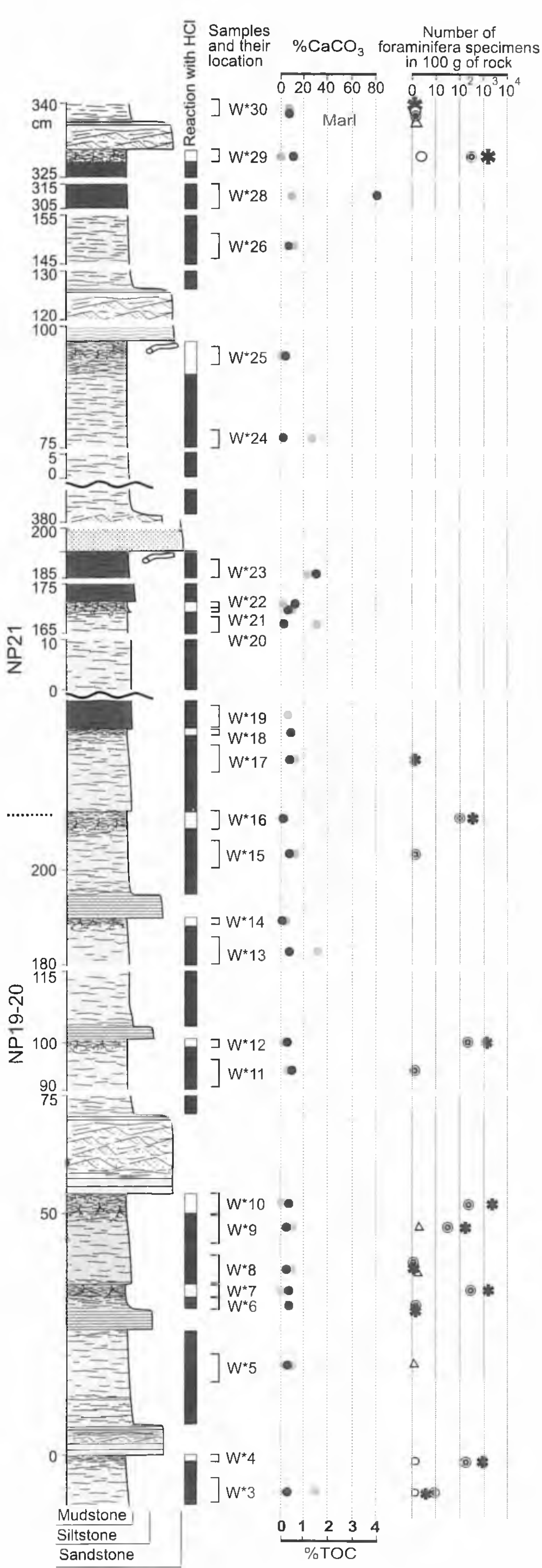


Fig. 27. Graphic log of the sampled lower part of Magura Beds outcropped along the road between Kobielnik and Węglówka villages (see Fig. 4A for section location), reaction with diluted HCl, TOC, $CaCO_3$ and foraminifera contents in the fine-grained sediments. Calcareous nannoplankton zones cf. Tab. 1. For other symbols, see Fig. 9

Table 2

Foraminiferal assemblages recorded in the investigated samples. Samples Fl4–Fl24 represent the Szymbark Shale, other samples are from the Magura Beds. Other data concerning samples location see Figs 3–5

	Samples	Fl 4	Fl 5	Fl 6	Fl 7	Fl 9	Fl 10	Fl 11	Fl 12	Fl 13	Fl 14	Fl 15	Fl 16	Fl 17	Fl 18	Fl 19	Fl 22	Fl 24	Krc17	Krc18	Krc14	Krc27	Krc28	Krc28'	W*4	W*7	W*10	W*12	W*16	W*25	W*29
		Late Eocene																E/O	Late Eocene		?		Early Oligocene		Late Eocene						
Agglutinated foraminifera	*Astrorhizacea* (tube-like taxa)	x	X	X		X	X	x	X	x	x	x	x	x	X	X	X			X	X	X	x	X	X	X	X	X	X	X	X
	Psammosphaera cf. *fusca*																				+	+	+	+							
	Psammosphaera sp.			F									R	F	R	F															
	Saccammina sp.			+												+	+			+		+									
	Hyperammina sp.		+	R											+							F	+	+		+					
	Ammodiscus tenuissimus																						R								
	Glomospira glomerata		+	F		+	+									F	R				R	F	R	R						A	F
	Glomospira gordialis	+							+												+	+		+							
	Glomospira irregularis					+															+		+							+	
	Glomospirella sp.																					+		+							
	Aschemocella sp.																							+							
	Reophax pilulifer																													F	+
	Reophax sp.			+						+				+			+														
	Subreophax guttifer			+			+																								
	Subreophax splendidus		+													+															
	Subreophax sp.																														+
	Haplophragmoides parvulus																								A	A	A	A	A	A	A
	Haplophragmoides cf. *scitulus*										+				R	R								+						+	
	Haplophragmoides walteri		+	R																											
	Haplophragmoides sp.					R	+		R	+			+		R		R			C	+	C	R	F	+	+	+	+	+	+	+
	Sphaerammina subgaleata																							+							
	Sphaerammina sp.																					R		+			+				
	Lituotuba lituiformis																				+										
	Paratrochamminoides spp.		F	F		R	F		F	+			+			R				F	F	C	+	F	R	F	F	F	C	C	C
	Trochamminoides coronatus																													+	
	Phenacophragma sp.					+											+														
	Ammosph. pseudopauciloculata	R	+	R		R	R	+	R	A	A	A	A	C	A	A	A														
	Recurvoides spp.			F			F		R	R		R				+				+		+		+						+	
	Popovia sp.																					F	R	R							
	Trochammina sp.														+								+	+							
Calcareous benthic foraminifera	*Dentalina* sp.																				+		+								
	Nodosaria sp.										+		+	R				+					+	+							
	Lagena sp.																				+										
	Fissurina cf. *laevigata*																							+							
	Bolivina spp. / *Brizallina* spp.	F			R										+			R													
	Aragonia cf. *janoscheki*																	+													
	Globocassidulina sp.	+																													
	?Uvigerina sp.																	R													
	Reussella sp.																	+													
	Stilostomella longiscata									F	F	R			A	+															
	Pleurostomella sp.																							+							
	Eponides umbonatus																						+								
	Cibicidoides sp.			+	+																										
	Cibicides lopjanicus																	+						+							
	Cibicides sp.	R			+													F						+							
	Nuttallides truempyi	+					+	+																+							
	Osangularia sp.							R																							
	Chilostomella spp.											R	+	+	R				F	R			+	+							
Planktonic foraminifera	*Chiloguembelina gracillima*	+																						+							
	?Acarinina sp.	+																													
	Muricoglobigerina senni														+																
	Testacarinata sp.	R			+																										
	?Praetenuitella sp.	R																													
	Tenuitella liverovskae																							+							
	Tenuitella munda																						+	+							
	Tenuitella sp./*Tenuitellinata* sp.	A		+	F			C									+						+	C							
	Tenuitellinata angustiumbilicata																														
	Catapsydrax unicavus																						+								
	Globoquadrina tripartita																						+								
	Globanom. naguewichiensis																							+							
	Globanomalina sp.	+																													
	Globigerina leroyi																	+					+								
	Parasubbotina karpatica																	+					+								
	Calcareous specimens indet.																+	+			+	+			+						+

+ – 1–5 specimens; R (rare) – 6–10; F (frequent) – 11–24; C (common) – 25–50; A (abundant) – >50; x – 30–100 and X >150 pieces of highly fragmented tubular form

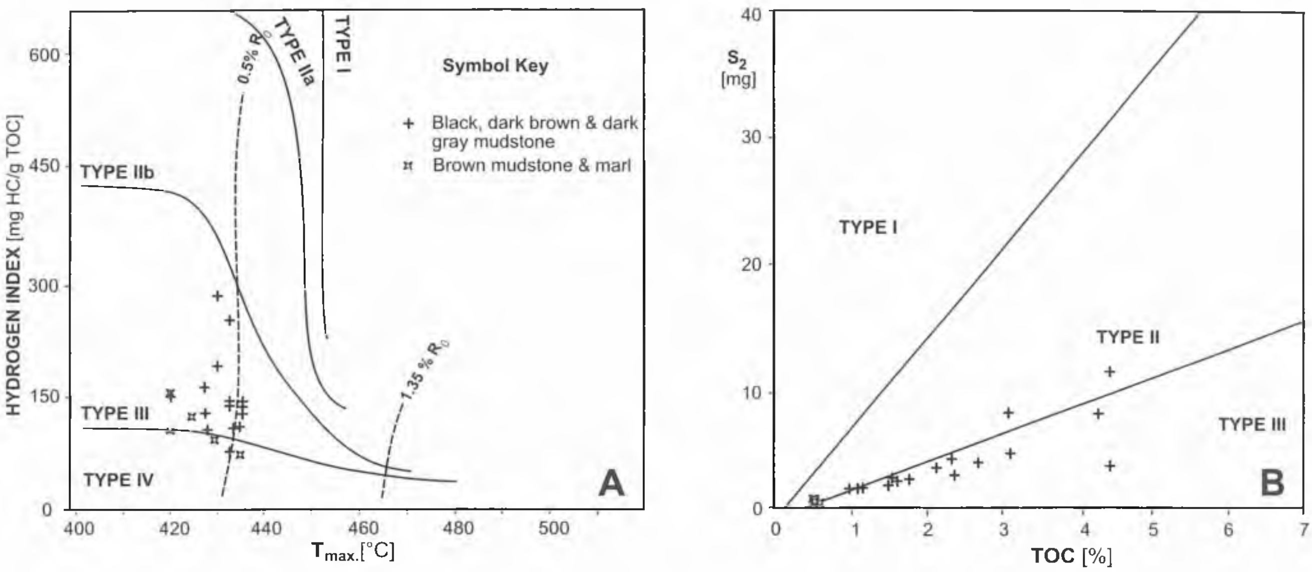


Fig. 28. Type of kerogen determined by Rock-Eval pyrolysis in the fine-grained rocks in which TOC exceeds 0.5%. **A.** Type of kerogen indicated by the relation between hydrogen index and the temperature of maximum hydrocarbon evolution (T_{max}). **B.** Type of kerogen indicated by the relation between total organic carbon content (TOC, in %) and the amount of hydrocarbons evolved from the thermal alteration of the kerogen (S; in milligrams, normalized to sample weight)

characteristic of the neritic zone. *Svratkina perlata* (Andrea) has been reported from outer shelf–upper slope. Other genera *Brizalina*, *Cibicides* are known from the wide range of bathyal depths (Murray, 1991; Olszewska, 1984). Among planktonic taxa there occur some middle Eocene forms as well as such that are typical components of the Sub-Menilite Globigerina Marl from the outer flysch nappes *Globigerina officinalis* Subbotina, *G. praebulloides* Blow and *Globorotaloides suteri* Bolli. The single specimens of the Oligocene taxa, represented by *Tenuitella munda* (Jenkins) and *Globoquadrina tapuriensis* (Blow et Banner) indicate the lower age limit of this assemblage (Olszewska *et al.*, 1996).

Geochemistry of fine-grained sediments

Carbonate and TOC

Calcium carbonate content in the fine-grained sediments ranges from 0 to 56.6% (Appendix 1). Strong differences occur between neighbouring layers (Figs 26, 27). Of the 83 analysed samples, in 16 samples $CaCO_3$ content is higher than 25%, of these, it exceeds 30% in 7 and in only 1 is it higher than 39%. Distinctively increased $CaCO_3$ content is recorded in the NP21 zone and in the top part of the succession, in the eastern part of the Siary zone. Effervescent reaction with dilute HCl is displayed by all the rocks where $CaCO_3$ content exceeds 10%. Those, where $CaCO_3$ ranges between 3 and 10% show effervescence only in some places, where large enough calcareous grains (primarily foraminifera) probably occur. $CaCO_3$ content, generally below a few per cent, occurs in green coloured, fine-grained sediments.

TOC values range between 0.1–5.4%. Sediments with TOC above 1% represent an accessory constituent of the succession. In the most characteristic grey-green, khaki and grey shales, TOC ranges between 0.1–0.7%, and rarely exceeds 0.3% (see Figs 26, 27).

Carbonate minerals

X-ray diffraction analysis has shown that calcite is the predominating carbonate phase in the calcareous fine-grained sediments. Ankerite and siderite equal or slightly surpass calcite in the hard concretionary bodies.

Kerogen

The results of Rock-Eval pyrolysis indicate that organic matter in the rocks where TOC exceeds 0.5% mainly gives signatures of the hydrogen-poor Type III kerogen (Fig. 28). There, HI values range between 71 and 288. In only two samples (Krc25 and KW14), both taken from the upper part of the MB of the western part of the Siary zone, is admixture of the Type II kerogen significantly increased.

Major and trace elements

Analysis of major and trace elements in the Szymbark Shale and the lower part of the MB in Folusz indicates rather moderate geochemical differentiation of these sediments (Appendix 2). Dark-brown shales show generally slightly different geochemical signals than the remaining ones. All samples are relatively rich in the lithophile elements (Si, Al, Na, K, Ti, Zr, Cr, V, Sc, Rb and Th). The dark-brown shales (Fl 17, 34, 41) are generally impoverished in all these elements. Of the biophile elements, only Fe, Mn, Mg and Ba occur in increased amounts in all samples. However, Ba shows increased values in the dark-brown shales whereas the other three elements occur here in lowered amounts. Ca, V, Cu, Zn and Co show low to moderate values, close to shale standard (see Turekian & Wedepohl, 1961) in all samples, P and particularly Se and Mo occur here in very low amounts. It is noteworthy that MgO ex-

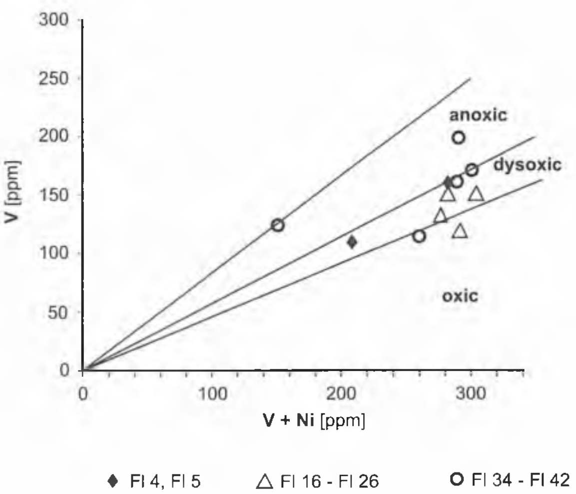


Fig. 29. Vanadium/vanadium + nickel plot of the fine grained-sediments from the Szymbark Shale (samples Fl4, 5 – lower part; samples Fl16-Fl26 – upper part) and the lower part of Magura Beds (samples Fl34-Fl42) in the Folusz section. The fields of oxygenation regime are after Lewan (1984)

ceeds CaO in six samples. Uranium occurs in generally decreased amounts but in the dark-brown shales it occurs in distinctively higher amounts. The ratios V : V+Ni, used for interpretation of oxygenation regime at the sea floor (see Wignall, 1994), except for two samples, range between 0.6–0.4 (Fig. 29).

Calcareous components of fine-grained sediments

Analyses of sediment texture in SEM show that calcareous material occurs mainly as cement. Coccoliths represent the second type of calcareous particles. When analysed on broken rock surfaces, they are recorded primarily in the rocks where $CaCO_3$ content surpasses 20%. Poorly preserved, corroded and recrystallized specimens were recorded. In smear slides, their content varies between 0 and 20 specimens per observation field. They were recorded in smear slides of rocks with as little as 3% $CaCO_3$ and were absent in rocks with as much as 8.5% calcium carbonate (cf. Appendix 1 and Tab. 1). Their number in smear slides is roughly proportional to $CaCO_3$ content and does not show any dependence on TOC in the range 0.15–4.18%, recorded in samples where coccoliths were investigated. Moreover, the sample with the highest TOC (Krc15) shows a $CaCO_3$ content of 4.75%; nevertheless 22 species were recognised here. For comparison, 22 species were also recognised in a sample (Krc32) with a $CaCO_3$ content of 28.58% and TOC 0.98%. Altogether, 44 species were recognised in the 40 investigated samples. Their distribution appears to show only stratigraphic changes and does not display any dependence on the $CaCO_3$ and TOC content. An accessory component of the calcareous material are, besides cement and coccoliths, calcareous foraminifera.

DISCUSSION

Sediment provenance and sedimentary environment

Facies of the studied sediments and particularly their foraminiferal assemblages indicate sedimentation in a deep-marine environment. Paleocurrent direction points to the supply of the clastic material from sources located on the northern margins of the Magura basin. Mineral and textural composition of the coarse-grained fraction evidences its differentiated, though generally high maturity, and dominance of terrigenous components. Shallow-marine fossils occurring in some sandstone beds (e.g., large foraminifera, coralline alge) and ubiquitous presence of relatively fresh glaucony indicate that the sand was transferred through a shelf and an upper slope setting. At the same time, the glaucony indicates (Odin & Fullagar, 1988) that the northern margins of the Magura basin were sites with slow sedimentation rate and moderate bottom oxygenation. The great thickness of the succession and the relatively short time of its sedimentation (see Fig. 8), together with the occurrence of glaucony, imply that it resulted from erosion of an earlier prepared sediment pile accumulated in the outer shelf environment.

The relatively high content of lithophile elements in the fine-grained sediments in the Folusz section evidences that the sediments are rich in terrigenous material. The thorium content 9.4–16.1 ppm suggests predominance of illite in the clay-mineral assemblage (see Rider, 1996). Some impoverishment in illite seems to occur in the dark-brown mudstones as they show lowered K_2O content. According to the Th/U ratio, ranging 2.73–5.04, the dark-brown mudstones in the Folusz section correspond to average grey-green marine shale (Adams & Weaver, 1958).

Sedimentary processes

Facies of the MB and the Pasierbiec Sandstone indicate their sedimentation basically by different mass gravity transport processes. The majority of the sediments were deposited by high-concentration turbidity currents *sensu* Lowe (1982) or by concentrated density flows *sensu* Mulder & Alexander (2001). This concerns the beds of sandstones, conglomerate-sandstone couplets and thick sandstone-shale couplets.

The cross-stratified sandstones result from reworking by strong bottom currents or by long lasting tractional sedimentation from concentrated density flows *sensu* Mulder & Alexander (2001). The latter process is also responsible for sedimentation of parallel-stratified sandstones (see Pickering *et al.*, 1986). The massive sandstones could have been deposited by fluidized flows. The same concerns disorganised muddy sandstones; however, the high content of fine-grained material and chaotic structure indicate sedimentation by cohesive flows. The chaotic brecciated and balled sediments were deposited by cohesive flows as well.

The medium and thin-bedded sandstone-shale couplets as well as the siltstone-shale couplets and the beds of graded shales are deposits of low-concentration turbidity currents *sensu* Lowe (1982) or turbidity currents *sensu* Mulder & Alexander (2001).

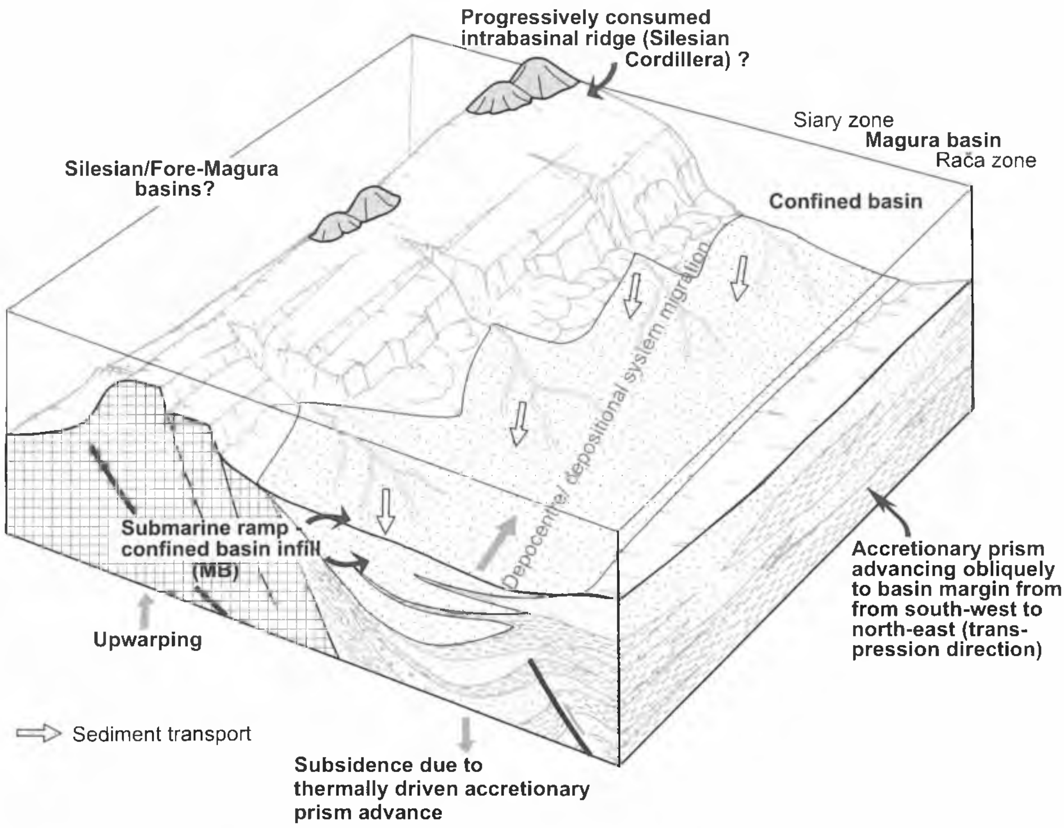


Fig. 30. Model of depositional system and sedimentation evolution of the Magura Beds during Priabonian–Rupelian

The varicoloured shales with gradual passages between laminae as well as the dark-green, and dark-grey to black, basically non-calcareous muddy shales that occur in mm–cm thick laminae in the top part of the massive shale layers and which underlie sandstone beds are hemipelagites. These are the background sediments in the entire succession (cf. Książkiewicz, 1966; Sikora, 1970). The sand-grade terrigenous particles recorded in these sediments, and their absence in the upper part of the underlying turbiditic shales may have resulted either from winnowing of the background sediment or from its contamination by the material from the overlying sandstone. The contamination may have occurred due to processes influencing the outcrops (weathering *sensu lato*) or during sampling.

The origin of the brown, dark brown and black shales that occur in cm laminae seems to be complex. The predominance of the Type III kerogen suggests their turbiditic or hemipelagic sedimentation. The laminae which display sharp lower boundaries or pass downward to siltstone, appear to have been deposited by turbidity currents. Those with gradational contacts with the underlying sediment appear to represent the background, hemipelagic sediment. However, the gradational contacts may also result from bioturbational smearing of the originally sharp boundaries.

Depositional system

Facies of the Szymbark Shale and the package underlying the Pasierbiec Sandstone together with the location of the Siary zone in the marginal part of the Magura basin indicate their sedimentation in the form of a drape at the base of the slope. The Pasierbiec Sandstone represents a channel fill or together with the MB locally form a fragment of the sedimentary cover of the Siary zone. Facies of the MB and their distribution correspond to those of the deep-sea fans. Continuous distribution of the MB in the entire Siary zone together with its sedimentation basically from mass gravity flows and general paleotransport towards south-west indicate sedimentation in a form of a submarine ramp (Leszczyński, 2001). This ramp may have extended along the margins of the Magura basin, and in the west encroached on the Rača zone. Diachronism of the MB suggests gradual upbuilding of the ramp toward east along the basin margin. Lack of distinctive proximal–distal changes in facies together with common occurrence of thick turbiditic shales point to sedimentation in a trough-shaped confined basin (Fig. 30). The basin was located between a sloping bottom of the Rača and Sącz zones and the margins of the Magura basin. Such configuration of the Rača zone is also indicated by increased amounts of $CaCO_3$ and shallow-water microfossil association in the sediments of the middle-upper Eocene of the Bystrica zone in the Czech Carpathians (see Stránik & Hanzlíková, 1968). The S–N diachronism in distribution of the Magura Formation suggests that during the Priabonian–Rupelian, the Rača zone represented the frontal part of the advancing accretionary prism in the Magura basin.

Gradual expansion of the glauconite-rich sandstones outside the Siary zone, particularly distinctive in its western part, indicates onlapping of the MB on the deposits of the

Table 3

Selected ecological data for the most common benthic foraminifera in the studied sections (after: 1 – Jones & Charnock, 1985; 2 – Murray, 1991; 3 – Gooday, 1994; 4 – Nagy *et al.*, 1995; 5 – Jones 1996; 6 – Bąk *et al.*, 1997)

Genera	Mode of life	Mode of feeding	References and other characteristics
Tube-like morphotypes	erect epifaunal erect epifaunal semi-infaunal	suspension feeders suspension feeders suspension feeders, detritivores	164
Psammosphaera	epifaunal–infaunal	passive deposit-feeders	1
Glomospira	epifaunal	detritivores	1, 6
Haplophragmoides	epifaunal infaunal to surficial shallow to deep infaunal	herbivores or detritivores detritivores detritivores	146
Paratrochamminoides	epifaunal	detritivores	6
Ammosphaeroidina	?surficial semi-infaunal	detritivores	4
Recurvoides	epifaunal semi-infaunal, infaunal epifaunal, shallow infaunal	detritivores detritivores detritivores	2; shelf–bathyal46
Nodosaria, Dentalina	infaunal	?detritivores	5
Bolivina	infaunal–epifaunal shallow infaunal	?detritivores	2; inner shelf–bathyal 3; low O_2 and/or high organic matter input
Brizallina	infaunal shallow infaunal	detritivores	2; shelf–bathyal 3; low O_2 and/or high organic matter input
Stilostomella	infaunal	?detritivores	5
Cibicides	epifaunal attached epifaunal	?passive suspension feeders	2; shelf–bathyal 3; well oxygenated environment
Chilostomella	infaunal deep infaunal	detritivores	2; outer shelf–bathyal 3; high organic matter input

Magura Formation. Moreover, this also suggests that the inner slopes of this part of the Magura basin became less steep with time.

The portions of the MB dominated by massive shales alternated with thin to thick-bedded sandstones (Fig. 9C–E) represent ramp lobes and drapes (see Stow, 1985). These sediments predominate in the entire MB. The sequences dominated by thick-bedded sandstones, with intercalations of brecciated sediment and muddy sandstones (Fig. 9A, B) constitute the channel fill sediments. Such sediments are the most frequent in the Magura Sandstone (Wątkowa Sandstone). They mainly represent the fills of distributary channels according to the interpretation by Stow (1985). Proximal channel fill represent the sequence of massive sandstones that form the Magura Wątkowska range in the area of Folusz.

Sedimentation controls

Bathymetry

The occurrence of basically non-calcareous background sediments throughout the entire succession suggests its sedimentation mainly below the calcite compensation depth (CCD). The foraminiferal assemblages contained in the background sediments indicate sedimentation generally below the foraminiferal lysocline (FL; usually situated 500–1000 m above CCD; Berger, 1974; Kennett, 1982), and occasionally below the CCD, at depths corresponding to the lower part of bathyal zone.

Sedimentation below CCD is indicated by assemblages of exclusively agglutinated foraminifera occurring in the background sediments in the Węglówka–Kobielnik section. Mixed assemblages of agglutinated and calcareous taxa of the background sediments, investigated in Krzczonów and Folusz, point to deposition above CCD but below the FL as the calcareous foraminifera consist of taxa most resistant to dissolution. The assemblages of agglutinated foraminifera alternating with mixed assemblages such as occurring in the sediments of the lower part of the Folusz section imply sedimentation close to fluctuating CCD.

Foraminiferal assemblages characteristic of sedimentation above FL, with rich and well preserved planktonic and calcareous benthics, like those known from the Priabonian Sub-Menilite Globigerina Marl of the outer flysch nappes (see Olszewska, 1984), and mentioned by Blaicher and Sikora (1963) and by Sikora (1970) from the Folusz section, have not been found in the studied material. The rich calcareous assemblage recorded in brecciated sandy mudstone in the lower part of the MB in the Folusz section (Fl 30) is allochthonous and reflects environmental conditions of the area from which this sediment was redeposited.

The absence of glaucony in the background sediments or its occurrence in single grains only, indicates that the sea bottom was located at depths greater than those at which glaucony is normally formed (i.e., below 550 m; Odin & Fullagar, 1988).

Sedimentation of the investigated sediments at depths greater than those of the CCD of the present day oceans seems to be doubtful because the Carpathian flysch sea was a small basin (see Książkiewicz, 1961; Behrmann *et al.*, 2000). A high proportion of terrigenous particles in the background sediments suggests intense supply of clastic material and, at the same time, a relatively high rate of background sedimentation. This factor could prevent the sea floor from colonisation by calcareous foraminifera on the one hand and highly dilute the settling tests of planktonic foraminifera and coccoliths on the other. With increased aggressivness of the bottom water relative to $CaCO_3$, the highly dispersed, tiny calcareous particles of coccoliths and tests of planktonic foraminifera had a little chance to become preserved in the background sediment. One can not exclude that the primary populations of calcareous plankton in the open-sea part of the Magura basin were impoverished. Thus, rather the depths close to the present-day foraminiferal lysocline (2000–3000 m) appear to be the greatest in the Siary zone during the Priabonian–Rupelian.

Oxygenation regime

Poor trace-fossil assemblage of the investigated succession suggests its sedimentation in rather poorly oxygenated bottom waters. However, the genera *Ophiomorpha* and *Thalassinoides* are generally considered to be indicative of rather fully oxic conditions.

The common occurrence of infaunal genera among calcareous benthic foraminifera and the dominance of epifaunal forms among agglutinated genera in the background sediments (Tab. 3) suggest neither fully oxic nor typical disoxic conditions at the sea floor (Jones, 1996). In the studied foraminiferal assemblages the following agglutinated genera (apart from tube-like morphotypes) are the most commonly occurring: *Psammosphaera*, *Glomospira*, *Haplophragmoides*, *Paratrochamminoides*, *Ammosphaeroidina*, and *Recurvoides* (see Tab. 2). Three of the mentioned agglutinated taxa as well as the tube-like morphotypes represent epifaunal suspension and deposit-feeders, the others are regarded as epifaunal or semi-infaunal – shallow infaunal organisms (see Tab. 3). Among the calcareous benthic taxa, such genera as *Nodosaria/Dentalina*, *Bolivina/Brizallina*, *Stilostomella*, *Cibicides*, and *Chilostomella* are noticed more often than the others. Among them only one represents epifaunal passive suspension feeders and the rest show the infaunal mode of life. *Bolivina* and *Brizallina* tolerate low oxygen content and along with *Chilostomella*, which is connected with oxygenated sediments, occur in areas of high organic matter input (Gooday, 1994). Thus, more numerous in specimens agglutinated taxa show close to equal proportion of epifauna to infauna genera while the less abundant calcareous benthic display infaunal dominance. Such distribution of foraminifera along with low species diversity suggest moderate oxygenation of the sea floor with considerable amount of organic matter flux (Gooday, 1994; Jones, 1996; Kuhnt *et al.*, 1996).

The absence of burrows and foraminifera in some beds of black and brownish-black shales and the neighbouring sediment indicate that anoxia could have appeared during, and for a short time after, sedimentation of such deposit. The basically Type III kerogen signatures of the fine-grained sediments with more than 0.5% TOC suggest that aerobically degraded organic matter predominates in these sediments (see Tyson, 1995). According to the classification by Jones (1987), organic matter enclosed in these sediments, except for two samples, is characteristic of an oxic regime, of the environments proximal to fluvio-deltaic source. It is possible that these are exclusively resedimented deposits and that aerobic degradation occurred elsewhere in shallower, better-oxygenated areas.

The geochemical parameters of eleven samples from the Szymbark Shale and the lower part of the MB in Folusz are inconsistent. V/Cr values are less than 1, except for one sample, and according to Dill (1986) indicate normal oxic conditions, similarly to the content of authigenic uranium calculated from the formula proposed by Wignall (1994). In contrast, the values of V/(V+Ni) ranging 0.41–0.82 (Fig. 26) suggest mainly dysoxic conditions (see Wignall, 1994). However, concentrations of the elements were measured in whole rock, and therefore the values can be slightly elevated (see Wignall, 1994). Considering all the mentioned features it seems that poorly oxic to slightly dysoxic conditions prevailed at the basin bottom in the Siary zone during Priabonian and Rupelian.

Tectonic regime and eustasy

The diachronism of the MB between the western and eastern parts of the Siary zone together with general paleotransport directions indicate sedimentation control by basin subsidence and migration of the subsidence centre obliquely to the Siary zone from the west to east. At the same time, intensive resedimentation of huge masses of clastic material points to intensive erosion of its source area. Considering that similarly intensive resedimentation occurred synchronously in the outer part of the Inner Carpathians (see Radomski, 1958, Marschalko, 1968; Janocko, 2001) and slowing down sedimentation took place in the inner part of the Magura basin (see Fig. 1), rollback of the subducted lithosphere beneath the evolving Western Carpathians appears to be a common factor responsible for the sedimentation development in the entire region (Figs 30, 31). Lateral changes of the succession suggest that the rollback expanded obliquely to the extension of the region, from west to east. It drove transpression in the Magura basin, which resulted there in accretionary wedge progress and enhanced subsidence in front of the accretionary wedge. At the same time, the margins of the Magura basin underwent uplifting as a forbulge during sedimentation of the succession and were drowned and buried beneath the expanding accretionary wedge afterwards. This interpretation is compatible with

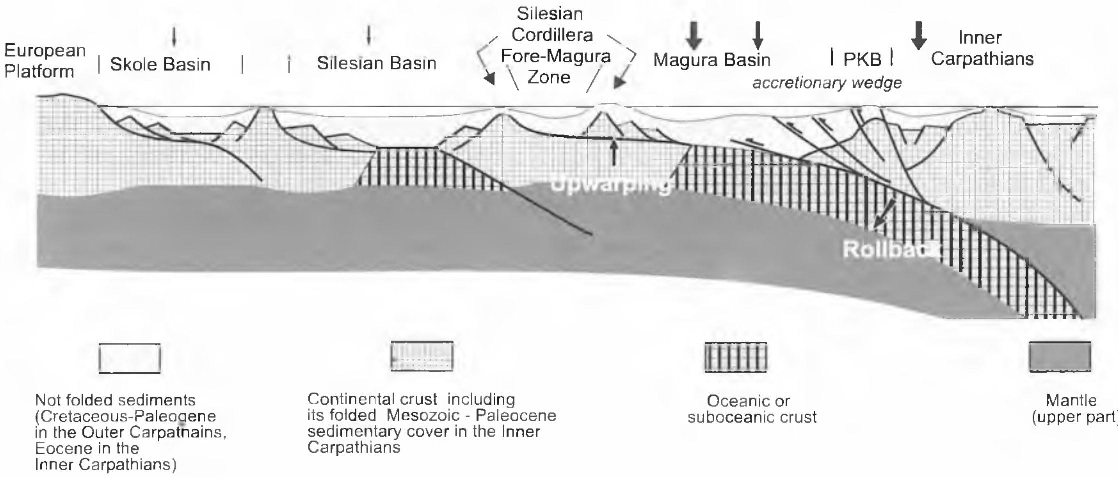


Fig. 31. Simplified palinspastic cross-section through the Northern Carpathians at the turn of the Eocene/Oligocene. Not to scale. Arrows denote relative subsidence rate

Morley's (1993) interpretation of deformation development in the Outer Carpathians. He argued that deformation was driven by extrusion tectonics and subduction rollback and rolled around the arc in a clockwise fashion.

The occurrence of debrites within the Małastów Shale, together with the great thickness of beds of massive shales, representing single turbidites, indicate sedimentation of this unit in a tectonic regime similar to that during sedimentation of the Wątkowa Sandstone. The basic difference was in composition of resedimented material, which was supplied from progressively deeper parts of the gradually destroyed basin margins.

The concentration of sandstones close to the Eocene–Oligocene boundary may have resulted from globally registered eustatic sea-level lowering (Haq *et al.*, 1988). Nevertheless the gradual disappearance of sandstones up the succession without any change in resedimentation intensity suggests that rather continuous uplifting of the source area during the Priabonian–Rupelian was responsible for such sedimentation development.

CONCLUSIONS

The Siary zone of the Magura nappe during the Priabonian–Rupelian represented a confined basin that was surrounded by the margins of the Magura basin in the north and by the northward sloping bottom of the Rača zone in the south. Its bottom formed a ramp that extended along the margin of the Magura basin and sloped to the south and southwest. The ramp was brought into prominence by sedimentation of the MB.

Intensive resedimentation by different mass-gravity flows, particularly high-concentration turbidity currents *sensu* Lowe (1982) took place during sedimentation of the entire succession in the western part of the Siary zone. Such sedimentation in the eastern part of the zone occurred chiefly during the Rupelian, including the time when the Małastów Shale was deposited. Hemipelagic processes prevailed there locally during the whole Priabonian.

The basin bottom was located generally below the foraminiferal lysocline. Dark-green, rarely dark-brown and black, basically non-calcareous shales were deposited as the background sediments in the entire Siary zone during the whole time-span. Slightly calcareous background sediments were formed only occasionally, particularly in the eastern part of the Siary zone during the middle and late Priabonian. Intensive resedimentation and greater basin depths prevented accumulation of more calcareous sediments, similar to the globigerina marls deposited synchronously in the more outer part of the Carpathian flysch-sea. The increased content of calcareous material both in the event and background sediments that is characteristic of the late Priabonian and early Rupelian rocks of the outer parts of the Western Outer Carpathians, in the Siary zone is restricted mostly to the event sediments.

Poorly oxic and slightly dysoxic conditions prevailed at the basin bottom during the entire time-span. Strong dysoxia to anoxia probably appeared only for a short time during the Rupelian. Frequent large-scale resedimentation of material poor in organic matter drove replenishment of oxygen at the basin bottom and prevented longer periods of oxygen deficiency.

The differences in facies in relation to the coeval deposits of the other parts of the Carpathians result primarily from intensive resedimentation in the Siary zone during the Priabonian–Rupelian, and in part from the relatively low calcium carbonate supply in this area.

Sedimentary conditions and sedimentation development in the Siary zone, during the Priabonian–Rupelian, as well as in the remaining parts of the Magura basin and the Inner Western Carpathians, were controlled significantly by subduction rollback in this region. Gradual expansion of this process from west to east drove transpression in the Magura realm that resulted in an accretionary wedge progress and enhanced subsidence in front of the wedge. Moreover, the subduction rollback caused uplifting of the outer margins of the Magura basin during the Priabonian–Rupelian, but finally led to their drowning and burial.

Acknowledgements

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Appendix 1

Selected features of the fine-grained sediments of the investigated samples. Samples in which $CaCO_3$ and TOC content was determined are indicated in the table. Sand-grade particles were analysed only in part of these samples. Number of foraminifera specimens calculated for 200 g of dry rock. See Figs. 3–5 for sample location

Sample No.	Sediment colour	Reaction with HCl	Bed thickness [cm]	$CaCO_3$ [%]	TOC [%]	Sand fraction			Sediment origin
						Detritus [%]	Foram. number		
							Agglut.	Calc.	
Folusz									
Fl 4	brown-grey	+	5.0	17.70	0.46	0.175	572	3256	Turbidite
Fl 5	green	–	5.0	1.17	0.23	0.48	3008	10	Turbidite
Fl 6	dark brown	–	1.0	0.25	2.46	0.24	542	8	Turbidite
Fl 7	brown	+	16.0	21.98	0.50	s	3	43	Hemipelagite?
Fl 8	brown	+		19.67	0.39	s	1	0	
Fl 9	green	–	4.5	1.08	0.10	s	1940	0	Hemipelagite?
Fl 10	yellowish-green	(+)	2.0	8.75	0.18	0	630	4	Hemipelagite
Fl 11	yellowish-green	+	2.0	11.0	0.12	0	93	99	Hemipelagite
Fl 12	green	–	15.0	0.42	0.18	s	678	1	Hemipelagite
Fl 13	khaki	+	2.5	7.58	0.22	tr	5926	370	Hemipelagite?
Fl 16	beige	+	2.0	10.25	0.30	s	504	48	Hemipelagite?
Fl 17	dark-brown	–	0.7	1.17	1.74	tr	200	18	Hemipelagite?
Fl 19	green	–	5.0	0.75	0.25	tr	1558	4	Hemipelagite?
Fl 20	brown	+	27.0	18.67	0.55	0	1	2	Tirbidite
Fl 21	brown	+	15.0	17.00	0.52	s	0	0	Turbidite
Fl 22	beige and green	+, –	30.0	6.17	0.28	tr	1132	16	Hemipelagite?
Fl 25	dark-brown	–	7.0	0.33	3.20	9.5	64	32	Turbidite
Fl 26	green	–	18.0	1.42	0.32	2.6	228	14	Turbidite
Krzczonów									
Krc 4	dark-brown	+	315.0	28.50	0.95	nd	nd	nd	Turbidite?
Krc 5	dark-grey	+	320.0	22.00	0.53	nd	nd	nd	Turbidite?
Krc 8	dark-brown	+	5.5	29.17	1.27	nd	nd	nd	Turbidite?
Krc 10	brown	+		32.08	0.88	nd	nd	nd	
Krc 9	bluish-grey	+	4.0	28.33	0.49	nd	nd	nd	Turbidite?
Krc 11	dark-brown	+	5.0	25.92	1.85	nd	nd	nd	Turbidite?
Krc 12	dark-brown	+		30.83	1.15	nd	nd	nd	
Krc 13	greyish-green	+	130.0	27.33	0.15	0.15	0	0	Turbidite
Krc 14	green	(+)	5.0	3.00	0.26	tr	446	24	Turbidite?
Krc 15	dark-brown	+	2.0	4.75	4.18	tr	22	0	Hemipelagite?
Krc 17	dark-grey	+	~150.0	7.33	0.44	tr	0	16	Turbidite?
Krc 18	grey	–	20.0	0.83	0.18	tr	1326	10	Hemipelagite?
Krc 19	green	–	3.0	0.58	0.19	tr	2380	6	Hemipelagite
Krc 20	brown	+	15.0	5.00	0.56	s	6	0	Turbidite
Krc 22	dark-brown	+	265.0	24.83	0.81	tr	nd	nd	Tubidite?
Krc 25	dark-brown	+	71.5	20.50	3.02	tr	nd	nd	Turbidite
Krc 27	green	–	1.0	5.00	0.39	0.21	3258	10	Hemipelagite
Krc 28	dark-brown	+	10.0	28.58	0.98	s	240	22	Turbidite

Sample No.	Sediment colour	Reaction with HCl	Bed thickness [cm]	$CaCO_3$ [%]	TOC [%]	Sand fraction			Sediment origin
						Detritus [%]	Foram. number		
							Agglut.	Calc.	
Kasina Wielka									
KW 13	dark-green	–	10.0	0.67	0.18	s	4826	0	Hemipelagite?
KW 14	black	+	9.0	12.33	4.43	s	0	0	Turbidite?
KW 15	brown	+	>25.0	18.67	0.43	s	1496	0	Hemipelagite?
Olchowiec Kolonia									
OK 1	green	+	2.0	7.67	0.26	0.15	436	7	Hemipelagite?
OK 2	grey	+	30.0	56.58	0.17	s			Turbidite
OK 3	black	+	40.0	19.19	2.39	0	0	1	Turbidite?
Przylęków									
P 2	dark-grey	+	5.0	9.58	1.15	tr	100	16	Turbidite
P 3	green	–	1.5	2.33	0.25	tr	276	0	Hemipelagite
P 5	black	–	10.0	0.33	2.74	tr	78	0	Turbidite?
Polany									
Pl 1	green	+ to –	5.0	21.75	0.15	tr	1113	61	Turbidite–hemipelagite
Pl 2	green	–	4.0	4.58	0.17	0.12	1963	0	Hemipelagite
Pl 3	black	+	20.0	25.50	1.58	s	0	54	Turbidite
Pl 4	dark-grey	+	330.0	36.83	0.24	s	0	4	Turbidite
Trzebinia									
T 8	brown	–	14.0	1.33	0.29	tr	366	0	Turbidite?
T 9	brown	–	1.0	3.58	0.30	tr	206	0	Hemipelagite?
T 10	khaki	–	1.0	0.33	0.16	0.7	646	0	Hemipelagite?
Węglówka									
W* 3	khaki	+	>10.0	28.33	0.34	s	32	2	Turbidite
W* 5	khaki	+	12.0	10.92	0.32	tr	0	0	Turbidite
W* 6	brown	–	2.5	8.33	0.36	tr	8	0	Turbidite
W* 7	khaki	–	2.5	0.33	0.37	tr	4400	0	Hemipelagite
W* 8	brown	+	15.0	10.75	0.25	tr	4	6	Turbidite
W* 9	brown	+		10.83	0.25	0	602	6	Turbidite–hemipelagite
W* 10	dark-green	–	4.0	0.17	0.30	tr	7240	0	Hemipelagite
W* 11	khaki	+	28.0	6.16	0.50	0	0	0	Turbidite
W* 12	green	–	1.5	1.08	0.36	s	2822	0	Hemipelagite
W* 13	khaki	+	85.0	31.16	0.32	nd	nd	nd	Turbidite
W* 14	green	+	1.0	9.00	0.13	nd	nd	nd	Hemipelagite
W* 15	beige	+	14.0	12.5	0.36	s	2	0	Turbidite
W* 16	green	–	3.5	0.58	0.17	0	1492	0	Hemipelagite
W* 17	beige	+	16.0	12.80	0.36	s	4	0	Turbidite
W* 18	green	+	1.0	11.66	0.44	nd	nd	nd	Hemipelagite
W* 19	dark-brown	+	14.3	7.42	5.40	nd	nd	nd	Turbidite
W* 20	greyish-green	+	170.0	32.17	0.14	nd	nd	nd	Turbidite
W* 21	khaki	+	1.2	12.83	0.28	nd	nd	nd	Turbidite
W* 22	dark-green	–	2.2	2.50	0.69	nd	nd	nd	Hemipelagite
W* 23	dark-brown	+	22.0	22.25	1.59	nd	nd	nd	Turbidite
W* 24	khaki	+	~90.0	25.08	0.11	nd	nd	nd	Turbidite
W* 25	green	–	7.0	1.00	0.20	nd	nd	nd	Hemipelagite
W* 26	khaki	+	45.5	13.50	0.38	nd	nd	nd	Turbidite
W* 27	dark-brown	+	21.0	38.92	1.02	nd	nd	nd	Turbidite
W* 28	dark-brown	+	45.0	9.17	4.09	s	0	0	Turbidite?
W* 29	green	–	2.5	0.25	0.60	tr	4502	8	Hemipelagite
W* 30	khaki	+	7.0	6.17	0.35	tr	0	0	Turbidite

tr – <0.1%, s – deveral grains; nd – not determined; "+" – distinctive effervescence; "(+)" – faint effervescence; "–" – lack of efferrvescence, "+ to –" – effervescence in some parts of rock; Foram. – foraminifera

Appendix 2

Major and trace element data for selected samples of the Szymbark Shale and the lower part of the Magura Beds in Folusz (see Fig. 26 and Tab. 2 for stratigraphic location of the samples)

Sample No.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	Total %	Ba ppm	Sr ppm	Y ppm	Zr ppm
Fl 4	44.68	10.94	9.34	0.934	3.01	9.51	0.50	2.15	0.630	0.10	81.794	277	288	31	169
Fl 5	56.16	17.53	6.52	0.063	3.41	1.21	0.66	3.44	0.779	0.09	89.862	462	119	24	134
Fl 16	54.52	14.38	6.28	0.135	3.56	5.43	1.09	2.51	0.758	0.12	88.783	297	150	26	154
Fl 17	50.54	21.39	6.19	0.056	2.30	1.66	0.42	2.73	0.997	0.06	86.343	433	130	23	162
Fl 19	55.58	18.63	6.79	0.049	3.47	0.83	0.74	3.42	0.864	0.11	90.483	366	107	28	214
Fl 26	57.88	17.53	6.18	0.069	3.01	1.16	0.91	2.99	0.888	0.10	90.717	388	106	27	192
Fl 34	43.08	18.85	5.10	0.008	1.25	0.19	0.13	1.98	0.884	0.04	71.512	359	64	22	118
Fl 36	51.23	17.12	6.26	0.063	2.69	1.98	0.16	3.60	0.783	0.08	83.966	295	144	37	128
Fl 40	49.26	17.21	6.28	0.072	3.39	5.64	0.46	3.65	0.798	0.16	86.920	331	161	32	141
Fl 41	40.70	16.94	5.49	0.024	1.38	5.75	0.15	2.20	0.796	0.04	73.470	319	276	24	130
Fl 42	50.16	18.66	7.17	0.118	3.52	3.58	0.64	4.04	0.921	0.12	88.929	411	129	25	156

Sample No.	V ppm	As ppm	Co ppm	Cr ppm	Mo ppm	Rb ppm	Th ppm	U ppm	Ag ppm	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	S %
Fl 4	109	15	21	135	>5	117	9.4	3.4	>0.3	0.3	41	99	7	75	0.483
Fl 5	160	12	20	186	>5	174	14.1	2.8	0.5	>0.3	64	121	>0.3	112	0.424
Fl 16	119	8	24	244	>5	120	10.9	2.5	>0.3	>0.3	38	172	>0.3	92	0.135
Fl 17	133	47	27	172	>5	143	15.8	3.9	0.4	>0.3	50	143	31	95	0.782
Fl 19	151	7	21	243	>5	173	16.1	3.3	>0.3	>0.3	44	153	21	106	0.062
Fl 26	151	9	23	259	>5	157	14.3	3.7	>0.3	>0.3	52	130	>0.3	113	0.905
Fl 34	124	17	6	135	>5	129	12.0	4.4	0.7	>0.3	28	27	30	51	0.647
Fl 36	199	10	16	156	>5	159	13.4	3.0	>0.3	>0.3	45	91	>0.3	122	0.704
Fl 40	160	11	22	255	>5	166	13.2	3.0	>0.3	>0.3	48	128	12	121	0.588
Fl 41	114	20	17	124	>5	143	13.0	4.2	0.4	>0.3	60	145	14	90	2.511
Fl 42	171	13	23	291	>5	200	14.1	3.7	>0.3	>0.3	53	129	>0.3	102	1.381

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Streszczenie

WARUNKI SEDYMENTACJI W STREFIE SIAR BASENU MAGURSKIEGO (KARPATY) W PÓŹNYM EOCENIE–WCZESNYM OLIGOCENIE

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Wprowadzenie

Praca poświęcona jest analizie utworów eocenu górnego–oligocenu dolnego (priabonu–rupelu) przeprowadzonej w 6 przekrojach przez strefę Siar płaszczowiny magurskiej (Fig. 1, 3–5) dla rozpoznania warunków ich sedymentacji. Utwory te stanowią główną, górną część sukcesji fliszowej strefy Siar (Fig. 2). Różnią się one facjalnie od ich odpowiedników stratygraficznych nie tylko z pozostałych płaszczowin ale również z pozostałej części płaszczowiny magurskiej, wskazując na specyficzne warunki w tej części karpackiego morza fliszowego na przełomie eocenu i oligocenu.

Według dotychczasowego rozpoznania (Sikora & Żytko, 1960; Jednorowska, 1966; Blaicher & Sikora 1963; Sikora, 1970; Oszczypko-Clowes, 1999, 2000, 2001; Malata, 1981, 2001), utwory priabonu–rupelu na całym obszarze strefy Siar, z wyjątkiem najbardziej zewnętrznej części jej wschodniego odcinka, mieszczą się zasadniczo w obrębie warstw magurskich facji galukonitowej (WM) w ujęciu Książkiewicza (1974). Jest to sukcesja o miąższości sięgającej 2000 m (Bromowicz, 1992), zbudowana z cienko- do bardzo gruboławicowych piaskowców wzbogaconych w glaukonit, przekładanych różnej miąższości warstwami zazwyczaj wapnistych utworów drobnoziarnistych (łupków *sensu lato*). W obrębie WM Książkiewicz (1974) umieścił trzy jednostki, wy- dzielone wcześniej jako jednostki niezależne. Dwie z nich to jednostki o przewadze łupków, jedna – przedzielająca jednostki łupkowe – to sukcesja o przewadze piaskowców. Jednostka niższa o przewadze łupków została wydzielona wcześniej (Książkiewicz, 1935) jako warstwy podmagurskie, później zaś nazwana została łupkami zembrzyckimi (Książkiewicz, 1974). Jednostka wyższa o przewadze łupków została wydzielona wcześniej (Książkiewicz, 1966) jako warstwy nadmagurskie, później zaś nazwana została łupkami budzowskimi (Książkiewicz, 1974). Dla kompleksu o przewadze piaskowców Książkiewicz (1974) pozostawił stosowaną już wcześniej nazwę piaskowiec magurski (Paul, 1868). We wschodniej części strefy Siar utwory wyodrębnione przez Książkiewicza (1974) jako WM, pod taką właśnie nazwą wydzielane były już wcześniej (Swidziński, 1934; Sikora, 1967; 1970; Koszarski & Tokarski, 1967; Ślączka, 1967; Fig. 7). W obrębie warstw magurskich wyróżniano tam kompleksy o przewadze łupków lub piaskowców, a ponadto kompleksy różniące się miąższościami ławic piaskowców. Kompleks warstw magurskich we wschodniej części strefy Siar, zdominowany piaskowcami średnio i gruboławicowymi, Koszarski i Koszarski (1985) nazwali piaskowcami wątkowskimi. Natomiast sukcesję łupkową, występującą powyżej kompleksu piaskowcowego WM tego obszaru, Bromowicz (1992) nazwał łupkami małastowskimi.

W rejonie Szymbark–Folusz, dolna część sukcesji priabonu–rupelu, obejmująca w Foluszu cały priabon, reprezentowana jest przez ok. 30 m miąższości pakiet łupkowy, zdominowany łupkami zielonymi wapnistymi i niewapnistymi. Kopciowski (1996) nazwał ten pakiet łupkami z Szymbarku zaś Oszczypko-Clowes (1999, 2000, 2001) włączyła go do warstw zembrzyckich.

Utwory priabonu–rupelu strefy Siar zalegają bądź to bezpośrednio na łupkach pstrych formacji z Łabowej, bądź też podścielone są niewielkiej miąższości kompleksami łupkowo-piaskowcowymi lub w przewadze piaskowcowymi (Książkiewicz, 1974; Sikora, 1970; Bogacz *et al.*, 1979). W rejonie Żywca utwory priabonu podścielone są bezpośrednio dolną częścią WM (Sikora & Żytko, 1960; Malata, 1981; Van Couvering *et al.*, 1981)

W zachodniej części strefy Siar zasadniczą część sukcesji stanowią utwory priabonu, zaś w części wschodniej – utwory rupelu (Sikora & Żytko, 1960; Książkiewicz, 1974; Malata, 1981, 2001; Oszczypko-Clowes, 1999, 2000, 2001). Na całym obszarze utwory priabonu–rupelu wykazują kierunki paleotransportu przeważnie z NE. W zachodniej części strefy Siar utwory WM zazębiają się z utworami formacji magurskiej (eocen dolny–rupel ?dolny Oszczypko *et al.*, 1999; Oszczypko-Clowes, 1999, 2000, 2001) i częściowo je przykrywają.

Charakterystyka profili

W badanych przekrojach utwory priabonu–rupelu mają miąższość w przedziale od 800 do około 1700 m (Fig. 6–8). Rozmieszczenie facji w profilach, szczególnie utworów drobnoziarnistych (głównie mułowców) względem gruboziarnistych (głównie piaskowców), zmienia się w dość dużym przedziale. Piaskowce nie tworzą jednego kartowalnego kompleksu, rozciągającego się w obrębie całej strefy, jak to sugerują dotychczasowe opracowania, w tym publikowane mapy geologiczne. W niektórych przekrojach zaznaczają się dwa kompleksy w innych zaś kartowalne kompleksy piaskowcowe nie występują w ogóle. W przekroju Stróża–Krzczonów, w dolnej części sukcesji zaliczanej dotychczas do warstw magurskich wykazano występowanie utworów o wykształceniu bliższym piaskowcom pasierbieckim i tak też kompleks ten nazywany jest w niniejszej pracy. Analiza nanoplanktonu wapiennego przeprowadzona przez M. Oszczypko-Clowes w ramach niniejszego projektu wykazała, że stropowa część warstw magurskich w przekroju Rajbrot–Kamionka może reprezentować poziom NP23, tj. rupel wyższy, natomiast w Polanach – NP24, tj. stropową część rupelu (Tab. 1).

Utwory priabonu–rupelu w badanych przekrojach cechują się zróżnicowaniem wapnistości, ocenianej po reakcji z HCl, w obrębie pojedynczych rytmów oraz pakietów (Fig. 9, 26, 27), przy czym, utwory drobnoziarniste burzące z HCl zawsze przeważają nad nieburzącymi. Najniższa wapnistość w obrębie utworów drobnoziarnistych zaznacza się w pakietach gdzie występują one w cienkich warstwach, przekładając się z podobnej miąższości piaskowcami. Wyraźnie podwyższona wapnistość utworów drobno- ziarnistych zaznacza się we wszystkich przekrojach w niższej części poziomu NP21 oraz w górnej części sukcesji (NP23-24) występującej w Beskidzie Niskim. W obrębie całej sukcesji, z róż- ną częstością występują struktury bioturbacyjne, głównie z grupy prostych (Książkiewicz, 1977; Fig. 17).

Wyodrębniono 17 facji o randze ławic (Fig. 10–25). Dominują utwory facji zespołów piaskowiec-łupek, szczególnie tych z bardzo grubym członem zazwyczaj wapnistego łupka masywnego. Jedynie w obrębie kompleksu zaliczonego do piaskowców pasierbieckich łupki są wyłącznie niewapniste. Piaskowce są w części masywne, w części zaś laminowane poziomo, przekątnie w małej skali i skorupowo. Człony o laminacji skorupowej mają miąższość do 1 m. Piaskowce zbudowane są głównie z kwarcu, ponadto, prawie zawsze zawierają glaukonit.

Kompleks łupków z Szymbarku zbudowany jest w przewadze z łupków mułowcowych jasnozielonych do ciemnozielonych, burzących i nieburzących z HCl. Łupki burzące z HCl mają największy udział w wyższej części kompleksu. Dla sukcesji WM charakterystyczne jest występowanie w stropie rytmów piaskowiec-łupek warstw łupków niewapnistych o miąższości kilku do kilkunastu milimetrów, sporadycznie lekko burzących z HCl, ciemnozielonych, rzadziej brunatnoczarnych. W obrębie całego profilu rozmieszczone są z różną częstością utwory chaotyczne.

Łupki masywne w wyższej części warstw zawierają tylko pojedyncze ziarna frakcji piaskowej (Appendix 1). W odróżnieniu od nich, łupki ze stropu rytmów cechują się większym udziałem materiału frakcji piaskowej. Tworzą ją ziarna kwarcu detrytycznego, pojedynczo innych minerałów, w tym glaukonitu oraz otwornice, rzadziej inne mikroskamieniałości. Glaukonit występuje głównie w warstwach mułowców piaszczystych oraz mułowców o wyraźnie zarysowanym spągu. Wśród otwornic przeważają formy aglutynujące (Fig. 26, 27). Otwornice wapienne występują tylko w niektórych próbkach. Zazwyczaj są to wyłącznie otwornice bentoniczne (Tab. 2). Wzbogacenie w otwornice wapienne zaznacza się w warstwach zawierających glaukonit. Łupki burzące z HCl prawie zawsze zawierają nanoplankton wapienny w ilości od kilku do ok. 20 okazów na jedno pole widzenia przy standardowej ana- lizie w mikroskopie optycznym.

Analiza zawartości węglanów w 83 próbkach łupków wskazała na ich udział w przedziale 0–56,6%. Wykazano, że w badanej sukcesji tylko niewielka część łupków burzących z rozcieńczonym HCl jest marglami. Badania rentgenowskie wykazały, że węglany w obrębie łupków, z wyjątkiem konkrecji, są reprezentowane zasadniczo przez kalcyt, zaś inne węglany występują jedynie w ilościach śladowych.

Zawartość całego węgla organicznego (TOC) w łupkach zielonych, ciemnoszarych, khaki i burych mieści się w przedziale 0,1–0,7 %, zaś w brunatnych i czarnych zazwyczaj oscyluje w przedziale 0,9–3,0 %, z maksimum 5,4%. Analiza typów kerogenu w 20 próbkach łupków z TOC >0,5% wykazała przewagę kerogenu typu III (Fig. 28).

Analiza zawartości pierwiastków głównych i śladowych w 11 próbkach łupków z pakietu łupków z Szymbarku i dolnej części WM wykazała wzbogacenie w pierwiastki litofilne (Appendix 2). Wszystkie próbki cechuje podwyższona zawartość pierwiastków biofilnych takich jak Fe, Mn, Mg i Ba oraz bardzo niska zawartość P, Se i Mo. Uran wykazuje niewielkie udziały we wszystkich próbkach, aczkolwiek są one wyraźnie podwyższone w próbkach mułowców brunatnoczarnych. Stosunek wanadu do sumy wanadu i niklu uważany za wskaźnikowy dla stopnia natlenienia wód na dnie basenu, z wyjątkiem dwóch próbek mieści się w przedziale 0,4–0,6 (Fig. 29).

Wnioski

Badane utwory to zasadniczo osady różnych grawitacyjnych spływów masowych, głównie spływów zawiesinowych *sensu* Lowe (1982). Śladowy udział mają osady tła depozycyjnego. Należą do nich łupki mułowe (wyłącznie hemipelagity) występujące w stropie rytmów o ziarnie drobniejącym ku górze, o znacznie niższej zawartości $CaCO_3$ niż osady resedymentowane. Osadami resedymentowanymi są również łupki masywne, szczególnie charakterystyczne dla górnej części sukcesji we wschodniej części strefy Siar.

Powszechne występowanie resedymentów z bardzo grubym członem drobnoziarnistym wskazuje na sedymentację sukcesji w niewielkim basenie, ograniczonym wyraźnymi stokami (ang. confined basin). Obecny kształt strefy Siar i jej geologiczna lokalizacja wskazują, że był to basen typu rowu, wyodrębniony w brzeżnej części nadrzędnego basenu magurskiego. Basen strefy Siar ograniczony był stokami wybrzeży basenu magurskiego od północy natomiast od strony przeciwnej – stokami bardziej wewnętrznej części basenu magurskiego, reprezentowanej obecnie przez strefę Raćy. Zespół facji WM odpowiada zespołowi facji stożka podmorskiego. Ciągła pokrywa WM w obrębie całej strefy Siar wskazuje, że osadzały się one w formie rampy rozwijającej się stopniowo od SW wzdłuż podnóży basenu (Fig. 30).

Występowanie w obrębie całego profilu ubogiego zespołu struktur bioturbacyjnych, niskie zawartości uranu oraz niskie stosunki wanadu do niklu, występowanie wyłącznie kerogenu typu III oraz zespoły otwornic bentonicznych wskazują na sedymentację badanych utworów zasadniczo w środowisku oksycznym bliskim dyzoksji. Zespół otwornic wskazuje ponadto na położenie dna basenu w obrębie batiału, poniżej lizokliny otwornicowej.

Różnica wykształcenia badanych utworów w stosunku do ich ekwiwalentów stratygraficznych z innych części fliszu karpackiego została spowodowana intensywną resedymentacją w obrębie strefy Siar w priabonie i rupelu. Narastanie resedymentacji od SW, a w końcowym etapie zmniejszająca się dostawa materiału gruboklastycznego zostały spowodowane postępującym od SW zwijaniem się litosfery subdukowanej pod obszarem rodzących się Karpat (Fig. 30, 31). Proces ten napędzał subsydencję obszaru, wzmacnianą naporem rozwijającej się zarazem pryzmy akrecyjnej, a w końcu spowodował pogrążenie obszaru źródłowego warstw magurskich strefy Siar.