Cycles of different scale in the turbidites of the Magura nappe on the northern Orava, Western Carpathians (Campanian - Upper Eocene)

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Abstract. The schematic lithostratigraphic sections of the Rača and the Bystrica Units of the Flysch belt are quite well correlated with 2nd and 3rd order sea-level fluctuations. Disagreement in some part of sections is explained by tectonic movements, especially by the Laramian tectonic movements. In the Szczawina beds of the Rača Subunit (Maastrichtian) the cycles controlled by the 4th order sea-level fluctuations were observed. The cycles in thin-bedded turbidites probably correspond by its duration with 5th and 6th order fluctuation (Milankovitch cycles).

Key words: turbidites, cycles, sea-level fluctuations, Milankovitch, Cretaceous-Paleogene

Introduction

Studied area on the northern Orava is a part of the Magura Nappe of the Flysch belt of the Western Carpathians. The Flysch belt is the neo-alpine accrecionary wedge. It is created of some nappes. Each of them is built from several tectonic slices. They are mainly composed of deep-sea turbidite sequences deposited in a remnant oceanic basin (Einsele, 1992). In the studied area there were determined lithostratigraphic formations and members of the Rača and the Bystrica Subunits. In the sections and some outcrops there were identified the cycles of bed thickness and grain size changes of different scale. It is possible to correlate the cycles with sea level fluctuations of the second, third, forth, fifth and sixth orders?

Lithostratigraphic units

The studied area in Pilsko mountain region is situated in the frontier between Slovakia and Poland. It was possible to arrange only schematic lithostratigraphic sections both of the Rača and both of the Bystrica Subunits in spite of covering of the area. Age of the formations was based on determination of nannofossils, agglutinated forams and correlation with similar formations in Poland part of the Magura Nappe. Names of the intervals of turbidite beds are based on Bouma (1962) and Lowe (1982).

Rača Subunit is composed of the following formations and members:

Haluszowa Formation - (Campanian - Lower Maastrichtian) is built by hemipelagic variegated mudstones with less portion of medium-bedded turbidite beds (see Malata & Oszczypko, 1990, Malata et al. 1996). The ideal bed is composed from sandstone and siltstone $T_{(ab)cd}$ and variegated marlstone T_e (Pivko, 1991, Pivko, 1994). The formation can be compared with Variegated shales (Sikora & Żytko, 1959), Cebula variegated marls (Golonka & Wójcik, 1978) and upper part (Campanian - Maastrichtian) of Kaumberg Formation (Švábenická et al., 1997).

The formation contained nannofossils: *Aspidolithus parcus* (STRADNER) NOËL, *Aspidolithus parcus contrictus* (HATTNER) PERCH-NIELSEN, *Arkhangelskiella cymbiformis* VEKSHINA, *Quadrum gothicum* (DEFLANDRE) PRINS & PERCH-NIELSEN, *Quadrum sissinghii* PERCH-NIELSEN, *Calculites obscurus* (DEFLANDRE) PRINS & SISSINGH, *Lucianorhabdus maleformis* REINHARDT, *Eifelithus eximius* (STOVER) PERCH-NIELSEN (POTFAJ in PIVKO et al., 1991).

Szczawina Member (Maastrichtian) is composed of massive sandstones (pebbly sandstones) S_3 or thick beds with the domination of sandstones T_{a-e}. It is interrupted by layers with variegated mudstones and thin-bedded turbidites T_{cde} (Pivko, 1994). The member is approximately comparable with Szczawina Sandstones (Sikora & Żytko, 1959, Cieszkowski et al., 1989, Ryłko et al. 1992, Malata et al. 1996) and lower part of Altlengbach Formation (Schnabel, 1992, Faupl, 1996).

The member belongs to zone *Caudammina gigantea* (GEROCH) with next species: *Caudammina ovulum* (GRZYBOWSKI), *Rhabdammina cylindrica* GLAESSNER, *Rhabdammina* ex gr. *discreta* (BRADY), *Dendrophrya excelsa* (GRZYBOWSKI), *Dendrophrya latissima* GRZYBOWSKI, *Saccammina placenta* (GRZYBOWSKI) (Pivko & Bubík, prepared paper, Korábová in Pivko et al. 1991).

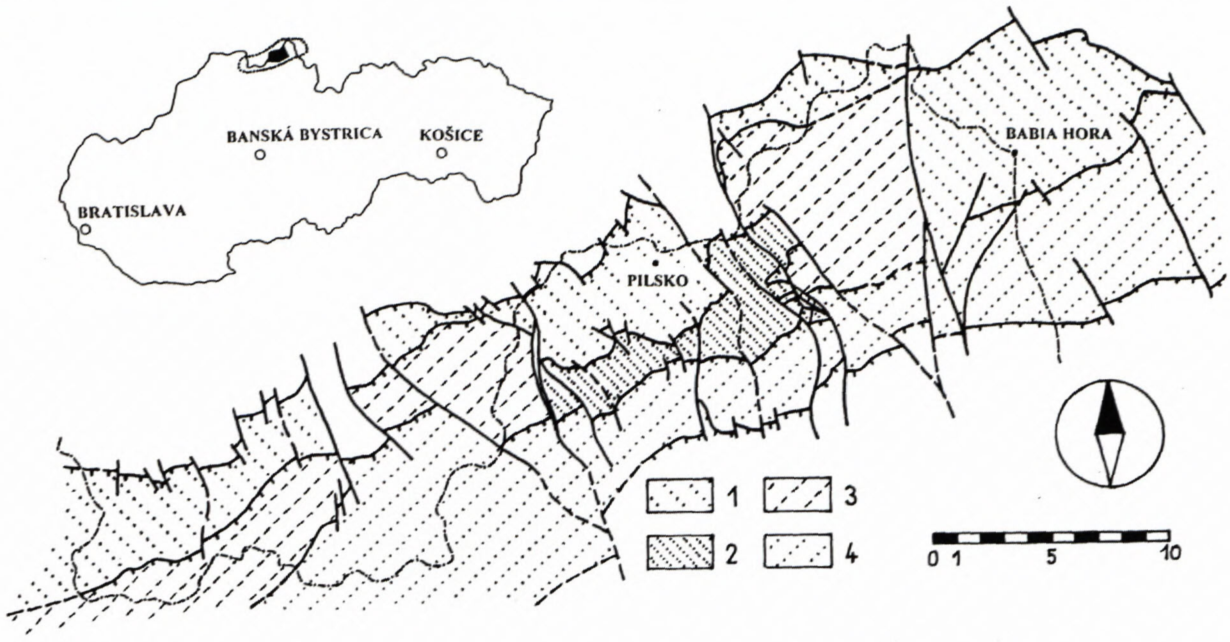

Fig.1 Position and tectonic map of the studied area and its surrounding. Names of the slices on the boundary of the Rača and Bystryca Subunits: 1 - „Outer Rača Unit„, 2 - „Inner Rača Unit„, 3 - „Outer Bystrica Unit„ and 4 - „Inner Bystrica Unit„.

Ropianka Member (Uppermost Maastrichtian - Upper Paleocene) is created with thin- to medium-bedded turbidites $T_{(ab)cde}$ and grey hemipelagic mudstones (see Ślączka & Miziołek, 1995). The beds are similar to Inoceramian Beds (Sikora & Żytko, 1959, Książkiewicz, 1966), Ropianka Beds (Golonka & Wójcik, 1978, Ryłko et al. 1992), Ropianka Formation (Oszczypko, 1992b), Shaly-sandstone member of Soláň Formation (Pesl, 1968) or Ráztoka Member of Soláň Formation (Švábenická et al., 1997). The closed is the upper part of the Altlengbach Formation (Schnabel, 1992, Faupl, 1996).

Age was based on litological comparison with neighborough area (Sikora & Żytko, 1959) and the position of the member.

Łabowa Shale Formation (Upper Paleocene - Lower Eocene) contains variegated hemipelagic mudstones and thin-bedded turbidites T_{cde} and T_{de} (see Oszczypko, 1991, Oszczypko, 1992b). Conglomeratic beds are very rare (Ciężkowice Sandstone type). It is possible to correlate the formations with Lower Variegated Shales and Ciężkowice Sandstones (Sikora & Żytko,1959) and Variegated shales or beds (Książkiewicz, 1966, Pesl, 1968, Golonka & Wójcik, 1978, Ryłko et al. 1992).

In the formation there are *Rhabdammina* ex gr. *discreta* (BRADY), *Dendrophrya excelsa* (GRZYBOWSKI), *Dendrophrya latissima* GRZYBOWSKI, *Sacammina placenta* (GRZYBOWSKI), *Glomospira charoides* (JONES et PARKER), *Glomospira gordialis* (JONES et PARKER), *Caudammina ovulum* (GRZYBOWSKI), *Trochammminoides irregularis* WHITE, *Globigerina* ex gr. *eocaena* GÜMBEL (Korábová in Pivko et al., 1991).

Veselé Formation. (Upper Maastrichtian - Lower Eocene) is composed by variegated and grey hemipelagic mudstones and thin-bedded turbidites T_{cde} and T_{de}. In the middle part there are medium- to thick-bedded turbidites T_{a-e} (Pivko & Bubík, prepared paper). The formation has some common features of the Ropianka Member and the Labowa Shale Formation.

Agglutinated forams in the formation are *Rhabdammina* ex gr. *discreta* (BRADY), *Dendrophrya* cf. *robusta* GRZYBOWSKI, *Saccammina placenta* (GRZYBOWSKI), *Glomospira charoides* (JONES et PARKER), *Glomospirella gorayskii* (GRZYBOWSKI), *Ammodiscus cretaceous* (REUSS), *Caudammina ovulum* (GRZYBOWSKI), *Hormosina ovuloides, Trochamminoides irregularis* WHITE, *Trochamminoides subcoronatus* (GRZYBOWSKI) (Korábová in Pivko et al., 1991).

Beloveža Formation (Uppermost Lower Eocene - Middle Eocene) is built by Hieroglyphic Member. In upper part of the formation there is the Osielec sandstone Member. *The Hieroglyphic Member* (Uppermost Lower Eocene - Middle Eocene) is created by thin-bedded turbidites T_{cde} with less portion of thick-bedded ones T_{abcde} (see Oszczypko, 1992b). *The Osielec Sandstone Member* (Middle Eocene) is composed of thick-bedded turbidites with prevailing of sandstones with glauconite over calcareous mudstones T_{a-e} (see Książkiewicz, 1966). The Hieroglyphic Member is comparable with Beloveža Member without red mudstones (Pesl, 1968). The Osielec Sandstone Member has some litological similarity to Vsetín Member (Pesl, 1968) and Steinberg „flysch„ (see Faupl, 1996) and some litological similarity but not age equivalent to Greifenstein Formation, Gablitz Member and Glauconite Formation (see Faupl, 1996). The sandstones of the member were also included to Pasierbiec Sandstones (Sikora & Żytko, 1959, Książkiewicz, 1966).

The next nannofossils were identified in the formation: *Chiasmolithus grandis* (BRAMLETTE et SULLIVAN) RADOMSKI, *Cyclicargolithus* cf. *floridanus* (ROTH et HAY) BUKRY, *Dictyococcites bisectus* (HAY, MOHLER et

WADE) BUKRY et PERCIVAL, *Dictyococcites* cf. *scrippsae* BUKRY et PERCIVAL, *Discoaster barbadiensis* TAN SIN HOK, *Discoaster binodosus* MARTINI, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Ericsonia formosa* (KAMPTNER) HAQ, *Reticulofenestra dictyoda* (DEFLANDRE) STRADNER, *Sphenolithus radians* DEFLANDRE (Potfaj in Pivko et al. 1991).

Zlín Formation - Kyčera Member (Upper Eocene) is very thick. Lower part of the Member is thick-bedded turbidites T_{a-e} to massive sandstones S_3, middle part massive sandstones and upper part massive to thick-bedded turbidites. The member corresponds to Magura Sandstone (Sikora & Żytko, 1959, Książkiewicz, 1966, Golonka & Wójcik, 1978), Magura Formation (see Oszczypko, 1992b) and bigger part of Babia hora Sandstone (Matějka & Roth, 1952).

Potfaj (in Pivko, 1991) determined the nannofossils: *Chiasmolithus grandis* (BRAMLETTE et SULLIVAN) RADOMSKI, *Chiasmolithus eograndis* PERCH-NIELSEN, *Chiasmolithus* cf. *modestus* PERCH-NIELSEN, *Chiasmolithus solitus* (PERCH-NIELSEN) LOCKER, *Cyclicargolithus floridanus* (ROTH et HAY) BUKRY, *Discoaster barbadiensis* TAN SIN HOK, *Discoaster binodosus* MARTINI, *Discoaster deflandrei* BRAMLETTE et RIEDEL, *Discoaster distinctus* MARTINI, *Discoaster diastypus* BRAMLETTE et SULLIVAN, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Discoaster nonaradiatus* KLUMP, *Discoaster saipanensis* BRAMLETTE et RIEDEL, *Discoaster sublodoensis* BRAMLETTE et SULLIVAN, *Discoaster tanii* BRAMLETTE et RIEDEL, *Ericsonia formosa* (KAMPTNER) HAQ, *Reticulofenestra dictyoda* (DEFLANDRE) STRADNER, *Sphenolithus radians* DEFLANDRE.

Bystrica Subunit is built of the formations and the members:

Ropianka Member (Paleocene) is composed of thin-bedded turbidites T_{cde} and T_{de} with variegated mudstones (see Ślączka & Miziołek, 1995). The member is similar to Inoceramian Beds (Książkiewicz, 1966), Ropianka Beds (Golonka & Wójcik, 1978, Ryłko, 1992 - „comlex b„, Malata et al., 1996), Ropianka Formation (Oszczypko, 1992b) and Shaly-sandstone member of Soláň Formation (Pesl, 1968).

Age was based on litological comparison with neighborough area (RYŁKO, 1992) and forams: *Rhabdammina* ex gr. *discreta* (BRADY), *Dendrophrya latissima* GRZYBOWSKI, *Sacammina placenta* (GRZYBOWSKI), *Glomospira serpens* (GRZYBOWSKI), *Trochammminoides irregularis* WHITE, *Trochammminoides proteus* (KARRER), *Globigerina* sp. (KORÁBOVÁ in PIVKO et al., 1991).

Szczawina Sandstone Member (Upper Paleocene) is the sequence of massive sandstones S_3 very similar to the Szczawina Sandstone in Rača Subunit, but other age. The member is litologically closed to Szczawina Sandstone (Cieszkowski et al., 1989, Oszczypko 1992b, Malata et al. 1996), „muscovite sandstones„ in Inoceramian Beds (Książkiewicz, 1966) and also by age closed to „comlex „c„ of Ropianka Beds (Ryłko, 1992).

Age was determined after the superposition of the member in the Inoceramian Member.

Beloveža Formation (Lower Eocene) is divided to the Lower and the Upper Beloveža Member. *The Lower Beloveža Member* (Lower Lower Eocene) is built by thin-bedded turbidites T_{cde} and variegated mudstones and *Upper Beloveža Member* (Upper Lower Eocene) of thin-bedded turbidites T_{cde}. The Lower Beloveža Member can be compared with Variegated shales (Golonka & Wójcik, 1978), „Beloveža Member with variegated shales„ (Ryłko, 1992) or Łabowa Shale Formation (Malata et al., 1996, partly Oszczypko, 1991). The Upper Beloveža Member is comparable with thin-bedded part of the Beloveža Formation (Golonka & Wójcik, 1978, Oszczypko, 1991, Ryłko, 1992, Malata et al., 1996).

The nannofossils of the formation are: *Discoaster barbadiensis* TAN SIN HOK, *Discoaster deflandrei* BRAMLETTE et RIEDEL, *Discoaster distinctus* MARTINI, *Discoaster gemmifer* STRADNER, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Chiasmolithus expansus* (BRAMLETTE et SULLIVAN) GARTNER, *Sphenolithus moriformis* (BRÖ NNIMANN et STRADNER) BRAMLETTE et WILCOXON, *Sphenolithus radians* DEFLANDRE, *Tribrachiatus orthostylus* SHAMRAI (Korábová in Pivko et al., 1991).

Vychylovka Formation (Uppermost Lower Eocene - Middle Eocene) consists of thin-bedded T_{cde} and medium- to thick-bedded turbidites $T_{(a)b-e}$ with prevailing of marlstones - closed to Łącko type (see Potfaj, 1989). The formation has similarity with upper part of Beloveža Formation and lower part of Łącko Beds or Marls (Sikora & Żytko, 1959, Książkiewicz, 1966, Golonka & Wójcik, 1978, Ryłko, 1992), with some parts of Beloveža, Żeleznikowa and Bystrica Formation (Oszczypko, 1991, Malata et al., 1996). Some features are similar to „transitional beds„ (Książkiewicz, 1966).

The formation belongs to nannofossils zones NP13-NP17: *Chiasmolithus expansus* (BRAMLETTE et SULLIVAN) GARTNER, *Chiasmolithus grandis* (BRAMLETTE et SULLIVAN) RADOMSKI, *Cribrocentrum coenurum* (REINHARDT) PERCH-NIELSEN, *Cyclicargolithus floridanus* (ROTH et HAY) BUKRY, *Dictyococcites bisectus* (HAY, MOHLER et WADE) BUKRY et PERCIVAL, *Discoaster barbadiensis* TAN SIN HOK, *Discoaster binodosus* MARTINI, *Discoaster deflandrei* BRAMLETTE et RIEDEL, *Discoaster distinctus* MARTINI, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Discoaster saipanensis* BRAMLETTE et RIEDEL, *Ericsonia formosa* (KAMPTNER) HAQ, *Nannotetrina cristata* (MARTINI) PERCH-NIELSEN, *Reticulofenestra dictyoda* (DEFLANDRE) STRADNER, *Reticulofenestra umbilica* (LEVIN) MARTINI et RITZKOWSKI, *Sphenolithus editus* PERCH-NIELSEN, *Sphenolithus moriformis* (BRÖNNIMANN et STRADNER), *Sphenolithus radians* DEFLANDRE (Korábová & Potfaj in Pivko et al., 1991).

Zlín Formation (Middle - Upper Eocene) is composed of Bystrica and Kýčera Member (see Pesl, 1968). In *the Bystrica Member* (Middle Eocene) there are marlstones (Łącko type), which prevails over sandstones in thick-bedded turbidites $T_{(a)b-e}$ and in *the Kýčera Member* (Middle - Upper Eocene) there are thick-bedded sandy turbidites T_{a-e} to massive sandstones S_3. The Bystrica

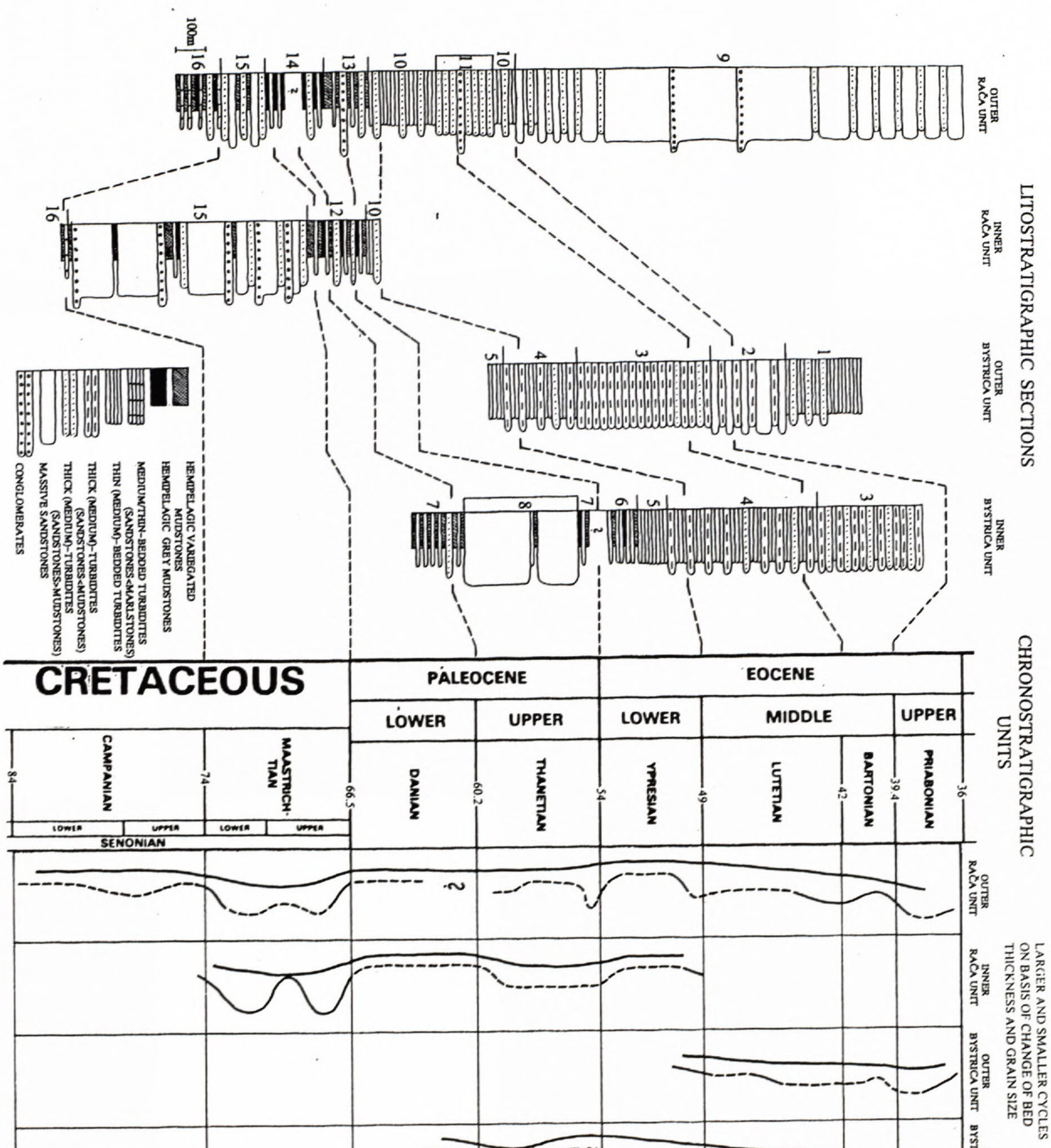

Fig. 2 Comparison of the schematic lithostratigraphic sections of the Rača and the and the Bystrica Subunits and their cycles of bed thickness and grain size with 2^{nd} and 3^{rd} order sea level fluctuations (Haq et al., 1987). Numbers in the sections: 1-8 - Bystrica Subunit: 1 - Malcov Formation, 2 - Zlín Formation - Kýčera Member, 3 - Zlín Formation- Bystrica Member, 4 - Vychylovka Formation, 5 - Beloveža Formation - Upper Beloveža Member, 6 - Beloveža Formation - Lower Beloveža Member, 7 - Ropianka Member, 8 - Szczawina Sandstone Member, 9-16 - Rača Subunit: 9 - Zlín Formation - Kyčera Member, 10 - Beloveža Formation - Hieroglyphic Member, 11 -Beloveža Formation - Osielec Sandstone Member, 12 - Veselé Formation, 13 - Labawa Shale Formation, 14 - Ropianka Member, 15 - Szczawina Member and 16 - Haluszowa Formation

Member is similar to Łącko Beds (Sikora & Żytko, 1959, Książkiewicz, 1966, Ryłko, 1992) and Bystrica Formation (Oszczypko, 1991). The Kýčera Member can be correlated with Magura Sandstone or Beds (Sikora & Żytko, 1959, Książkiewicz, 1966, Golonka & Wójcik, 1978) and Magura Formation (Oszczypko, 1991).

In the Bystrica Member there are *Cribrocentrum coenurum* (REINHARDT) PERCH-NIELSEN, *Cyclicargolithus floridanus* (ROTH et HAY) Bukry, *Chiasmolithus* cf. *expansus* (BRAML. et SUL.) GARTNER, *Chiasmolithus* cf. *modestus* PERCH-NIELSEN, *Discoaster barbadiensis* TAN SIN HOK, *Discoaster binodosus* MARTINI, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Reticulofenestra dictyoda* (DEFLANDRE) STRADNER, *Reticulofenestra umbilica* (LEVIN) MARTINI et RITZKOWSKI, *Sphenolithus moriformis* (BRÖNNIMANN et STRADNER) (Korábová & Potfaj in Pivko et al. 1991).

In the Kýčera Member there are *Chiasmolithus grandis* (BRAMLETTE et SULLIVAN) RADOMSKI, *Chiasmolithus eograndis* PERCH-NIELSEN, *Chiasmolithus modestus* PERCH-NIELSEN, *Chiasmolithus solitus* (PERCH-NIELSEN) LOCKER, *Cribrocentrum coenurum* (REINHARDT) PERCH-NIELSEN, *Cyclicargolithus floridanus* (ROTH et HAY) BUKRY, *Dictyococcites bisectus* (HAY, MOHLER et WADE) BUKRY et PERCIVAL, *Dictyococcites callidus* PERCH-NIELSEN, *Dictyococcites scrippsae* BUKRY et PERCIVAL, *Discoaster* barbadiensis TAN SIN HOK, *Discoaster deflandrei* BRAMLETTE et RIEDEL, *Discoaster* cf. *distinctus* MARTINI, *Discoaster lodoensis* BRAMLETTE et RIEDEL, *Discoaster nonaradiatus* KLUMP, *Discoaster saipanensis* BRAMLETTE et RIEDEL, *Discoaster sublodoensis* BRAMLETTE et SULLIVAN, *Ericsonia formosa* (KAMPTNER) HAQ, *Helicosphaera* cf. compacta BRAMLETTE et WILCOXON, *Reticulofenestra dictyoda* (DEFLANDRE) STRADNER, *Reticulofenestra umbilica* (LEVIN) MARTINI et RITZKOWSKI, *Sphenolithus radians* DEFLANDRE, *Sphenolithus spiniger* BUKRY (Korábová & Potfaj in Pivko et al. 1991).

Malcov Formation (Upper Eocene-?Oligocene) is composed of thin (medium)-bedded turbidites T_{cde}. The formation is very similar to the same one in the Krynica or possibly Rača Subunit (Birkenmajer & Oszczypko, 1989, Oszczypko et al., 1990, Potfaj et al., 1991, Oszczypko, 1992b).

The thickness of the lithostratigraphic units is visible in schematic sections on fig.2.

Cycles in deep-sea turbidites

In the formations of studied area there are the cycles on the basis of change of bed thickness, grain size and facies. The cycles are of a different scale. The cycles with thickening- and thinning-upward, coarsening- and fining-upward trends of turbidite beds are a common phenomenon in turbidite sequences. It is result of an interplay of sedimentary, topographic, tectonic and sea-level effects (Stow, 1986).

The cyclicity in sediments is of a global and a local origin. The local ones are control by mechanism in the sedimentary prism itself, for instance by switching of turbidite bodies and by a local tectonics. The sea-level fluctuations control changes in sediment, which are observed on all the Earth.

It was recognised sea level fluctuations of the first to sixth orders (Haq et al., 1987, Vail et al., 1991, Hoedemaeker & Leereveld, 1996). *1st order sea-level fluctuations* are major continental flooding cycles with duration over 50 million years. *2nd order fluctuations* are major transgressive - regressive cycles with time span of a few tens of millions years. *3rd order fluctuations* from half to a few million years produce sequences studied by sequence stratigraphy. Causes of 1st to 3rd order sea-level fluctuations are not quite understood. Probably there are some processes in earth mantle. *4th order fluctuations* are more expressive than 3rd order ones during icehouse (existence of polar caps). Their duration is from 80 to 500 thousand years. *5th order fluctuations* last from 30 to 80 thousand years and *6th order* one from 10 to 30 thousand years. During greenhouse (without polar caps) 4th to 6th order fluctuations are less expressive than 3rd order ones and they are most probably caused by climatic changes driven by orbital forcing. They are known like *Milankovitch cycles.*

4th order sea-level fluctuations are influenced by *Milankovitch cycle of eccentricity*, 5th order one by *cycle of obliquity* and 6th order one by *cycle of precession* (Hoedemaeker & Leereveld, 1996).

Turbidite sequences are restricted only to fall and low-stand of sea-level after models of sequence stratigraphy (Posamentier et al., 1988, Van Wagoner et al., 1988, Vail et al., 1991). It is very simplified. Turbidites are known also from transgressive and high-stand of sea-level (Shanmugam & Moiola, 1988, Mutti, 1992).

The thickness of deep-sea turbidites is controlled by global sea-level fluctuations. The fall of sea level means the increase of amount material transported to deep sea. This is the consequence of the approach of river deltas to deposition area in deep sea and of the erosion of emerged shallow sea sediments. On the contrary the rise of sea level causes the decrease of amount material, the enlargement of distance between the sources of clastic material and deep-sea. The tectonic uplift of source area and climate also control amount of material transported to deep-sea.

Rate and frequency of deposition

It was necessary to compute the frequency of deposition because of the knowledge of the duration of the cycles The input data are the thickness of lithostratigraphic units, the duration of lithostratigraphic units and average bed thickness of lithostratigraphic units. The thickness of lithostratigraphic units was estimated from the geologic profiles of the geologic map and the correlation with surrounding regions. The duration of lithostratigraphic units was based on biostratigraphy, correlation with surrounding areas and the third order fluctuations of sea-level (Haq et al. 1988, fig. 2). The average bed thickness was computed from data measured in outcrops.

From the thickness of a lithostratigraphic unit and the average bed thickness was computed the number of beds in a lithostratigraphic unit. From the duration of a lithostratigraphic unit and number of beds in a lithostratigraphic unit was gained the *frequency* of beds (number of years between deposition of two following turbidite beds).

Rate of deposition (thickness of sediment per thousand years) was computed from the thickness and the duration of a lithostratigraphic unit. All computed results are very approximated because of inaccurate input data. But they give good image of the rate and the frequency of deposition and are suit to the estimation of the duration of cycles.

The frequency of turbidite beds varies from about 1.5 to 30 thousand years per one bed. The rate of deposition change from 1.3 to 38 centimetres per thousand years (Tab.1).

Tab.1 Approximated frequencies and rates of deposition in some lithostratigraphic units

	thickness of a lithostrat. unit (m)	average thickness of bed (cm)	number of beds in a lithostrat. unit	duration of a lithostrat. unit (million years)	frequency of deposition (x thousands years / one turbidite bed)	rate of deposition (x cm / 1000 years)
Haluszowa Fm.	150	40	380	12	30	1.3
Szczawina Mb. (Rača S.)	800	?		4		
- thick-bedded parts	710	120	600	2	3.3	35
- middle thin-bedded part	60	? 15	? 300	2	? 5	3
Veselé Fm.	350	?		18		
- lower thin-bedded part	150	6	2 500	7	2.8	2
- upper thin-bedded part	125	7.5	1 700	? 3.5	? 2.5	? 3.5
Labowa Sh. Fm.	150	? 5	? 3 000	7	? 2.5	2
Hieroglyph Mb.	225	11	2 000	4.5	2.2	5
Upper Beloveža Mb.	? 100	6	? 1 700	2.5	? 1.5	? 4
Kýčera Mb. (Rača S.)	1 500	200	750	4	5.5	38

Cycles in the turbidites of the Magura unit

Cycles in the schematic sections

In the schematic sections of the Rača and the Bystrica Subunit there are the trends of changes of bed thickness and grain size of material (Fig. 2). We can distinguish larger and smaller trends. One cycle is the thickening/coarsening upward and following thinning/fining upward trend.

Larger cycles

On the curve of the trends (Fig. 2) we can see thickening/coarsening upward trend in the Lower Maastrichtian and the opposite one in the the Upper Maastrichtian. In the Upper Paleocene there is less the expressive thickening/coarsening upward and thinning/fining upward trend. From the Lower Eocene to the Upper Eocene there is the thickening/coarsening upward trend. The duration of the cycles is 13 and 20 million years.

Smaller cycles

Larger cycles are created by a few smaller ones (Fig. 2). Less expressive cycle is in the Haluszowa Formation of the Rača Subunit in the Campanian. Two more expressive cycles are in the Szczawina Member of the Rača Subunit during the Maastrichtian. One cycle is in the Veselé Formation of the Rača Subunit and the marked ones in the Ropianka Formation during the Upper Paleocene. On the border of the Paleocene and the Eocene there is one expressive cycle in the Labowa Shale Formation of the Rača Subunit and less visible one in the Beloveža Formation of the Bystrica Subunit. The marked cycle is in the Middle Eocene in the Beloveža Formation in the Rača Subunit and in the Vychylovka Formation and the Bystrica Member of the Bystrica Subunit. Very marked cycle is in the Kyčera beds in the Upper Eocene. The duration of the cycles is from 3 to 7 Ma.

Cycles in the Szczawina Member of the Rača Subunit

In the schematic section of the Inner Rača Subunit there were the sequences of the Szczawina Member worked out more detail. The sequences have thickness 300 and 410 metres. Both sequences probably correspond to falls of sea-level of 3rd order during the middle and upper Maastrichtian (Fig. 2) The sequences are divided to several parasequences (Fig. 3). The parasequences with the thick-bedded to massive sandstones are disturbed by the thin-bedded turbidites with variegated hemipelagic mudstones. The thickness of the parasequences is from about 50 to 200 metres. If both sequences lasted about 2 Ma, the parasequences approximately correspond to time

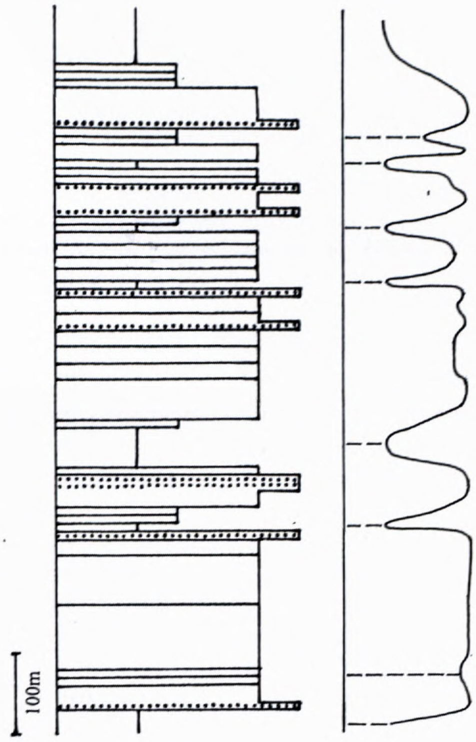

Fig. 3 - The cycles in the Szczawina Member of the Rača Subunit. In the first column there is the lithostratigraphic section of the member with conglomeratic beds, massive sandstones, medium-bedded and thin-bedded turbidites. The second column shows the cycles of bed thickness and grain size. The dotted lines marked the most probable borders of the cycles.

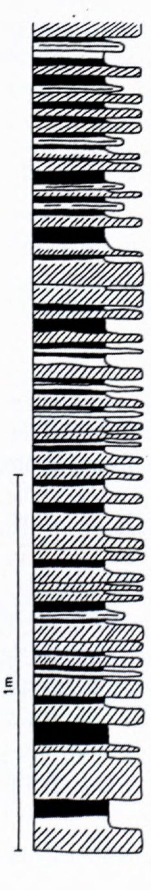

Fig.4 - Thin-bedded turbidites of the Upper Beloveža Member are created by cross-laminated sandstones (Tc), horizontally laminated siltstones (Td) and calcareous mudstones (Te). Between turbidite beds are hemipelagic non-calcareous mudstones (black colour).

span from 75 to 600 thousand years. Time span of the parasequences is not possible to compute from biostratigraphy. The biostratigraphy can resolve, in most cases, only the duration of 3rd-order cycles (Mutti 1992).

Cycles in the outcrops of thin-bedded turbidites

The cycles of smaller orders were searched in thin-bedded turbidites (Fig. 4) because of large amount beds in a outcrop and less influence of the processes in deep sea fan because this type of sediments were deposited on fringe of it. We observed cycles in the Upper Beloveža Member (Fig. 4) of the Bystrica Subunit, the Labowa Shale Formation and the Hieroglyphic Member of the Rača Subunit.

Firstly the rhythmograms of beds were arranged (Fig. 5-7). A rhythmogram is composed of thickness of sandstones (siltstones) and mudstones. On the rhythmograms there are possible to observe the various cycles of change of thickness. The changes of the bed thickness are not continuous. Bed by bed thickening (thinning)-upward cycles was not as often as oscillating (zigzag) ones. The arrangement of three beds with the oscillating changes of the thickness has approximately twice frequency than continuous thickening (thinning) of three beds. It corresponds to the theoretically computed random arrangement.

Because of better readability of a rhythmogram it was necessary to reduce influence of random arrangement. The curve of the three point moving average (average from tree values - thickness of bed and thickness of closed ones) was computed both for sandstones and for whole beds, on which the cycles of about 4 to 9 beds are visible (Fig. 5-7). The peaks of the cycles computed from sandstones and whole beds are not quite in accord. It is caused by less reliable data from whole beds because hemipelagic mudstones are included here. The duration of the cycles is after the frequency of deposition (Tab. 1) about 7 to 20 thousand years.

Because of better readability of the larger cycles the curve of the nine point moving average was arranged only for sandstones because of better reliability (Fig. 5-7). On the curve there are visible the cycles of about 11 to 30 beds. The duration of the cycles is about 28 to 75 thousand years. The extreme values were excluded when the cycles was computed.

Discussion - possible causes of the cycles

The cycles in schematic sections and outcrops were correlated with sea-level fluctuations. The rise on the sea-level curve was approximately expressed by thinning-upward and fining-upward turbidite beds. On the contrary the sea-level fall meant thickening-upward and coarsening -upward ones. The differences off this law are discussed.

The large cycles in the schematic sections approximately correspond to *2nd order sea-level fluctuations* (Fig. 2). Agreement is interrupted on some parts of the sections probably because of tectonic movements. For

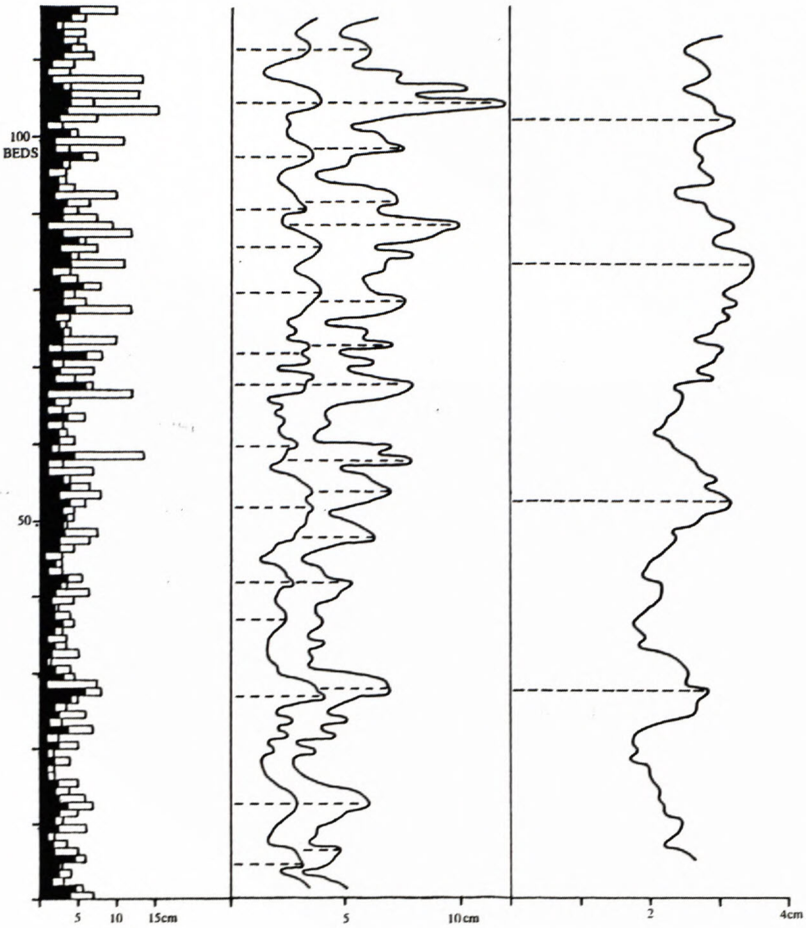

Fig. 5 Upper Beloveža Member of the Bystrica Subunit. On the first column there is rhythmogram with bed thickness of sandstones (black) and mudstones (white). The second column shows the curves of the three point moving average one for sandstones and the other for whole beds. The peaks of cycles are marked with dotted lines. The third column pictures the curve of the nine point moving average from sandstone parts of beds. Similarly dotted lines indicate the peaks of cycles.

instance during the Campanian when sea-level rose the thickness of turbidite beds were approximately uniform. The tectonic control of the sequences was expressive on the border of the Maastrichtian and the Paleocene. At that time there was marked thinning/fining-upward beds while sea-level fell slowly. Probably in the Paleocene (from the uppermost Maastrichtian) subsidence prevailed over sea-level fall, maybe expression of the Laramian tectonic movements (Roth, 1980).

Pyrite, glauconite, phosphorite nodules, authigenic dolomite and organic rich sediment are typical for relative rise of sea-level - transgressive systems of 3rd order sea-level fluctuation (Hoedemaeker & Leereveld, 1996). In some part of the lithostratigraphic section there was found increased amount of *glauconite*, but it is not possible to link his appearance with transgressive sequences of 3rd order sea-level fluctuation. Probably the occurrence of glauconite has connection with 2nd order fluctuation. Glauconite is the most abundant in the Middle Eocene, when sea-level of 2nd order fluctuation fell. In the time probably the shallow sea sediment were eroded and redeposited to deep-sea. The shallow sea sediment with large amount of glauconite were deposited during the rise of 2nd order fluctuation on border of the Paleocene and the Eocene.

The smaller cycles in the lithostratigraphic sections are well correlated with *3rd order sea-level fluctuations* (Fig. 2). Because of insufficient biostratigraphy some parts of the lithostratigraphic sections agree with 3rd order sea-level curve only approximately. Some of the cycles are longer than fluctuations on the curve of 3rd order. Some of the cycles really correspond to two or more 3rd order fluctuations. It is caused by the insufficient preciseness of some parts of the lithostratigraphic sections because of small outcropping.

The large rate of deposition in the Maastrichtian and the Upper Eocene, when the material was derived from south source, probable has not only connection with the fall of sea level (Oszczypko, 1992a) but also has connection with the tectonic movements (uplift) during the Laramian (Maastrichtian) tectonic phase in the area of Klippen belt and the Ilyrian (Upper Eocene) tectonic phase in the inner parts of Magura basin.

The cycles in schematic lithostratigraphic sections confirm the opinion that the large scale cyclicity results from sea level fluctuation (Shanmugam & Moiola, 1988) or variation in tectonic activity in the source area (Klein, 1985).

The cycles in the schematic sections seem to be deposited continuously without respect to high- or low-stand of sea-level. Sequence stratigraphy restricts the timing of deep-water siliciclastic systems to periods of relative low-stand of sea level (Posamentier et al., 1988, Van Wagoner et al., 1988 Vail et al., 1991). Mutti (1992) considers it as a lack of the model.

The parasequences in the Szczawina Member of the Rača Subunit with time span from 75 to 600 thousand years the most probably correspond with *4th order sea-level fluctuations* (Tab. 2). The fluctuations are controlled by climatic changes developed by orbital cycles of eccentricity (Milankovitch cycle). Because of insufficient outcropping and tectonic complications it was not possible to find all the cycles.

Turbidites seem to be not suitable to search the cycles of smaller scales. They are event deposits and not reflect continuous change of sea-level or other conditions. But from results the evident cyclicity at least two scales are visible in thin-bedded turbidites. The turbidites are point records of that time conditions. Similarly the continuous changes of sea-level or climate are searched from point samples from carbonates.

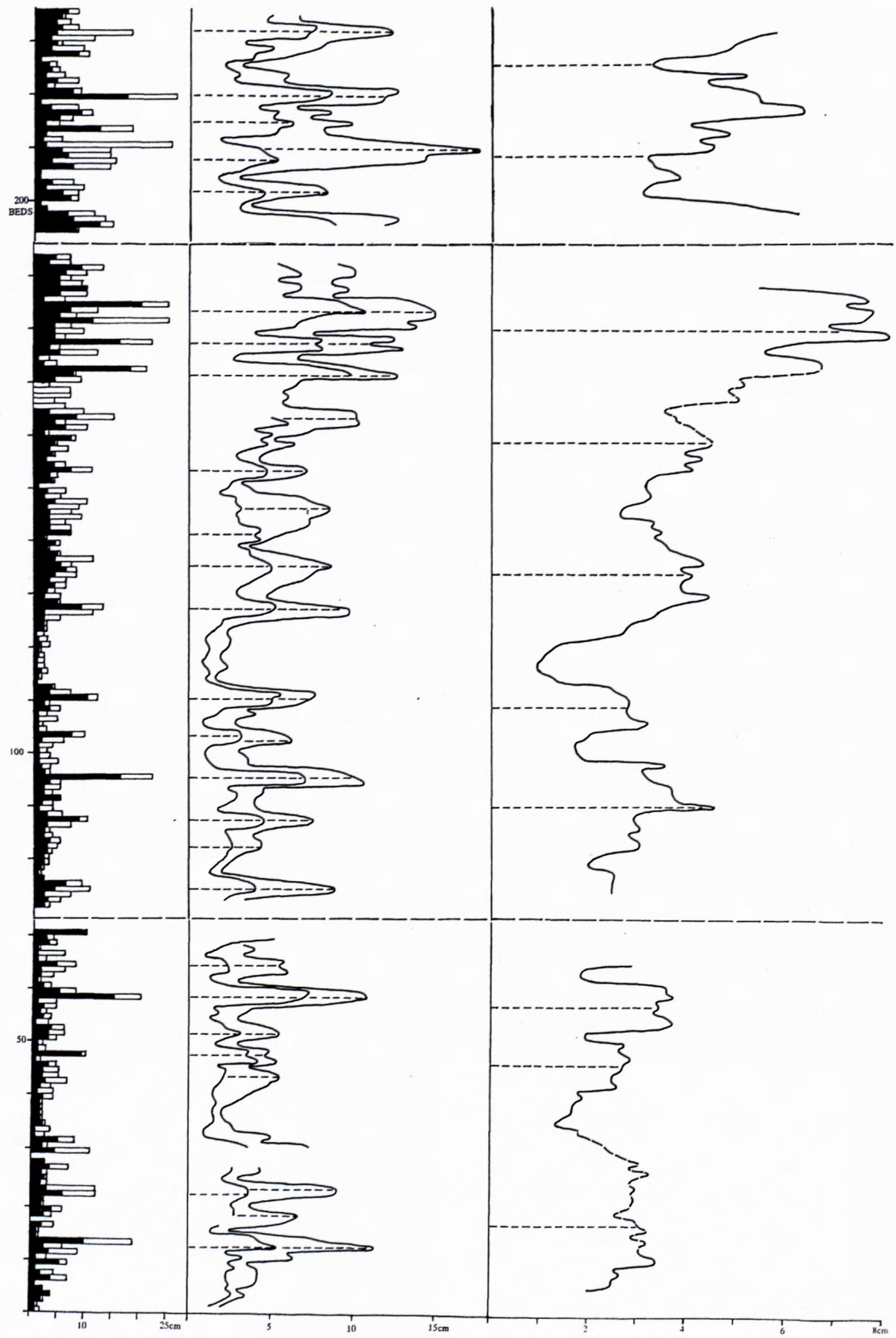

Fig. 6 Boundary of the Labowa Shale and the Hieroglyphic Formation of the Rača Subunit. See explanation on fig. 4.

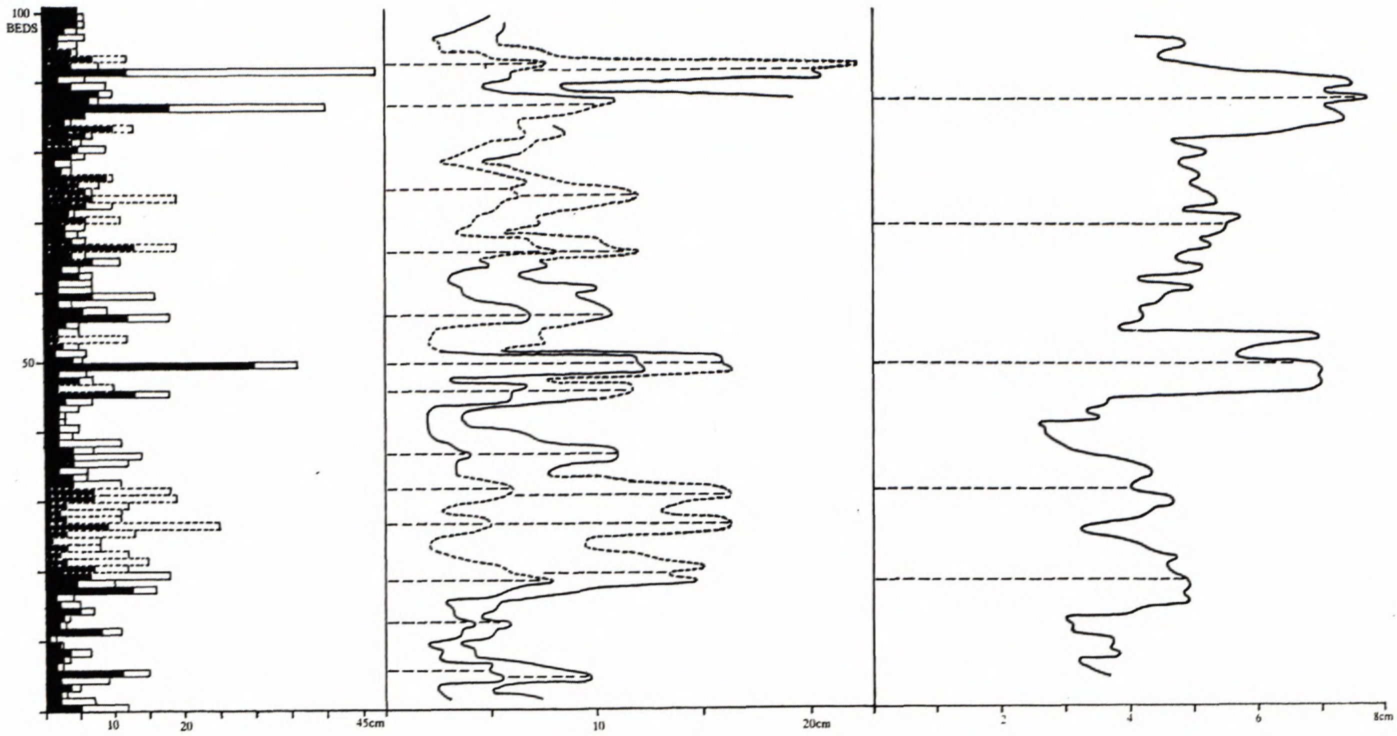

Fig. 7 Hieroglyphic Member of the Rača Subunit. See explanation on fig. 4.

In the outcrops with thin-bedded turbidites there were identified two scale of cycles. The cycles with the approximated duration of 28 to 75 thousand years can be correlated with *5th order sea-level fluctuations* (Tab. 2). They are caused probably by Milankovitch cycles of obliquity.

The more expressive are the cycles with time span 7 to 20 thousand years, which probably correspond with *6th order sea-level fluctuations* (Tab. 2). The origin of them is controlled by Milankovitch cycles of precession.

The inaccuracy between the duration of searched cycles and sea-level fluctuations of 4th, 5th and 6th order is caused the approximate input data for the computing of rate and duration of cycles (Tab. 2). Some of turbidite beds was probably reworked by bottom current to conturites. It could distort the data. Mutti (1992) declares, that the activity of bottom-current in turbidite systems of thrust-fold belts was negligible.

The thin-bedded turbidites are common deposited on the lobe fringe of deep-sea fan. The cycles in them can be also influenced by distributary switching (avulsion) - rearrangement of deposition lobe on deep-sea fan (Shanmugam & Moiola, 1988). Thickness of individual lobe of submarine fan is between 3 and 15 metres. They are composed from medium- to thick-bedded turbidite (Mutti, 1992). After computing the lobes comsist of some tens of beds. It corresponds with 5th and 6th order sea-level fluctuations.

Sun with its cycles plays some role in change of climate. It can be change of sun activity and of orbit around centre of gravity of Sun system (Friedman et al., 1992).

The least *frequency and rate of deposition* (Tab.1) has the Haluszowa Formation (Cebula Member). The frequency of it belongs to low one. The rest tested formations and members have medium frequency of deposition (Einsele, 1992) and have the frequency falling under the interval 1 to 10 thousand years for lower fan and basin plain (Einsele, 1997). The highest rate of deposition was computed at the thick-bedded Kýčera and the Szczawina Members. By the rate of deposition the Haluszowa, the Veselé and the Labowa Shale Formations belongs to continental rise or slope and other tested lithostratigraphic units to deep-sea fan (Einsele, 1992).

Because of simplification there was not taken into account change of frequency in terms of one lithostratigraphic unit. Therefore the obtain results are average values. The frequency of turbidite events depend on the rate of deposition in their source area. Frequent earthquakes, volcanic eruptions or rapid uplift in the source area may shorten time between redepositional event (Klein, 1985). Small and medium-size mountainous rivers of tectonically active setting play a fundamental role in triggering submarine gravity flows and therefore in turbidite sedimentation. (Mutti, 1996). The question of frequency of turbidite events are still open.

Tab. 2 Comparison of Milankovitch cycles with the cycles in the studied area

Order of sea-level fluctuation	causes of fluctuations - Milankovitch cycles and their periodicity (thousand years)	duration of parasequences (thousand years)	lithostratigraphic units	thickness and number of beds in one cycle	approximate duration of cycles (thousand years)
4th	eccentricity 100 & 413	80 - 500	Szczawina Mb. (Rača Subunit)	30 - 180 m (25 - 150 beds)	75 - 600
5th	obliquity 41	30 - 80	Upper Beloveža Mb. Hieroglyphic Mb. Labowa Shale Fm. - Hieroglyphic Mb.	19 - 30 beds 13 - 20 beds 11 - 30 beds	29 - 45 29 - 44 28 - 75
6th	precession 19 & 23	10 - 30	Upper Beloveža Mb. Hieroglyphic Mb. Labowa Shale Fm. - Hieroglyphic Mb.	5 - 8 (15) beds 4 - 9 beds 4 - 8 beds	7 - 12 (22) 9 - 20 10 - 20

Conclusion

The cycles of bed thickness and grain size of five orders were identified in the turbidites of the Flysch belt of the Upper Cretaceous to the Upper Eocene age.

The larger and smaller cycles in the schematic lithostratigraphic sections of the Rača and the Bystrica Subunits were well correlated with 2nd and 3rd order sea-level fluctuations. The duration of larger cycles is 13 and 20 and smaller ones 3 to 7 million years. Some parts of the sections were bad comparable because of influence of tectonic movements. Marked disagree with 2nd order fluctuations is probably caused by the Laramian tectonic movements on the border of the Maastrichtian and the Paleocene. Probably in the Paleocene (from the uppermost Maastrichtian) subsidence prevailed over sea-level fall. Very rapid deposition during the Maastrichtian (Szczawina Member - 35 cm per thousand years) and the Upper Eocene (Kýčera Member - 38 cm per thousand years) has probably connection with tectonic uplift of south source area during the Laramian (Maastrichtian) and the Ilyrian (Upper Eocene) phase.

Large amount of glauconite in the Middle Eocene is probably linked with redeposition of glauconite rich sediments deposited during rise of sea-level of the 2nd order on the border of the Paleocene and the Eocene.

The parasequences in the Szczawina Member with time span from 75 to 600 thousand years the most probably correspond with 4th order sea-level fluctuations.

In the outcrops with thin-bedded turbidites there were identified two scale of cycles. The cycles with approximated duration of 28 to 75 thousand years can be correlated with 5th order sea-level fluctuations. The more expressive are the cycles with time span 7 to 20 thousand years, which probably correspond with 6th order sea-level fluctuations. The origin of 4th to 6th sea-level fluctuations is linked with Milankovitch cycle of eccentricity, obliquity and precession.

The less probably explanations for the cycles in thin-bedded turbidites are rearrangement of deposition lobes on deep-sea fan (distributary switching) or some sunny cycles.

From approximate data of the thickness, the duration and average bed thickness of some lithostratigraphic units the frequency and rate of deposition were computed. By the frequency and the rate the deposition during the Campanian (Haluszowa Formation), partly the Veselé and the Labowa Shale Formations has not character of sedimentation on deep-sea fan but on deep-sea slope. Other lithostratigraphic units was probably created on lower part of deep-sea fan or on basin plain.

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