

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

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Abstract: Sediment features, including foraminifera and nannoplankton content, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ 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 eccentricity 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 $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ i $\delta^{34}\text{S}$, 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 wewnętrznych 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.

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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 & Ślaczka, 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 & Ślaczka, 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 se-

quence 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 Znamirówice (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 Znamirówice 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, con-

cretionary 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 Siekierczyzna (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 Znamirówice.