GEOLOGICA CARPATHICA, 46, 3, BRATISLAVA, JUNE 1995
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LITHOLOGICAL AND BIOLOGICAL INDICATORS OF ORBITAL CHANGES IN TITHONIAN AND LOWER CRETACEOUS SEQUENCES, WESTERN CARPATHIANS, SLOVAKIA

IUGS UNESCO
PROJECT 362

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(Manuscript received December 12, 1993; accepted in revised form September 22, 1994)

Abstract: Rhythms in the Upper Jurassic-Lower Cretaceous carbonate sequences expressed by lithological-, micropaleontological data in several Central Carpathian sections were interpreted as a record of orbitally induced climate fluctuations. The rhythmic changes of the bed thickness are associated with regular fluctuations in abundance of microplankton content. These lithological rhythms can be correlated with the excentricity Milankovich cycles (periodicities of 120 and 480 Ka); the calcareous microplankton assemblages alternate with radiolarian associations in successive rhythms of 200 -300 Ka. The first (late Valanginian) episode of Early Cretaceous greenhouse conditions is recorded by a low frequence fluctuations of $\delta^{13}C$ values in the Western Carpathian sections.

Key words: Western Carpathians, Late Jurassic-Early Cretaceous, geochemistry, stable isotopes, sedimentary rhythms, carbonate lithology, microplankton abundance.

Introduction

This paper documents the relationships between the structural-, lithological-, biological- and chemical record of rhytmically repeating changes in Upper Jurassic and Lower Cretaceous carbonate sequences of the Western Carpathian sections.

Our interpretation is based on lithological- and microbiostratigraphical analyses of several dozens of Western Carpathian (as well as Pannonian- and Eastern Alpine-) sections, that have been studied in the past few years (Michalík et al. 1990a-c, 1992; Reháková & Michalík 1992, 1993b, 1994; Vašíček et al. 1994; Haas et al. 1994). Most sections have been sampled for paleobiogeographical purposes only. Only two of them (Rochovica and Strážovce sections) were sampled in more detail, partially also for geochemical study. Because of different sampling, the results of the present study are not uniform. Characterization and better interpretation of the different scale cyclicities as well as the documentation of the relationships between sedimentation and plankton evolution in the Western Carpathians with oceanographic changes in the whole Mediterranean Tethys is the matter for ongoing and future work.

General setting

During Mesozoic, Western Carpathian sequences developed in two separate areas close to the northern shore of the Tethys. The Outer Carpathians constituted a rifted margin of the north European shelf, SE of the Bohemian Massif; the Central Carpathians were part of the Alpine-Carpathian microcontinent, separated from Europe by the Pennine Rift Basin (Fig. 1).

Upper Jurassic to Lower Cretaceous sequences of the Western Carpathians are mostly represented by pelagic limestones. Two main groups of Upper Jurassic lithofacies characterize this area (Figs. 2, 3). The Ammonitico Rosso represents a well oxigenated environment with slow sedimentation, with local subsolution and submarine erosion; it was deposited on elevated zones. The depressions are characterized by marly limestones and marlstones, resulting from sedimentation in a reducing environment. Inserts of a calciturbiditic character are present only locally. Increased production of biogenic carbonate at the beginning of the Early Cretaceous resulted in sedimentation of pelagic limestones similar to the "Biancone" and "Majolica" facies. The Lower Cretaceous sequence contains admixture of clayey material and calciturbidite layers.

Lithological indicators

Methods

Most characters were derived from the sedimentological field study. At a later stage, this study was supplemented by laboratory analyses of microfacies and microbiostratigraphically calibrated by the use of both thin- and polished sections. The thicknesses of layers defined by bedding planes (usually with marly laminae), were measured in continuous sections and the values were plotted on a linear graph (Figs. 4, 5).

Sedimentation rates (Tab. 1) were estimated according to the geochronological scale of Cowie & Basett (1989). The thickness of the original sedimentary record was corrected by its latter reduction and related to biostratigraphically dated inter-

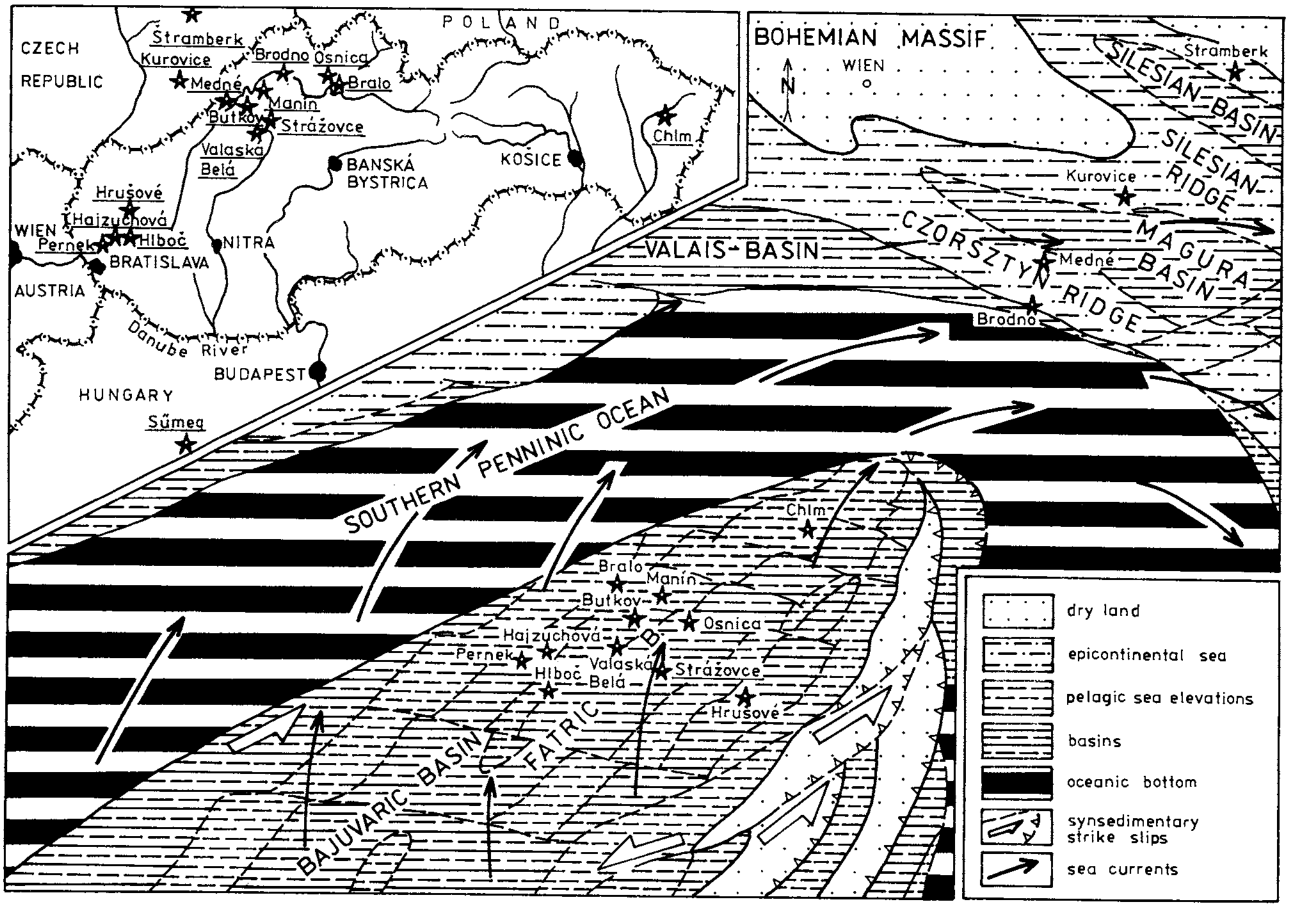

Fig. 1. Location of the 14 studied sections in the Lower Cretaceous sequence of the Western Carpathians.

vals. The compaction of carbonate rocks was related to clayey admixture. This effect was the most expressive in the Jasenina Formation. The lost of volume of primary sediment (including diagenetic effect as compaction, diagenetic recrystallisation, subsolution, stylolitisation etc.) was estimated to be as much as 70 % according to deformation of fossil remnants.

Nodular Ammonitico Rosso limestones (Czorsztyn Limestone Formation) were also considerably affected by post- sedimentary reduction: 40 % lost of the volume was estimated. Clayey content hampered diagenetic recrystallization of limestone. In accordance, the effect of diagenesis on the preservation of microorganism tests was different. Reháková & Michalík (1993) stated an important role of early diagenesis in the preservation of calpionellid (mainly *Chitinoidella*) tests. This is why the limestone nodules in the Czorsztyn Limestone contain well preserved calpionellids. On the other hand, the internodular "matrix" contains less abundant, poorly preserved tests dispersed in debris of echinoderms.

More uniform environments of Lower Cretaceous formations resulted in similarities in their lithology. The lost of volume of both the Pieniny- and Osnica Formations was estimated as 30 %. Therefore, the differencies in preservation of microfauna resulted as an effect of late- and post diagenetic changes in both formations, caused by their different tectonic and thermal history: while the Pieniny Formation (in the Pieniny Klippen Belt) was affected mostly by lateral shear movements only, the Osnica Formation as part of the Križna Nappe sequence suffered by intensive thrust tectonics forming Paleoalpine Central Carpathian nappe structure.

Lithology and sedimentology

In the Pieniny Klippen Belt of the Outer Carpathians [in the previous articles on the Brodno- (Michalík et al. 1990a) and Rochovica (Vašíček et al. 1992) sections: Fig. 2], the Ammonitico Rosso facies is represented by the Czorsztyn Formation. Depending on the palaeobathymetry, it is possible to distinguish two main facies (in accordance with Aubouin 1964): the "Rosso Ammonitico Calcaire" (RAC) was deposited on the elevations, whereas the slopes were covered by the "Rosso Ammonitico Marneaux" (RAM).

The RAC is represented by pink, pinkish-grey, red, brownish-red to yellowish nodular limestones with a variable quantity of ferruginous-calcareous cement, containing lumachelles of ammonites, aptychi, abundant belemnites, rhyncholites, nucleatid- or pygopid brachiopods and fish teeth. It was deposited on elevations, at depths from several tens to several hundreds of metres. Local intercalations and/or transitions to a facies of crinoidal and shelly limestones indicate proximity to shallower zones, characterised by a biofacies of crinoidal meadows (Gluchowski 1987). The bedding planes of the Czorsztyn Limestone are uneven, nodular, and the upper surfaces of beds are often marked by subsolution, which also affects the fossil remains. Inter-bed laminae of red marl are very thin, often not continuous or miss-

Table 1: Overview of the thicknesses and sedimentation rates for beds in the Brodno, Rochovica and Strážovce sections. The measured thicknesses of individual beds were correlated with the diagenetic compaction rate in particular lithologies.

	Time scale in Ma		Calpionellid zones	BRODNO & ROCHOVICA SECTIONS				STRÁŽOVCE SECTION			
				thickness (orig. t.) in m	number of beds	duration one bed in Ka	total sed. rate (mm/Ka)	thickness (orig. t.) in m	number of beds	duration one bed in Ka	total sed. rate (mm/Ka)
BERRIASIAN		2.50	Calpionellites								
		0.60	Lorenziella hungarica								
		1.30	oblonga								
			Calpionellopsis	8.79	28	91	4.83	5.17	19	134	2.84
	7	1.25	simplex	(12.31)				(7.24)			
			Calpionella	7.59	12	221	4.01	19.04	20	132.5	10.06
		2.65	elliptica	(10.63)				(26.65)			
		0.60	Remaniella	0.55	5	120	1.28	5.46	6	100	12.74
			Calpionella	0.96					6.43		
		1.20	alpina	(1.34)	6	200	1.12	(9)	9	133	7.5
TITHONIAN		0.75	remanei								
			Crassicollaria	0.31	2	750	0.31	14.38	25	60	16.3
		0.75	intermedia	(0.47)				(24.45)			
		0.3	Praetintinnopsella	0.16	1	300	0.8				
		0.2	boneti					1.65	2	350	4
	4		Chitinoidella	0.19	1	400	0.725	(2.8)			
		0.2	dobeni	(0.29)							
		0.6	Carpistom. tithonica								
				1.24				7.65			
		0.5	Carpistom. borzai	(1.86)	4	450	1.03	(12.85)	11	164	7.14
		0.7	Parastom. malmica								

ing. Periods of deposition of calcareous ooze evidently alternated with long breaks in deposition of sediment, lithification and submarine corrosion (Jenkyns 1974; Wieczorek 1983; Borza & Michalík 1987).

The RAM facies of the Czorsztyn Limestone is represented by violet-red, more rarely grey, greenish grey to dark grey nodular limestones. The nodules are often marked by redeposition, which is sometimes evidenced by breakage, and in places the rocks acquire the character of slump-breccia. The proportion of marly interbeds versus limestones is usually high, while signs of subsolution are rarer. In comparison with the previous facies, microorganisms are rarer, but the limestones are rich in macrofossils. This facies sedimented on slopes, possibly as deep as thousand meters (Wieczorek 1983).

In the area of the Central Western Carpathians and in the Austroalpine sector of the Eastern Alps, the "elevation" facies is represented by the Tegernsee Formation. Its characteristics are similar to those of the Czorsztyn Formation.

Upper Jurassic basinal facies are represented by Tithonian/Lower Berriasian Lower Těšín Formation in the area of the Outer Carpathians, but by the Jasenina Formation (Vašíček et al. 1983; Michalík et al. 1990b) in the Central Western Carpathians (represented by the Strážovce section, Fig. 3). Both units are composed of marlstones with a rhythmically varying proportion of the calcareous component (up to marly limestone), fine siliceous silt and bituminous admixture. Occasional sorting of juvenile aptychi into thin shell layers, especially in the lower part of the Jasenina Formation, indicates an indistinct gradation, evidently of turbidic origin.

The onset of the pelagic limestones of the "Majolica" facies was diachronous in different units (Boorová et al. 1993). While poorly aerated basinal facies (Jasenina Formation) were replaced by pelagic calpionellid limestone sedimentation (Osnica Formation) during the *Calpionella alpina* Subzone, the oxidic facies of the Czorsztyn Formation in the Brodno section ends with the calpionellid *Praetintinnopsella* Zone. The sediments of the calpionellid *Crassicollaria* Zone resemble the Pieniny Formation. On the other hand, the sedimentation of the Czorsztyn Formation continued until the Valanginian (locally until the Hauterivian) on the proper Czorsztyn Ridge, and in the Tegernsee Formation of the Alpine Bajuvaric.

According to Wieczorek (1988) the mass distribution of the "Majolica" facies may be connected with special conditions in the western part of Tethys (and Pacific, as well), with the creation of an anti-estuarine system of currents, with the development of calcareous micro- and nannoplankton, and with the decrease of CCD level at the beginning of the Cretaceous. The Lower Cretaceous basinal sedimentation at the Outer Carpathian margin is typically represented by white-grey or grey, radiolarian-calpionellid and radiolarian-nannoconid micritic wackestones with dark cherts, concentrated into nodules to stratiform layers. Both the marly admixture an bioturbation in this complex named as the Pieniny Formation (Fig. 2) increase upwards. Macrofauna is represented by occasional rostra of

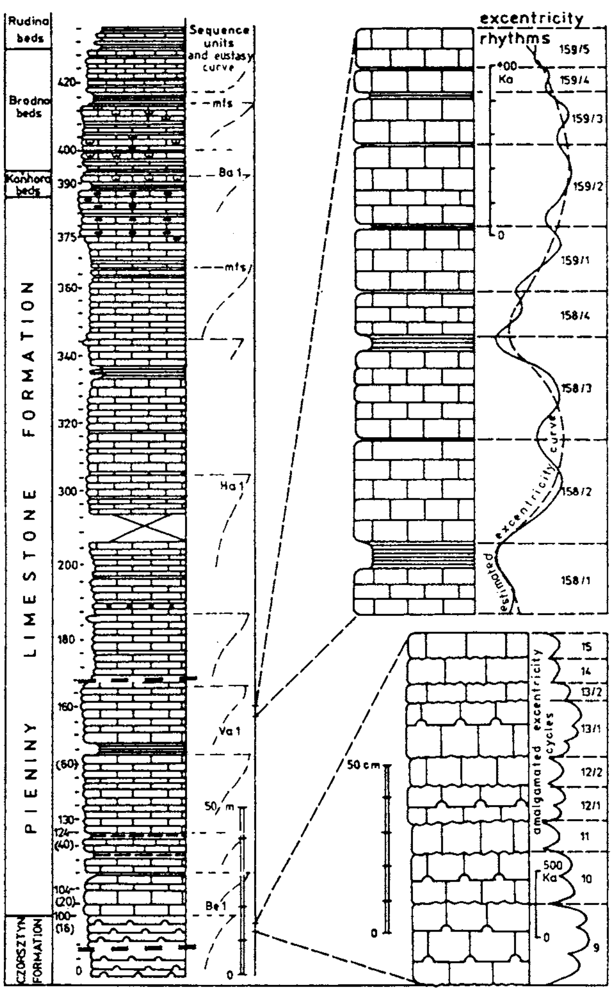

Fig. 2. Lithostratigraphy of the Rochovica section (lower part correlated with the numbered Brodno section: numbers in brackets). The numbers denote the samples for lithological, biostratigraphic and isotopic study. The types of sedimentary rhythms are shown in the right part of figure.

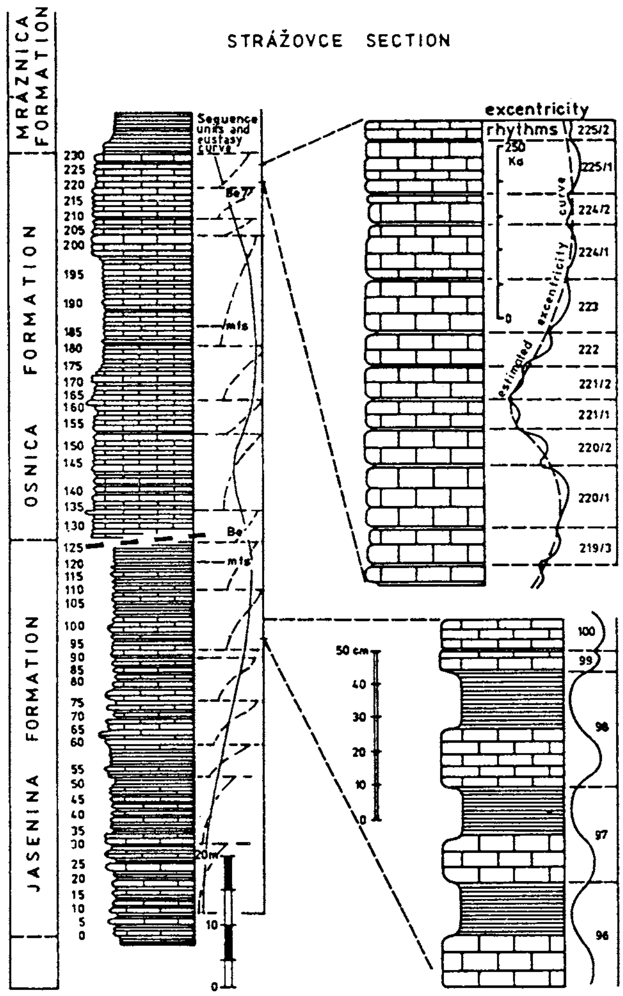

Fig. 3. Lithostratigraphic divisions of the Strážovce section, collection of samples for lithological, biostratigraphic and isotopic study, and types of sedimentary rhythms (see Fig. 2).

belemnites, irregular sea urchins, aptychi, more rarely by ammonites.

Berriasian-Valanginian sedimentation in the basin areas of the Central Western Carpathians is characterised by hemipelagic limestones of the "Biancone" type (Osnica Formation) (Fig. 3) consisting of light grey micritic mudstones to biopelmicrites. Diagenetic recrystallisation of the rocks is higher than in the Pieniny Formation; macrofauna is scarce and includes poorly preserved aptychi, ammonites and belemnites.

Distinct bedding is a common feature of the studied formations. Average time interval of the origin of the beds in the sequences of the described lithostratigraphic units corresponds to a sedimentary rhythm lasting about 120 Ka. Only the rhythms of the Czorsztyn Formation are not so clearly differentiated (clearly partly amalgamated by subsolution, and they correspond to periods lasting about 500 Ka (Figs. 2-6).

The sedimentation rate of of the Ammonitico Rosso limestones (Fig. 6) rarely reached 2 mm/Ka (Czorsztyn Formation on average 0.33-5.7 mm/Ka, Tegernsee Formation 0.23-1.56 mm/Ka). The highest part of the Czorsztyn Formation sedimented slower than 1.5 mm/Ka. At first, the overlying Pieniny limestone sedimented equally slowly, but later, in the *Calpionella elliptica* Subzone, the sedimentary regime was influenced by distal calciturbidites, and the sedimentation rate increased up to 28.6 mm/Ka. The Jasenina Formation sedimented at a rate of 5-10 mm/Ka, in contrast to 33-45 mm/Ka in the coeval Lower Těšín Formation in the Outer Carpathians. After the beginning of sedimentation of the Osnica Limestone, the rate of deposition increased to 15.2 mm/Ka, but later it fell again to average values of 4.5-9 mm/Ka. Only the sedimentation of the Nozdrovica Breccia from synsedimentary eroded fault escarpments represents a short-term acceleration of deposition.

Discussion

The origin of rhythmic sequences could have been connected with global factors, such as changes in the tilt of the Earth's axis, precession and changes in the excentricity of the Earth's orbit around the Sun (Milankovitch 1941; Schwarzacher & Fischer 1982; Fischer et al. 1990). Such changes cause variations in the insolation of the Earth's surface in different geographical areas, and lead to periodic changes of climate (Mangin 1974). It is not easy to separate the sea-level changes caused by endogene factors from those evoked by extra-terrestrial phenomena. Both kinds of influences resulted in complex interplay of factors, which controlled pulsating global oceanographic regime.

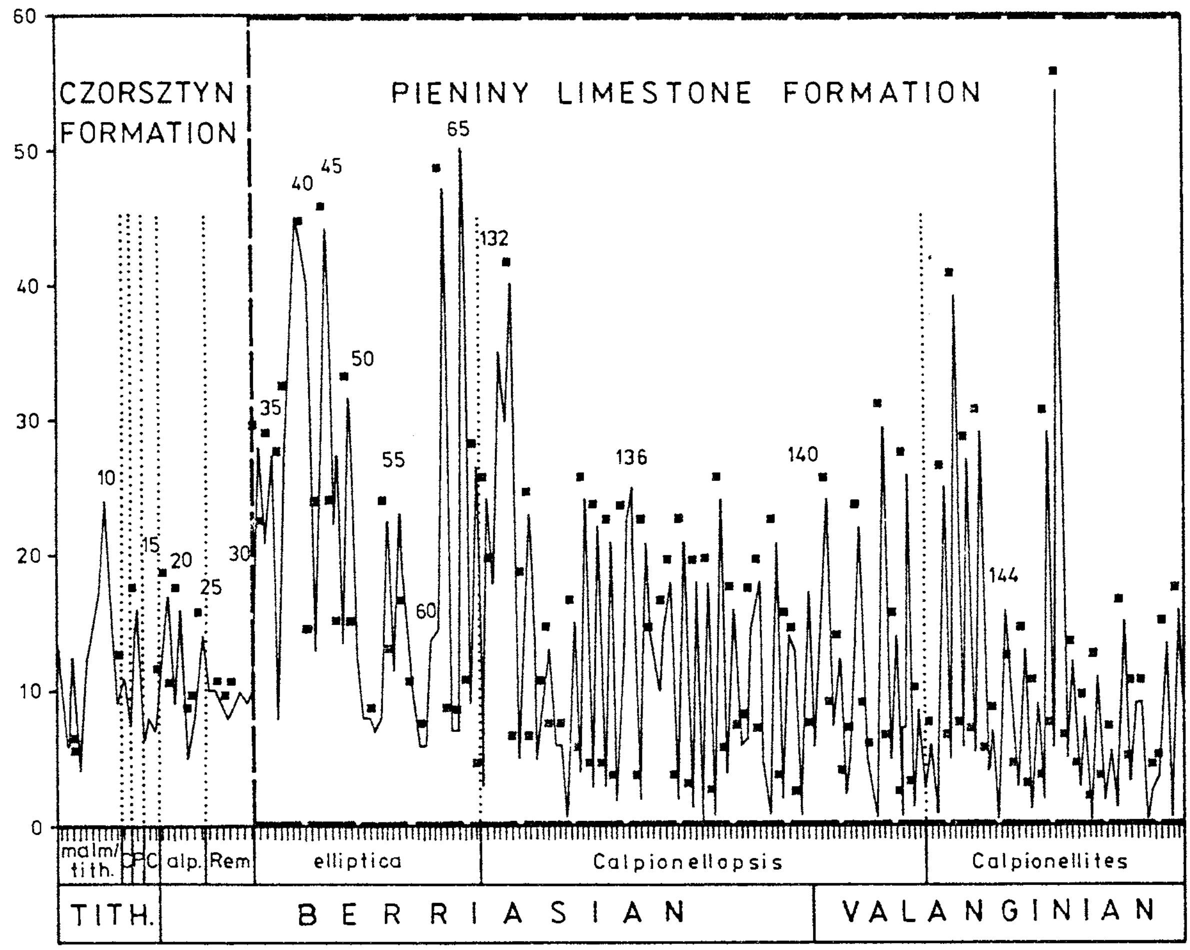

Fig. 4. Fluctuations of bed thickness in the Lower Tithonian-Lower Valanginian part of the Rochovica section.

In the geological record (Beaudoin et al. 1974; Tisljar & Füchtbauer 1975; Einsele 1982; Garcia et al. 1987; Bersezio 1993; Reháková & Michalík 1994), three hierarchical systems of cycles from 20 Ka to 2 million years are most clearly preserved (Hilgen 1991).

Analysis of periodic changes in Cretaceous pelagic sequences shows a geological record of Milankovitch cycles. A model simulation (Barron et al. 1989) of the northern part of the Cretaceous Tethys Ocean, especially sensitive to orbital changes, indicates periods of intensive precipitation on the boundary between the subtropical Tethys and the cooler Laurasia. The best examples of Milankovitch cycles were documented from southern France and northern Italy (Erba, pers. comm.).

Although the sedimentary basins of the Western Carpathians still lay in the Tethys area, the proximity to the northern region manifested itself in increased sensitivity to orbitally directed climatic changes. The most significant record of these changes is given by the Valanginian and Hauterivian sequences, especially from the area of the Outer Carpathians.

Biological indicators

Methods

The abundance of microplankton was calculated from thin sections of fourteen Upper Jurassic-Lower Cretaceous sections in the Central Western Carpathians (Fig. 1), mostly sampled at metre intervals. The Strážovce and Brodno/Rochovica sections were sampled in more detail (the Osnica Formation of the Strážovce section according to the bed-by-bed method). The quantitative percentage representation of microplankton in the thin sections was determined with an optical microscope, using the tables of Schäfer (1969) and Soudant (1972). We divided the association of microplankton into three groups: (a) *Saccocoma*, calcareous dinoflagellates and calpionellids; (b) Radiolarians and (c) *Globochaete alpina* Lombard zoospores. The proportion of nannoplankton, including nannoconids, which formed an important, sometimes even dominant component of the Lower Cretaceous plankton, can be only seldomly quantified with the help of an optical microscope (cf. Erba 1994). However it appears (Reháková & Michalík 1994), that the regions with greatest abundance of nannoconids during the upper Valanginian and Hauterivian coincided with the areas of the greatest abundance of Berriasian and Valanginian calpionellids.

Results

In the Brodno/Rochovica sections, the Kimmeridgian and early Tithonian maximum of calcareous microplankton is dominated by microcrinoids (*Saccocoma* Agassiz) along with algal zoospores (*Globochaete alpina* Lomb.). Here, as well as in other West-Carpathian sections, the changes in the Kimmeridgian and Tithonian globochaetes abundance were generally synchronous with the changes in composition of calcareous microplankton. Calpionel-

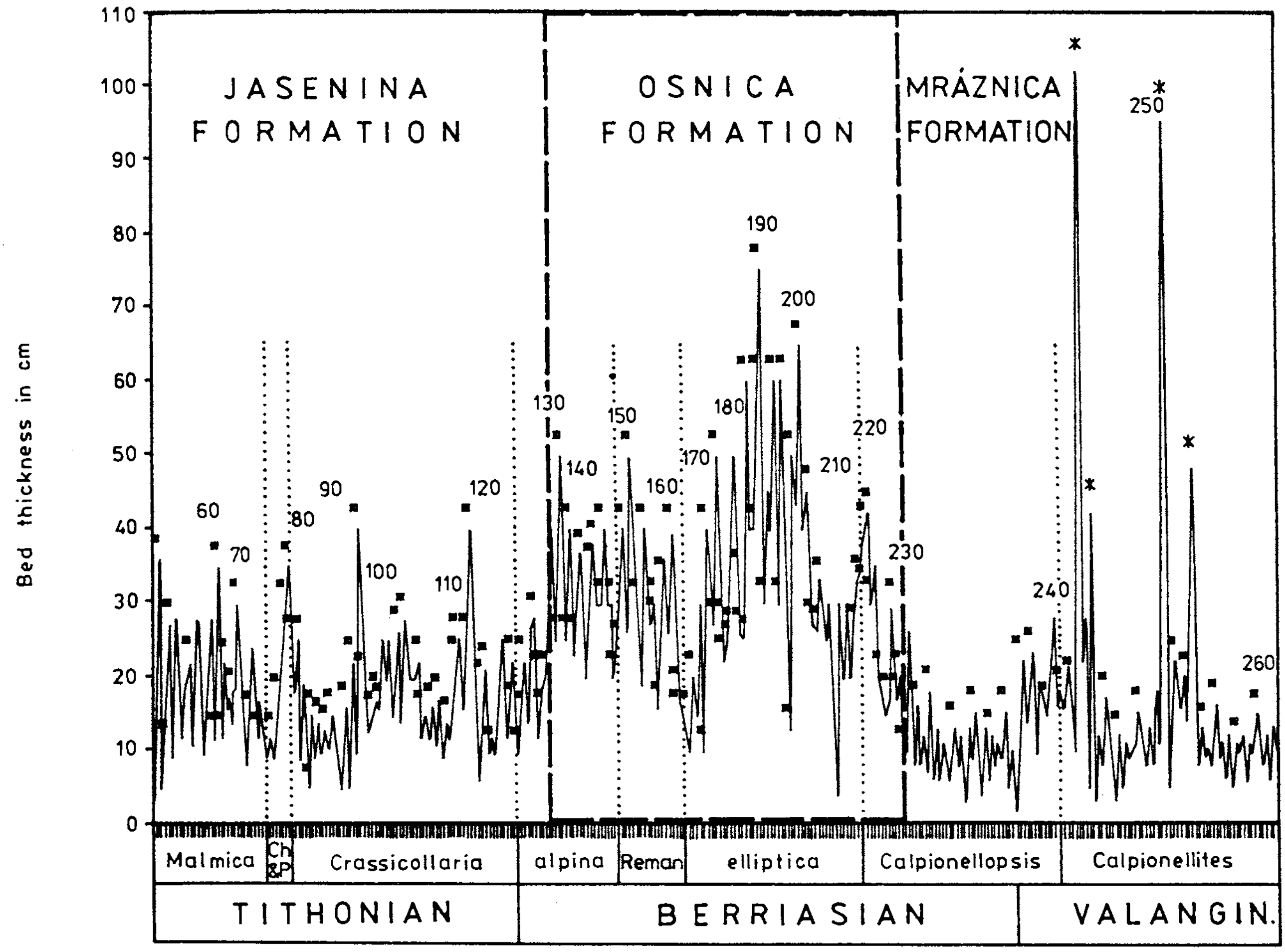

Fig. 5. Fluctuations of bed thickness in the Strážovce section. Layers of Nozdrovica Breccia indicated by asterisks.

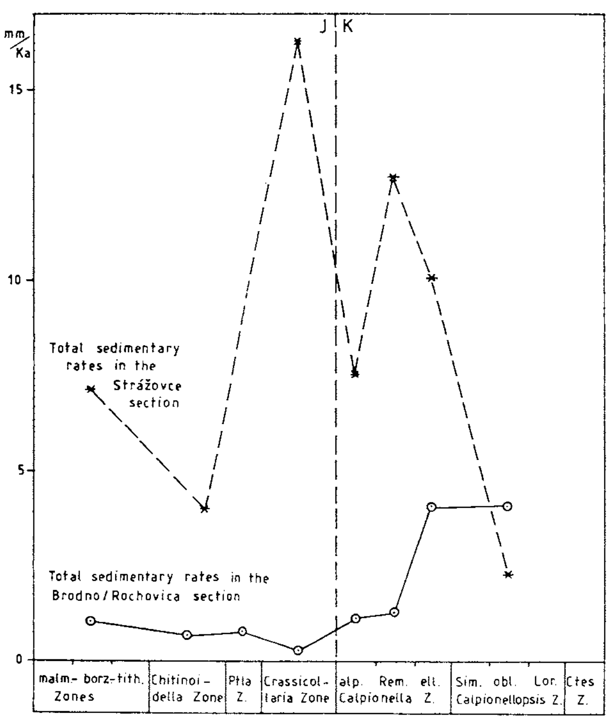

Fig. 6. Sedimentation rates calculated according to measured parameters.

lid development started during the middle Tithonian, accelerated in the upper part of the *Crassicollaria* Zone and culminated at the base of the *Calpionella* Zone (Alpina Subzone). The crisis of calpionellid abundance occurred during the top of the *Elliptica* Subzone. The abundance of siliceous microplankton fluctuated from the *Chitinoidella*- to *Calpionella* Zones. Its rapid development started in the *Calpionellopsis* Zone and culminated during the *Calpionellites* Zone. Abundance of globochaetes rapidly decreased since the beginning of the *Calpionellopsis* Zone. Since the Late Tithonian, especially during the *Calpionellites*- and *Tintinnopsella* Zones, the calpionellid abundance alternated with the abundance maxima of radiolarians in cycles of 0.2-0.3 Ma (Fig. 7).

The abundance of the Kimmeridgian-Tithonian calcareous microplankton in the Strážovce section declined at the base of the *Praetintinnopsella* Zone. A new phase started at the end of the *Crassicollaria* Zone and continued until the start of the *Calpionellopsis* Zone. A crisis, corresponding to a major decrease in abundance of the calpionellid microplankton, occurred during the upper *Calpionellopsis* Zone. In the *Calpionellites* Zone, this decrease was locally compensated by an increase of cadosinids. The *Tintinnopsella* Zone was represented by general decrease in the calcareous microplankton abundance. The maxima of more- or less regular cycles (0.2-0.3 millions of years) in the abundance of Early Cretaceous radiolarians were isochronous with the abundance minima of microplankton and globochaetes. The radiolarians occurred

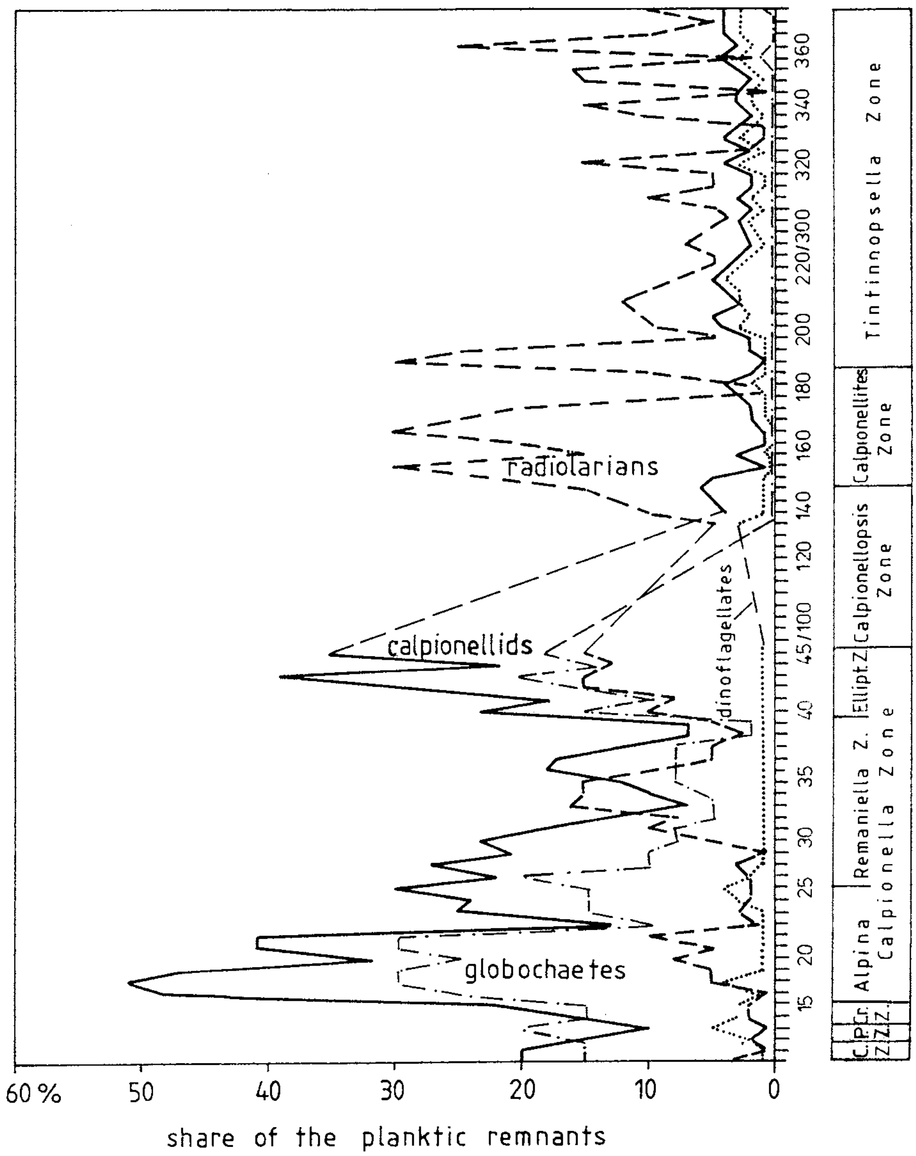

Fig. 7. Rhythmic changes in abundance of micro-plankton in the Rochovica section. The dotted line indicates the abundance of calcareous dinoflagellates (cadosinids etc.). The line and dot line shows the abundance of globochaetes. The solid line indicates the abundance of other calcareous plankton (calpionellids, saccocomas, ostracods etc.). The broken line shows the abundance of siliceous microplankton (radiolarians).

currently until the *Calpionellopsis* Zone. The globochaetes abundance maxima were more-or-less synchronneous with the calcareous microplankton. Their frequence pulsated until the *Tintinnopsella* Zone (Fig. 8).

Discussion

Quantitative analysis of microplankton is a useful tool for tracing paleo-biogeographic divisions, relationships between planktonic organisms, and changes induced by the environment. Erba et al. (1992) and Hubberten et al. (1993) correlated the rhythmic fluctuations in abundance of nannoplankton with the Milankovitch orbital cycles. Reháková & Michalík (1993b) considered the relationships between the size of calpionellid loricas and changes in water temperature. Erbacher & Thurrow (1993) interpreted the mass occurrence and changes in radiolarians during the middle Cretaceous as the results of orbitally induced transgressions, accompanied by climate changes. Reháková & Michalík (1994) related rhythmic changes in the abundance of Tithonian to Hauterivian microplankton in the Western Carpathians with intensive upwelling, influenced by global climatic factors. Similarly, cyclical changes in the quantity of calcareous and siliceous microfossils in an Upper Jurassic/Lower Cretaceous pelagic basin succession from Hungarian Bakony Mts. have been recently (Haas et al. 1994) considered as orbitally forced phenomena.

An interpretation of the areal distribution of individual groups of microplankton flows from tracing their mutual relations. It appears that calcareous dinoflagellates were most abundant in continental shelf environments, globochaetes close to open sea thresholds, while calpionellids represented the typical plankton of the open sea. On the other hand, radiolarians, which have similar bathymetric demands on the extent of diurnal migration as calpionellids, also required more nutrients. Therefore, the maximum development of globochaetes and calpionellids may represent a warm period, while a maximum of development of

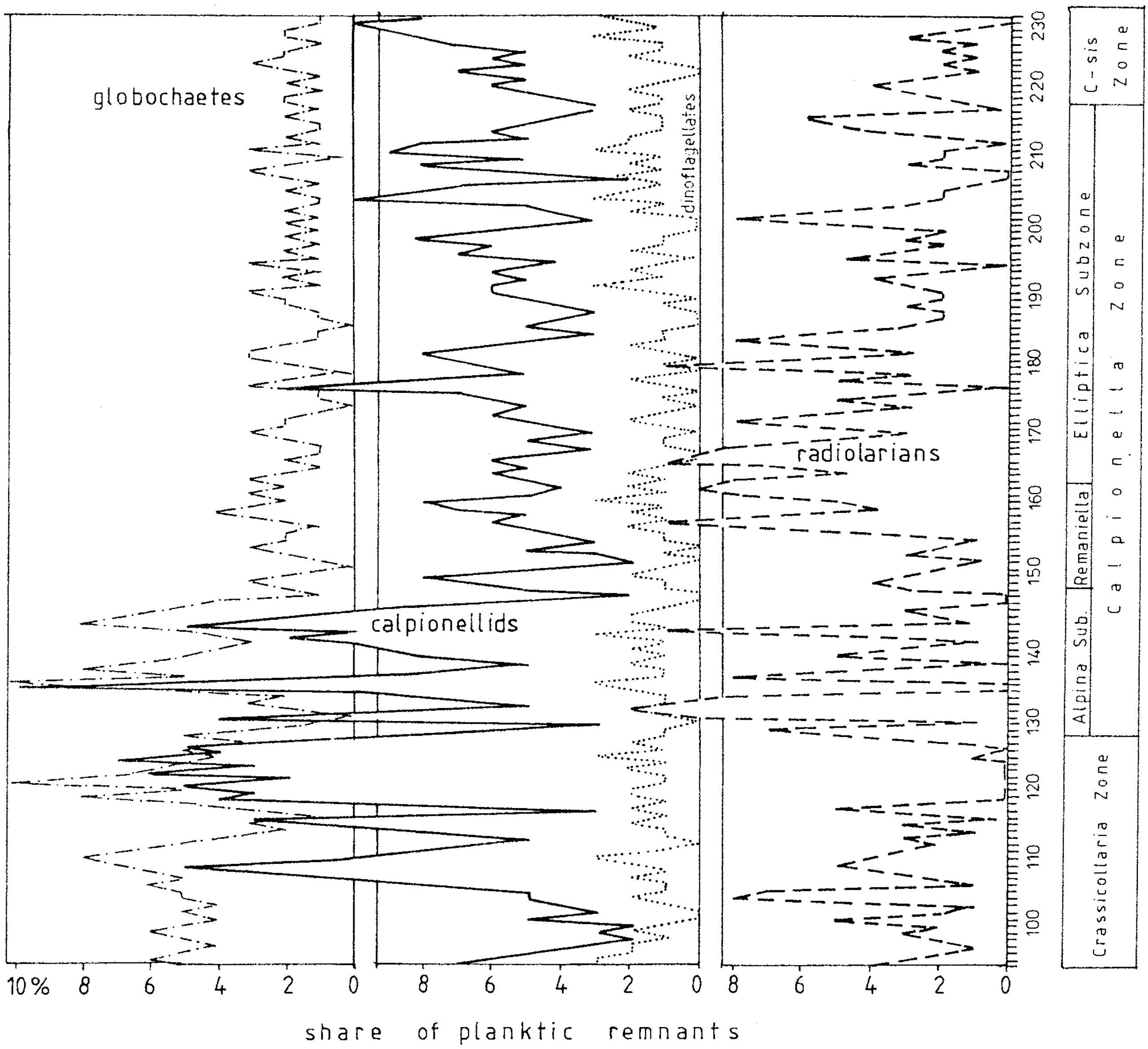

Fig. 8. Rhythmic changes in microplankton abundance in the Strážovce section. Explanations as for Fig.7.

radiolarians and dinoflagellates may mean a period with an increased intensity of upwelling. However, it will be necessary to confirm such conclusions, and perform more detailed studies of the distribution and mutual relations of individual components of the Jurassic-Cretaceous microplankton.

Chemical composition and isotope study

Methods

The chemical composition of pelagic limestone samples from the Osnica, Strážovce, Rochovica and Brodno sections (partly published in Lintnerová & Peterčáková 1994) was analysed by X-ray fluorescence method. The mineral composition of the limestones by X-ray diffraction analysis and scanning electron microscope (SEM) was also investigated. The concentration of elements - Mg, Fe, Mn, Sr, Na, K, Zn, was analyzed in the carbonate part of the rocks by the standard AAS method. The content of CaO in the samples was determined by complexometric analysis, insoluble residuum (IR) gravimetrically.

Stable isotopes were analysed after disolving the micro-samples of the micritic limestone matrix (taken from rock plates) in 100 % H_3PO_4 (McCrea 1950). A Finigan MAT 2 mass-spectrometer was used to measure the isotopic ratios of O and C from evolved CO_2. The analyses were done at the Czech Geological Institute in Prague. The isotopic ratio results are reported in usual ‰ notation relative to the international isotopic standard PDB. The accuracy of the analyses is better than 0.1 ‰. The isotopic temperatures were calculated according to Craig's paleotemperature equation for calcite (Dickson & Coleman 1980) $T = 16.9 - 4.21\ (\delta_c - \delta_w) + 0.14\ (\delta_c - \delta_w)^2$, where δ_c is $\delta^{18}O$ CO_2 evolved from calcite and δ_w is $\delta^{18}O$ CO_2 in balance with sea water at 25 °C, both in PDB. For δ_w we used the value -1.0 ‰ (PDB) given for Mesozoic sea water.

Results of the isotope study

The O and C isotopes ratios were tested in connection with lithology, facies and microplankton abundance (Figs. 10, 11, 12; Tab. 2). The isotopic values (Fig. 12) differs mainly in the

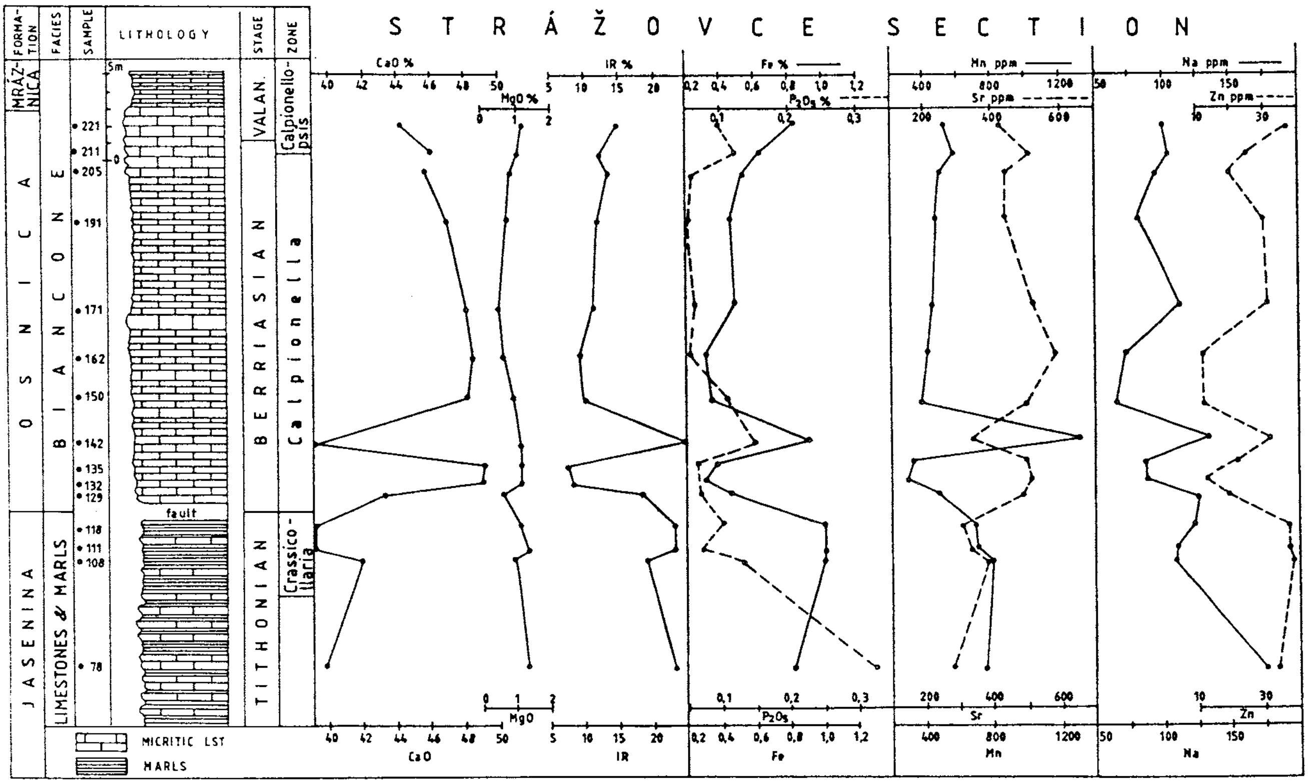

Fig. 9. Chemical composition of the rocks in the Strážovce section.

$\delta^{18}O$ content: Strážovce -4.3 to -2.9 ‰, Rochovica -2.8 to -1.8 ‰. These, as well as several previously published results from these two sections (Vašíček et al. 1983, 1992; Michalík et al. 1990a-b) along with special studies on the microplankton tests (Reháková & Michalík 1993a) indicate that the oxygen isotopic ratio decrease could be a result of postsedimentary/diagenetic transformation of the limestone. We have calculated a relatively narrow O-isotopic temperature ranges for the both the Rochovica (20-25 °C) and the Strážovce (25-32 °C) sections. The samples from the Strážovce section yielded the highest temperatures, or values of the isotopic ratio, without significant variations in the composition of Tithonian and Berriasian carbonates. In conclusion, these data confirm the increase in intensity of diagenesis in the Central Carpathians, in comparison with the Klippen Belt. However, the oxygen isotope values do not deviate from the values of the Jurassic-Cretaceous Formations (Lini et al. 1992; Jenkyns & Clayton 1986; De Boer 1982).

The periods of low $\delta^{13}C$ values, near +1.00 ‰ (Sholle & Arthur 1980; Weissert & Channell 1989) are commonly associated with normal oceanographic conditions with normal cycling organic carbon rate. The Strážovce section chart express well this type excursion of isotope results.

The "Majolica" (Pieniny) limestones C-isotope excursion of the Rochovica section shows increased values of $\delta^{13}C$, approximately on the Valanginian/Hauterivian boundary. The common $\delta^{13}C$ values of range +1.0 to +1.7 ‰ have been moved up to +2.2 to +2.8 ‰. Such low frequence C -isotope fluctuation have been interpreted in South Alpine pelagic limestones sections by Lini et al. (1992) as a record of the first episode of Cretaceous "greenhouse" conditions.

The carbon and oxygen isotope date show no covariance. C-isotope composition of the analysed sediments has not been signinificantly altered by burial diagenesis. C-isotopic excursions in different limestone facies (Rochovica and Strážovce charts) are practically same. It is unlikely, that low frequence fluctuations of C-isotope date have been produced by diagenesis.

Results of the chemical studies

We did not find any particularly substantial differences in chemical composition, from evaluation of the set of elements in the chemical analyses (Tab. 3). They showed substantially higher proportions of silica material or IR (Tab. 3, Fig. 9) in the Jurassic pelagic limestones (up to 40 % IR, apart from the layers of marly shales, which were not separately analysed), in comparison with Lower Cretaceous pelagic to hemipelagic limestones (less than 20 %, partly also less than 10 %). These values give some expression of the accumulation of silicate material in these facies, as an important factor in the rhythmic development of sediments.

We observed an increased content of Fe, Mn and partly also Mg in samples from the Strážovce section, in comparison with the values in the Rochovica and Brodno sections (Tab. 3). However, this increase does not exceed the average range of elements traced in hemi-pelagic limestones. We did not succeed in identifying Mn-, typical of anoxic conditions, or Fe carbonate minerals (Jenkyns et al. 1991; Rad & Botz 1987). The presence of grains of diagenetic dolomite was observed in some thin sections of the Central Carpathian sections (Strážovce section - Tab. 3, increased content of MgO in the carbonate portion of the rock). We did not reliably identify dolomite in the diffraction results (below 5 %). We would expect the presence of dolomite with more intensive diagenesis in the marly layers (e.g. shales - different migration, higher contents of Mg, Masaryk et al. 1993; McHargue & Price 1982). Boorová et al. (1993)

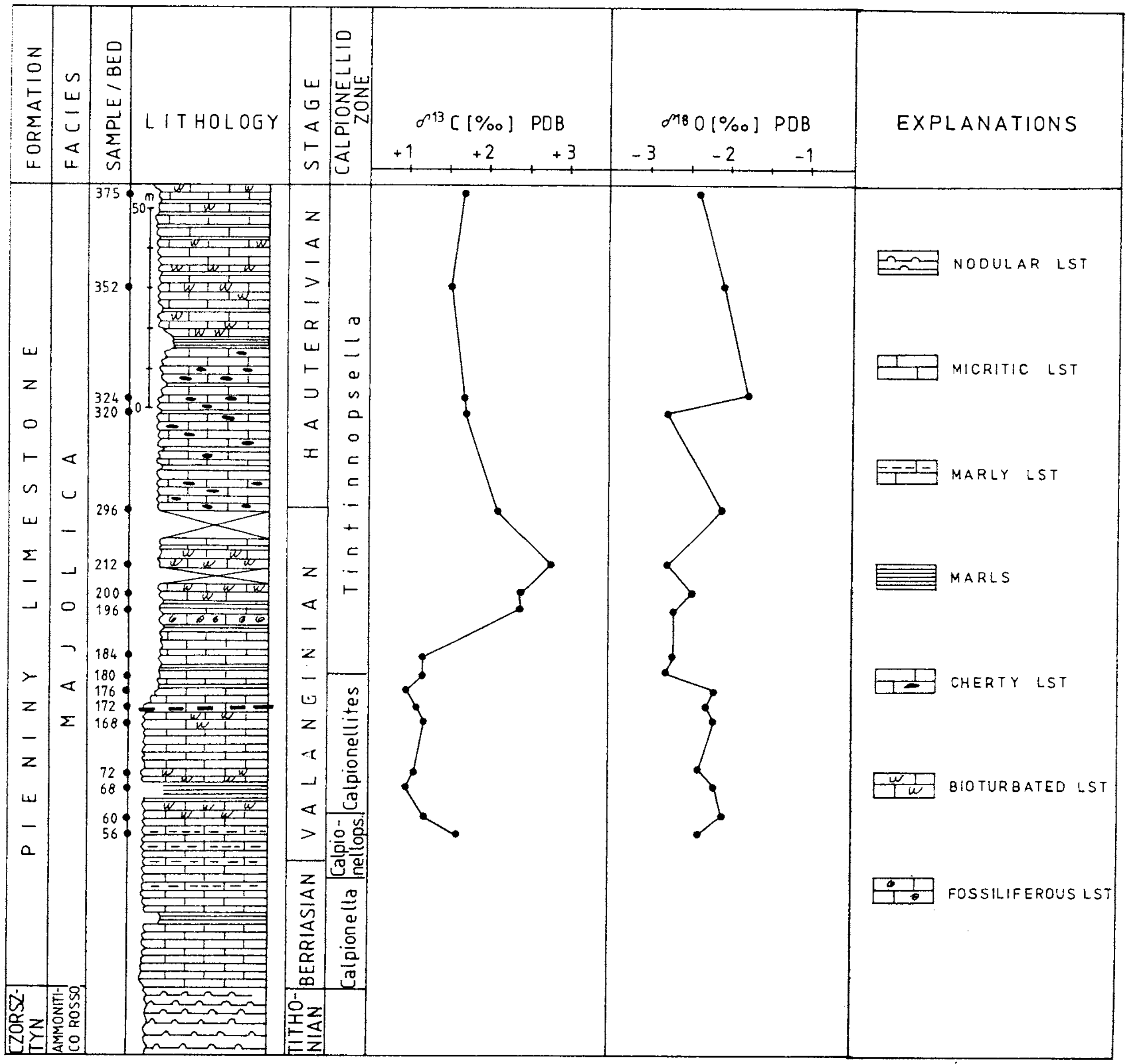

Fig. 10. $\delta^{18}O$ and $\delta^{13}C$ isotope variations in the Rochovica section.

also assumed the presence of dolomite in samples from the Strážovce according to chemical analyses, but did not specify its presence in more detail.

The relative differences in the Sr content in the studied pelagic/slope limestones (Fig. 9; Tab. 3) may partly reflect the origin of the material (mineralogy, depth) of the carbonate sediment. However as a result of the indicated diagenetic differences, as well as the number and character of the samples, it is not possible to be more specific about the raised values for Sr from the samples from Strážovce. It appears that increased Sr corresponds more with increasing diagenesis (increased uptake of Sr into low Mg calcite in a relatively closed environment). In the diagram of the Strážovce section (Fig. 9), it is possible to roughly compare the chemical characteristics of the Upper Jurassic and Lower Cretaceous pelagic sedimentation. In both parts, the dependence of IR and CaO is dominant, and the content of MgO in the carbonate does not change substantially.

IR in the limestones are frequently influenced by an increased proportion of SiO_2, that is silicification and different, mostly nodular forms of cherts, formed by micro- crystalline quartz. We assume that the tests of organisms were the source of SiO_2 (sections from the Outer Carpathians e.g. Rochovica: Lintnerová & Peterčáková 1994), although other sources (e.g. transformation of clay minerals) could not be excluded. Boorová et al. (1993) mentioned illite with a smaller proportion of chlorite in the fraction under 2 micrometres. During SEM study of cherts, we recorded diagenetic/authigenic clay minerals, morphologically most similar to illite.

Discussion

The samples for geochemical analysis have been taken from selected limestone beds in which higher abundance of microplankton had been documented by previous study (Reháková

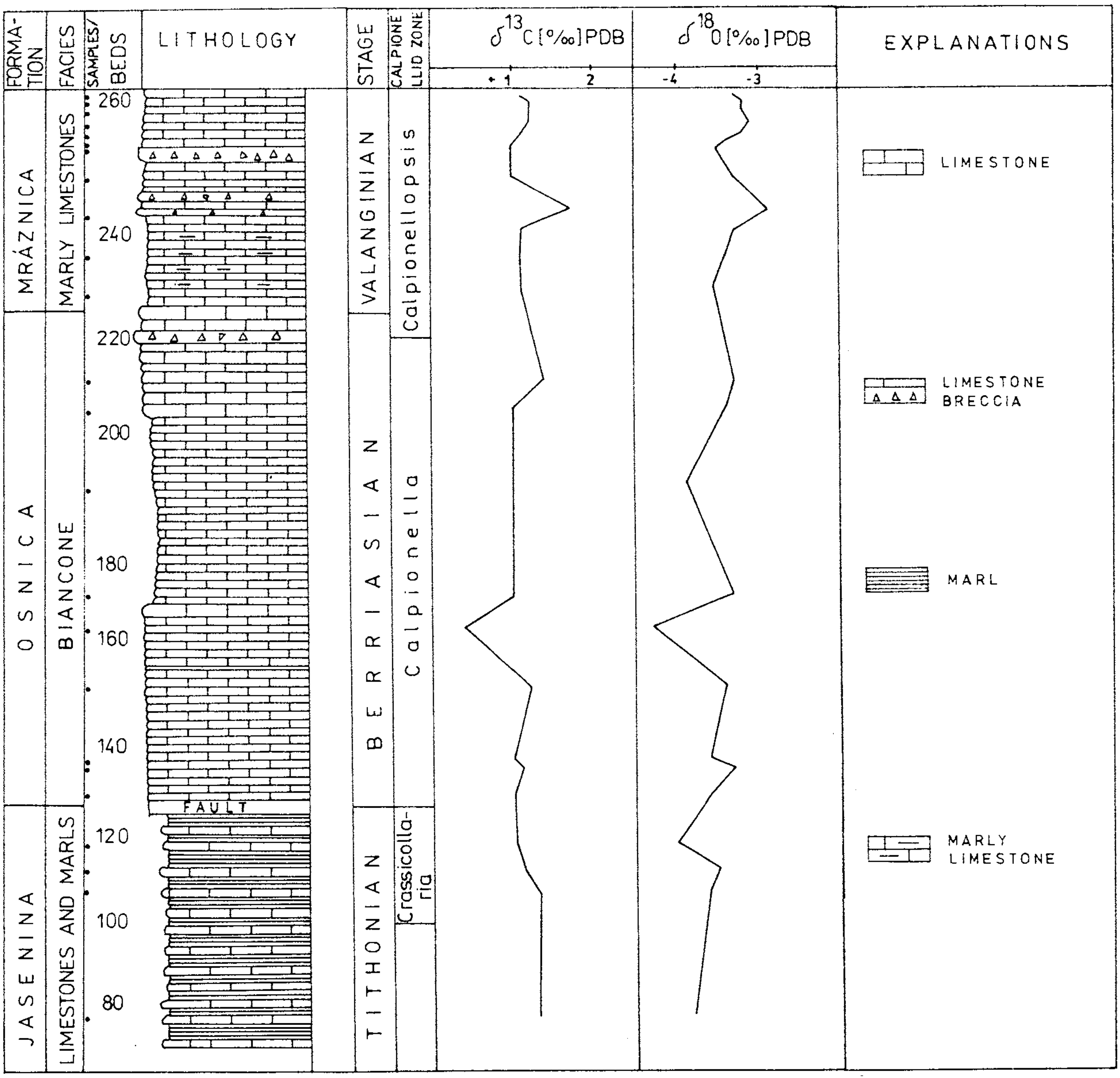

Fig. 11. $\delta^{18}O$ and $\delta^{13}C$ isotope variations in the Strážovce section.

& Michalík 1993b). However, the relation between microplankton concentrations and isotopic composition of the relevant rock samples remains uncertain due to scarcity of sampling.

C-isotope stratigraphy could help to monitor ancient terrestrial environmental conditions. This first isotopic study of Jurassic-Cretaceous pelagic sequence in Western Carpathians has been aimed to comparison with South Alpine sections and to possible identification of climatic events. The isotopic excursion could identify a period of accelerated cycling of carbonaceous material. However, the results of this method must be correlated with the changes in other paleoenvironmental tracers. We try to compare it with distribution of microfossil tests.

Weissert & Channel (1989) regarded Late Jurassic as a time of slow material cycling resulting due to dry climatic condition. We can not confirm these changes in Tithonian and Berriasian ocean chemistry and paleoclimate on the base of our provisional results until, yet. However, the Early Berriasian maximum of calpionellid abundance was not directly geochemically tested. No changes in the C and O isotope distribution have been found in the Jurassic - Cretaceous boundary interval in the Strážovce section (Fig. 11). Relatively even character of the O isotope record in the whole section (Fig. 12) confirms the effect of diagenesis (raised temperature), which however, did not influenced the distribution of C isotopes (Lini et al. 1992). Interesting results could have been obtained from basinal Jasenina Formation with signs of poorly aerated environment.

The Valanginian - Hauterivian distinct decrease of calpionellid microplankton as well as the abundance maximum of nannoplankton partially corresponds to the relative increase of $\delta^{13}C$ in carbonates. In accordance with Lini et al. (1992) or Channell et al. (1993), we identify it with the first episode of Lower Cretaceous greenhouse condition. It should be accompanied by an increased content of organic C in the rock. In the geochemical cycle, an isotopic balance exists between atmospheric CO_2 and dissolved marine bicarbonate carbon. CO_2 is supplemented by origin from the decay of organic ma-

Table 2: The results of the isotopic analyses from the Strážovce and Rochovica sections.

Strážovce Samples	$\delta^{13}C$ PDB	$\delta^{18}O$ ‰	Rochovica Samples	$\delta^{13}C$ PDB	$\delta^{18}O$ ‰
21	+1.3	-3.9	56	+1.6	-2.4
78	+1.3	-3.8	60	+1.2	-2.1
108	+1.3	-3.6	68	+1.0	-2.2
111	+1.1	-3.5	72	+1.1	-2.4
129	+1.0	-4.0	168	+1.2	-2.2
132	+1.0	-3.6	172	+1.1	-2.3
135	+1.1	-3.3	176	+1.0	-2.2
142	+1.0	-3.6	180	+1.2	-2.8
150	+1.2	-3.4	184	+1.2	-2.7
162	+0.4	-4.3	196	+2.4	-2.7
171	+1.0	-3.3	200	+2.4	-2.5
191	+1.0	-3.9	212	+2.8	-2.8
205	+1.0	-3.4	296	+2.1	-2.1
211	+1.4	-3.3	320	+1.7	-2.8
235	+1.1	-3.6	324	+1.7	-1.8
238	+1.1	-3.4	352	+1.5	-2.1
240	+1.1	-3.3	375	+1.7	-2.4
243	+1.6	-2.9			
248	+1.0	-3.3			
251	+1.0	-3.5			
252	+1.0	-3.4			
253	+1.1	-3.2			
256	+1.2	-3.1			
258	+1.2	-3.2			
259	+1.2	-3.2			
260	+1.1	-3.3			

Table 3: Chemical analyses from the Strážovce, Rochovica and Brodno sections.

Section Samples	CaO	MgO	IR	P_2O_5	Fe	Na	K
	wt. %						
Strážovce							
21	29.43	0.91	40.44	0.113	1.209	130	550
78	39.56	1.33	23.57	0.329	0.810	170	535
108	41.92	0.99	19.09	0.131	0.998	115	450
111	39.00	1.30	23.31	0.073	1.069	117	425
118	39.28	1.09	23.40	0.104	1.006	122	415
129	43.31	0.60	18.11	0.073	0.460	125	640
132	49.42	1.09	8.15		0.304	87	180
135	49.28	1.14	7.97	0.070	0.374	87	317
142	38.87	1.14	24.46	0.152	0.912	132	460
150	48.44	0.87	9.35	0.119	0.359	67	225
162	48.86	0.66	9.08	0.048	0.312	72	222
171	47.20	0.43	11.04	0.065	0.484	110	320
191	47.05	0.74	11.73	0.052	0.452	80	220
205	45.81	0.84	13.79	0.059	0.530	95	277
211	46.09	1.05	12.76	0.121	0.624	105	395
221	44.28	1.15	14.92	0.095	0.834	102	417
Rochovica							
60	48.09	0.40	12.80		0.200	122	427
72	52.34	0.43	5.20		0.180	107	210
168	46.53	0.45	15.44		0.310	125	337
184	44.84	0.35	18.62		0.280	85	320
200	45.01	0.54	17.68		0.440	80	375
356	49.30	0.50	10.17		0.320	85	282
Brodno							
16	50.91	0.66	7.03		0.280	120	400
20	52.58	0.64	4.46		0.200	117	250
28	52.70	0.48	4.35		0.130	117	207
33	53.24	0.39	3.77		0.170	90	200
35	48.16	0.38	12.62		0.260	95	330
43	52.57	0.45	4.80		0.130	107	325

terial. Bicarbonate C is precipitated into carbonates, and is also used by phytoplankton (especially ^{12}C). In the case of an overproduction of phytoplankton, and a drop in the quantity of oxygen available for the oxidation of organic matter, anoxic conditions are created and the addition of organic CO_2 to the hydro-carbon marine reservoir also diminishes. The result is the deposition of carbonates with a proportion of isotope ^{13}C or a growth in the value of $\delta^{13}C$ in the carbonate in comparison with carbonates in the "normal" carbon cycle. The greenhouse condition result due to increased content of CO_2 in the atmosphere, and the resulting warming may have caused also change in production of phytoplankton and the creation of anoxic conditions in the sediment. Climatic changes accompanied by Late Cretaceous oceanic anoxic events were described by Arthur et al. (1987), Hladíková et al. (1979), or Uličný et al. (1993).

The distribution of $\delta^{18}O$ gives information on the range of forming temperatures of the rock and on relative differences in the degree of its post-sedimentary modifications. The sedimentary temperatures of described sequences could partly change due to facies development in a range of several degrees (basin - slope).

The relationships between $\delta^{18}O$ and the contents of studied elements (especially Sr) could not be interpreted. The diagenetic trend partly between increasing temperature and growing MgO (relatively higher proportion of diagenetic dolomite in the Strážovce section) was manifested.

Conclusions

Although the sedimentary record in the Czorsztyn Formation is partly modified (amalgamated rhythms lasting 500 Ka), the sedimentary rhythms in the Upper Jurassic Jasenina Formation and in the Berriasian-Valanginian Pieniny and Osnica Formations are a reflection of orbital cycles interpreted as cycles of excentricity lasting approximately 120 Ka. Despite of limited number of microbiostratigraphical samples evaluated, rhythms

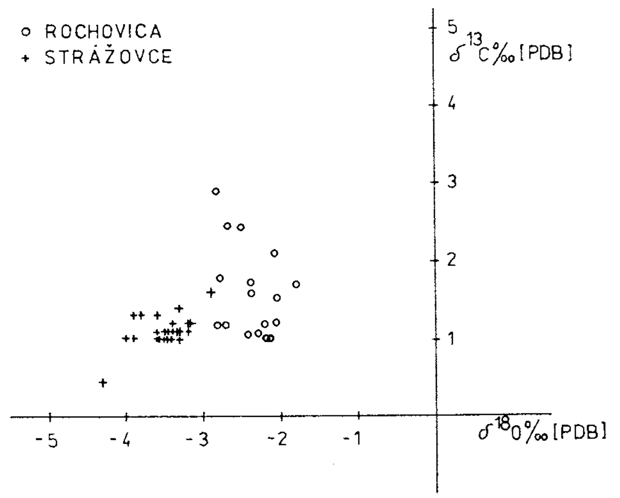

Fig. 12. Isotopic composition of the samples from the studied sections.

in calcareous and siliceous microplankton abundance in periods of 200 to 300 Ka could have been observed.

The results of $\delta^{13}C$ study in the Rochovica and Strážovce sections indicate record of a possible change in oceanic carbon cycle. The low frequence fluctuation of $\delta^{13}C$ values indicated the first (Late Valanginian) episode of Early Cretaceous greenhouse condition in the Western Carpathian sections.

The documentation and interpretation of the types, distribution and causes of rhythmic changes in Mesozoic sediments is a key to the understanding of the connections between sedimentation, tectonics, global changes and orbital factors. However, a synthesis still requires further studies before producing of a coherent model.

Acknowledgments: We thank to Prof. M.Mišík from Bratislava Comenius University for his discussion. The manuscript benefitted from critical comments of Dr. E. Erba from the Milano University. We acknowledge also to Mrs. M. Tinková for drawing of figures. The paper was supported by the Grant GAV 1081 as a part of IGCP Project No 362.

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