GEOLOGICA CARPATHICA, 47, 2, BRATISLAVA, APRIL 1996
119–130

FORAMINIFERAL ASSEMBLAGES: INDICATORS OF THE PALEOENVIRONMENTAL EVOLUTION OF MARINE BASINS AND EUSTATIC CHANGES (KISCELLIAN-KARPATIAN OF THE SOUTH SLOVAK AND DANUBE BASINS)

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(Manuscript received March 15, 1994; accepted in revised form December 12, 1995)

Abstract: The results of paleoecological analysis of the foraminiferal assemblages enabled estimation of oscillations of O_2-content, salinity, paleodepth and sediment supply from the Upper Kiscellian to the Karpatian in the South Slovak, Danube and partly the East Slovak Basins. These conclusions have been used for reconstruction of eustatic changes in the analysed area. The local oscillations have been correlated with the global eustatic changes. The global cycles manifested themselves in the semi-closed Central Paratethys basins. There are differences in the amplitude of the oscillations (in the whole studied interval), and in the timing of the initiation (the Upper Ottnangian, the Karpatian) and the termination (the Upper Egerian) of the cycles between the hinterland and frontal part of the Western Carpathians. From the differences in amplitude the timing of initiation of global and local cycles and the changes in sediment supply, the Kiscellian-Eggenburgian and the Upper Ottnangian-Karpatian tectonic cycles can be distinguished in the hinterland and the Eggenburgian-Ottnangian and the Karpatian cycles in the frontal part of the Western Carpathians. The global cycles with low amplitude of sea level rise correlate with the periods when the low-oxic environment was recognized in the whole basin (the Kiscellian, the Ottnangian) or in the deepest part of the basin (the Egerian) can be correlated with the global eustatic lowerings. A hyposaline environment was widespread at the beginning of significant transgressions (Lowermost Eggenburgian, Lowermost Karpatian). Changes in numbers of the foraminiferal species reflect significant sea-level changes. High percentages of new planktonic species characterise the widespread transgressions (the Eggenburgian, the Karpatian). Regressions connected with enclosing of basins are accompanied by decreases in species numbers (the Upper Egerian, the Ottnangian).

Key words: Upper Oligocene, Lower Miocene, Central Paratethys, Foraminifera, paleoecology, sea-level oscillation.

Introduction

Eustatic fluctuations cause various changes in the marine environment. Specific changes occur in semi-closed, tectonicly active basins (e.g. the Central Paratethys). Bathymetric analysis represents a basis for an interpretation of the eustatic changes (Boltovskoy & Wright 1976; Olsson 1988). Inspiration for the interpretation of sea-level changes in the semi-closed tectonically active basins can be drawn from the papers which show a more global approach to the interpretation of the eustatic changes: e.g. Ishman & Webb (1988), Paulay (1990), Armentrout (1991), Fürsich et al. (1991), Gaskell (1991), Olóriz et al. (1993), etc.

On the base of the changes in foraminiferal assemblages, environmental changes caused by tectonic events should be specified in tectonicly active basins (Arnstein & Cabrera 1992). Characteristic environmental evolution coincides with the period of isolation of the semi-closed marine basin (e.g. an appearance of the hyposaline environment, low-oxic environment or endemic species).

The first correlation of the transgressive and regressive cycles in the Central Paratethys with the global sea-level oscillations (Vail et al. 1977) was published by Rögl & Steininger (1983).

The sea-level oscillations interpreted on the basis of the paleoenvironmental evolution of the basin determined mainly on the basis of changes in the foraminiferal assemblages will be presented in the following paper.

Characteristics of the studied area

Detailed paleoenvironmental study was focused on the territory of Southern Slovakia (hinterland of the Western Carpathians). For comparison, material has been analysed from the areas with different structural position in the frontal part of the Western Carpathians, in the orogen belt (the present-day northern part of Danube Basin and East Slovak Basin).

According to the Recent patterns, the Tertiary sediments of Southern Slovakia belong to 3 partial depressions (from West to East): the Ipeľská kotlina, Lučenská kotlina and Rimavská kotlina Depressions. Many data exist on the geology, sedimentology, stratigraphy and paleogeography of this area (comprehensive data given by Vass et al. 1979, 1983, 1986, 1989, 1992). Lithological scheme is given on Fig. 1.

Paleoenvironmental changes were studied from the Upper Oligocene to the Lower Miocene (from the Kiscellian to the Karpatian). The global conception of the evolution of the Western Carpathians in this time interval is mentioned in Kováč et al. (1989, 1993), Csontos et al. (1992).

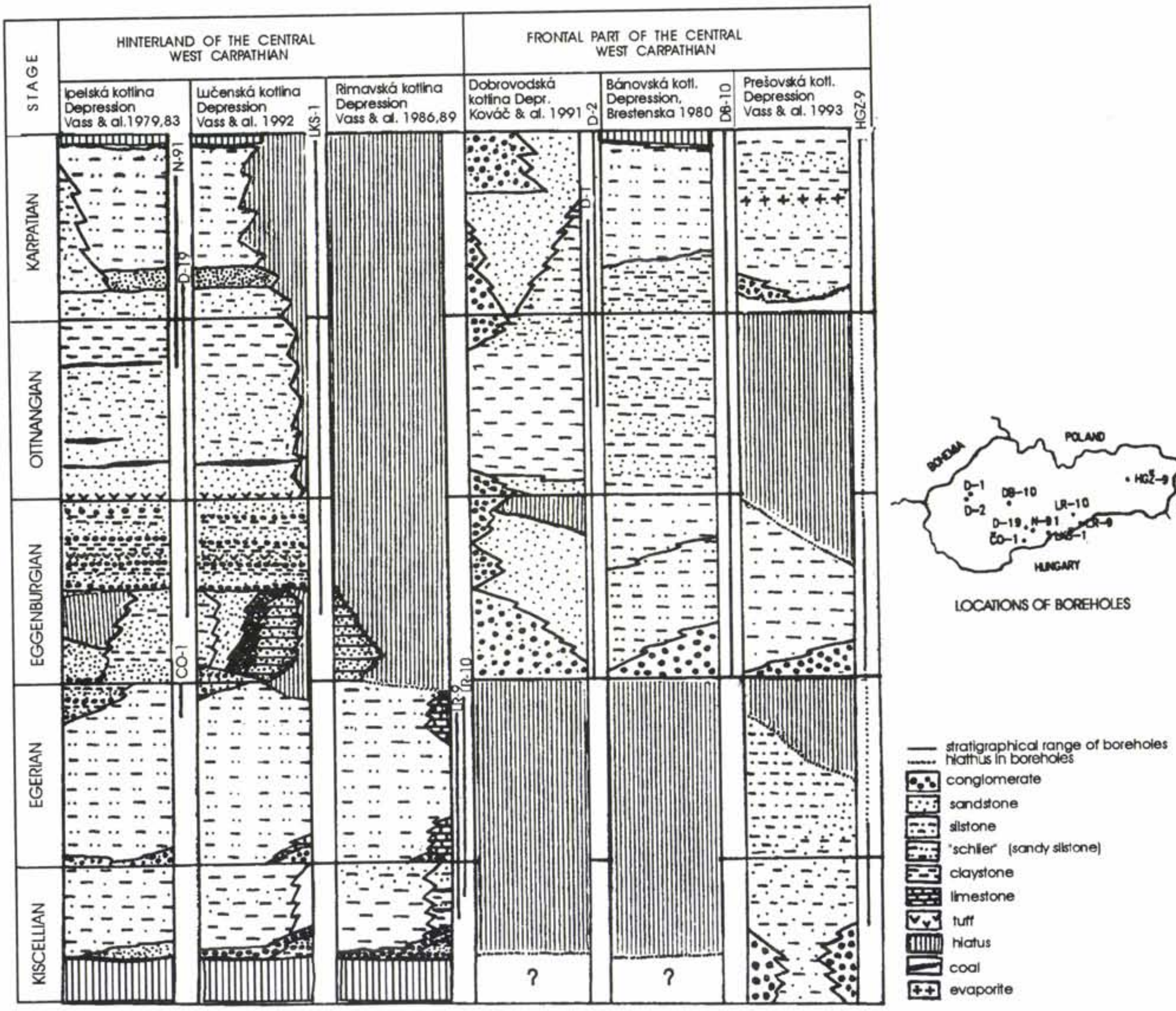


Fig. 1. Lithological scheme of the studied area and locations of the analysed boreholes.

The analysis of the paleoenvironmental changes rests on a detailed study of 10 boreholes (Fig. 1) completed by the study of other boreholes, of material from the files of the Dionýz Štúr Institute of Geology in Bratislava and of outcrops (Šutovská 1990) and on the quantitative data of Kantorová (1968).

Methods

The analysis of the paleoenvironment in the studied basins proceeded principally from the quantitative evaluation of the foraminiferal assemblages. Percentage of species, Simpsons's diversity index and P/B-ratio (counted using at least 300 specimens) and foraminiferal number (= number of foraminifera in 1 g of dry weight of sediment) have been quantified. Sedimentological data of Vass et al. (1979, 1983, 1986, 1989, 1992, 1993), Vass & Čverčko (1985) and Brestenská (1980) were taken into account. The foraminiferal assemblages have been paleoecologically interpreted on the basis of actuoecology (e.g. Phleger 1965; Murray 1973, 1991; Boltovskoy & Wright 1976; Reiss & Hottinger 1984; etc.). A large lateral variability of the foraminiferal assemblages in the shelf, the shift of the paleoecological requirements of taxa (Van der Zwaan 1983; Kurihara & Kennett 1988) and specific paleoecological conditions in the marginal sea (e.g. Cimerman & Drobne 1988) were taken into consideration. The assemblages were classified into the types which can be well determined in the analysed material. The foraminiferal assemblages were clustered in wide paleoecological groups (especially into a group of the foraminifers indicating a normal marine, well-aerated shelf environment) to avoid mistakes in the paleoecological interpretation (especially in the paleobathymetry). It is in agreement with the opinion of Murray (1992) that the foraminiferal assemblages can be distinguished only the inner, outer shelf, slope, etc. The basic types of the foraminiferal assemblages are given on Fig. 2.

Review of the applied procedures of the paleoecological interpretation is given on Fig. 3. The spatial distribution of the types of marine environment (interpreted from the types of the foraminiferal assemblages) serves as a basis for a reconstruction of the paleoenvironment in the analysed basins in several time horizons (Fig. 4). On the basis of the Fig. 4, a scheme of paleoenvironmental evolution of the analysed basin have been compiled (Fig. 5).

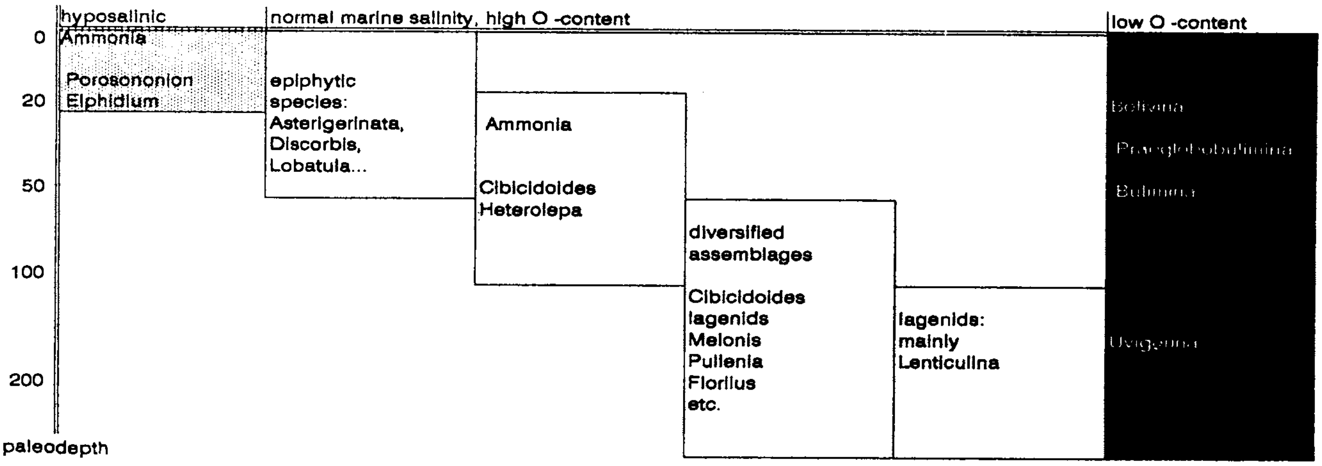
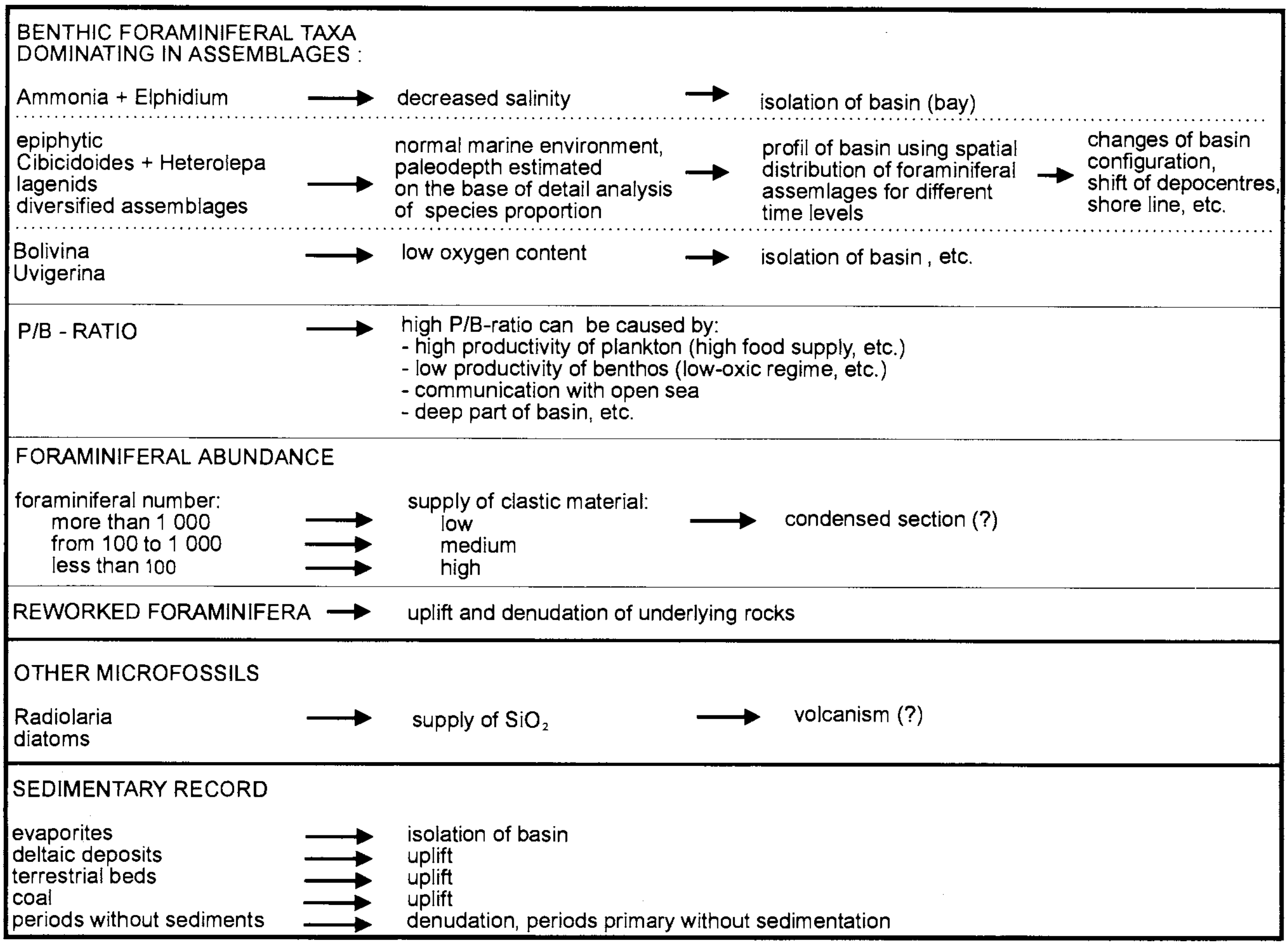


Fig. 2. Basic types of the foraminiferal assemblages in the analysed material and their schematic paleoecological interpretation.



BENTHIC FORAMINIFERAL TAXA DOMINATING IN ASSEMBLAGES :

Ammonia + Elphidium → decreased salinity → isolation of basin (bay)

epiphytic
Cibicidoides + Heterolepa
lagenids
diversified assemblages → normal marine environment, paleodepth estimated on the base of detail analysis of species proportion → profil of basin using spatial distribution of foraminiferal assemlages for different time levels → changes of basin configuration, shift of depocentres, shore line, etc.

Bolivina
Uvigerina → low oxygen content → isolation of basin , etc.

P/B - RATIO → high P/B-ratio can be caused by:
- high productivity of plankton (high food supply, etc.)
- low productivity of benthos (low-oxic regime, etc.)
- communication with open sea
- deep part of basin, etc.

FORAMINIFERAL ABUNDANCE

foraminiferal number: supply of clastic material:
more than 1 000 → low → condensed section (?)
from 100 to 1 000 → medium
less than 100 → high

REWORKED FORAMINIFERA → uplift and denudation of underlying rocks

OTHER MICROFOSSILS

Radiolaria
diatoms → supply of SiO_2 → volcanism (?)

SEDIMENTARY RECORD

evaporites → isolation of basin
deltaic deposits → uplift
terrestrial beds → uplift
coal → uplift
periods without sediments → denudation, periods primary without sedimentation

Fig. 3. Scheme of the input data for the reconstruction of paleoenvironment and their interpretation.

Differences in eustatic changes in analysed basins

The following assumptions result from the scheme in the Fig. 5:

The character of eustatic changes in the hinterland of the Central Western Carpathians (Southern Slovakia) was different from that in the frontal part (the Danube and East Slovak Basins) during the main part of the studied time interval. There are differences in the timing of uplift (in the Southern Slovakia from the Upper Eggenburgian to the Lower Ottnangian; in the frontal part of the Western Carpathians (Bánovská kotlina and Dobrovodská kotlina Depressions) in the Egerian), in the timing of initiations and terminations of the cycles of sea-level oscillations and in the amplitude of the sea-level oscillations.

Determination of the short-term oscillations of the paleoenvironment depends on the density of sampling as well as on

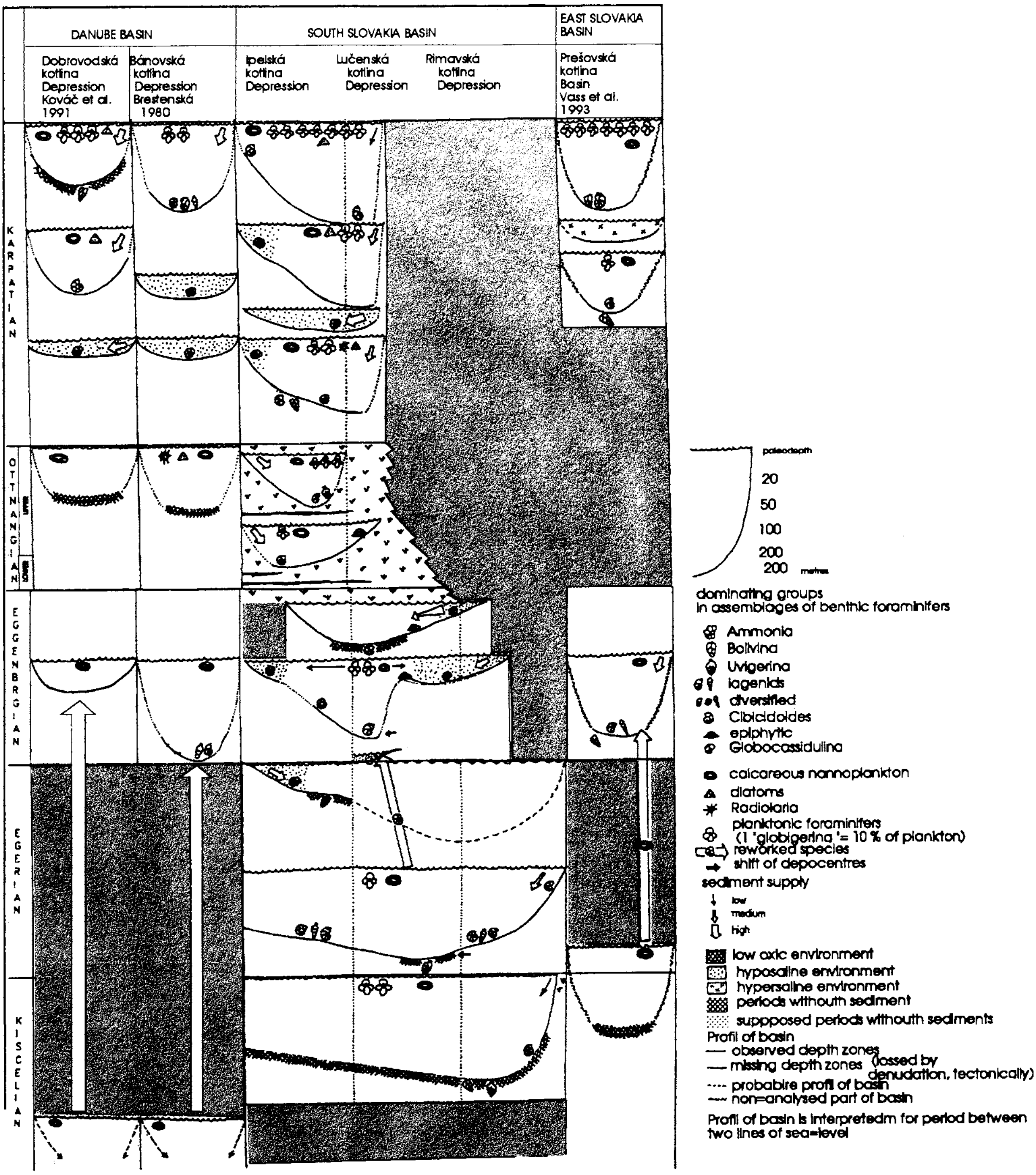


Fig. 4. Reconstruction of the marine paleoenvironment according to foraminiferal assemblages (from the Upper Kiscellian to the Karpatian in the South Slovak, the Danube and the East Slovak Basins).

the paleoenvironment (e.g. short-time oscillations of paleobathymetry cannot be noted in a deeper part of the basin). Therefore, the differences in the short-term oscillations between individual basins have been considered as not important.

The sea-level changes determined in the studied area have been compared with the eustatic changes described by Rögl & Steininger (1983) for the Central Paratethys. Their interpretations are based mainly on the study of the Vienna Basin and Carpathian Foredeep. The differences have been observed in the Lower Eggenburgian and the Upper Ottnangian. No transgression has been recognized in the analysed area during this time interval. The Karpatian cycle is more significant in the studied area than in the interpretation of Rögl & Steininger (1983).

Relations between the global eustatic cycles and the local paleobathymetric changes

The global eustatic changes (Haq 1991) have been correlated with the local bathymetric changes in the analysed basin according to radiometric ages. The dating of the cycles of the

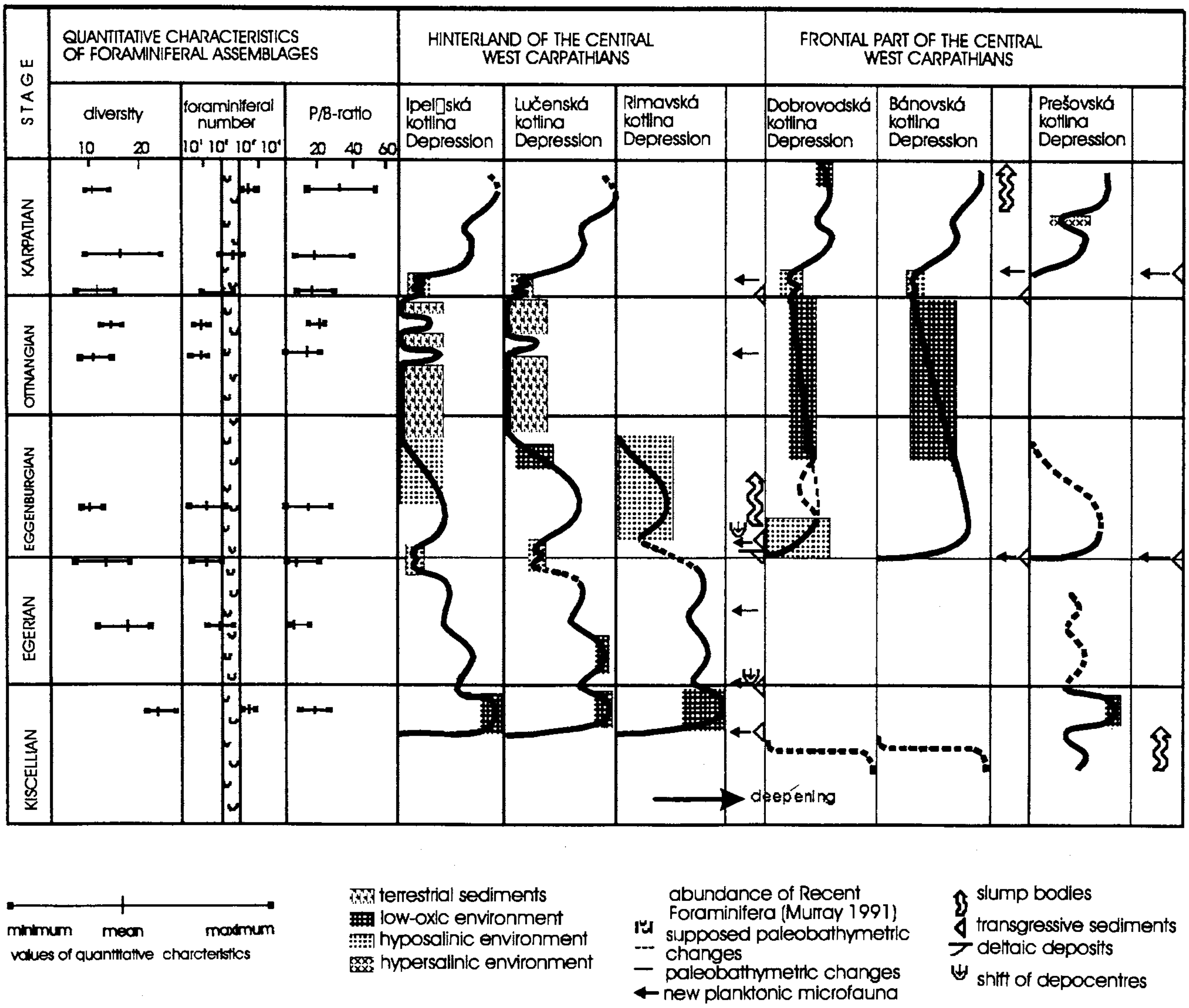


Fig. 5. Correlation of the paleoenvironmental changes in the hinterland of the Central Western Carpathians (the Southern Slovakia), and the frontal part (the Danube and the East Slovak Basins) from the Upper Kiscellian to the Karpatian compared with changes of some quantitative characteristics of foraminiferal assemblages for the studied area.

global eustatic changes was compared with the dating of the boundaries of the Central Paratethys stages. Two radiometric scales for the Central Paratethys have been used for the correlation: the scale of Vass et al. (1987) and that of Steininger et al. (1991) (Fig. 6).

The comparison of the local and the global sea-level oscillations shows:

— The Kiscellian marine inundation (? cycle TA 4.5) was probable in the Danube Basin because reworked nannofossils of NP 24 biozone occur in the younger sediments (Kováč et al. 1991).

— The Egerian eustatic changes observed in the South Slovak Basin may correspond to the cycles TB 1.2-TB 1.4., or more probably to TB 1.3 and 1.4. The lower cycles might be present in the East Slovak Basin (Vass et al. 1993). A hiatus is described in the Danube Basin during this period.

— The transgressive part of the TB 1.5 cycle (the Eggenburgian) became evident in the whole studied area, only the amplitude of the sea-level changes is different. The regressive part of the cycle proceeded heterochronously in the basins.

— The cycle TB 2.1 manifested itself in the analysed area only in the Dobrovodská kotlina Depression (hiatus between the Eggenburgian sandstones and Ottnangian silstones). Gradual changes in lithology and sediments without foraminifera have not permitted us to distinguish the cycle TB 2.1. in the Bánovská kotlina Depression. Terrigenous sediments were observed in the Southern Slovakia while hiatus was described in the East Slovak Basin.

— The initiation of the cycle T.B 2.2 appears gradually in the whole analysed area in the Uppermost Ottnangian and the Lowermost Karpatian. Cycles of the 4th order are well observed at the beginning of the cycle in all basins. The regressive part of the cycle is recorded very rarely.

The amplitude of the local and the global sea-level changes differs.

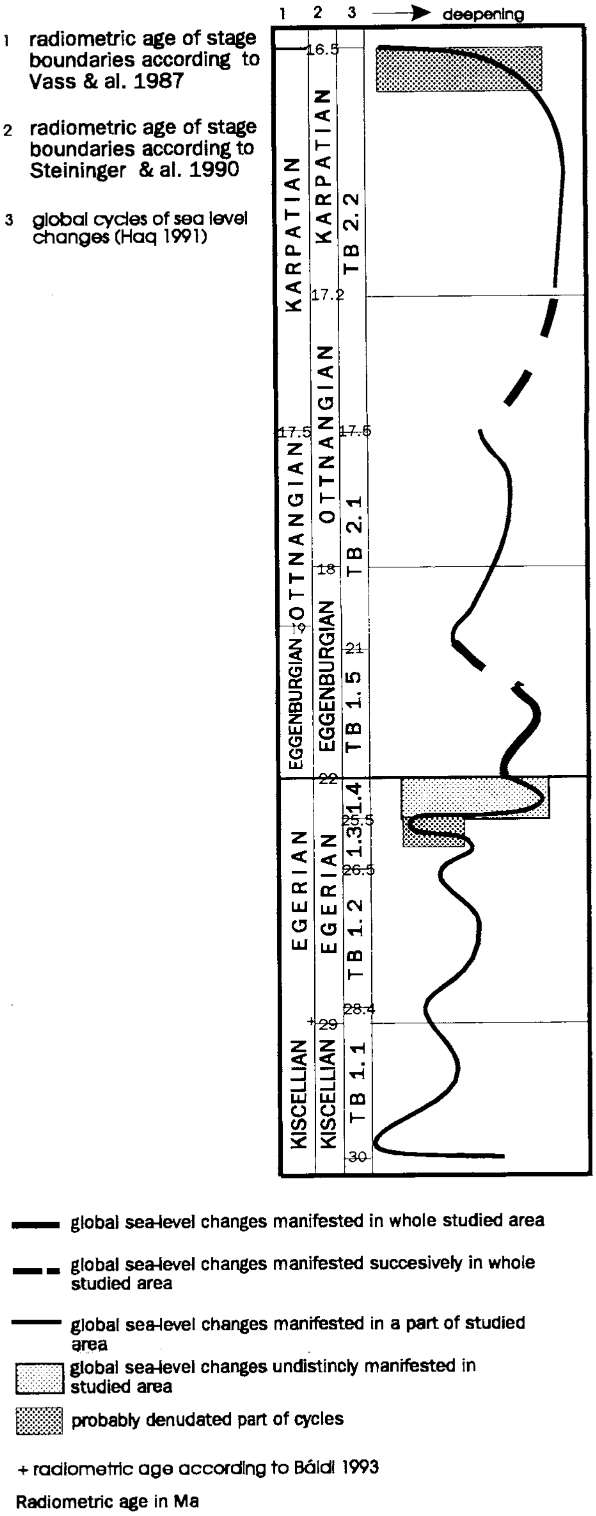


Fig. 6. Correlation of the Central Paratethys stages with the cycles of the global eustatic changes according to the radiometric age.

Relations between the paleobathymetric oscillations and the changes in salinity and oxygen content

Oscillations of salinity have been evaluated on the basis of the euryhalinic foraminiferal assemblages (Fig. 2). Hypersaline environment has been determined from evaporites.

Oscillations of salinity are characteristic of marginal lagoons (the Eggenburgian in the Rimavská kotlina and Lučenská kotlina Depressions) and the bays (the Kiscellian of the Ipeľská kotlina Depressions) and deltaic deposits (the Uppermost Egerian of the Ipeľská kotlina and Lučenská kotlina Depressions). The hyposaline environment is widespread at the beginning of the significant Eggenburgian and Karpatian transgressions, where widespread shallow-water bays appeared. It has been interpreted in both the Southern Slovakia and the Danube Basins.

A low-oxic environment can be recognized from the characteristic foraminiferal assemblages (Mullins et al. 1985; Wismara-Shilling & Coulbourn 1991; Sen Gupta & Machain-Castillo 1993) (Fig. 2) as well as from the laminated, dark sediments with high content of pyrite (in the Ottnangian).

A low-oxic environment appeared either throughout the basins (in the Kiscellian and the Ottnangian) or in the deepest part of a basin (in the Egerian) in the stratigraphic level corresponding to the global eustatic lowerings (cycles TB 1.1–1.3 and TB 2.1). The same relations have been observed in the Upper Badenian (Šutovská 1990) which can be correlated with the global cycle TB 2.5. In other levels (the Eggenburgian, the Karpatian) the low-oxic environment occurred in the shallow part of a basin during regression as a consequence of the isolation of the basins.

According to these observations, a model of shifting of the paleoenvironment in a semi-closed basin in relations to the eustatic changes has been compiled (Fig. 7).

Relationship between quantitative characteristics of the foraminiferal assemblages and eustatic changes

Changes of diversity of benthic foraminiferal assemblages, P/B-ratio and foraminiferal number were compared with local eustatic changes. Values of the quantitative characteristics of foraminiferal assemblages from the analysed boreholes are plotted on Fig. 8.

Generally, an index of diversity represents an index of favourable (or unfavourable) ecological conditions. Low values of diversity indicate an influence of a stress environmental factor. High values could also indicate a penetration of new fauna during a period of comunication with open sea in semiclosed basins. Recent observations show that a correlation between depth and diversity does not exist (Gibson & Buzas 1973; Thies 1991; etc.). Diversity changes randomly in interrelations to sea-level oscillations in our material.

Several authors showed that P/B-ratio can be an indicator of depth (Gibson 1989; Van der Zwaan et al. 1990). In the following interpretation, the influence of the current system, the communication with open sea and low productivity of benthos (e.g. in low-oxic regime) has also been taken into account. High P/B-ratios in the analysed material correlate with the initiation of transgressions (Ottnangian in the Southern Slovakia), high paleodepth (Upper Karpatian in the Southern Slovakia) and low-oxic environment (Upper Karpatian in the Dobrovodská kotlina Depression).

Foraminiferal number has been used as an index of a sediment supply. The density of the living foraminifera increases in different shelf and upper slope biotopes from 10× to 20× (Murray 1992), while the foraminiferal number in fossil material may increase up to 1000× (e.g. Boltovskoy et al. 1992 gave average values of the foraminiferal numbers from Qua-

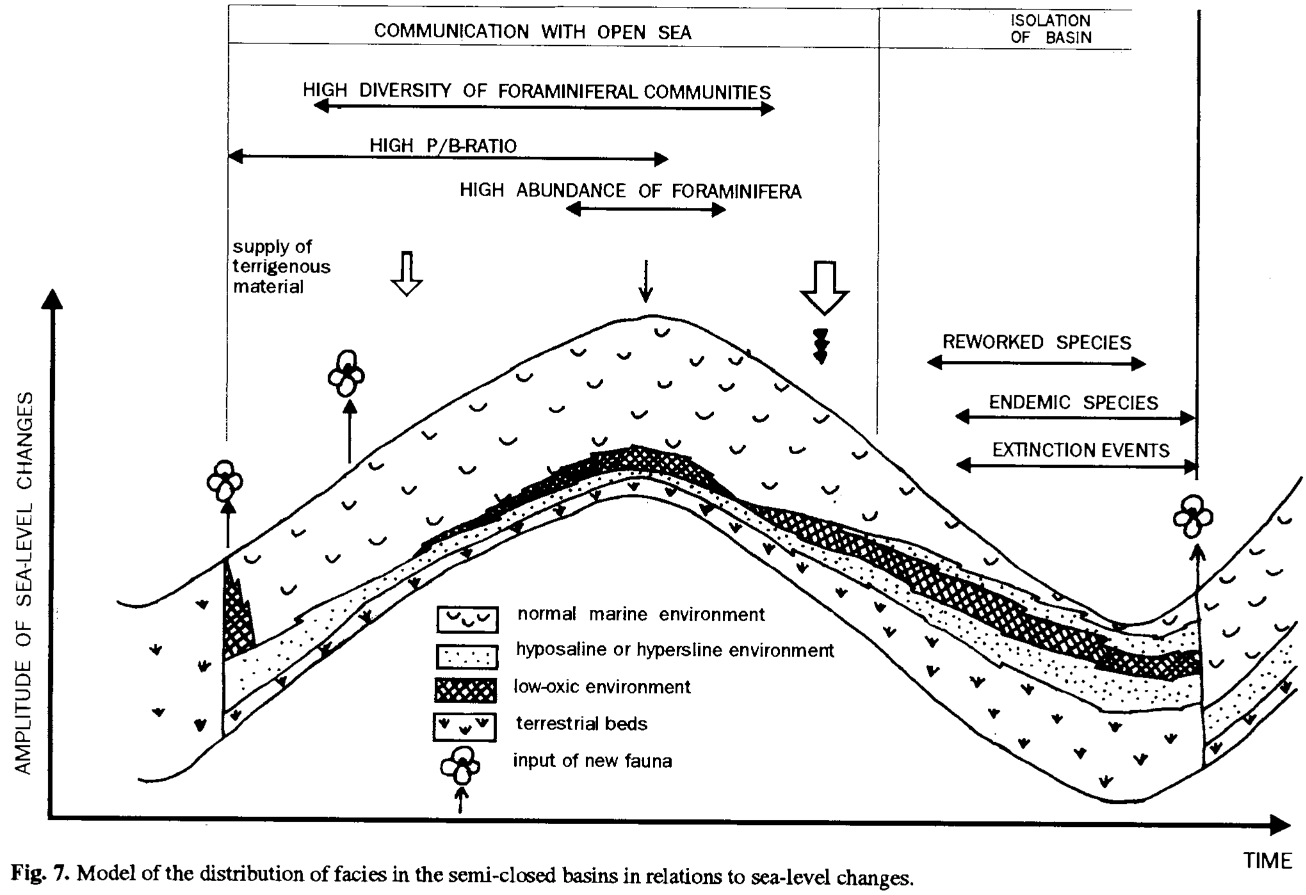


Fig. 7. Model of the distribution of facies in the semi-closed basins in relations to sea-level changes.

ternary to Eocene from 44 to 5578, in our material the foraminiferal numbers vary from 8 to 5000). Therefore, a decisive influence of the sediment supply on foraminiferal number is supposed. For that reason only significant differences in the value of the foraminiferal number were noted (foraminiferal number = n.10^1, or n.10^2 or n.10^3).

The intensity of sediment supply correlates with estimated paleodepth. Sediment supply is low in the stages with estimated higher paleodepth (the Kiscellian, the Karpatian), while high sediment supply is considered in the Ottnangian and the Eggenburgian in the South Slovak Basin, where a shallow water environment have been interpreted. The horizons of high foraminiferal abundance are considered to be candidates for condensed section in sequence stratigraphy (Armentrout et al. 1990). This agrees with correlation of high foraminiferal abundance and high paleodepth.

According to the data of Rögl, Cicha et al. (in prep.), the number of the first and the last occurrences of foraminiferal species have been counted in the Central Paratethys stages from the Upper Kiscellian to the Karpatian. In addition to the range of the paleoenvironmental changes, these numbers can determine communication with the open sea in a semi-closed basin.

The values of the indexes (the first and the last occurrence of foraminiferal species, the numbers of species both total and planktonic, the average values of diversity of benthonic foraminiferal assemblages and P/B-ratio for specimens and for species) are given on the Fig. 9. Because some indexes are counted for the whole Central Paratethys (the first and the last occurrence of species, the numbers of species, P/B-ratio for species) and some indexes are evaluated only for the studied area (diversity and P/B-ratio for specimens), the data are not fully comparable.

The high percentage of new planktonic species reflects the initiation of the transgression and the opening of a new seaway observed in the analysed area as well as in other basins of the Central Paratethys in the Lower Eggenburgian and in Karpatian (Kováč et al. 1993).

The Ottnangian foraminiferal assemblages can be characterized by the lowest number of planktonic species, low number of benthonic species and no new planktonic species. It may indicate the isolation of the Central Paratethys in the Ottnangian (Kováč & al. 1993). The high P/B-ratio observed in studied area shows the new transgression which started in the Upper Ottnangian in the South Slovak Basin.

At the Egerian/Eggenburgian boundary, the highest number of the last occurrences of the planktonic and benthonic species occurred. The high extinction ratio could be caused by the significant regression described in the Upper Egerian (Rögl & Steininger 1983; Steininger & Rögl 1984). Decreases in species number have been observed during widespread regressions (Valentine 1973; Jablonski 1985; etc.). An influence of the global foraminiferal fauna turnovers could also be expected, although global turnover was described in the Lowermost Oligocene (Miller et al. 1992).

Tectonic evolution of the basins and eustatic changes

Tectonic control of sea-level oscillations in the analysed area results from differences of the amplitude of the eustatic changes, from the shift of depocentres and differences be-

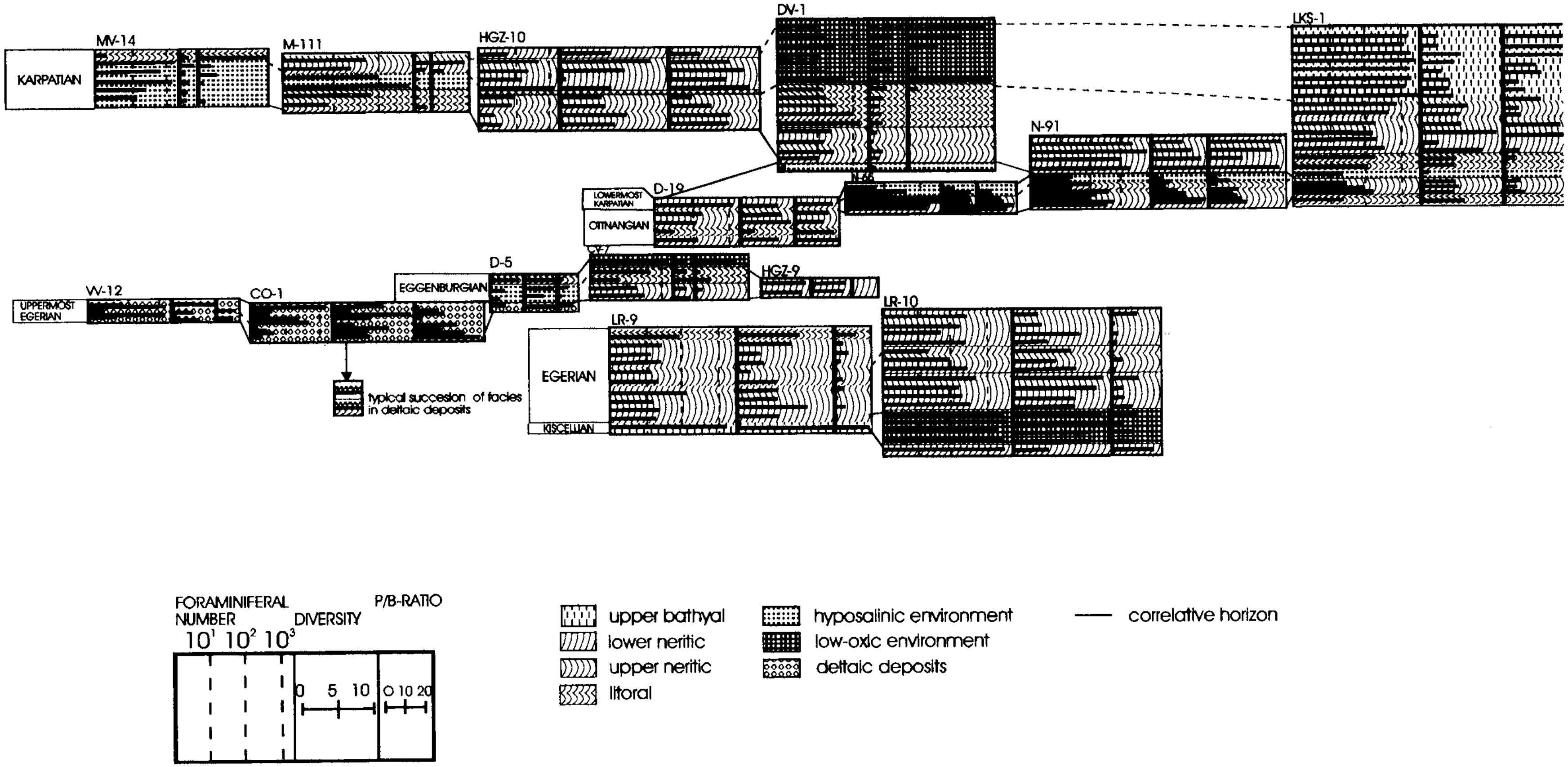


Fig. 8. Quantitative characteristics of foraminiferal assemlages in analysed boreholes used for correlation in different paleoenvironments. For localization of boreholes see Fig. 1. Quantitative data for MV-14 and MV-111 boreholes from Kantorová (1968).

tween periods of maximal area of marine inundation and maximal paleodepth.

The amplitude of the local sea-level changes (= maximal paleodepth in the transgression/regression cycle) depends on the amplitude of the global sea level oscillations, subsidence rate, sediment supply and tectonics. From the study of foraminiferal assemblages, the data about sediment supply have been available. A relationship between positive deviations of amplitude of the local oscillation and low sediment supply and negative deviations and high sediment supply can be observed. The level of sediment supply in the studied area increases or decreases gradually. Changes in these trends could represent the 2nd order tectonic events of Vail et al. (1991). In the hinterland of the Western Carpathians (Southern Slovakia) the trend from low to high sediment supply (or from positive to negative deviations between amplitude of the local and the global sea-level oscillations) is observed from the Kiscellian to the Eggenburgian. Another cycle can be observed from the Upper Ottnangian to the Karpatian characterized by the opposite trend (from high to low sediment supply). In the frontal part of the Western Carpathians these cycles are not well observed. The Eggenburgian-Ottnangian and Karpatian cycles can be distinguished according to the event of high sediment supply in the Lowermost Karpatian.

Shift of depocentres, and differences in period of maximal area of marine inundation and maximal paleodepth could indicate the 3rd order tectonics events. They have been observed in the Kiscellian-Eggenburgian of the Southern Slovakia. No sufficient data for this analysis have been obtained from other analysed areas.

The area of marine inundation was estimated from the paleogeographical maps of Vass et al. (1979, 1986). Significant denudation in some stratigraphical levels (e.g. in the Eggenburgian) caused that the determination of the inundated area is questionable in these levels.

The cycles with maximal area of marine inundation do not correspond to the cycles in which maximal paleodepth has been estimated (in the Kiscellian and the Egerian in the Southern Slovakia, where maximal paleodepth in the Kiscellian was observed while maximal inundation was estimated for the Egerian) if the maximal inundation is well reconstructed in the case of wide-spread denudation. The position of depocentres also changed on the Kiscellian/Egerian and the Egerian/Eggenburgian boundaries which may support this assumption. The preliminary results of stuctural analysis (Kováč P. et al. 1993) show that the most important tectonic events in the studied time interval occurred in the South Slovak Basin in the Egerian.

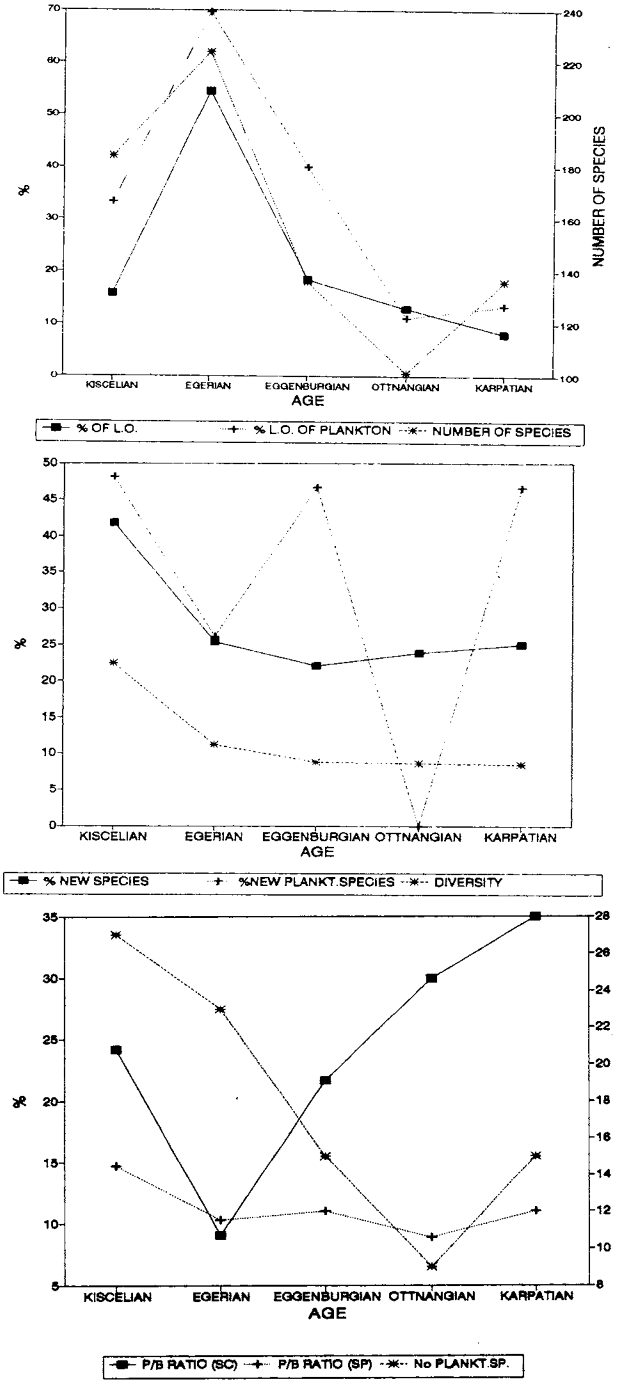


Fig. 9. Correlation of the percentage of the last occurrences of foraminiferal species (% L.O.), the last occurrences of planktonic foraminiferal species (% L.O. OF PLAKTON), the numbers of foraminiferal species (NUMBER OF SPECIES), the percentage of the first occurrences of foraminiferal species (% NEW SPECIES), the percentage of the first occurrences of planktonic species (% NEW PLANKT. SP.),the percentage of planktonic species (P/B RATIO (SC.)) and the numbers of planktonic species (No PLANKT.SP.) (counted according to the data of Rögl, Cicha et al. (in prep.) for the whole Central Paratethys) and the diversities of bethonic foraminiferal assemblages (DIVERSITY) and percentage of planktonic specimens (P/B RATIO (SP.) (counted from the own data for the studied area).

Conclusions

From the quantitative analysis of the foraminiferal assemblages, the oscillations of O_2-content, salinity, paleodepth and sediment supply have been estimated from the Upper Kiscellian to the Karpatian in the hinterland of the Western Carpathians (Southern Slovakia) and in the frontal part of the Western Carpathians (the Bánovská kotlina and Dobrovodská kotlina Depressions and partly in the Prešovská kotlina Depression). The influence of the global eustatic changes on the evolution of the semi-closed, synsedimentary tectonically active basins has been studied. The following conclusions can be given:

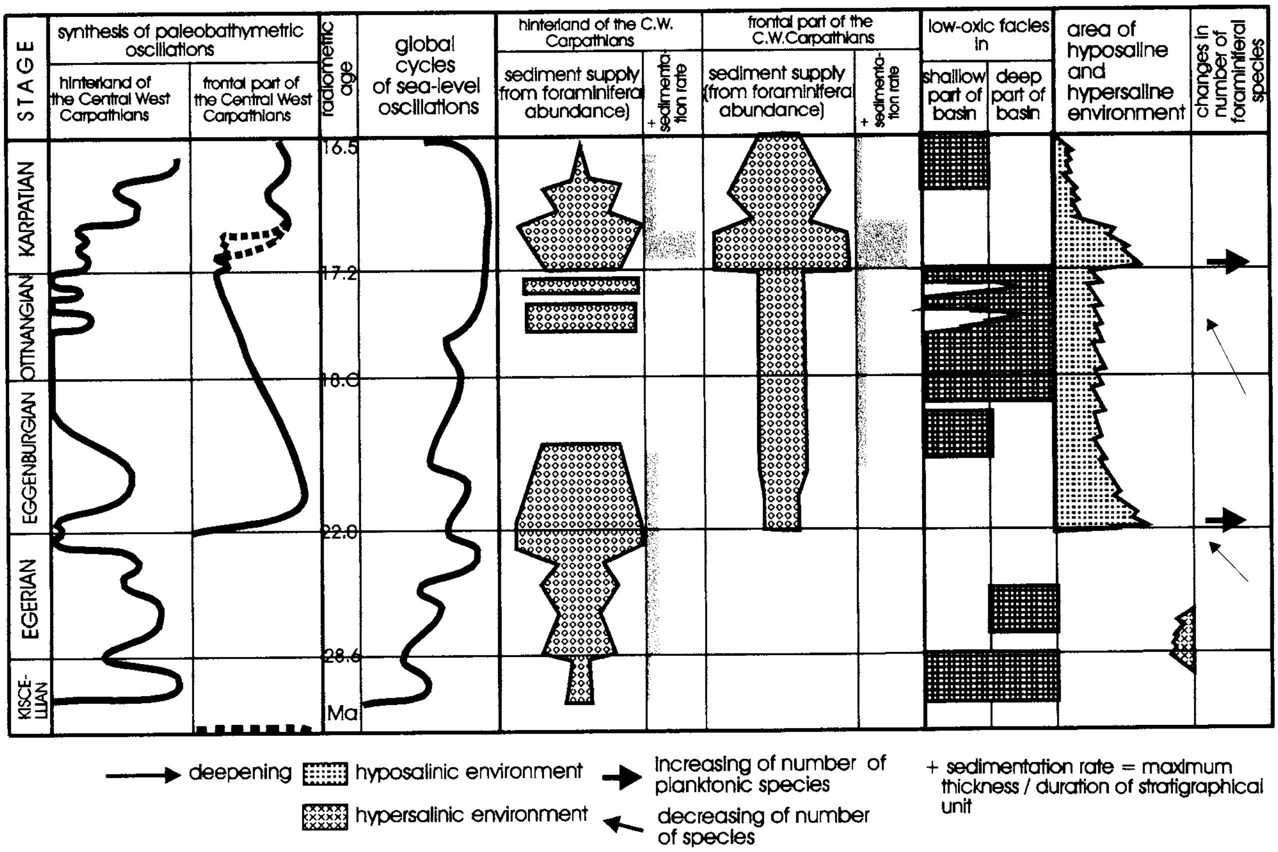


Fig. 10. Correlation of the global and local sea-level oscillations and the changes of O_2-content, salinity, number of foraminiferal species and sediment supply. Sedimentation rate was counted from data of Vass et al. (1983, 1986, 1992) and Brestenská et al. (1980).

1 — Correlation of the local eustatic changes showed significant differences between hinterland (Southern Slovakia) and the frontal part of the Central Western Carpathians. There are differences in the timing of the uplift (in the South Slovak Basin from the Upper Eggenburgian to the Lower Ottnangian; in the Dobrovodská kotlina and Bánovská kotlina Depressions in the Egerian); in the amplitude of sea-level changes (= paleobathymetry) in the entire studied time interval; and in the observable initiations and terminations of the eustatic cycles (e.g. initiation of the "Karpatian" cycle manifested itself gradually from the Upper Ottnangian to the Lower Karpatian).

2 — It is possible to correlate local eustatic changes with the global cycles, but there are differences in the amplitude of sea-level changes, and the observable initiation of the cycles are not fully isochronous.

3 — Conclusions 1 and 2 showed an influence of tectonic control on the basin evolution in the analysed area. The Kiscellian-Eggenburgian and the Upper Ottnangian-Karpatian tectonic cycles can be distinguished in the hinterland of the Central Western Carpathians. The Eggenburgian-Ottnangian and the Karpatian cycles were recognized in the frontal part. Kiscellian, Egerian and Uppermost Egerian-Eggenburgian tectonic cycles of a lower hierarchical level were observed in the Kiscellian-Eggenburgian in Southern Slovakia.

4 — The time intervals characterized by occurrence of the low-oxic environment in a whole basin (or in the deepest part of the basin) correlate well with global eustatic lowerings (the Upper Kiscellian and the Egerian — the cycles TB 1.2-1.3; the Ottnangian — the cycle TB 2.1), independently of amplitude of the local sea-level changes. Hyposaline environment was widespread at the beginning of significant transgressions (Lowermost Eggenburgian, Lowermost Karpatian) which means that new areas were inundated by shallow-water hyposaline bays at the beginning of these transgressions.

5 — Changes in numbers of the first and the last occurrences of the foraminiferal species correlate with the sea-level oscillations connected with the opening or closing of the seaways. The high number of new planktonic species is most evident in the Eggenburgian and the Karpatian when the transgression and opening of the new sea ways are considered for the whole studied area. The isolation of the Central Paratethys in the Ottnangian is reflected in the low number of foraminiferal species and no new planktonic species. The extinction event in the Egerian can be connected with the regression in the Upper Egerian.

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