Annales Societatis Geologorum Poloniae (1997), vol. 67: 367–427.

ORIGIN OF THE SUB-MENILITE GLOBIGERINA MARL (EOCENE–OLIGOCENE TRANSITION) IN THE POLISH OUTER CARPATHIANS

Stanisław LESZCZYŃSKI

Institute of Geological Sciences, Jagiellonian University, ul. Oleandry 2a, 30-063 Kraków

Leszczyński, S., 1997. Origin of the Sub-Menilite Globigerina Marl (Eocene–Oligocene transition) in the Polish Outer Carpathians. *Ann. Soc. Geol. Polon.*, 67: 367–427.

Abstract: Sediment features, including foraminifera and nannoplankton content, $\delta^{18}O$, $\delta^{13}C$ and $\delta^{34}S$ signals, TOC and kerogen type, together with sequence patterns, were analysed to interpret the origin of the Sub-Menilite globigerina marl sequence (SMGMS) in the Polish Carpathians. Hemipelagites and fine-grained turbidites are shown to represent the dominant deposits of the SMGMS. The entire unit is interpreted to have originated primarily from increased calcareous nannoplankton and foraminifera production and consequently lowered calcite compensation depth (CCD) due to climate evolution within one long eccentrcity cycle (414 ky). Climatic changes forced by the obliquity (41 ky) and the short eccentricity cycles (ca. 100 ky) are suggested to be of the primary responsibility for the distinctive vertical fluctuation of the $CaCO_3$ content in the fine-grained deposits of the SMGMS. Lateral changes in the fluctuation patterns are interpreted as due to the highly contrasted morphology of the seafloor relative to the CCD. This factor, together with the regionally varying supply of terrigenous material, were responsible for the lateral sequence changes. The clastic supply was controlled by the orbitally forced climate changes and varied tectonic activity in the area. The SMGMS was not formed in areas typified by high terrigenous input.

Enhanced resedimentation of organic and siliciclastic material and oceanographic changes that lowered carbonate production, were the main factors responsible for the retreat of the SMGM facies and the onset of the Menilite beds.

Abstrakt: Praca prezentuje wyniki badań cech osadów, w tym analizy zróżnicowania zespołów otwornic i nanoplanktonu, sygnałów $\delta^{18}O$, $\delta^{13}C$ i $\delta^{34}S$, całkowitej zawartości węgla organicznego i typów kerogenu oraz analizy wzorów sekwencji podmenilitowych margli globigerynowych (SMGMS) w Karpatach Polskich. Wykazano, że SMGMS zbudowana jest w przewadze z hemipelagitów i turbidytów drobnoziarnistych. Cała sekwencja jest interpretowana jako efekt wzmożonej produkcji nanoplanktonu wapiennego i otwornic i w konsekwencji obniżonej głębokości kompensacji kalcytu. Procesy te były spowodowane zasadniczo zmianami klimatu w ramach jednego długiego cyklu ekscentryczności orbity Ziemi (414 tys. lat). Łączne wpływy różnych czynników zewnętrznych i wewnątrzbasenowych są wskazywane jako odpowiedzialne za cechy osadów i wzory SMGMS. Okresowe zmiany produkcji $CaCO_3$, kontrolowane przez sterowane orbitalnie zmiany klimatu w ramach krótkiego cyklu ekscentryczności (100 tys. lat) oraz cyklu skośności (41 tys. lat) są wskazywane jako główne czynniki odpowiedzialne za wyraźną pionową fluktuację zawartości $CaCO_3$ w osadach drobnoziarnistych. Lateralne różnice we wzorach fluktuacji są interpretowane jako efekt silnego zróżnicowania batymetrii basenów sedymentacji fliszu względem CCD oraz regionalnie zróżnicowanej dostawy materiału terygenicznego. Dostawa materiału terygenicznego była kontrolowana przez orbitalnie sterowane zmiany klimatu oraz zróżnicowaną aktywność tektoniczną obszaru.

Wzmożona resedymentacja materiału organicznego i silikoklastycznego oraz zmiany oceanograficzne, które spowodowały zmniejszenie produkcji węglanów, są wskazywane jako odpowiedzialne za ustąpienie facji podmenilitowych margli globigerynowych i rozwój sedymentacji warstw menilitowych.

Key words: marls, shales, deep sea deposits, cyclicity, productivity, orbital forcing, Eocene–Oligocene transition, Carpathians, Poland.

Manuscript received 20 June 1997, accepted 17 December 1997

INTRODUCTION

The Sub-Menilite globigerina marl sequence (SMGMS) represents one of the chief stratigraphic markers in the Carpathian flysch. The peculiarity of this sequence lies in the concentrated occurrence of cream-yellow and greenish to reddish marls rich in planktonic foraminifera. Moreover, the SMGMS is enclosed in a part of the flysch sequence showing striking changes in fine-grained deposits. These changes start with the disappearance of red shales (generally upper Middle Eocene) and terminate with the onset of dark-coloured deposits which become to prevail in the fine-grained facies (lowermost Oligocene). The SMGMS occurs immediately beneath a unit in which the fine-grained deposits are essentially dark-coloured, i.e. the Menilite beds. The above-mentioned changes across the Eocene–Oligocene boundary are characteristic over the entire Carpathians. They mark sedimentation in a gradually changing sedimentary environment.

Marls rich in globigerina are known to occur at the Eocene–Oligocene transition along the entire northern margin of the Alpine orogenic belt between the Western Alps and Caucasus (see Rögl & Steininger, 1983). Such extensive distribution suggests that at this time period sedimentation in the entire region was strongly forced by overregional factors. Global changes of climate and paleogeographic changes within and around the Tethys (e.g. Pomerol & Premoli-Silva, 1986; Prothero and Berggren, 1992; Prothero, 1995; Dercourt *et al.*, 1985), are implied to be of chief responsibility for the sedimentation development in the Carpathians (see Olszewska, 1983, 1984). However, the style in which these factors influenced sedimentation of the entire SMGMS is only generally known so far.

The SMGMS displays distinctive thickness and lithology variability. The variability has been described in general in the literature (e.g. Jasionowicz, 1961a; Bieda *et al.*, 1963; Gucwa & Ślączka, 1972; Rajchel, 1990). Nevertheless, its origin has not been investigated more critically until very recently (see Krhovský *et al.*, 1993; Leszczyński, 1996). In the older literature, the SMGMS was generally regarded as consisting of entirely pelagic deposits. Moreover, sedimentary conditions of the SMGMS were interpreted relative to those preceding and succeeding deposition of this unit (e.g. Gucwa & Ślączka, 1972). Paleogeographic transformations of the Carpathian area, global oceanic changes and volcanic activity in the Carpathians were suggested to represent the primary controls of sedimentation of the SMGMS-characteristic marl (see Książkiewicz, 1960; Gucwa & Wieser, 1980; Olszewska, 1983, 1984; Danysh *et al.*, 1987). Van Couvering *et al.* (1981) and Olszewska (1983, 1984) recognised that the microfossil assemblages contained in the SMGMS are indicative of a cool sea. The sedimentation of this unit was ascribed to a period of global sea level and associated CCD drop (see Van Couvering *et al.*, 1981; Olszewska, 1983, 1984; Rajchel, 1990).

The first detailed analysis of the entire SMGMS, referred to as the Sheshory marl unit, was accomplished by Krhovský *et al.* (1993) in several closely spaced sections in the area of Uherčice (Czech Carpathians). Krhovský *et al.* (1993) focused on vertical lithologic variability of the sequence and interpreted it as resulting from both simultaneous long-term trend of climate and paleogeography changes in the Carpathian area and short-term climate fluctuations forced by Milankovitch orbital cyclicity. A similar interpretation was also proposed by the present author in a short note based on five SMGMS sections in the Silesian nappe of the Polish Carpathians (Leszczyński, 1993a). Further investigations suggested that the sedimentation of the SMGMS was possibly controlled by a long-term change in the sedimentary environment and mass resedimentation processes (Leszczyński, 1993b). The detailed analysis of the SMGMS at Znamirowice (Leszczyński, 1996) led to the conclusion on orbitally forced climate changes accompanied by intermittently changing tectonic activity of the area. These factors were inferred to have influenced the sedimentation both directly and through their derivatives, i.e. sea level changes and changes of terrigenous input. The entire section was interpreted as formed within one 414 ky eccentricity cycle.

This paper aims at analysing the nature of the SMGMS deposits in the entire Polish Outer Carpathians. Its main goal is (1) to document the SMGMS details, (2) to evaluate the SMGMS distribution, (3) evaluate the lithological variability of the uppermost Eocene–lowermost Oligocene in the Carpathians, and (4) to interpret the origin of rocks embraced in the SMGMS, particularly with respect to the chief factors responsible for sedimentation of the light-coloured marls and for the overall SMGMS patterns.

MATERIAL AND METHODS

Twenty-five sections from different areas of the Polish Outer Carpathians (Fig. 1) were examined in detail. Unfortunately, the SMGMS is usually hidden under a thick cover of Quaternary deposits. Moreover, this part of the flysch sequence is usually significantly deformed. In many sections, the SMGMS is tectonically reduced or occurs in lumps beneath overthrusts. Thus the accessibility of sections significantly influenced the investigation methods and the gathered data.

Rock type, colour, reaction with HCl, bed thickness, sedimentary structures and textures, and the nature of bed contacts were recorded for each mesoscopically distinguishable layer in the section. These features were used to determine facies, their vertical arrangement, and lateral sequence variability. The deposits were related to the facies of the Pickering *et al.* (1986) classification scheme (Tab. 1).

The gathered data supplemented with facts from the literature were used for preparation of lithostratigraphic schemes and facies maps.

Laboratory work followed the procedure employed earlier in the analysis of the Znamirowice section (see Leszczyński, 1996, also for description of the methods). The following parameters were examined in the laboratory:

- microfeatures of the deposits;
- foraminifera and their distribution;
- calcareous nannofossils and their distribution;
- amount and type of carbonates;
- amount and type of organic matter;
- major elements and their concentration;

Fig. 1. Tectonic sketch map of the Polish Carpathians showing the locations of examined sections. *1* – sections examined in detail within this project; *2* – sections illustrated according to the descriptions by Koszarski & Wieser, 1960. Krościenko-G. = Krościenko-Granica; Krościenko-S. = Krościenko-Strwiąż (section in river Strwiąż between Brzegi Dolne and Krościenko)

– signals of oxygen, carbon and sulphur stable isotopes.

Microfeatures, i.e. deposit texture and microstructures, and mineralogical composition were investigated in 40 thin sections, mainly of marl and sandstone, from different sections.

Foraminifera content was checked in 45 washed samples of the fine-grained deposits from the Bóbrka (11), Żubracze (4), Wisłok Wielki (7), and Gródek-Koszarka (23) SMGMS sections. At Bóbrka and Gródek-Koszarka, sampling was performed on the entire SMGMS sections, including the immediately subjacent and overlying rocks. The proportion of planktonic, benthonic calcareous and agglutinating species was estimated in each sample. In the samples from the Wisłok Wielki section, the amount of specimens of particular group was counted with the help of E. Malata. Foraminifera distribution in the rock mass and their size variability were examined in thin sections. Data concerning taxonomic composition of the foraminifera assemblages of the SMGMS was taken from the literature.

The content of calcareous nannofossils and their preservation were investigated briefly using scanning electron microscope (SEM) in 10 samples. The data concerning taxonomic composition of nannofossil assemblages was taken from the literature.

Carbonate content was determined from the amount of inorganic C, in 62 samples from the sections at Krościenko (30), Żubracze (14), Wisłok Wielki (7), Gródek-Koszarka (8), using Coulomat 702 at the Institute of Geological Sciences of the Jagiellonian University. The total inorganic carbon content as determined by Coulomat, was recalculated into $CaCO_3$. Consequently, the results show only the maximum possible content of this compound. Carbonate types of and their relative amounts in the soft and hard light-coloured marl were analysed by conventional X-ray diffraction technique (XRD). The analysis was executed at the Institute of Geological Sciences of the Jagiellonian University in 6 samples of a soft marl and four samples of its hard, concretionary variety.

The type and amount of organic matter (i.e. type of kerogen and total organic carbon content; TOC) were determined in 47 samples by the Rock-Eval pyrolysis. Bulk rock samples from the SMGMS and the adjacent rocks, from the section at Krościenko-Granica (22), Obarzym (3), Darów (5), Bóbrka (3), and Żubracze (14) were analysed. The analysis was executed at the Faculty of Geology, Geophysics and Environmental Protection of the Mining and Metallurgy Academy in Kraków. The determinations were made according to the method of Espitalié *et al.* (1977). The hydrogen and maximum temperature indices (HI and T_{max}) were plotted on a diagram of Delvaux *et al.* (1990). In fifty-nine samples, TOC content was determined additionally by Coulomat. Samples from the sections at Krościenko-Granica (30), Żubracze (14), Wisłok Wielki (7), Gródek-Koszarka (8) were analysed. The analysis was executed at the Institute of Geological Sciences of the Jagiellonian University.

X-ray fluorescence analysis (XRF) of ten samples from the SMGMS from Leluchów (5) and Siekierczyna (5) was applied to recognise ten major elements and their concentration in greenish and reddish marls and shales. The analysis was executed by the spectrometer Phillips PW-1450 at Activation Laboratories Ltd in Canada. The results were also used to interpret the chief mineral phases of these rocks.

The oxygen and carbon stable isotope analysis was made on bulk rock in 37 samples from the sections at Krościenko-Granica (17) Żubracze (14), and Wisłok Wielki (6). The analysis was executed at the Institute of Geochemistry, Mineralogy and Ore Formation of the Ukrainian Academy of Sciences in Kiev. Isotopes were measured with mass-spectrometer Mi 12-01 Sumy on CO_2 released by phosphoric acid digestion of carbonates contained in the bulk rock. Moreover, sulphur stable isotopes in sulphides were also determined in that laboratory, in 30 samples from the SMGMS at Znamirowice.

Table 1

Deep-water facies classification scheme of Pickering *et al.* (1986) adapted to lithified rocks

FACIES CLASS	FACIES GROUP	FACIES 1	2	3	4	5	6	7	8
A	A1	Disorganized conglomerates	Disorganized muddy conglomerates	Disorganized gravelly mudstones	Disorganized pebbly sandstones				
	A2	Stratified conglomerates	Inversely graded conglomerates	Normally graded conglomerates	Graded stratified conglomerates	Stratified pebbly sandstones	Inversely graded pebbly sandstones	Normally graded pebbly sandstones	Graded stratified pebbly sandstones
B	B1	Thick/medium-bedded disorgan. sandstones	Thin-bedded dis-organized sandstones						
	B2	Parallel-stratified sandstones:	Cross-stratified sandstones						
C	C1	Poorly sorted muddy sandstones	Mottled muddy sandstones						
	C2	Very thick/thick-bedded sandstone-dominated sandst.-mudst. couplets	Medium-bedded sandstone-mudstone (muddy shale) couplets	Thin-bedded sandstone-mudstone (muddy shale) couplets	Very thick-bedded mudstone dominated sandst.-mudst. couplets				
D	D1	Medium/thick-bedded structureless siltstones	Poorly sorted structureless to poorly graded muddy siltstones	Mottled siltstones & mudstones					
	D2	Graded stratified siltstones	Mudstones with len-ticular & irregular silty laminae	Mudstones with thin regular silty laminae					
E	E1	Structureless mudstones	Varicoloured mudstones (muddy shales)	Mottled mudstones					
	E2	Graded mudstones (muddy shales)	Laminated mudstones (muddy shales)						
F	F1	Rubblestones	Dropstones and isolated ejecta						
	F2	Coherent folded/ contorted strata	Dislocated, brecciated and balled strata						
G	G1	Biogenic oozes	Muddy pelagic oozes (arls)						
	G2	Hemipelagites							
	G3	Chemogenic sediments							

STRATIGRAPHY

PREVIOUS WORK

The Sub-Menilite globigerina marl was originally distinguished in the area of Krosno by Grzybowski (1897; see Fig. 1 for location). Grzybowski described this unit as a 8-metres thick package of light-coloured marly shales rich in globigerina that occurs below the Menilite beds, and grades downwards into a 10-metres thick package of grey shaly clays. Moreover, Grzybowski suggested a Late Eocene age for the "marly shales". Deposits of this type were further recorded also in other areas.

Nowak (1927) was first who concluded that the light-coloured marls representing the type facies of the SMGMS are characteristic of the uppermost part of the Eocene over the entire Outer Carpathians. Hiltermann (1943) distinguished the sequence embracing these deposits as the Globigerina beds. Bieda (1946) called these deposits "Globigerina marls". He also emphasised their significance for the stratigraphy of flysch of the Polish Carpathians (Bieda, 1951). On the basis of his foraminifera research, Bieda (1951) interpreted the Globigerina marls as representing upper part of the Middle Eocene and lower part of the Upper Eocene (Tab. 2). In many papers, the globigerina marls were mentioned exclusively as a rock type (e.g. Bieda, 1951; Jasionowicz, 1961a, b; Blaicher, 1961, 1967; Książkiewicz, 1962). The entire sequence embracing the SMGMS-characteristic marls was frequently mentioned as the Globigerina marl horizon. Jucha and Kotlarczyk (1961) questioned the stratigraphic significance of this unit. In subsequent papers, however, Kotlarczyk (1985, 1988b) admitted the widespread occurrence of the Globigerina marl horizon in the Carpathians.

The name "Sub-Menilite globigerina marls" was proposed by Koszarski and Wieser (1960) in order to distinguish these deposits from other globigerina-bearing marls. Koszarski and Żytko (1961) showed further that the stratigraphic location of the Sub-Menilite globigerina marls in the rock sequence of the Dukla, Silesian, Sub-Silesian and the Skole nappes is slightly different. Bieda *et al.* (1963) noted lateral differentiation in the thickness of the SMGMS.

The sequence embracing the marls became portrayed in many papers (e.g., Koszarski & Wieser, 1960; Szymakowska, 1962; Blaicher & Sikora, 1963; Gucwa & Ślączka, 1972). Green and dark-grey shale, brown marl and different sandstone types were shown to alternate with the SMGMS-characteristic light-coloured marls. In some sections, the Sub-Menilite globigerina marls were not registered (e.g. Koszarski & Wieser, 1960; Jasionowicz, 1961b). Green shales were there recorded to pass into the Menilite beds.

In the Magura nappe, the rock sequence embracing the SMGMS chronostratigraphically equivalent marls was recently distinguished as the Leluchów Marl Member within the Malcov Formation (Birkenmajer & Oszczypko, 1989). In the Skole nappe, the SMGMS was distinguished as the Strwiąż Globigerina Marl Member within the Hieroglyphic Formation (Rajchel, 1990), and as the Globigerina Marl Formation by Malata (1996).

Since the interpretation by Blaicher (1961), the SMGMS has been considered as representing the uppermost Eocene (Tab. 2). However, there is some controversy in assigning the upper boundary of this unit. According to the earlier proposals by Blaicher (1961, 1963, 1964), the uppermost Eocene is spaned by the entire package. Similar interpretations were further proposed also by Van Couvering *et al.* (1981) for the SMGMS at Znamirowice and Krosno and by Malata (in Oszczypko *et al.*, 1990) and Oszczypko (1996) for the SMGMS lithostratigraphic equivalent, the Leluchów Marl Member. According to the subsequent papers by Blaicher (1967, 1970), Olszewska & Smagowicz (1977) and Olszewska (1983, 1984, 1985), the top part of the SMGMS belongs to the lowest Oligocene.

The SMGMS was correlated with the P 17 and partly P 16 (Van Couvering *et al.*, 1981) or P 18 (Olszewska, 1985) foraminifera zones and with the NP 20 and lower part of NP 21 (Van Couvering *et al.*, 1981) or with the NP 19/20 (Oszczypko, 1996) calcareous nannoplankton zones. However, the relationship of the standard foraminifera and calcareous nannoplankton zonations to the foraminifera and nannoplankton distribution in flysch of the Polish Carpathians is not precisely known. The accuracy in the stratigraphic assignement of the SMGMS is constrained by imperfect biostratigraphic zonation and problems arising with correlating different zonations (e.g. Bolli *et al.*, 1985; Berggren & Miller, 1988; Berggren *et al.*, 1995; see Tab. 3). In light of the available biostratigraphic data, coupled with the recently proposed Cenozoic time scale (Berggren *et al.*, 1995), the SMGMS appears to span at least the upper part of the P 16 to lower part of P 18 foraminifera zones and the upper part of the Zone NP 19/20 ?to lower part of NP 21 (Tab. 2).

DEFINITION OF THE SMGMS IN THIS PAPER

The SMGMS is here considered as a package of rocks dominated by cream-yellow, beige, yellowish-green, greenish-grey and/or reddish marl that occurs above the sequence in which fine-grained deposits are predominantly green (i.e. the Green shale unit or its chronostratigraphic equivalents), and beneath the sequence in which fine-grained deposits are predominantly dark-coloured (i.e. the Sub-Chert beds, representing lower part of the Menilite beds or Menilite Formation, cf. Świdziński, 1948).

SMGMS AND THE PRIABONIAN–LOWER RUPELIAN ROCKS IN THE POLISH CARPATHIANS

Inner Carpathians

The Priabonian–lower Rupelian rocks occur in the lower part of the Podhale Palaeogene (see Roniewicz, 1979). The SMGMS chronostratigraphic equivalent seems to be represented by calcareous shales and marls that occur locally between the Nummulitic limestone and the mudstones and sandstones of the Zakopane or Szaflary beds (see Radomski, 1958; Roniewicz, 1979), and, in some areas, by the uppermost part or the entire(?) unit of the Nummulitic limestone (see Blaicher, 1973; Sokołowski, 1985; Cieszkowski, 1996 – personal inform.; Kępińska, 1997).

Table 2

Stratigraphy of the SMGMS in the Polish Outer Carpathians fitted to the time scale by Berggren *et al.* (1995)

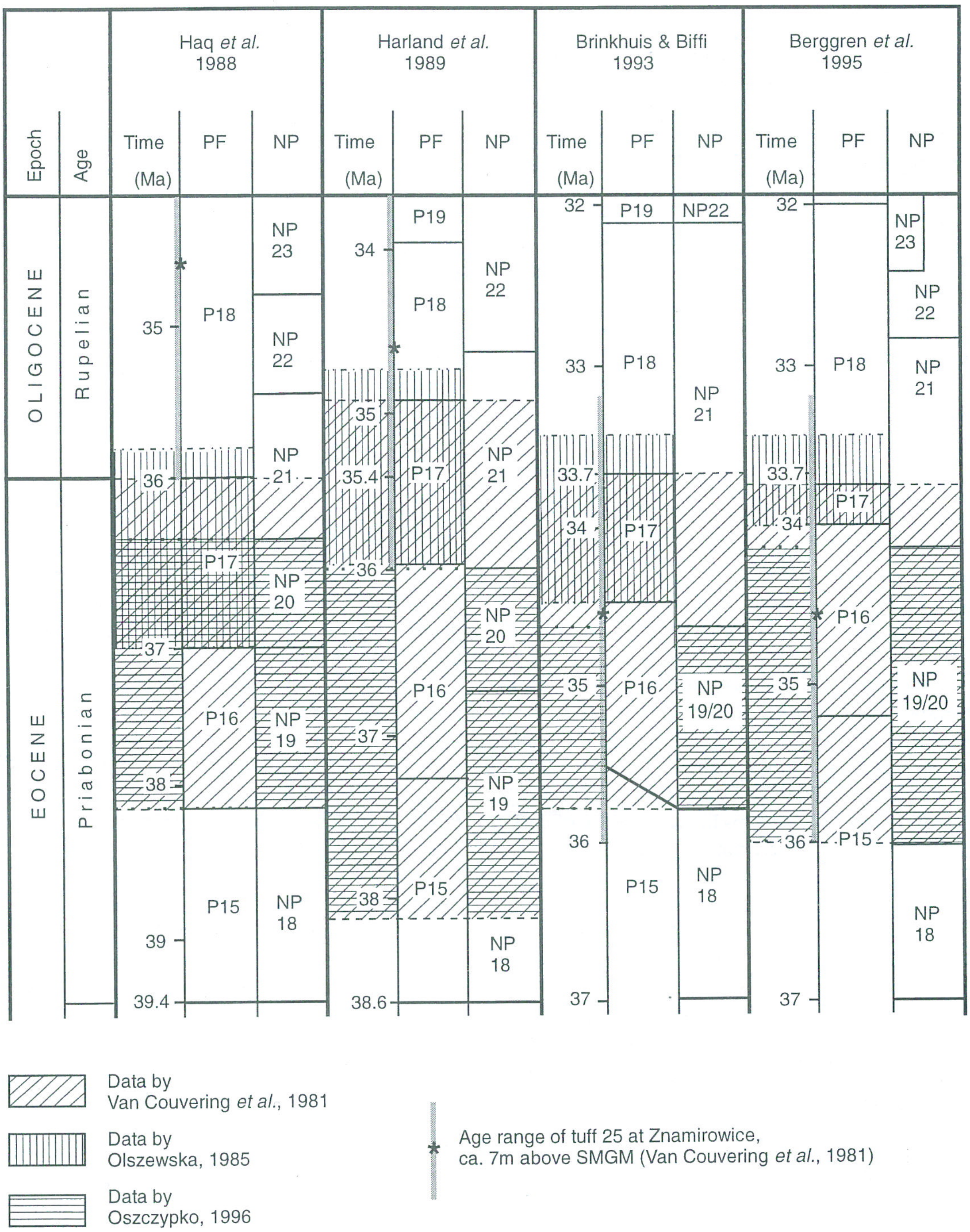
Time (Ma)	Series	Stage	Biozones NP	Biozones PF
32	OLIGOCENE	Rupelian	NP 22	19
33			NP 21	P18
34	EOCENE	Priabonian		P17
35			NP 19/20	P16
36			NP 18	P15
37				

Bieda (1951) (+)	Blaicher (1961) (+)	Bieda *et al.*, (1963) (+)	Blaicher (1967) (+)	Blaicher (1970) (+)	Van Couvering *et al.*, (1981) (+, *)	Olszewska (1985) (+)	Oszczypko (1996) (*)	this paper (evaluation of the hitherto published data)
GM (Globigerina Marl = Sub-Menilite Globigerina Marl = SMGM; upper part of Middle Eocene to lower part of Upper Eocene)	Sub-Chert Beds (SCB)	SCB	SCB	SCB	Menilitic Clay (lower part = SCB)	SCB	Smereczek Shale Member (lower part = SCB)	SCB
	SMGMS (Upper Eocene)	SMGMS (upper part of Upper Eocene; below the zone of Eocene - Oligocene transition)	SMGMS (uppermost Upper Eocene)	SMGMS (upper part of Upper Eocene to lower part of Lower Oligocene)	SMGMS (upper part of P16 & P17; NP 20 to lower part of NP 21)	SMGMS (P17 to lower part of P18)	Leluchów Marl Member (= GM; NP 19/20)	SMGMS (upper part NP 19-20 ?to lower part NP 21; upper part P16 to lower part P 18)
	Olive-Green Shale (OGS)	OGS	OGS	OGS	OGS	OGS	Green Shale	OGS

NP – calcareous nannofossil zones; PF – planktonic foraminifera zones; Time scale acc. Berggren *et al.*, 1995; + – stratigraphy based on foraminifera; * – stratigraphy based on calcareous nannofossils; heavy lines denote limits precisely indicated by the author; dashed lines denote limits imprecisely defined.

Table 3

SMGMS stratigraphic interpretations in terms of different time scales



Magura nappe

The Priabonian sequence in the Magura nappe is dominated by thick-bedded sandstones (Poprad Sandstone Member of Birkenmajer & Oszczypko, 1989) in the southern and central part of the nappe, corresponding to the Krynica, Sącz and Gorlice subunits (see Oszczypko, 1992a, b, c; Fig. 2). In the northern zone, i.e. in the Siary subunit (Węcławik, 1969), fine-grained deposits predominate in the Priabonian (Bieda *et al.*, 1963; Oszczypko, 1992a, c). These are greenish- and bluish-grey, green, (?red), grey and dark-grey calcareous and noncalcareous shales and marls of the Sub-Magura beds and the upper part of the Variegated shale unit (see Blaicher & Sikora, 1963; Książkiewicz, 1966, 1974; Sikora, 1970; Cieszkowski, 1992a).

Calcareous fine-grained deposits are concentrated in the top part of the Priabonian sequence, except for the Nowy Targ area. These are represented by dark-grey to greenish-grey shales and greenish-grey to yellowish-green, cream-yellow and reddish globigerina-bearing marls. This part of the sequence corresponds chronostratigraphically and in part lithostratigraphically to the SMGMS (see Blaicher & Sikora, 1963, 1967; Sikora, 1970; Oszczypko, 1973). In the Siary unit, such sequence is enclosed in the Sub-Magura beds (see Blaicher & Sikora, 1963; Sikora, 1970; Jednorowska, 1966). In the remaining part of the nappe, it is represented by the Leluchów Marl Member (Birkenmajer & Oszczypko, 1989) known from Leluchów (Świdziński, 1961; Blaicher & Sikora, 1967) in the Krynica unit and from the Nowy Sącz area in the Gorlice unit (Oszczypko, 1973). In the Nowy Targ area (Krynica unit), the upper part of Priabonian is equivocal. The normal to sandy flysch deposits of the Malcow Formation (Lower Oligocene) occcur there immediately above the Poprad Sandstone Memebr (Cieszkowski, 1985b).

The Leluchów Marl Member at Leluchów (investigated also by the present author; Fig. 3) comprises mainly pinkish-red and and greenish-grey marl (Fig. 3A-C). Khaki-coloured and dark-brown marl, green and dark-grey calcareous to noncalcareous shale and several very thin sandstone layers occur intercalating the green marl in the upper part of the sequence. The red marl is intensely bioturbated. *Planolites*, *Chondrites* and *Thalassinoides* are there the most common burrows. The sequence is underlain by green calcareous shale (see Oszczypko, 1996) and is overlain by dark-coloured shale with intercalations of cherts, tuffites and sandstones (Smereczek Shale Member included to the Lower Oligocene Malcov Formation – Birkenmajer & Oszczypko, 1989).

In the Nowy Sącz area, a several metres thick package of cream-yellow, light-grey to dark-grey and olive-green marls with bluish calcareous shale and glauconitic sandstone intercalations was included to the Leluchów Marl Member (see Oszczypko, 1973; Oszczypko *et al.*, 1990). The unit is underlain by a 10 metres thick sequence of dark-grey shale with sandstone intercalations, whereas the normal to sandy flysch of the Malcov Formation occurs above (see Oszczypko, 1973; Oszczypko *et al.*, 1990).

In the Siary unit, the upper Priabonian deposits are overlain by the sandy to normal flysch of the Magura glauconitic sandstone unit and/or the shaly flysch of the Supra-Magura beds, both representing the Rupelian (see Oszczypko, 1992a, b, c). Green and dark-grey calcareous to noncalcareous shales mainly represent the fine-grained deposits in these units (see Książkiewicz, 1966; Bromowicz, 1992; Cieszkowski, 1992a).

Sub-Magura units (SMU)

The tectono-facies units located between the Magura nappe and the Silesian nappe, i.e. the Dukla nappe, Fore-Magura thrust-folds, Grybów unit, Obidowa-Słopnice unit, Jasło nappe and the Michalczowa unit, are here considered jointly as the Sub-Magura units (SMU). The Priabonian sequence in the SMU, except for the Jasło nappe and the Fore-Magura thrust folds, is represented in its lower part by primarily green and grey shales alternating with grey to greenish-grey siliceous to calcareous thin-bedded fine-grained sandstones (Hieroglyphic beds; Tab. 4, Fig. 2; Ślączka, 1970; Cieszkowski, 1992a). In the northern Fore-Magura thrust-fold, locally in the southern fold, and in the Jasło nappe, variegated shales or marls (red and green) are recorded in the Upper Eocene (see Koszarski, 1985; Paul *et al.*, 1992; Tab. 4).

A several metres- to several tens of metres-thick package dominated by dark-green noncalcareous shales (Olive-Green shale unit or simply the Green shale; Koszarski & Żytko, 1961) occurs usually above the Variegated shale, Variegated marl or the Hieroglyphic beds. Dark-coloured shales become more common in the upper part of the unit. Locally, e.g. between Darów and Komańcza in the Dukla nappe, the Green shale unit is not individualised. The Hieroglyphic beds pass there upwards immediately into the SMGMS.

The Green shale is usually overlain by a several metres to several tens of metres thick sequence in which greenish-grey, beige-grey, and grey globigerina-bearing marls occur concentrated (Tab. 4; Figs. 4, 5). This unit is generally regarded as the SMGMS (see Ślączka, 1959; Koszarski *et al.*, 1961). It was investigated by the author in detail in one section, in the Ropa window and in four sections in the Dukla unit (Fig. 1).

The marl within the SMGMS occurs in thin to thick beds (Figs. 6–7). Thin to medium-thick layers of grey to dark-grey calcareous to noncalcareous mudstones, green calcareous to noncalcareous muddy to clayey shales, as well as thin to thick sandstone beds alternate the marls in different proportion. Single sandstone beds, with the maximum thickness up to 2 metres, are also present. Moreover, single thick beds of chaotic deposits and thin layers of syderitic marl occur there as well. The chaotic deposits were recorded most frequently in the upper part of the SMGMS at the Darów section (Figs. 5; 8A). The package dominated by the globigerina-bearing marl is there ca. 30 metres thick. In contrast, the SMGMS lacking chaotic and coarse-grained deposits is only several metres thick (Figs. 4, 5). Mottling is characteristic of the greenish-grey marl and shale. Concentrated *Chondrites intricatus*, *Ch. targionii* and *Planolites* div. isp. burrows occur in some layers. Moreover, burrows in a form of knobs and slightly curved hyporeliefs, up to 2 cm long and 1–2 mm in cross-section, occur on the soles of thin sandstone and siltstone beds.

The coarse-grained deposits of the SMGMS are dominated by fine- to medium-grained, glauconite-bearing calcareous sandstones. The psammitic and psefitic fraction in these deposits frequently includes a variety of biogenic elements similar to those in the Hieroglyphic beds.

In some sections, e.g. in the Obidowa-Słopnice unit, marls characteristic of the SMGMS are lacking (see Cieszkowski, 1985a, 1992a; Burtan *et al.*, 1992; Tab. 4). Fine-grained deposits are here represented chiefly by greenish-grey to yellowish-green calcareous mudstones and/or dark-grey muddy shales. An intermediate-type sequence occurs in the section at Ropa (Fig. 9). Fine-grained calcareous deposits include here mainly greenish-grey, yellowish-grey and grey, poorly calcareous marls (maximum $CaCO_3$ content ca. 40%, see Gucwa, 1973), mudstones and muddy shales.

In the southern Fore-Magura thrust fold, the unit embracing detrital limestones or conglomerates to sandstones rich in bioclasts of shallow-marine origin (Łużna of Uhlig, 1886; Koniaków limestone of Szajnocha, 1925; Burtan &

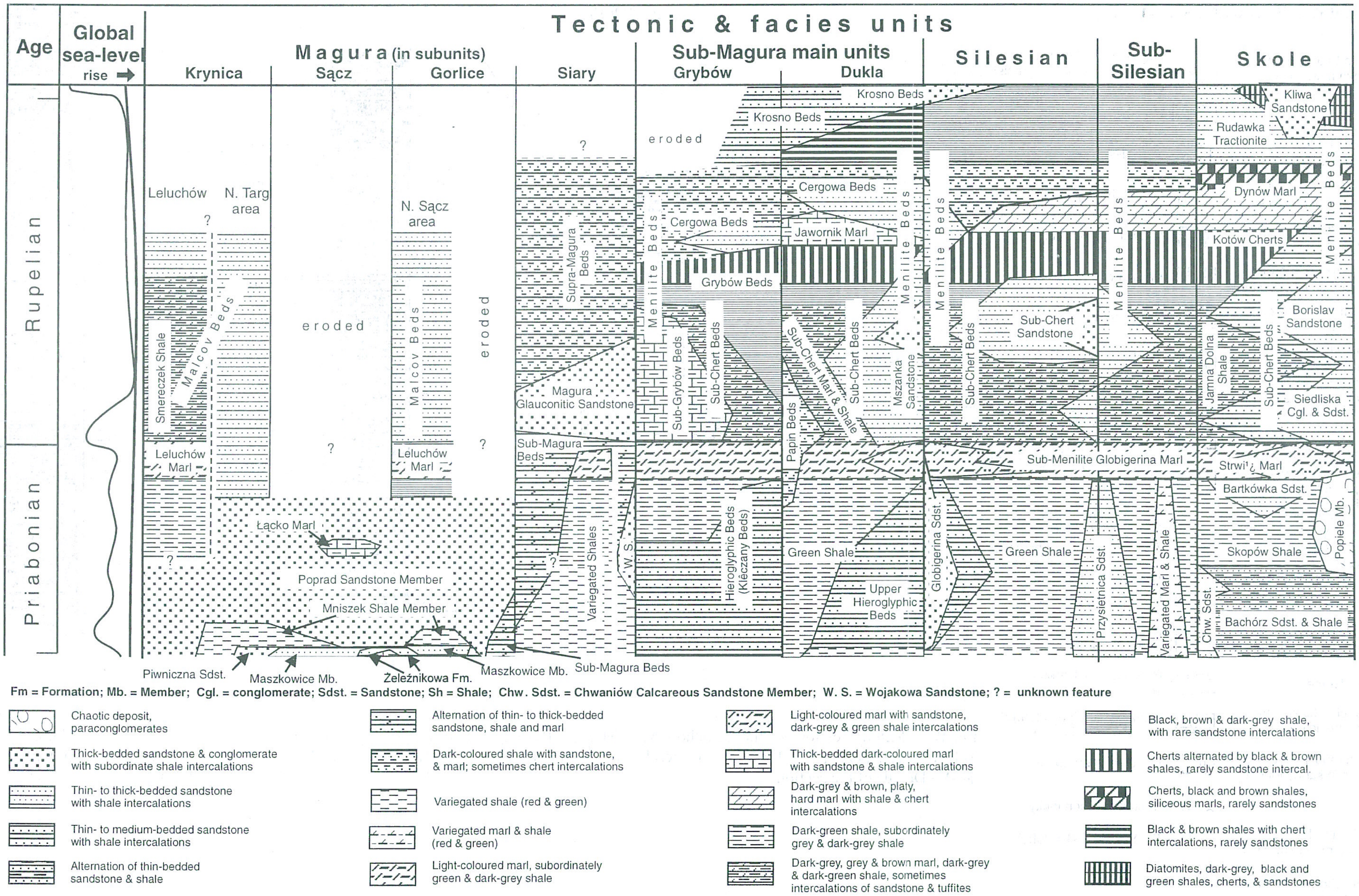
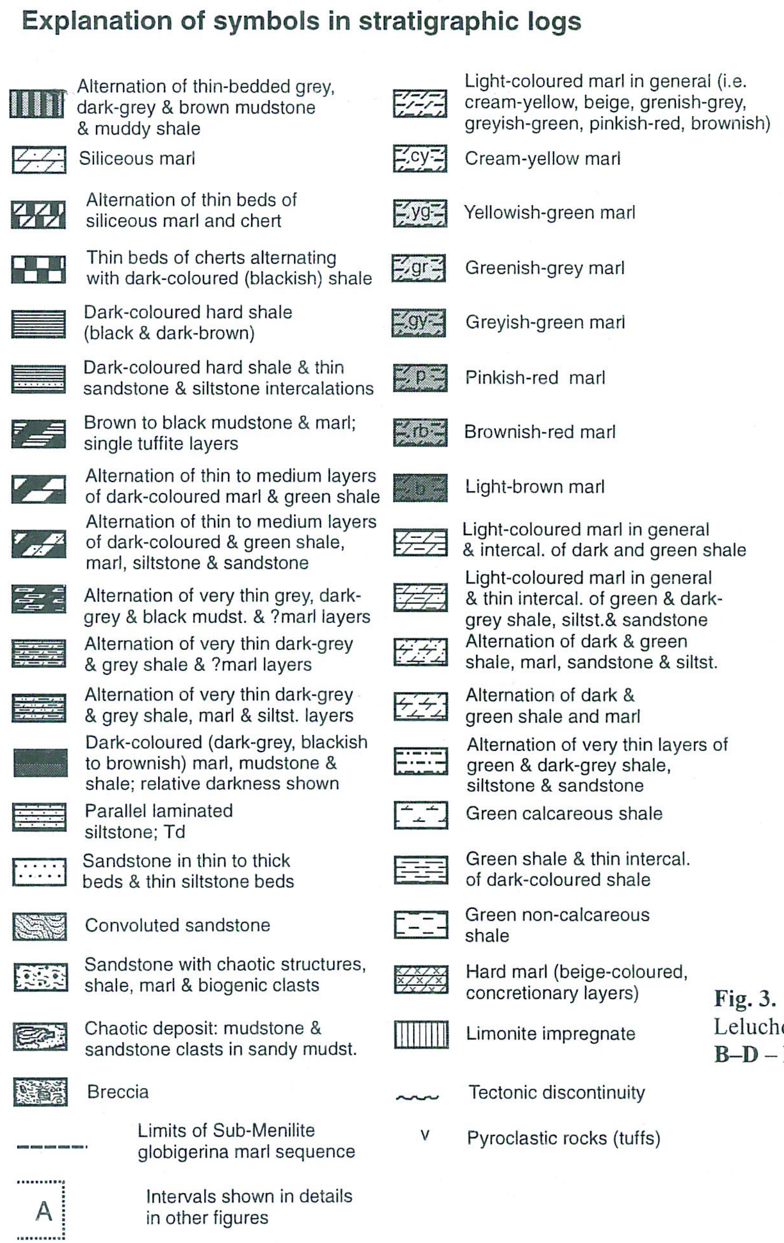


Fig. 2. Generalized stratigraphy of Priabonian–Rupelian deposits in the Polish Outer Carpathians. Unit names given in simplified form



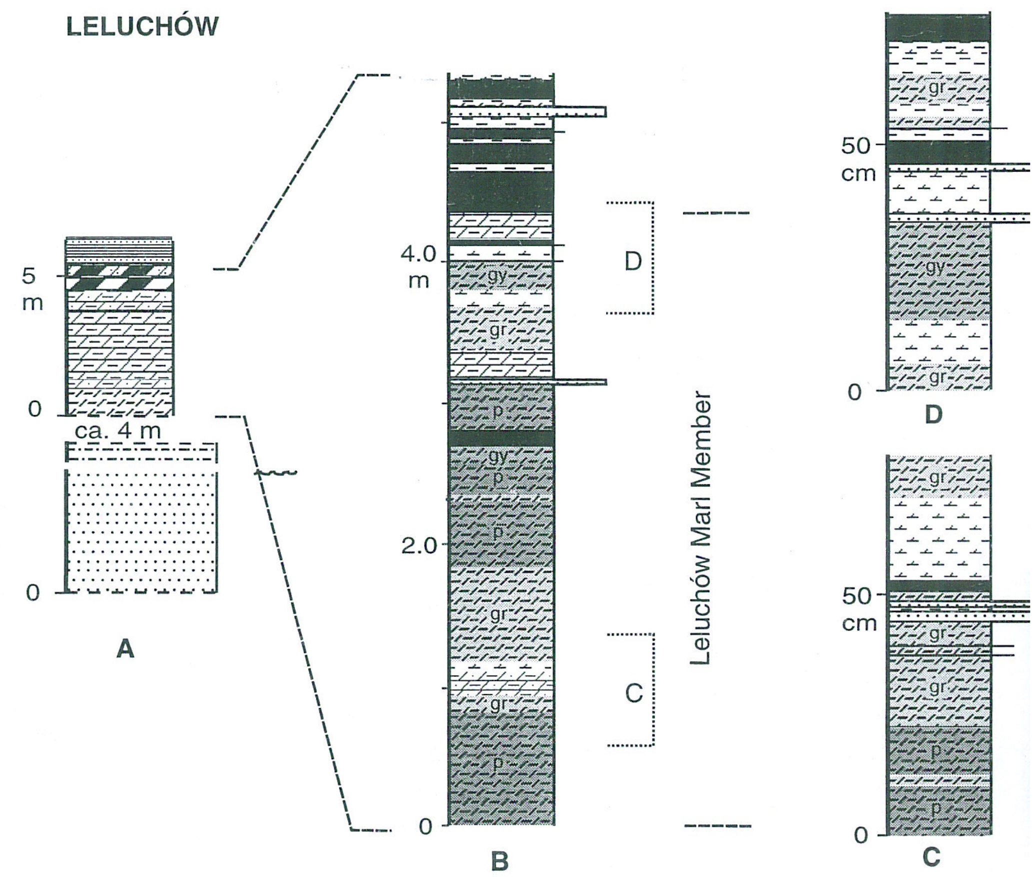


Fig. 3. Lithofacies logs of tne Leluchów Marl Member (SMGMS-lithostratigraphic equivalent) in road-cutting above the church at Leluchów (cf. Oszczypko, 1996). **A** – Generalized log of the Leluchów Marl Member (LMM) and adjoining parts of surrounding units. **B–D** – Details of the section

Upper Eocene–Lower Oligocene stratigraphy of the Sub-Magura Group of tectono-facies units

Series	Stage	S Fore-Magura Thrust Fold (Grybów Unit) acc. Paul *et al.* 1996	N Fore-Magura Thrust Fold (Dukla Unit) acc. Paul *et al.* 1996	Obidowa-Słopnice Unit acc. Cieszkowski, 1985a; Burtan *et al.*, 1992	Grybów Unit (Mszana D. window) acc. Burtan *et al.*, 1992	Dukla Nappe (Mszana D.window) acc. Burtan *et al.*, 1992	Michalczowa Unit acc. Cieszkowski, 1992a	Grybów Unit S (Męcina area) acc.Cieszkowski, 1992a	Grybów Unit N (Klęczany - Libranto-wa area) acc. Cieszkowski, 1992a	Jasło Nappe acc. Koszarski 1985	Dukla Nappe (Dukla - Komańcza area)	Dukla Nappe (Żubracze area)
OLIGOCENE	Rupelian	**Menilite Beds** (Grybów type) **Barutka Beds** (Sub-Grybów Beds) (d.-grey, hard marl, shale & syderites)	**Krosno Beds** (thin-bedded sandstones and shales) **Krosno Beds** (thick-bedded sandstones) **Menilite Beds** (black & brown shale & thin beds of sand stones)	**Cergowa Beds** (shales) **Rdzawka Beds** (thin- to thick-bedded sandstones, black shales & conglomerates)	**Cergowa Sandstone** **Menilite Beds** Grybów type (black shales with chert intercalations) **Grybów Beds** (dark-grey to black sh. & marls, intercal. of thin sandstones) **Koniaków Limest.** (i.e. Łużna Lmst.; detritic limestone)	**Cergowa Sandstone** **Menilite Beds** Grybów type (black shales with chert intercalations) ?	**Cergowa Beds** (sandstone/shale & shale complexes) **Grybów Shale** (d.-brown calcareous shales & marls, rare intercal. of thin sandstone beds, some chert layers) **Michalczowa Sdst.** (thick- to thin-bed. sandstones, rarely cgl.; Łużna Lmst. in several levels)	**Sub-Grybów Beds** (grey to brown marl, black shale, rare sdst. intercalations; beds of Łużna Lmst in the middle)	**Sub-Cergowa Marl** (d.brown & grey marl, intercal. of thin sdstones sporadically cherts) **Sub-Grybów Beds** (brown shale & d.-grey marl; cherts in some places; green shale in the bottom part)	Menilite type shales with marl blocks & silicified shale in the upper part **Duląbka Beds** (greenish to beige calc. shale altern. with thin to thick sdst. beds, & olistostrome type deposits)	**Jawornik Marl** (d.-brown & grey marl, intercal. of thin sdst; sporadically cherts) **Sub-Chert Beds** black & d.-grey shale; grey marl; some chert layers in the top) **Mszanka Sdst** (thick-bedded)	**Jawornik Marl** (d.-brown & grey marl & intercal. of thin sdstones) **Menilite Shales** black & d.-grey shale some chert intercal. in the top part) **Sub-Chert Marl** (alternation of very thin & thin light-grey to black layers of marl and shale
EOCENE	Priabonian	**Łużna Limestone** (i.e. Koniaków Lmst.; detritic limestones) **Hieroglyphic Beds** (thin-bedded normal flysch) **Variegated Shales** (red-brown and greenish-grey clayey shales)	**Sub-Menilite Globigerina Marl** (yellowish & greenish marl) **Variegated Marls**	**Hieroglyphic Beds** (thin-bedded, normal flysch)	**"Black Eocene"** (alternation of glauconitic sandstones and d.-grey shales) **Green Shales** & **Hieroglyphic Beds** (thin-bedded, normal flysch)	**"Black Eocene"** (alternation of glauconitic sandstones and d.-grey shales; conglomerate in bottom part) ? **Hieroglyphic Beds** (thin-bedded, normal flysch)	**Globigerina Marl** (greenish-grey calc.shale, cream-yellow & beige marl) **Green Shales** (green noncalc.shale intercalations of green calc. shale and brown shale) **Hieroglyphic Beds** (thin-bedded, normal flysch)	**Green Shales** (green, rarely black shale) **Hieroglyphic Beds** (thin-bedded, normal flysch)	**Globigerina Marl ?** **Green Shales** (green, greenish-grey rarely d.-grey & brown shale & thin beds of sandstones) **Hieroglyphic Beds** (thin-bedded, normal flysch)	**Globigerina Marl** dark-green & dark-brown shales **Variegated Shales** (red & green shales)	**Globigerina Marl** (beige, l.-grey & green.marl & intercal.olive-green & dark-grey shale) **Green Shales** (green, greenish-grey rarely dark-grey & brown shale & thin sdst. beds) **Hieroglyphic Beds** (chiefly thin- to medium-bedded flysch; green to d.-grey shales & fine-grained quartzose-galuconitic sandstones)	**Globigerina Marl** (beige, light-grey & greenish marl & intercalations of olive-green and dark-grey shale) **Green Shales** (green, greenish-grey rarely d.-grey & brown shale) **Hieroglyphic Beds** (thin-bedded normal & shaly flysch)

The ranges of lithostratigraphic units were in most cases determined at a stage level, thus the boundaries are approximate only; Data for Dukla unit mainly from Ślączka, 1970; Olszewska & Smagowicz, 1977; Olszewska, 1980 and author's personal investigations.

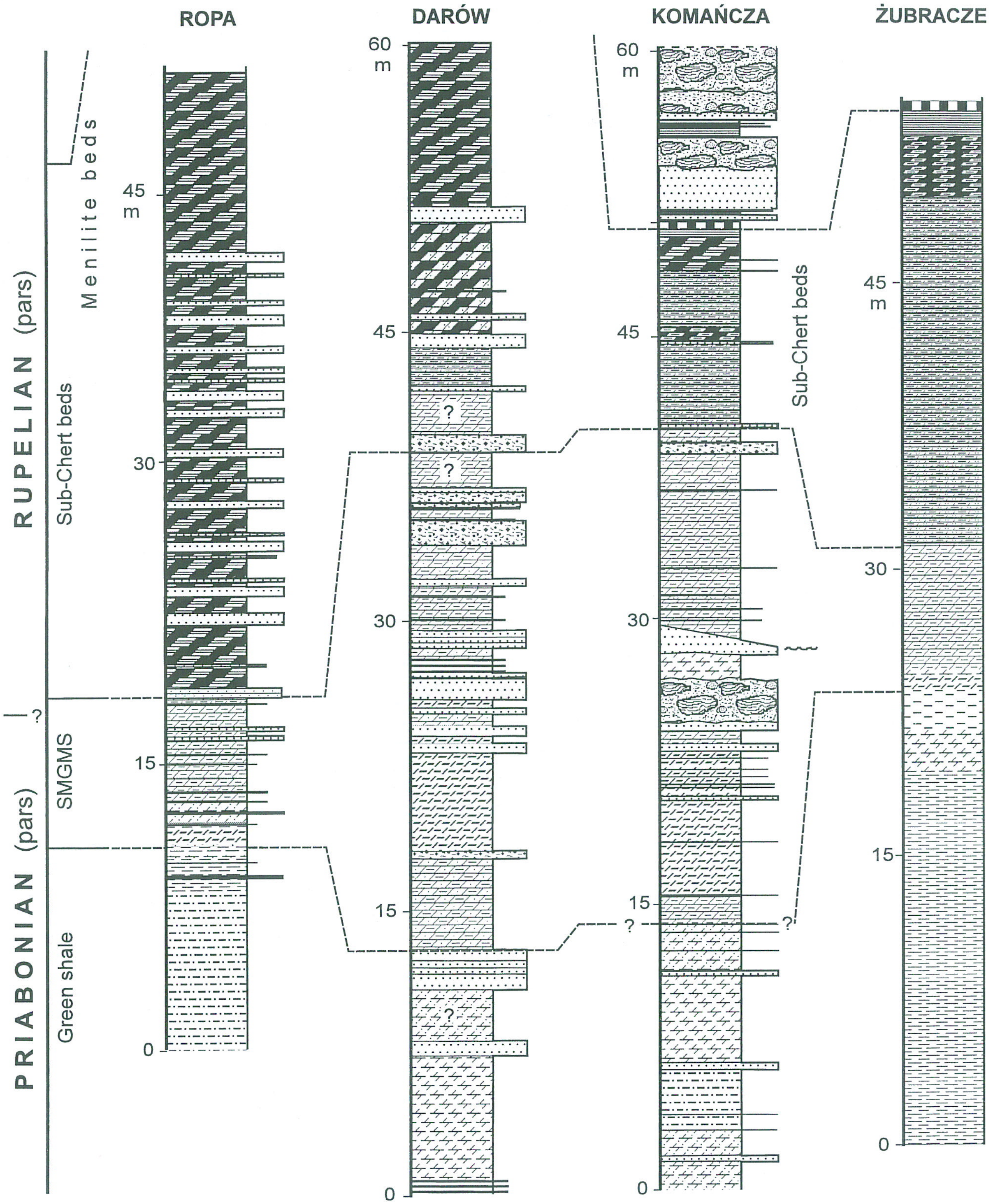


Fig. 4. Lithofacies logs of the Eocene–Oligocene transition in selected sections of the Sub-Magura tectono-facies units (SMU). The section at Ropa shows the Grybów unit in the Ropa window. The other sections are from the Dukla nappe. For explanation of symbols see Fig. 3

Sokołowski, 1956) is regarded as the chronostratigraphic equivalent of the SMGMS (Paul *et al.*, 1996). In the other units of the SMU, such rocks occur frequently in the lowermost Oligocene (e.g. Szymakowska, 1966; Burtan *et al.*, 1992; Cieszkowski, 1992a; Tab. 4).

In the southern marginal part of the Dukla nappe at the Polish–Slovakian boundary (S of Jaśliska), grey, brown and green shales and thin- to medium-bedded quartzose sand-

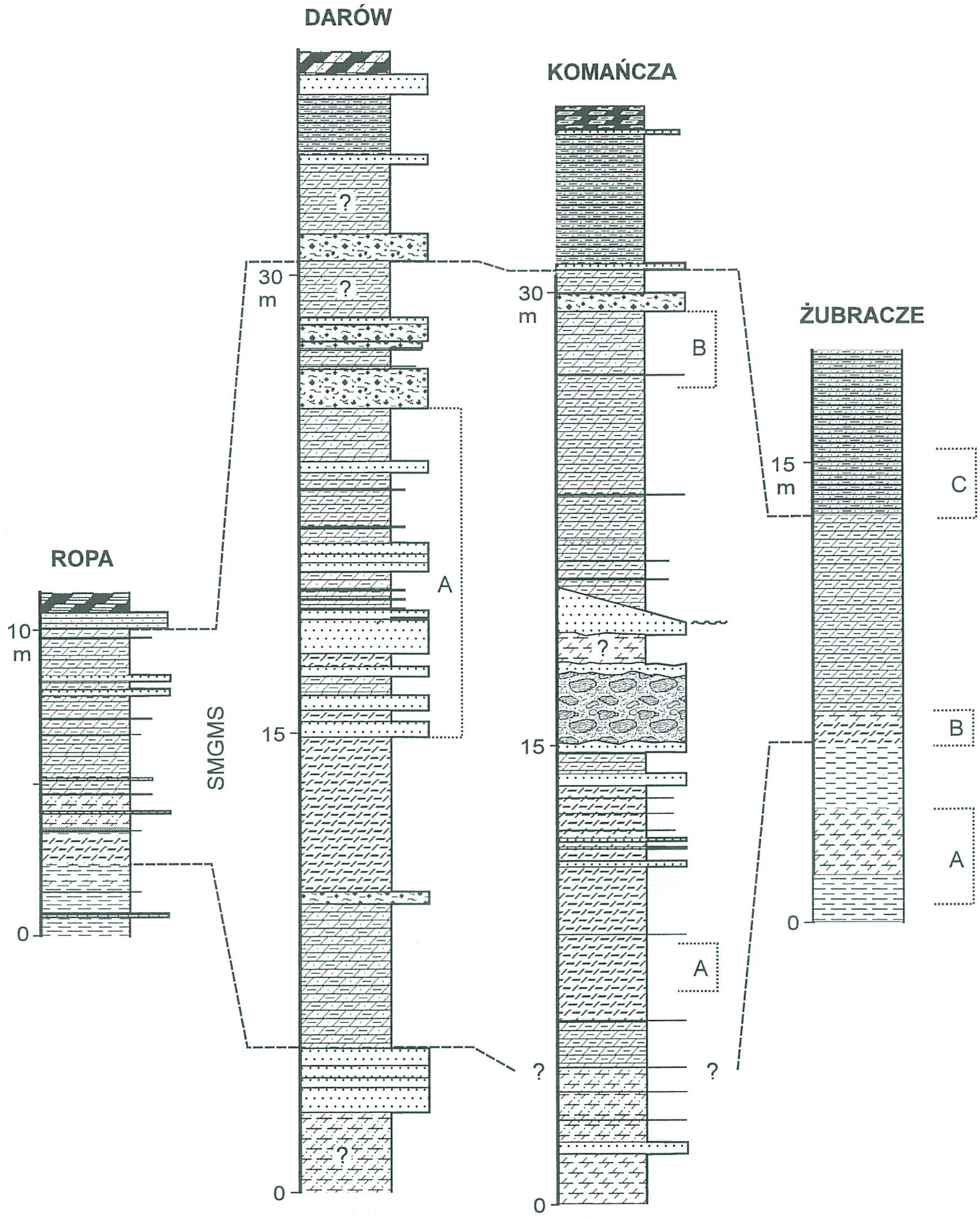


Fig. 5. Lithofacies logs of the SMGMS in selected sections of Sub-Magura tectono-facies units (cf. Fig. 4). For explanation of symbols see Fig. 3

stones represent equivalents of the SMGMS. According to Ślączka (1970), these deposits may represent a passage to the Papin beds, characteristic of this part of the Dukla nappe in Slovakia.

The SMGMS and its chronostratigraphic equivalents are overlain generally by deposits in which the fine-grained facies is predominantly dark-coloured (dark-grey and grey muddy calcareous shales, mudstones and marls, dark-brown marls, black muddy to clayey shales). These deposits represent the Sub-Chert beds that are Rupelian in age. The sequence shows a significant lateral differentiation. Several lithostratigraphic units have been recognised here (Tab. 4; see Świdziński, 1950; Kozikowski, 1953; Burtan & Sokołowski, 1956; Koszarski *et al.*, 1961; Sikora, 1970; Sikora & Szymakowska, 1977). Calcareous fine-grained deposits disappear generally near the top of the Sub-Chert beds.

In the Michalczowa unit and in the bulk of the Dukla nappe, an up to 250 m thick sequence embracing thick-bedded coarse-grained sandstones intercalated by greenish-grey and brown shales, and grey to dark-brown marls occurs

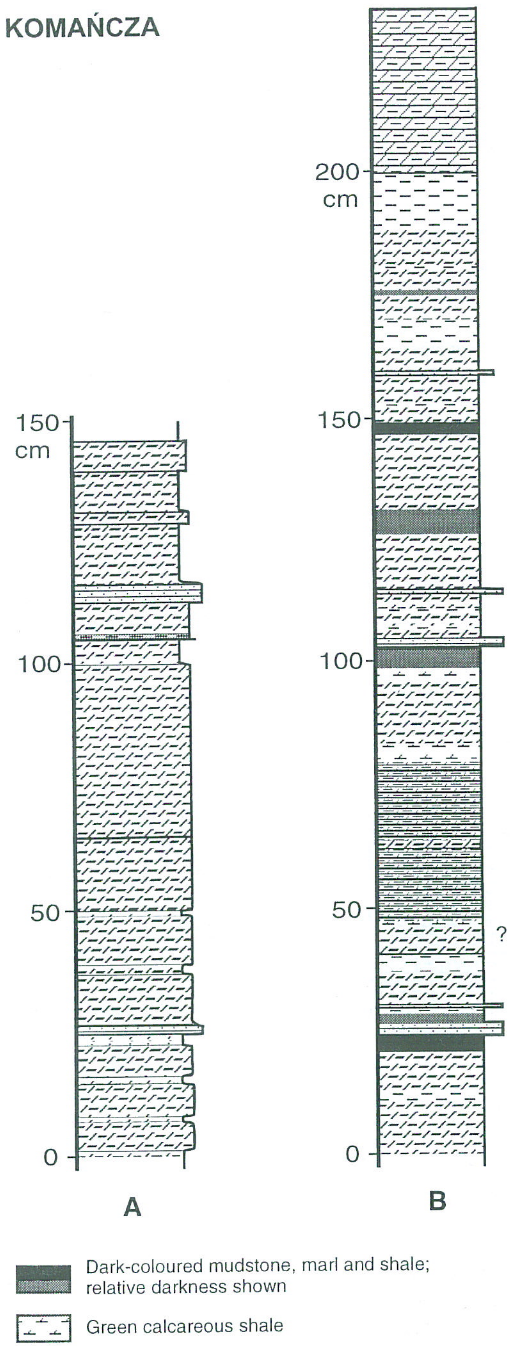


Fig. 6. Detailed lithofacies logs of the lower (**A**) and upper part (**B**) of the SMGMS at Komańcza. The section is located in the stream Dolżycki Potok, S of Komańcza (cf. Ślączka, 1973b, 1977). The exact location of the logs within the SMGMS are indicated in Fig. 5. For explanation of symbols see Fig. 3

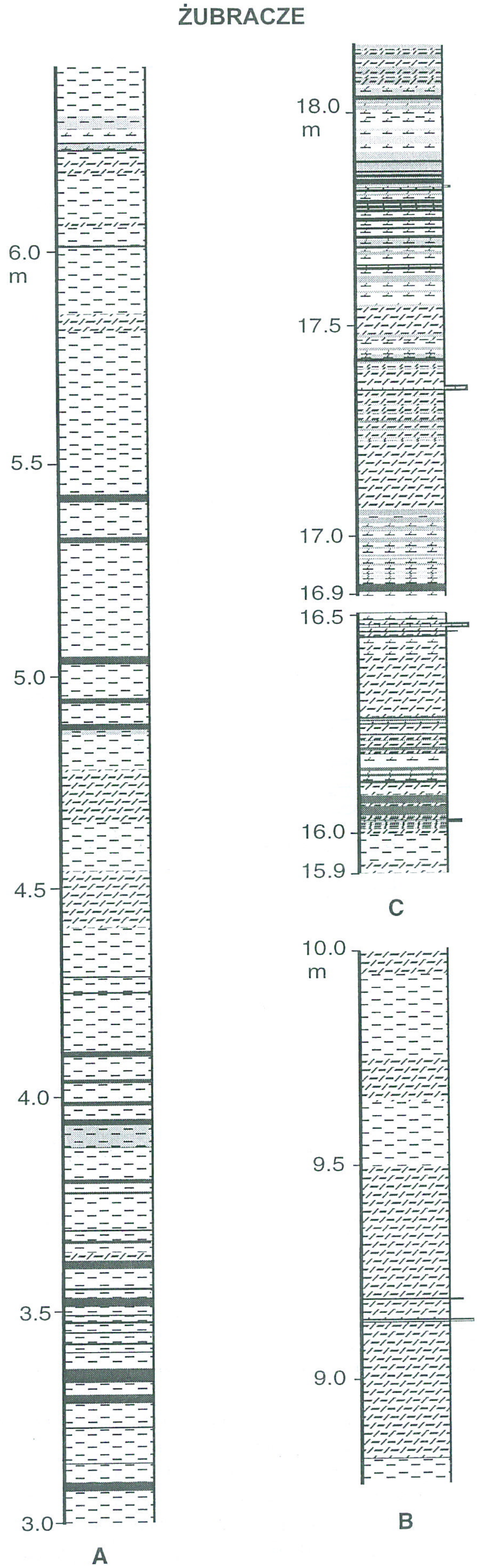


Fig. 7. Detailed lithofacies logs of the upper part of the Olive-green shale unit (**A**), bottom part of the SMGMS (**B**) and the bottom part of the Sub-Chert beds (**C**) in the Solinka river bed at Żubracze (cf. Ślączka, 1973d). The exact location of logs within the SMGMS are shown in Fig. 5. Facies symbols explained in Fig. 3. Shaded layers denote grey to black, usually calcareous mudstone (?marl) and shale

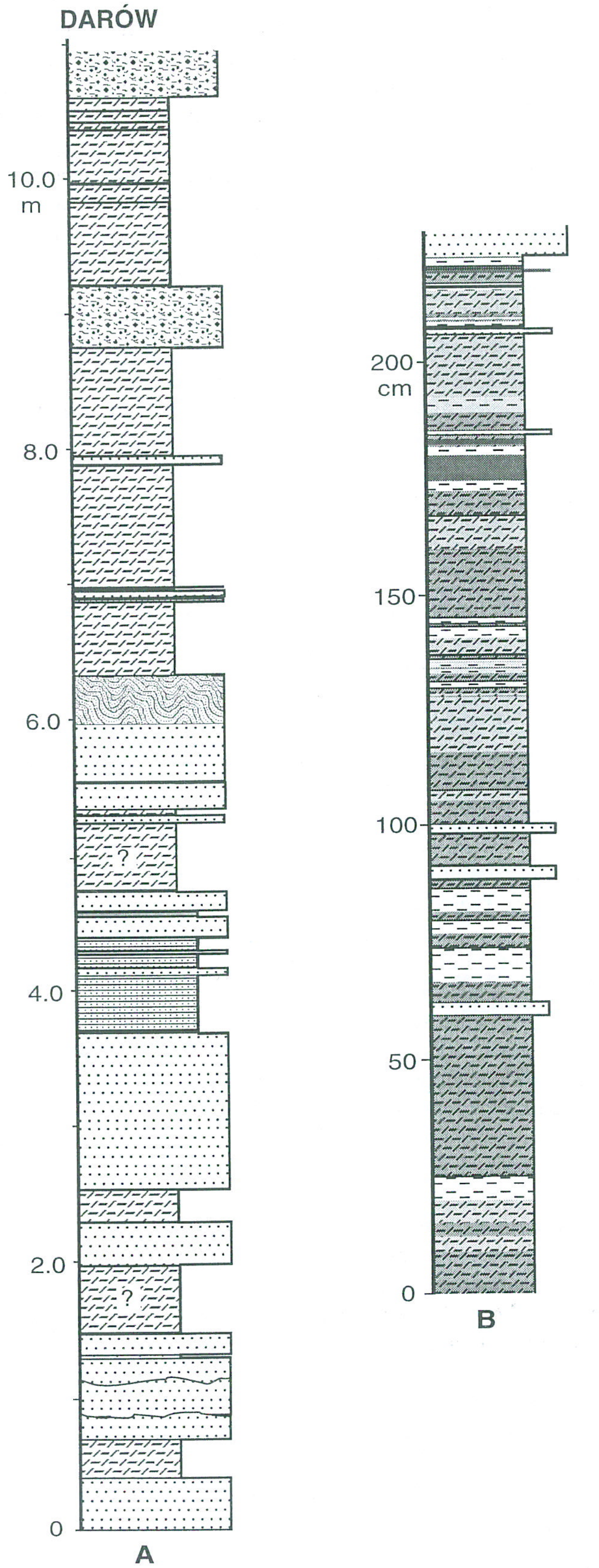


Fig. 8. Detailed lithofacies logs of the middle part of the SMGMS (**A**) and the lower part of the Sub-Chert beds, 7 m above the SMGMS (**B**) exposed in the river Wisłok near Darów, 4 km to the west of the village Wisłok Wielki. The exact location of A within the SMGMS is indicated in Fig. 5B. For explanation of symbols see Fig. 3

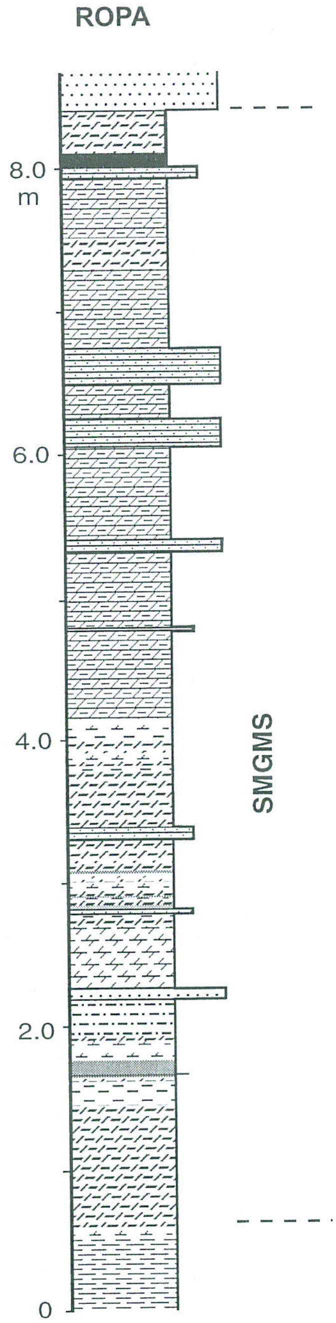


Fig. 9. Main features of the SMGMS in the Chełmski stream bed at Ropa (cf. Sikora, 1970). For explanation of symbols see Fig. 3

above the SMGMS (see Cieszkowski, 1992a; Ślączka, 1970). This sequence in the first mentioned unit was distinguished as the Michalczowa sandstone (Skoczylas-Ciszewska, 1960), whereas in the Dukla nape as the Mszanka sandstone (Warchołowska-Pazdrowa, 1929). The Mszanka sandstone is locally underlain immediately by the Green shale unit or by a package of predominantly dark-coloured marls and shales (Ślączka, 1970). Its contacts with the SMGMS or with older deposits are either erosional (Ślączka, 1970) or tectonic in origin. Several sandstone types were distinguished in both units, depending upon differences in texture, sedimentary structures, bed thickness, and petrographic composition (see Cieszkowski, 1992a; Ślączka, 1970). Biogenic particles occur frequently among the accessory constituents of these sandstones (Ślączka & Unrug, 1966; Cieszkowski, 1992a). In the Jasło nappe, the SMGMS is overlain by normal to shaly flysch containing olistostromes in some areas (Duląbka beds of Koszarski & Koszarski, 1985b).

In some sections, e.g., in the Żubracze area, a "zebra"-type facies occurs at the passage from the SMGMS to the Sub-Chert beds. This facies consists of alternating 0.5 to 5 cm thick layers of greenish-grey to grey marl and greenish-grey to black calcareous to noncalcareous mudstone and shale. Moreover, 30 to 50 cm-thick bundles of lighter layers alternate with darker ones (Fig. 7A, C).

Silesian nappe

The Priabonian–lower Rupelian rocks of the Silesian nappe are best known from the area between the Dunajec river and the meridian of Sanok (Fig. 1). To the west of Dunajec, their occurrences are scarce and poorly preserved (cf. Książkiewicz, 1962). To the east of Sanok, except for the southern and northern marginal parts of the nappe, the sequence is known from subsurface sections only.

The Priabonian, except for the south-eastern part of the nappe, appears to be comprised predominantly of dark-green clayey to muddy shales (Green shale unit of Bieda *et al.*, 1963; Koszarski, 1985). These shales are intercalated locally by very thin beds of greenish-grey and grey noncalcareous, hard-indurated sandstone and siltstone and thin to very thin layers of grey and dark-grey, noncalcareous muddy to clayey shales. Manganese concretions are frequent in these deposits (e.g. Koszarski & Koszarski, 1985a). The proportion of dark-coloured shales tends to increase up the sequence. In the western nappe segment, the Variegated shale appears to continue up into the Priabonian (see Książkiewicz, 1962).

In the south-eastern part of the Silesian nappe, south of Sanok, thin-to very thick-bedded sandstones occur concentrated in a several metres- to nearly 200 metres-thick sequence of the Upper Eocene (Priabonian). The sequence interfingers with or replaces the SMGMS (Fig. 10 – Rudawka Rymanowska; see Ślączka, 1968; 1973c). The sandstone unit is called the Globigerina sandstone (Czernikowski, 1950; cf. Tokarski, 1968; Wdowiarz *et al.*, 1991), or the Mszanka sandstone (see Ślączka, 1956, 1968; Bieda *et al.*, 1963; Blaicher, 1970). Thick-and very thick-bedded coarse-grained, quartzose sandstones are particularly common here (cf. Ślączka, 1968). Thin to medium-thick layers of clayey to muddy dark-grey, brownish and dark-green shales alternate with the sandstones. The intercalations of calcareous dark-grey shales occur in the upper part of the unit (cf. Wdowiarz *et al.*, 1991). Moreover, thin beds of syderite are frequent in the entire sequence.

The sandstone unit is overlain either by a several tens of centimetres-to several metres-thick package of dark-green shale, by the SMGMS, or by the Menilite beds (see Ślączka, 1956). However, up to 10 metres-thick SMGMS occurs usually above the Green shale unit and the Mszanka/Globigerina sandstone in the Silesian nappe.

The SMGMS and the adjacent deposits were examined in detail in 11 sections (Fig. 1). Cream-yellow, beige, yellowish-green and reddish marls are characteristic of the SMGMS in the entire Silesian nappe. The marls occur in thin to thick homogeneous beds intercalated by grey and dark-grey calcareous to noncalcareous muddy to clayey shales, dark-grey to brownish, usually calcareous mudstones, thin siltstone and usually thin sandstone beds. The amount of intercalations and their distribution vary in the sequence (Figs. 10, 11). The marls show either gradual passages both down- and upwards into green shale, or are sharply terminated at top by a siltstone, sandstone or dark-coloured mudstone. Fine-grained deposits frequently display bioturbation. *Chondrites targionii*, *Ch. intricatus* and *Planolites* div. isp. are the most common burrows.

The lower boundary of the SMGMS is gradual in undisturbed sections (Figs. 12, 13), whereas its top is sharp or indistinct. Thinning upward layers of a light-coloured marl are characteristic of the uppermost SMGMS. Moreover, the proportion of dark-grey and brown to black calcareous mudstones and marls increases generally up the sequence (Fig. 14).

Single, thick sandstone beds within the SMGMS were recorded only in the south-eastern part of the nappe, where the Globigerina/Mszanka sandstone occurs. The sandstones are commonly grey, calcareous, fine-to medium grained. Some variability is displayed in their composition, texture and sedimentary structures. All sandstone types known from the Globigerina sandstone unit have been recorded here. The calcareous material consists of carbonate mud and different bioclasts in the coarser fraction. Echinoderms, calcareous foraminifera, bryozoans, corallinae algae and molluscs are represented in the biogenic material. A primary lack of the SMGMS characteristic light-coloured marls is suggested in some areas (e.g. near Sanok; Koszarski and Wieser, 1960). Green shale is observed to pass there immediately into the Sub-Chert beds.

The deposits overlying the SMGMS, i.e. the Sub-Chert beds (lower Rupelian), comprise predominantly dark-coloured calcareous mudstones and muddy to clayey shales and diverse proportions of different sandstone types. Similarly as in the above described nappes, the "zebra"-type facies is very characteristic of the 1 to ca. 2 m-thick passage between the SMGMS and the Sub-Chert beds. The Sub-Chert beds dominated by fine-grained deposits (Sub-Chert Menilite shales of Koszarski & Żytko, 1959) are up to 20 m thick, whereas those containing sandstone lenses can be several times thicker.

Intercalations of several thin and very thin tuffite layers are characteristic of the sequence segment several metres above the SMGMS top (Koszarski and Wieser, 1960). Van Couvering *et al.* (1981) dated zircons from two layers situated ca. 2 m apart in the Znamirowice section as 34.6 and 28.9 Ma in age.

Sub-Silesian nappe

The Priabonian–lower Rupelian deposits are known chiefly from fragmentary sections in the western and eastern nappe segment (see Książkiewicz, 1962). Variegated marls and shales appear to embrace the entire Upper Eocene sequence (Priabonian; Fig. 2) in the western nappe segment (see Liszkowa, 1956; Nowak, 1959; Książkiewicz, 1962).

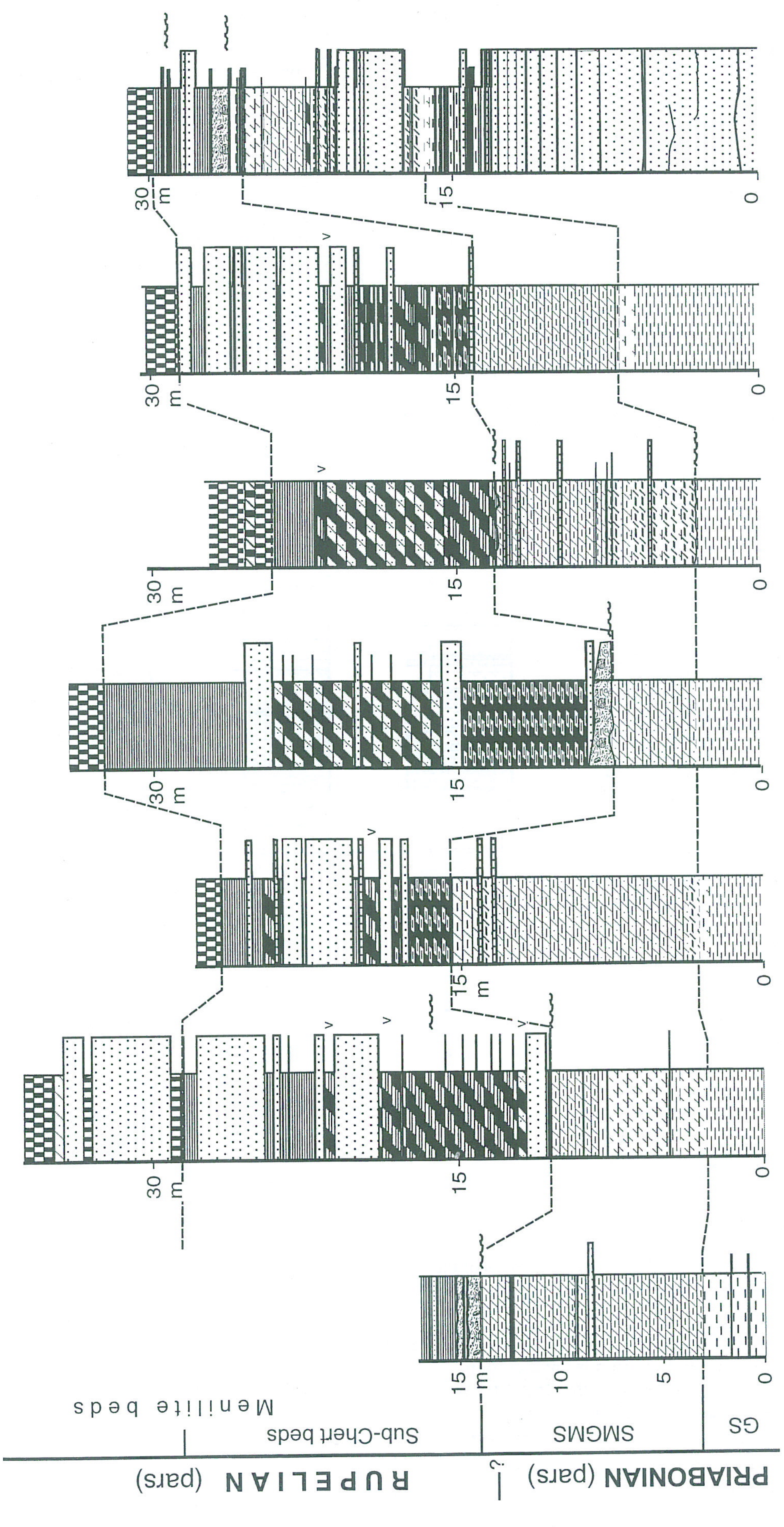


Fig. 10. Lithofacies logs of the Eocene–Oligocene transition in selected sections of the Silesian nappe. The sections are ordered generally from the north-west to south-east. For explanation of symbols see Fig. 3

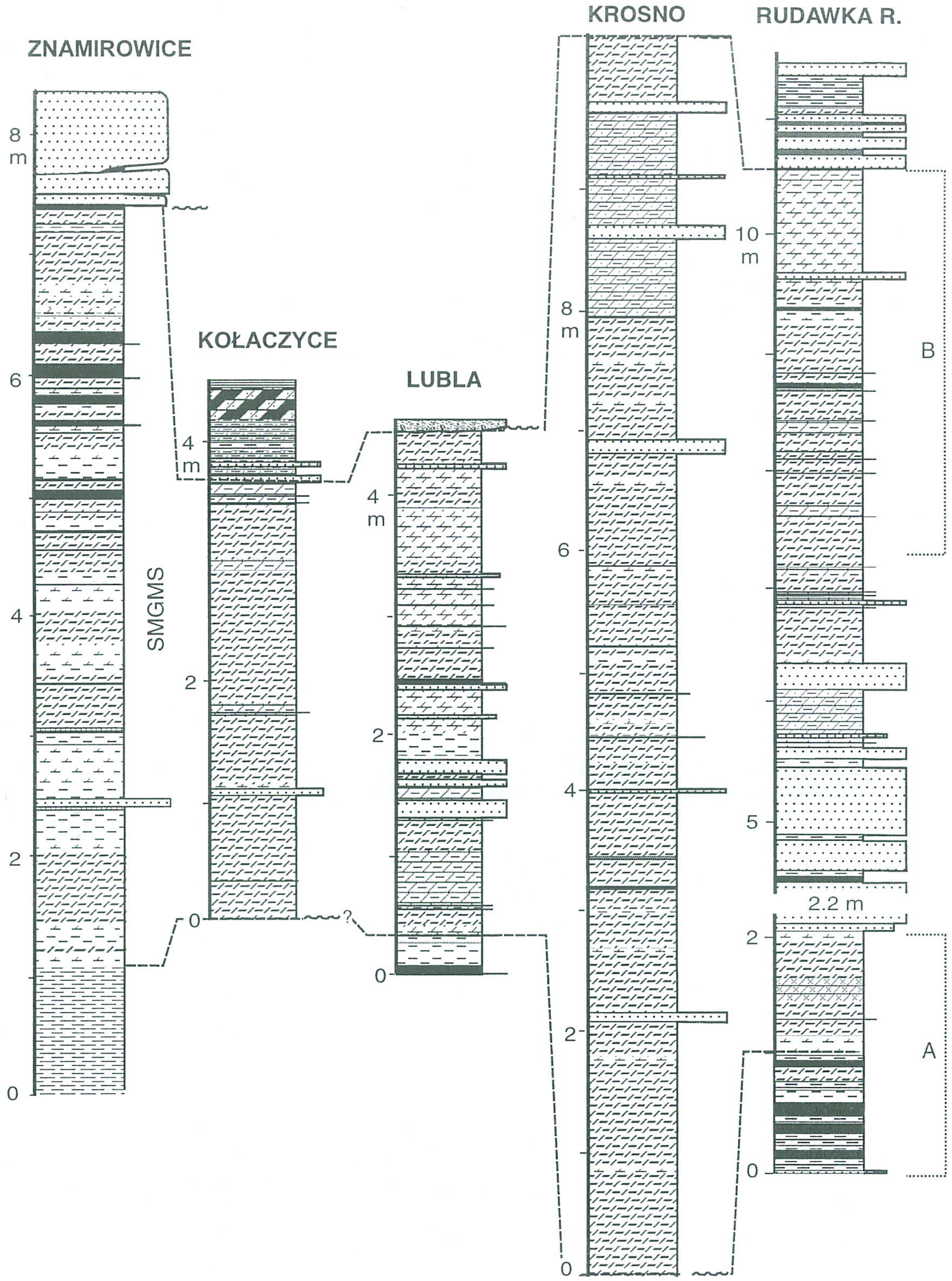


Fig. 11. Lithofacies logs of the SMGMS in selected sections of the Silesian nappe (cf. Fig. 10). For explanation of symbols see Fig. 3

Green shales with subordinate intercalations of thin-bedded sandstones, manganese oxides and hydroxides and carbonate concretions were recognised to underlie the SMGMS in the central and eastern nappe segment (see Koszarski, 1956; Olewicz, 1968; Burtan, 1978). Thick-bedded, yellowish-grey and grey, calcareous, quartzose and micaceous sandstones replace the green shales in some places in the area of Sanok (Przysietnica sandstones, Koszarski & Żgiet, 1961). A 1.5 m-thick package of SMGMS, overlying the Green shale, was described at Niebocko (ca. 15 km to south-west of Sanok, see Blaicher, 1967). The package was illustrated as consisting of a 1.4 m-thick marl bed underlain by three thin beds of marl alternating with green shale that continues further beneath the unit. Dark-coloured fine-grained depos-

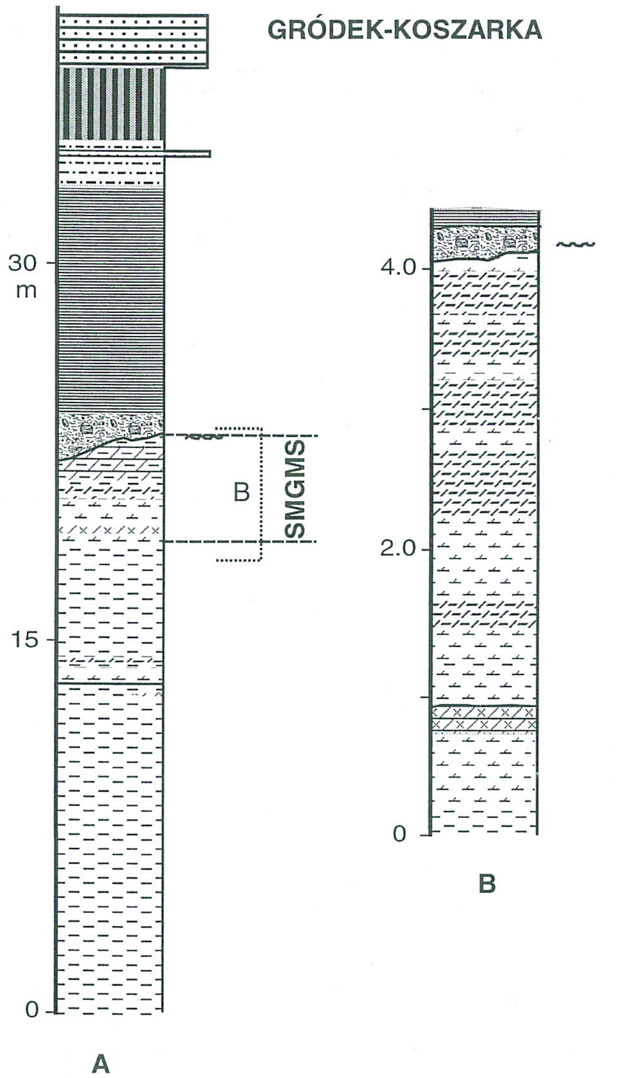


Fig. 12. Generalized lithofacies log of the uppermost Eocene – Lower Oligocene (A) and detailed log of the SMGMS (B; only lower part of the unit is preserved) at Gródek-Koszarka. The section is located in a small valey 2 km to E from the Rożnów lake, in the southern limb of the Rożnów anticline. For explanation of symbols see Fig. 3

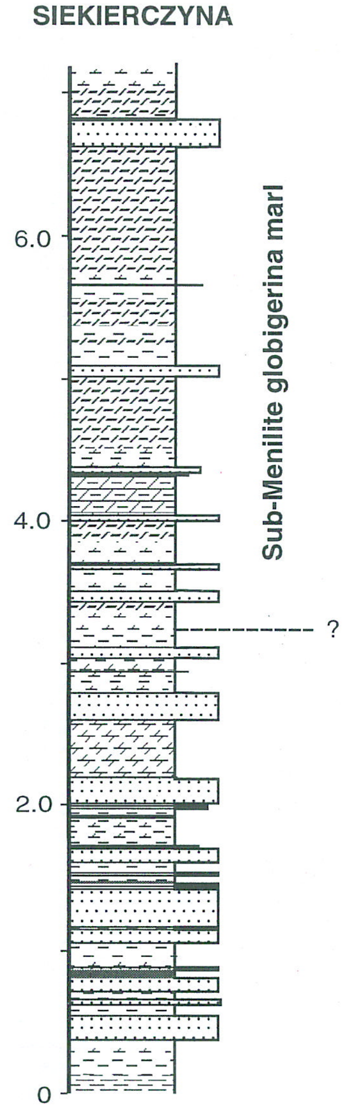


Fig. 13. Lithofacies logs of the SMGMS and the immediately underlying deposits at Siekierczyna. The section is located in a valley slope, ca. 1 km to N of the church in the village Bruśnik, southern limb of the Rożnów anticline. For explanation of symbols see Fig. 3

its (?marls, shales, mudstones) of the Menilite beds occur above the SMGMS.

The deposits overlying the SMGMS in the Sub-Silesian nappe, similarly to adjacent nappes, represent the Sub-Chert beds. These appear to be developed in the facies of the Sub-Chert Menilite shale (see Koszarski & Żytko, 1959). Dark-brown marls rich in fish remains are mentioned from many places. Sandstones appear to occur here subordinately and mainly in a thin-bedded glauconitic variety. Single beds of paraconglomerate occur here locally as well (Burtan, 1978).

Skole nappe

The Priabonian – lower Rupelian deposits are widely distributed in the Skole nappe being well recognised in the nappe segment east of the Wisłok river. They were broadly evaluated lithostratigraphically by Rajchel (1990) and Kotlarczyk and Leśniak (1990). Another classification was proposed by Malata (1996).

The lower part of the Priabonian sequence comprises predominantly thin-bedded normal to shaly flysch (Bachórz Shale and Sandstone Member of Rajchel, 1990; earlier assigned to the Hieroglyphic beds; Fig. 2). Medium to thick-bedded calcareous sandstones alternate the deposits characteristic of the Bachórz Shale and Sandstone Member in the south-eastern part of the nappe (Chwaniów Calcareous Sandstone Member of Rajchel, 1990). Moreover, highly glauconitic and highly silicified sandstones and siltstones (Wojtkowa Sandstone Bed and Wola Krzywiecka Chert Bed of Rajchel, 1990) occur in the upper part of the Bachórz Shale and Sandstone Member.

The overlying deposits are represented mainly by a shaly package dominated by green and grey clayey shales up to several tens of metres thick (Skopów Green Shale Member of Rajchel, 1990). In the eastern part of the nappe,

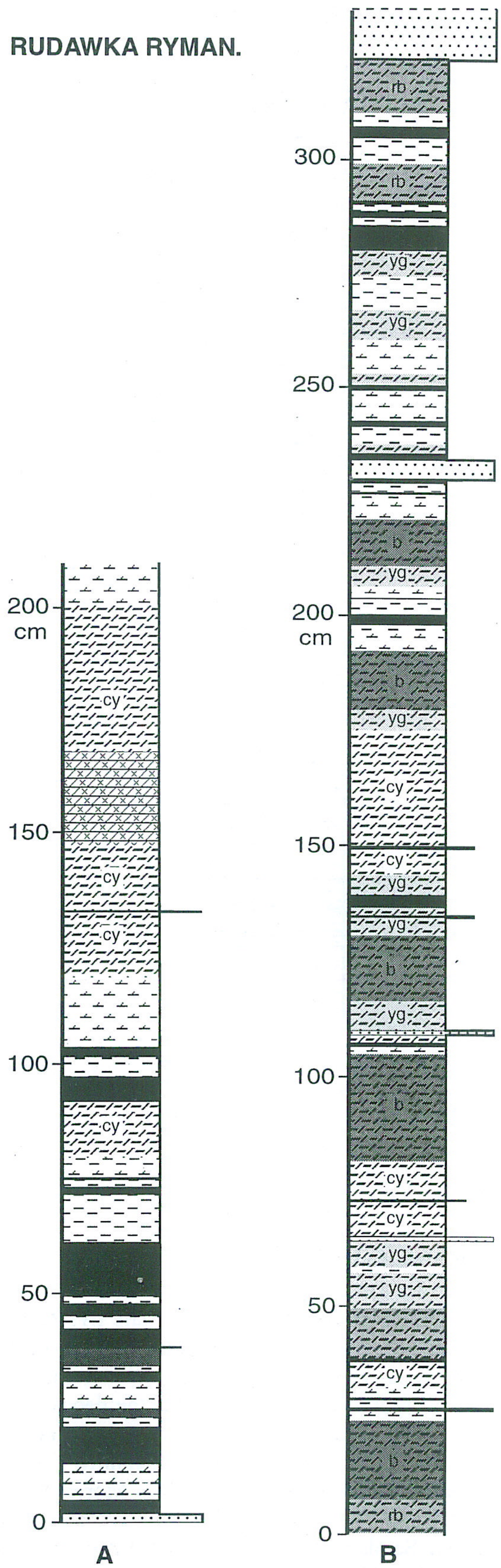


Fig. 14. Detailed lithofacies logs of the passage from SMGMS to the underlying deposits (**A**) and the upper part of the SMGMS (**B**) at Rudawka Rymanowska; section in the river Wisłok (cf. Ślączka, 1973a). The exact location of logs within the sequence is indicated in Fig. 11. For explanation of symbols see Fig. 3

these deposits are replaced by chaotic deposits (Popiele beds acc. Kropaczek, 1919; Popiele Member acc. Rajchel, 1990).

Different sandstone types are concentrated near the top of the Skopów Green Shale Member in the central part of the nappe (see Rajchel, 1990). A package embracing grey, calcareous sandstones, bioclast-rich conglomerates, green, grey and brown clayey to muddy shales, thick beds of grey mudstones and rare siderite layers, was distinguished by Rajchel (1990) as the Bartkówka Calcareous Sandstone Member. Moreover, zebra-type deposits, consisting of alternating very thin, green and grey calcareous to noncalcareous clayey to muddy shale laminae, occur in some sections in the topmost part of the Skopów Green Shale Member (e.g. at Leszczawa Górna and Sośnice).

The above mentioned deposits are overlain by the SMGMS (Strwiąż Globigerina Marl Member acc. Rajchel, 1990; Globigerina Marl Formation acc. Malata, 1996).The present author examined this unit in detail in six sections along the central part of the nappe (Figs. 1, 15, 16). A cream-yellow, yellowish-green and beige soft marl is the most common lithotype within the SMGMS. A reddish and chocolate-coloured soft marl as well as layers and lenses of hard marl occur there subordinately. Moreover, green and grey, calcareous to noncalcareous, muddy to clayey shales, brown, calcareous mudstones, thin and very thin siltstone beds, thin, rarely thick sandstone beds, limonite impregnate lenses and thin layers occur as intercalations in the soft marls (cf. Rajchel, 1990).

The light coloured soft marl occurs in usually indistinctively bounded beds of variable thickness. Sharp bases occur only at contacts with some sandstone beds. Bed tops are most frequently sharp. Proportion of the light coloured marl to other rocks in the sequence is variable. It appears to not exceed 80% in the most complete sections. Like in the previously described nappes, marls appear and disappear gradually in undisturbed sections (Fig. 17). Concentrated *Chondrites intricatus* and *Planolites* div. isp. occur particularly within the T_{cd} division of turbidites and in dark-coloured fine-grained deposit. Different sandstone-types occur within the SMGMS (see Rajchel, 1990). Bluish, turning to beige and brown, calcareous fine-grained sandstones are represented most profusely. Bioclasts are commonly recognizable in the psephitic fraction. The thickness of the complete SMGMS varies between 6 and 12 metres. According to Jasionowicz (1961b), the SMGMS is lacking near Łodyna (SE part of the nappe) and the Hieroglyphic beds pass there upwards into the Menilite beds.

Zebra type deposits, consisting of alternating very thin and thin layers of green, dark-grey and dark-brown calcareous to noncalcareous clayey to muddy shale, locally beige marls, fine-grained sandstone and siltstone, occur usually above the SMGMS. Their maximum thickness does not exceed 2 metres. Such deposits pass upwards into a thin to medium-bedded alternation of brown marl, mudstone and shale, black shale, grey siltstone, sandstone and in places conglomerate (Jamna Dolna Member of Kotlarczyk & Leśniak, 1990).

In the western and central nappe segment, the SMGMS is overlain by a several to 70 m thick sequence of thin- to thick-bedded grey and brown conglomerates and sandstones

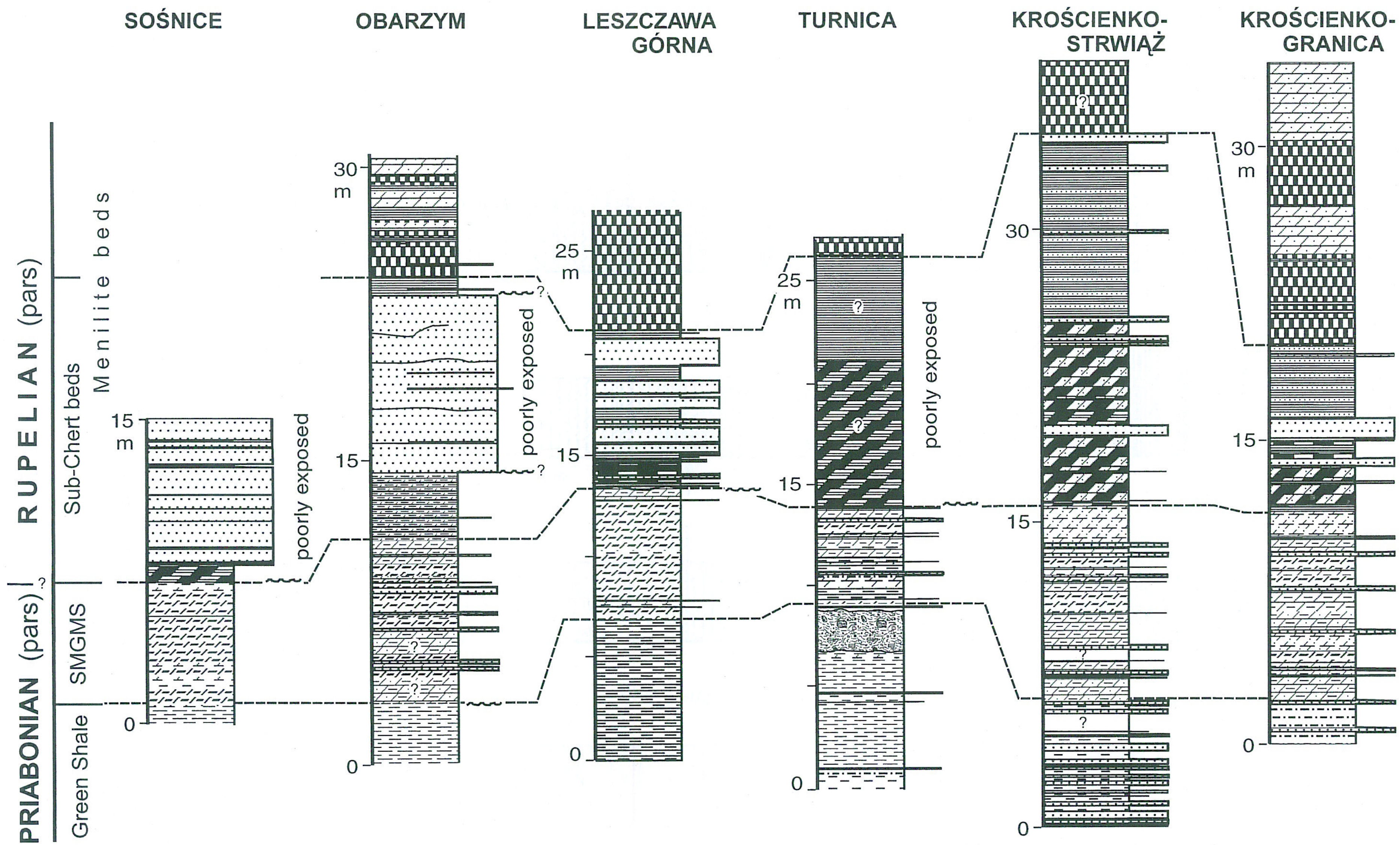


Fig. 15. Lithofacies logs of the Eocene–Oligocene transition in selected sections of the Skole nappe. The sections are ordered generally from north-west to south-east. For explanation of symbols see Fig. 3

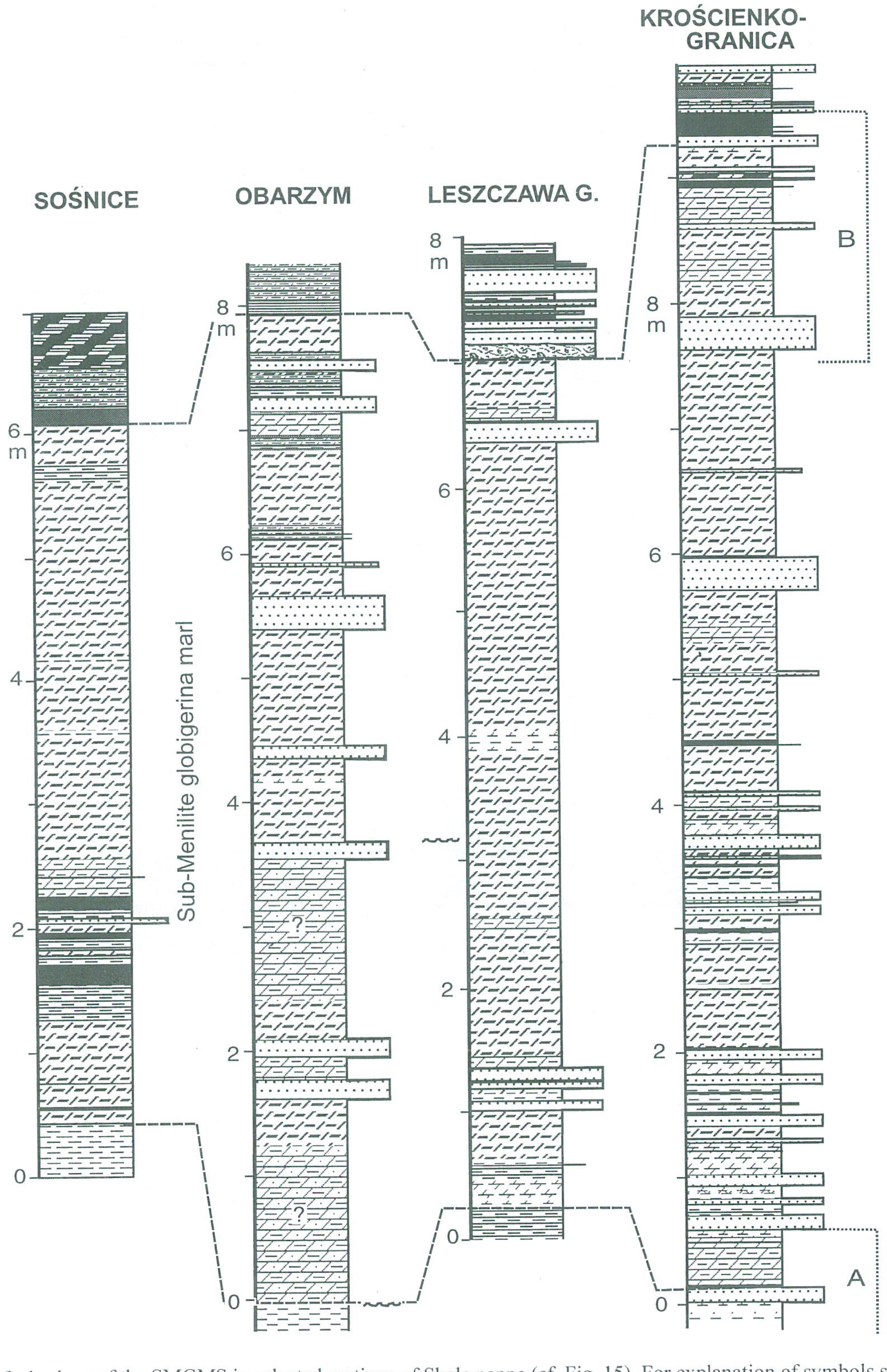


Fig. 16. Lithofacies logs of the SMGMS in selected sections of Skole nappe (cf. Fig. 15). For explanation of symbols see Fig. 3

rich in bioclasts, yellowish sandstones, brown marls and mudstones, and beige marls (Siedliska Member of Kotlarczyk & Leśniak, 1990). A 20–30 metres-thick sequence of medium to very thick-bedded, poorly cemented, cream-yellow, medium and fine-grained sandstone alternated by dark-grey and black muddy to clayey shale (Borysław sandstone acc. Tołwiński, 1917; Borysław Member acc. Kotlarczyk & Leśniak, 1990) occurs either above the Siedliska Member or the zebra-type deposits. The upper part of this unit interfingers with cherts (Kotów Chert Member of Kotlarczyk, 1988a; Kotlarczyk and Leśniak, 1990).

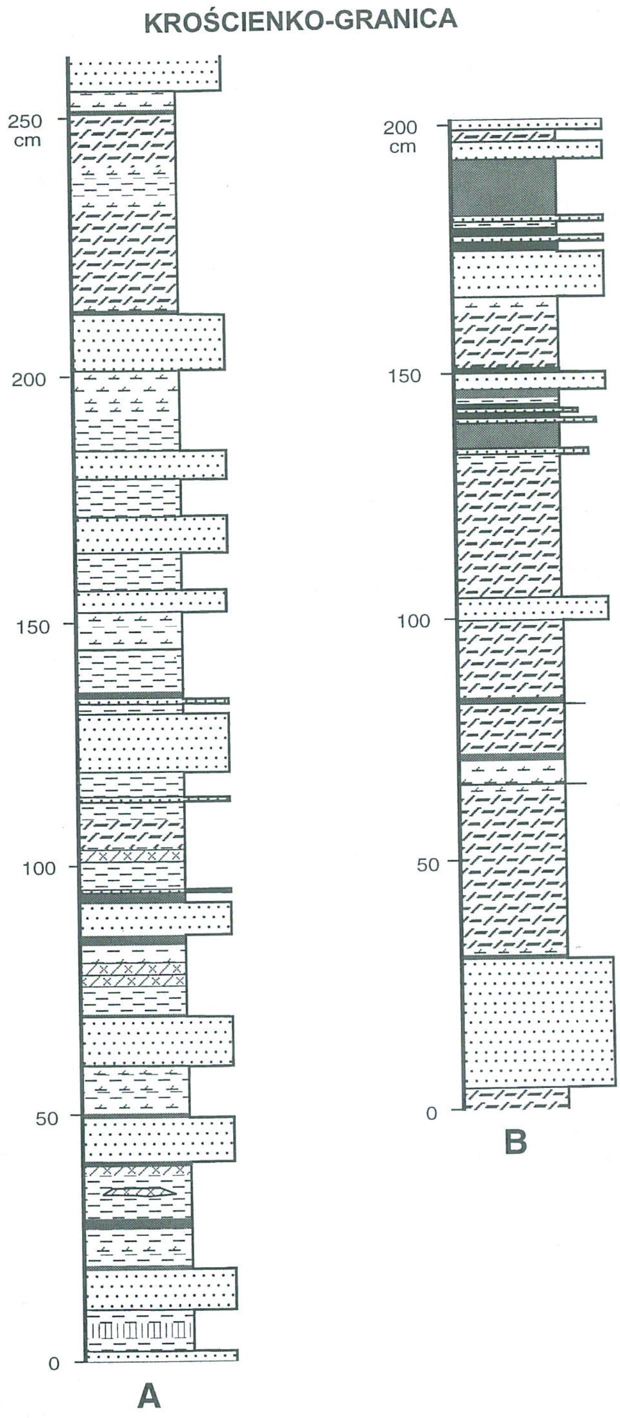


Fig. 17. Detailed lithofacies logs of the SMGMS and the underlying Bartkówka Sandstone Member (**A**) and upper part of the SMGMS with passage to the Jamna Dolna Member (**B**) at Krościenko-Granica; section in southern slope of the river Strwiąż, ca. 1 km from the Polish–Ukrainian frontier. The exact location of logs within the sequence indicated in Fig. 16. For explanation of symbols see Fig. 3

GLOBIGERINA MARL AT THE EOCENE–OLIGOCENE TRANSITION IN THE ALPINE–CARPATHIAN OROGEN AND ITS FORELAND OUTSIDE THE POLISH CARPATHIANS

Globigerina marls occur in different sequences at the Eocene–Oligocene transition in the Alpine–Carpathian orogen and its foreland (Tab. 5). The sequences differ in facies and stratigraphy. In the Czech, Slovak and Ukrainian Carpathians, litho- and chronostratigraphic equivalents of the SMGMS are present (Tab. 5; see Mahel' *et al.*, 1968; Samuel, 1973; Vialov, Andreyeva-Grigorovich *et al.*, 1987). Like in the Polish Carpathians, the sequence embracing the SMGMS-characteristic globigerina marl is underlain by green shales dispersed locally by sandstones or chaotic deposits. It passes upwards into a sequence in which the fine-grained deposits are predominantly dark-coloured.

In the Czech Carpathians, the SMGMS lithostratigraphic equivalent is known from the outer part of the orogen, being best recognised at Uherčice, in the Ždanice unit (see Krhovský *et al.*, 1993). These deposits were described recently within the Sheshory Marl unit together with those included in Poland to the Sub-Chert beds (see Krhovský *et al.*, 1993). The lower part of this unit was interpreted as belonging to the calcareous nannoplankton Zone NP 20 (Krhovský *et al.*, 1993). According to Roth & Hanzlíkova (1982), the SMGMS equivalent package in the Czech Carpathians, together with the lower part of the Sub-Chert beds, represents Blow's (1969) foraminifera Zones P 18 and P 19.

In Slovakia, the SMGMS lithostratigraphically equivalent unit, named the Globigerina marl, is known from the Pieniny Klippen Belt, and the Magura and Dukla nappes. Samuel's (1973) dating of these deposits appear to be still valid there. The unit was interpreted as representing a lower part of the Upper Eocene and becoming slightly younger northwards. In fact, the sequence displays close litho- and chronostratigraphic similarity to the SMGMS and its lithostratigraphic equivalent within the Sheshory marl of the neighbouring parts of the Carpathians.

In the Ukrainian Carpathians, the SMGMS lithostratigraphically equivalent deposits were distinguished as the Sheshory Horizon (Vialov, 1951) together with the overlying rocks, distinguished in Poland as the Sub-Chert beds. Subsequently, the Sheshory Horizon became restricted to the lower part of the sequence (Vialov *et al.*, 1965). Its descriptions show, however, that quite different deposits are there included (see Vialov, Gavura & Ponomaryeva, 1987; Vialov, Gavura & Danysh *et al.*, 1987; Dabagyan *et al.*, 1987; Andreyeva-Grigorovich *et al.*, 1987). The unit is generally interpreted as representing the calcareous nannoplankton Zone NP 21 (Vialov, Andreyeva-Grigorovich *et al.*, 1987; Vialov *et al.*, 1988). In the Marmarosh area, that was elevated relative to the flysch basins, marls rich in globigerina constitute the entire Middle and Upper Eocene (Andreyeva-Grigorovich *et al.*, 1987).

In Romania, globigerina marl occurs in different lithostratigraphic units spanning various time intervals (see Bombita & Rusu, 1981). The closest equivalent to the SMGMS occurs in the outer flysch nappes. It is represented by a

Table 5

Upper Eocene–Lower Oligocene stratigraphy of the Sub-Magura Group of tectono-facies units fitted to the time scale by Berggren *et al.* (1995)

Time (Ma)	Series	Stage	Biozones NP	Biozones PF
32	OLIGOCENE	Rupelian	NP 22	19
33	OLIGOCENE	Rupelian	NP 22 / NP 21	P18
34	EOCENE	Priabonian	NP 21 / NP 19/20	P17
35	EOCENE	Priabonian	NP 19/20	P16
36	EOCENE	Priabonian	NP 19/20 / NP 18	P15
37	EOCENE	Priabonian	NP 18	P15

Swiss Alps Helvetic domain (Herb, 1988) (+)	Alpine foreland in Germany (Gramann *et al.*, 1986) (+)	Czech Carpath. (Krhovsky *et al.*, 1993) (*)	Slovak. Inner Carpathians (Samuel, 1973) (+)	Slovak. Outer Carpathians (Samuel, 1973) (+)	Ukrainian Outer Carpathians (Vialov *et al.*, 1987) (+, *)	Hungary Baldi, 1984) (+, *)	Romanian Outer Carpathians (Micu, 1987) (*)
Different units of South Helvetic flysch	Schoenecker Fisch Shale	Upper part of Sheshory Marl = lower part of Sub -Chert Beds in Poland (upper part of NP 20 & lower part of NP 21)			Lower part of Ombronskiy Complex (Ribnitsa Horizon; NP 22); deposits generally as in the Sub-Chert Beds in Polish Carp.	Tard Clay	Slaty Bituminous Shales & Fierastrau Sandstone (NP 23)
Globigerina Marl (P 7 to P 17; diachronous, younger to WNW)	Globigerina Marl (?lower part of NP 19 to ?lower part of NP 21)	Low. part of Sheshory Marl = SMGM (upper part of NP 20 & lower part of NP 21)	Different lithostrat. units depending on the area; deposits generally of the Sub-Chert Beds-type	Different lithostrat. units depending on the area; deposits generally of the Sub-Chert Beds-type	Sheshory Horizon +/- SMGM (NP 21)	Buda Marl (marl rich in globigerina)	Globigerina Marls & Lucacesti Sdst.; Ardeluta Beds (upper part of NP 21 to lower part of NP 23)
Different units depending on region	Stockletten Lithotamnium Lmst.	Green Clay = Olive-Green Shale in Poland	Globigerina Marl (lower part of Upper Eocene)	Globigerina Marl (lower part of Upper Eocene; slightly younger than in Inner Carpathians)	Upper part of Karpinskiy Complex (different lithostrat. units depending on region, mainly Bystritsa Unit; deposits generally as in Polish Carpathians)	Bryozoa Marl	Plopu Beds, Biseri-cani Beds & Podu Secu Beds (normal & shaly flysch in inner part & chaotic deposits in the outer part)
			Variegated Shale	Variegated Shale		Globigerina Marl	

NP - calcareous nannofossil zones; PF - planktonic foraminifera zones; + - stratigraphy based on foraminifera; * - stratigraphy based on calcareous nannofossils; heavy lines denote limits precisely indicated; dashed lines denote limits imprecisely defined; arrow indicates biostratigraphic location of the boundary;

package of globigerina marl that interfingers with thin to medium bedded micaceous sandstones (Lucacesti sandstone, see Micu *et al.*, 1981). The foraminifera Zones P15-17, and calcareous nannoplankton Zone NP 21 were recognised there (Bombita & Rusu, 1981). However, Micu (1987) interpreted the unit as embracing the upper part of NP 21 to lower part of NP 23. The Ardeluta beds represent the equivalent of the Globigerina marl unit in some areas (see Sandulescu *et al.*, 1987). Either the thin-bedded flysch of the Plopu beds or marly and shaly deposits of the Bisericani beds occur beneath the sequence embracing the Globigerina marl and Lucacesti sandstone. The overlying deposits are represented by the Slaty-Bituminous shale and Fierastrau sandstone, that are lithostratigraphically equivalent to the Sub-Chert beds in the Polish Carpathians (see Sandulescu *et al.*, 1987).

In Transylvania, marl rich in globigerina, called the Brebi marl, occurs at the Eocene Oligocene transition. The NP 21 and lower part of NP 22 Zones are there recognised. In the Getic depression, the globigerina marl is enclosed in the Olanesti marl unit that is characteristic of the Middle and Upper Eocene. The Buciumeni marl, called also Globigerina marl, underlain by the Sortile marls, is characteristic of the Priabonian (NP 19/20) in the inner flysch nappes. This unit terminates there the flysch sequence.

In Hungary, the globigerina-bearing marl is typical for the entire Priabonian (see Báldi, 1984). The Buda marl, representing calcareous nannoplankton zones NP 19/20 and lower part of NP 21, is most closely related chronostratigraphically to the SMGMS. The Buda marl passes upwards into the Tard clay that belongs to the upper part of NP 21 and the NP 22 to NP 23 zones, and corresponds in facies to the Sub-Chert beds in the Polish Carpathians (see Krhovský *et al.*, 1993).

In the Alpine foreland of Germany, the Globigerina marl occurs in the upper part of Priabonian (Gramann *et al.*, 1986). The marl is enclosed by the neritic deposits of the Stockletten lithotamnium limestones below and the Schoenecker fish shale above. The latter resembles in facies the Menilite beds in the Carpathians.

In the Swiss Alps, the Upper Eocene Globigerina marl is known from the Helvetic domain. The sequence starts at the Lower–Middle Eocene transition in the eastern Switzerland and in the Priabonian in the central part of the country (Herb, 1988).

SMGMS PECULIARITIES AND FACIES DETAILS

The SMGMS shows significant lateral variability in thickness, composition and vertical pattern over the entire area of its occurrence in the Polish Carpathians. Except for the Dukla nappe, the thickness of the complete unit appears to range between 5 and 10 metres. There appears to be a slight tendency for the cumulative thickness increase of light-coloured marl and green shale parallel with a thickness decrease of noncalcareous green shale (Fig. 18A) as well as with an increase of the number of the noncalcareous green shale layers (Fig. 18B). The most characteristic feature of the SMGMS is the presence of the light marl and fluctuating changes in the carbonate content in the fine-grained deposits. However, patterns of these fluctuations differ laterally even within a distance of several kilometres (Fig. 11, comp. the Znamirowice section with the section in Fig. 12B).

The following facies differing in texture, sedimentary structures, and carbonate content were distinguished within the SMGMS deposits: (1) light marl, (2) green shale, (3) dark shale, mudstone and marl, (4) sandstone and siltstone, and (5) chaotic deposits.

The individual facies occur in beds of different thickness, and alternate with variable frequency in particular sections. A very distinctive, recurrent, vertical facies stacking is recognizable in many sections (Fig. 19): the light marl

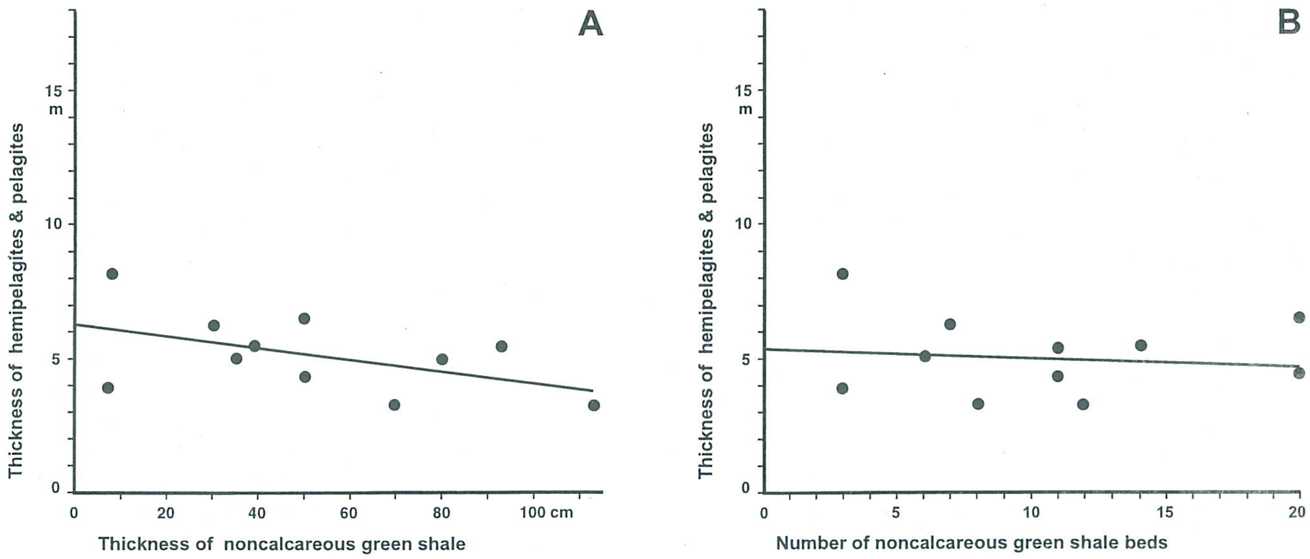


Fig. 18. Relationship between the cummulative thickness of light-coloured fine-grained deposits (hemipelagites plus pelagites) in the most complete SMGMS sections and the cumulative thickness of noncalcareous green shale (**A**), and between the cummulative thickness of light-coloured fine-grained deposits and the number of the noncalcareous green shale beds (**B**)

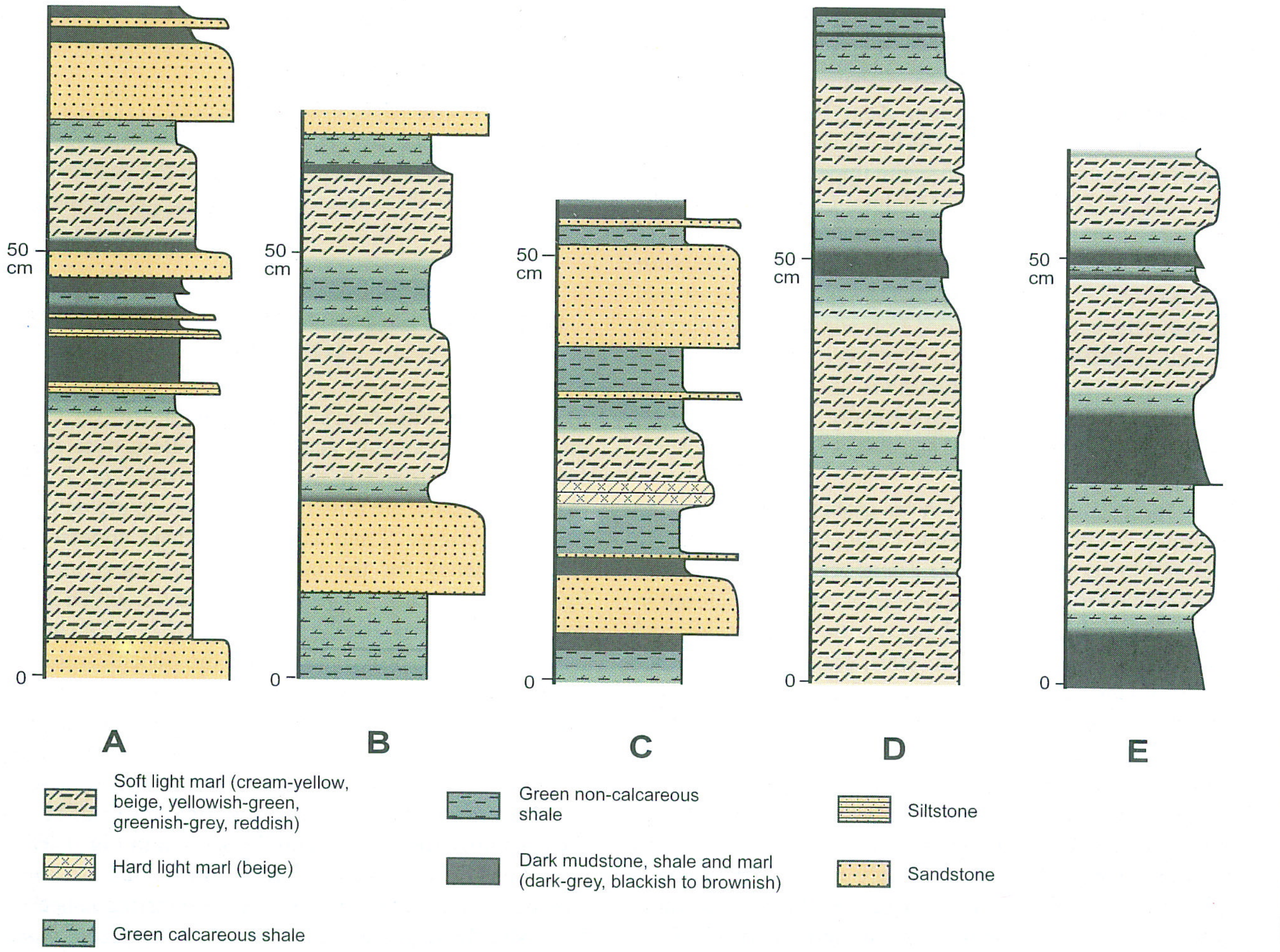


Fig. 19. Sequence styles and relationships between different facies within the SMGMS. Light marl usually passes down- and upwards into green shale (**B–E**). Occasionally, light marl is sharply bound by a sandstone or siltstone layer (**A**). Dark-coloured mudstone, marl or shale occurs sharply bounded from beneath, being underlain by green shale (**A**, **D**, **E**) or grades downwards into siltstone or sandstone (**A–D**), and upwards into green shale. The relative $CaCO_3$ content in fine-grained layers is shown by log width.

passes down- and upwards into the green shale or is sharply bound from above either by the dark shale, marl, or by a sandstone, whereas the green shale passes downwards into the light marl or in dark shale, mudstone or marl. Rarely, the light marl is sharply bound at the base by a sandstone. Coarse-grained deposits usually occur within the less calcareous parts of the SMGMS. Bioturbation is common in these deposits, disappearing generally near the top of the SMGMS. Mottling and the *Chondrites intricatus* burrows disappear last from the sequence. In its last occurrences, *Ch. intricatus* penetrates only several millimetres beneath a bed top (cf. Leszczyński, 1996).

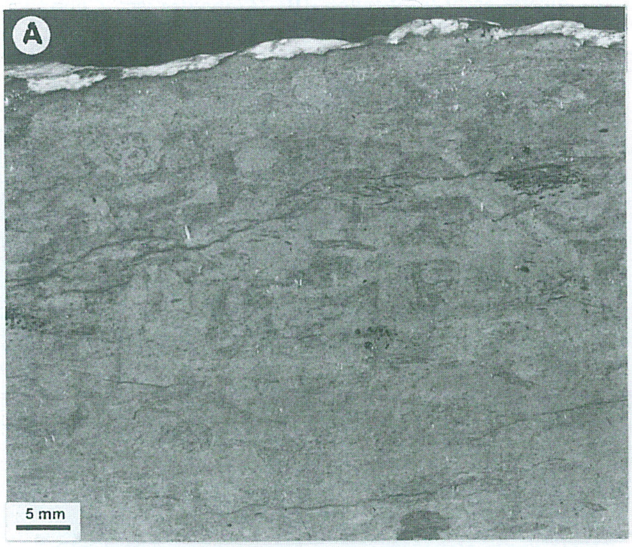
LIGHT MARL

Soft, cream-yellow, beige, yellowish-green, greenish-grey, beige-grey, and red, and hard beige marls were included in this facies. Concentrated occurrence of soft light marl beds is typical of the SMGMS as a whole. Cream-yellow and beige marl is distinctive of the SMGMS within the Silesian, Sub-Silesian and Skole nappes. In the Dukla, Grybów and partly in the Magura nappe, greenish-grey and beige-grey marl appears to predominate within the unit. Red marl typifies the SMGMS in the Leluchów section. All these marl varieties occur in beds several centimetres to nearly a metre thick, interbedded with other rocks. The beds of the light marl facies display gradual passages both downward and upward to green shale (Figs. 19B, D, E; Fig. 20). The passages are accompanied by a decrease of the rock consistency. The internal parts of the light marl beds are sometimes made usually up of a harder rock than their outer zones. Slight, bedding parallel fluctuations in the colour and consistency occur in some thick beds of the light marl. These fluctuations are locally accompanied by flat or wavy streaks and laminae of silt (Fig. 21). Moreover, pyrite and limonite concretions, and lenses of limonite impregnated rock occur within some beds of the light soft marl. Hard marl layers are scattered in the sequence. Some of them occur within green shale, some other within the soft marl beds. The hard marl frequently displays limonite coatings on weathered surfaces.

Mottled structures, accentuated by changes in the rock-colour and texture are characteristic of the light marl within the SMGMS. Mottling is best visible on polished and

Fig. 20. Gradual passage of light marl (in the middle) both downwards (to the left) and upwards into dark shale; passage from the SMGM to the Sub-Chert beds at Krościenko-Granica (section location as in Fig. 17)

Fig. 21. Dark-coloured layers of flat-laminated and wavy-laminated silt and muddy silt, and lenses of cross-laminated silt interbedded with greenish-yellow marl; upper part of the SMGMS at Krościenko-Granica (section as in Fig. 17)



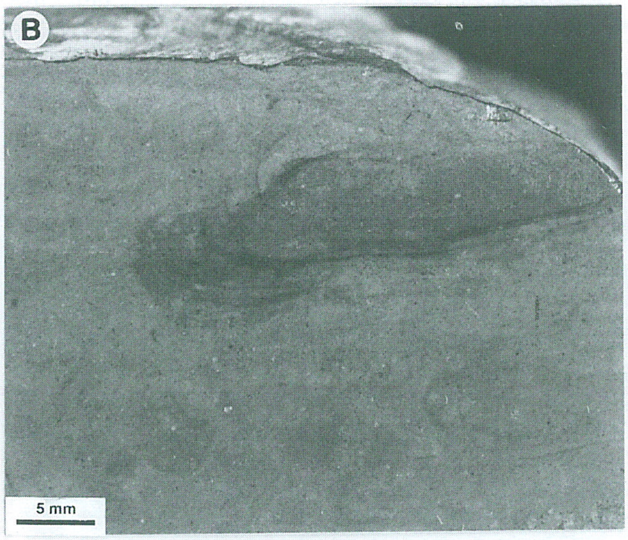


Fig. 22. Mottling in beige marl accentuated by colour differentiation. (**A**) Distinctive mottling, suggesting burrowing at least several centimetres deep; SMGMS at Znamirowice (for section location see Leszczyński, 1996). (**B**) Weak mottling and *Teichichnus*-type burrow in hard marl, SMGMS at Korzenna (section in southern limb of the Jankowa anticline, ca. 1 km to NW of the church)

stained surfaces (Fig. 22). Distinctive burrows, particularly *Chondrites intricatus* and *Planolites* ?div. isp. (Fig. 23) are concentrated in thin beds and in the less calcareous levels of thick beds. Less common are the burrows *Thalassinoides* ?div. isp. and *Helminthopsis* isp. Moreover, *Alcyonidiopsis pharmaceus,* and granulated structures resembling *Echinospira* and *Zoophycos*, *Zoophycos* isp. and *Teichichnus* isp. also are recorded in some places (e.g. Leszczyński, 1996). Most distinctive are burrows displaying bed junction preservation within hard marl beds (Fig. 24).

Thin section analysis have revealed highly differentiated texture in the light marl facies. Its coarsest fraction consists usually of planktonic foraminifera. The coarsest particles are distributed either chaotically (Fig. 25), or are concentrated within and around burrows (Fig. 26), or along bedding parallel laminae (Fig. 27). These laminae occur single or in sets consisting of several units. Coarse fraction disappears gradually down- and upwards away from the lamina's centre. Some layers of the light marl, up to several centimetres thick, display normal grading and bedding-parallel alignment of elongated particles (Fig. 28). T5 to T7 divisions of the Stow & Shanmugam (1980) sequence or E_2 and E_3 divisions of the Piper (1978) sequence are recognizable in such layers. Such features were recorded particularly in the greenish-grey and light-grey marl of the SMGMS within the Dukla nappe and within the zebra-type deposits at the passage to the Sub-Chert beds. Bioturbation appears to be lacking there.

Analysis in scanning electron microscope has shown that calcareous nannoplankton is the chief constituent of the calcareous material of the light soft marl (Fig. 29; see also Krhovský *et al.*, 1993; Oszczypko, 1996). According to the

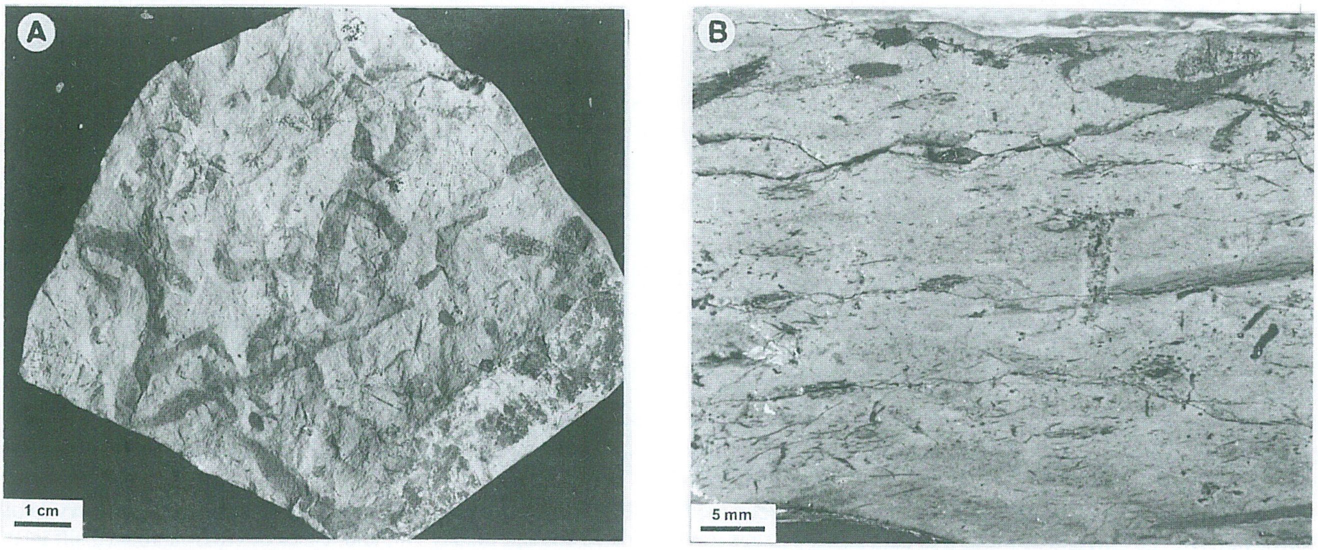


Fig. 23. Distinctive burrows overprinting poorly expresed mottling in hard marl; *Chondrites intricatus* follows many of the large burrows; SMGMS at Korzenna (section location see Fig. 22B). (**A**) ?*Planolites* isp., *Chondrites intricatus*, *Thalassinoides* isp., and ?*Helminthopsis* isp. Lack of deformation in the most distinctive burrows indicates early lithification. (**B**) ?*Planolites* isp., *Chondrites intricatus*, *Thalassinoides* isp.

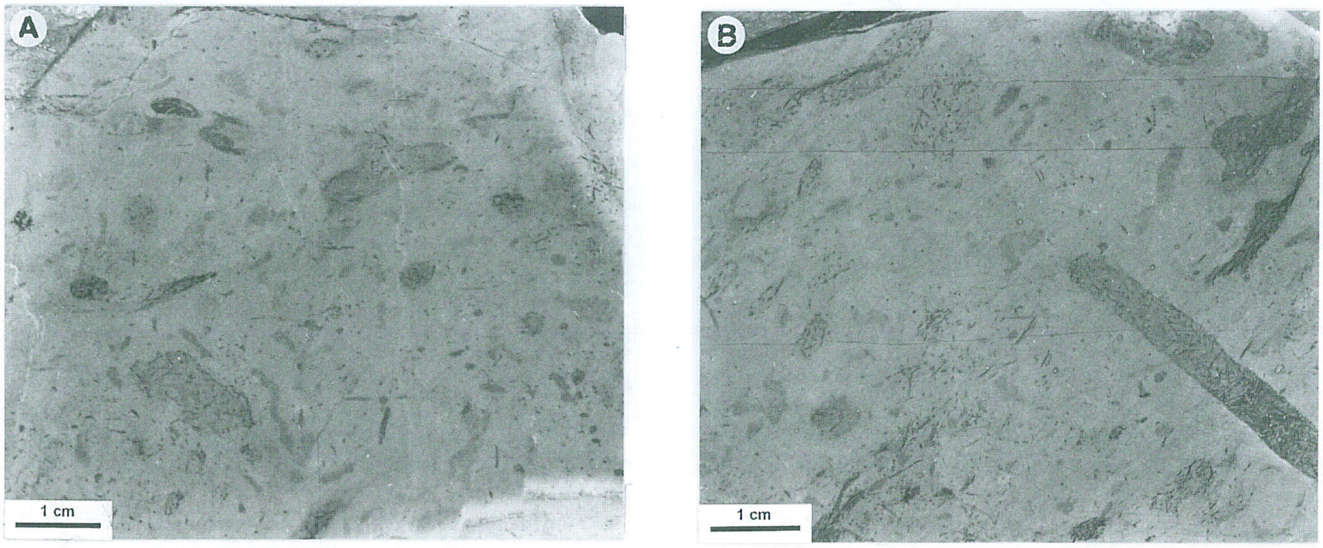


Fig. 24. Concentration of ?*Planolites* isp. and *Chondrites intricatus* in yellowish-green marl; SMGMS section at Znamirowice (section location see Leszczyński, 1996). Burrows show bed junction preservation. (**A**) Plane view of *Ch.*, poorly visible at this scale, concentrates within larger burows. (**B**) Cross-sectional view of large burrows crowded in the upper part of the layer. Some large burows are filled and surrounded by *Chondrites*

texture, sedimentary structures and the composition (see below), the soft marl corresponds to the Pickering *et al.* (1986) facies G1.2 and G2.1, whereas the hard marl can be correlated with their facies G3.

GREEN SHALE

This facies is represented by the light green, grey-green to dark-green (olive-green) muddy to clayey, calcareous to noncalcareous shale. The green shale facies is particularly characteristic of the lower part of the SMGMS. It disappears nearly completely in the upper part of the sequence. The number of green shale layers as well as their distribution in the sequence varies from section to section.

The green shale facies is poorly bedded and shows a tendency to split parallel with bedding. The shale showing shiny splitting surfaces was considered as clayey whereas that where the surfaces are rough and dull was found as a more muddy. The latter tends to disintegrate into thicker and more irregular pieces than do more clayey shales. Moreover, the clayey shale tends to be greener, whereas the muddy shale is rather grey-green. The colour changes are gradational. They correlate to some extent also with the $CaCO_3$ content. A $CaCO_3$ increase is reflected in a passage to light-green or pale-green sediment. Calcareous green shale occurs essentially within the SMGMS. The the green shale facies within the SMGMS grades upward into light marl or is sharply bounded by dark mudstone, marl, siltstone or sand-

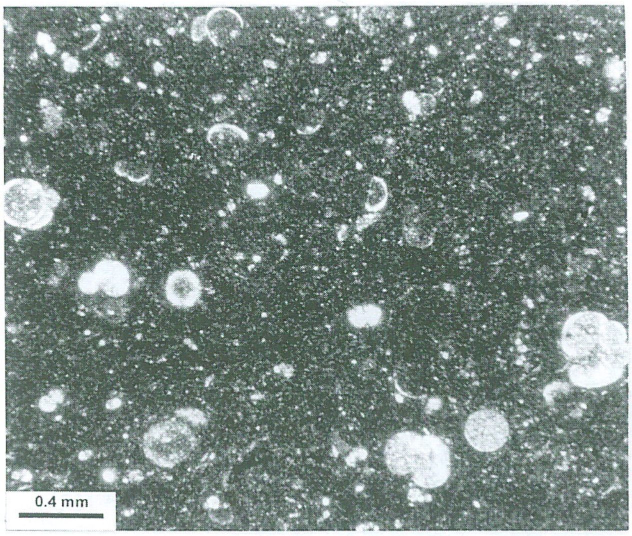
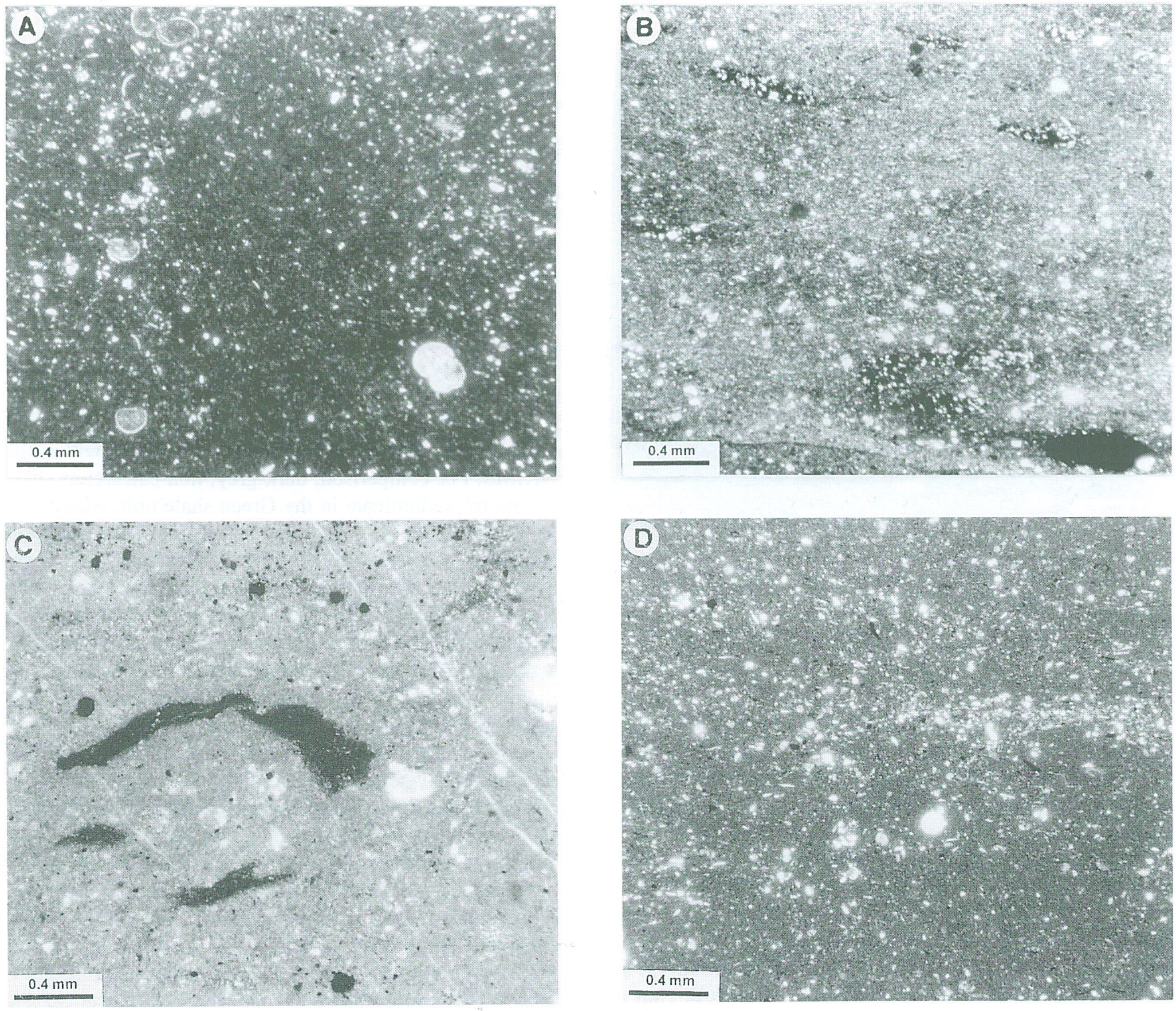


Fig. 25. Chaotic distribution of coarse fraction within light, hard marl. SMGMS at Rudawka Rymanowska (section location as in Fig. 14)

Fig. 26. Bioturbational segregation of particles within light marl. (**A**) Beige, hard marl with dark spot in the centre representing a burrow fill composed of distinctively finer material than the surroundings. SMGMS at Komańcza (section location as in Fig. 6). (**B**) Concentration of coarse particles and organic matter within ?compacted *Chondrites intricatus* burrows in beige marl. SMGMS at Krościenko-Strwiąż (section in the river Strwiąż, ca. 2 km to SW of Krościenko, southern limb of the Kiczera anticline). (**C**) Beige, hard marl showing the concentric segregation of particles within burrow. SMGMS at Korzenna (section location as in Fig. 22B). (**D**) Greenish-gray, hard marl showing the irregular distribution of particles ?due to bioturbation; elongate particles show parallel alignment. SMGMS at Komańcza (section location as in Fig. 6)



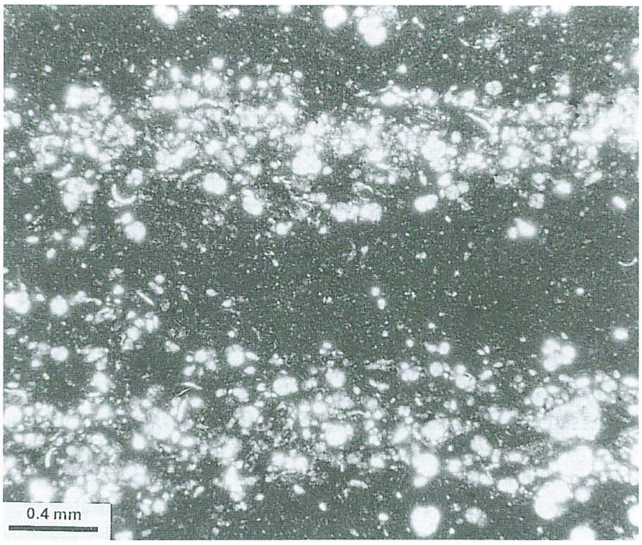


Fig. 27. Beige, hard marl showing the coarsest fraction composed predominantly of planktonic foraminifera tests, concentrated in laminae. SMGMS at Korzenna (section location as in Fig. 22B)

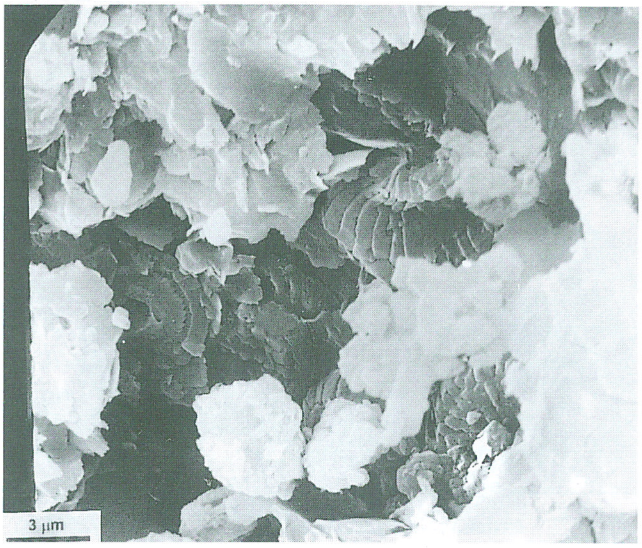


Fig. 29. SEM image showing the calcareous nannofossils as being the main constituents of light marl. Sample from SMGMS section at Gródek-Koszarka (section location as in Fig. 12)

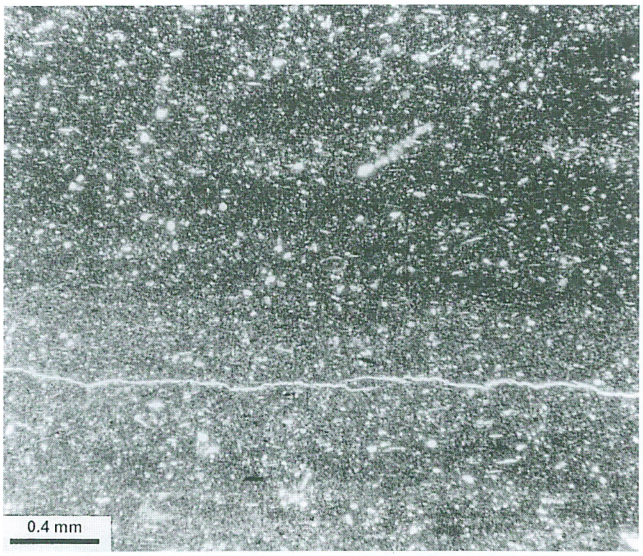


Fig. 28. Bedding parallel alignement of elongated particles in greenish-gray hard marl; SMGMS at Komańcza (section location as in Fig. 6)

stone (Fig. 19). The contacts of the green shale with the light marl, as well as with some laminae of the dark-grey shale, are gradational and many contacts are highly bioturbated.

Chondrites intricatus, *Planolites* isp., rarely *Thalassinoides* isp., *Helminthopsis* isp., and *Alcyonidiopsis pharmaceus* occur at some levels in the green shale. Their most common occurrences are recorded in layers showing colour fluctuations. These burrows are usually emphasised there with a slightly darker colouration or a slightly coarser fill with respect to the host sediment (see Leszczyński, 1996). Burrow concentration tends to increase towards the top of such layers. Moreover, highly irregular changes of sediment colour, recorded primarily at parting surfaces, suggest a heavy sediment mottling. Nevertheless, similarly to the light marl, scattered silty streaks are there recorded as well.

The mottled, non-graded green shale corresponds to the Pickering *et al.* (1986) facies E1.3 and G2. The graded shale corresponds to facies E2.1. The interbedded laminae or thicker layers of green, grey to dark-grey shale, including relevant zebra type deposits, represent facies E1.2.

DARK SHALE, MUDSTONE AND MARL

Dark-grey to black, muddy to clayey, calcareous to non-calcareous shale and chocolate-brown marl are included to this facies. Dark-grey, calcareous muddy shale and mudstone are the chief representatives of this facies within the SMGMS. For comparison, dark-grey, non-calcareous shale appears to predominate in the Green shale unit, whereas in the lower part of the Sub-Chert beds, this facies is represented nearly exclusively by dark-brown marls and dark-grey to black calcareous mudstones. This facies is usually inferior in occurrence compared to the green shale facies in the SMGMS. The former occurs in trace amounts in some sections (e.g. at Skawinki or Siekierczyna). However, its amount increases generally up the SMGMS. The dark shale, mudstone and marl occur there mainly in several millimetres thick laminae to several centimetres thick layers. The laminae and layers are underlain by green shale, sandstone or siltstone and grade upward into green shale or are sharply bound at the top by a sandstone or siltstone (Fig. 19A, C-E). The layers underlain by green shale show usually sharp soles. Layers, 1–3 cm thick, enclosed within green shale and the upper parts of the thicker layers tend to be heavily bioturbated (see Leszczyński, 1996).

Silty to fine sandy, horizontal to small-scale cross-laminated deposits occur commonly in the bottom part of the dark mudstone or marl layers (Fig. 30). The cross-laminated division is usually followed upwards by a millimetre-thick

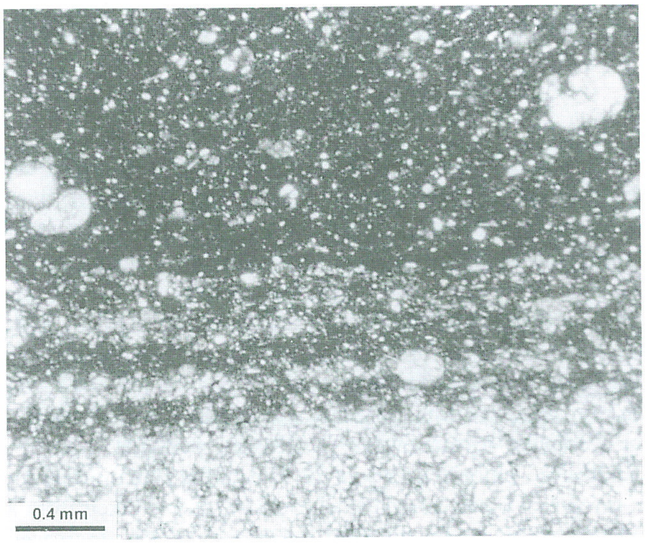


Fig. 30. Concentration of terrigenous silt in the wavy laminated lower part of dark-gray marl layer in the zebra-type deposits at the transition from the SMGMS to the Sub-Chert beds at Żubracze (section location as in Fig. 7)

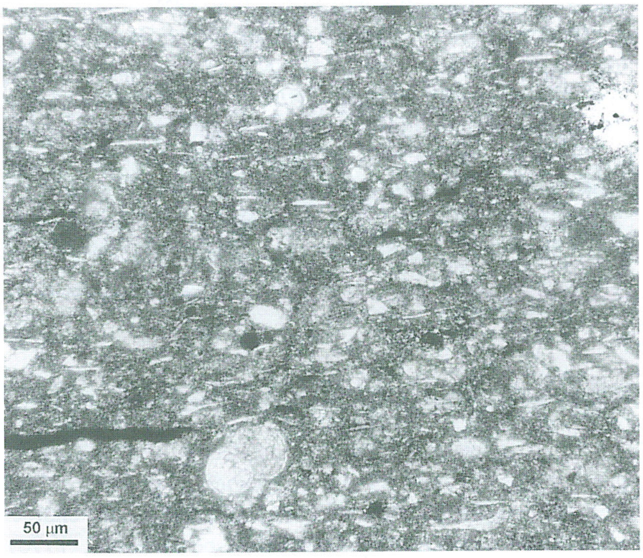


Fig. 31. Distinctive parallel alignment of the elongated particles within unbioturbated dark-gray marl. SMGMS at Komańcza (section location as in Fig. 6)

set of parallel laminae. The overlying deposit displays a distinctive bedding-parallel alignment of elongated particles (Fig. 31). Mottling appears in the top part of such layers. The sequence of features resembles that characteristic of fine-grained turbidites (Piper, 1978; Stow & Shanmugam, 1980). According to the Pickering *et al.* (1986) classification scheme, the layers starting with the silty division represent facies D2.1 and D2.3. The graded mud layers represent facies E2.1, whereas those showing subtle lamination correlate with facies E2.2. The centimetre-thick and the thicker layers consist frequently of several graded/laminated sequences of the above type. The dark mudstone and shale that grade downwards into siltstone or sandstone represent the T_{de} divisions of the Bouma sequence.

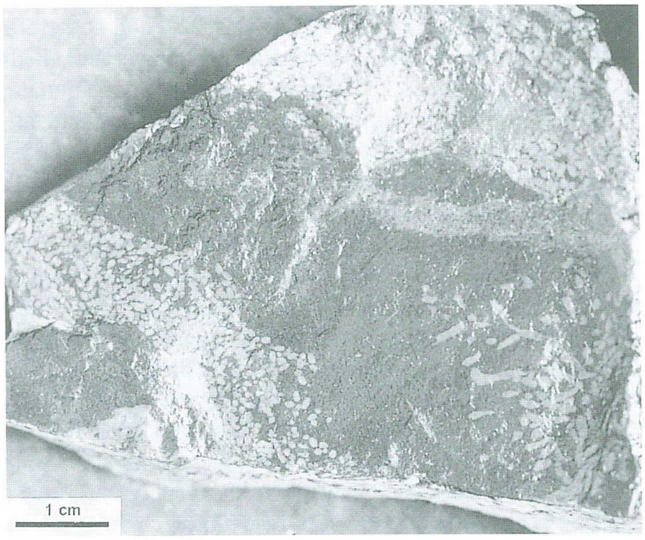


Fig. 32. *Chondrites targionii* and *?Echinospira* isp. in the top part of brownish-black calcareous mudstone layer. SMGMS at Znamirowice (section as in Leszczyński, 1996)

Chondrites intricatus and *Planolites* isp. represent the most common burrows in this facies within the Green shale and the SMGMS. *Thalassinoides* isp. occurs concentrated in the top parts of some layers (see Leszczyński, 1996). Less frequent are *Ch. targionii*, *Alcyonidiopsis pharmaceus*, *?Echinospira* isp., (Fig. 32), *Helminthopsis* isp. and *Hormosiroidea caliciformis*.

SANDSTONE AND SILTSTONE

Very thin and thin siltstone beds and very thin to very thick beds of sandstone and conglomerate-sandstone couplets were included to this facies. The thick sandstone beds and the beds of the conglomerate-sandstone couplets occur in single beds within the SMGMS and in some sections only. The majority of beds display sharp bases and indistinctive tops (Figs. 19, 21). Such sandstones and siltstones usually grade upwards into dark-coloured calcareous mudstone or shale. Noncalcareous dark-coloured mudstone, green shale or light marl overlies some of the thin and very thin sandstone and siltstone beds. The passage from sandstone or siltstone to green shale or light marl is rather abrupt. The contacts are, however, blurred by intense bioturbation. Some sandstone beds, particularly the very thin ones, are entirely bioturbated. These beds also display indistinctive bases. Like in the fine-grained deposits, *Chondrites targionii* and *Planolites* isp. are there the most common trace fossils. Characteristically, the sandstones and siltstones underlain by noncalcareous green or dark-coloured shale usually are also overlain by a noncalcareous deposit.

Poorly bioturbated, thin and very thin sandstone and siltstone beds display features of the $T_{(b)cd}$ and T_{cd} divisions of the Bouma sequence. Some siltstone and very-fine grained sandstone beds are entirely convoluted. Such feature is displayed by highly cemented, bluish-grey and greenish calcareous and siliceous rocks. All these rock types represent the Pickering *et al.* (1986) facies C2.3 and D2.1. The highly bioturbated, poorly cemented, thin and very thin beds of muddy-sandstone, and those composed of medium to coarse grained sand appear to be non-laminated and un-graded or normally graded. The former represent facies C1.2, whereas the latter appear to correspond to facies B1.2.

Thick sandstone beds display features of the T_{abcd} divisions of the Bouma sequence. A pebbly sandstone was recorded in the sections at Rudawka Rymanowska and Darów only. The pebbly sandstones, occasionally fine conglomerates, occur in the lower part of beds and pass upwards into a medium- to fine-grained sandstone. The bases of the thick sandstone beds are sharp flat or irregular and are covered by the casts of different current marks. The sandstones displaying the Bouma's T_{abcd} sequence correspond to the Pickering *et al.* (1986) facies C2.1, whereas the pebbly sandstones starting with fine conglomerate resemble facies A2.7. The deposits of this type, including the beds starting with conglomerate, are known also from the SMGMS sections of the Skole nâppe (see Rajchel, 1990).

Mud-rich sandstone beds were recorded primarily at Darów. These are massive rocks displaying marl and shale chips and clasts chaotically dispersed within entire beds. According to the Pickering *et al.* (1986) classification scheme these rocks represent facies C1.1.

CHAOTIC DEPOSITS

Beds of contorted and brecciated deposit, parts of the mud-rich sandstone beds displaying brecciated texture, beds of breccia, and massive mudstone rich in coarse sand-size grains and small clasts were included to this facies. Beds and lenses of breccia composed of angular fragments of rocks similar to those beneath and above that occur within tectonically disturbed zones are here ommited. The chaotic deposits consist actually of balled, and brecciated package of marl, shale and thin sandstone beds. Such deposits occur in three beds in the middle part of the SMGMS at Komańcza. They correspond to the Pickering *et al.* (1986) facies F2.1. The brecciated deposits making up some parts of the mud rich sandstone beds were encountered at Darów. These deposits reveal concentrations of clasts of greenish marl and green to dark-grey shale set in a muddy sand. They appear to represent facies F2.2 of the Pickering *et al.* (1986) classification scheme.

In many sections, dark-brown to chocolate-brown calcareous to non-calcareous massive mudstone, containing significant admixture of irregularly distributed coarse-grained material, occurs in thick beds, immediately above the SMGMS, within the Sub-Chert beds. Its coarse fraction consists of grains and granules of quartz, plant fragments, calcareous bioclasts and shale chips up to 5 cm in size. Such deposits occur in beds several centimetres to several tens of centimetres thick. They tend to overly sandstone and pass upwards into black shale or brownish black marl. These deposits correspond to the Pickering *et al.* (1986) facies D1.2 or E1.1.

COMPOSITION OF THE FINE-GRAINED DEPOSITS

MAIN FEATURES

Hydromicas, detrital quartz and $CaCO_3$ represent the chief mineralogical constituents of the examined fine-grained deposits of the SMGMS. Smectite appears to occur frequently in the green shale (see Gucwa & Ślączka, 1972; Gucwa, 1973; J. Köster, personal inform.), whereas increased organic carbon content is characteristic of the dark shales, mudstones and marls. Illite-smectite mixed layer minerals were recorded to exceed (58%) illite (38 and 24%) in two samples from the lower part of the SMGMS section at Rudawka Rymanowska (J. Köster, personal inform.). Kaolinite + chlorite accounts for 12% of the clay minerals in a sample of brownish marl, whereas in sample taken from a light-grey marl, this mineral reaches only 4%. Increased amounts of syderite, dolomite and subordinately rodochrosite are recorded besides $CaCO_3$ in the hard marl when compared to its soft variety. The carbonates, expressed as the $CaCO_3$, range from null to 78.5% within the fine-grained deposits. The carbonate material consists mainly of calcareous nannofossils and tests of planktonic foraminifera. Quartz in the silt fraction amounts only several percent in the light-coloured marls, whereas it reaches up to 40% in their dark-coloured varieties. Pyrite is the common constituent of the dark-coloured shales, marls and mudstones. The organic carbon and carbonate content, signals of O, C and S stable isotopes, and the amounts of foraminifera and calcareous nannofossils, all discussed below, were recognised to be strongly depended on the deposit type (Fig. 33). Hence, vertical distributions of these parameters show a distinctive, facies dependent pattern.

FORAMINIFERA AND THEIR DISTRIBUTION

Foraminifera represent the best-recognised constituent of the SMGMS deposits. Large species of planktonic and benthonic group (0.3–0.6 mm in cross-section) are characteristic of the lower sequence part (see Blaicher, 1970). These species appear just in the Green shale unit. *Globigerina corpulenta*, *G. eocaena*, *G. tripartita*, *G. yeguaensis*, and *G. hagni* are the most characteristic large planktonic species within the SMGMS (see Blaicher, 1970; Dabagian, 1987). The full list of the planktonic species recognised in the SMGMS deposits encompasses forty-three species (Olszewska, 1983). Among these, *G. linaperta* Finlay, *G. ampliapertura*, *G. apertura*, *G. pera*, *G. tapuriensis* and *Globoratalia cocoaensis* are indicated as stratigraphically most important.

An assemblage recorded in the upper part of the SMGMS consists of rare large species known from the lower part of the sequence, and of several new species of small foraminifera. The latter are represented mainly by chiloguembelinids, globanomalinids and bolivinids (see Blaicher, 1970). Agglutinated species become strongly reduced near the top of the SMGMS (see Olszewska, 1984).

Calcareous benthic foraminifera in the SMGMS are represented mainly by the Miliolidae, Bullimnidae, Rotalii-

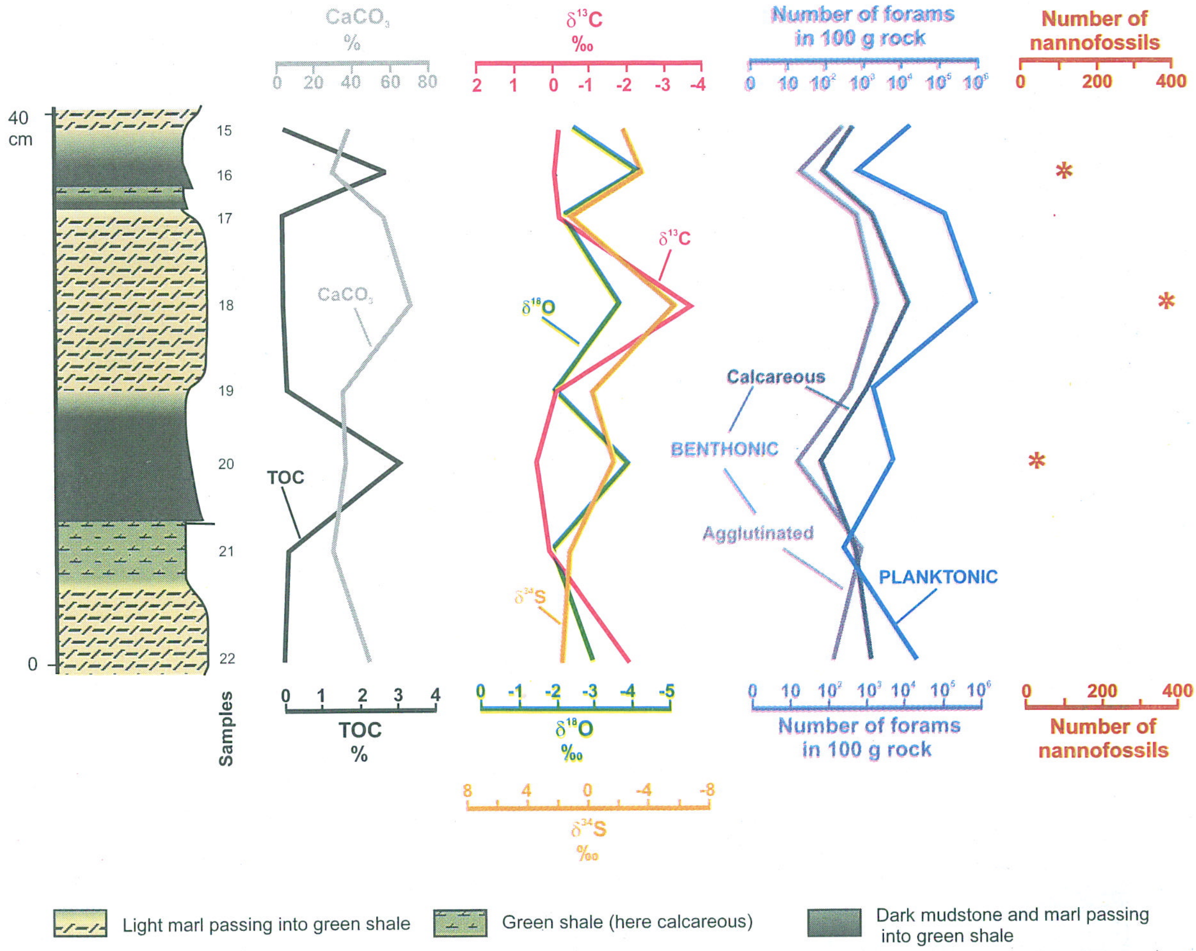


Fig. 33. Vertical pattern of the SMGMS typical fine-grained facies and their compositional trends. Part of the SMGMS at Znamirowice (see Figs. 11, 34). Nannoplankton content represents number of specimens in 20 fields of a smear slide, observed at magnification 800x.

dae and Anomaliniidae families (Blaicher, 1970). Hundred fifty species of the calcareous benthic foraminifera and 25 agglutinated species were recognised in the SMGMS (Olszewska, 1984). Ammodiscidae and Vulvulinidae are most abundant (Blaicher, 1970).

A detailed analysis of the foraminifera distribution in the SMGMS indicates a high variability of their assemblages depending upon facies (see Szymakowska, 1962; Leszczyński, 1996). However, this variability is yet poorly recognised. The richest assemblages are recorded in the light marl facies. As expected, the amount of planktonic foraminifera increases distinctively with the $CaCO_3$ content of the deposit. In beds containing more than 50% $CaCO_3$, as much as about 30% of the carbonate material consists of tests of planktonic foraminifers. In the Znamirowice section, the amount of specimens in the fine-grained deposits was recorded to vary from ca. 40 to nearly 750 thousands per 100 g of rock (Fig. 34; Leszczyński, 1996). The cream-yellow marl is there the richest in the foraminifera, whereas in the green and dark-grey to black marl and shale, the assemblages are far less numerous and less differentiated. Planktonic foraminifera are particularly abundant in the cream-yellow marl. The ratio of benthonic to planktonic specimens is highest in the dark-grey to black and the greenish, less calcareous deposits. The amount of benthonic foraminifera fluctuates insignificantly as compared to that of plankton. The calcareous specimens disappear entirely in the green shale.

The highest correlation of the foraminifera assemblages with the deposit type is recorded in the fine-grained facies of the upper part of the SMGMS. In its lower part, calcareous shale and marl layers show rare calcareous foraminifera (Fig. 35; cf. Blaicher, 1961; Oszczypko *et al.*, 1990). Corroded tests of calcareous species are common in less calcareous deposits (cf. Blaicher, 1970). In some samples of the black and cream-yellow marl, agglutinated species were not recorded at all.

In the deposits immediately above the SMGMS, foraminifera are less frequent (cf. Blaicher, 1961; Olszewska, 1980; Gruzman, 1987). Tiny, frequently pyritized and corroded globigerinids, chiloguembelinids and bollivinids, 0.03–0.1 mm in size, are there characteristic (Fig. 36; cf. Blaicher, 1970; Olszewska, 1980).

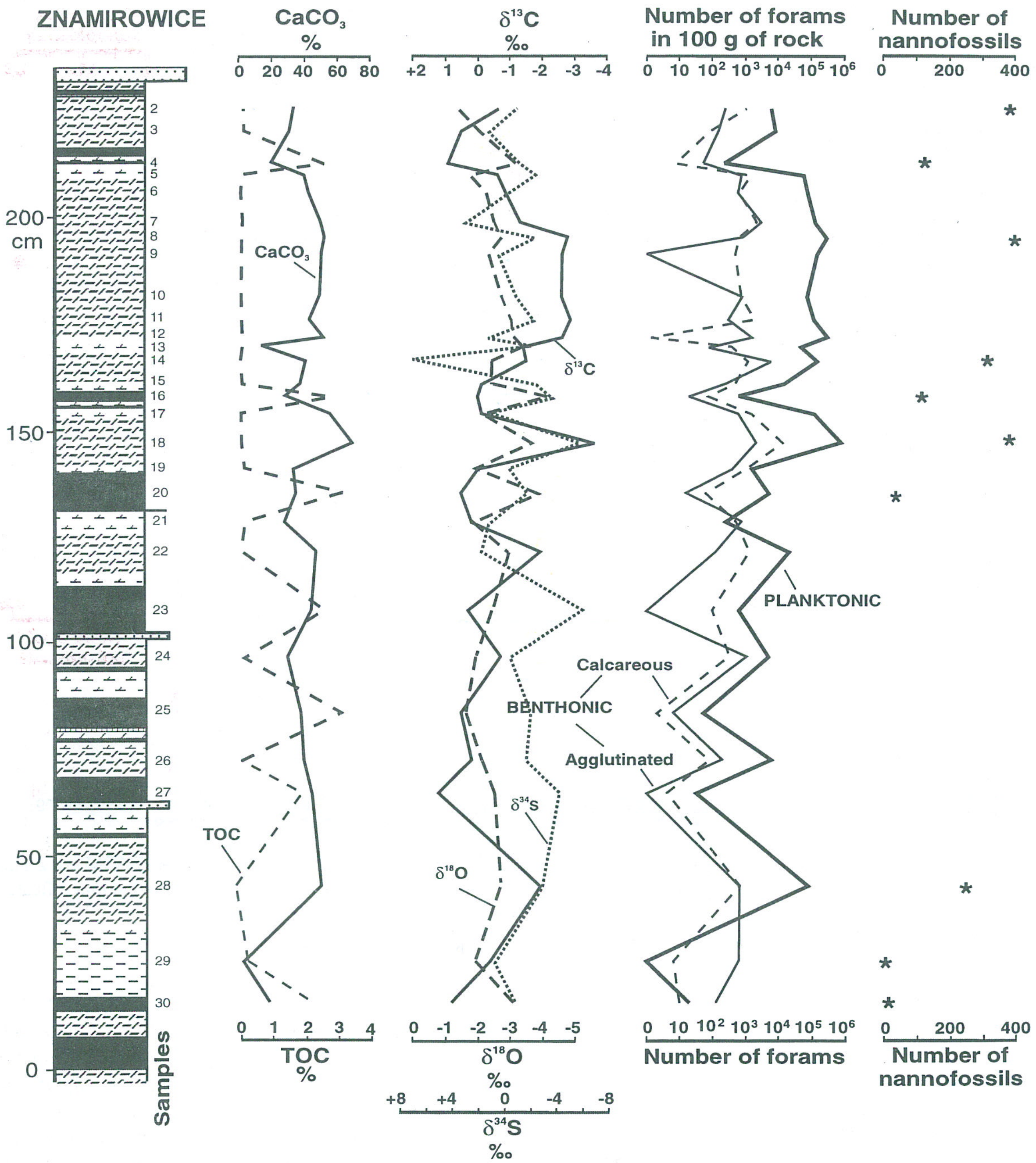


Fig. 34. TOC and carbonate contents, signals of C, O and S stable isotopes, and foraminifera and calcareous nannoplankton distribution in the upper part of the SMGMS at Znamirowice (cf. Fig. 11; details in Fig. 33). Nannofossil number explained in Fig. 33; extended from Leszczyński, 1996. For explanation of facies symbols see Figs. 3 & 33

CALCAREOUS NANNOFOSSILS AND THEIR DISTRIBUTION

Calcareous nannofossils are the chief constituents in the carbonate material of the fine-grained rocks examined. In smear slides, their content varies between 0 and 34 specimens per one observation field, depending upon sediment type (Fig. 34; Leszczyński, 1996). The specimens are most numerous (50–80% of the carbonate material) in a highly calcareous, weakly cemented light-coloured marl, as estimated in SEM. As expected, nannofossils disappear in the noncalcareous shales. Impoverished assemblages were recorded in dark-grey to black marls (Fig. 37) and in slightly calcareous green shales (cf. Krhovský *et al.*, 1993). Poorly preserved, corroded and recrystallised specimens were recorded in less calcareous dark-coloured deposits and a hard, light marl (Fig. 37B; see also Krhovský *et al.*, 1993; cf. Leszczyński, 1996).

Several tens of species were recognised in the SMGMS equivalent deposits (Krhovský *et al.*, 1993; Oszczypko, 1996). Representatives of the Prinsiaceae, Coccolithaceae, Discoasteraceae and Zygodiscaceae families are there most

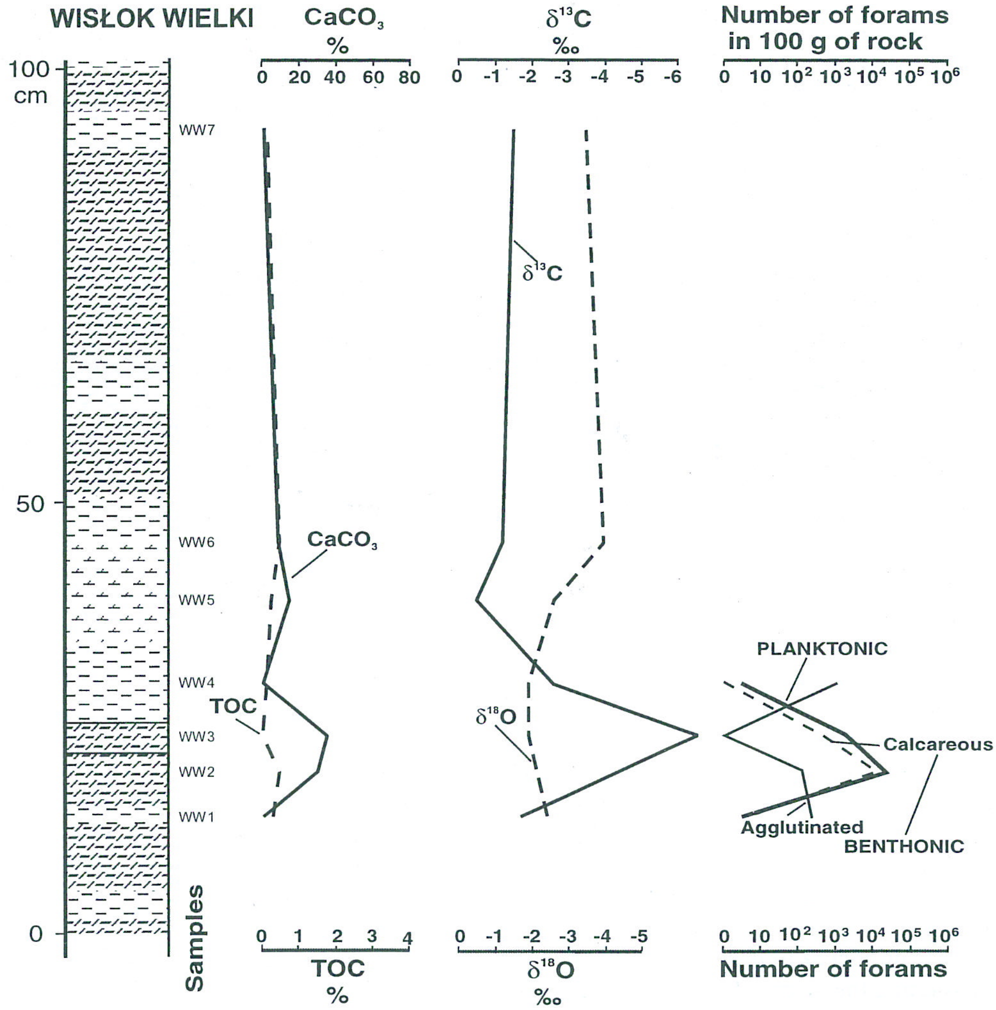


Fig. 35. TOC and carbonate contents, signals of C, O and S stable isotopes, and foraminifera distribution in the lower part of the SMGMS at Wisłok Wielki. The section is located in small valley, 2 km to N of the church in Wisłok Wielki. For explanation of lithofacies symbols see Figs. 3 & 33

profusely represented. However, the assemblages vary in composition, both vertically and laterally (cf. Radomski, 1968; Van Couvering *et al.*, 1981; Krhovský *et al.*, 1993; Oszczypko, 1996).

Krhovský *et al.* (1993) recognised five calcareous nannofossil assemblages in the SMGMS equivalent in the Czech Carpathians. These assemblages were interpreted to reflect various ecological demands and different vulnerability to dissolution. The spectrum increases with increasing carbonate content. The assemblage containing small Noelaerhabdaceae was considered as characteristic for high-productivity, normal marine settings. The other assemblage, containing *Dictyococcites bisectus*, was interpreted as indicative of near shore, nutrient-rich areas. Species interpreted as demanding a high nutrient supply and tolerant to considerable salinity fluctuations were distinguished in the third assemblage. The fourth assemblage includes species such as *Isthmolithus recurvus*, supposed to reflect a complex dependence on temperature, fertility, CCD, and dissolution vulnerability. Species supposed to characterise open-sea conditions, i.e. low nutrient content and normal salinity, rep-

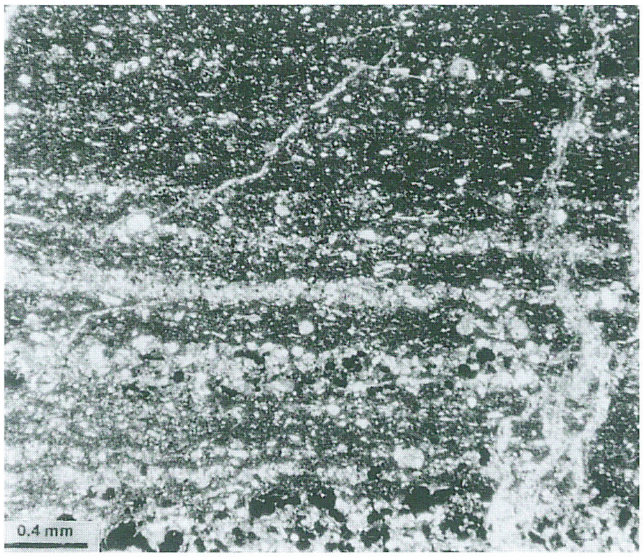


Fig. 36. Light-grey marl with silt laminae in the zebra-type facies of the Sub-Chert beds, at Żubracze (section location as in Fig. 7). Black material represents pyrite. Note the frequent occurrence of tiny foraminifera with pyrite fills

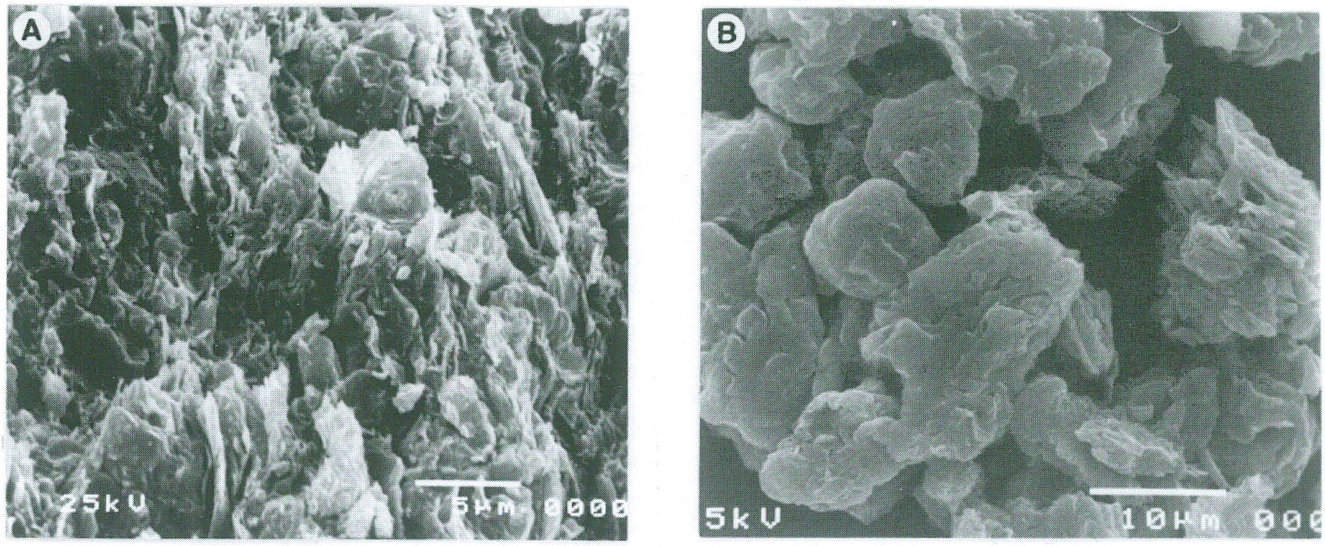


Fig. 37. Calcareous nannofossils in dark-coloured and hard light-coloured marl. SMGMS at Znamirowice (section location as in Leszczyński, 1996). (**A**) Poorly preserved and recrystalized nannofossils in hard marl. (**B**) Poorly preserved nannofossils in smear slide from dark-coloured marl

resent the fifth assemblage. *Discoaster tani, D. Nodifer* and *Reticulofenestra umbilica* are typical for this assemblage.

Krhovský *et al.* (1993) interpreted the calcareous nannofossil distribution as resulting primarily from different sedimentary conditions of the nannofossil-rich and the nannofossil-poor deposits. Diagenetic modifications were considered as of a minor significance. Because of a marked vertical variability in the amount and assemblage composition, nannofossils are considered to play a particularly important role in interpreting the origin of the entire SMGMS (see below).

CARBON AND CARBONATE CONTENT

There are distinctive differences in the content of both total organic carbon and carbonate content between the all facies distinguished in the SMGMS and the immediately overlying deposits (Figs. 33–35, 38). The TOC content in cream-yellow and beige marl is usually close to null. Values between 0.1 and 0.5% are characteristic of green shale and yellowish-green and grey marl. In the dark shale, mudstone and marl, TOC ranges 0.5–3.5%. Slightly elevated TOC contents are recorded in the layers of the light-coloured marl adjacent to the dark-grey to black marls and shales (Fig. 33, cf. Leszczyński, 1996). The frequent occurrence of burrows filled with dark-coloured material suggests that the TOC enrichment may result from bioturbation. Lowered TOC contents are characteristically recorded in the dark mudstones, shales and marls of the Sub-Chert beds at Żubracze.

The carbonates, expressed as the $CaCO_3$, attain their highest concentrations, ranging 50–80%, in a hard concretionary cream yellow and beige marl. Concentrations 40–50% are recorded in cream-yellow and beige soft marl. In the dark-grey to black shale and marl, carbonates amount up to 44.0%. The values obtained by wet titration of samples from Znamirowice are distinctively higher than those derived from the Coulomat data and from the data reported by Gucwa & Ślączka (1972), and Gucwa (1973; cf. Gucwa & Pelczar, 1992). X-ray diffraction analysis, besides the wet titration, has shown that calcite is the predominating carbonate phase in the calcareous shales and the soft light-coloured marl of the SMGMS. Siderite and ferroan dolomite equal or slightly surpass calcite in the hard, concretionary marl (Fig. 39). Rhodochrosite occurs also there in slightly increased amounts, particularly in the hard marl. Irrespective of the mineralogical composition of the carbonates, their concentration shows significant vertical variability reflected in the lithological changes (Figs. 33–35, 40, 41).

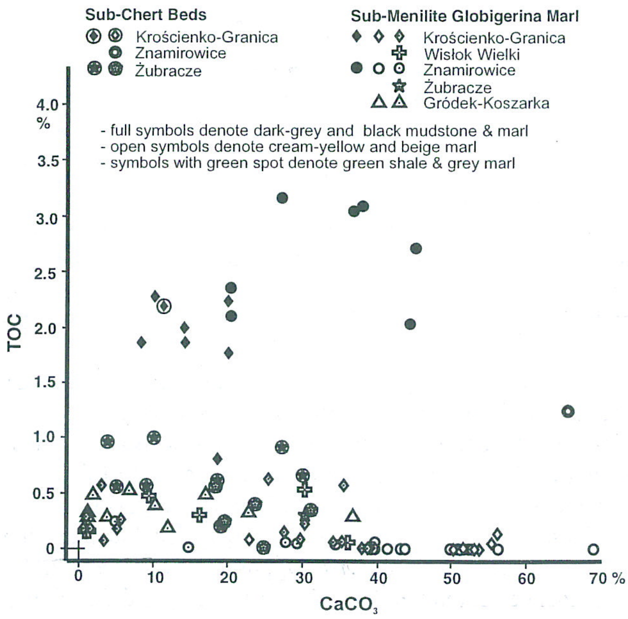


Fig. 38. TOC vs. carbonate content in the SMGMS and the immediately overlying deposits

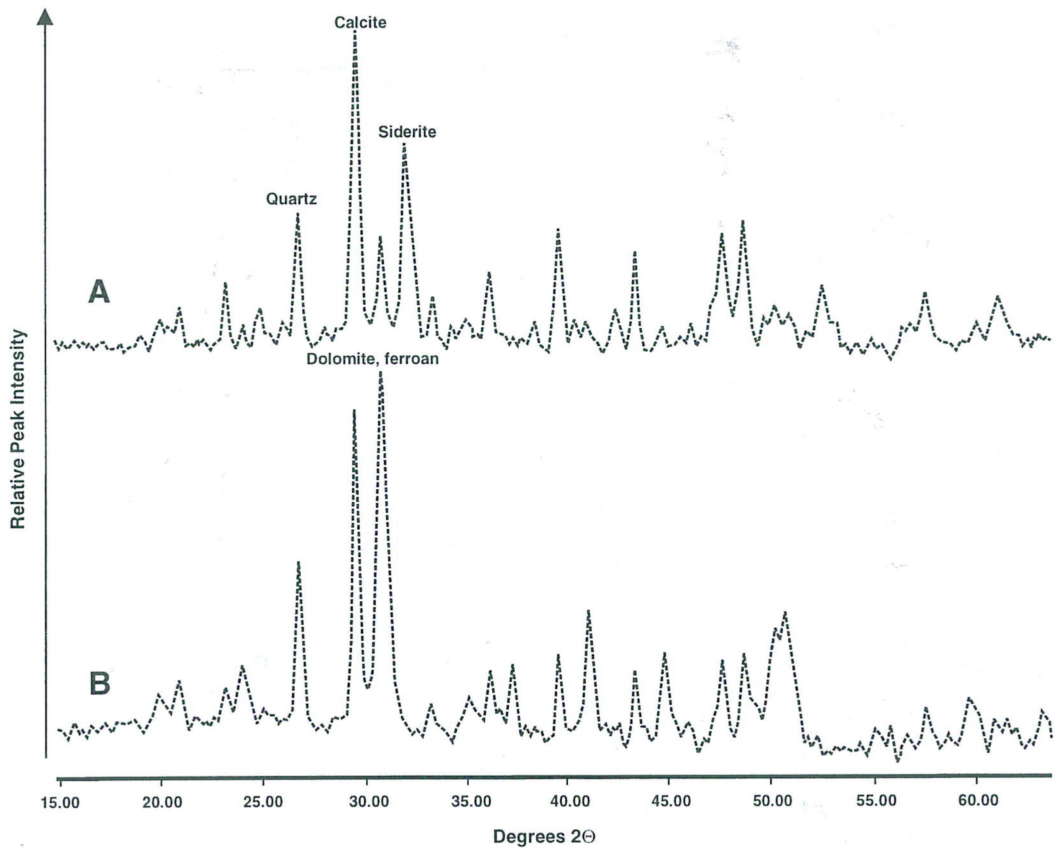


Fig. 39. Examples of X-ray diffractograms of hard marl. (**A**) Marl dominated by calcite, siderite, quartz and ferroan dolomite. SMGMS at Korzenna (section as in Fig. 22B). (**B**) Marl dominated by ferroan dolomite, calcite and quartz; SMGMS at Rudawka Rymanowska (section as in Fig. 14)

TYPE OF ORGANIC MATTER

The results of Rock-Eval pyrolysis (Tab. 6), when plotted in a diagram of HI (hydrogen index, i.e. milligrams of hydrocarbons evolved during kerogen breakdown, divided by wt % TOC content, x 100) versus $_{max}T$ (temperature of maximum hydrocarbon evolution from kerogen, °C), indicate that the organic matter is dominated by a hydrogen-poor Type III component (Fig. 42). However, a low TOC content in many samples (below 0.5%; Fig. 42C) precludes any reliable recognition of their kerogen type (see Lallier-Vergés *et al.*, 1993). Type II kerogen, determined at bulk sediment, as it was in this study, is strongly undervalued (Stein, 1991). The dominance of the Type II kerogen was recorded only in samples from the higher part of the Sub-Chert beds.

The temperatures of maximum hydrocarbon evolution from the kerogen (T_{max}) indicate that immature to highly mature organic carbon occurs in the examined samples (Fig. 42A). The immature, less thermally degraded organic matter is contained mainly in the samples from the Skole nappe. The highly thermally degraded organic matter occurs exclusively in the samples from the Sub-Chert beds at Żubracze.

The Type III kerogen consists mainly of polycyclic aromatic hydrocarbons and oxygenated functional groups. Such constituents are particularly characteristic of continental plants (see Tyson, 1995). Thus, the domination of the Type III kerogen in the analysed samples, particularly where the TOC content is >0.5%, indicates that their organic matter is basically of a terrestrial origin. The Type II kerogen, characteristic of marine organic matter (see Tissot & Welte, 1984) appears to be scarce in the SMGMS deposits. However, Gucwa & Wieser (1980) recorded significant influences of marine organic matter on the trace elements composition of these deposits.

MAJOR ELEMENTS AND THEIR CONCENTRATIONS

SiO_2, CaO and Al_2O_3 concentrations display high values irrespective of the deposit type (cf. Gucwa & Pelczar, 1992). Their proportion, however, distinguishes marls from shales and mudstones. Moreover, CaO shows a significantly higher variability than do SiO_2 and Al_2O_3 (cf. Gucwa & Pelczar, 1992). The SiO_2 content does not fall below 20%, Al_2O_3 content ranges 3–25%, whereas the CaO concentration varies between 0 and 34% (Tab. 7; cf. Gucwa & Pelczar, 1992).

Fe_2O_3, K_2O and MgO concentrations range usually from 1 to 5%. The Fe_2O_3 concentration amounts sometimes about 10%. Among the examined samples, the Fe_2O_3 concentrations in red and pinkish red deposits are higher than those in the adjacent green, light-green and light-grey ones. However, it is worth to note that the Fe_2O_3 concentrations in

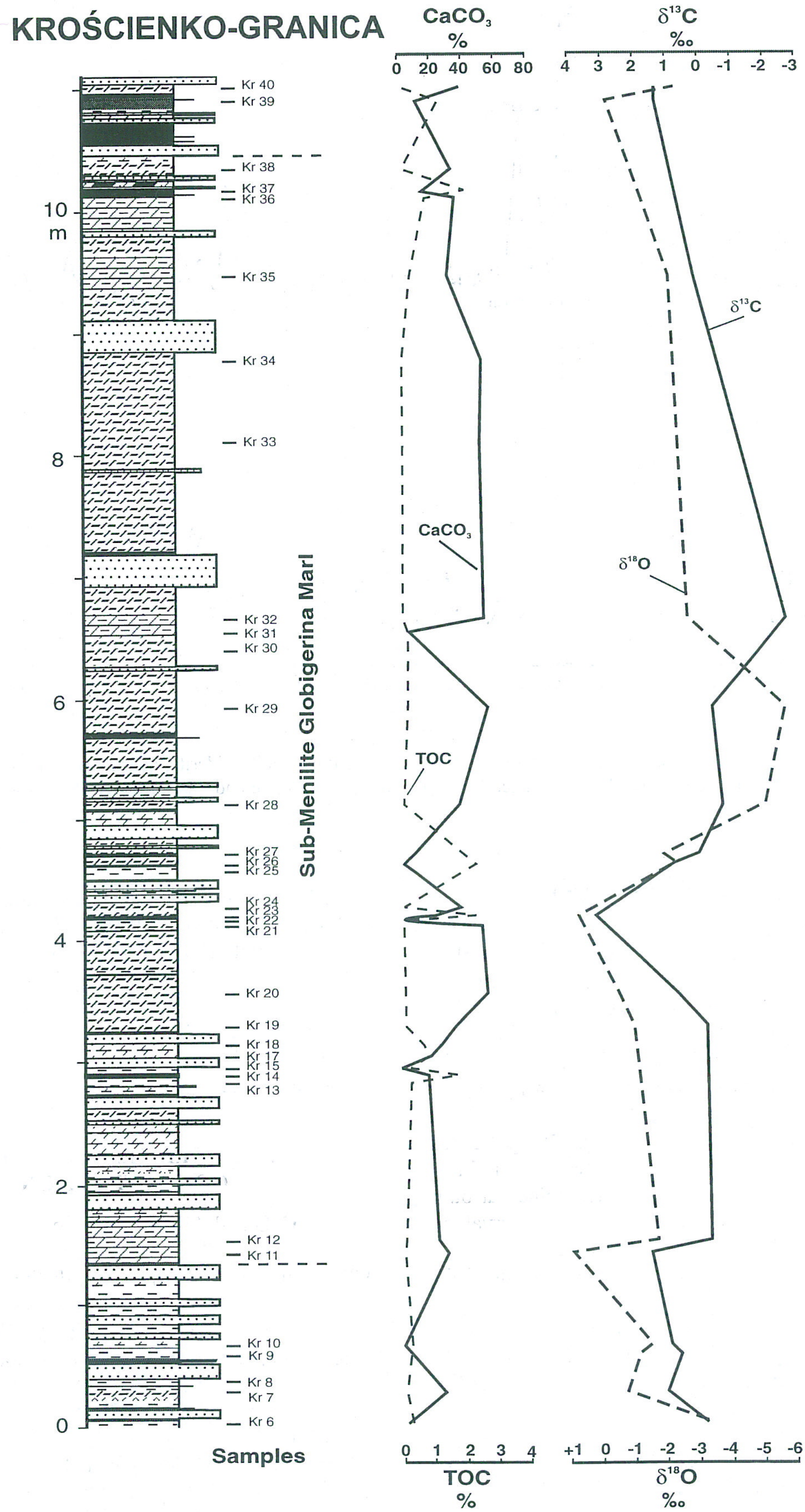


Fig. 40. TOC and carbonate contents, and signals of C and O stable isotopes in the SMGMS and the immediately underlying and overlying deposits at Krościenko-Granica (cf. Fig. 16). Carbonate content explained in text

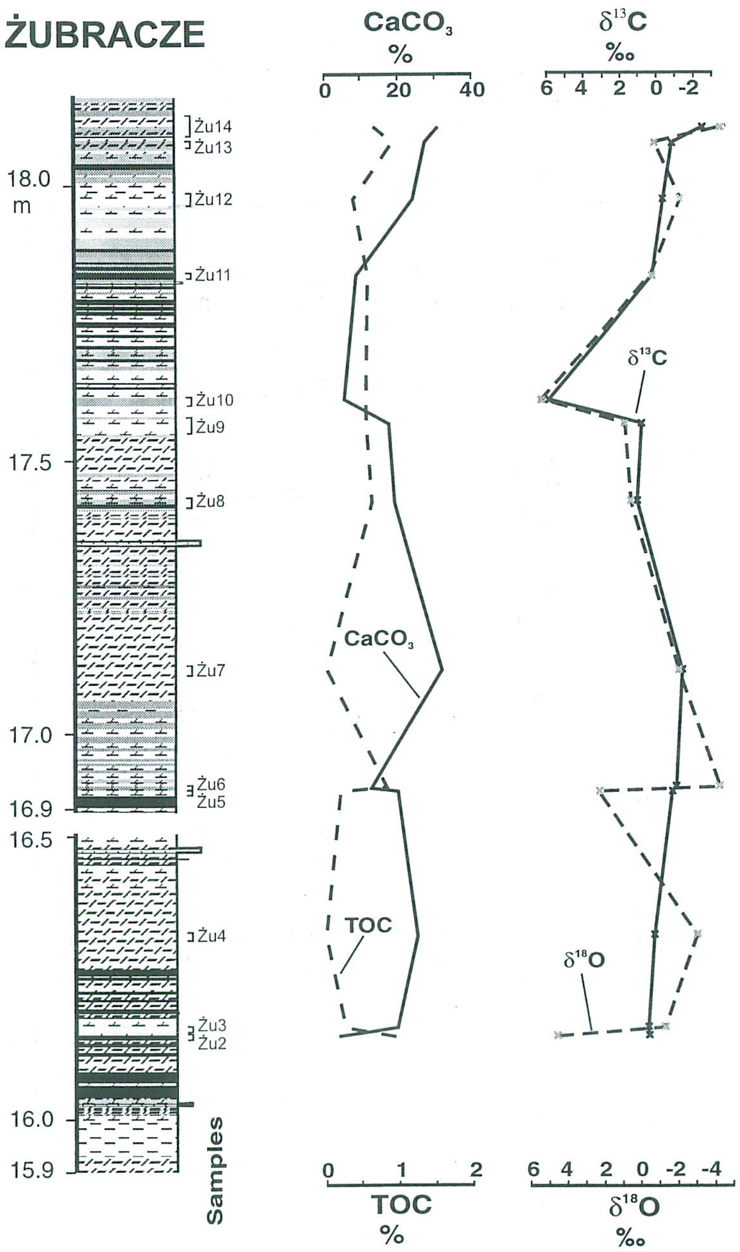


Fig. 41. TOC and carbonate contents and signals of C and O stable isotopes in the lower part of the Sub-Chert beds at Żubracze (cf. Fig. 7C). Carbonate content explained in text

the green shale at Siekierczyna are higher than those in the red and pinkish-red marl at Leluchów. The TiO_2 concentrations range usually 0.2–0.5%, whereas the MnO content does not exceed 0–0.2% (Gucwa & Pelczar, 1992). A higher amount of the latter compound, ranging 0.2–1.0%, appears to occur in the red and pink marl (Tab. 7).

ISOTOPES

The $\delta^{18}O$ and $\delta^{13}C$, and $\delta^{34}S$ values in the examined material range as follows (Fig. 43): -5.62 – +5.2 for $\delta^{18}O$, -6.50 – +3.2 for $\delta^{13}C$, -7.60 – +7.0 for $\delta^{34}S$. The ranges of the $\delta^{18}O$ and $\delta^{13}C$ signals are very wide and are generally significantly lower than those recorded globally in Upper Eocene and Lower Oligocene sediments (see Miller, 1992; Oberhänsli, 1996). The values of both isotope indices show a generally ca 2 to 5‰ negative shift relative to those reported by Krhovský *et al.* (1993) from the SMGMS and the lower part of the Sub-Chert beds equivalent deposits in the Czech Carpathians.

In the here examined samples, the $\delta^{18}O$ and $\delta^{13}C$ signals are generally lowest in the cream-yellow and beige marls, intermediate in the green shales and grey to yellowish green marls, and highest in the dark-coloured mudstones, shales and marls (Fig. 43). Such a tendency is particularly well marked in the $\delta^{13}C$ values. The $\delta^{18}O$ signals in the dark-coloured deposits are similar or lower as compared to those in the green ones. This is best expressed in the Znamirowice section (see Leszczyński, 1996). There are no marked differences in the range of both isotope indices between the lowest and the uppermost part of the section.

The $\delta^{18}O$ and $\delta^{13}C$ values show some correlation with each other, and with the $CaCO_3$ and TOC contents (Tab. 8; Figs. 33, 40, 41). The correlation is, however, different in particular sections. Most variable is the correlation between the isotope signals themselves. It is significant only in the Krościenko-Granica and Żubracze sections. In the Znamirowice section, only the light-coloured marl and green shale show a distinct positive correlation between $\delta^{18}O$ and $\delta^{13}C$ (correlation coefficient, r= 0.765; cf. Leszczyński, 1996). There is no significant correlation between the $\delta^{18}O$ and $CaCO_3$ and TOC contents, except for the Sub-Chert beds section at Żubracze. On the contrary, the $\delta^{13}C$ values show a quite good inverse correlation with the $CaCO_3$ content, and are positively correlated with the TOC contents. The increased carbonate content correlates well with the negative shifts of the $\delta^{13}C$ values.

A strong positive correlation between $\delta^{18}O$ and $\delta^{13}C$ in the SMGMS-equivalent section was recorded by Krhovský *et al.* (1993). The isotopic pattern recognised in that section was mentioned as possibly reflecting environmental signal. However, they emphasized an antithetic tendency of this pattern with respect to the global trend, as a factor complicating the interpretation.

The $\delta^{18}O$ and $\delta^{13}C$ data recorded in this study apparently reflect mainly the isotopic signal of the carbonate fine-fraction, mostly of calcareous nannofossils which dominate the calcareous material. Moreover, calcareous foraminifera, mainly planktonic, and carbonate cement may have influenced the bulk rock signals. The foraminiferal signal has probably not significantly altered that inherent to calcareous nannofossils (?±1‰). Much more important are the influences of cement. Early diagenetic cement is known to shift the bulk rock $\delta^{18}O$ and $\delta^{13}C$ signals towards lighter values. In contrast, late cements, e.g. those formed after methanogenesis can make the $\delta^{13}C$ of the bulk rock significantly

Table 6

Rock-Eval pyrolysis results

L.p.	Section, unit, sample number and rock type	Pyrolysis parameters							
		TOC wt %	T_{max} °C	S_1	S_2	S_3	PI	HI	OI
	Bóbrka, Sub-Chert Beds								
1.	Bó1: brown marl	1.53	422	0.13	4.32	0.88	0.03	282	57
2.	Bó4: brown marl	5.49	420	0.58	20.29	1.27	0.03	369	23
	Bóbrka, SMGM								
3.	Bó10: black shale	1.59	435	0.06	1.19	1.93	0.05	74	121
	Darów, Sub-Chert Beds								
4.	Da13: dark-brown marl	1.58	427	0.16	4.36	0.57	0.04	275	36
5.	Da12: dark-brown marl	4.30	427	0.27	11.07	0.89	0.02	257	20
6.	Da11: brown marl	0.82	427	0.04	1.41	0.44	0.03	171	53
	Darów, Hieroglyph. Beds								
7.	Da8: dark-green shale	0.58	427	0.04	0.38	0.60	0.10	65	103
8.	Da7: black shale	4.15	425	0.09	3.59	1.52	0.02	86	36
	Krościenko-Granice, Sub-Chert Beds								
9.	Kr39: brown mudstone	2.19	434	0.02	2.23	2.29	0.01	101	104
	Krościenko-Granice, SMGM								
10.	Kr27: brown mudstone	1.82	425	0.05	2.11	2.21	0.02	115	121
11.	Kr26: dark-brown mdst.	3.23	427	0.04	4.47	1.79	0.01	138	55
12.	Kr23: dark-grey mdst.	2.99	431	0.03	3.37	2.12	0.01	112	70
	Krościenko-Granice, Bartkówka Sdst. Member								
13.	Kr10: dark-green shale	0.75	431	0.02	0.44	0.64	0.04	58	85
14.	Kr5: green shale	0.37	419	0.00	0.18	0.66	0.00	48	178
15.	Kr4: dark-grey shale	1.69	435	0.02	1.43	1.40	0.01	84	82
	Obarzym, Sub-Chert Beds								
16.	Ob2: dark-grey shale	1.40	426	0.03	1.30	1.75	0.02	92	125
	Obarzym, SMGM								
17.	Ob4: green.-yellow marl	0.76	419	0.04	0.74	1.24	0.05	97	163
18.	Ob6: dark-brown shale	2.40	425	0.08	2.25	2.39	0.03	93	99
	Znamirowice, Sub-Chert Beds								
19.	Zn1: beige marl	1.29	435	0.05	1.52	1.75	0.03	117	135
	Znamirowice, SMGM								
20.	Zn4: dark-grey shale	2.45	435	0.04	1.89	1.91	0.02	77	77
21.	Zn16: black marl	2.80	434	0.04	2.16	2.01	0.02	77	71
22.	Zn20: black marl	3.11	433	0.07	3.27	2.08	0.02	105	66
23.	Zn23: black marl	2.50	434	0.05	2.48	1.94	0.02	99	77
24.	Zn25: black marl	3.12	436	0.07	3.01	2.10	0.02	96	67
25.	Zn27: dark-grey marl	2.01	434	0.05	1.80	1.62	0.03	89	80
26.	Zn29: green shale	0.25	436	0.00	0.10	0.46	0.00	40	184
27.	Zn30: black shale	2.19	436	0.05	1.72	1.98	0.03	78	90
	Żubracze, Sub-Chert Beds								
28.	Żu2: dark-grey shale	0.54	456	0.05	0.45	0.28	0.10	83	51
29.	Żu3: light-grey shale	0.44	457	0.06	0.38	0.16	0.14	86	36
30.	Żu5: light-grey shale	0.30	457	0.02	0.19	0.24	0.10	63	80
31.	Żu6: dark-grey shale	0.65	455	0.09	0.47	0.56	0.16	72	86
32.	Żu8: dark-grey shale	0.59	454	0.06	0.41	0.26	0.13	69	44
33.	Żu9: light-grey shale	0.25	468	0.02	0.14	0.25	0.12	56	100
34.	Żu10: grey shale	0.29	452	0.04	0.25	0.28	0.14	86	96
35.	Żu11: dark-grey shale	0.24	?	0.04	0.18	0.15	0.18	75	62
36.	Żu13: dark-grey shale	0.69	456	0.11	0.43	0.15	0.20	62	21
37.	Żu14: dark-grey shale	0.53	454	0.09	0.25	0.12	0.26	47	22

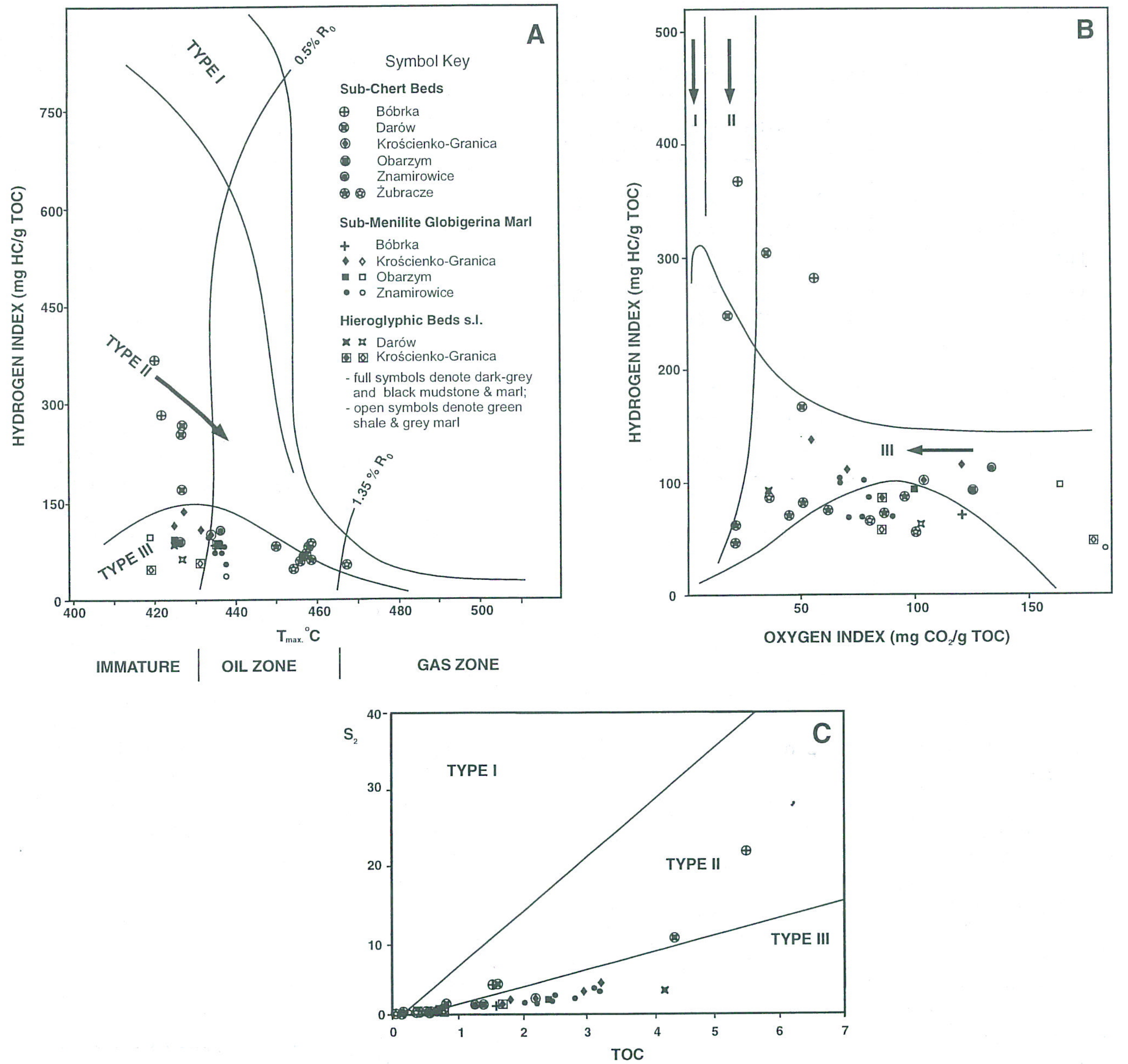


Fig. 42. Type of kerogen determined by Rock-Eval pyrolysis in the fine-grained rocks of the SMGMS and the immediately underlying and overlying deposits. (**A**) Type of kerogen indicated by the relation between hydrogen index (HI) and the temperature of maximum hydrocarbon evolution (T_{max}). (**B**) Type of kerogen indicated by the relation between hydrogen index (HI) and oxygen index (OI). (**C**) 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)

heavier (see Arthur *et al.*, 1989; Tucker & Wright, 1990).

The wide range of the $\delta^{18}O$ and $\delta^{13}C$ signals recorded in the examined sections and the stable composition of the primary carbonate material both suggest a substantial modification of the isotopic record by diagenesis (cf. Leszczyński, 1996). This is indicated primarily by the shift of the isotope signals toward lighter values, relative to those recorded globally for the late Priabonian by the foraminifera. Two different diagenesis types have presumably modelled the signals. Early diagenesis related to shallow-burial organic matter decay, besides synsedimentary environmental conditions, appears to have been responsible for the strongly negative $\delta^{13}C$ values characteristic of the light marl. Such values may result from an increased proportion of $CaCO_3$ formed by CO_2 released due to the degradation of organic matter in oxic and sulphate-reducing conditions (see Irwin *et al.*, 1977; Berner, 1981; Broecker & Peng, 1982; Maynard, 1982; Shackleton *et al.*, 1983; Tucker & Wright, 1990).

The $\delta^{13}C$ values in the TOC-enriched dark-coloured deposits, being significantly heavier than in adjacent beds, while their $\delta^{18}O$ are similar to those in the light-coloured marls (Figs. 33), suggest modelling by carbonates formed after methane fermentation in the sediment. Methane is formed from the organic matter that escapes earlier oxic degradation. CO_2 displaying heavy $\delta^{13}C$ and, consequently,

Table 7

Concentration of 10 major-element oxides in marl and shale of different colour

Section, sample number and rock type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	Total %
Leluchów												
Lu7: light-green marl	38.72	13.12	4.14	0.22	1.70	19.43	0.50	2.65	0.58	0.09	19.76	100.9
Lu11: light-grey marl	35.96	13.23	4.29	0.29	1.74	20.44	0.43	3.03	0.52	0.10	20.58	100.6
Lu12: red marl	39.78	11.51	4.98	0.30	1.78	18.79	0.61	2.52	0.51	0.12	18.91	99.8
Lu13: pinkish-red marl	36.64	11.58	4.71	0.22	1.70	21.72	0.58	2.56	0.48	0.11	20.54	100.9
Lu14: red marl	22.92	7.42	4.34	0.39	1.28	33.61	0.30	1.66	0.30	0.08	28.63	100.9
Siekierczyna												
Si13: green shale	57.03	18.27	5.08	0.06	1.92	2.31	0.43	3.73	0.81	0.09	9.59	99.3
Si14: pinkish-red marl	37.98	13.06	9.87	0.46	1.41	14.73	0.28	2.51	0.55	0.08	18.72	99.6
Si16: green shale	56.46	19.24	5.41	0.05	2.09	1.37	0.46	3.78	0.84	0.09	9.47	99.3
Si18: pinkish-red marl	33.27	11.00	10.56	0.94	1.25	18.92	0.26	2.25	0.47	0.09	21.28	100.3
Si22: light-green shale	52.99	14.35	4.13	0.08	1.60	9.22	0.36	2.96	0.66	0.09	13.38	99.8

adequate carbonates are the result of such a process (see e.g. Tucker & Wright, 1990). Hence, this process affected primarily the significantly TOC-enriched deposits. The $\delta^{13}C$ signals in some light marls suggest that such carbonates occur not only in the deposits which presently contain more TOC. The enrichment in ^{13}C is particularly characteristic for the carbonates of the Menilite beds (see Koltun, 1992). However, this is not the case of the Żubracze section.

The dependence of the $\delta^{18}O$ and $\delta^{13}C$ signal modifications on the primary $CaCO_3$ and organic matter concentration in the sediment suggests that the least distorted signals come from green shales. In contrast, most complexely modified are the $\delta^{13}C$ signals in the dark-coloured rocks. The $\delta^{18}O$ values in this rocks as well as the signals of both indices in the light-coloured marls appear to differ from the original ones only by their negative amplification. (cf. Leszczyński, 1996).

The $\delta^{34}S$ values in the examined upper part of the SMGMS at Znamirowice are relatively high. Distinctively lighter signals come from the TOC-enriched beds as compared with those from the surrounding green shales (Fig. 34). In general, the signals are, however, not very precise because of a relatively low sulphur content in these rocks (0–0.24 wt %; see Gucwa & Ślączka, 1972). Paleontological data point to sedimentation of these deposits on an well-oxygenated sea floor. Thus, the sulphate reducing conditions (sulphidic acc. Berner, 1981) could have developed there only well below the sediment/water interface. Moreover, the sulphates enclosed in pore waters may chiefly have been used for the sulphide formation. Still, the sulphidic conditions developed earlier in the deposits richer in organic matter. Such process of the sulphide formation is also suggested by the lighter $\delta^{34}S$ in the dark-coloured beds. A bacterially preferred ^{32}S was used in a higher proportion in the production of sulphides contained in the dark-coloured beds.

In contrast, the sulphides in the light-coloured beds could have been formed after a deeper burial of these deposits. H_2S produced *in situ* and/or supplied from other beds was there used. The sulphides generated from the indigenous H_2S should display slightly lighter $\delta^{34}S$ signals, more close to those of the sulphates contained in the bottom water, than the other ones (see Maynard, 1980).

Table 8

Correlation of $\delta^{18}O$ and $\delta^{13}C$ signals and $CaCO_3$, and TOC contents in the SMGMS sections. Section stratigraphy explained in the text

Correlated parameters	Correlation coefficients in particular sections: Krościenko-Granica	Wisłok Wielki	Znamirowice	Żubracze
$\delta^{13}C/\delta^{18}O$	0.634	-0.125	0.231	0.644
$\delta^{18}O/CaCO_3$	-0.285	-0.114	-0.147	-0.670
$\delta^{13}C/CaCO_3$	-0.371	-0.776	-0.506	-0.637
$\delta^{18}O$/TOC	0.272	-0.257	-0.361	0.311
$\delta^{13}C$/TOC	0.449	0.639	0.589	0.040

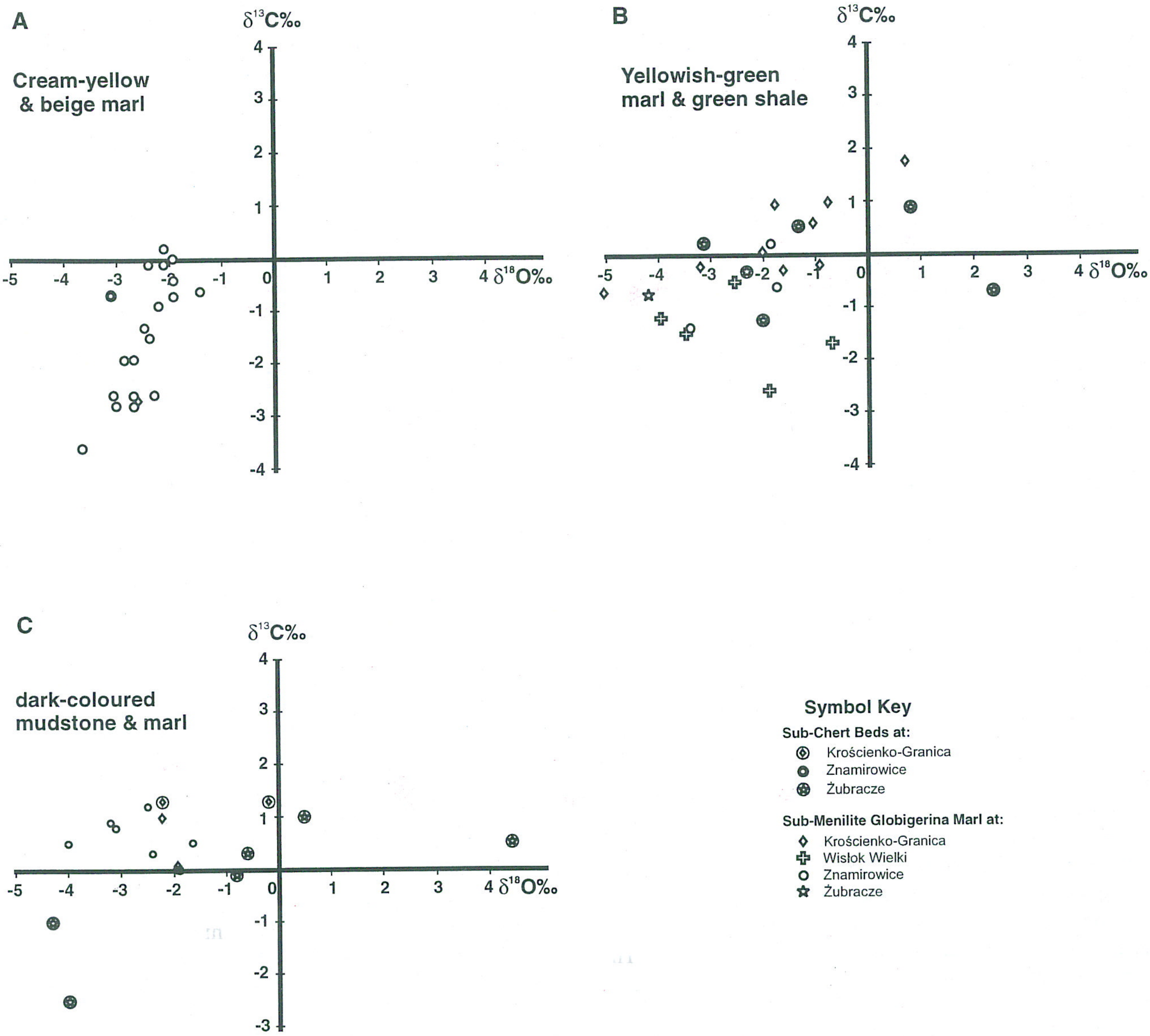


Fig. 43. Stable isotope signals of carbonates contained in cream-yellow and beige marl (**A**), yellowish-green marl and green shale (**B**), and dark-grey to black mudstone and marl (**C**) of the SMGMS and the lower part of the Sub-Chert beds. Extreme signals, $\delta^{18}O = 5.3$ (sample Żu10 from Sub-Chert Beds, Żubracze section), $\delta^{18}O = -5.62$ (sample Kr 29 from SMGMS at Krościenko-Granica), and $\delta^{13}C = -6.5$ (sample WW1, lower part of SMGMS at Wisłok Wielki) not included (see Figs. 34, 38, 39 for sample location)

DEPOSITIONAL PROCESSES

The earlier discussed textures and sedimentary structures of the fine-grained deposits dominating in the SMGMS indicate sedimentation mainly particle-by-particle from the water column with some influences of a lateral transport along the sea floor. The cream-yellow and beige, non-laminated marl, most characteristic for the SMGMS, as well as the red marl in which clay-sized terrigenous particles dominate, represent muddy pelagic ooze (arl; see Pickering *et al.*, 1986, facies G1.2). Similarly, the mottled, non-graded clayey green shales appear to represent the pelagic deposits (facies E1.2 of Pickering *et al.*, 1986). The grey, yellowish-green, greenish-grey, and beige-grey nonlaminated marls, as well as the cream-yellow marl distinctively enriched in terrigenous silty material and the muddy, non-graded shales, appear to represent mainly hemipelagites, i.e. deposits accumulated slowly by vertical settling, with substantial contribution from the land runoff (facies G2 of Pickering *et al.*, 1986). Also the dark-coloured laminae showing indistinctive bounding surfaces, that occur surrounded by green shale, represent hemipelagic deposit. This is supported by the domination of the type III kerogen in these laminae. Hence, the zebra-type deposits may be considered as of a mixed, pelagic and hemipelagic origin.

The marl and shale layers showing subtle silt streaks and mottles were deposited particle-by-particle with occasional lateral transport by bottom currents. These deposits may represent muddy contourites (facies E1.3 of Pickering *et al.*, 1986).

The several millimetres to a few centimetres thick silty and fine sandy laminae within green shale or light marl may have originated from traction currents (contour currents) and from low-concentration turbidity currents (facies D1.3 of Pickering *et al.*, 1986).

The shales, mudstones and marls, which occur in layers showing sharp lower boundaries and normal grading, were deposited from turbidity currents (facies E1.1 and E2.1 of Pickering *et al.*, 1986). This concerns mainly the dark-coloured and greenish-grey variety of these deposits. The foraminifera assemblages contained in the middle or upper part of such beds suggest that they were redeposited from an outer shelf or upper slope. The medium-thick and thick beds of dark-coloured marl, lacking lamination in their lower part, such as those in the Sub-Chert beds of the Grybów unit, could have resulted either from high-concentration turbidity currents or from ponding of thick dilute turbidity currents (cf. Ślączka, 1990).

The hard marl layers represent a diagenetically modified deposit (concretionary beds). This is indicated by the high proportion of siderite and ferroan dolomite in their carbonate material. They represent diagenetically changed muddy ooze (facies G3 of Pickering *et al.*, 1986). The beds and lenses of the limonite impregnated deposit belong also to this facies. Their origin is, however, more complex. The impregnation by iron hydroxides appears to have resulted from the subaerial weathering of iron sulphides and siderite contained in the original rock. The bedding parallel layers of the impregnate may have been formed along zones of intensified water circulation.

The sandstone-mudstone and siltstone-mudstone couplets, as well as the lithologic sets consisting of conglomerate–sandstone–siltstone–mudstone or sandstone–siltstone–mudstone, sharply bounded beds of muddy sandstone and the graded and the ungraded sandstone beds, all are chiefly turbidites. Low-concentration turbidites (facies C2.3, D2 of Pickering *et al.*, 1986) dominate in the SMGMS over other turbiditic facies. The conglomerate–sandstone–mudstone sets as well as the thick sandstone–mudstone couplets were deposited from high- to low-concentration turbidity currents. The mottled sandstones appear to have been deposited from turbidity currents as well. The sharp bounded sandstone beds were probably laid down from turbidity currents which deposited their finer-grained load further in the basin. This concerns primarily the non-laminated, nongraded to normally graded beds. The laminated variety of such beds and the several millimetres to several centimetres thick sharply bounded layers of coarse grained sandstone may be of a similar origin. However, the latter may also represent a lag deposit resulting from winnowing by strong bottom currents (cf. Mutti & Ricci Lucchi, 1975). The thick muddy sandstone beds were deposited from high-concentration turbidity currents or from debris flows (facies C1.1 of Pickering *et al.*, 1986). The single beds of contorted and balled strata resemble those generally interpreted as formed by sliding and slumping.

The Green shale unit, underlying the SMGMS, appears to be composed mainly of hemipelagites. Various turbidites, including thick muddy beds, as well as fluidized flow, debris flow, and slump deposits occur besides hemipelagites and pelagites, and chemogenic deposits in the Sub-Chert beds. The mass-gravity deposits prevail in some parts of this unit.

SEDIMENTARY ENVIRONMENT

Structural reconstructions indicate that at the Eocene–Oligocene transition the Outer Carpathians formed a complex remnant basin (see Einsele, 1992; Figs. 44, 45). This basin consisted of several subbasins separated by subaqueous to subaerial elevations (ridges; see Książkiewicz, 1956, 1960, 1962). The separation of this basin from the main part of the Tethyan Ocean by emerged and elevated fold-thrust areas suggests that it was a sort of an adjacent sea (*sensu* Einsele, 1992).

According to Olszewska (1984), the foraminifera assemblages of the SMGMS point to sedimentation outside the shelf in the upper bathyal zone. A similar interpretation was suggested earlier by Książkiewicz (1975). In his opinion, the absence of *Trochamminoides* precludes sedimentation of the SMGMS deposits at greater depths. Książkiewicz (1975) interpreted the Hieroglyphic beds underlying the SMGMS as deposited in the upper mesobathyal zone. *Trochamminoides*, however, was recorded by Olszewska (1984) in the lower part of the SMGMS. Moreover, other taxa characteristic of the lower and mesobathyal depths (600–2000 m) she recorded there as well.

The bathymetric interpretations by Książkiewicz (1975) and Olszewska (1984) suggest sedimentation of the SMGMS and the underlying and overlying deposits well above the calcite compensation depth suggested for the Eocene oceans (see Melguen, 1978). Such interpretation, however, appears controversial for the present author. The non-calcareous background deposits underlying the SMGMS in the Silesian nappe, with their essentially deep-water agglutinated foraminifera assemblage (Geroch *et al.*, 1967; Blaicher, 1967), suggest sedimentation well below the CCD (cf. Winkler, 1984). At the same time, sedimentation above CCD is indicated by the stratigraphically equivalent, predominantly calcareous background deposits in the Sub-Silesian nappe and the Fore-Magura thrust folds. Consequently, a significant CCD drop may have occurred with the onset of the SMGMS sedimentation (cf. Olszewska, 1984). This coincides with the globally recorded drastic CCD drop. Thus, this coincidence does not appear accidental. Moreover, the lateral variability of the SMGMS pattern appears to result in part from the CCD fluctuation relative to the bathymetry of the flysch basins.

The laterally variable distribution of the fine-grained calcareous deposits together with the significant thickness variations of the SMGMS appear to have resulted from markedly contrasted bathymetry of particular basins relative to CCD. Furthermore, the upward growing thickness of the marl beds at the cost of that of the green shale interbeds, together with a change in the benthic foraminifera assemblage (see Olszewska, 1984), appear to reflect a progressive, though fluctuating CCD drop. According to Krhovský *et al.* (1993), sedimentation at depths close to CCD is evidenced by the abundant occurrence of *Isthmolithus recurvus*. Thus,

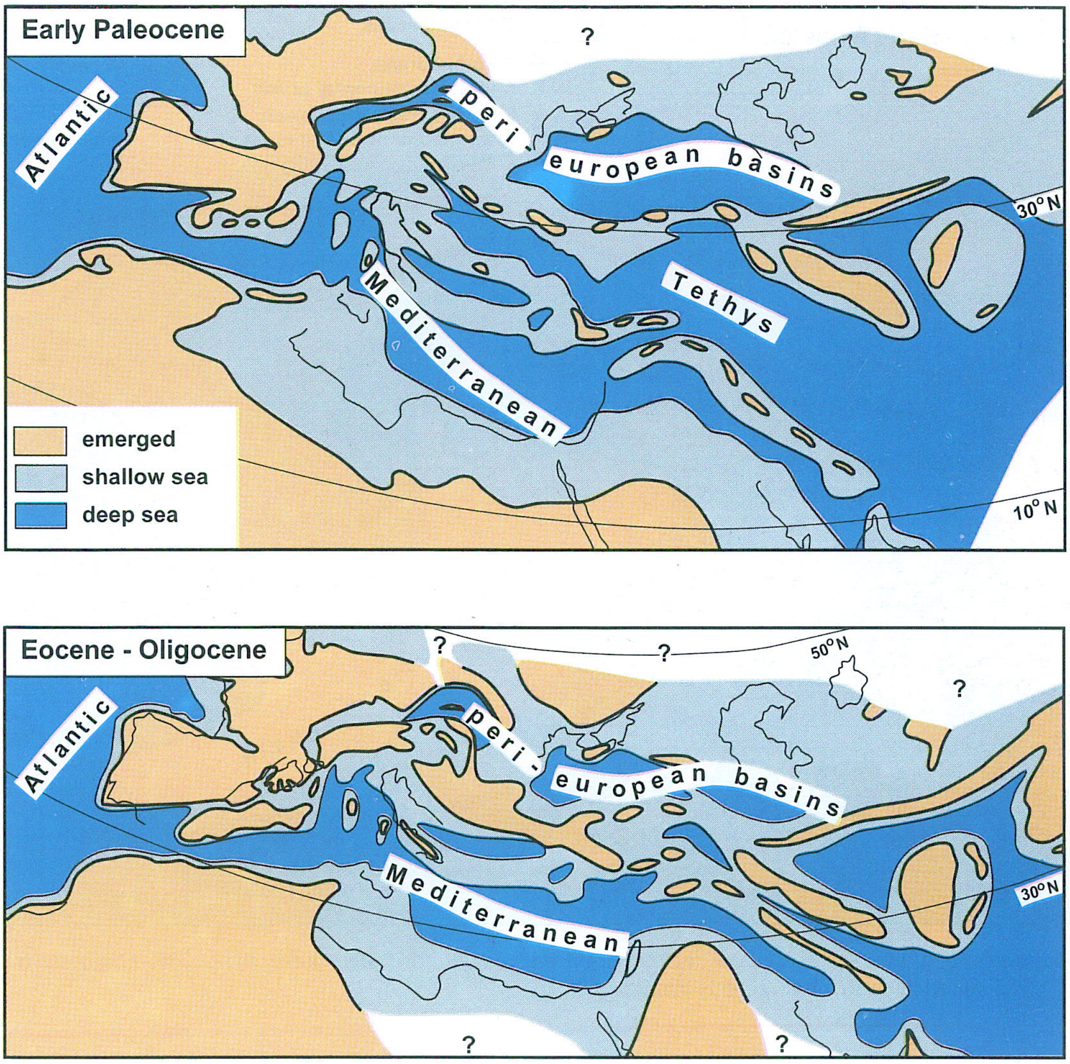


Fig. 44. Paleogeography of the Mediterranean Tethys during the Paleogene (modified from Dercourt *et al.*, 1985 and Ricou *et al.*, 1986)

such sedimentation is recorded in the SMGMS at Znamirowice and in the lower part of this sequence at Krosno (Van Couvering *et al.*, 1981). Consequently, the sections at Skawinki, Śmierdziączka (see Radomski, 1968), and Leluchów (see Oszczypko, 1996) appear to be deposited at slightly shallower depths. The sedimentation at relatively shallow depths of the Leluchów section and of the sections in the SMGU and the Sub-Silesian nappe, is also indicated also by the extensive occurrence of calcareous fine-grained deposits in the sequence underlying the SMGMS. In contrast, the deepest sites in the basins are represented by sections lacking the SMGMS equivalent calcareous background deposits.

The dominance and abundant occurrence of *Isthmolithus recurvus* together with *Coccolithus pelagicus* and different reticulofenestrids, as well as the occurrence of *Chiasmolithus oamaruensis* and subordinate amounts of discoasterids and *Sphenolithus pseudoradians* in the SMGMS, point to sedimentation in a temperate cool sea (Van Couvering *et al.*, 1981; Aubry, 1992). Similar conditions are indicated by the foraminifera assemblages (Olszewska, 1983). However, the vertical variability of the calcareous nannofossils recognised in the SMGMS equivalent in the Czech Carpathians (Krhovský *et al.*, 1993), suggest fluctuation of salinity, evaporation and fertility in the flysch basins.

The high proportion of terrigenous silt in the fine-grained deposits and the frequent occurrence of turbidites composed chiefly of terrigenous material point to a significant influence of lands on the sedimentation of the SMGMS. Moreover, the TOC-enriched dark shales, mudstones and marls dominated by the type III kerogen, and usually displaying features indicative of mass resedimentation, suggest an intense influx of organic matter from lands. The lateral variability in the proportion and character of terrigenous deposits suggests that the land impact varied laterally. Its scale was controlled by basin morphology (cf. Koszarski & Żytko, 1959) and the distance from the main pathways of the terrigenous material supply. The land impact decreased generally with the growing distance from tectonically active basin margins. The intense supply of terrigenous material precluded the sedimentation of the SMGMS-characteristic marls in some areas (Figs. 2, 46B). The distribution of coarse-grained deposits and their features, except for those of the Skole nappe, point to island chains (cordilleras) that

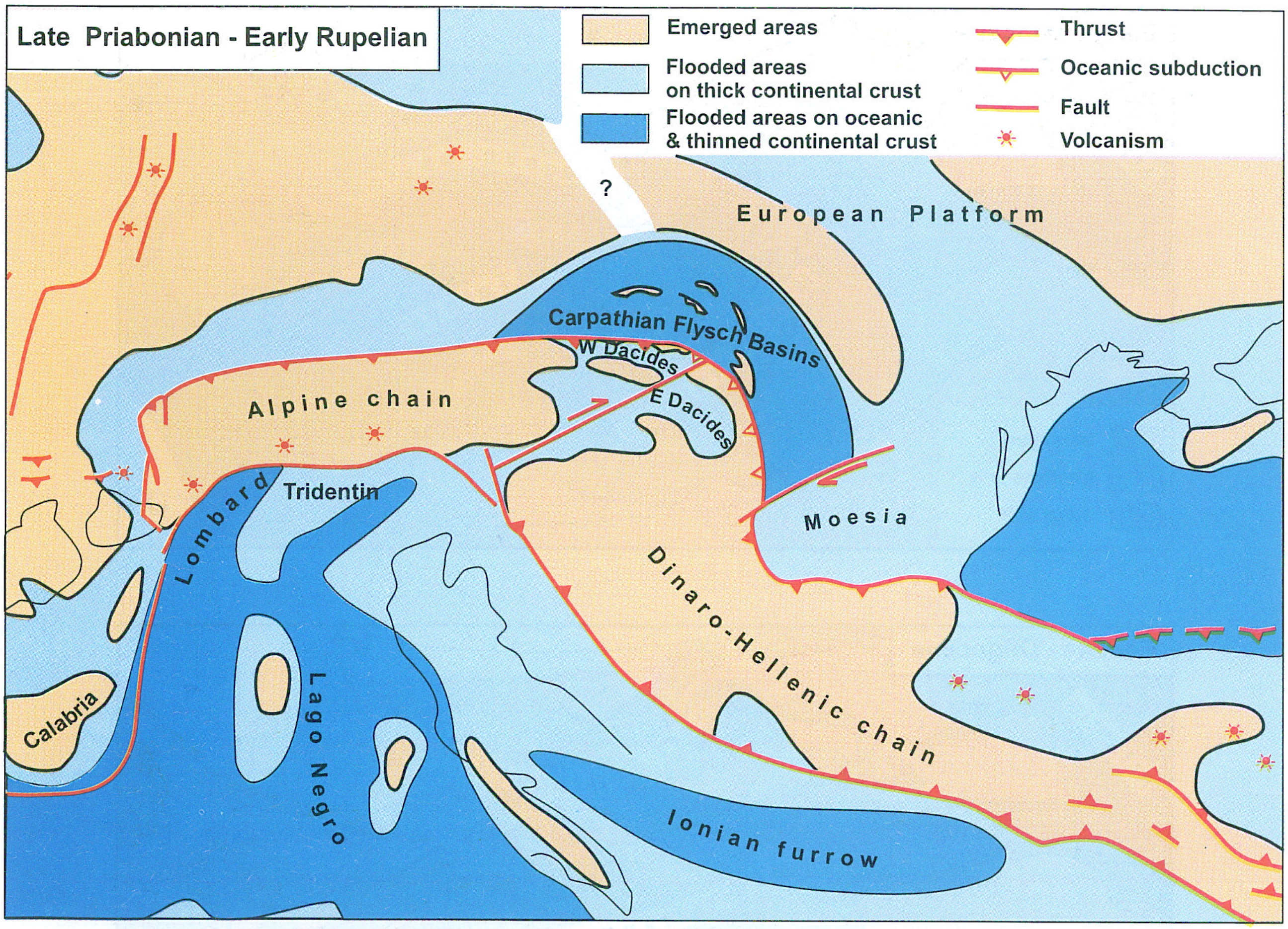


Fig. 45. Paleogeography of the Alpine–Hellenic segment of the northern part of Tethys during the Eocene–Oligocene transition (from Dercourt *et al.*, 1985 and Ricou *et al.*, 1986 slightly changed)

surrounded the flysch basins, as the chief source of their terrigenous material. The Skole basin was fed predominantly from the Noth European Platform (Książkiewicz, 1962; Kotlarczyk & Leśniak, 1990; Rajchel, 1990). The northerly supply for all basins appears to have been strongest at the Eocene–Oligocene transition.

The very low TOC content in the background deposits of the SMGMS, together with their pervasive bioturbation, indicate rather a well-oxygenated basin bottom. Vigorous deep-water circulation is suggested by the traces of lamination recorded in the light marl. However, the calcareous nannofossil assemblages contained in the SMGMS equivalent deposits indicate temporal fluctuation of both parameters (Krhovský *et al.*, 1993). The predominantly red marls at Leluchów suggest the strongest oxic conditions in the area of their sedimentation. Such a red colour results typically from a hematite pigment. The last is formed in oxic conditions, in sediments enriched in Fe and deprived of a 'labile' organic matter. Hence, low organic matter supply to the basin floor, their good aeration and increased supply of iron may be inferred from the occurrence of the red marls. In contrast, the mainly greenish-grey and beige-grey background deposits of the SMGMS, as recorded in the Siary unit of the Magura nappe, in the Ropa window and the Dukla nappe, seem to result from an increased amount of terrigenous material and high level of organic matter. The aeration of the sea bottom deteriorated rapidly at the end of the SMGMS sedimentation. The overlying Sub-Chert beds appear to have been deposited on a highly dysoxic to anoxic bottom.

SEDIMENTATION TIME SPAN AND SEDIMENTATION RATE

In the light of the available biostratigraphic control (Blaicher, 1967, 1970; Radomski, 1968; Olszewska, 1985; Olszewska, Smagowicz, 1977; van Couvering *et al.*, 1981; Oszczypko, 1996), the SMGMS represents an unit isochronous on a scale of a single foraminifera or nannoplankton zone (ca. 1 my). A time span 0.6 to 2 my, is indicated, depending upon the dating method and the time scale used (Tab. 3). The thickness differences between particular sections suggest heterochroneity of the SMGMS boundaries. The heterochroneity appears to be bound particularly to the lower boundary. The differences in thickness of the complete SMGMS, including its primary absence in some areas, suggest variation of the time span inherent in the unit from 0 to exceeding twice its average value.

The average time span of the SMGMS is here estimated from the biostratigraphic data and from the average cumulative thickness of its background deposits (cf. Leszczyński, 1996). The mass gravity deposits are neglected, as their deposition was instantaneous. However, thick mass flow beds may have eroded the background deposits and therefore reduced the time contained in the sequence. In fact, such beds occur rarely in the SMGMS, so that their influence on the average thickness of the background deposits appears, therefore, to be insignificant.

The present cumulative thickness (T_p) of the background deposits of the SMGMS, estimated from the examined sections, is ca. 7 m. Assuming a rather exaggerated 0.7 (i.e. 70%) original mean porosity (n_1) and only a 0.05 (i.e. 5%) present mean porosity (n_p), the original thickness (T_o) of the deposits was

$$T_o = (1 - n_p/1 - n_1)T_p = (1 - 0.05/1 - 0.7)7 = 22.17 \text{ m}$$

Considering the shortest time span (ca. 0.6 my), as indicated by the Olszewska's (1985) data related to the time scale by Berggren *et al.* (1995), the average sedimentation rate of the SMGMS fine-grained deposits equals ca. 37 mm ky^{-1}. Such sedimentation rate is, however, markedly lower than the minimum (50 mm ky^{-1}) indicated for hemipelagic deposits (see Stow *et al.*, 1996). Thus, either the average time span inherent in the SMGMS is much shorter or its sedimentation rate was much lower. The latter appears little probable in the light of the present knowledge of deep-sea environments. Actually, a time span of about 0.4 my appears to be reasonable for the average SMGMS. A similar interpretation was proposed earlier for the SMGMS equivalent in the Czech Carpathians (Krhovský *et al.*, 1993) and for the SMGMS itself at Znamirowice (Leszczyński, 1996). The SMGMS sections displaying the highest cumulative thickness of the background deposits may embrace a slightly longer time span than the average sections.

The disappearance of the green shales towards the top of the SMGMS, their occurrence in thin and very thin layers as well as the extremely low TOC contents in the light marl, all suggest different sedimentation rate of these background deposits. The slight tendency of cumulative thickness increase of the SMGMS background deposits with the decrease of the amount of the non-calcareous green shale (Fig. 18A) suggest that the marl may have been deposited at a higher rate than the shale. One cannot exclude that there was some correlation between the $CaCO_3$ content in the sediment and its sedimentation rate.

ORIGIN OF SEQUENCE PATTERNS

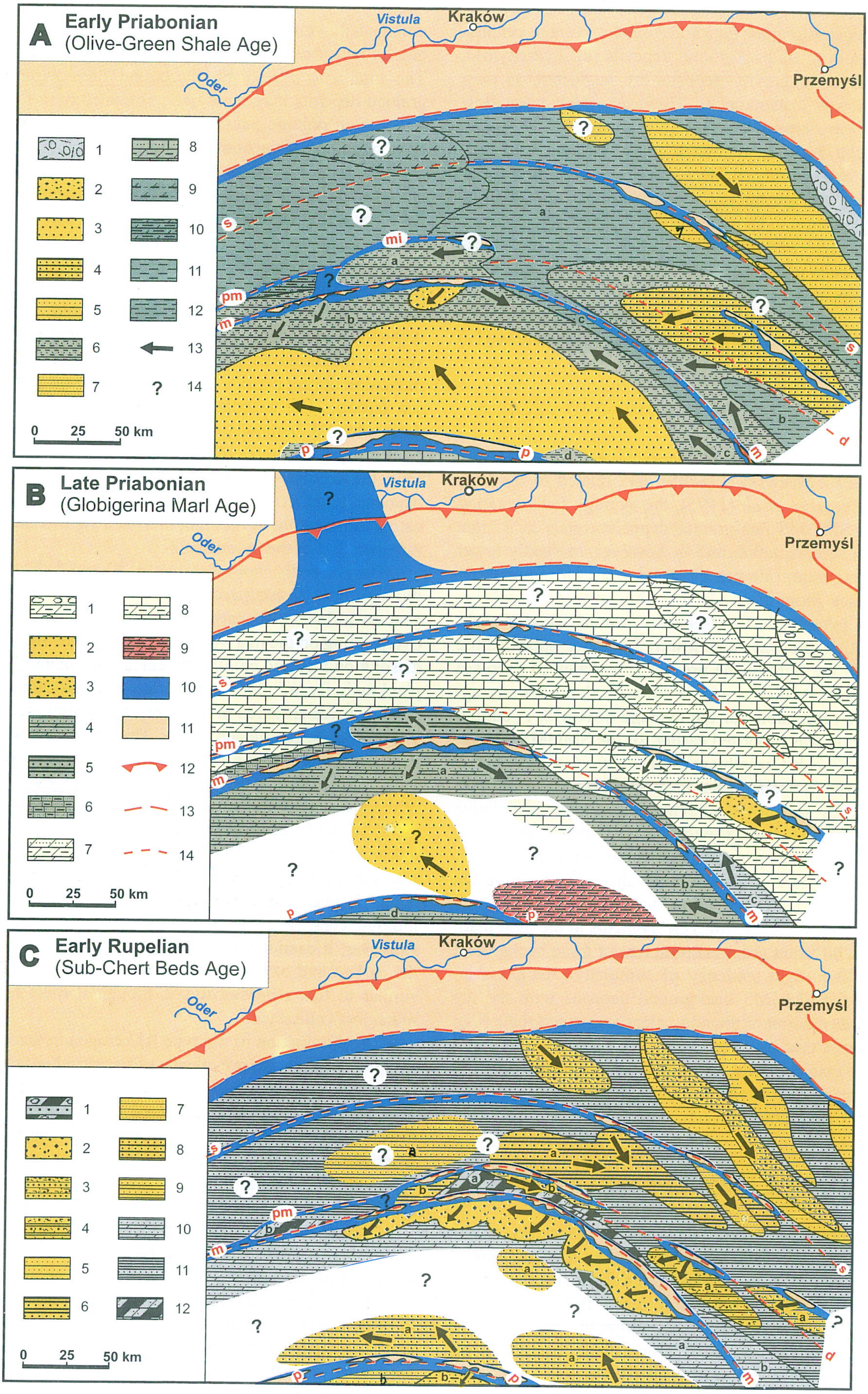
The above portrayed features and the origin of the SMGMS suggest a complex nature of the sequence pattern. The alternation of light marl and green shale, similarly to the limestone-marl alternations, may result from variation in carbonate production, terrigenous dilution, and carbonate dissolution, (see Einsele & Ricken, 1991). Moreover, diagenesis may enhance the original contrasts in the proportions of the carbonate and siliciclastic sediment components. The interbeds of siltstone, sandstone and the dark-coloured shale, mudstone and marl that occur in normally graded layers reflect an intermittent mass resedimentation. The interbeds of indistinctly bound dark-coloured fine-grained deposits may have been produced by a fluctuating intensity of organic matter supply or by fluctuations in redox conditions of the bottom waters.

The markedly higher content of calcareous nannofossils and planktonic foraminifera, and the only slightly increased contents of the benthic forams in the light marl suggest that variations in carbonate production and/or its dissolution may be chiefly responsible for the light marl–green shale alternation. The slightly lower amounts of agglutinated foraminifera in the less calcareous, light-coloured, fine-grained deposits may result from their sedimentation under a slightly increased supply of terrigenous material or sedimentation during periods of decreased nutrient inflow to the sea bottom. The associated occurrence of turbidites and dark-coloured hemipelagites with the green shale facies points to variable rates of terrigenous dilution. At the same time, the decreasing upward thickness of the noncalcareous deposits, together with their negligible TOC contents indicate sedimentation of the light marl at a significantly higher rate than that of the green shale.

The markedly more negative $\delta^{18}O$ and $\delta^{13}C$ signals of the light marl as compared to those of the green shale suggest an influence of carbonate dissolution and diagenetic overprinting on the marl–shale rhythms in the SMGMS. The dissolution affected chiefly the calcareous nannofossils and planktonic foraminifera in the originally less calcareous deposit that was enriched in labile organic matter (see Roth, P. 1981; Roth & Krumbach, 1986; Thierstein & Roth, 1991). This seems also to be the cause for a significantly better preservation of the calcareous nannofossils in the red marls of the SMGMS at Leluchów (see Oszczypko, 1996) as compared to that recorded in the cream-yellow and greenish marls in other SMGMS sections. The dissolved carbonate was subsequently precipitated in a more carbonate rich deposit. Hence, the dissolution enhanced the original lithologic contrast in the carbonate content of these deposits. However, it cannot be excluded that the original pattern of the carbon and oxygen isotope signals in the SMGMS was similar to that recorded today, though it must have been much less contrasted.

The domination of the type III kerogen in the examined samples suggests the prevalence of terrestrial organic matter in the dark-coloured shales, and additionally evidences their hemipelagic origin. The increased organic matter content lowered the redox level in such deposits and could also have deteriorated oxygenation close to the basin bottom. More apparent indicators of anoxic conditions above the sea bottom during SMGMS sedimentation are, however, lacking.

Changes of water circulation and consequent changes in the supply of nutrients are generally considered as the primary controls of carbonate production in a sedimentary basin. The changes of water circulation are strongly dependent on global and regional climatic variation. Changes in the earth's orbital parameters were recognised to cause cyclic variations in the global and regional climate and oceanographic processes on a scale of 20–400 ky. The periods of eccentricity (ca. 100 and 410 ky), obliquity (ca. 40 ky), and


A
Early Priabonian
(Olive-Green Shale Age)
Vistula
Kraków
Oder
Przemyśl
1 2 3 4 5 6 7 8 9 10 11 12 13 14
0 25 50 km
s
mi
pm
m
p
d
a
b
c
B
Late Priabonian
(Globigerina Marl Age)
Vistula
Kraków
Oder
Przemyśl
1 2 3 4 5 6 7 8 9 10 11 12 13 14
0 25 50 km
s
pm
m
p
a
b
c
d
C
Early Rupelian
(Sub-Chert Beds Age)
Vistula
Kraków
Oder
Przemyśl
1 2 3 4 5 6 7 8 9 10 11 12
0 25 50 km
s
pm
m
p
d
a
b

precession (ca. 20 ky) have been identified in a variety of sedimentary sequences. The sedimentary signals of the orbital variations are amplified by different climatic-oceanic feedback systems (Einsele & Ricken, 1991). The resultant periodicity in the sediment tends to display considerably varying amplitude and changing importance of the various time intervals (Einsele, 1992). Moreover, depositional background noise is usually superimposed on the combined orbital signals. As a result, varve-scale lamination of the zebra-type may have been produced in some sequences (Einsele & Ricken, 1991). These complications, together with the restraints in interpretations of time periods involved, cause that the detection of the Milankovitch frequencies in sedimentary sequences is seriously limited.

All the above mentioned limitations appear to particularly concern the SMGMS. Its complex origin (both episodic and continuous sedimentation) makes it difficult to precisely sort out the frequencies resulting from global processes from those caused by local ones. Moreover, the interpretation is restricted also by the high variability of thickness of the lithologic couplets which show varying carbonate contents. The small thickness of the SMGMS and its poor time matching call in the question of the applicability of the spectral analysis to this sequence as is widely used in recognition of the astronomically induced cyclicities in the sedimentary record. Thus, the here proposed interpretation of the SMGMS patterns should be as a sort of approximation of the spectrum processes involved.

The well-defined nature and regional occurrence of the SMGMS suggests its origination in a specific time period. The increasing to decreasing-upward trend of the carbonate content, together with the predominantly biogenic nature of the carbonate material, point to the deposition of the entire sequence in conditions of strongly enhanced carbonate production and consequent CCD drop. The calcareous nannofossil assemblages and the distinctively increased standing stock of benthic foraminifera of the light marl facies suggest sedimentation in times of increased productivity and adequately increased nutrient supply (cf. Krhovský *et al.*, 1993; see also Thunell *et al.*, 1991). In contrast, the assemblages of fossils contained in the less calcareous to noncalcareous green shales suggest sedimentation in times of lowered productivity and increased salinity at the basin floor (see Krhovský *et al.*, 1993). Such contrasting sedimentary conditions point to climate and basinal regime as the primary controls of the SMGMS development.

The several hundred kiloyears sedimentation time span estimated for the average SMGMS suggests sedimentation under climatic and basinal regime that may have been forced by the 410 ky eccentricity cycle. More than one such cycle may be represented by the longest SMGMS sections, particularly those in the Dukla nappe. In contrast, only part of the cycle appears to be reflected in the shortest sections. Such differentiation is here considered as resulting primarily from sedimentation at different depths relative to CCD and variable terrigenous dilution. The longest sections were

Fig. 46. Generalized palaeogeography and the facies distribution of the northern Carpathian area at the Eocene–Oligocene transition. Based on differrent sources

Explanation of symbols (symbols common to all maps explained in the maps of Early and Late Priabonian).

A. Early Priabonian: *1* - Popiele Member underlain by Bachórz Sandstone and Shale Member, locally by Skopów Shale Member, and overlain by Skopów Shale Member or by SMGMS; *2* – Wojakowa sandstone overlain by the Sub-Magura beds; *3* – Poprad Sandstone Member overlain locally by the Green shale; *4* – Mszanka/Globigerina sandstone locally underlain and overlain by the Green shale; *5* – Bartkówka Sandstone Member underlain by the Bachórz Sandstone and Shale Member, Skopów Shale Member, and locally by the Chwaniów Calcareous Sandstone Member; *6* – Hieroglyphic beds locally overlain by the Green shale (*a*), Hieroglyphic beds overlain by the Sub-Magura beds (*b*), Zlin beds (*c*), and Marginal flysch (*d*); *7* – Przysietnica sandstone interfingering with the Green shale; *8* – marl and detritic limestones beneath the Zakopane beds; *9* – Variegated shale, locally marl; *10* – Variegated marl and shale; *11* – Variegated shale overlain by the Green shale; *12* – Green shale predominantly (*a*), Skopów Shale Member underlain by the Bachórz Sandstone and Shale Member, locally by the Chwaniów Calcareous Sandstone Member and overlain locally by the Bartkówka Sandstone Member (*b*), Variegated shale overlain by the Green shale, locally interfingering with the Hieroglyphic beds (*c*), (*d*) Green shale underlain by the Variegated shale and/or Hieroglyphic beds; *13* – transport directions; *14* – poorly documented.

B. Late Priabonian: *1* – Popiele Member interfingering with and overlain by the Sub-Menilite Globigerina Marl; *2* – Poprad Sandstone (see Cieszkowski, 1992a); **4** – upper part of the Sub-Magura beds (*a*) and Zlin beds (*b*), Papin beds (*c*), and lowermost part of the Zakopane and Szaflary beds (*d*); **5** – "Black Eocene" and Rdzawka beds; **3** – Mszanka/Globigerina sandstone; *6* – Hieroglyphic beds type deposits embracing Łużna (Koniaków) limestone; *7* – Sub-Menilite globigerina marl with frequent sandstone intercalations (fine-grained deposits/sandstone = 1-5); *8* – Sub-Menilite globigerina marl with predominantly greenish-gray, cream-yellow to yellowish-gray marl (fine-grained deposits/coarse-grained deposits >5); *9* – Leluchów Marl Member in variegated facies; *10* – presumed shallow-marine areas; *11* – emerged areas; *12* – present northern border of the Carpathian flysch nappes; *13* – presumed shoreline; *14* – approximate position of the northern limit of the Pieniny Klippen Belt (p), Magura basin (m), sedimentary area of the Sub-Magura Units (pm, mi, d), Silesian basin (s).

C. Early Rupelian: *1* – Duląbka beds overlain by Menilite type shales; *2* – Wątkowa sandstone underlain locally by the Sub-Magura beds, and overlain by Supra-Magura beds; *3* – Sub-Chert beds with Siedliska conglomerate and locally with the Borislav sandstone, *4* – Mszanka sandstone, locally with overlying marls and shales of the Sub- Chert beds (*a*), Michalczowa sandstone overlain by the Grybów shale (*b*); *5* – Sub-Chert beds with the Borislav sandstone; *6* – Sub-Chert beds with Krosno-type sandstones (*a*); Rdzawka beds overlain by the Cergowa beds (*b*); *7* – Sub-Chert beds with the Kombornia sandstone; *8* – Malcov Formation locally underlain by the Smereczek Shale Member (*a*), sandstone packages in lower part of the Szaflary beds (*b*); *9* – Sub-Chert beds with sandstones and conglomerates (*a*), shales, sandstones and marls in lower part of the Zakopane beds (*b*); *10* – Supra-Magura beds (*a*), undivided Sub-Chert beds in Slovakia (*b*); *11* – Sub-Chert beds dominated by marls and shales; *12* – Sub-Chert beds in the facies of Sub-Grybów beds and Grybów shale (*a*), Barutka beds (*b*)

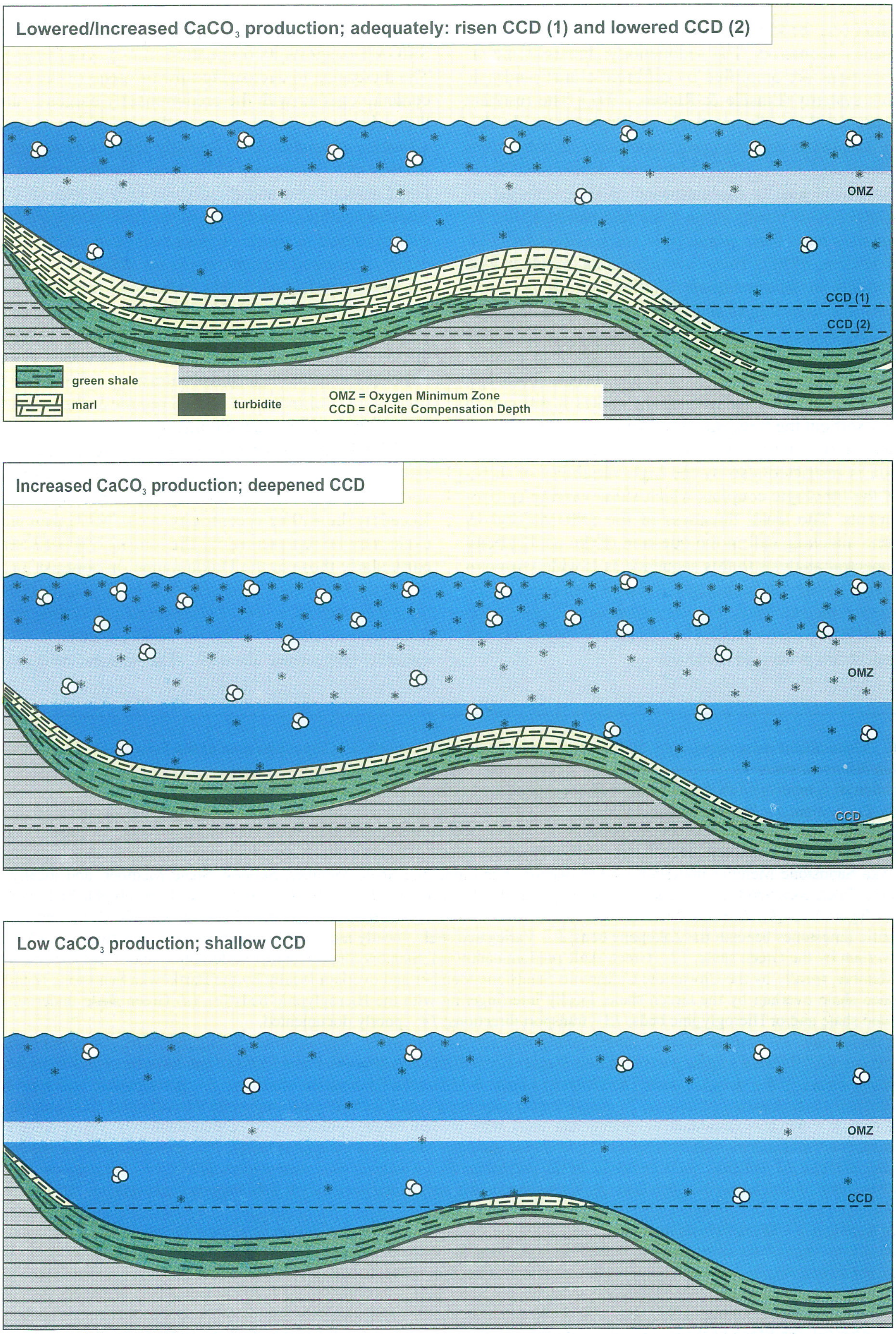


Fig. 47. Simplified depositional model for the sedimentary development of the SMGMS. The fluctuating CCD due to different intensity of carbonate sedimentation and dissolution together with the markedly bathymetrically differentiated basin morphology and resedimentation frequency appear to be chiefly responsible for the sequence patterns

formed at presumably shallower depths than the average ones since such sites are affected earlier by the growing supply of carbonate material. Moreover, the $CaCO_3$ content of the background deposits can be expected to fluctuate there less distinctively than in the sections deposited at greater depths (Fig. 47).

Short eccentricity (ca. 100 ky) and obliquity cycles, besides depositional noise, appear to be reflected by the smaller fluctuations of the carbonate content in the background deposits. The former cycles seem to be reflected in the most pronounced fluctuations recorded on a scale of 1.5–2.0 m of the background deposit thickness. These fluctuations usually embrace two more distinctive marl–shale couplets. These couplets imply forcing by the obliquity cycle. Such fluctuations are best expressed in the SMGMS at Znamirowice, Rudawka Rymanowska and Krościenko-Granica. In other sections, the variability is less distinctive. As it has been mentioned earlier, lateral differences in the pattern of the background deposit distribution in the SMGMS, point to sedimentation on a bottom markedly contrasted bathymetricaly relative to the CCD. The sections where the background deposits show greater variation of the $CaCO_3$ content represent probably the deeper areas of the basins. This is also suggested by the increased amounts of resediments. In contrast, sections deposited in the shallowest areas tend to be deprived of the noncalcareous green shale interbeds. The SMGMS was not formed at sites below the limits of the CCD fluctuation, whereas in areas continuously above the CCD, the sequence evolved from the underlying calcareous deposits.

The subtle variability of the $CaCO_3$ content recorded on a cm-scale seems to result from varying supply of terrigenous and calcareous material. The supply varied in time and space. Thus, such variability, together with the general distribution of mass resedimentation deposits (episodic deposits), seem to represent a depositional noise. However, the concentrated occurrence of episodic deposits in the less calcareous divisions of the SMGMS enhances its rhythmicity. It cannot be excluded that some small-scale fluctuation in the $CaCO_3$ content was forced by the precession cycle (e.g. Fig. 33; cf. Krhovský *et al.*, 1993). However, the Carpathian territory was located at latitudes rather beyond significant influence of this cyclicity (see Berger, 1978).

Intermittent and regionally changing tectonic activity of the area, together with expanding and laterally shifting deltaic lobes, as well as the sediment redistribution by mass-gravity processes, accompanied by more regular climate changes, seem to be all responsible for the present distribution of terrigenous material within the SMGMS (cf. Leszczyński, 1996). The increased proportion of terrigenous material and resediments in the SMGMS indicates generally more proximal location of such section relative to the basin margin and/or the main resedimentation paths.

SEDIMENTATION DEVELOPMENT

The Priabonian–Rupelian facies and their distribution show that the Carpathian flysch was deposited in a set of deep-sea troughs bordered to the north, west and east by the emerged to shallowly submerged European Platform and to the south by shallow-marine to emerged area of the Alpine–Carpathian–Dynaric Orogen (Figs. 44, 45). The fossil assemblages suggest that the communication of the area with the rest of Tethys was ample until the end of Priabonian (see Báldi, 1980). Moreover, the nature of these deposits implies rather aerobic conditions at the basin floors. However, the disappearance of red shales recorded since the middle Eocene, suggests a gradual decrease in oxygenation. The disappearance of red shales coincided both with severely intensified resedimentation in the Magura basin and significant tectonic reorganisation of the western Tethys. This coincidence points therefore to a reduction in communication between the basins and the open ocean as a main cause of decreased oxygenation at the basin floors. The communication became most restricted with the onset of anoxia that happened during the sedimentation of the Menilite beds (Książkiewicz, 1960). Similar facies appeared then nearly synchronously along the entire northern margin of the Alpine orogenic belt between Provence in the west and the Aral Lake in the east (see Roth & Hanzlíková, 1982; Báldi, 1984). The appearance of anoxic facies corresponds to the disappearance of Mediterranean fossil assemblages in the Carpathian sea. According to Báldi (1980), the latter event took place in the Pannonian basin somewhere in the middle of the calcareous nannoplankton zone NP 21. A vast marine area, called Paratethys (see Báldi, 1980), was then separated from the main part of the Tethyan Ocean. At the beginning, the Paratethys was linked mainly with the Caucasian– Indo–Pacific realm and to a lesser extent with the Boreal province (see Roth & Hanzlíková, 1982). Its communication with the Mediterranean Tethys is not clear (e.g., Báldi, 1980). According to Roth & Hanzlíková (1982), the internal part of the Magura nappe formed a low emerged peninsula within the Paratethys. Orogenic movements recorded in the Alps and Dinaric Mountains at the Eocene–Oligocene transition are suggested to be responsible for the separation of the Paratethys (see Báldi, 1980).

The paleogeographic reorganisation within the Tethys at the Eocene–Oligocene transition influenced the oceanographic regime and climate not only in the realm itself but is considered to have added to the global changes as well. Nevertheless, the global reorganisation of lithospheric plates recorded between the middle Eocene and early Oligocene is considered to have amplified the changes of the global climate recorded in the above time span. The opening of the circum-Antarctic circulation and the connection of the Arctic Ocean with the North Atlantic are actually regarded as the main causes of these global climate changes (see Prothero, 1994). The paleoclimatic data clearly indicate that global cooling and increased aridity occurred during the middle Eocene, across the Eocene–Oligocene boundary and during the earliest Oligocene (Berggren & Prothero, 1992).

As compared to the underlying and the overlying deposits, the SMGMS was formed during an overall subdued resedimentation intensity which, however, varied laterally in the Carpathian flysch basins. Prior to the deposition of the SMGMS, the most intense resedimentation occurred in the Magura basin where huge masses of the Poprad Sandstone Member were formed (Fig. 46A; Oszczypko, 1992a–c).

However, according to Cieszkowski (1992a), vigorous sedimentation continued locally throughout the entire time span of the SMGMS as well. According to Marta Oszczypko (1996), the SMGMS was deposited synchronously with the Poprad Sandstone Member although no compelling evidence for this conclusion has been given. In other basins, intensified resedimentation in the Priabonian occurred only locally with the Popiele Member, Przysietnica sandstone and the Globigerina\Mszanka sandstone being the most remarkable results. Similarly differentiated sedimentary conditions are recorded synchronously also in other areas of the Alpine Europe and particularly in other parts of the Carpathians (see Tab. 5). The lowered terrigenous input together with the synchronous expansion of the Podhale flysch and the Pannonian basin, suggest sedimentation of the Priabonian succesion generally during a relative sea-level rise and highstand (cf. Książkiewicz, 1960). However, with respect to the global long-term sea-level changes, the entire Priabonian represents a lowstand time (Haq *et al.*, 1988). The widespread pre-SMGMS resedimentation and its later localised occurrence suggest intensified tectonic activity in some parts of the region. A simple interpretation of sand influxes in terms of sea-level changes only (see Oszczypko, 1992a, c) appears therefore rather unjustified. Eustatic influence on relative sea level appears to have been minor and superimposed on tectonic activity that caused profound subsidence in the entire Carpathian area. The generally higher amount of the mass-gravity deposits below the SMGMS implies sedimentation at a relatively low base level.

The predominantly terrigenous fine-grained deposits, together with their low TOC contents, indicate low productivity in the flysch basins prior to the SMGM sedimentation. However, as compared to older sequence that includes red shales, the productivity appears slightly higher. The increased sedimentation of carbonate material, recorded in some areas in calcareous shale and marl packages surrounded by noncalcareous deposits (e.g. in the Dukla nappe), was restricted probably to elevated parts of the sea floor (cf. Koszarski & Żytko, 1965). The lack of calcareous deposits in other parts of the basins was probably caused by their location below the CCD. Still, dissolution after burial could have also added to the present absence of the carbonates in some sections. The influence of dissolution is recorded in scattered concretions of siderite, ferroan dolomite and rodochrosite (Narębski, 1957). An increased dissolution can be expected in areas of intensified terrigenous input as this material is distinctively enriched in organic matter.

Low productivity in flysch basins suggests lack of significant vertical water mixing as well as restricted runoff from lands. Both parameters depend on climate and global circulation pattern. In the eastern and central Europe, a humid climate is broadly evidenced in the Eocene whereas large areas of the present Arabic peninsula and Iran were arid (Oberhänsli, 1996). Facies and their distribution show that in general in the western Tethys aridification proceeded during the late Eocene (see Báldi, 1984). This is interpreted as caused by a shift of atmospheric circulation. The latter is considered as a consequence of significant topography changes suggested by the maximum tectonic activity in the western Tethys during the late Eocene (see Oberhänsli, 1996).

The extensive areas of large evaporation excess in the Tethys are considered as sources of a warm saline bottom water that was transported towards the Indian and the southern Atlantic oceans during the Eocene. The westward transportation must have proceeded also through the Carpathian flysch basins and was probably responsible for the aeration of basin floors until the end of Eocene. A similar circulation originates in the present Persian Gulf and the Mediterranean Sea. However, this circulation is considered to be at least one order weaker than that during the Eocene. Still, according to Miller (1992), the global circulation of the deep waters during middle to late Eocene was generally sluggish. These circumstances he contradicted to those during the early Oligocene when a vigorous deep-water circulation is evidenced in the oceans.

The low runoff, suggested by the low productivity of the Carpathian flysch basins during the Early and Middle Eocene, was probably due to limited drainage areas. However, the surrounding lands supplied growing amounts of organic matter, as indicated by the episodic deposits (grey to dark-grey turbidite shales are overlain by green hemipelagic or pelagic shale, and green turbidite shales are overlain by red hemipelagic or pelagic shale). Because of a low carbonate production, the CCD was apparently shallow during the Early and Middle Eocene. Calcareous deposits were accumulated therefore only on elevated areas, far away from the pathways of the terrigenous flux.

The growing aridity towards the western Tethys, together with global cooling at the Eocene–Oligocene transition (see Prothero, 1994), both imply increased seasonal contrasts. This may have resulted in an intensified vertical water mixing and, consequently, in increased biogenic production. There are also opinions that the fertility of the Carpathian flysch basins at the close of the Eocene grew mainly due to increased supply of volcanic material (Gucwa & Wieser, 1980). Nevertheless, the increased carbonate production and the consequent CCD drop must have resulted in a gradual expansion of carbonate material within the flysch basins. Marls appeared earlier and were deposited more continuously on elevated areas than in depressions (cf. Krhovský *et al.*, 1993). The lower boundary of the SMGMS and its lithostratigraphic equivalents is therefore slightly heterochronous. The heterochroneity, however, is misportrayed in the available Carpathian literature (Tab. 5). This is mainly because of different origin of the datations. The most intense sedimentation of marls typical for the SMGMS occurred apparently at the end of Priabonian and persisted locally to the beginning of the Rupelian. The strong climatic control on marl deposition, together with the inferred several hundred kiloyears sedimentation time span and the sequence pattern, suggest that the SMGMS was basically deposited within one 414 ky eccentricity cycle. Nevertheless, in some parts of the Alpine–Carpathian Tethys, the globigerina marl was deposited throughout the entire Lutetian and Priabonian (see Herb, 1988). Still, in some other areas, the globigerina marl did not originate at all. The calcareous material may have been dispersed in predominantly siliciclastic deposits. This pertains particularly to the northern part of the Magura nappe and some areas of the SMU (Fig. 46B).

The highest contrasts between seasons at high latitudes in the northern hemisphere occur during the maximum obliquity of the Earth's axis and the summer perihelion. These were probably the periods of the most intense carbonate sedimentation in the Carpathian flysch basins. Noteworthy, the increased amounts of nannofossils suggest that the primary productivity was only moderate (Berger, 1991). Seasonal, decreased carbonate sedimentation may have occurred in times of lowered difference between the seasons. The green shale facies was then deposited. The lowered amounts of benthic foraminifera in the green shale suggest that its deposition was accompanied by slightly increased terrigenous input. Moreover, the occurrence of turbidites within the less calcareous sequence segments suggests that they may also reflect times of intensified resedimentation. Thus, there are two possibilities of the origin of the noncalcareous to poorly calcareous divisions: (1) sedimentation during lowered sea level stands, or (2) sedimentation in periods of increased river runoff. The latter seems to be more probable for the SMGMS as the range of eustatic sea-level changes within an obliquity cycle in the late Priabonian was rather insignificant.

The growing upward proportion of the dark-coloured fine-grained deposits dominated by the type III kerogen in the Priabonian sequence suggests intensification of terrestrial plant detritus supply during the Late Eocene. The latter process may have been caused by increased erosion of adjacent lands due to the earlier mentioned, globally lowered sea-level inferred for the Middle and Late Eocene. The laterally changing quantity of the dark-coloured fine-grained deposits seems to reflect the distribution of river mouths and deltas around the flysch sea. The occurrence of fossils similar to those in the green shale, though in a significantly poorer assemblage, suggests resedimentation of the TOC-enriched deposits from outer shelf, i.e. from a prodelta or a delta front. The significant increase in organic matter and terrigenous material supply stopped the SMGMS development just at the beginning of the Oligocene (Fig. 46C).

The appearance of the type II kerogen in the Sub-Chert beds together with the disappearance of the benthic meio- and macrofauna and, consequently, the disappearance of bioturbation, all imply the onset of anoxia at the basin bottom. This was accompanied by a switch to the predominantly marine organic matter reflecting a significant increase in the primary productivity in the flysch basins. A gradual decrease in the content of calcareous material in the background deposits implies ecological changes in the flysch basins. The onset of anoxia was presumably mainly due to a reduced deep-water circulation and increased supply of labile organic matter. Growing isolation from the global ocean is generally regarded as responsible for the restriction of deep-water circulation (Figs. 44, 45, cf. Báldi, 1984). Hence, the increase in productivity was there caused presumably by a high fluvial supply of nutrients (cf. Krhovský *et al.*, 1993). This is best evidenced in the package of cherts and diatomites of the Menilite beds. The concentration of diatomites in the marginal parts of the basins (see Jucha & Kotlarczyk, 1961) points to strongly increased supply of silica from adjacent lands. The common occurrence of volcanic material in the Sub-Chert beds suggests that it also added to the fertility of the flysch basins (Gucwa & Wieser, 1980; Roth Z., 1981; Roth & Hanzlíková, 1982). Moreover, the increased productivity together with the bottom anoxia imply that shallow estuarine circulation may have developed in the flysch basins in the early Rupelian (see Einsele, 1992). Such circulation may have induced upwelling (Vetö, 1987) that additionally enhanced the fertility. Finally, the photic zone anoxia recorded in the Menilite beds (Köster *et al.*, 1996) suggests that water column in the flysch basins was stratified (cf. Roth & Hanzlíková, 1982), and a strongly oxygen depleted zone occurred there.

The cessation of the SMGMS development coincided with intensified resedimentation in the entire region (Koszarski & Żytko, 1959). The resedimentation first affected the organic-rich deposits of the outer basin margin and culminated in predominantly siliciclastic deposits (the sandstones of the Sub-Chert beds, and the glauconitic Magura sandstone). Such extensive intensification of resedimentation points to a rather overregional control (cf. Koszarski & Wieser, 1960). An influence of the globally recorded sea-level fall cannot be excluded here (cf. Báldi, 1980). However, in contrast to other periods, the resedimentation in the early Rupelian was subordinate in the Carpathian area. This suggests that the relative sea-level fall was there rather moderate and/or the morphology of the surrounding lands was flattened.

The domination of hemipelagic and pelagic deposits in the SMGMS, together with the increased proportion of mass-gravity transport deposits in the overlying Sub-Chert beds and the significant enrichment of the latter in shallow-marine bioclastic material, all suggest sedimentation of the SMGMS during a sea-level highstand. In contrast, the Sub-Chert beds appear to be deposited during relative sea-level fall and lowstand (?source area uplift). Hence, the sequence embracing the Green shale unit, SMGMS and the Sub-Chert beds corresponds to a genetic stratigraphic sequence (Galloway, 1989).

The zebra-type deposits at the base of the Sub-Chert beds appear to reflect intensification of resedimentation. Those, in higher parts of the unit seem to represent a distal record of intensified resedimentation and short-term fluctuations in primary productivity.

POSTDEPOSITIONAL CHANGES

As it has been shown earlier, the $\delta^{13}C$ signals suggest diagenetic modification of the SMGMS deposits proceeding in two stages. In the first stage, these deposits underwent recrystalisation influenced by the isotopically light CO_2 (cf. Broecker & Peng, 1982; Shackleton *et al.*, 1983). Its occurrence is indicated by the well preserved, uncompacted burrows recorded in the strongest cemented marl (concretionary beds; see also Bohrmann & Thiede, 1989). Siderite, ferroan dolomite (ankerite) and rodochrosite were formed besides calcite. This kind of diagenesis was pointed out by Krhovský *et al.* (1993) as the only one responsible for the features of the SMGMS equivalent deposits. The highly negative isotopic signals of the light marl and its increased hardness suggest that it originally contained considerable amounts of easily metabolizable organic substances.

The second stage of diagenesis is recorded primarily in the dark-coloured mudstones, shales and marls showing distinctively heavier $\delta^{13}C$ than that in the light marl and the green shale. The enrichment in the ^{13}C appears to result from the occurrence of $CaCO_3$ formed of CO_2 that was modelled by methane formation. The exclusively negative $\delta^{18}O$ in the SMGMS, together with the high pyrolitic T_{max}, suggest that the isotopically heavy $CaCO_3$ formed during a deep burial of the sequence. The methane-related recrystalisation affected primarily the significantly TOC-enriched deposits. The $\delta^{13}C$ signals in some light marls suggest that these were not necessarily only the deposits which presently contain more organic matter.

CONCLUSIONS

The following features of the SMGMS were determined and interpreted for the first time based on investigations in the entire Polish Carpathians:

1. The SMGMS, though dominated by light marls, includes facies belonging to all classes of the Pickering *et al.* (1986) classification scheme. The marls display a variety of textures and sedimentary structures and are compositionally heterogeneous, differing in the proportion of siliciclastic and calcareous material, type of iron compounds and the amount of organic matter. The SMGMS characteristic light marls in the lower and the upper part of the sequence are in places poor in planktonic foraminifera. In contrast to the foraminifera, calcareous nannofossils appear to be always abundant in these deposits. Compositionally, the light marls characteristic for the SMGMS represent nanno-foram-muddy oozes, called also arls.

2. The present distribution of the SMGMS results chiefly from orogenic deformation and postorogenic erosion of the flysch sequence. This particularly concerns the Magura nappe. However, intense sedimentation of noncalcareous material during the late Priabonian restricted the development of typical SMGMS in the Magura basin.

3. The SMGMS consists mainly of hemipelagites and fine-grained turbidites. The light marls are mainly hemipelagites, rarely pelagites, turbidites or bottom-current reworked deposits. The ratio of mass-flow deposits to the hemipelagites plus pelagites varies from nearly null to one. Contourites, suggested earlier by Rajchel (1990) in the SMGMS of the Skole nappe, appear to be also present in other areas. Thin and very thin beds of dark-coloured mudstones and marls, siltstones and fine-grained sandstones are the most common mass-flow deposits.

4. The markedly increased proportion of fine-grained deposits in the top part of the Priabonian sequence in the entire Carpathians indicates their sedimentation in a period of lowered tectonic activity of the region and relative sea-level rise.

5. The vertical pattern and lateral variability of the SMGMS point to deposition under fairly variable sedimentary conditions both in time and space. The periodically changing production of nannoplankton and planktonic foraminifera and the consequent CCD changes, recognized earlier by Krhovský *et al.* (1993) in the SMGMS equivalent deposits in the Czech Carpathians, together with basin morphology and spasmodic resedimentation, all are here considered as the main factors responsible for the SMGMS development.

6. The variability in the type and amount of pelagic and hemipelagic material supplied to the sea floor is believed to have resulted primarily from orbitally forced climate and paleogeography changes over the sedimentary basin and its surroundings. The SMGMS is interpreted to have resulted from sedimentation forced generally by one 410 ky eccentricity cycle. The thickest SMGMS, as in the Dukla nappe, may have been deposited within more than one above mentioned cycle. Their development is presumed to have started earlier due to their location at shallower depths. The distinctive vertical fluctuations of $CaCO_3$ content within background deposits appear to result from climate and consequent environmental changes forced by short eccentricity and obliquity cycles. Any stronger impact of precession cycles as suggested by Krhovský *et al.* (1993), is here questioned. The intermittent resedimentation of terrigenous material usually rich in organic matter contributed to the sequence pattern, depending mainly on section location with respect to the main pathways of the terrigenous influx.

7. The sedimentation of the carbonate-enriched background deposit (particularly the light marl) occurred in periods of intensified water circulation. Contrary to Krhovský *et al.* (1993), such periods are here considered as typified by strongly contrasted (dry/wet) seasons with an overall low terrigenous influx. Moreover, the less calcareous background deposits (particularly the green shale) are here considered as deposited during more equable seasons, increased humidity and consequently lowered water circulation. The influence of enhanced runoff on the sedimentation of the carbonate-rich deposits, suggested by Krhovský *et al.* (1993), appears doubtful in the light of the present data.

8. The lateral variability of the calcareous background deposits is here considered to reflect bathymetric differentiation of the basin bottom relative to CCD and temporal CCD fluctuations.

9. The domination of type III kerogen in the TOC-rich deposits evidences their supply from deltas or basin margin influenced by river mouths. Consequently, this suggests that the sedimentation of the turbidites in the SMGMS was controlled by the growth of deltas and local tectonic activity. The SMGMS sections enriched in the dark-coloured deposits record therefore a proximity to basin margins and/or resedimentation routes. The presence of impoverished foraminifera assemblages in such deposits implies dysaerobic or poorly areobic conditions on the basin bottom in their source areas.

10. The $\delta^{18}O$ and $\delta^{13}C$ signals in the fine-grained deposits of the SMGMS indicate significant diagenetic modifications of these deposits. Their character and scale depended upon the availability of easily degradable organic matter and the content of easily soluble carbonate particles in the sediment. The light marl and green shale were affected mainly by diagenesis due to oxic degradation of organic matter. Therefore, the isotopically light carbonate was there introduced proportionally to the original $CaCO_3$ con-

tent. The dark-coloured mudstones and marls, as well as some light marls and shales underwent additionally a later diagenesis related to methane formation. It resulted in the introduction of isotopically heavy carbonate. Nevertheless, the original periodic variation of the $\delta^{18}O$ and $\delta^{13}C$ in the water column of sedimentary basin was of the primary significance for the observed alternation of the distinctively calcareous and non-calcareous light-coloured background deposits. The diagenetic processes enhanced only the original record of various sedimentary conditions.

11. The SMGMS development was halted due to both the significant increase of resedimentation and the decrease of carbonate production. The increase in resedimentation was mainly due to relative sea level fall. Influence of increased tectonic activity appears rather subordinate. The reduction of carbonate production was caused primarily by a climate change. The increased supply of organic matter waned the deposition of the light-coloured marl. To some extent, the intensified accumulation of organic matter, and the development of anoxic conditions at the seafloor resulted from the cessation of water circulation in the Carpathian sea. This was caused by a significant reduction of the connections of this area with the world oceans. Intensified primary production, evidenced by the domination of the type II kerogen in the Sub-Chert beds, may have significantly added to the deoxygenation of the basin bottom.

12. The primarily climatic control of the SMGMS development suggests its isochroneity. The heterochroneity suggested in the literature results from regional variability of the rock sequence, its inconsistent lithostratigraphic classification, differences between the biostratigraphic zonations used and from the restricted applicability of particular biostratigraphic methods used. Some diachroneity cannot, however, be excluded as well.

13. In sequence stratigraphy terms, the SMGMS together with the immediately underlying Green shale unit and the overlying Sub-Chert beds represent a genetic stratigraphic sequence.

Acknowledgements

This study has been financed by the Statute Research Fund of the Institute of Geological Sciences, Jagiellonian University. The author is deeply indebted to E. Malata M. Sc. for her kindly help in the foraminifera investigations, to Dr. E. Koszowska and A. Łatkiewicz M. Sc. for their help in XRD analyses, to Dr. M. A. Gasiński and Dr. M. Kaminski for enabling the Author to study at the University College London, as well as to T. Leszczyńska M. Sc. for her invaluable assistance during entire work on this paper.

Warm thanks are to W. Habas and K. Olejak for their help in accessing the literature, W. Wyżga and T. Mrukot for preparing thin sections, P. Radzicki for making photos, E. Faber for her assistance during SEM investigations, and to J. Köster for offering his unpublished data concerning clay minerals.

Many thanks are offered to collegues from the Institute of Geological Sciences, Jagiellonian University, for productive cooperation and helpful comments.

The Author offers his sincere thanks to Professors A. Radomski and A. Ślączka for critical reading of the first version of the paper, and to Dr. Sz. Porębski for linguistic and editorial corrections as well as for helpful comments.

REFERENCES

Andreyeva-Grigorovich, A. S., Gruzman, A. D., Lozynyak, P. Y. & Smirnov, S. E., 1987. Key sections of the boundary layers of Eocene–Lower Oligocene of the Dukla and Marmarosh zones. (in Russian, English summary). *Paleontol. Sbornik*, Lvov, 24: 33–37.

Arthur, M. A., Dean, W. E., Zachos, J. C., Kaminski, M., Hagerty Rieg, S. & Elmstrom, K., 1989. Geochemical expression of early diagenesis in Middle Eocene–Lower Oligocene pelagic sediments in the southern Labrador Sea, Site 647, ODP Leg 105. *Proc. ODP, Sci. Results*, 105: 111–135.

Aubry, M. P., 1992. Late Paleogene calcareous nannoplankton evolution: a tale of climatic deterioration. In: Prothero, D. R. & Beggren, W. A. (eds), *Eocene–Oligocene Climatic and Biotic Evolution*. Princeton Univ. Press, Princeton, pp. 272–309.

Báldi, T., 1980. The early history of Paratethys. *Földtani Közlöny* (*Bull. Hung. Geol. Soc.*), 110: 473–484.

Báldi, T., 1984. The terminal Eocene and early Oligocene events in Hungary and the separation of an anoxic, cold Paratethys. *Eclogae Geol. Helv.*, 77: 1–27.

Berger, A. L., 1978. Long-term variations of caloric insolation resulting from the earth's orbital elements. *Quatern. Res.*, 9: 139–167.

Berger, A. L., 1991. Produktivität des Ozeans aus geologischer Sicht: Denkmodelle und Beispiele. *Zeitschr. Deutsch. Geol. Ges.*, 142: 149–178.

Berggren, W. A., Kent, D. V., Swisher, C. C. & Aubry, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. *Soc. Econ. Paleont. Miner., Spec. Publ.*, 54: 129–212.

Berggren, W. A. & Miller, K. G., 1988. Paleogene tropical planktonic foraminiferal biostratigraphy and magnetostratigraphy. *Micropaleontology*, 34: 362–380.

Berggren, W. A. & Prothero, D. R., 1992. Eocene–Oligocene Climatic and Biotic Evolution: An Overview. In: Prothero, D. R. & Berggren, W. A. (eds), *Eocene–Oligocene Climatic and Biotic Evolution*. Princeton Univ. Press, Princeton, pp. 1–28.

Berner, R. A., 1981. A new geochemical classification of sedimentary environments. *J. Sediment. Petrol.*, 51: 359–365.

Bieda, F., 1946. La stratigraphie du Flysch des Karpates centrales polonaises basée sur les grands Foraminiféres. (in Polish, French summary). *Rocz. Pol. Tow. Geol.*, 16: 1–45.

Bieda, F., 1951. Starszy Trzeciorzęd. (In Polish only). In: *Geologia Regionalna Polski*, t. 1, cz. 1. Polskie Towarzystwo Geologiczne, Kraków, pp. 113–155.

Bieda, F., Geroch, S., Koszarski, L., Książkiewicz, M. & Żytko, K., 1963. Stratigraphie des Karpates externes polonaises. *Inst. Geol., Biul.*, 181: 1–174.

Birkenmajer, K. & Oszczypko, N., 1989. Cretaceous and Palaeogene lithostratigraphic units of the Magura Nappe, Krynica Subunit, Carpathians. *Ann. Soc. Geol. Polon.*, 59: 145–181.

Blaicher, J., 1961. Microfauna of *Globigerina* marls from region of Podzamcze fold (Carpathians). (In Polish, English summary). *Kwart. Geol.*, 5: 602–611.

Blaicher, J., 1963. Zones microfaunistiques de corrlation dans la nappe de charriage de Magura en Pologne. *Assoc. Géol. Karpato-Balkanique, VI-čme Congr. Rčs. des Communications*, Warszawa, pp. 32–34.

Blaicher, J., 1964. Niektóre globigeryny paleogenu Karpat i ich znaczenie stratygraficzne (in Polish only). *Kwart. Geol.*, 8: 985–986.

Blaicher, J., 1967. Assemblages of small foraminifera from the Sub-menilite Globigerina Marls in the Carpathians. *Inst. Geol., Biul.*, 211: 355–364.

Blaicher, J., 1970. "Globigerinae" of the Sub-Menilite Globigerina

Marls. (In Polish, English summary). *Inst. Geol,. Biul.*, 221: 137–175.

Blaicher, J., 1973. Microfauna of the Podhale Flysch in the Zakopane IG-1 borehole. (In Polish, English summary). *Inst. Geol., Biul.*, 265: 105–125.

Blaicher, J., & Sikora, W., 1963. Attempt to correlate the Magura beds in eastern part of Magura nappe with sediments of external group. (In Polish, English summary). *Kwart. Geol.*, 7: 620–626.

Blaicher, J., & Sikora, W., 1967. Stratygrafia jednostki rychwałdzkiej w Leluchowie. (In Polish only). *Kwart. Geol.*, 11: 453–454.

Blow, W. H., 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Brönnimann, P. & Renz, H. H. (eds), *Proceedings First Intern. Conf. on Planktonic Microfossils (Geneva, 1967)*, E. J. Brill, Leiden, v. 1, pp. 199–422.

Bohrmann, G. & Thiede, J., 1989. Diagenesis in Eocene claystones, ODP Site 647, Labrador Sea: Formation of complex authigenic carbonates, smectites, and apatite. *ODP, Sci. Results*, 105: 137–154.

Bolli, H. M., Saunders, J. B., & Perch-Nilsen, K. (eds), 1985. *Plankton Stratigraphy.* Cambridge Univ. Press, Cambridge, 1032 pp.

Bombita, G. & Rusu, A., 1981. New data on the Eocene/Oligocene boundary in the Romanian Carpathians. *Palaeogeogr., Paleoclimatol., Palaeoecol.*, 36: 213–222.

Brinkhuis, H. & Biffi, U., 1993. Dinoflagellate cyst stratigraphy of the Eocene/Oligocene transition in central Italy. *Mar. Micropaleont.*, 22: 131–183.

Broecker, W. S. & Peng, T.-H., 1982. *Tracers in the Sea.* Eldigio Press, Palisades, N.Y., 690 pp.

Bromowicz, J., 1992. The Sedimentary Basin and Source Areas of the Magura Sandstones. (In Polish, English summary). *Zesz. Naukowe AGH, Nr 1485, Geologia*, 54: 1–116.

Burtan, J., 1978. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50000. Arkusz Mszana Dolna.*(In Polish only). Wydawnictwa Geologiczne, Warszawa, 70 pp.

Burtan, J., Cieszkowski, M. & Paul, Z., 1992. Płaszczowina magurska na obrzeżeniu okna tektonicznego Mszany Dolnej. (In Polish only). In: Zuchiewicz, W. & Oszczypko, N. (eds), *Przewodnik 63 Zjazdu Pol. Tow. Geol., Koninki, 17-19 września, 1992*, Wydawnictwo Instytutu Nauk Geologicznych, Polska Akademia Nauk, Kraków, pp. 65–68

Burtan, J. & Sokołowski, S., 1956. Nowe badania nad stosunkiem regionu magurskiego do krośnieńskiego w Beskidach Zachodnich. (In Polish only). *Przegl. Geol.*, 10: 457–458.

Cieszkowski, M., 1985a. Stop 21: Obidowa. In: Birkenmajer, K. (ed.). *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 2.* Wydawnictwa Geologiczne, Warszawa, pp. 48–54.

Cieszkowski, M., 1985b. Stop 22: Nowy Targ, Samorody. In: Birkenmajer, K. (ed.). *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 2.* Wydawnictwa Geologiczne, Warszawa, pp. 54–58.

Cieszkowski, M., 1992a. Michalczowa zone: a new unit of the fore-Magura zone, Outer West Carpathians, South Poland. (In Polish, English summary). *Zesz. Naukowe AGH, Nr 1463, Geologia, Kwartalnik*, 18: 1–110.

Cieszkowski, M., 1992b. Magura Nappe and its substrate north of the Nowy Sącz Basin. (In Polish, English summary). *Przegl. Geol.*, 40: 410–417.

Czernikowski, J., 1950. Otwornice tzw. "pstrego eocenu" i jego paleogeografia na obszarze pomiędzy Sanokiem a Gorlicami. (In Polish only). *Nafta*, 5: 118–122.

Dabagyan, N. V., Kulchitsky, J. O., Kuzovenko, V. V. & Shlapinsky, V. E., 1987. Key sections of the boundary layers of Upper Eocene–Lower Oligocene of the southern part of Skiba, Krosno and Chernogora zones. (In Russian, English summary). *Paleontol. Sbornik*, 24: 27–32. Lvov.

Danysh, V. V., Kruglov, S. S., Kulchitsky, J. O., Lozynyak, P. J., Maximov, A. V., Pilipchuk, A. S., Reyfman, L. M., Smirnov, S. E. & Sovchik, J. V., 1987. Paleogeographical peculiarities of Eocene–Oligocene boundary on the territory of the Ukrainian Carpathians. (In Russian, English summary). *Paleontol. Sbornik*, 24: 38–42. Lvov.

Delvaux, D., Martin, H., Leplat, P. & Paulet, J., 1990. Geochemical characterization of sedimentary organic matter by means of pyrolysis kinetic parameters. *Org. Geochem.*, 16: 175–187

Dercourt, J., Zonenshain, L. P., Ricou, L. E., Kazmin, V. G., Le Pichon, X., Knipper, A. L,. Grandjacquet, C., Sborshchikov, I. M., Boulin, J., Sorokhtin, O., Geyssant, J., Lepvrier, C., Biju-Duval, B., Sibuet, J. C., Savostin, L. A., Westphal, M. & Lauer, J. P., 1985. Présentation de 9 cartes paléogéographiques au 1/20.000.000^{e} s'étendant de l'Atlantique au Pamir pour la période du Lias á l'Actuel. *Bull. Soc. Géol. France*, Sér. 8, 1: 637–652.

Einsele, G., 1992. *Sedimentary Basins.* Springer Verlag, Berlin, 628 pp.

Einsele, G. & Ricken, W., 1991. Limestone-marl alternation – an overview. In: Einsele, G., Ricken, W. & Seilacher, A., (eds), *Cycles and Events in Stratigraphy.* Springer Verlag, Berlin, pp. 23–41

Espitalié, J., Madec, M., Tissot, B., Mennig, J. J. & Leplat, P., 1977. Source rock characterization method for petroleum exploration. *Proceedings of the 9th Annual Offshore Technology Conference*, Houston, pp. 439–444.

Galloway, W. E., 1989. Genetic stratigraphic sequences in basin analysis In: Architecture and genesis of flooding-surface bounded depositional units. *Am. Assoc. Petrol. Geol., Bull.*, 73: 125–142.

Geroch, S., Jednorowska, A., Książkiewicz, M. & Liszkowa, J., 1967. V. Stratigraphy based upon microfauna in the western Polish Carpathians. *Inst. Geol., Biul.*, 211: 187–269.

Gramann, F., Hagn, H., Ritzkowski, S. & Sonne, V., 1986. Eocene–Oligocene boundary in Western Germany. In: Pomerol, Ch. & Premoli-Silva, I. (eds), *Terminal Eocene Events. Developments in Palaeontology and Stratigraphy*, 9, Elsevier. Amsterdam, pp. 101–107.

Gruzman, A. D., 1987. Foraminifera from the *Globigerina vialovi* beds of Lower Oligocene of the Ukrainian Carpathians. (In Russian, English summary). *Paleontol. Sbornik*, 24: 53–59. Lvov.

Grzybowski, J., 1897. Otwornice pokładów naftonośnych okolicy Krosna. (In Polish only). *Pol. Akad. Umiej., Rozprawy Wydz. Mat. Przyr.*, 33: 257–305.

Gucwa, I., 1973. The geochemistry of siliceous and calcareous biogenic deposits exemplified by the deposits of the Carpathian Flysch. (In Polish, English summary). *Inst. Geol., Biul.*, 271: 1–80.

Gucwa, I. & Pelczar, A., 1992. *Katalog Analiz Chemicznych Skał Karpat Polskich za Lata 1963–1985.* (In Polish only). Państwowy Instytut Geologiczny, Warszawa, 298 pp.

Gucwa, I. & Ślączka, A., 1972. Changes in geochemical conditions within the Silesian Basin (Polish Flysch Carpathians) at the Eocene–Oligocene boundary. *Sediment. Geol.*, 8: 199–223.

Gucwa, I. & Wieser, T., 1980. Geochemistry and mineralogy of sedimentary rocks of the Carpathian flysch rich in organic matter. (In Polish, English summary). *Prace Mineral. Oddz.*

PAN w Krakowie, 69: 1–39.

Haq, B. U., Hardenbol J., & Vail, P., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: Wilgus, C. K., Hastings, B. S., Posamentier, H., van Wagoner, J., Ross, C. A., & Kendall, C. G., St C. (eds), *Sea-Level Changes: An Integrated Approach. Soc. Econ. Paleont. Miner., Spec. Publ.*, 42: 71–108.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G. & Smith, D. G., 1990. *A Geologic Time Scale 1989.* Cambridge University Press, Cambridge, 263 pp.

Herb, R., 1988. Eocaene Paläogeographie und Paläotektonik des Helvetikums. *Eclogae Geol. Helv.*, 81: 611–657.

Hiltermann, H., 1943. Zur Stratigraphie und Mikrofossilführung der Mittelkarpathen. *Öl Kohle*, 39: 745–755.

Irwin, H., Curtis, C. & Coleman, M., 1977. Isotopic evidence for source of diagenetic carbonates formed during burial of organic-rich sediments. *Nature*, 269: 209–213.

Jasionowicz, J., 1961a. *Globigerina* marls from region of Podzamcze fold (Middle Carpathians). (In Polish, English summary). *Kwart. Geol.*, 5: 631–645.

Jasionowicz, J., 1961b. . Geology of the Wańkowa-village – Łodyna fold between Serednica and Łodyna (Flysch Carpathians). (In Polish, English summary). *Inst. Geol., Biul.*, 166: 58–86.

Jednorowska, A., 1966. Zespoły małych otwornic w warstwach jednostki magurskiej rejonu Babiej Góry i ich znaczenie stratygraficzne. (In Polish only). In: *Przew. 39 Zjazdu Pol. Tow. Geol.*, Wydawnictwa Geologiczne, Warszawa, pp. 71–90.

Jucha, S. & Kotlarczyk, J., 1961. La série des couches ŕ Ménilite et des couches de Krosno dans le flysch des Karpates. (In Polish, French summary). *Prace Geol. Oddz. PAN w Krakowie*, 4: 1–71.

Kępińska, B., 1997. Model geologiczno-geotermalny niecki podhalańskiej. (In Polish only). *Studia, Rozprawy, Monografie*, Wydawnictwo Centrum Podstawowych Problemów Gospodarki Surowcami Mineralnymi i Energią PAN, Kraków. 48: 3–111,

Koltun, Y. V., 1992. Organic matter in Oligocene Menilite formation rocks of the Ukrainian Carpathians: palaeoenvironment and geochemical evolution. *Org. Geochem.*, 18: 423–430.

Koszarski, L., 1956. Stratigraphy of the Silesian and sub-Silesian series North of Sanok. (In Polish only). *Przegl. Geol.*, 4: 461–462.

Koszarski, L. (ed.), 1985. Geology of the middle Carpathians and the Carpathian Foredeep. In: Koszarski, L. (ed.), *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 3.* Geological Institute, Warszawa, 254 pp.

Koszarski, A. & Koszarski, L., 1985a. Lower Cretaceous – Lower Oligocene sequence of the external part of the Silesian nappe and their sedimentological features. Stop 30. In: Koszarski, L. (ed.), *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 3.* Geological Institute, Warszawa, pp. 136–141.

Koszarski, A. & Koszarski, L., 1985b. Marginal Zone of the Magura Nappe and its relation to the lower units. In: Koszarski, L. (ed.), *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 3.* Geological Institute, Warszawa, pp. 216–224.

Koszarski, L., Ślączka, A. & Żytko, K., 1961. Stratigraphy and paleogeography of the Dukla Unit in the Bieszczady Mountauins. (In Polish, English summary). *Kwart. Geol.*, 5: 551–578.

Koszarski, L. & Wieser, T., 1960. New tuff horizons in older Palaeogene of Flysch Carpathians. (In Polish, English summary). *Kwart. Geol.*, 4: 749–771.

Koszarski, L. & Żgiet, J., 1961. Spostrzeżenia nad sedymentacją piaskowców typu krośnieńskiego w pstrych łupkach eoceńskich Karpat Fliszowych (In Polish only). *Spraw. z Pos. Kom. Pol. Akad. Nauk., I-IV.* pp. 234–237, Kraków.

Koszarski, L. & Żytko, K., 1959. Remarks on development and stratigraphical of the Jasło shales in the Menilitic and Krosno series of the Middle Carpathians. (In Polish, English summary). *Kwart. Geol.*, 3: 996–1014.

Koszarski, L. & Żytko, K., 1961. Jasło shales within the Menilite-Krosno series in the Middle Carpathians. (In Polish, English summary). *Inst. Geol., Biul.*, 166: 87–218.

Koszarski, L. & Żytko, K., 1965. Le probléme de la profondeur de la mer du géosynclinal karpatique de flysch. In: *Reports, Carp.-Balk. Geol. Ass. VII Congr.*, Part 2, v. 2: 81–86, Sofia.

Kotlarczyk, J., 1985. Remarks on the tectonics of the Carpathian orogen between the Wisłok and Wiar rivers. In: Kotlarczyk, J. (ed.), *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 4.* Wydawnictwa Geologiczne, Warszawa, pp. 32–64.

Kotlarczyk, J., 1988. Problemy sedymentologii, stratygrafii i tektoniki Karpat Przemyskich oraz ich najbliższego przedpola. (In Polish only). In: Kotlarczyk, J., Pękala, K. & Gucik, S. (eds), *Przew. 59 Zjazdu Pol. Tow. Geol.* Państwowy Instytut Geologiczny, Warszawa pp. 23–62.

Kotlarczyk, J. & Leśniak, T., 1990. *Lower Part of the Menilite Formation and Related Futoma Diatomite Member in the Skole Unit of the Polish Carpathians.* (In Polish, English summary). Wydawnictwo Akademii Górniczo-Hutniczej, Kraków, pp. 1–74.

Kozikowski, 1953. Geological structure of the region of Klęczany-Pisarzowa. (In Polish, English summary). *Inst. Geol., Biul.*, 85: 1–18.

Köster, J., Rospondek, M., Kotarba, M., Zubrzycki, A., De Leeuw, J. W. & Sinninghe Damsté, J. S., 1996. Biological markers and stable carbon isotope ratios as tools in palaeoenvironmental reconstructions: examples from the Menilite Formation (Oligocene) of the Flysch Carpathians of SE Poland. In: Wagreich, M. & Daurer, A., (eds), *SEDIMENT '96. 11 Sedimentologentreffen, Wien,* Geologische Bundesanstalt, Wien, p. 83.

Krhovský, J., Adamová, J., Hladíková, J. & Maslovská, H., 1993. Paleoenvironmental changes across the Eocene/Oligocene boundary in the Zdánice and Pouzdřany units (Western Carpathians, Czechoslovakia): the long term trend and orbitally forced changes in calcareous nannofossil assemblages. *Knihovnicka Zemního Plynu a Nafty*, 14b: 105–187. Hodonin.

Kropaczek, B., 1919. *Borysław, étude géologique.* (In Polish, French summary). Stacja Geologiczna Borysław, Kraków, 41 pp.

Książkiewicz, M., 1951. *Objaśnienia arkusza Wadowice.* (In Polish only). Państwowy Instytut Geologiczny, Warszawa, 283 pp.

Książkiewicz, M., 1956. Geology of the Northern Carpathians. *Geol. Rundsch.*, 45: 369–411.

Książkiewicz, M., 1960. Outline of the palaeogeography in the Polish Flysch Carpathians. (In Polish, English summary). *Inst. Geol., Prace*, 30: 236–249.

Książkiewicz, M. (ed.), 1962. *Geological Atlas of Poland. Stratigraphic and Facial Problems. fasc. 13. Cretaceous and Early Tertiary in the Polish External Carpathians.* Instytut Geologiczny, Warszawa.

Książkiewicz, M., 1966. Geologia regionu babiogórskiego. (In Polish only). *Przewodnik 39 Zjazdu Pol. Tow. Geol. Babia*

Góra, 2–5 czerwca, 1956. pp. 5–59.

Książkiewicz, M., 1974. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski. Arkusz Sucha Beskidzka (1014), 1:50000.* (In Polish only). Wydawnictwa Geologiczne, Warszawa, 83 pp.

Książkiewicz, M., 1975. Bathymetry of the Carpathian Flysch Basin. *Acta Geol. Polon.*, 25: 309–367.

Lallier-Vergés, E., Bertrand, P. & Desprairies, A., 1993. Organic matter composition and sulfate reduction intensity in Oman Margin sediments. *Mar. Geol.*, 112: 57–69.

Leszczyński, S., 1993a. Origin of sediment variability in Upper Eocene of the Polish Flysch Carpathians. In: *8. Sedimentologen-Treffen 3.-5. Juni 1993 an der Philipps-Universität Marburg. Kurzfassungen von Vorträgen und Postern.* Marburg, p. 57.

Leszczyński, S., 1993b. Utwory górnego eocenu Karpat zewnętrznych: interpretacja sposobu euksynizacji basenu. (In Polish only). In: *II Krajowe Spotkanie Sedymentologów, Wrocław, Sudety, 4-7 września 1993, Przewodnik*, Wrocław, p. 157.

Leszczyński, S., 1996. Origin of lithological variation in the sequence of the Sub-Menilite globigerina marl at Znamirowice (Eocene–Oligocene transition, Polish Outer Carpathians). *Ann. Soc. Geol. Polon.*, 66: 245–267

Liszkowa, J., 1956. Mikrofauna serii podśląskiej. (In Polish only). *Przegl. Geol.*, 4: 463–469.

Mahel', M., Buday, T. *et al.*, 1968. *Regional Geology of Czechoslovakia, Part II.* Geological Survey of Czechoslovakia, Praha, 723 pp.

Malata, T., 1996. Analysis of formal lithostratigraphic subdivisions and proposal of subdivisions of the Skole unit of the Polish Flysch Carpathians. (In Polish, English summary). *Przegl. Geol.*, 44: 509–513.

Maynard, J. B., 1980. Sulfur isotopes of iron sulfides in Devonian–Mississippian shales of the Appalachian Basin: control by rate of sedimentation. *Am. J. Sci.*, 280: 772–786.

Maynard, J. B., 1982. Extension of Berner's "new geochemical classification of sedimentary environments" to ancient sediments. *J. Sediment. Petrol.*, 52: 1325–1331.

Melguen, M., 1978. Facies, evolution, carbonate dissolution cycles in sediments from the eastern South Atlantic (DSDP Leg 40) since the Early Cretaceous. *Initial Repts. Deep Sea Drilling Project*, 40: 981–1024.

Micu, M., 1987. Eocene–Oligocene boundary in the East Carpathian Flysch – a case history. In: Ghergari, L., Mészáros, N., Nicorici, E. & Petrescu, I. (eds), *Geological Formations of Transilvania, Romania, 1. The Eocene from the Transilvanian Basin.* University Cluj-Napoca, Cluj-Napoca, pp. 155–158.

Micu, M., Gheta, N., Tátu, E. & Bratu, E., 1981. Contributions to the stratigraphy of the Tazlau basin, Paleogene (Bistrita half-window, East Carpathians). *Dari Seama Inst. Geol. Geofiz.*, 68: 105–118.

Miller, K. G., 1992. Middle Eocene to Oligocene stable isotopes, climate, and deep-water history: the terminal Eocene Event? In: Prothero, D. R. & Beggren, W. A. (eds), *Eocene–Oligocene Climatic and Biotic Evolution.* Princeton Univ. Press, Princeton, pp. 160–177.

Miller, K. G., Tucholke, B. E., 1983. Development of Cenozoic abyssal circulation south of the Greenland–Scotland Ridge. In: Bott, M. H. P., Saxov, S., Talwani, M. & Thiede, J. (eds), *Structure and Development of the Greenland–Scotland Ridge.* Plenum Press, New York, pp. 549–589.

Mutti, E. & Ricci Lucchi, F., 1975. Turbidite facies and facies associations. In: Mutti, E., Parea, G. C., Ricci Lucchi, F., Sagri, M., Zanzucchi, G., Ghibaudo, G. & Iaccarino, S., (eds), *Examples of Turbidite Facies and Facies Associations from Selected Formations of the Northern Apennines. Field Trip Guidebook A-11, 9th International Association of Sedimentologists Congress, Nice.* pp. 21–36.

Narębski, W., 1957. Mineralogy and geochemical conditions of formation of so called siderites of the Carpathian Flysch. (In Polish,. English summary). *Arch. Mineral.*, 21: 5–91.

Nowak, J., 1927. Esquisse de la tectonique de Pologne. (In Polish, French summary). *Zarys tektoniki Polski.* II Zjazd Słowiańskich Geografów i Etnografów w Polsce, Kraków, 160 pp.

Nowak, W., 1959. Geologia brzegu karpackiego między Andrychowem a Sołą. (In Polish, English summary). *Inst. Geol., Biul.*, 131: 149–189.

Oberhänsli, H., 1996. Klimatische und ozeanographische Veränderungen im Eozän. *Zeit. Deutsch. Geol. Ges.*, 147: 303–413

Olewicz, Z. R., 1968. *Stratigraphy of the beds of the Bochnia unit and the border of the Silesian unit between Wieliczka and Bochnia and their original position in the Carpathian or foreland sedimentary basins.* (In Polish, English summary). Prace Inst. Naft., Katowice, 72 pp.

Olszewska, B., 1980. Foraminiferal stratigraphy of the Upper Cretaceous and Paleogene Sediments of the Central Part of the Dukla Unit. (In Polish, English summary). *Inst. Geol., Biul.*, 326: 59–102.

Olszewska, B., 1983. A contribution to the knowledge of planktonic foraminifers of the Globigerina Submenilite Marls in the Polish Outer Carpathians. (In Polish, English summary). *Kwart. Geol.*, 27: 547–570.

Olszewska, B., 1984. Benthonic foraminifera of the Sub-Menilite Globigerina Marls of Polish Outer Carpathians. (In Polish, English summary). *Inst. Geol., Prace*, 110: 1–33.

Olszewska, B., 1985. Remarks concerning the Eocene–Oligocene boundary in the Polish External Carpathians: Results of foraminiferal investigations. In: *Proceeding Reports of the XIII-th Congress of the Carpatho-Balkan Geological Association, Part I*, Wydawnictwa Geologiczne, Warszawa, pp. 57–59.

Olszewska, B. & Smagowicz, M., 1977. Comparison of biostratigraphic subdivisions of the Upper Cretaceous and Paleogene of the Dukla Unit on the basis of planktonic foraminifers and nannoplankton. (In Polish, English summary). *Przegl. Geol.*, 25: 359–364.

Oszczypko, M., 1996. Calcareous nannoplankton of the Globigerina Marls (Leluchów Marls Member), Magura Nappe, West Carpathians. *Ann. Soc. Geol. Polon.*, 66: 1–15.

Oszczypko, N., 1973. The geology of the Nowy Sącz Basin (the Middle Carpathians). (In Polish, English summary). *Inst. Geol., Biul.*, 271: 101–189.

Oszczypko, N., 1992a. Evolution of the Magura Basin in Late Cretaceous and Paleogene. (In Polish, English summary). *Przegl. Geol.*, 40: 397–403.

Oszczypko, N., 1992b. Zarys stratygrafii płaszczowiny magurskiej. (In Polish, English summary). In: Zuchiewicz, W. & Oszczypko, N. (eds), *Przewodnik 63 Zjazdu Pol. Tow. Geol., Koninki, 17-19 września, 1992*, Wydawnictwo Instytutu Nauk Geologicznych, Polska Akademia Nauk, Kraków, pp. 11–20.

Oszczypko, N., 1992c. Late Cretaceous through Paleogene evolution of Magura Basin. *Geol. Carpath.*, 43: 333–338

Oszczypko, N., Dudziak, J. & Malata, E., 1990. Stratigraphy of the Cretaceous through Palaeogene deposits of the Magura Nappe in the Beskid Sądecki Range, Polish Outer Carpathians. (In Polish, English summary). *Studia Geol. Polon.*, 97: 109–163.

Paul, Z., Rączkowski, W., Ryłko, W. & Tomaś, A., 1996. Budowa geologiczna zachodniej części Karpat polskich. (In Polish only). In: Poprawa, D. & Rączkowski, W. (eds), *Przewodnik*

67 Zjazdu Pol. Tow. Gol., Szczyrk, 6-9 czerwca, 1996, Wydawnictwo Państwowego Instytutu Geologicznego, Kraków, pp. 8–31.

Pazdro, Z., 1928. Etudes géologique dans les environs de Brzostek. *Kosmos*, 53: 887–903.

Pickering, K., Stow, D., Watson, M. & Hiscott, R., 1986. Deep-water facies, processes and models: a review and classification scheme for modern and ancient sediments. *Earth-Sci. Rev.*, 23: 75–174

Piper, D. J. W., 1978. Turbidite muds and silts on deep-sea fans and abyssal plains. In:. Stanley, D. J & Kelling, G. (eds), *Sedimentation in Submarine Canyons, Fans, and Trenches.* Dowden, Hutchinson and Ross, Stroudsburg, Penn., pp. 727–755.

Pomerol, Ch. & Premoli Silva, I., 1986. The Eocene–Oligocene transition: events and boundary. In: Pomerol, Ch. & Premoli Silva, I. (eds), *Terminal Eocene Events. Developments in Palaeontology and Stratigraphy*, 9, Elsevier, Amsterdam, pp. 1–24.

Prothero, D. R., 1994. *The Eocene–Oligocene Transition. Paradise Lost.* Columbia Univ. Press, New York, 291 pp.

Prothero, D. R. & Berggren, W. A. (eds), 1992. *Eocene–Oligocene Climatic and Biotic Evolution.* Princeton Univ. Press, Princeton, 568 pp.

Radomski, A., 1958. The sedimentological character of the Podhale Flysch. (In Polish, English summary). *Acta Geol. Polon.*, 8: 335–409.

Radomski, A., 1968. Calcareous nannoplankton zones in Paleogene of the western Polish Carpathians. (in Polish, English summary). *Rocz. Pol. Tow. Geol.*, 38: 545–595.

Rajchel, J., 1990. Lithostratigraphy of the Upper Palaeocene and Eocene Sediments from the Skole Unit. (In Polish, English summary). *Zesz. Naukowe AGH, Nr 1369, Geologia*, 48: 1–112.

Ricou, L. E., Mercier de Lepinay, B. & Marcoux, J., 1986. Evolution of the Tethyan seaways and implications for the oceanic circulation around the Eocene–Oligocene boundary. In: Pomerol, Ch. & Premoli Silva, I. (eds), *Terminal Eocene Events. Developments in Palaeontology and Stratigraphy*, 9, Elsevier, Amsterdam, pp. 387–394.

Roniewicz, P., 1979. Paleogen Tatr i Podhala. (In Polish only). In: Lefeld, J. (ed.), *Przewodnik 51 Zjazdu Pol. Tow. Geol., Zakopane, 13-15 września 1979*, Wydawnictwa Geologiczne, Warszawa, pp. 57–72

Roth, P. H., 1981. Mid-Cretaceous calcareous nannoplankton from the central Pacific: Implications for paleoceanography. *Init. Rep. Deep Sea Drill. Proj.*, 62: 471–489.

Roth, P. H. & Krumbach, K. R., 1986. Middle Cretaceous calcareous nannofossil biogeography and preservation in the Atlantic and Indian Oceans: implications for paleoceanography. *Mar. Micropaleont.*, 10: 235–266.

Roth, Z., 1981. Die Menilitformation der Karpaten und ihre paläographische Stellung. (In Czech, German summary). *Zemni Plyn Nafta*, 26: 3–7.

Roth, Z. & Hanzlíková, E., 1982. Palaeotectonic and palaeo-ecological position of the Menilitic Formation in the Carpathian Mts. *Casopis Mineral. Geol.*, 27: 113–126.

Rögl, F. & Steininger, F., 1983. Vom Zerfall der Tethys zu Mediterran und Paratethys. Die Neogene Paläogeographie und Palinspastik des zirkum-mediterranen Raumes. *Ann. Naturhist. Mus. Wien*, 85: 135–163.

Samuel, O., 1973. Paleogeographical outline and manifestations of orogenetic phases in the Paleogene of the West Carpathians in Slovakia and the adjacent part of the Hungarian Midmountains. (In Slovak, English summary). *Geol. Práce, Spravy*, 60: 55–83. Bratislava.

Sandulescu, M., Micu, M. & Bratu, E., 1987. Stratigraphy of the Eocene flysch formations of the East Carpathians. In: Ghergari, L., Mészáros, N., Nicorici, E. & Petrescu, I. (eds), *Geological Formations of Transilvania, Romania, 1. The Eocene from the Transilvanian Basin.* University Cluj-Napoca, Cluj-Napoca pp. 159–164.

Shackleton, N. J., Imbrie, J. & Hall, M. A., 1983. Oxygen and carbon isotope record of East Pacific core V19-30: Implications for the formation of deep water in the late Pleistocene North Atlantic. *Earth Planet. Sci. Lett.* 65: 233–244.

Sikora, W., 1970. Geology of the Magura nappe between Szymbark Ruski and Nawojowa. (In Polish, English summary). *Inst. Geol., Biul.*, 235: 1–97.

Sikora, W. & Szymakowska, F., 1977. Problem 1B – Geneza płatów magurskich oraz rozwój facjalny brzeżnej strefy płaszczowiny magurskiej i utworów okna tektonicznego Ropy. (In Polish only). In: Ślączka, A. (ed.), *Przewodnik 59 Zjazdu Pol. Tow. Geol. Krosno, 22-25 września 1977*, Wydawnictwa Geologiczne, Warszawa, pp. 88–106.

Skoczylas-Ciszewska, K., 1960. Geology of the Żegocina Zone (Western Flysch Carpathians). (in Polish, English summary). *Acta Geol. Polon.*, 10: 485–591.

Sokołowski, J., 1985. Borehole Bańska IG 1. In: Birkenmajer, K. (ed.). *Carpatho-Balkan Geological Association 13th Congress, Cracow, Poland, 1985, Guide to Excursion 2.* Wydawnictwa Geologiczne, Warszawa, pp. 62–66.

Stow, D. A. V. & Shanmugam, G., 1980. Sequence of structures in fine-grained turbidites, comparisons of recent deep-sea and ancient flysch sediments. *Sediment. Geol.*, 25: 23–42.

Stow, D. A. V., Reading, H. G. & Collinson, J. D., 1996. Deep seas. In: Reading, H. G. (ed.), *Sedimentary Environments: Processes, Facies and Stratigraphy.* Blackwell Science, Oxford, pp. 395–453.

Szajnocha, W., 1925. Der geologische Bau des Quellengebietes der Olza bei Istebna. (In Polish, German summary). *Rocz. Pol. Tow. Geol.*, 11: 3–34.

Szymakowska, F., 1962. Budowa geologiczna NW części depresji strzyżowskiej. (In Polish only). *Kwart Geol.*, 6: 798–799.

Szymakowska, F., 1966. Outliers of the Magura nappe in the Jasło area and their relation with the Fore-Magura series. *Rocz. Pol. Tow. Geol.*, 36: 41–61.

Ślączka, A., 1956. Stratygrafia serii śląskiej na przedpolu fałdów dukielskich. (In Polish only). *Przegl. Geol.*, 4: 459–460.

Ślączka, A., 1959. Stratigraphy of the Dukla folds in the Komańcza – Wisłok Wielki region (Carpathians). (In Polish, English summary). *Kwart. Geol.*, 3: 583–604.

Ślączka, A., 1968. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski, Arkusz Bukowsko* (In Polish only). Wydawnictwa Geologiczne, Warszawa, 79 pp.

Ślączka, A., 1970. Geology of the Dukla unit. (In Polish, English summary). *Inst. Geol., Prace*, 63: 1–124.

Ślączka, A., 1973a. Wycieczka 6. (In Polish only). In: Żytko, K. (ed.), *Przewodnik geologiczny po wschodnich Karpatach fliszowych.* Wydawnictwa Geologiczne, Warszawa, pp. 121–134.

Ślączka, A., 1973b. Wycieczka 7. (In Polish only). In: Żytko, K. (ed.), *Przewodnik geologiczny po wschodnich Karpatach fliszowych.* Wydawnictwa Geologiczne, Warszawa, pp. 135–145.

Ślączka, A., 1973c. Wycieczka 8. (In Polish only). In: Żytko, K. (ed.), *Przewodnik geologiczny po wschodnich Karpatach fliszowych.* Wydawnictwa Geologiczne, Warszawa, pp. 146–159

Ślączka, A., 1973d. Wycieczka 9. (In Polish only). In: Żytko, K.

(ed.), *Przewodnik geologiczny po wschodnich Karpatach fliszowych.* Wydawnictwa Geologiczne, Warszawa, pp. 160–171.

Ślączka, A., 1977. Problem IA – Rozwój facjalny i problemy paleogeograficzne młodszego paleogenu jednostki dukielskiej. (In Polish only). In: Ślączka, A. (ed.), *Przewodnik 59 Zjazdu Pol. Tow. Geol. Krosno, 22-25 września 1977*, Wydawnictwa Geologiczne, Warszawa, pp. 73–87.

Ślączka, A., 1990. Redeposited marls from the Carpathian flysch. *13th International Sedimentological Congress Nottingham,, Abstracts -Papers*, pp. 501–502.

Ślączka, A. & Unrug, R., 1966. Sedimentary structures and petrology of some sandstone members of the Menilite beds, Carpathians. (In Polish, English summary). *Rocz. Pol. Tow. Geol.*, 36: 155–177.

Świdziński, H., 1948. Stratigraphical index of the Northern Flysch Carpathians. *Pol. Inst. Geol., Bull.*, 37: 1–128.

Świdziński, H., 1950. Stróże scale near Grybów (Middle Carpathians). (In Polish, English summary). *Państw. Inst. Geol., Biul.*, 59: 5–70.

Świdziński, H., 1961. Observations géologiques faites dans les environs de Leluchów, de Plavec sur le Poprad et d'Ujak (Karpates polono-slovaques). *Bull. Acad. Pol., Sci., Sér. chim., géol. et geogr.*, 9: 109–119.

Thierstein, H. R. & Roth, P. H., 1991. Stable isotopic and carbonate cyclicity in Lower Cretaceous deep-sea sediments: dominance of diagenetic effects. *Mar. Geol.*, 97: 1239–1249.

Thunell, R., Rio, D., Sprovieri, R. & Raffi, I., 1991. Limestone-marl couplets: origin of the early Pliocene Trubi marls in Calabria, southern Italy. *J. Sediment. Petrol.*, 61: 1109–1122.

Tissot, B. P. & Welte, D. H., 1984. *Petroleum Formation and Occurrence.* Springer Verlag, Berlin, 699 pp.

Tokarski, A., 1968. The tectonics of Mt. Przedziwna in the southwestern rear of bath-Iwonicz. (In Polish, English summary). *Acta Geol. Polon.*, 18: 832–844.

Tołwiński, K., 1917. Przyczynki do geologii Borysławia i okolic. (In Polish only). *Czas. Górn.-Hutn.*, 8: 217. Krakow.

Tucker, M. & Wright, 1990. *Carbonate Sedimentology.* Blackwell, 482 pp.

Tyson, R.V., 1995. *Sedimentary Organic Matter: Organic Facies and Palynofacies.* Chapman & Hall, 615 pp.

Uhlig, V., 1886. Über eine Mikrofauna aus dem Alttertiär der west-galizischen Karpathen. *Jrb. Geol. Reichsanst.*, 36: 141–214.

Van Couvering, J. A., Aubry, M. -P., Berggren, W. A., Bujak, J. P., Naeser, C. W. & Wieser, T., 1981. The terminal Eocene event and the Polish connections. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 36: 321–362.

Vetö, I., 1987. An Oligocene sink for organic carbon: upwelling in the Paratethys? *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 60: 143–153.

Vialov, O. S., 1951. Skhema stratigrafii severnogo sklona Karpat. (In Russian only). *Dokl. Akad. Nauk. SSSR*, 77: 689–696.

Vialov, O. S., Dabagian, I. V., Mjatluk, E. V., 1965. O sheshorskom gorizontie v Vostochnykh Karpatakh. (In Russian only). In: *Materialy VI Sjezda KBGA, Dokl. sovietskikh geologov.* Naukova Dumka, Kiev, pp. 157–168.

Vialov, O. S., Dabagian, N. V., Miatluk, E. V. & Pishvanova, L. S., 1974. O sheshorskom gorizontie v Vostochnykh Karpatakh. (In Russian only). In: *Bull. du VI Congress de l'Association Geol. Carp.-Balcanique. v. 1. Stratigraphie*, fasc. 3, Warszawa, pp. 369–376.

Vialov, O. S., Andreyeva-Grigorovich, A. S., Gavura, S. P., Gruzman, A. D., Dabagian, N. V., Danysh, V. V., Kulchitsky, J. O., Lozyniak, P. J., Ponomareva, L. D., Romaniv, A. M. & Smirnov, S. E., 1987. The Boundary of Eocene and Oligocene in the Ukrainian Carpathians. (In Russian, English summary). *Paleontol. Sbornik*, 24: 6–12. Lvov.

Vialov, O. S. Gavura, S. P. & Ponomareva, L. D., 1987. Key sections of Oligocene and Eocene border deposits of the Inner zone of the Pre-Carpathian foredeep (Pokutye). (In Russian, English summary). *Paleontol. Sbornik*, 24: 12–20. Lvov.

Vialov, O. S. Gavura, S. P., Danysh, V. V. & Smirnov, S. E., 1987. Eocene and Oligocene key Boundary sections of the north slope of the Ukrainian Carpathians. (In Russian, English summary). *Paleontol. Sbornik*, 24: 20–26. Lvov.

Vialov, O. S. Gavura, S. P., Danysh, V. V., Lemishko, O. D., Leshchukh, R. I., Ponomaryeva, L. D., Romaiv, A. M., Smirnov, S. E., Smolinskaya, N. I. & Tsarnienko, P. N., 1988. *Stratotypy myelovikh i paleogenovikh otlozsheniy Ukrainskikh Karpat.* (In Russian only). Naukova Dumka, Kiev, 204 pp.

Warchołowska-Pazdrowa, O. 1929 (ed. in 1930). Sur la structure géologique de la région de Dukla et Żmigród (Carpates polonaise centrales). *Kosmos*, 54: 917–928.

Wdowiarz, S., Zubrzycki, A. & Frysztak-Wołkowska, A., 1991. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1 : 50000 ark. Rymanów.* (In Polish only). Wydawnictwa Geologiczne, Warszawa, 92 pp.

Węcławik, S., 1969. The geological structure of the Magura Nappe between Uście Gorlickie and Tylicz. Carpathians (Lower Beskid). (In Polish, English summary). *Prace Geol. Kom. Nauk Geol. PAN Oddz. Kraków*, 59: 1–70.

Winkler, W., 1984. *Rhabdammina*-fauna: what relation to turbidites? Evidence from the Gurnigel-Schlieren flysch. In: *Benthos '83; 2nd Int. Symp. Benthic Foraminifera (Pau, April 1983)*, Pau and Bordeaux, pp. 611–617.

Streszczenie

GENEZA UTWORÓW SEKWENCJI PODMENILITOWYCH MARGLI GLOBIGERYNOWYCH (PRZEŁOM EOCENU I OLIGOCENU) KARPAT POLSKICH

Stanisław Leszczyński

WSTĘP

Sekwencja podmenilitowych margli globigerynowych (SMGMS) reprezentuje jeden z ważniejszych poziomów charakterystycznych we fliszu Karpat zewnętrznych. Sekwencja ta wyróżnia się skoncentrowanym występowaniem kremowo-żółtych i zielonych do czerwonawych margli bogatych w otwornice planktoniczne. Mieści się ona w obrębie części sekwencji fliszu charakteryzującej się ostrymi zmianami w obrębie utworów drobnoziarnistych.

Szerokie rozprzestrzenienie margli bogatych w globigeryny na przełomie eocenu i oligocenu na obszarze od Alp Zachodnich po Kaukaz (patrz Rögl & Steininger, 1983) sugeruje sterowanie sedymentacji tych utworów przez czynniki ponadregionalne. Zasadnicze znaczenie przypisywane jest globalnym zmianom klimatu oraz zmianom paleogeografii w obrębie i wokół Tetydy (patrz Olszewska, 1983, 1984).

Celem niniejszej pracy jest interpretacja genezy osadów

SMGMS, ze szczególnym uwzględnieniem głównych czynników odpowiedzialnych za sedymentację charakterystycznych dla tej sekwencji jasnych margli oraz za wzór sekwencji.

METODY

Przeprowadzono ogólną analizę sekwencji górnego eocenu–dolnego oligocenu w całych Karpatach. W 25 przekrojach z różnych części Polskich Karpat zewnętrznych (Fig. 1) przeprowadzone zostały makroskopowe badania szczegółowe. W badaniach makroskopowych rejestrowane były wszystkie cechy skał. Facje odnoszono do schematu klasyfikacyjnego facji osadów głębokowodnych opracowanego przez Pickeringa *et al.* (1986; Tab. 1).

W oparciu o dane z przekrojów badanych bezpośrednio oraz dane z literatury opracowane zostały schematy litostratygrafii i mapy facji późnego eocenu–wczesnego oligocenu.

Badania terenowe uzupełnione były badaniami laboratoryjnymi:

- mikrocech osadów,
- rozmieszczenia otwornic i nanoplanktonu wapiennego,
- zawartości i rodzaju węglanów,
- zawartości i rodzaju materii organicznej,
- zawartości 10 głównych pierwiastków,
- sygnałów stabilnych izotopów tlenu, węgla i siarki.

STRATYGRAFIA

Definicja i datowania

Jako SMGMS, w pracy niniejszej opisywany jest pakiet skał zdominowany marglami kremowo-żółtymi, żółtawo-zielonymi, zielonawo-szarymi lub czerwonawymi występujący powyżej sekwencji z przeważnie zielonymi utworami drobnoziarnistymi lub powyżej jej odpowiedników chronostratygraficznych, a poniżej sekwencji, w której utwory drobnoziarniste są w przewadze ciemne. Jest ona opisywana jako warstwy menilitowe lub jako formacja menilitowa. W pracy niniejszej wzmiankowana jest przede wszystkim dolna część warstw menilitowych, poniżej poziomu rogowców, nazywana warstwami podrogowcowymi (por. Świdziński, 1948).

Datowania SMGMS, podobnie jak i jej litostratygrafia, prezentowane są różnie w dotychczasowej literaturze (Tab. 2). Według ostatnich prac, SMGMS obejmuje poziomy otwornicowe P 17, częściowo P 16 (Van Couvering *et al.*, 1981) oraz P 18 (Olszewska, 1985), a także poziomy nanoplanktonu wapiennego NP 20 i dolną część NP 21 (Van Couvering *et al.*, 1981) lub wyłącznie nierozdzielny poziom NP 19/20 (Oszczypko, 1996). Datowania te pozostają do siebie w różnych relacjach, zależnie od rodzaju skali odniesienia (Tab. 3).

SMGMS a utwory priabonu–wczesnego rupelu w Karpatach Polskich

Karpaty wewnętrzne

Uwory priabonu–wczesnego rupelu dokumentowane są w dolnej części paleogenu Podhala (v. Blaicher, 1973; Sokołowski, 1985; Cieszkowski, inf. ustna). Odpowiedniki chronostratygraficznie SMGMS występują na przejściu od wapiennych utworów eocenu numulitowego do fliszu warstw zakopiańskich i szaflarskich.

Karpaty zewnętrzne

Utwory priabonu w Karpatach zewnętrznych, z wyjątkiem płaszczowiny magurskiej, są zdominowane łupkami zielonymi (Fig. 2; Tab. 4). W płaszczowinie magurskiej, w jednostkach krynickiej, sądeckiej i gorlickiej, priabon jest reprezentowany głównie przez serię fliszu ogniwa piaskowców z Popradu (v. Oszczypko, 1992a, b, c). Lokalnie mogą one sięgać po granicę eocen–oligocen (v. Cieszkowski, 1992a). W jednostce Siar płaszczowiny magurskiej, utwory priabonu są przeważnie drobnoziarniste o barwach zielonych i szarych (łupki pstre, warstwy podmagurskie i hieroglifowe; v. Oszczypko, 1992b, c).

W stropie priabonu, na przejściu do rupelu, na całym obszarze Karpat zewnętrznych występują utwory wzbogacone w materiał wapienny. Jest to w większości SMGMS (por. Koszarski, 1985). W płaszczowinie magurskiej, sekwencję takich utworów wydzielono jako ogniwo margli z Leluchowa (Birkenmajer & Oszczypko, 1989), natomiast w płaszczowinie skolskiej jako ogniwo margli ze Strwiąża (Rajchel, 1990). Wykształcenie SMGMS pod względem składu litologicznego i rozmieszczenia poszczególnych rodzajów skał w profilu jest różne i zmienia się już na dystansie paru kilometrów (Fig. 3–17).

Powyżej SMGMS, w jednostkach tektonicznych grupy przedmagurskiej i położonych bardziej na północ, zalega zróżnicowana litologicznie sekwencja warstw podrogowcowych, stanowiących dolną część warstw menilitowych. Jej wyróżnikiem są ciemnoszare i brunatne do czarnych utwory drobnoziarniste (mułowce, margle, łupki) podścielające poziom rogowców. Występujące tam utwory gruboklastyczne cechują się dużym udziałem bioklastów pochodzenia płytkomorskiego. Na przejściu od SMGMS do warstw podrogowcowych występuje przekładaniec centymetrowych lamin jasnych i ciemnych osadu drobnoziarnistego (łupek ilasty do mułowego, mułowiec, margiel). Wapnistość utworów drobnoziarnistych spada wyraźnie w stropie warstw podrogowcowych.

Margle globigerynowe na przełomie eocenu–oligocenu w innych regionach

Znaczne wzbogacenie utworów przełomu eocenu–oligocenu w drobnoziarnisty materiał wapienny, włącznie z występowaniem margli globigerynowych, zaznacza się na całym obszarze alpidów Europy środkowej. Jednakowoż, pozycja skoncentrowanego występowania materiału wapiennego jest interpretowana dosyć rozbieżnie (Tab. 5). Rozbieżności te, przynajmniej w części, wydają się wynikać z różnych metod datowania, jak również z różnej klasyfikacji litostratygraficznej tych utworów. Ich pozycja litostratygraficzna w całych Karpatach zewnętrznych wydaje się być stała.

SPECYFIKA I FACJE SMGMS

Na całym badanym obszarze, SMGMS wykazuje znaczne lateralne zróżnicowanie miąższości, składu i wzoru. Z wyjątkiem płaszczowiny dukielskiej, jej miąższość wydaje się oscylować między 5–10 metrów. Zaznacza się słaby trend wzrostu skumulowanej miąższości margli jasnych i łupków zielonych ze spadkiem skumulowanej miąższości niewapnistych łupków zielonych (Fig. 18A) oraz wzrostem ilości przewarstwień tych ostatnich (Fig. 18B). Różnice we wzorze sekwencji zaznaczają się na przestrzeni kilku kilometrów (por. profil Znamirowice na Fig. 11 z profilem na Fig. 12B). Chociaż, pewien wzór zdaje się powtarzać w niektórych profilach.

Ze względu na teksturę, barwę, struktury sedymentacyjne i zawartość $CaCO_3$ utworów SMGMS wyodrębnione zostały w nich następujące facje:

- margle jasne,
- łupki zielone,
- ciemne łupki, mułowce i margle,
- piaskowce i pyłowce,
- utwory chaotyczne

Wyróżnione facje wykazują pewne powiązanie ze sobą (Fig.

19). Dotyczy ono szczególnie stopniowego przechodzenia margli jasnych w łupki zielone. Osady gruboziarniste koncentrują się w słabiej wapnistych odcinkach profilu. W górnej części SMGMS zaznacza się zanik bioturbacji. Są one generalnie nieobecne w leżących wyżej warstwach menilitowych.

Margle jasne

Facja ta obejmuje miękkie margle żółto-kremowe, beżowe, żółto-zielone, beżowo-szare, szaro-zielone i czerwonawe oraz twarde, konkrecyjne margle beżowe. Ich skoncentrowane występowanie jest podstawą wydzielania SMGMS. Utwory te wykazują pewne zróżnicowanie tekstury i struktur sedymentacyjnych, widoczne przede wszystkim pod mikroskopem (Fig. 20–28). Najgrubszą frakcję jasnych margli tworzą najczęściej skorupki otwornic planktonicznych. Obserwacje w mikroskopie skaningowym wskazują, że materiał wapienny jest głównie pochodzenia nannoplanktonowego (Fig. 29; por. Krhovský *et al.*, 1993; Oszczypko, 1996). Margle miękkie tej facji odpowiadają facjom G1.2 i G2.1 ze schematu klasyfikacyjnego Pickeringa *et al.* (1986), zaś margle twarde mają charakter facji G3.

Łupki zielone

Zaliczono tu łupki jasnozielone, szarozielone do oliwkowych, mułowe do ilastych, tak wapniste jak i niewapniste. Ich udział i rozmieszczenie w badanych przekrojach są dosyć zróżnicowane. Zanikają one prawie zupełnie w stropie SMGMS. W utworach tych reprezentowane są facje E1.2, E1.3, G2 i E2.1 ze schematu klasyfikacyjnego Pickeringa *et al.* (1986).

Łupki, mułowce i margle ciemne

Facja ta obejmuje ciemnoszare do czarnych łupki ilaste do mułowych, ciemnoszare do czarnych i brunatne mułowce i margle. Udział tych utworów wzrasta ku górze SMGMS. Oprócz zróżnicowania barwy i zawartości $CaCO_3$ wykazują one dość duże zróżnicowanie pod względem składu petrograficznego, tekstury i struktur (Fig. 30–32).

W odniesieniu do schematu klasyfikacyjnego Pickeringa *et al.* (1986), utwory te reprezentują facje D2.1, D2.3, E2.1, oraz E2.2.

Piaskowce i pyłowce

Facja ta reprezentowana jest przede wszystkim przez cienkie i bardzo cienkie ławice pyłowców i piaskowców, przechodzących ku górze w ciemny mułowiec, odpowiadające w schemacie klasyfikacyjnym Pickeringa *et al.* (1986) facjom C2.3 i D2.1. Podrzędny udział mają utwory reprezentujące facje C2.1, B1.2 oraz C1.1.

Utwory chaotyczne

Facja ta obejmuje utwory odpowiadające facjom F2.1 i F2.2 ze schematu klasyfikacyjnego Pickeringa *et al.* (1986). Występują one w pojedynczych ławicach, szczególnie w obrębie SMGMS w płaszczowinie dukielskiej.

SKŁAD UTWORÓW DROBNOZIARNISTYCH

Głównymi składnikami mineralnymi badanych drobnoziarnistych utworów SMGMS są hydromiki, kwarc detrytyczny oraz kalcyt. W marglach twardych występują większe ilości syderytu, dolomitów żelazistych, i w mniejszym stopniu rodochrozytu (Fig. 39).Częstym składnikiem ciemnych łupków, mułowców i margli jest piryt. Zawartość węglanów wyrażana jako $CaCO_3$ waha się w przedziale 0–78.5%. Materiał wapienny tworzą głównie nannoskamieniałości (v. Radomski, 1967; van Couvering *et al.*, 1981; Oszczypko, 1996; Fig. 37) oraz skorupki otwornic planktonicznych (v. Blaicher, 1961, 1970; Olszewska, 1983, 1984; Fig. 36). Zawartość węglanów, materii organicznej, sygnały stabilnych izotopów O, C i S, jak również udział otwornic i nannoplanktonu wykazują silną zależność od rodzaju osadu (Fig. 33–35; 38, 40, 41, 43; Tab. 8).

Całkowita zawartość materii organicznej (TOC) mieści się w przedziale 0–3,5%. W marglach jasnych jej udział jest bliski zera. Największy udział ma ona w łupkach, mułowcach i marglach ciemnych. Reprezentowana jest tam głównie przez kerogen typu III (Tab. 6, Fig. 42).

Spośród 10 pierwiastków głównych, najbardziej zmienny udział wykazują: Si, Ca, Fe, Al i K (Tab. 7)

GENEZA OSADÓW

Tekstura i struktury sedymentacyjne osadów drobnoziarnistych dominujących w SMGMS wskazują na sedymentację głównie poprzez swobodne osiadanie ze słupa wody. Duża zawartość pyłowego materiału terygenicznego wskazuje, że są to zasadniczo osady hemipelagiczne. Część osadów drobnoziarnistych deponowana była przy pewnym udziale transportu po dnie.

Margle twarde są osadami ukształtowanymi znacząco przez procesy diagenetyczne. Tym samym reprezentują one fację osadów chemogenicznych: G3, w schemacie klasyfikacyjnym Pickeringa *et al.* (1986).

Margle i łupki z laminami pyłowymi, podobnie jak kilkumilimetrowe do kilkucentymetrowych laminy pylaste i drobnopiaszczyste mogą reprezentować osad prądów konturowych lub osad silnie rozcieńczonych prądów zawiesinowych.

Łupki, mułowce i margle tworzące warstwy o wyraźnie zaznaczonym spągu i wykazujące normalne uziarnienie frakcjonalne, podobnie jak i cienkie i średnie ławice piaskowców i pyłowców są turbidytami osadzonymi z prądów zawiesinowych o niskiej gęstości. Piaskowce grubołąwicowe są turbidytami osadzonymi z prądów zawiesinowych o wysokiej gęstości.

Utwory chaotyczne zostały osadzone przez spływy kohezyjne i osuwiska.

Ze względu na skład, charakterystyczne dla SMGMS margle jasne reprezentują mułowe oozy nannoplanktonowo-otwornicowe, zwane też arlami nannoplanktonowo-otwornicowymi.

Cechy osadów eoceńsko-oligoceńskich Karpat zewnętrznych oraz ich rozmieszczenie wskazują na sedymentację w zamykającym się basenie (ang. remnant basin) głębokomorskim (Fig. 44, 45). Ze względu na stosunkowo niewielkie rozmiary i wyraźne oddzielenie morfologiczne od głównej części Tetydy basen ten miał charakter "morza przyległego" (ang. adjacent sea, Einsele, 1992).

Utwory SMGMS deponowane były na głębokościach położonych w przedziale CCD. Zmieniające się lateralnie rozmieszczenie drobnoziarnistych osadów wapiennych wydaje się wynikać ze znacznego zróżnicowania batymetrii basenów względem CCD.

Zespoły nanoplanktonu i otwornic planktonicznych w utworach SMGMS wskazują na ich osadzanie w morzu umiarkowanie chłodnym (van Couvering *et al.*, 1981; Olszewska, 1983). Pionowe zmiany zespołów obu grup skamieniałości sugerują fluktuację zasolenia, ewaporacji i żyzności basenów fliszowych (Krhovský *et al.*, 1993). Intensywna bioturbacja osadów tła wskazuje aerobowe warunki na dnie basenów podczas sedymentacji utworów SMGMS. Zakończenie ich sedymentacji wiąże się z załamaniem aeracji i nastaniem warunków anoksycznych i bliskich anoksji. W warunkach takich deponowane były utwory warstw menilitowych. Nastanie ich sedymentacji spowodowane zostało ograniczeniem połączeń basenów fliszowych z otwartym oceanem w wyniku ruchów orogenicznych na obszarze Tetydy oraz globalnych zmianami klimatu (v. Berggren & Prothero, 1992; Prothero, 1994; Oberhänsli, 1996)

Zróżnicowanie lateralne udziału i rodzaju materiału terygenicznego w SMGMS wskazuje na różne wpływy lądów. Parametry te sterowane były przez klimat, zróżnicowaną aktywność tektoniczną obrzeżeń basenów fliszowych ich morfologię i odległość od głównych dróg roznoszenia materiału. Charakterystyczna była dostawa materiału z północnych obrzeżeń basenów (Fig. 46). Generalnie, w porównaniu do utworów podścielających i nadległych, SMGMS formowana była w okresie znacznego obniżenia intensywności resedymentacji w basenach fliszowych.

Fluktuacja wapnistości utworów SMGMS, wynikająca zasadniczo ze zmieniającej się zawartości nanoplanktonu wapiennego i otwornic planktonicznych, sugeruje sterowanie sedymentacji całej sekwencji przez klimat i czynniki pochodne. Łączna miąższość osadów tła SMGMS oraz jej parametry stratygraficzne sugerują powstanie całej sekwencji pod wpływem warunków klimatycznych ukształtowanych przez jeden dłuższy cykl ekscentryczności orbity Ziemi (414 tys. lat; por. Krhovský *et al.*, 1993; Leszczyński, 1996). Stopa sedymentacji osadów tła wynosiła ok. 37 mm/tys. lat.

Wzór SMGMS kształtowany był zasadniczo przez zmiany klimatu wynikające z krótszego cyklu ekscentryczności orbity Ziemi (ok. 100 tys. lat) oraz cyklu skośności (ok. 40 tys. lat), batymetrię i geometrię basenów fliszowych oraz aktywność tektoniczną obszaru. Zmiany klimatu wpływały na rozwój SMGMS poprzez sterowanie produkcją nanoplanktonu wapiennego i otwornic planktonicznych i w konsekwencji położeniem CCD (Fig. 47). Batymetria i geometria basenów fliszowych wpływała na lokalny rozwój sedymentacji, określając położenie miejsca względem fluktuującej CCD i dopływ materiału węglanowego oraz intensywność i sposób dostawy materiału terygenicznego. Ostatnie dwa parametry były równocześnie uzależnione od aktywności tektonicznej obrzeżeń basenów. Najsłabszą fluktuacją wapnistości osadów tła oraz stratygraficznie największym zasięgiem cechuje się SMGMS w przekrojach powstałych w miejscach najpłytszych, poza głównymi drogami dystrybucji materiału terygenicznego.

Silne wzbogacenie jasnych margli w ^{16}O i ^{12}C sugeruje że obecne zróżnicowanie wapnistości utworów SMGMS jest w części efektem diagenezy. Diageneza prowadząca do takich przemian osadu powodowana jest tlenowym rozkładem materii organicznej. Wyraźne wzbogacenie mułowców i margli ciemnych w ^{13}C wska-zuje, że podlegały one diagenezie po etapie metanogenezy, a za-tem uległy silniejszemu przekształceniu diagenetycznemu niż margle jasne i łupki zielone.