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ORIGIN OF LITHOLOGICAL VARIATION IN THE SEQUENCE OF THE SUB-MENILITE GLOBIGERINA MARL AT ZNAMIROWICE (EOCENE-OLIGOCENE TRANSITION, POLISH OUTER CARPATHIANS)

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Abstract. Sediment features, including foraminifera and nannoplankton diversity, $\delta^{18}O$ and $\delta^{13}C$ signals, total organic carbon content, and type of kerogen show that the combined influence of periodically changing productivity of calcareous material and the intermittent supply of material from land and shelf during one 414 ky eccentricity cycle are the main factors responsible for the pattern of the Sub-Menilite Globigerina Marl sequence at Znamirowice.

The vertical fluctuations from calcareous green shale and light-coloured marl to noncalcareous green shale, in the lower part of the sequence, are shown to result primarily from temporary changes in calcareous nannoplankton and planktonic foraminifera productivity. Climate and water circulation changes forced by the 90 ky fluctuation of the Earth's orbit eccentricity, are presumed to be the chief cause of the productivity variation.

Minor fluctuations in carbonate content as well as the distribution of dark-gray to black shale and marl layers are regarded as resulting from changing supply of terrigenous material and mass resedimentation events. Intermittent and regionally changing tectonic activity, together with expansion and lateral shifting of deltaic lobes accompanied by more regular climate changes, are considered as responsible for the supply of terrigenous material.

Abstrakt. Analiza cech osadu wraz z oceną zróżnicowania otwornic i nannoplanktonu, wartości $\delta^{18}O$ i $\delta^{13}C$, całkowitej zawartości węgla organicznego i rodzaju kerogenu wykazała, że badany profil ukształtowany został głównie przez zmienną produkcję materiału wapiennego oraz zróżnicowaną w czasie dostawę materiału z lądu i szelfu w czasie i pod wpływem jednego cyklu ekscentryczności orbity Ziemi o okresie 414 tys. lat.

Zmieniająca się w czasie produkcja nannoplanktonu wapiennego i otwornic planktonicznych interpretowana jest jako główna przyczyna występujących w dolnej części profilu fluktuacji przejawiających się przechodzeniem wapnistych łupków zielonych lub jasnych margli w łupki zielone niewapniste. Jako główny czynnik odpowiedzialny za zmiany produkcji wskazywane są okresowe zmiany klimatu i cyrkulacji wody powodowane fluktuacjami ekscentryczności orbity Ziemi o okresie 90 tys. lat.

Mniejszej skali fluktuacje zawartości $CaCO_3$ oraz rozmieszczenie w profilu łupków i margli ciemnoszarych do czarnych są interpretowane jako efekt nieregularnie zmieniającej się dostawy materiału terygenicznego oraz występującej w nieregularnych odstępach czasowych resedymentacji masowej. Dostawa materiału terygenicznego kształtowana była zasadniczo przez zróżnicowną w czasie aktywność tektoniczą otoczenia basenu, rozrost i oboczne przemieszczanie się płatów deltowych, a także przez zmiany klimatu.

Key words: shales, marls, vertical sequence, cyclicity, productivity, orbital forcing, diagenesis, Eocene-Oligocene transition, Silesian Nappe, Carpathians, Poland.

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INTRODUCTION

The Eocene-Oligocene transition is recorded worldwide as a time of major changes. These changes are recognized as resulting from a major climate transformation from a warm "greenhouse" type, during the Early Eocene, to an "icehouse" type during the Oligocene. In the Carpathian Mountains, these Eocene-Oligocene changes are most prominently recorded in fine-grained sediments of the Outer Carpathian flysch, composed of a few thousand metres of pre-

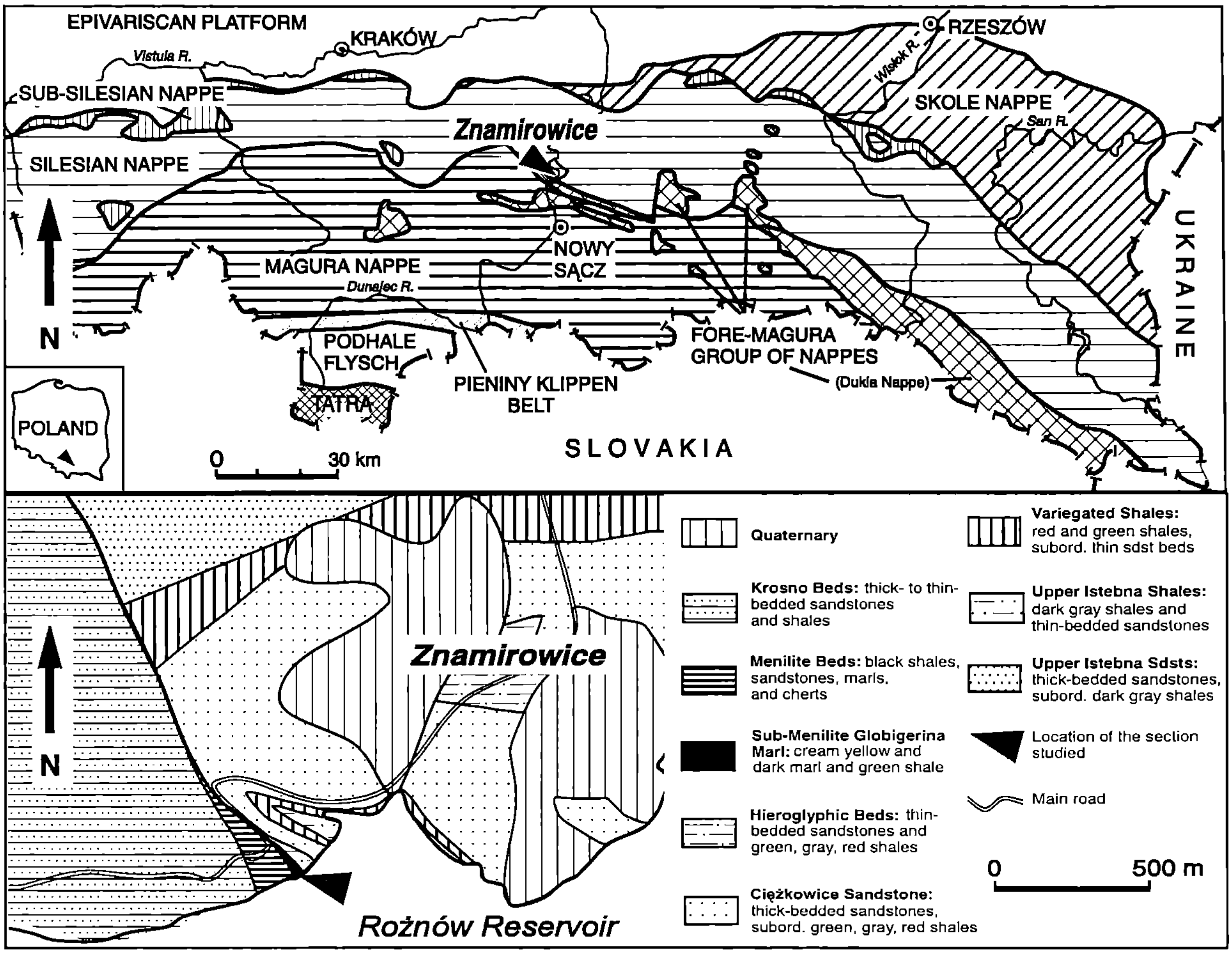

Fig. 1 Location of the examined section. **A.** Location of the section relative to regional geology. **B.** Location of the section at Znamirowice

dominantly siliciclastic deposits of turbidite facies association. The sediments of the several metres thick Sub-Menilite Globigerina Marl package (Grzybowski, 1897; Bieda, 1946; Koszarski & Wieser, 1960) called also Sheshory Horizon (Vialov, 1951; Vialov *et al.*, 1965), Leluchów Marl Member (Birkenmajer & Oszczypko, 1989), and the Strwiąż Globigerina Marl Member (Rajchel, 1990), are particularly characteristic of this period in the Outer Carpathians. The Sub-Menilite Globigerina Marl (SMGM) package is conspicuous by its cream-yellow marls, rich in planktonic foraminifera. It forms a persistent horizon at the top of the chiefly carbonate-free and light-coloured Eocene sequence and at the base of the lower Oligocene sequence dominated by dark-coloured shales. Moreover, sediments of the SMGM-type are konwn to occur widely in the Upper Eocene of the entire northern part of the Alpine belt between the Western Alps and the Caucasus (see Rögl & Steininger, 1983).

Unitil recently, the origin of the SMGM has been interpreted on the basis of extensive foraminiferal data, of general sediment features (see Olszewska, 1983, 1984), and of geochemical and other micropaleontological evidence derived from selected sections (e.g. Gucwa & Ślączka, 1972; Gucwa, 1973; Gucwa & Wieser, 1980; Van Couvering *et al.*, 1981). According to these interpretations, the SMGM package is dominated by pelagic sediments deposited in a cool sea during a global sea-level and CCD drop. Palaeogeographic transformations of the Carpathian area and of the global ocean as well as volcanic activity in the Carpathians were suggested as the primary controls of the SMGM sedimentation (see Książkiewicz, 1960; Gucwa & Wieser, 1980; Olszewska, 1983, 1984; Danysh *et al.*, 1987).

Recent evaluations of the Eocene-Oligocene stratigraphy and interpretations of global oceanographic conditions at the Eocene-Oligocene transition (see Prothero & Berggren, 1992), encourage to revise the hitherto established interpretations of the SMGM. Moreover, this sequence displays a characteristic sediment variation reflected in rhythmical gradual changes of its colour and $CaCO_3$ content. This variation suggests that the sequence results from fluctuating changes of sedimentary conditions. This peculiarity has not been examined previously, however it is of importance for unravelling both stratigraphy and sedimentology of this package.

The first comprehensive analysis of sediment variation of the SMGM was provided by Krhovský *et al.* (1993) from several closely spaced sections in the Czech Carpathians. Initial results of similar investigations in the Polish Carpathians were mentioned by Leszczyński (1993a, b). Sediment

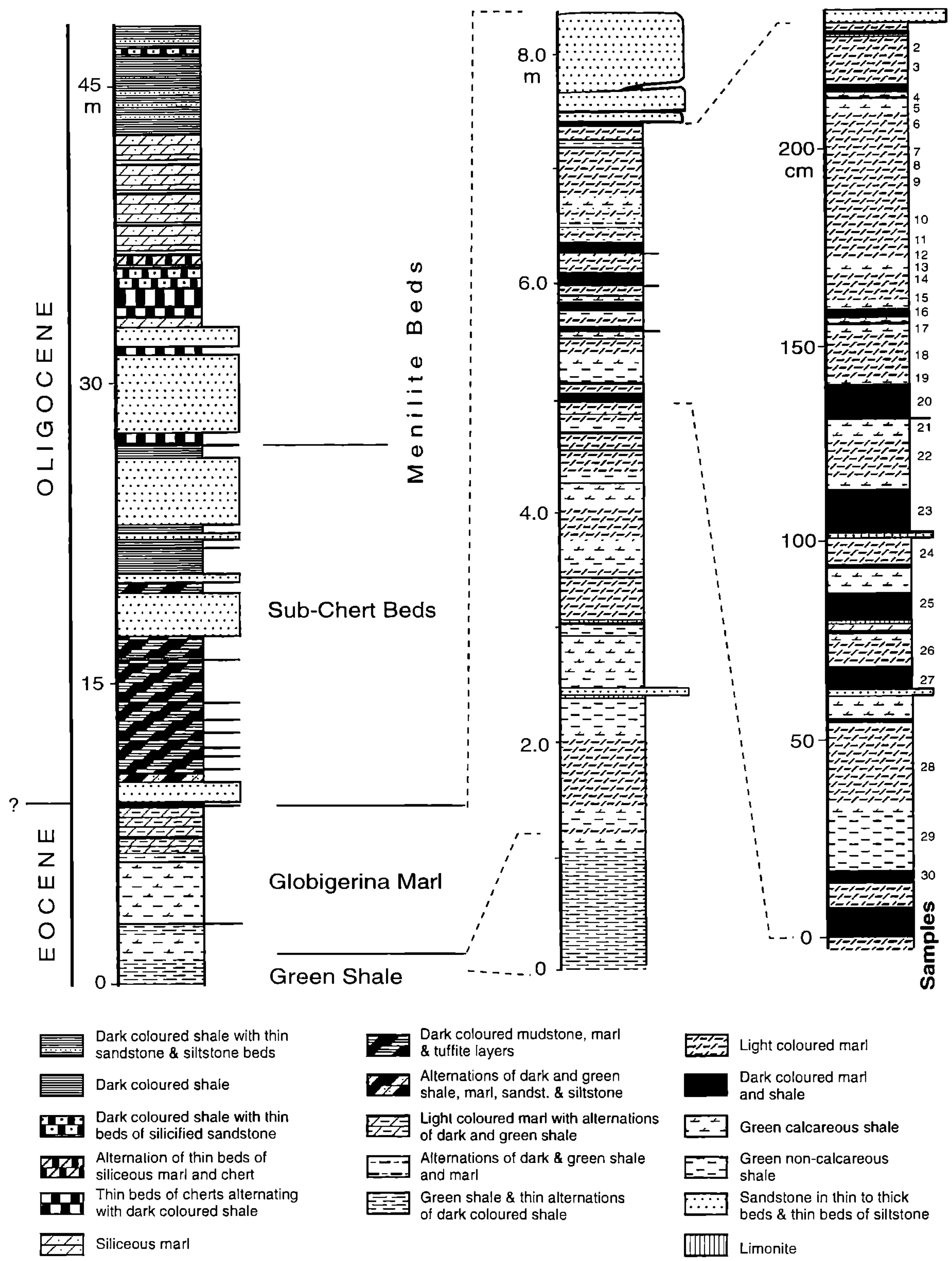

Fig. 2 Stratigraphy and lithofacies logs of the Znamirowice section

variability in the SMGM was interpreted by Krhovský *et al.* (1993) as reflecting the orbitally forced changes of nannoplankton productivity. These authors inferred influence of Milankovitch cyclicity on the development of this sequence. According to Leszczyński (1993a, b), the fluctuations of $CaCO_3$ content and related changes in foraminifera assemblages were forced by Milankovitch cyclicity, whereas the principal change in the sequence resulted from narrowing of the connections between the North European Tethys and the world ocean (see Dercourt *et al*, 1985; Ricou *et al.*, 1986). In the next short note, Leszczyński (1993b) interpreted the entire sediment variability as due to a long-term change of sedimentary environment and mass resedimentation which varied in time and space.

The present paper aims at interpreting sediment variability of the SMGM in one section (Fig. 1). The interpretation is based on detailed mesoscopic and microscopic facies analysis. Moreover, analysis of foraminifera and calcareous nannoplankton, type and amount of organic matter and oxygen and carbon stable isotopes signal was also applied. The collected data allowed to interpret origin of these sediments, the range and character of sedimentation changes as well as the chief factors responsible for the sequence pattern.

METHODS

The sequence of the SMGM together with the immediately underlying and overlying sediments, was examined bed-by-bed. Rock type, colour, reaction with HCl, bed thickness, sedimentary structures and textures, and nature of bed contacts were recorded for each mesoscopically distinguishable layer.

Thirty samples were taken for laboratory investigations from each lithologically distinctive horizon of the upper two metres of the SMGM sequence (Fig. 2). This part of the sequence displays the most distinctive variability of lithology and $CaCO_3$ content. In the thickest marl bed, samples were taken from each level that appeared to differ in lithology (differences in hardness, tendency to splitting, reaction with HCl). Thin sections were made only of hard rocks. Relative abundance of different components, primarily foraminifers, coarse lithic components and matrix, was estimated in thin sections. $CaCO_3$ content was determined in 30 samples by the standard wet titration.

Foraminifera distribution was investigated in thirty 100-g samples. Samples were disaggregated through repeated boiling and subsequent crystallisation of a sample mixed with water and Na_2SO_4 (procedure repeated up to 10 times). After disaggregation, samples were wet sieved on 0.39 mm and 0.09 mm mesh sieves. Residue fractions of each sample were dried and weighed separately. At least 300 foram specimens were examined in the foraminifera-rich samples, whereas all specimens were counted in the foraminifera-poor samples. Samples containing the counted specimens were weighed to calculate the percentage of particular groups. In samples where all forams were counted the result refers just to the 100 g of the raw sample. Additional data as to the foraminifera distribution and their size variability were achieved from thin sections. Taxonomic composition of the foraminifera in the investigated section is presented after Van Couvering *et al.* (1981). Valuable information concerning foraminifera assemblages of the SMGM was found in papers by Blaicher (1967, 1970) and Olszewska (1983, 1984).

Nannofossils were examined in smear slides of ten samples. Slides were prepared from 5-g samples by settling technique. Sample was first crushed and treated with a 3 % solution of H_2O_2 for 24 hours. The mixture was then boiled for 30 minutes. After 3 minutes the supernatant was poured into a beaker that was subsequently filled up with distilled water so that the column of the sample-fluid mixture was 6 cm high. The mixture was then vigorously stirred and after 45 minutes the supernatant was poured off whereas the residue was repeatedly treated as in the last stage. Such procedure was repeated until the fluid became fully transparent after 45 minutes of settling. Smear slide was prepared from a drop of the residue. Distribution of nannofossils was examined in optical microscope. Amount of nannofossils was determined as an average of 20 fields of view in the centre of the slide, at magnification 800x. Moreover, data concerning taxonomic composition of nannoplankton in the investigated section were taken from the paper by Van Couvering *et al.* (1981). The paper by Krhovský *et al.* (1993) provided rich data on the content and diversity of calcareous nannoplankton in the SMGM sequence of the Czech Carpathians.

Total organic carbon content (TOC) and kerogen type were determined by the Rock-Eval pyrolysis of bulk rock samples 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). Because of low TOC, kerogen type was determined only in 9 samples having TOC > 0.25%. The hydrogen and maximum temperature indices (HI and T_{max}) were plotted in a diagram of Delvaux *et al.* (1990).

The oxygen and carbon stable isotope analysis was made on bulk rock in 30 samples 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 gas produced by phosphoric acid digestion of carbonates contained in the bulk rock.

LOCATION AND STRATIGRAPHY

The examined section is located on the western bank of the Rożnów reservoir on the Dunajec River, some 11 km downstream from Nowy Sącz, at the southern end of the village Znamirowice (Fig. 1). About 45-m thick sequence of Upper Eocene-Lower Oligocene deposits of the Silesian Nappe is there exposed (Fig. 2).

The section begins with a 5-m thick package of poorly bedded green non-clacareous clayey to muddy shales and rare, very thin interbeds of dark-gray shales (Fig. 2). These sediments represent the Olive-Green Shale unit. The bottom part of this unit is not exposed, whereas its top is transitional and needs an arbitrary determination. According to Van Couvering *et al.* (1981), this unit may represent a lower part of the P16 Zone and the NP19 Zone. For this unit in the Czech Carpathians, Krhovský *et al.* (1993) suggested an upper part of the NP 19 and NP 20 Zone (i.e. middle-upper Priabonian). These sediments in the Znamirowice section pass gradually upwards into a 6.3 m-thick package composed of alternating non-calcareous green shales, calcareous green and dark-gray to black shales, and cream-yellow, beige to pinkish and dark-gray to black marls. This package represents the Sub-Menilite Globigerina Marl unit

(SMGM), here under consideration. Two thin layers impregnated with limonite occur in the upper part of the package and one sandstone layer in its lower part. The "limonite impregnate" occurs also in lenses within marl layers of the upper part of the package.

The light colour of the SMGM causes that it distinctly stands out from the sequence below and above. The SMGM is made up of generally poorly lithified rocks falling easily apart into irregular chips. Proportion of calcareous material increases gradually up the sequence. Marls dominate in its upper 2 metres. The first layer of the calcareous fine-grained sediment occurs 6.3 m below the tectonically truncated upper part of the SMGM package (at the SW bend of the slope face). Comparison with other sections suggests several tens of centimetres tectonic reduction of the package.

According to Van Couvering *et al.* (1981), in Znamirowice and Krosno, the SMGM package embraces the calcareous nannoplankton zone NP 20 and may pass to NP 21. Thus it is of latest Eocene age. Similar interpretations were proposed for the SMGM in the Ukrainian and the Czech Carpathians (see Vialov *et al.*, 1987; Krhovský *et al.*, 1993). All these interpretations differ from those by Blaicher (1970) and Olszewska (1983, 1984, 1985) who claimed that the SMGM of the Polish Carpathians crosses the Eocene-Oligocene boundary. According to Olszewska (1985), the SMGM in the Polish Carpathians encompasses the entire P17 zone and lower part of P 18.

The overlying 25 m of the sequence consist chiefly of dark-brown and dark-gray mudstones and thin- to very thick-bedded sandstones. Moreover, very thin layers of gray siliceous shales and light-green or beige soft and hard marls occur there in subordinate amounts. The marls are concentrated in the lower part of this sequence whereas the amount of silica significantly increases towards the top where very thin-layered cherts appear. Furthermore, several tuff layers occur there as well. This part of the sequence is distinguished as the Sub-Chert Beds or the Sub-Menilite Beds. It constitutes the bottom part of the Menilite Beds. The Sub-Chert Beds represent the Early Oligocene. Nannoplankton Zone NP21 was inferred by Van Couvering *et al.* (1981) for the samples taken about 2.5 m above the top of the SMGM in the section in question. According to Krhovský *et al.* (1993), in the Czech Carpathians, this unit represents NP 22 Zone. Calibration of this zone against the current Paleogene radioisotopic dates and biostratigraphy shows that it encompasses upper part of NP 21 and the ?entire NP 22 (see Krhovský & Kučera, 1994).

RESULTS

MACROFACIES

Following facies were distinguished on the basis of field examination of the SMGM package and the immediately underlying and overlying sediments:

– green shale,
– dark shale and marl,
– light marl,
– limonite impregnate,
– dark mudstone
– sandstone.

These facies alternate with different frequency. A very distinctive vertical facies order is present in the SMGM package. Dark shale and marl are overlain and sometimes also underlain by the green shale. Bioturbation is recorded only in the Olive-Green Shale unit and the SMGM. The uppermost occurrence of bioturbation is recorded in a 9-mm thick layer of black shale, just 2 cm below the top of the SMGM package. *Chondrites intricatus* burrows, 0.5 mm in diameter occur only in a 5-mm thick upper part of the layer.

Green shale

The green shale facies is particularly characteristic of the lower part of the section and it disappears nearly completely in its upper part. This is a poorly bedded sediment showing a tendency to split parallel to bedding. The occurrence of pronounced fractures, 1 - 2 cm apart, on weathered surfaces gives frequently the impression of bedding. Usually, there is no visible difference in texture between the sediments divided by a fissure, however, the texture is not homogeneous. Smooth and shiny splitting surfaces occur in some its parts, whereas in places the surfaces are rough and dull. The first mentioned variety was considered as clayey shale whereas the latter as more a muddy one. The shales displaying rough splitting surfaces tend to disintegrate into thicker and more irregular pieces than do the shales showing smooth surfaces. Moreover, the clayey shale tends to be more green, whereas the muddy shale is rather gray-green. Furthermore, the changes in colour correlate to some extent with the $CaCO_3$ content. The increase in $CaCO_3$ content is reflected in a passage to light-green or pale-green sediment. Calcareous green shale occurs essentially within the SMGM. The contacts of the green shale with the light-coloured marl are vague and many of them are highly bioturbated (Fig. 3), whereas those with the overlying dark-gray

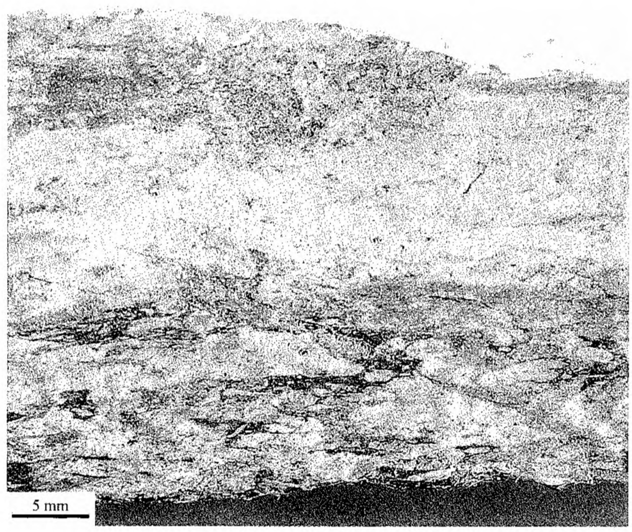

Fig. 3 Passage from dark-coloured marl through green shale (lower half of the specimen) to light-coloured marl. Note distinctive bioturbation in the green shale

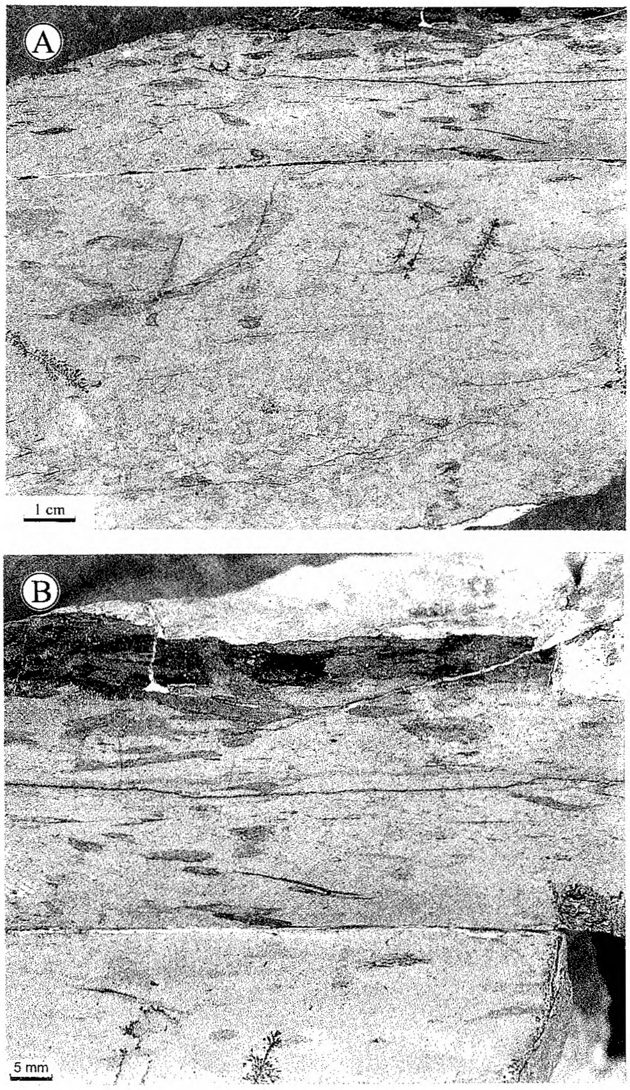

Fig. 4 Upward passage from light- to dark-coloured marl (top part of specimen). **A.** Sediment change at a distance of 10 cm in vertical section; **B.** detail of A. The boundary with the overlying dark-coloured marl is indistinctive due to bioturbation. Note three bioturbation generations in the light marl. The oldest one is accentuated with a maze slightly darker than the enclosing rock. This feature indicates production of the mazes in sediment of soupground consistency. The youngest bioturbation is marked with the most distinctive dark-coloured burrows pointing out their producion in a softground

or black sediment are rather sharp. According to Ślączka and Unrug (1979), some layers of the greenish-cream-coloured fine-grained sediment in the SMGM package represent volcanic ash.

Distinctive trace fossils *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 within the SMGM package. Burrows are usually emphasised there with a slightly darker colouration or a slightly coarser fill with respect to the host sediment (Fig. 3). They are best visible at the contact with the dark gray layers. Burrow concentration tends to be inversely graded there. Moreover, highly irregular changes of sediment colour recorded primarily at parting surfaces suggest a heavy sediment mottling.

Dark shale and marl

This is a subordinate yet very distinctive facies in the examined sequence. Dark-gray shales to brownish-black marls are the main constituents of this facies. Dark non-calcareous shale exclusively occurs in the package of the Olive Green Shale unit. It occurs there in rare thin laminae that usually are heavily bioturbated. Lower boundaries of the laminae appear to be slightly more distinctive than the upper ones. Layers of the dark-coloured sediment become more distinctive up the sequence where they are thicker and more densely spaced.

Within the SMGM package, the dark-coloured fine-grained sediment occurs in five layers, 6 - 11 cm thick, and in several thinner laminae. It is represented there by calcareous shale and marl. Lower boundary of the thickest layers is distinctively sharp. It appears to be less distinctive in the thin and particularly in the very thin layers (Fig. 4). Moreover, the thickest layers are distinctively bioturbated in their upper parts (Fig. 5), whereas their lower portions display subtle horizontal lamination accentuated by the laminae of silty and fine sandy material (Fig. 2). The thin layers are rather uniformly bioturbated and include numerous *Chondrites intricatus* and *Planolites* isp. (Fig. 5). *Thalassinoides* isp. occurs concentrated in the top parts of some layers (Fig. 5). Less frequent are *Ch. targionii*, *Alcyonidiopsis pharmaceus*, *?Echinospira* isp., (Fig. 6), and *Hormosiroidea caliciformis*. Burrows are accentuated with gray or pale-green fill.

In the Sub-Chert Beds, dark shale occurs chiefly in their upper part, whereas dark marl concentrates in the lower part of this unit, where black shale occurs in subordinate amount and in thin and very thin layers only. It tends to overlie the beds of the dark-brown mudstone or marl and shows passages to the marl.

Light marl

This facies encompasses cream-yellow, greenish-yellow, beige and pinkish, usually soft, marls. These are typical sediments of the SMGM package. They disappear both down and up the section. In the SMGM, this facies occurs in layers displaying gradual passages both downward and upward to green shale (Fig. 2). In two layers, light marl is sharply bounded from above by a black marl.

Internal parts of the light marl beds appear to consist of harder rock than their outer zones. Moreover, one 5-cm thick layer of hard syderitic(?) marl occurs in the lower part of the SMGM package. Pyrite concretions and layers of limonite impregnate occur at some levels within the light marl.

Mottled structures accentuated by a change in colour and texture of the sediment (Figs. 3, 4, 7) are characteristic of the light marl within the SMGM. Mottling is best recorded on stained rock surfaces. Moreover, distinctive burrows, particularly *Chondrites intricatus* and *Planolites* isp., occur at some levels (Figs. 4, 8). Concentration of these

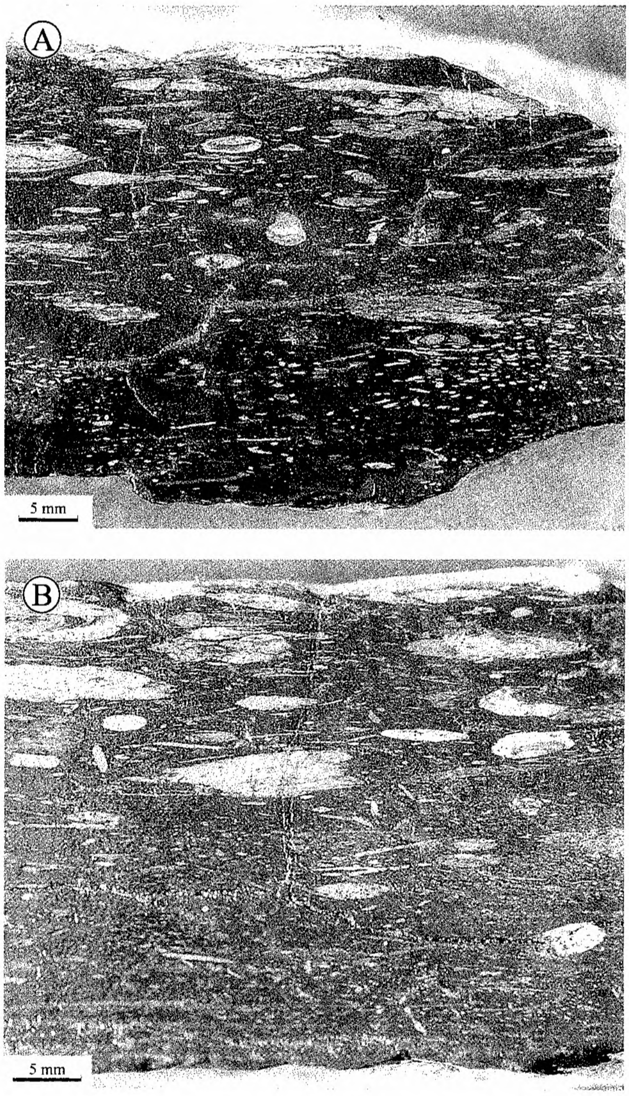

Fig. 5 Inverse grading of bioturbation in top part of a black marl layer. Larger burrows, with recognizable *Thalassinoides* isp., *Alcyonidiopsis* isp., and *Planolites* isp. concentrate near the layer top, whereas *Chondrites intricatus* occupies a deeper tier. Note two generations of *Chondrites*. The older one is gray whereas the younger is whitish. **A.** Layer with distinctive concentration of two generations of *Ch. intricatus* in a deeper tier; **B.** Layer with chiefly gray (older generation) *Chondrites*

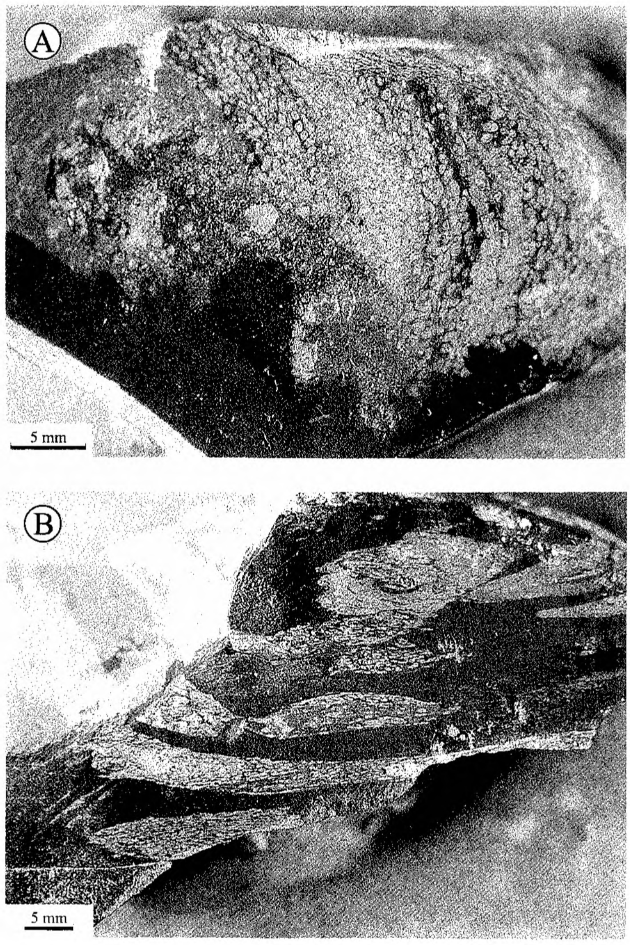

Fig. 6 ?*Echinospira* isp. in top part of a layer of black marl. **A.** view at bedding parallel surface; **B.** view in vertical section

traces is recorded in thin beds and at some levels in the thick ones. Less frequent are the burrows *Thalassinoides suevicus* (Fig. 9), *T.* isp., *Alcyonidiopsis pharmaceus,* and granulated structures resembling *Echinospira* and *Zoophycos* (cf. Fig. 6). Moreover, single traces *Zoophycos* isp. and *Teichichnus* isp. were also recorded. Burrows in thin beds are marked with colour similar to that of the neighbouring, usually overlying bed (Figs. 4, 8, 10). This suggests bed junction preservation of the traces. Such burrows, and particularly *Chondrites intricatus* disappear in the middle part of beds thicker than 5 cm.

Within the Sub-Chert Beds, the light-coloured marl occurs only in very thin layers and is represented there by a soft, light-green and a very hard, beige variety. The beige hard marl tends to break along flat, bedding parallel surfaces or conchoidal surfaces oblique to bedding. A faint horizontal lamination is visible in some layers. The light-green marl

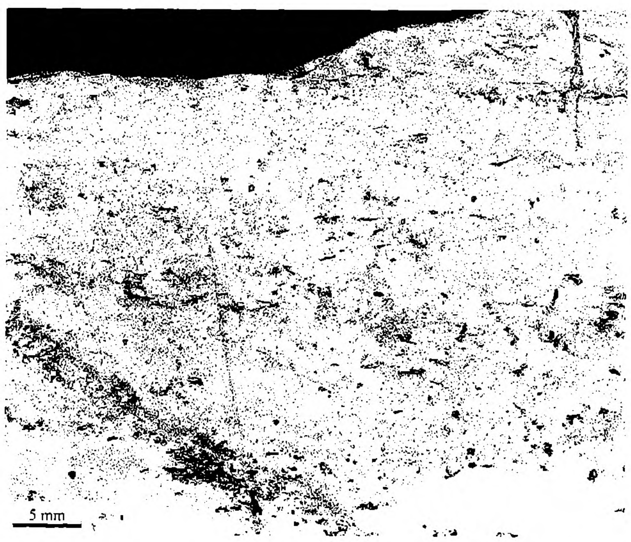

Fig. 7 Mottled structure of light-coloured marl. Irregular and fuzzy structures indicate that mottling was formed when the sediment had a soupground consistency

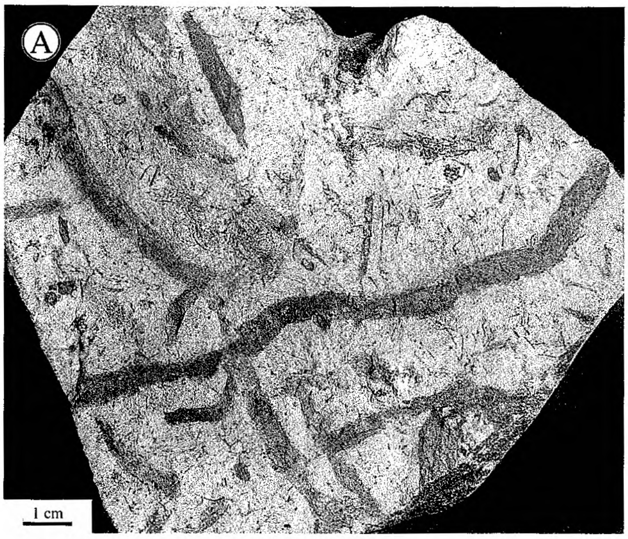

Fig. 8 Bioturbation in greenish marl overlain by thin lamina of dark-coloured marl. Burrows are accentuated by dark colour of their fill. **A.** View on bedding-parallel fracture surface; **B.** View in vertical cross-section. Note inverse grading of burrow concentration towards the layer top

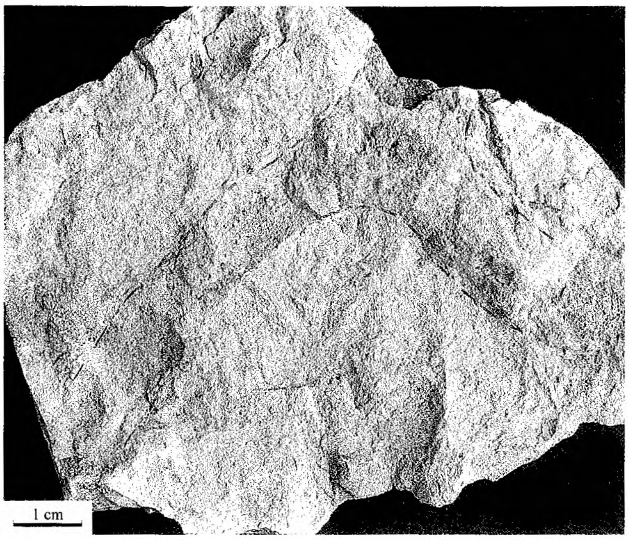

Fig. 9 *Thalassinoides suevicus* in cream-yellow marl. The burrow is accentuated by material different from that of the enclosing sediment

is enclosed by black shale or is overlain by the beige marl. The soles of the light-green marl are diffuse, and the marl tends to pass upwards into the beige marl.

Limonite impregnate

This is a light-brown and yellowish fine-grained soft rock. It occurs in two layers bounded by black and green shale and is rich in the *Chondrites targionii* burrows. Moreover, lenses of limonite impregnate, as much as 10 cm thick, occur within some light marl beds. Impregnation with limonite resulted presumably from oxidation of iron contained in the sequence, however, the primary nature of the two layers as well as the type of the original iron minerals are unclear. Presumably, they formed due to weathering of iron sulphides or siderite contained in marl.

Dark mudstone

Dark-brown to chocolate-brown calcareous to non-calcareous mudstone is characteristic of the Sub-Chert Beds. Highly calcareous variety occurs in lower part of the unit. It is a massive and irregularly breaking rock, yellowish on weathered surfaces. In some beds, the mudstone contains a significant admixture of irregularly distributed coarse-grained material consisting of grains and granules of quartz, plant fragments, calcareous bioclasts and shale chips up to 5 cm in size. Such mudstone occurs in beds several centimetres to several tens of centimetres thick. They tend to overlie sandstone and pass upwards into black shale or brownish black marl.

Sandstone

The sandstone facies within the SMGM package occurs as a single bed, 7.5 cm thick. It is medium- to fine-grained, highly calcareous rock greenish-gray in fresh parts and rusty

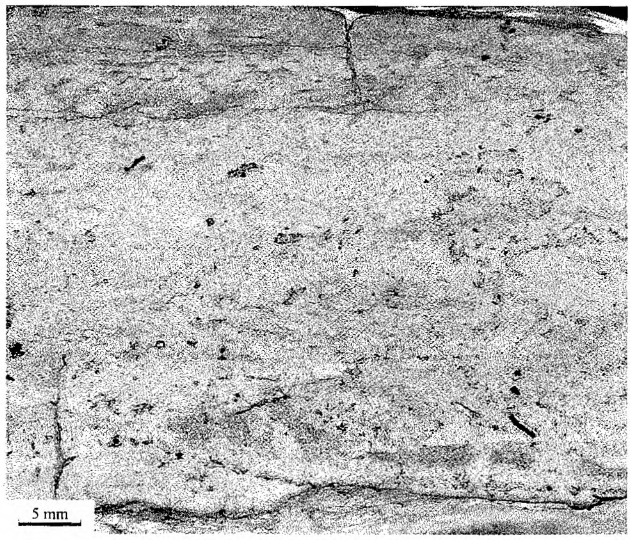

Fig. 10 Bioturbation in light-coloured marl accentuated at a level of slight colour change (greenish, more clayey sediment)

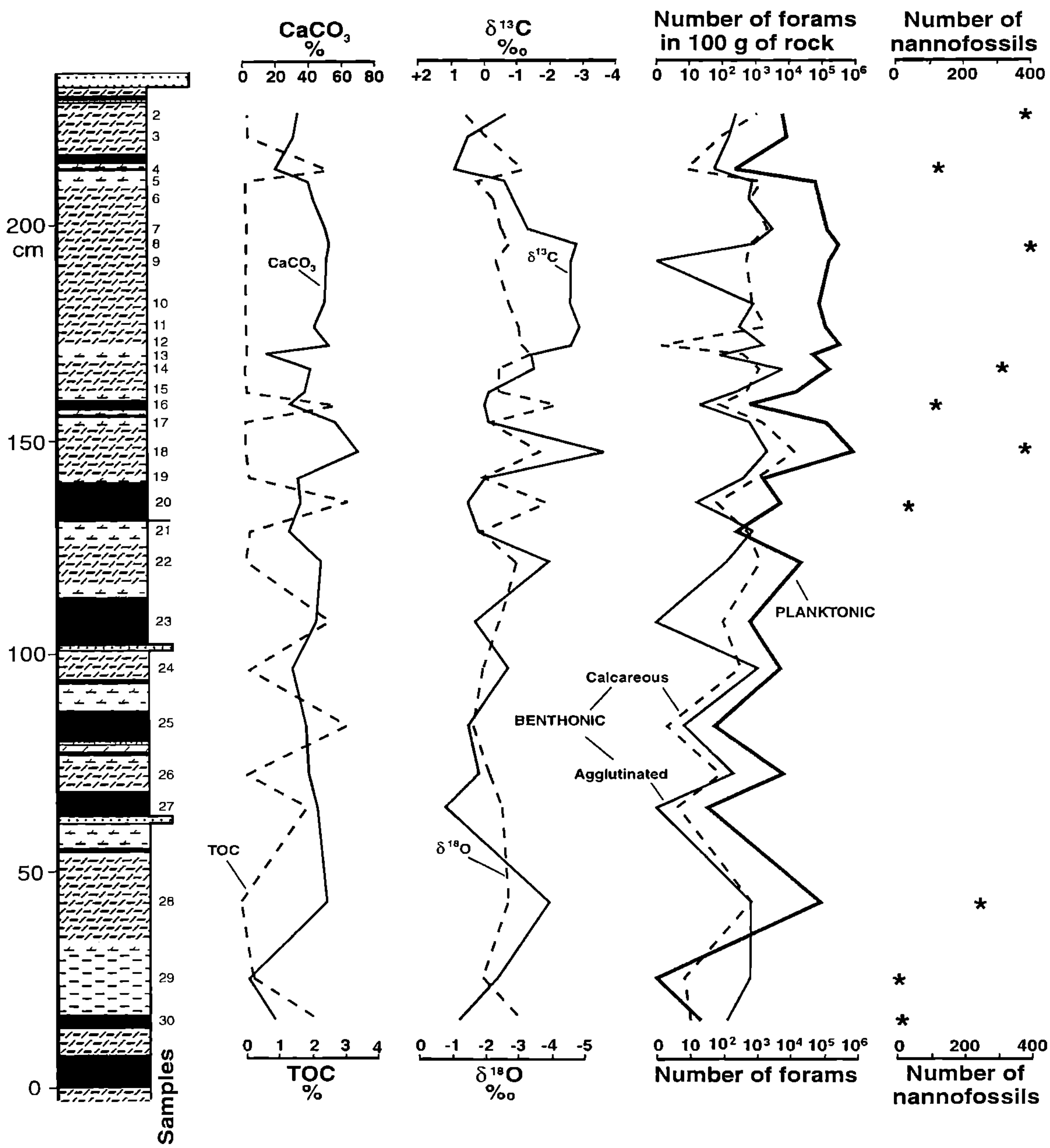

Fig. 11 TOC, $CaCO_3$, C and O stable isotopes, foraminifera and nannoplankton signals in upper part of the SMGM package at Znamirowice

on weathered surfaces. The base of the bed is sharp, whereas its top is indistinctive and bounded by green, non-calcareous shale. The sandstone seems to be a $T_{c(d)}$ turbidite.

The sandstone facies constitutes an important element of the Sub-Chert Beds. Pale-beige and brownish-beige, medium- to coarse-grained, thin- to very thick-bedded sandstone varieties occur in this unit. The beds are poorly sorted, show a faint normal grading near their basal and top parts. Horizontal lamination occurs in some beds. Bed soles are sharp and usually flat. Top surfaces are less distinctive, however, they are frequently remarkably sharp and flat. The beds are overlain by brown to black mudstone or black shale several centimetres thick. Some beds display a chaotic structure accentuated by irregularly distributed clasts of dark-grey, green and black shale or marl.

SEDIMENT COMPOSITION AND MICROFEATURES

Hydromicas, $CaCO_3$, detrital quartz and organic matter (TOC up to 3%) are the chief mineralogical constituents of the examined rocks. Illite and montmorillonite, detrital quartz and micas are recorded, besides $CaCO_3$, in marls and shales (cf. Gucwa & Ślączka, 1972). $CaCO_3$ content is from 0 to 70%. Its highest values are recorded in the hardest, cream yellow and beige marl (Fig. 11). Some parts of the light-coloured marl represent actually a marly limestone. The dark-gray to black shale and marl contain up to 44% $CaCO_3$. Quartz, in the silt fraction, amounts to 7% of the light-coloured marls and up to 20% of their dark-coloured

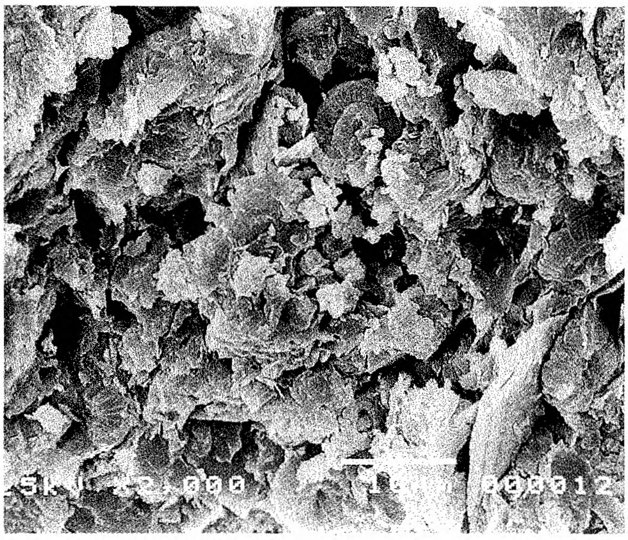

Fig. 12 Nannofeatures of light marl visible in SEM micrograph. Nannofossils constitute about 80 per cent of the sediment volume

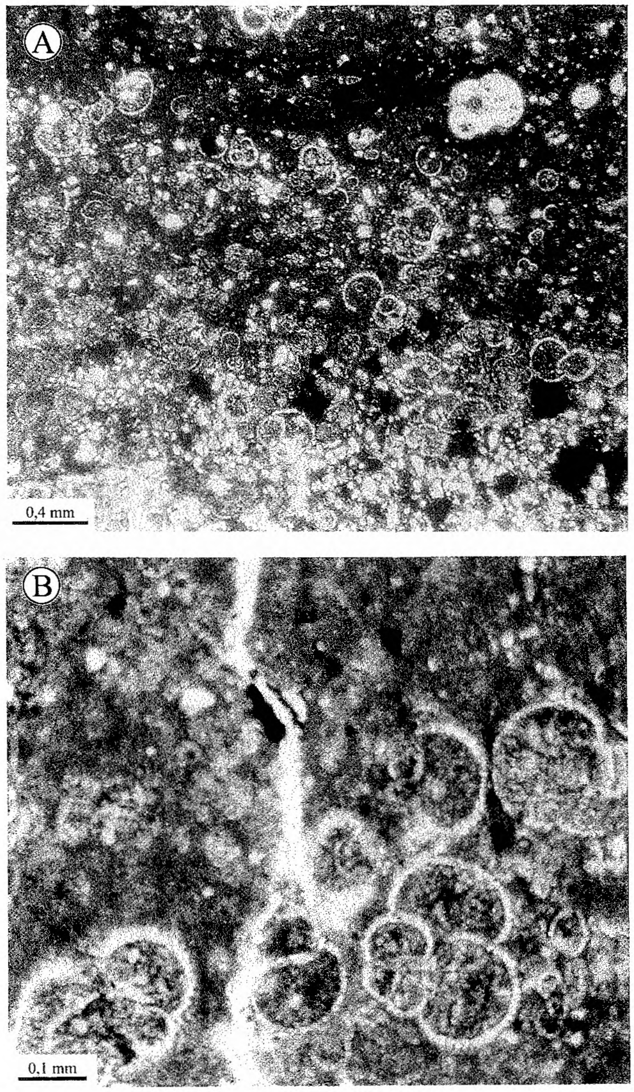

Fig. 13 Concentration of planktonic foraminifera in the light-coloured marl (sample 7). **A.** Irregular distribution of sediment constituents; **B.** Different preservation of foraminifera tests

varieties (cf. Gucwa & Ślączka, 1972). Pyrite is common in washed residues of the dark-coloured shales, marls and mudstones. Gucwa and Ślączka (1972) recorded one layer composed of montmorillonite in the SMGM package. The sediment was interpreted as pyroclastic in origin.

The carbonate material in the light-coloured marl consists in 50 - 80% of nannofossils (Fig. 12; see also Krhovský *et al.*, 1993). In beds containing more than 50% $CaCO_3$, as much as about 30% of the carbonate material consists of tests of planktonic foraminifers (Fig. 13). In the dark-coloured shale and marl as well as in the green shale, $CaCO_3$ appears to occur predominantly as cement. Nannofossils and calcareous foraminifera are rare (Fig. 14). In the fine-grained sediment of the Sub-Chert Beds, diatoms are additional important microfossils (cf. Gucwa & Ślączka, 1972).

In thin sections, the light-coloured marl shows usually a very irregular, clustered distribution of the coarsest particles (i.e. chiefly tests of planktonic foraminifera; Fig. 15). Nevertheless, distinctive 1 - 2 mm thick laminae rich in planktonic foraminifera are locally recognizable (Fig. 16). The lower boundaries of the foraminifera-rich laminae appear to be sharp.

The sandstone within the SMGM consists predominantly of monocrystalline, angular quartz grains. Feldspars, micas, rock fragments and bioclasts are their subordinate constituents. Monocrystalline, angular quartz grains are also the main constituents of the sandstones in the Sub-Chert Beds (see Gucwa & Ślączka, 1972). K-feldspars, muscovite and hydrobiotite, small clasts of carbonate rocks, siliceous rocks, sporadically grains of gneiss and plagioclase occur there subordinately. According to Gucwa and Ślączka (1972), the feldspars are commonly sericitized, kaolinitized or calcitized. Moreover, these authors recorded replacement of $CaCO_3$ by $MgCO_3$ toward the top of the Sub-Chert Beds.

FORAMINIFERA DISTRIBUTION

Foraminifera assemblages in the examined samples vary between 37 and 734536 specimens per 100 g of the rock (Fig. 11). The distribution of the three distinguished groups shows a distinct correlation with the sediment type (cf. Blaicher, 1961; Szymakowska, 1962). The cream-yellow marl is the richest in foraminifera, whereas the dark gray to black marl and shale are the poorest. Foraminifera of the three examined groups are most abundant in the cream yellow marl. Proportion of benthonic to planktonic group is highest in the dark-gray to black and the greenish, less calcareous sediments. On the contrary, in the cream-yellow marl, the proportion of planktonic species is significantly greater. Moreover, the proportion of agglutinating species relative to their calcareous counterparts tends to be higher in the dark-gray and black marl and shale as well as in the green shale. Planktonic foraminifera were absent in a sam-

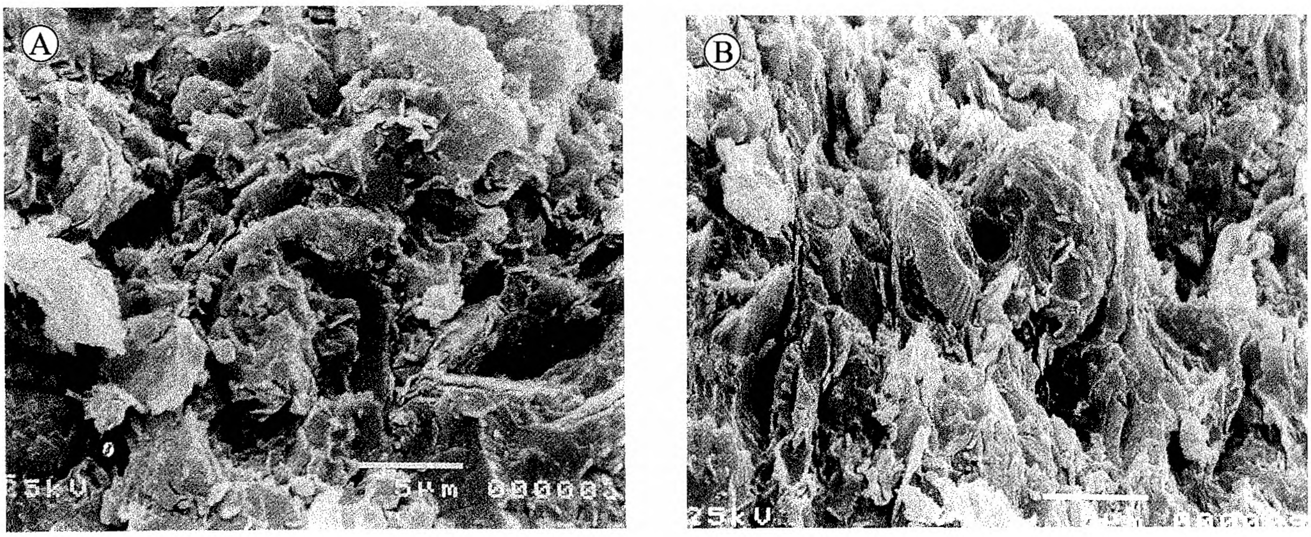

Fig. 14 Nannofeatures of green and dark-coloured shales visible in SEM micrographs. Note rare occurence of nannofossils. **A.** Green calcareous shale (sample 13). **B.** Dark-gray calcareous shale (sample 4)

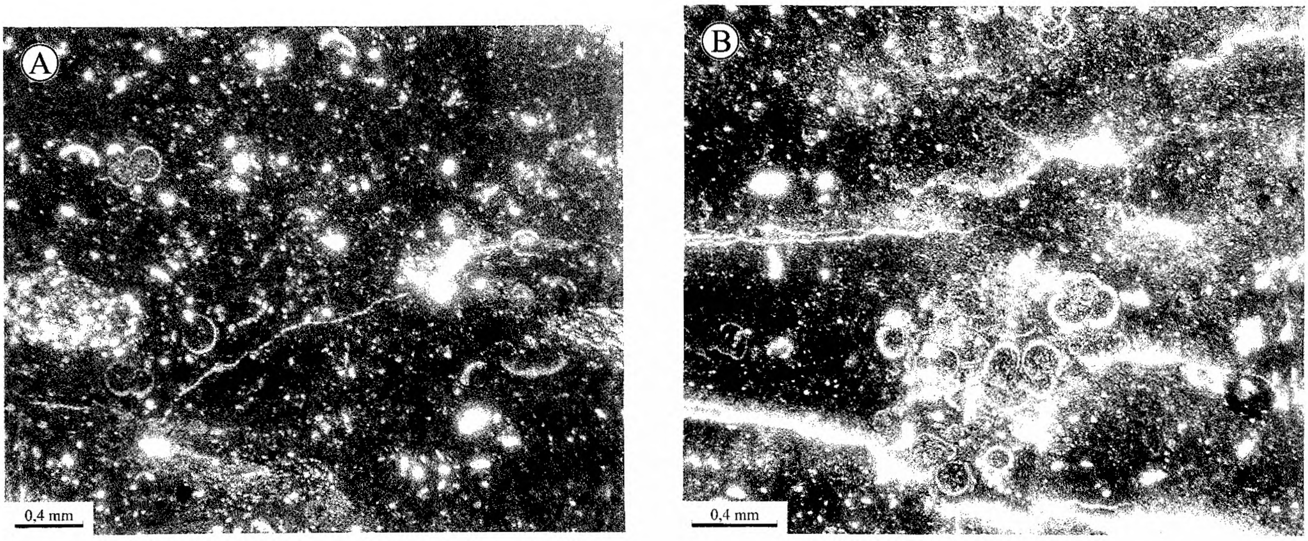

Fig. 15 Irregular and clustered distribution of the coarsest grains (chiefly tests of planktonic foraminifera) probably due to bioturbation. **A.** Irregular distribution due to mottling and filling of burrow tunnels. Note tiny burrow on the left, filled with crushed foraminfera tests. (sample 30); **B.** Sediment mottling and tube of a burrow filled with intact foraminifera tests probably due to passive filling of the tube (sample 25)

ple from the lowermost examined layer of green shale. Agglutinated species were not recorded in two samples of black marl and in one sample in the thickest layer of the cream-yellow marl. One sample taken from a 2.5 cm thick layer of hard marl in the Sub-Chert Beds, 4 m above the SMGM top, contained exclusively rare and tiny planktonic species, 0.03 - 0.05 mm in size (Fig. 17) . These foraminifera were recorded in thin section only. For comparison, in the SMGM sequence, the size of planktonic individuals ranges 0.1 -0.3

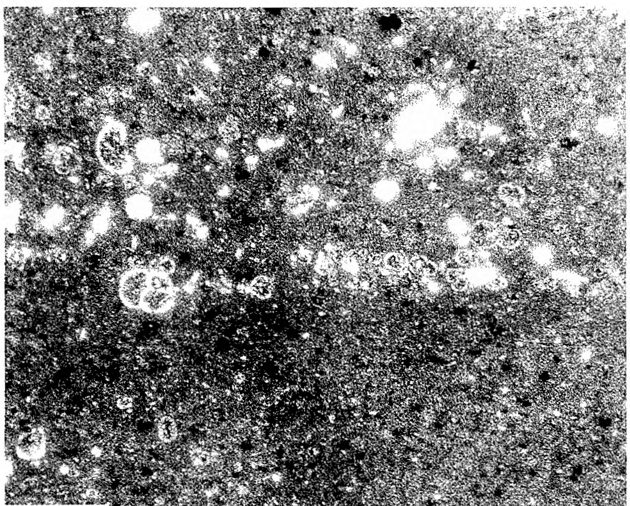

Fig. 16 Relics of lamination in the light-coloured marl. The lamination is accentuated by distribution of coarse grains, chiefly tests of planktonic foraminifera

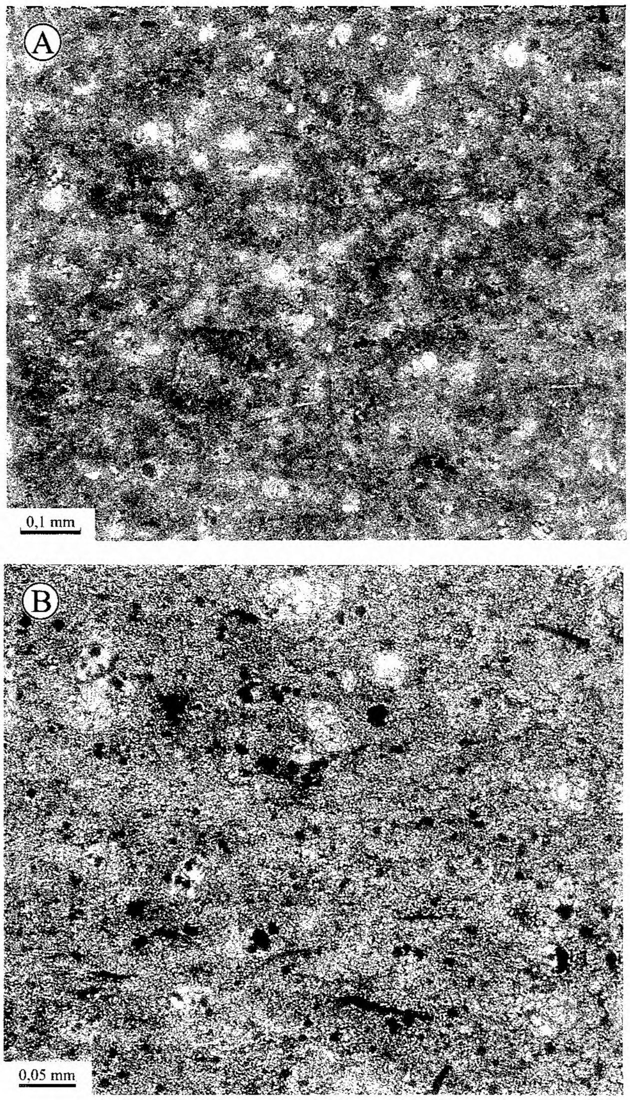

Fig. 17 Microfeatures of the light-coloured marl of the Sub-Chert Beds. At same magnification as in Figs. 13A, 15, 16, it appears that foraminifera are absent in this sediment. **A.** Only single, larger foraminifera appear at this magnification; **B.** Significantly higher amount of foraminifera is visible at a higher magnification. Note the common occurrence of pyrite (black) in chambers of foraminifera tests and the parrallel arrangement of elongated grains (mica flakes and coalified plant fragments)

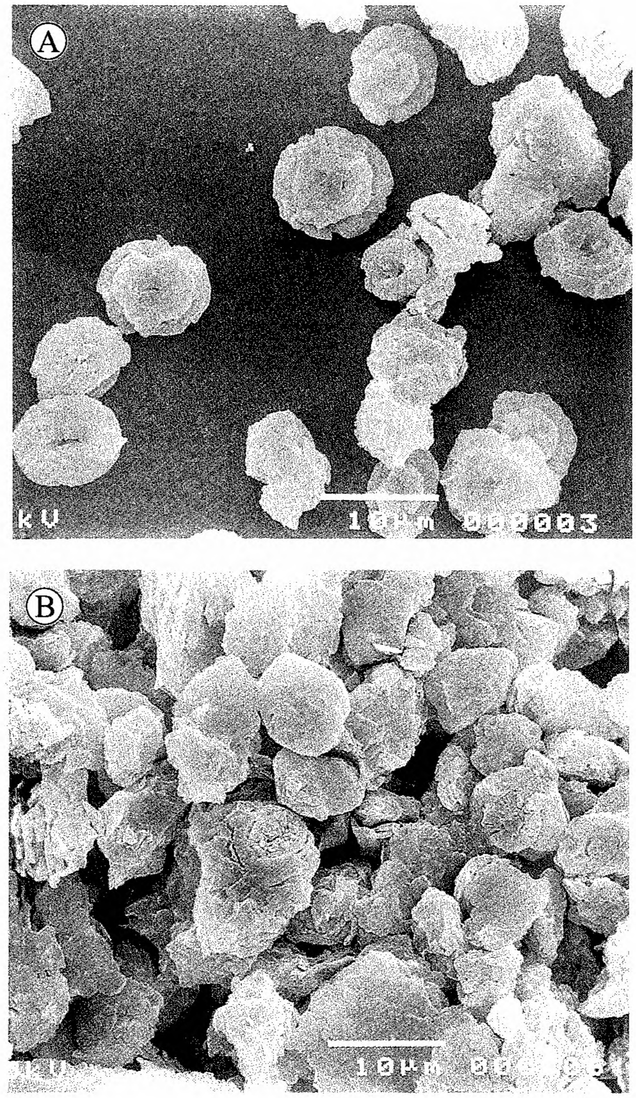

Fig. 18 Nannofossils in smear slides. **A.** Highly calcareous marl (sample 8); **B.** Dark-brown shale. Note single, highly corroded and recrystalized specimens (sample 4)

mm. Corroded tests of calcareous species are frequent in the less calcareous sediment.

NANNOFOSSIL DISTRIBUTION

The content of calcareous nannofossils in smear slides varies between 0 and 34 specimens per one observation field, depending upon the sediment type (Fig. 11). The most numerous occurrences are recorded in the highly calcareous weakly cemented light-coloured marl (Figs. 12, 18A). In contrast, nannofossils disappear in the non-calcareous shales. In the dark-gray to black marls and the slightly calcareous green shales, the assemblages are significantly impoverished (Figs. 14, 18B). Moreover, poorly preserved, corroded and recrystallized specimens occur frequently in the less calcareous sediments (Fig. 18B), and the hardest marl (Fig. 19).

TOC AND KEROGEN TYPE

TOC content in the examined samples ranges between 0 and 3.12% (Fig. 11). The highest values, 1.29 - 3.12 %, were recorded in the dark gray and black marls and shales. Except for one sample, values below 0.1 %, were recorded in the green shales and marls. In the lowermost sample of the green shale (sample 29), TOC reaches 0.25 %. In eleven marl samples, TOC values close to zero were recorded. Characteristically, slightly elevated TOC values occur in layers contacting with dark gray and black marls and shales.

The results of the Rock-Eval Pyrolysis plotted in the 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

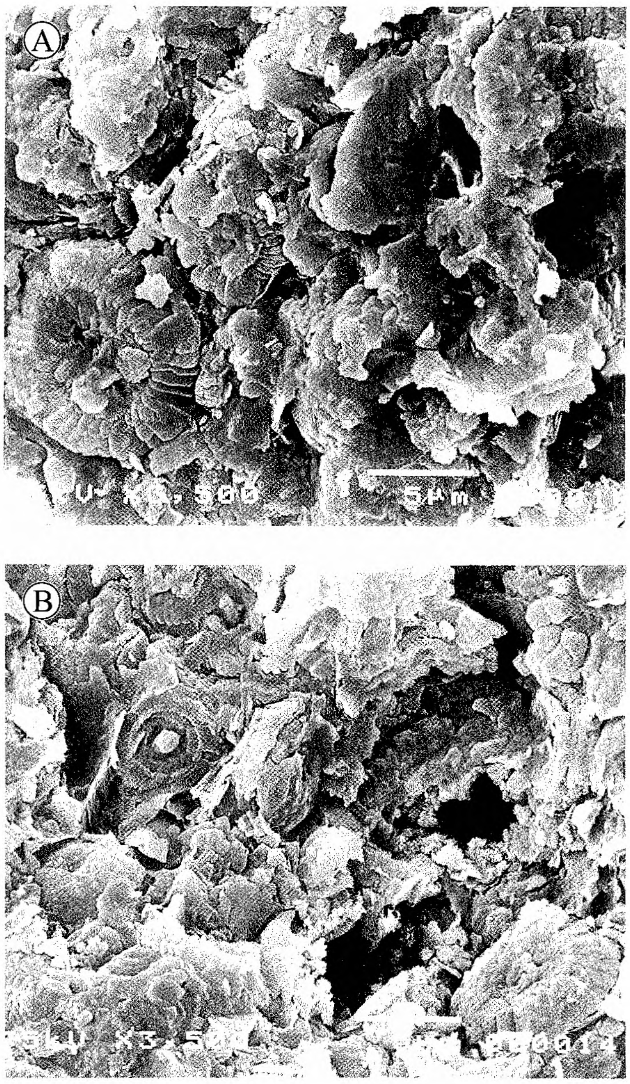

Fig. 19 Nannofossils in hard marl. Note the poor preservation, overgrowth and recrystalization of specimens (sample 8); **A.** Specimen to the right of the centre disappears in newly formed mineral matter; **B.** Concentration of highly altered nannofossils

organic matter of the analyzed samples is dominated by a hydrogen-poor Type III component (Fig. 20).

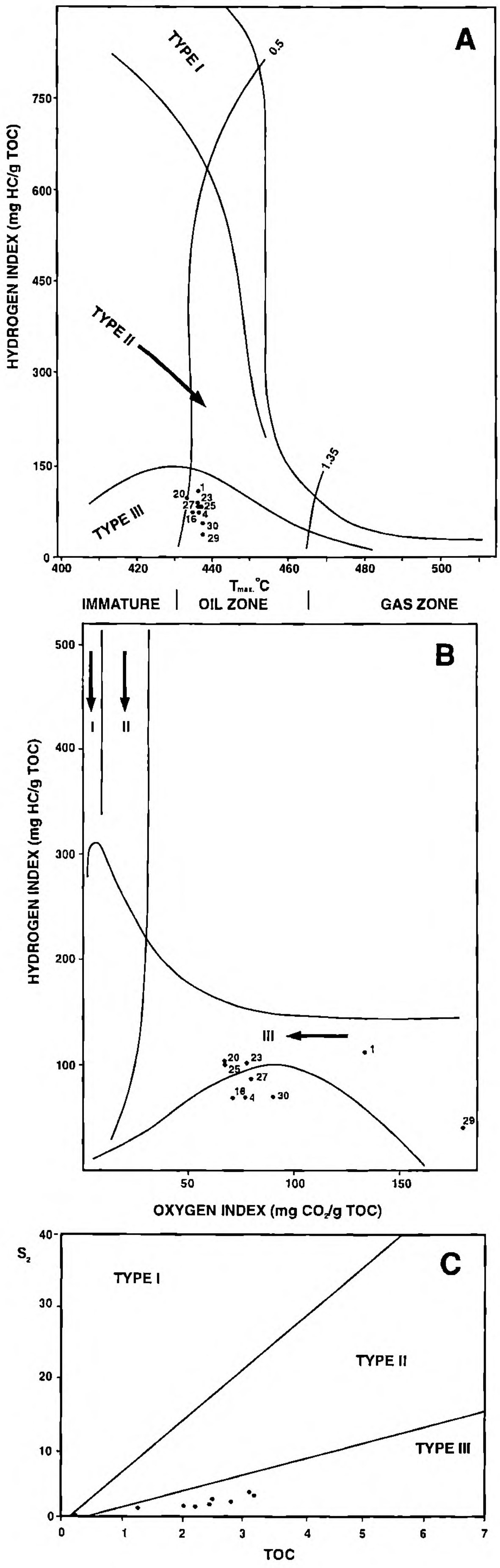

Fig. 20 Type of kerogen determined with Rock-Eval pyrolysis. Type III suggests predominance of terrigenous organic matter in examined samples. **A.** Type of kerogen indicated by relation between hydrogen index versus temperature of maximum hydrocarbon evolution (T_{max}); **B.** Type of kerogen indicated by relation between hydrogen index and oxygen index; **C.** Type of kerogen indicated by relation between total organic carbon content (TOC, in %) and amount of hydrocarbons evolved from thermal alteration of the kerogen (S_2 in milligrams, normalized to sample weight)

ISOTOPES

Values of $\delta^{18}O$ range between -1.6 and -4.3, whereas $\delta^{13}C$ range from +1.2 to -3.6 (Fig. 11). The highest values of indices are recorded in the least calcareous sediments, particularly in the green shales. The lowest values are characteristic of the highly calcareous cream-yellow and beige marls. Nevertheless, the highest $\delta^{13}C$ was recorded in the dark-gray and black marls and shales. In contrast, $\delta^{18}O$ was there low, and similar to that in the highly calcareous beds (beige- and cream-yellow marl).

The fluctuations of both indices show a strong positive correlation (correlation coefficient, r = 0.765) throughout the section in the green shales and the cream-yellow to beige marls (Fig. 21). The increased carbonate content in these deposits correlates quite well with the negative shifts of the $\delta^{13}C$ values H (r = -0.589) and less distinctively with the negative shifts of $\delta^{18}O$ (r = -0.435). Correlation is disturbed in the dark-gray to black marls and shales. $\delta^{18}O$ tends to be significantly lower in these sediments than in the adjacent green shales and light-coloured marls (negative shift), whereas $\delta^{13}C$ tends to show slightly higher values (positive shift).

DISCUSSION

SEDIMENT MACROFEATURES

The features of the light-coloured marl and the associated green shale suggest their sedimentation thorough particle-by-particle fallout from the water column. Thus, these deposits can be considered as pelagites. The features of the dark-coloured shale and marl layers (laminae) as well as of the sandstone beds, such as normal grading, sharp soles, inverse concentration of burrows in the vertical layer section, point to deposition by turbidity currents. Some layers of the dark-coloured shale and marl, showing indistinctive bases, could have been deposited by slow particle-by-particle sedimentation. In contrast, the green laminae enriched in terrigeneous material and displaying sharp bottom surfaces are hemipelagites. The dark-coloured mudstones occurring in the Sub-Chert Beds appear to be deposited by high-density turbidity currents and mud flows.

The occurrence of flat lamination with foraminifera concentrations in the light marl suggests local reworking by bottom currents. The extent of such reworking cannot, however, be determined as the sediment is heavily bioturbated. Moreover, the occurrence of the levels rich in discrete burrows (*Chondrites, Planolites, Thalassinoides)* that are filled with sediment different from the host rock, suggests a more complex primary differentiation of the sequence. The very thin laminae might have even been blurred by burrowing animals. Moreover, bioturbation could have significantly changed the original foraminifera and nannoplankton distribution as well as the original sediment composition. The bioturbation was accomplished mainly by the animals which penetrated that shallowest part of the sediment which had consistency of a dense fluid, i.e. soupy sediment. Such bioturbation is displayed by the fuzzy, poorly individualized

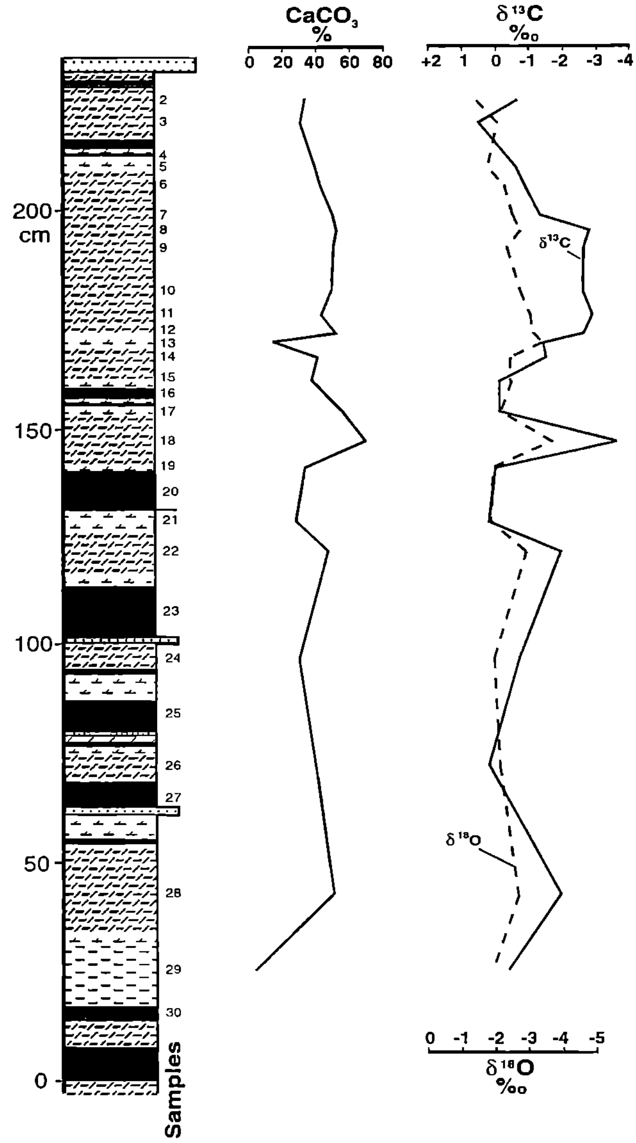

Fig. 21 Relationships between $CaCO_3$ content, $\delta^{18}O$, and $\delta^{13}C$ in light marls and green shales

and very irregular structures accentuated by slight changes in the sediment colour (Figs. 3, 4, 7, 8B, 10). In contrast, the distinctive burrows were produced at a greater depth below the bottom surface, where the sediment consistency was of a soft-ground type. The features of the surrounding sediment together with the confined occurrence of the burrows (i.e. at discrete sediment levels) indicate, however, that only a minor blurring of the sediment structure was due to their production.

The upward passages from the dark-coloured sediment to the green shale imply redeposition of some part of the green shales. The occurrence of planktonic foraminifera in all examined samples indicates that sediment was redeposited from a zone dominated by open-sea sedimentation. It might have been an outer shelf or upper slope tract.

The presence of burrows filled with dark sediment in the top parts of some light-coloured marl layers (Fig. 4) as well as the lack of distinctive normal particle grading in the overlying dark-coloured marl, both suggest that some layers of the dark marls might have also been deposited by a slow particle-by-particle fallout from the water column. Such kind of deposition may be ascribed essentially to the very thin laminae of the dark-coloured fine-grained sediment.

FORAMINIFERA

The distinctive correlation between the abundance of the three distinguished foraminifera groups and the sediment type can result from different sedimentation conditions of the foraminifera-rich and the foraminifera-poor sediments. However, the recorded variability of the foraminifera distribution can also be explained by differences in preservation potential (susceptibility to dissolution) of individual species within the distinguished groups.

Van Couvering *et al.* (1981) interpreted the foraminifera assemblages recorded in the SMGM section at Znamirowice as characteristic of cool-temperate, high latitudes. The lack of species indicative of warm, subtropical conditions was emphasized by these authors. The assemblage of benthonic foraminifera was interpreted there after Książkiewicz (1975), who suggested sedimentation of these deposits at bathyal depths. Olszewska (1984) argued that the predominance of plankton in the SMGM foraminifera assemblages indicates sedimentation beyond the shelf edge in an open marine realm. In her view, the assemblage of benthonic foraminifers is indicative of 600-2000 m water depths and shows evidence of gradual shallowing. It is the shallowing that she considered responsible for the transformation of the assemblage recorded up the sequence.

The results of the present analysis differ from those published by Van Couvering and others (1981) in that all three foraminifera groups were recorded in the entire examined section. Van Couvering *et al.* did not mention neither agglutinated species in the upper part of the SMGM nor calcareous species in the lower part of the section.

CALCAREOUS NANNOFOSSILS

The recorded calcareous nannofossil distribution is thought to result primarily from different sedimentary conditions of the nannofossil-rich and the nannofossil-poor sediments (see Krhovský *et al.*, 1993). Diagenetic modifications are considered as of a minor significance.

Intensified nannoplankton sedimentation occurs in times of its enhanced production. This happens generally in periods of increased nutrient supply that often follows intensification of water circulation in the sedimentary basin. The last mentioned process is strongly dependent on geographic location of the area as well as on the global climate pattern and the sea-level stand. Productivity changes are recorded at different scales. Some changes are proven to follow the Milankovitch orbital cyclicity.

The distribution of calcareous nannofossils in sedimentary sequence may, however, be modified due to dissolution of the less resistant forms during degradation of the organic matter contained in the sediment (see e.g. Emerson & Bender, 1981). The extent of such modification in the examined section is suggested by the occurrence of poorly preserved, partly dissolved and recrystallized nannofossils (Figs. 18B, 19; cf. Van Couvering *et al.*, 1981; Krhovský *et al.*, 1993). The less resistant forms might have been completely dissolved, particularly where higher amounts of more easily degradable organic matter were present.

According to Van Couvering *et al.* (1981), the predominance and abundant occurrence of *Isthmolithus recurvus* together with other reticulofenestrids, particularly *Coccolithus pelagicus,* as well as the occurrence of *Chiasmolithus oamaruensis* and the rarity of discoasterids and *Sphenolithus pseudoradians* in the SMGM of the section in question (7 samples), similarly to its foraminifera assemblage, are all indicative of a cool-water environment (cf. Aubry, 1992).

The variability of the nannofossil assemblages of the SMGM in the Czech Carpathians was interpreted by Krhovský *et al.* (1993) as resulting essentially from variations of nannoplankton productivity related to the Milankovitch cyclicity. Their data show, however, that the difference between the assemblages of the less and the more calcareous sediment is not very distinctive. It is displayed chiefly by increased amounts of Noelaerhabdaceae in the more calcareous samples. This enrichment was suggested to result from higher susceptibility to dissolution of these forms. The interpretation by Krhovský *et al.* (1993) suggests, however, that such changes were of minor significance in their section. Actually, the less calcareous greenish clay in that section resembles the green shale and marl in Znamirowice. The TOC contents of such sediment were shown in the Znamirowice section to be higher than in the light-coloured marl. Therefore, the probability that the recorded differences in nannofossil assemblages recorded in the section studied by Krhovský *et al.* (1993) mirror also the primary differences in TOC content of these sediments seems to be quite high. Hence, consideration of the influence of dissolution on modelling of this assemblage, at least in some parts of that sequence, appears to be necessary also there.

TOC CONTENT AND KEROGENE TYPE

TOC content in the examined samples shows a noticeable variability. As pointed out earlier, the sediments displaying the highest TOC contents bear features implying sedimentation essentially from mass-gravity flows. This suggests in turn, that a zone of increased organic matter accumulation existed in shallower environs of this area. The present position of the section suggests that it could have been located in a zone somewhere within the southern margin of the Silesian Basin. The presence of planktonic foraminifers in the resediments of the section in question indicates that it was located in an open-sea influenced zone (cf. Olszewska, 1983). The impoverished benthic foraminifera assemblages imply dysaerobic or poorly areobic conditions at that area of the basin bottom.

The slightly elevated TOC contents in the layers of the light-coloured marl adjacent to the dark-gray to black marls and shales may result from bioturbation. This is suggested by the burrows filled with the dark-coloured material. Elevated TOC contents in the green shale or the light-coloured marl overlying the dark-coloured sediment are also explained in the same way. These sediments could become enriched in organic matter when bioturbation affected synchronously the layer of the dark sediment and the overlying green shale or marl.

The predominance of the Type III kerogen in the examined samples suggests that it may consist mainly of polycyclic aromatic hydrocarbons and oxygenated functional groups (chiefly phenols; see Tyson, 1995). According to Tissot and Welte (1984, *fide* Tyson, 1995) these constituents are derived essentially from continental plants. The subordinate marine organic matter in the SMGM of the section in question is represented by diverse dinoflagellate cysts (see Van Couvering *et al.*, 1981). However, one has to note the statement by Tyson (1995) that the signal of Type III kerogen can be present also in sediments whose kerogen is dominated by aerobically degraded amorphous organic matter. Moreover, Tyson (1995) stressed that selective preservation of the more refractory terrestrial material (oxidation of the Type II amorphous organic matter to the Type III kerogen), can reinforce formation of the Type III kerogen. It cannot also be excluded that the type of organic matter contained in the analyzed samples was to some extent determined by its oxidation in the exposure. The organic matter of predominantly marine origin was recorded in the SMGM by Gucwa and Wieser (1980). However, the source of their data is not very precise. If the organic matter of the TOC-rich sediments is chiefly of terrestrial origin then it points to resedimentation from a zone influenced by a river mouth. Otherwise, it would have originate in a zone of very high organic productivity such as that observed in the upwelling affected areas.

A distinctively increased accumulation of marine organic matter appears to be recorded in a sample taken from a 2.5 cm thick marl layer of the Sub-Chert Beds, 4 m above the top of the SMGM. The lack of bioturbation and benthic fauna in this sequence indicates deposition on an anoxic bottom. Such setting also favours preservation of the easily degradable organic matter that forms kerogen Type II and I.

ISOTOPES

The $\delta^{18}O$ and $\delta^{13}C$ values recorded in the examined samples show some correlation with $CaCO_3$ content. However, the values of both isotope indices show a negative shift, up to 2 promille, relative to the data published by Krhovský *et al.* (1993) from the SMGM of one section in the Czech Carpathians. Sediments in that section appear to be slightly less calcareous than in Znamirowice. Moreover, dark-coloured marls and shales are absent there except for the highest examined part of the sequence. However, sediments of this part of the sequence are considered in the Polish Carpathians as belonging to the Sub-Chert Beds. Unfortunately, the data presented by Krhovský *et al.* (1993) do not show how $\delta^{18}O$ and $\delta^{13}C$ in brown marls do relate to those in green shale and marl. A strong positive correlation of $\delta^{18}O$ and $\delta^{13}C$ is recorded in their section. They suggested that an environmental signal is reflected by the isotopic pattern they have recorded. However, the tendency of the changes of the isotope signal recorded by these authors, antithetical to the global trend, they declared as complicating their interpretation.

There are two basic possibilities for the origin of the $\delta^{18}O$ and $\delta^{13}C$ signal recorded in the examined section: (1) specific history of the sediment, (2) inaccurate determination of the isotope content. Values of $\delta^{18}O$ and $\delta^{13}C$ lower that the globally reported ones were also recorded in bulk samples of late Eocene sediments cored in the southern Labrador Sea (Arthur *et al.*, 1989). Early diagenesis related to shallow-burial organic matter decay was there inferred as responsible for the recorded $\delta^{18}O$ and $\delta^{13}C$ values. Such interpretation appears also to fit to the here examined rocks. Moreover, the discrepancy in the style of the change of the isotope values between the green shale and light marl on one side and the dark marl on the other side implies that isotope signal in the SMGM sequence was modelled by diagenesis in at least two stages.

In the first stage, $CaCO_3$ enriched in ^{12}C was formed by degradation of organic matter in shallow burial conditions and release of isotopically light CO_2 (see Wright & Tucker, 1990). Such process was presumably the main control responsible for the consequently lowest $\delta^{18}O$ and $\delta^{13}C$ values in the hardest light-coloured marl (most strongly affected by cementation) as well as for the remarkably lower $\delta^{18}O$ values in the dark-coloured marl in the upper part of the sampled section. These rocks probably underwent the most intensive recrystalization of the above indicated type (cf. Broecker & Peng, 1982; Shackleton *et al.*, 1983). Its progression at shallow burial is indicated also by the well-preserved, not compacted burrows as recorded in the strongest cemented marl (carbonate concretions; see also Bohrmann & Thiede, 1989). Siderite, rodochrosite and ankerite concretions could have been formed due to such diagenetic process as well. This kind of diagenesis was also pointed out by Krhovský *et al.* (1993) as the only one responsible for the observed features of the sediments.

The very low TOC values recorded in the light-coloured marl can result from a nearly complete degradation of its primary organic matter. Moreover, the above mentioned features, such as the isotopic signal, high degree of lithification and carbonate concretions, suggest that these sediments must have originally contained considerable amount of easily metabolizable organic substances. Consequently, one can suppose that the sediments displaying higher $\delta^{18}O$ and $\delta^{13}C$ (e.g. samples 5, 6, 14, and 15), might have contained lower amounts of such substances. Moreover, the $\delta^{18}O$ values recorded in the latter sediments must therefore have been altered least at this stage of diagenesis.

The second stage of diagenesis occurred during deep burial, after formation of methane from the organic matter that escaped the earlier oxic degradation. This process affected primarily the significantly TOC-enriched dark gray and black marls and shales (e.g. samples 4, 16, 20, 23, 25, 27, and 30; see Fig. 11). Their carbonates show higher values of $\delta^{13}C$ and, therefore, suggest recrystalization influenced by CO_2 enriched in ^{13}C. Such CO_2 is known to form due to thermal alteration of organic matter (see e.g. Tucker & Wright, 1990). The enrichment in ^{13}C labels the carbonates formed from such CO_2. Carbonates produced during deep burial are particularly characteristic for the Menilite Beds (Koltun, 1992).

Accuracy of the analysis and determination of the isotope content cannot be evaluated here. However, the uniform fluctuation of the isotope signal suggests that if it is erroneous then principally in a constant negative shift.

Despite of the possibly lower actual values, it has been shown above that the $\delta^{18}O$ and $\delta^{13}C$ isotopic signal in the examined part of the SMGM sequence was modelled differently by diagenesis. The extent and the style of diagenetic alteration of the primary isotopic index depended on the sediment type, i.e. chiefly on the amount and type of contained organic matter (easily degradable/hardly degradable) as well as on the content of the easily soluble carbonate particles.

Inverse correlation has been shown between nannofossil preservation and TOC content in sediments (see e.g. Roth, 1981; Roth & Krumbach, 1986; Thierstein & Roth, 1991). A high TOC content induces increased bacterial breakdown of organic carbon that leads to elevated content of dissolved carbon dioxide in pore waters and, therefore, to increased carbonate dissolution (e.g. Emerson & Bender, 1981). Thus, the positively correlated fluctuation of the $\delta^{18}O$, $\delta^{13}C$ and the sediment type, in the green shale and the light-coloured marl, that is recorded throughout the examined section, need not necessarily to reflect the pattern achieved at the sedimentogenesis stage as it was suggested by Krhovský *et al.* (1993). The current pattern can just reflect differences in diagenesis depending upon the original sediment composition.

One cannot exclude that the $\delta^{18}O$ and $\delta^{13}C$ signal in the original carbonate material displayed a pattern far different from the recent one. The original signal in the sediment that is represented now by the green shale or marl could have been even the same as in the sediment that is now hard marl. Nevertheless, periodic variation of the $\delta^{18}O$ and $\delta^{13}C$ in the water column of a sedimentary basin appears to be of primary significance for the observed alternation of the distinctively calcareous and non-calcareous fine-grained sediments. Such alternations occur in the lower part of the here described SMGM sequence.

LITHOLOGICAL VARIATION

As it has been shown earlier, the examined SMGM section consists essentially of pelagites and hemipelagites, with subordinate amount of turbidites. Sediments of each of these groups display some variability primarily in colour/mineral composition, texture and bed thickness, indicating some differences in their origin. Thus, the origin of the sediment variability of the entire SMGM sequence appears to be quite complex.

The variation between pelagites and hemipelagites manifest in their different colours and therefore different mineral (chemical) compositions. Moreover, these sediments are also differentiated in bed thickness and to a lesser extent in sediment texture. The variability of colour results chiefly from different $CaCO_3$ content, type of iron compounds contained in the rock and to some extent from amount of organic matter. All these parameters, particularly the type of the iron compounds are modelled by sedimentary, diagenetic and weathering conditions. Sedimentary conditions, however, are of a basic significance. They influence the manner of the possible rock alteration.

The type of iron compounds is related to the $CaCO_3$ content, the amount of organic matter buried and the extent of weathering. The last is particularly significant in rocks containing siderite and iron sulphides, and is reflected in the presence of limonite impregnate as in the section in question. The proportions of $CaCO_3$ and organic matter, together with the intensity of bottom aeration, are responsible for the type of the primary iron compounds. The permanently oxic conditions at the sea floor, indicated by sediment bioturbation, suggest that the variability of iron compounds in the examined section is derivative chiefly of the $CaCO_3$ and organic matter distribution in the entire sequence. Increase in $CaCO_3$ is manifested by fading of the rock colour. The non-calcareous shales are green, olive green, whereas the marls containing the highest amounts of $CaCO_3$ are cream-yellow or light-beige. Some thin, dark-gray and black laminae that appear to be of pelagic or hemipelagic origin have their colour chiefly due to increased content of organic matter (above 0.7 % TOC).

The present distribution of $CaCO_3$ in the examined section appears to reflect modelling by sedimentary conditions and diagenesis. Diagenetic processes usually enhance the original record of varying sedimentary conditions. This is also the case in the lower part of the SMGM where alternations in sedimentary conditions gave rise to the alternation of clearly individualized layers of calcareous and noncalcareous fine-grained sediments. Periodically changing intensity of sedimentation of the calcareous material, i.e. nannoplankton and planktonic foraminifera, relative to the non-calcareous, i.e. siliciclastic and organic particles, is considered to be chiefly responsible for such sediment variation. The changes in the type and amount of pelagic and hemipelagic material supplied to the sea floor result primarily from the climate and paleogeography changes over the sedimentary basin and its surroundings. All these parameters are vitally forced by the Earth's orbital cyclicity (e.g. De Boer & Smith, 1994). This factor also appears to be of the chief responsibility for the development of the entire SMGM sequence and the most distinctive variation of its pelagic and hemipelagic sediments.

Biostratigraphic data calibrated against radioisotopic timescale by Aubry (1992) suggest that the 6.3 m thick SMGM package spans ca. 1 million years. There are, however, significant differences in defining the biostratigraphic zonations and problems resulting from diachronous occurrence of fossils (see e.g. Aubry, 1992). Thus the above time span must be treated as a very rough estimation. According to Krhovský *et al.* (1993), the SMGM package in the Czech Carpathians spans ca. 0.5 My years. This interpretation seems to be more reasonable also for the Znamirowice SMGM section. The sediments deposited by particle-by-particle fallout from water column (pelagic and hemipelagic) are there about 5.5 m thick. Lack of evidence of significant erosion in the package suggests that it includes nearly all sediment originally deposited. Assuming 30 - 50% compaction of the pelagites and hemipelagites and their deposition for 500 ky, their sedimentation rate appears to have ranged 37 - 22 mm ky^{-1}. Such sedimentation rate appears to be quite reasonable if even not slightly small as for the depositional setting inferred for the section in question.

If the development of this sequence was orbitally forced then the time span it seems to represent suggests that as a whole this sequence results from climate and associated paleogeography changes due to a long eccentricity cycle (414 ky; cf. Krhovský *et al.*, 1993). Moreover, the tectonic reduction of the top part of the sequence, together with its asymmetry relative to the $CaCO_3$ content both suggest that this sequence represents in fact no more than 90% of the original eccentricity cycle, i.e. about 370 ky.

The frequency of the most distinctive variation of the $CaCO_3$ content recorded in ca. 1.5 m divisions, (ca.90 ky), particularly in the lower part of the SMGM package, indicates forcing of this variation by short eccentricity cycles. The smaller-scale fluctuation of carbonate content in the pelagic/hemipelagic sediment appears to have a much more complex origin. Spasmodic sedimentation of increased amounts of terrigeneous material enriched in organic matter was probably one of the chief factors of this fluctuation. This process diluted the carbonate material. Moreover, some carbonates could have been relocated after sediment burial from the levels enriched in easily decomposable organic matter to the more calcareous sites. The predominance of Type III kerogen in these sediments suggests that the supply of terrigeneous material was controlled directly by lateral shifting of deltaic lobes and river mouths. Some control could have also been exerted by changes in tectonic activity in the area and the climate changes forced by the obliquity (41 ky) cycle. Influence of the 20 ky cyclicity cannot be proved in this package (see Krhovský *et al.*, 1993). It was rather unimportant there because the area was located at a high latitude.

The distribution of the thickest resediment layers and the closely spaced resediment sets suggest 30 - 50 ky frequency of intensified resedimentation. The resedimentation frequency appears, however, to have varied much more than the intensity of pelagic sedimentation. The maximum concentration of resediments in the upper half of the SMGM package suggests that it represents a period of increased slope instability of the area. However, much more significant increase of the amount of resediments occurs immediately above the SMGM package. It suggests that this part of the sequence represents a period of the highest slope instability of the area (cf. Koszarski & Wieser, 1960). This could have been due either to increased tectonic activity, relative sea-level lowering, or expansion of a deltaic lobe over the surrounding slope.

The dinocyst assemblages described by Van Couvering *et al.* (1981) from the SMGM section at Znamirowice as well as from Krosno, suggest that the concentration of resediments in the upper part of the SMGM package in Znamirowice reflects its sedimentation during a sea-level fall (cf. Brinkhuis & Biffi, 1993; Brinkhuis, 1994). However, this appears to be much more evident in areas of the occurrence of the Siedliska Conglomerate or the Mszanka Sandstone (see Koszarski & Wieser, 1960; Koszarski & Żytko, 1961). These coarse clastics, and particularly the Siedliska Conglomerate, reveal concentrations of shallow-water biota (cf. Bieda, 1946), clearly pointing to resedimentation from near-shore areas. Nevertheless, the amount of resediments still appears to be not very high in the Polish Carpathians. It was, perhaps due either to coincidence of this event with a period of relative tectonic quiescence of the area or the morphology of this area was significantly flattened at that time.

Sedimentation of the SMGM during a cold period and in a shallowed basin, the signal of oxygen isotopes, and bioturbation pattern all suggest that intensified sedimentation of calcareous material present in this unit occurred in times of decreased water salinity and enhanced water circulation (cf. Krhovský *et al.*, 1993). These could have been times of relatively elevated sea level. On the contrary, the less calcareous green shale layers appear to be deposited in times of enhanced evaporation and salinity increase as it is indicated by their high values of $\delta^{18}O$. Krhovský *et al.* (1993) recorded increased amount of boron and miliolid foraminifera in the less calcareous layers which also evidence increased salinity. All these parameters together with the common occurrence of resediments together with the green shales in adjacent layers suggest that all these sediments represent times of lowered sea level. However, the enrichment of resediments in organic matter suggests that diagenetic modification of such levels, due to removal of carbonates, should be also considered in their interpretation.

CONCLUSIONS

The data analyzed in this paper indicate complex origin of the SMGM package in the Znamirowice section. The light-coloured marls and green shales are pelagites and hemipelagites, whereas the dark-coloured shales and marls similarly as sandstones are resediments, chiefly turbidites. The SMGM package appears to result from sedimentation controlled predominantly by orbitally forced climatic and oceanographic changes within a 414 ky eccentricity cycle.

The assemblages of fossils contained in the SMGM package point to its sedimentation in a basin margin setting. The sediment variation within the SMGM package displays features indicative of its sedimentation chiefly due to combined influences of periodically changing productivity of calcareous material and intermittently changing supply of terrigeneous and basin margin (shelf) material. The gradual passages from the calcareous green shale and light-coloured marl to the distinctive layers of the noncalcareous green shale are considered as resulting primarily from periodic changes of calcareous nannoplankton and planktonic foraminifera productivity. Orbitally forced climate and water circulation changes of the 90 ky eccentricity fluctuation are thought to be their main control.

The minor changes of the carbonate content as well as the quite abrupt changes beneath and above the dark gray to black shale and marl layers are regarded as resulting from intermittent supply of terrigeneous material and consequent diagenetic changes. Irregularly changing tectonic activity of the area together with shifting of deltaic lobes as well as the consequences of the more regular climate changes are suggested to be responsible for such supply of terrigeneous material.

Variable diagenesis, depending upon the changing original sediment composition and the extent of its contrast, shaped finally the sequence and amplified the original compositional differences (proportion of $CaCO_3$, nannoplankton assemblages, $\delta^{18}O$ and $\delta^{13}C$, kerogen types, and TOC content).

Distribution of turbidites in the section in question indicates that mass resedimentation controlled the lithological variation with frequency of several tens of thousand years. It reached its peak during sedimentation of the upper half of the SMGM package and coincided probably with a maximum drop of sea-level.

Variations of pelagic and hemipelagic sediment features at a scale of several millimetres and less (i.e. less than several hundred years) were blurred by bioturbation. Their occurrence is recorded in slight changes of carbonate content and in levels where distinctive soft-ground burrows filled with sediment different from that of the enclosing rock occur.

The $\delta^{18}O$ and $\delta^{13}C$ signal in the examined rocks was differently modelled by diagenesis. The positively correlated fluctuation of the $\delta^{18}O$ and $\delta^{13}C$ in the green shale and light-coloured marl recorded throughout the examined section is interpreted as reflecting different style and distinct extent of diagenesis depending on the original sediment composition.

The entire SMGM package reflects a period of increased productivity of calcareous plankton and nannoplankton. Such phenomenon is recorded globally at the end of the Eocene (see Beggren & Prothero, 1992). However, the enhanced resedimentation of the material significantly enriched in organic matter appears to indicate some specific local conditions within the sedimentary basins of the Carpathian flysch. Narrowing of connections of these basins with the open ocean, recognized long ago (see Ricou *et al.*, 1986), acted opposedly to the global trends (see Kennet 1977; Miller & Tucholke, 1983). This process caused the reduction of deep-water circulation and, therefore, significantly accelerated eutrophication of these basins. The basins became eutrophic during sedimentation of the Menilite Beds.

Detailed investigations of other sections including the immediately under- and overlying deposits, particularly a detailed examination of different geochemical parameters, foraminifera, nannoplankton and dinoflagellate cyst assemblages are necessary to test the above interpretation and to interpret the origin of the SMGM sequence in the entire area of their occurrence. Peculiarity of the period of their sedimentation, not only in the history of the Carpathian flysch, makes such investigations of particular validity.

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Streszczenie

GENEZA ZMIENNOŚCI OSADÓW PODMENILITOWYCH MARGLI GLOBIGRYNOWYCH W ZNAMIROWICACH (POGRANICZE EOCENU I OLIGOCENU, POLSKIE KARPATY ZEWNĘTRZNE)

Stanisław Leszczyński

Przejście od eocenu do oligocenu na obszarze całego globu zaznacza się wielkimi zmianami. Ich charakter wskazuje drastyczne przekształcenia klimatu z ciepłego – typu "greenhouse", we wczesnym eocenie, na zimny – typu "icehouse", w oligocenie. Na obszarze Karpat zmiany te najostrzej zaznaczają się w wykształceniu osadów drobnoziarnistych we fliszu Karpat zewnętrznych. Wyrazem tych zmian jest pakiet wydzielany pod nazwą podmenilitowych margli globigerynowych (Grzybowski, 1897; Bieda, 1946; Koszarski & Wieser, 1960; SMGM), nazywany również poziomem szeszorskim (Vialov *et al.*, 1965), a ostatnio wydzielony jako ogniwo margli globigerynowych ze Strwiąża (Rajchel, 1990). Utwory typu SMGM znane są ze stropu eocenu całego północnego obrzeżenia alpidów, od Alp Zachodnich po Kaukaz (patrz Rögl & Steininger, 1983).

Na podstawie wcześniejszych badań interpretowane były różne parametry dotyczące ogólnej genezy SMGM. Same margle interpretowane były jako osady pelagiczne, zdeponowane w środowisku wód chłodnych, w efekcie globalnej regresji i obniżenia CCD. Jako główne czynniki odpowiedzialne za sedymentację pakietu SMGM wskazane zostały przekształcenia paleogeograficzne obszaru basenów fliszowych i oceanu światowego oraz wulkanizm na obszarze Karpat (patrz Danysh *et al.*, 1987; Gucwa & Ślączka, 1972; Gucwa & Wieser, 1980; Książkiewicz, 1960, 1975; Olszewska, 1983, 1984; Van Couvering *et al.*, 1981).

Znaczne zmiany, jakie nastąpiły w ostatnich latach w stratygrafii pogranicza eocenu i oligocenu, a także w interpretacji uwarunkowań sedymentacji (patrz Prothero & Berggren, 1992) były podstawą podjęcia badań prezentowanych w niniejszej pracy. Ich celem była interpretacja genezy pakietu SMGM odsłaniającego się nad Jeziorem Rożnowskim w Znamirowicach (Fig. 1). Szczególną uwagę zwrócono na poznanie rozwoju tej sekwencji ze względu na zaznaczającą się w niej fluktuację wapnistości i występowanie przewarstwień osadów ciemnych (por. Leszczyński, 1993a, b). Podobne badania przeprowadzone zostały wcześniej w Karpatach czeskich (Krhovský *et al.*, 1993, 1994). Występującą tam zmienność osadów w sekwencji SMGM zinterpretowano jako efekt fluktuującej produktywności nannolanktonu, sterowanej cyklami Milankowicza.

Stratygrafia profilu

Badany pakiet SMGM ma miąższość 6,3 m (Fig. 2). Tworzą go przekładające się niewapniste i wapniste łupki zielone, wapniste łupki mułowe ciemnoszare, żółtokremowe, beżowe, różowawe i ciemnoszare do czarnych margle, jedna ławica piaskowca i dwie cienkie warstwy przesycone limonitem ("impregnat limonitowy"). Z wyjątkiem niewielkich partii marglu i ławicy piaskowca są to skały słabo zwięzłe. Udział materiału wapiennego wzrasta ku górze pakietu, w efekcie margle dominują w jego górnym, dwumetrowym odcinku. Ten odcinek profilu został też najbardziej wnikliwie zbadany. W obrębie marglu, w górnej części pakietu, występują soczewki osadu impregnowanego limonitem.

Dolna granica pakietu SMGM jest nieostra. Uznano za nią spąg pierwszej od dołu profilu warstwy łupku wapnistego. Poniżej zalegają niewapniste łupki ciemnozielone (oliwkowozielone) z nielicznymi cienkimi przewarstwieniami łupków ciemnoszarych, odsłonięte w około 5 m miąższości profilu.

Od góry, pakiet SMGM obcięty jest tektonicznie. Porównanie z innymi profilami SMGM sugeruje brak kilkudziesięciu centymetrów tego profilu. Powyżej zalega dwudziestopięciometrowa sekwencja zbudowana głownie z mułowców brunatnych i ciemnoszarych i cienko- do bardzo gruboławicowych piaskowców. Sekwencja ta reprezentuje dolną część warstw menilitowych. W niniejszej pracy nazywana jest ona warstwami podrogowcowymi. Podrzędnym ich składnikiem są występujące w cienkich i bardzo cienkich warstwach, twarde łupki szare i zielonawe oraz beżowe twarde i miękkie margle. Występuje tam ponadto kilka warstw tufitów (patrz Gucwa & Ślączka, 1972), a w stropie tej sekwencji pojawiają się bardzo cienkie przewarstwienia rogowców.

Według dotychczasowych datowań, pakiet SMGM w Znamirowicach reprezentuje poziom NP 20 i być może dolną część NP 21 oraz górną część P 16 i P 17 (Van Couvering *et al.*, 1981).

Metoda badań

Cały profil SMGM wraz z utworami podścielającymi i nadległymi badany był warstwa po warstwie pod względem makroskopowych cech skał. Z 2 m górnej części profilu pobrane zostały próby do badań zawartości $CaCO_3$, otwornic, nannoplaktonu, całkowitej zawartości węgla organicznego (TOC), typu kerogenu oraz zawartości izotopów trwałych tlenu i węgla. Zawartość $CaCO_3$ oznaczono na podstawie miareczkowania.

Otwornice badane były pod względem udziału ilościowego osobników bentonicznych i planktonicznych w próbach o wadze 100 g. Osobno liczone były okazy bentosu aglutynującego i wapiennego.

Nannoplankton badany był za pomocą mikroskopu optycznego oraz skaningowego mikroskopu elektronowego. Udział ilościowy nannoplanktonu określony został w specjalnie przygotowanych preparatach proszkowych z 10 próbek.

Materię organiczną badano metodą Rock-Eval w Akademii Górniczo-Hutniczej w Krakowie, natomiast udział izotopów określony został w Instytucie Geochemii Ukraińskiej Akademii Nauk w Kijowie.

Wyniki

Makrofacje

W obrębie SMGM i utworów otaczających wyróżniają się następujące makrofacje:

- łupki zielone,
- łupki i margle ciemne,
- margle jasne,
- impregnat limonitowy,
- mułowce ciemne,
- piaskowce.

Rozmieszczenie osadów poszczególnych facji w profilu jest różne. Łupki i margle ciemne są zwykle podścielone i przykryte łupkami zielonymi. Dolne granice warstw osadów ciemnych są ostre podczas gdy ich stropy są niewyraźne. Łupki zielone wykazują tendencję do przechodzenia w dół w łupek lub margiel ciemny albo też w margiel jasny. Ku górze zaś, przechodzą one w margiel jasny lub też ograniczone są ostro łupkiem lub marglem ciemnym. W obrębie pakietu łupków zielonych podścielającego SMGM oraz w tym ostatnim występują bioturbacje. Brak jest ich natomiast w utworach warstw podrogowcowych.

Łupki zielone są charakterystyczne dla pakietu podścielającego SMGM oraz dla dolnej części tego ostatniego. Są to utwory niewyraźnie warstwowane, mułowe i ilaste, zbioturbowane. Dominują w nich struktury biodeformacyjne (Fig. 3) natomiast ichnofosylia występują podrzędnie. W obrębie pakietu SMGM dominują łupki zielone wapniste.

Łupki i margle ciemne to osady o barwie ciemnoszarej do czarnej i brunatnej. W obrębie pakietu podścielającego SMGM są to wyłącznie łupki niewapniste, natomiast w tym ostatnim występują tak łupki wapniste jak i niewapniste i margle. Udział łupków wapnistych i margli ciemnych wzrasta wyraźnie ku górze pakietu SMGM. Cienkie warstwy tych osadów są zbioturbowane w całym przekroju natomiast w warstwach grubszych bioturbacje widoczne są jedynie w ich górnej części, ponadto ilość bioturbacji rośnie ku górze warstw (Fig. 4, 5, 6). W dolnej części grubszych warstw tych osadów zaznacza się delikatna laminacja równoległa do uławicenia, podkreślona laminami pyłowymi. W obrębie warstw podrogowcowych łupki ciemne występują w górnej części jednostki, natomiast margle ciemne koncentrują się w jej części dolnej.

Facja margli jasnych obejmuje margle żółtokremowe, zielonawożółte, beżowe oraz różowawe. Są to w większości margle miękkie. Są one charakterystycznymi utworami pakietu SMGM. W podrzędnej ilości margle jasne występują również w obrębie warstw podrogowcowych. Dla jednostki tej charakterystyczne są margle twarde występujące w cienkich przewarstwieniach z innymi utworami. W obrębie pakietu SMGM charakterystyczne jest stopniowe przechodzenie tak w dół jak i w górę warstw margli jasnych w łupki zielone. Centralne części niektórych warstw margli jasnych cechują się większą zwięzłością. Ponadto, w dolnej części pakietu SMGM występuje ostro wyodrębniająca się warstwa marglu twardego. W niektórych warstwach liczne są drobne skupienia pirytu oraz soczewki impregnatu limonitowego. Margle jasne w obrębie pakietu SMGM cechują się silnym zbioturbowaniem (Fig. 3, 4, 7-9). Najwyraźniej bioturbacje widoczne są na kontakcie z osadem o innej barwie.

Facja impregnatu limonitowego reprezentuje drobnoziarnisty osad rdzawożółty. Jego warstwy ograniczone są łupkiem zielonym i ciemnym i przepełnione są bioturbacjami *Chondrites targionii.* W obrębie grubszych warstw marglu ciemnego występują soczewki impregnatu limonitowego mierzące do 10 cm w przekroju. Utwory te powstały niewątpliwie z utlenienia żelaza, prawdopodobnie głównie z pirytu, w części zaś syderytu.

Fację mułowców ciemnych tworzą ciemnobrunatne i czekoladowe mułowce wapniste i niewapniste. Są to utwory masywne, o nieregularnej oddzielności, żółtawe na powierzchniach zwietrzałych. Występują one w warstwach o miąższości od kilkunastu do kilkudziesięciu centymetrów. W niektórych warstwach mułowce ciemne zawierają znaczną domieszkę, nieregularnie rozmieszczonego materiału grubszego. Utwory te są charakterystyczne dla warstw podrogowcowych. W dolnej części tej jednostki występują mułowce ciemne silnie wapniste. Mułowce ciemne wykazują tendencję do występowania nad piaskowcem i przechodzenia ku górze w łupek lub margiel ciemny.

Piaskowiec występujący w obrębie pakietu SMGM tworzy ławicę o miąższości 7,5 cm. Jest to piaskowiec średnioziarnisty do drobnoziarnistego, silnie wapnisty, szarozielonawy na powierzchniach świeżych, do rdzawożółtego na powierzchniach zwietrzałych. Zdaje się on reprezentować sekwencję turbidytową $T_{c(d)}$. W obrębie warstw podrogowcowych występują piaskowce jasnobeżowe, gruboziarniste do drobnoziarnistych, niefrakcjonowane oraz z niewyraźnym normalnym uziarnieniem frakcjonalnym w spągu i stropie warstw. Wiele ławic cechuje się ostrym stropem. Ławice piaskowców przykryte są zwykle mułowcem ciemnym. Niektóre ławice piaskowców wykazują strukturę chaotyczną, podkreśloną rozmieszczeniem klastów łupków zielonych, ciemnoszarych i margli.

Skład i mikrocechy osadów

Głównymi składnikami mineralnymi badanych skał są: $CaCO_3$, hydromiki, kwarc detrytyczny oraz materia organiczna (por. Fig. 11). W marglach i łupkach podstawowe znaczenie mają: $CaCO_3$, illit, montmorylonit, kwarc detrytyczny oraz łyszczyki (por. Gucwa & Ślączka, 1972). Największe zawartości $CaCO_3$ rejestrowane są w marglach twardych. Kwarc występuje we frakcji pyłowej. Jego udział w marglach jsnych sięga 7%, natomiast w marglach ciemnych dochodzi do 20% (por. Gucwa & Ślączka, 1972).

Materiał węglanowy w marglach jasnych składa się w 50 do 80% ze skamieniałości nannoplanktonu (Fig. 12; por. Krhovský *et al.*, 1993). Są one najliczniejsze w miękkich (słabo scementowanych) marglach silnie wapnistych (Fig. 11, 12, 18A). W marglach ciemnych, podobnie jak i w silnie wapnistych, twardych marglach jasnych, nannoskamieniałości są rzadsze, a przy tym gorzej zachowane (Fig. 11, 14, 18B, 19).

W marglach, w których udział $CaCO_3$ przekracza 50%, do 30% jego objętości stanowią skorupki planktonicznych otwornic (Fig. 13). Są one najliczniejsze w marglach jasnych (Fig. 11). W łupkach i marglach ciemnych, podobnie jak i w łupkach zielonych, dominują otwornice bentoniczne aglutynujące. Otwornice planktoniczne są tam nieliczne, często są skorodowane, lub też są nieobecne. W łupkach niewapnistych, występujących w obrębie SMGM i utworów podścielających, występują jedynie niezbyt liczne bentoniczne otwornice aglutynujące. W marglach jasnych z warstw podrogowcowych obserwuje się wyłącznie bardzo drobne otwornice planktoniczne, mierzące w przekroju 0,03 do 0,05 mm (Fig. 17).

W łupkach i marglach ciemnych oraz w łupkach zielonych $CaCO_3$ zdaje się występować głównie w postaci cementu (Fig. 14). W marglach jasnych, ziarna najgrubszej frakcji są zazwyczaj rozmieszczone nieregularnie i skupiskowo (Fig. 15). W jednej płytce cienkiej z marglu jasnego zaznaczały się 1 - 2 mm grubości laminy podkreślone koncentracją skorupek otwornic plaknktonicznych (Fig. 16).

Piaskowiec z pakietu SMGM, podobnie jak i piaskowce warstw podrogowcowych, składa się głównie z kanciastych, monokrystalicznych ziarn kwarcu. Podrzędnymi jego składnikami są skalenie, łyszczyki, okruchy skał i bioklasty.

TOC i typ kerogenu

Udział TOC w badanych próbach mieści się w przedziale 0-3,12% (Fig. 11). Największe wartości zarejestrowane zostały w łupkach i marglach ciemnych. W łupkach zielonych, sąsiadujacych z łupkami i marglami ciemnymi, rejestruje się wartości TOC lekko podwyższone w porównaniu z innymi osadami jasnymi.

Analiza kerogenu wykazała dominację kerogenu typu III we wszystkich badanych próbach (Fig. 20).

Izotopy

Wartości $\delta^{18}O$ mieszczą się w przedziale -1,6 – -4,3, natomiast dla $\delta^{13}C$ wynoszą one +1,2 – -3,6 (Fig. 11). Najwyższe wartości dla obu pierwiastków zarejestrowane zostały w osadach słabiej wapnistych, a szczególnie w łupkach zielonych, natomiast w marglach jasnych wartości te są najniższe. Wyraźnie wyodrębniają się przy tym warstwy margli i łupków ciemnych, w których $\delta^{13}C$ osiąga wartości maksymalne, natomiast wartość $\delta^{18}O$ jest tam niska, taka jak w warstwach silnie wapnistych margli jasnych.

Fluktuacja wartości $\delta^{18}O$ i $\delta^{13}C$ w sekwencji warstw łupków zielonych i margli jasnych wykazuje wyraźną korelację dodatnią (współczynnik korelacji 0,765; Fig. 21). Jednocześnie, wartość $\delta^{13}C$ znacznie spada ze wzrostem zawartości $CaCO_3$ w tych osadach (współczynnik korelacji -0,589). Podobne, chociaż nieco słabiej wyrażone są relacje $\delta^{18}O$ do zawartości $CaCO_3$ (współczynnik korelacji -0,435). W warstwach łupków i margli ciemnych $\delta^{18}O$ jest wyraźnie niższa niż w sąsiadujacych warstwach łupków zielonych czy też margli jasnych, natomiast $\delta^{13}C$ jest tam nieco wyższa (Fig. 11).

Wnioski

Opisane w niniejszej pracy cechy skał pakietu SMGM wskazują na jego złożoną genezę. Margle jasne oraz łupki zielone są zasadniczo osadami pelagicznymi i hemipelagicznymi, nato-miast łupki i margle ciemne, podobnie jak i piaskowiec są turbidytami.

Dominacja kerogenu typu III w materiale organicznym zawartym w badanych osadach wskazuje, że pochodzi on głównie z lądu. Jego koncentracja w warstwach łupków i margli ciemnych, zawierających tak skamieniałości organizmów morza otwartego jak i szelfu, wskazuje na jego resedymentację ze strefy o charakterze szelfu zewnętrznego. Dosyć prawdopodobna wydaje się resedymentacja tego materiału z delty lub jej przedpola.

Korelacja poziomów skamieniałości nannoplanktonu wapiennego i otwornic planktonicznych stwierdzonych w SMGM, ze skalą wieku izotopowego paleogenu (Aubry, 1992) sugeruje, że badany pakiet SMGM reprezentuje interwał wiekowy ok. 1 mln lat (por. Krhovský *et al.*, 1993). Różnice w interpretacji zasięgu poziomów biostratygraficznych, ich relacji jak również czasu ich trwania (por. Aubry, 1992 i Brinkhuis, 1994) pokazują, że wiek badanego profilu SMGM może mieścić się w przedziale już od ok. 0,5 do ok. 1,3 mln lat. Według Krhovský *et al.* (1993), pakiet SMGM w Karpatach czeskich osadzał się w czasie ok. 0,5 mln lat. Sześciometrowa miąższość profilu SMGM w Znamirowicach, wraz jego położeniem w niewielkiej odległości od wybrzeży basenu sedymentacyjnego, pomimo dominacji osadów pelagicznych i hemipelagicznych sugeruje sedymentację tworzących go osadów w czasie znacznie krótszm od 1 mln lat. Stopniowy wzrost, a następnie spadek wapnistości profilu, wynikającej ze zmieniającej się produktywności organicznej, wskazuje na jego powstanie pod wpływem zmian klimatu. Prawdopodobne wydaje się powstanie badanego profilu SMGM pod wpływem zmian klimatu powodowanych zmianami ekscentryczności orbity Ziemi, w ramach jednego cyklu o okresie 414 tys. lat (dłuższy cykl ekscentryczności; por. Krhovský *et al.*, 1993).

Sekwencja osadów w profilu pakietu SMGM wykazuje cechy świadczące o ich sedymentacji głównie pod wpływem fluktuującej produktywności nannoplanktonu wapiennego i otwornic planktonicznych oraz nieregularnie zmieniającej się intensywności dostawy materiału terygenicznego z wybrzeży basenu.

Fluktuująca produktywność nannoplanktonu wapiennego oraz otwornic planktonicznych wydaje się być główną przyczyną stopniowych zmian wapnistości osadów pelagicznych (margli jasnych i łupków zielonych). Wyraźna fluktuacja wapnistości w skali 1,5 m profilu wskazuje na sterowanie zmianami klimatu, wynikającymi z krótkiego cyklu ekscentryczności orbity Ziemi (90 tys. lat).

Fluktuacje wapnistości w krótszych odcinkach profilu, jak również jej szybkie zmiany poniżej i powyżej warstw łupków i margli ciemnych, wydają się wynikać z nieregularnie zmieniającej się intensywności dostawy materiału terygenicznego, a częściowo są one efektem diagenezy osadu. Dostawa materiału terygenicznego sterowana była zmieniającą się nieregularnie w czasie aktywnością tektoniczną obszaru, przemieszczaniem się płatów depozycyjnych delty lub też ujścia rzeki, a także bardziej regularnymi zmianami klimatu.

Zróżnicowana diageneza, zależnie od pierwotnego składu osadu, wzmocniła kontrast w rozmieszczeniu $CaCO_3$, rozmieszczeniu nannoskamieniałości, $\delta^{18}O$ and $\delta^{13}C$, typu kerogenu oraz wartości TOC w badanym pakiecie SMGM.

Rozmieszczenie resedymentów w badanym profilu wskazuje, że wzmożona resedymentacja występowała tam co kilkadziesiąt tysięcy lat. Znaczne jej zintensyfikowanie nastąpiło bezpośrednio po osadzeniu się pakietu SMGM.

Pierwotne zróżnicowanie składu osadów pelagicznych, w skali kilku milimetrów (reprezentujące okresy do kilkuset lat), zostało zatarte bioturbacyjnie. Jego obecność sugerują niewielkie zmiany zawartości $CaCO_3$, zachowane szczątkowo laminy oraz poziomy wyraźniejszych bioturbacji, podkreślone barwami nieco odmiennymi od barwy osadu tła.

Wartości $\delta^{18}O$ i $\delta^{13}C$ w badanym pakiecie przedstawiają stosunki pierwotne tych izotopów, przemodelowane w różnym stopniu podczas diagenezy osadu. Fluktuowanie wartości tak $\delta^{18}O$ jak i $\delta^{13}C$ zależnie od rodzaju skały wskazuje, że decydujący wpływ na przekształcenia stosunku izotopów tak węgla jak i tlenu miał rodzaj i ilość materii organicznej zawartej pierwotnie w osadzie (patrz Tucker & Wright, 1990). Zmiany $\delta^{18}O$ i $\delta^{13}C$, zaznaczające się w sekwencji łupków zielonych i margli jasnych, odzwierciedlaja fluktuację stosunku tych izotopów w czasie sedymentacji pakietu, wzmocnione przez diagenezę. Warstwy margli jasnych zostały prawdopodobnie znacznie wzbogacone w izotopy lekkie tak węgla jak i tlenu, natomiast w łupkach zielonych przemiany stosunku izotopów obu pierwiastków wydają się być nieznaczne.

Ogólnie, pakiet SMGM odzwierciedla okres wzmożonego rozwoju planktonu i nannoplanktonu wapiennego, rejestrowany na obszarze całego globu u schyłku eocenu (patrz Beggren & Prothero, 1992). Wzmożona resedymentacja materiału wyraźnie wzbogaconego w materię organiczną zdaje się wskazywać pewną odmienność rozwoju basenów sedymentacji fliszu karpackiego w porównaniu z oceanem światowym. Specyfika ta była prawdopodobnie spowodowana zwężaniem się połączeń obszaru karpackiego z oceanem (patrz Ricou *et al.*, 1986). Proces ten tłumił cyrkulację głębokowodną i umożliwiał eutrofizację basenów fliszowych.