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Sequence stratigraphy approach to the Central Carpathian Paleogene (Eastern Slovakia): eustasy and tectonics as controls of deep-sea fan deposition

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Abstract: The Central Carpathian Paleogene shows a sequence stratigraphy pattern developed as follows: - alluvial-fan deposition; - transgressive onlap by shore zone and carbonate platform deposits, mainly Nummulitic banks (Upper Lutetian - Bartonian); - drowning of carbonate platform and highstand aggradation marked by high productivity of Globigerina Marls (Priabonian); - interference of lowstand and rapid tectonic subsidence in fault-controlled accumulation of marginal slope fans (Priabonian - Early Oligocene); - highstand deposition of mud-rich fans associated with condensation (manganese beds) and Menilite episodes (Lower Oligocene); - lowstand, progradational wedging out of sandy-rich fans (Late Oligocene - Early Miocene). Correspondence of sequence-stratigraphy events (e.g. Globigerina-rich, Menilite as well as Krosno) indicates connection of the basinal systems of the Central and Outer Carpathians accommodating the destructive plate margin, trench zone and accretionary terranes.

Key words: Central Carpathian Paleogene, deep-sea fans, sequence stratigraphy, eustasy, tectonics.

Introduction

In the deep-sea fan envinonments, the application of sequence stratigraphy is still questionable. In the passive margin settings, the deep-sea fan deposition is clearly influenced by the eustatic sea-level changes (Vail et al. 1984, 1987 etc.). Hovewer, in active margins where the frequency of tectonic events is greater than that of eustatic changes, the sequence development responds to the integrated effects of both these parameters (Posamentier et al. 1991). The deep-sea fan system of the Central Carpathian Paleogene shows an organization responsible for the geodynamic setting of active margin-fans (cf. Shanmugam & Moiola 1988) having an elongate shape, development of attached lobes as well as suprafan lobes (cf. Marschalko 1981, 1987, Soták et al. 1996, Janočko et al. 1998). Therefore, the depositional stacking of the Central Carpathian Paleogene is constrained to be a result of eustasy and/or tectonics.

Sequence stratigraphy approach[+]

The Central Carpathian Paleogene is commonly divided into lithostratigraphic formations of Subtatric Group (Gross et al. 1984) and Podhale Flysch (Golab 1959). From the base, the sedimentary sequence is developed as follows (Fig.1A): ***Borové Formation*** (Eocen Tatranski) - basal transgressive facies consisting of breccias, conglomerates, polymict sandstones to siltstones (Tomášovce Member - Filo et al. 1996), marlstones, organodetrital and organogenic limestones; ***Huty Formation*** (Zakopane Fm.) - claystone/siltstone lithofacies less frequently with interbeds of fine- to medium-grained sandstones and "Menilite"-type shales; ***Zuberec Formation*** (Chocholów Fm.) - a sandier, medium- rhythmical flysch sediments; Biely Potok Formation (Ostrysz Fm.) - massive sandstone banks. Each of the Central Carpathian Paleogene formations contain a coarse clastic fans named Pucov Member. The thickness of these formations is highly variable depending on bottom configuration and differential subsidence. As for the age, the sediments of the Central Carpathian Paleogene belong to the Bartonian - Lower Oligocene (e.g. Samuel & Fusán 1992, Gross et al. 1993), but their nannoplankton zoning extends up to the Latest Oligocene (Nagymarosi, Harmšmíd & Švábenická in Soták et al. 1996, Olszewska & Wieczorek, 1998).

In fact, the lithostratigraphic units of the Central Carpathian Paleogene appear to be depositional sequences, that developed from the continental alluvial-fan deposits, overlapped by shoreface sands and carbonate platform deposits, through synrift accumulation of shaly flysch deposits and scarp breccias (Šambron Beds), claystone subflysch deposits of mud-rich fans, progradational stacking of deep-sea fans with complex facial zones (slope and channel deposits, lobe-levee deposits, fan-fring lobes, basin-plaine deposits, etc.) to sandy-rich deposits of "suprafan" (Fig. 1B). Considering that, the basin-fill formations of the Central Carpathian Paleogene basin show a sequence stratigraphy pattern of systems tracks (Fig. 2).

The alluvial-fan sediments of the Central Carpathian Paleogene (Marschalko 1970) consist of subaeric and

[+] Communication of ESSE Conference, Bratislava 1997 subaquatic cycles of conglomerates and boulder breccias, which were deposited from stream flows, fluidal surge flows, debris flows, traction currents and high-density turbidite currents (Baráth & Kováč 1995). Continental footplain sediments of alluvial fans were flooded to subaquatic zone and than overlapped by shoreface sands (Tomášovce Beds) and carbonate platform deposits. Upper Lutetian transgression (Andrusov & Köhler 1963) led to shallow-marine deposition of Nummulitic banks developed in two 3rd order cycles of deepening-upward

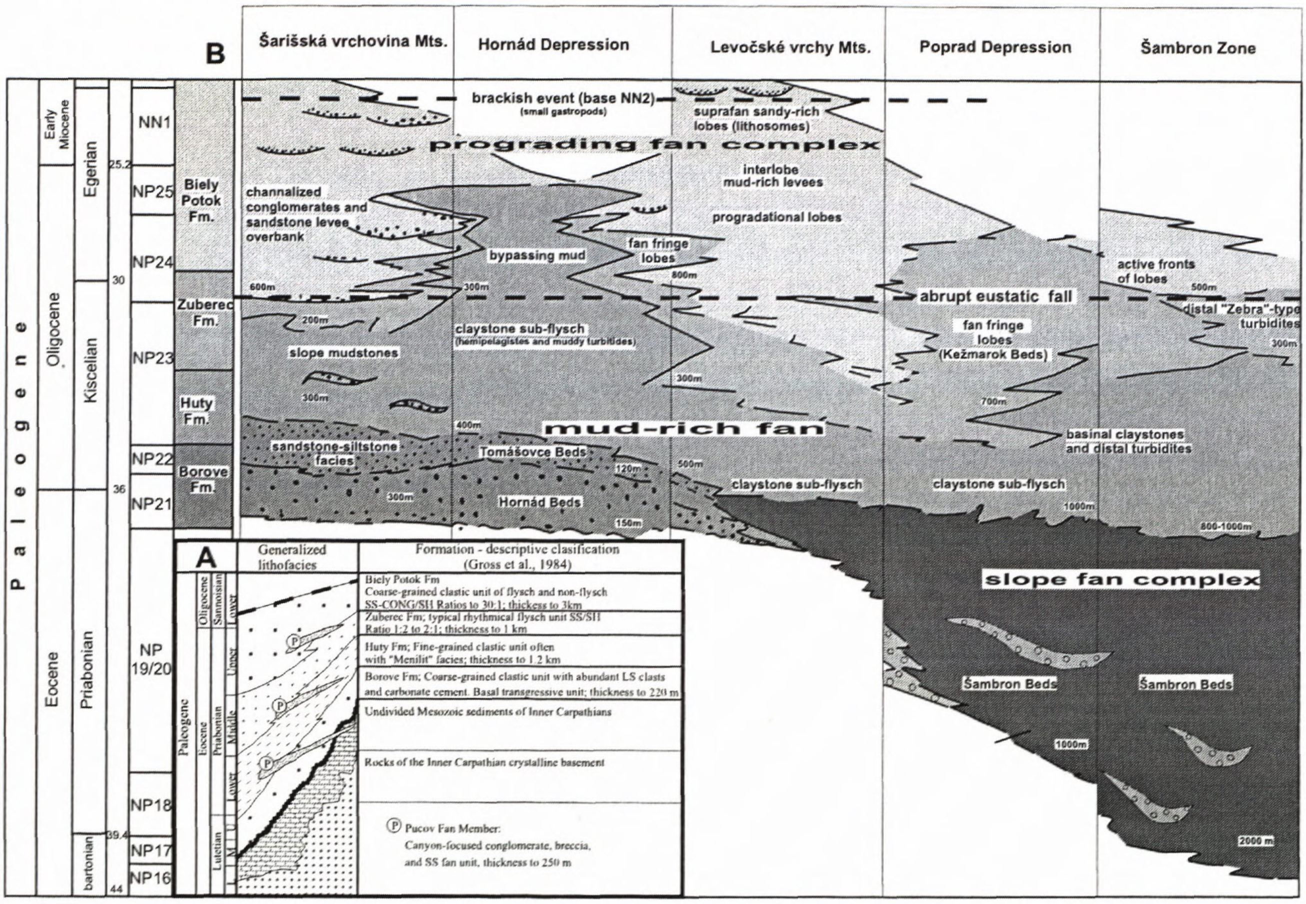


Fig. 1 Schematic lithostratigraphy of the Central Carpathian Paleogene after Gross et al. 1984 (A) and depositional stacking of the Levoča Basin interpreted as a facies tracks of the deep- sea fans (B) Tomášovce Beds - sensu Filo and Siráňová, 1996; Hornád Beds - sensu Filo and Siráňová, 1998; Kežmarok Beds / sensu Gross, in press.

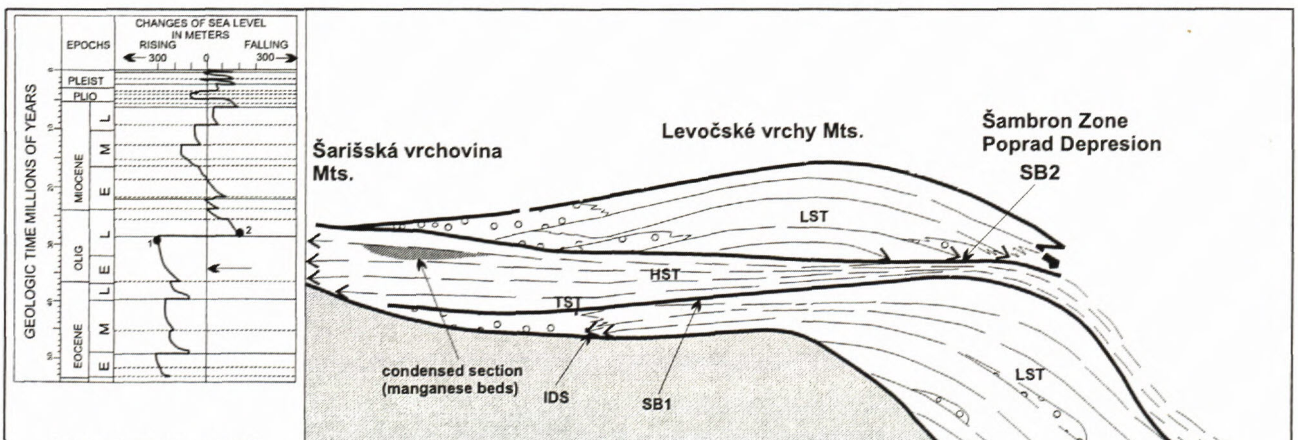


Fig. 2 Sequence stratigraphy pattern of the Central Carpathian Paleogene showing a lowstand accumulation of the slope fan complex (Šambron Beds), transgressive onlap and highstand deposition of mud-rich fans with maximim condensation in manganese beds (Huty Formation) and lowstand cycle of the upper prograding wedge. Sequence boundary SB2 coincides with the abrupt sea-level fall near 30 Ma (see the Tertiary sea-level curve on the left).

successions (Bartholdy 1997, Bartholdy & Bellas 1998). In the Priabonian, the sea-level rise grades up to early highstand marked by dominance of hemipelagic deposition and high productivity of Globigerina Marls (Samuel 1973, Blaicher 1973, Nemčok et al. 1990, Leszczynski 1997). With onset of differentiated subsidence, the Globigerina Marls occurred synchronously with turbidite fans deposited in intrabasinal depressions (Šambron Beds). Subsequently, the Central Carpathian Paleogene basin occurred in dominancy of turbidite fan deposition forced by tectonics and/or eustasy.

It is obvious, that the Central Carpathian Paleogene basin was founded as a consequence of the regional tectonic subsidence (e.g. Marschalko 1978, Köhler & Salaj 1997). When the tectonic subsidence rate decreased, the turbidite fan deposition became broadly influenced by eustasy. Thus, the depositional sequences of the Central Carpathian Paleogene could correspond with the global eustatic events. Especially, the sequence boundary of the mud-rich subflysch facies and sandy-rich deep-sea fan deposits closely correspods with the dramatic sea-level fall (for about 300 m) between Lower and Upper Oligocene, which is the most distinct global record on the Tertiary sea-level curve (see Haq et al., 1988) occurred at the time of 30 Ma (near transition of NP23/NP 24-25 biochrons) This indicates, that the Late Oligocene deep-sea fan deposition of the Central Carpathian Paleogene should be accelerated by the global sea-level fall and formed as a lowstand system track. The Upper Oligocene is regarded as a beginning of the Antarctic glaciation under which the Northern Hemisphere became significantly cooler (Robin 1988). It is well known that the frequency of turbidite currents increase in time of the glaciation (ratio of turbidity currents in postglacial time to those in glacial time is at least 1 : 10 - Shanmugam & Moiola 1982, Eberli 1991). Therefore, the acceleration of turbidite deposition in the Late Oligocene deep-sea fans of the Central Carpathian Paleogene could really result from sea-level fall. Eustatic force of the Late Oligocene sedimentation is also apparent when the subsidence curves are compared with rate of accumulation and sea-level history (Fig. 3). These curves show an interference of rapid tectonic subsidence with a high rate of synrift sediment accumulation during the Late Eocene (Šambron Beds). Conversely, an increased supply of the deep-sea fan deposits in the Late Oligocene lacks a tectonic subsidence record, and that it revealed most likely an allocyclic initiation probably in the sea-level fall near 30 Ma.

From the sequence stratigraphy viewpoint, the turbidite fan system of the Central Carpathian Paleogene can be divided into three depositional sequences (DS) comparable to third-order cycles (estimated duration of 1-5 Ma). Lower cycle of the basin-fill sequence is represented by the Priabonian to Early Rupelian sediments of the Šambron Beds. The high accumulation rate of shaly flysch deposits, turbidites and scarp breccias of the Šambron Beds (cca 800 m/Ma, duration 39 - 36 Ma) points to fault-control lowstand deposition of the marginal slope fans (like as Szaflary Fm. - Wieczorek 1989). The lowstand setting of the Šambron Beds is also expressed by the presence of large amount of shallow-marine detrital components (nummulites, coralline algae, etc.) in the deep-water flysch lithologies (shelfs exposed by sea-level fall). The sedimentation of the Šambron Beds occurred probably in the Oxygen minimum zone (anoxic facies, scarcity of microfossils, dark sulphide-rich claystones, etc.) and below upwelled calcite compensation depth (non- or weakly calcareous claystones). The younger third-order cycle of the Central Carpathian Paleogene is represented by the mud-rich subflysch formation. This cycle kept on for about 5 Ma (36 - 31 Ma) with a slow accumulation rate of mudstone deposits (cca 80 - 160 m/Ma). Such dominance of pelagic sedimentation in the basin responds to the highstand system track. Maximum flooding of this highstand formation falls into the horizons of manganese layers that occur mainly in the Poprad Depression (the sequence division below the manganese layers can also be assumed as a transgressive system track). The manganese layers represent a condensed section of the highstand deposition associated with relative abundance of biota (e.g. nannofossils, fish fauna, etc.), glauconite-rich arenites (as a contrary to the lowstand turbiditic sandstones of the Šambron Beds and Upper Oligocene sediments), pelocarbonates and sporadically also tuffaceous intercalations (e.g. loc. Bajerovce, Plavnica). The depositional environment of the claystone lithofacies became well-oxygenated as can be seen from the appearance of bathyal ichnofossils (e.g. Zoophycos - Plička 1987). The Early Oligocene highstand sedimentation of the Central Carpathian Paleogene correspods to so-called Menilite event in the Outer Flysch Carpathians. The sediments of the Menilite Formation and associated nanno-chalk horizons in the Outer Flysch Carpathians (Jaslo Limestones, Dinów Marlstone, Štibořice Member, etc.) were deposited during the coeval sea-level highstand in the Rupelian (cf. Krhovský & Djurasinovič 1993).

The last third-order cycle of the Central Carpathian Paleogene reflects an abrupt sea-level fall near the time of 30 Ma which introduced the Upper Oligocene deep-sea fan deposition. The lowstand setting of the Late Oligocene sedimentation of the Central Carpathian Paleogene is expressed by an offlap break of prior highstand sediments which were eroded and reworked into conglomerate-slope accumulations of the deep-sea fans (e.g. blocks of Mn carbonatic ores - Marschalko 1966). During the Late Oligocene, the fan became progradational, and developed from sandy-poor turbidite system (Zuberec Fm.) to sandy-rich turbidite system (Biely Potok Fm.) sensu Mutti (1985). The sandy-rich deposition of the Central Carpathian Paleogene lasted till to the Early Miocene, as has been already indicated by some nannoplankton and foraminiferal species (e.g. *Helicosphaera scissura*, *H. kamptneri*, *H.* cf. *carteri*, *H.* cf. *ampliaperta*, *Reticulofenestra* cf. *pseudoumbilicus*, *Triquetrorhabdulus* cf. *carinatus*? - Nagymarosi, Hamršíd & Švábenická in Soták et al. 1996, Molnár et al. 1992) and by sandstone content of the neovolcanic clasts related to the Early Miocene volcanic activity (Soták et al. 1996). Hovewer, the Early

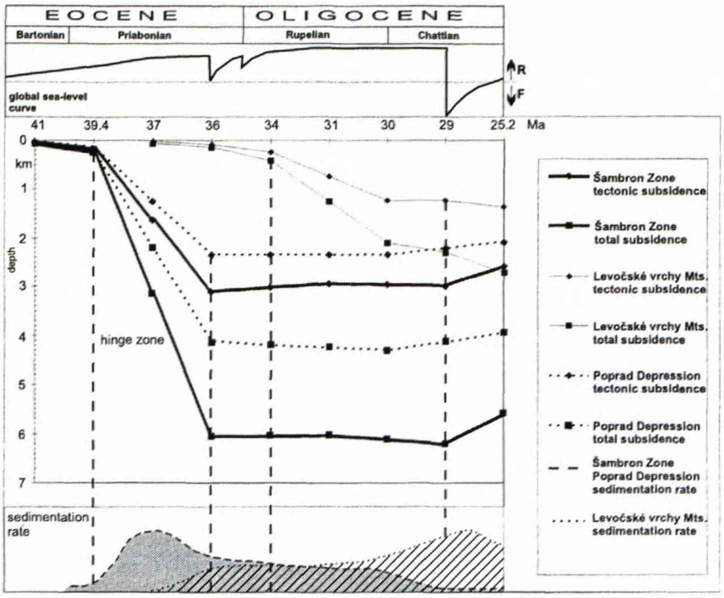


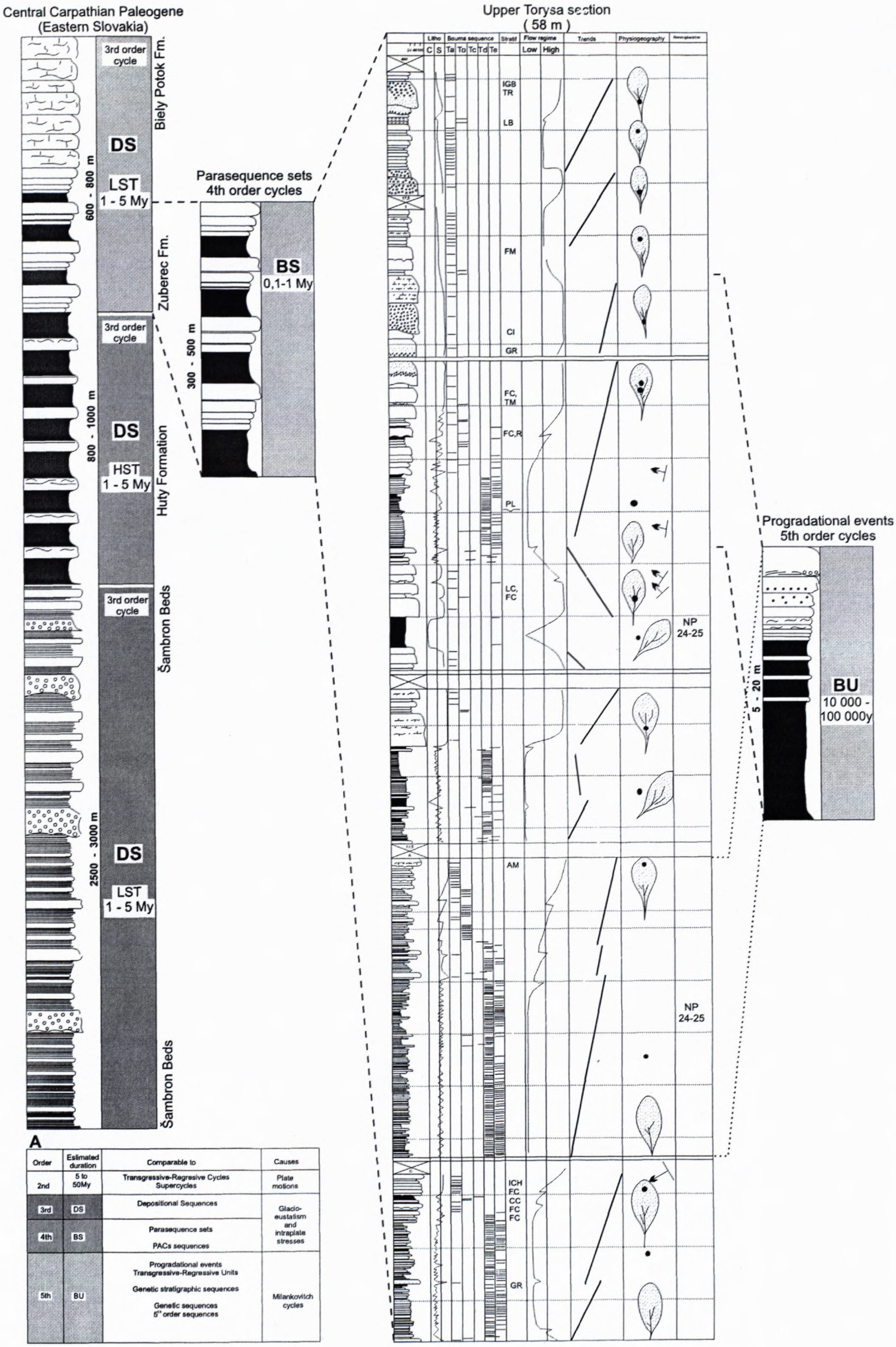
Fig. 3 Subsidence patterns of the Central Carpathian Paleogene derived from backstripping of the basin-fill sequences, compared with sea-level fluctuations and sedimentation rates

Miocene age is more apparent from the sequence stratigraphy correlations. During the Late Oligocene - Early Miocene, the global eustasy occurred under a distinctive regression, which led to gradual shallowing and brackishing of Paratethyan basins. In the Central Carpathian Paleogene basin, the Late Oligocene regression is recorded by the Biely Potok Fm. providing an input of sandy-rich deposits and shallow-water brackish species of dinoflagellates (Hudáčková 1998). Regressive trend of the Late Oligocene - Early Miocene sedimentation reached the maximum lowstand on the base of the NN2 zone, when the brackish fauna became to appear (Steininger et al. 1995). Such brackish event, indicating by the fauna of small gastropods, has been recently detected in the sandstone lithosome sediments of the Levočské vrchy (Soták in prep.). By this, the deposition of the Biely Potok Fm. should terminated till to the Early Eggenburgian (Late Egerian sensu Berggren et al. 1995), i.e. to the lowstand phase at the beginning of the NN2 zone, which proceded next transgressive cycle TB 1.5 sensu Haq (1991) occurred on the base of the Prešov Fm. (Hudáčková et al. 1996, Kováč & Zlinská 1998). In fact, the gastropod-bearing sandstones and overlying sandstone lithosomes of the Biely Potok Fm. (cca 300 m in the Levočské vrchy Mts.) could not be assigned to "flysch", but rather to molassa sediments deposited during a retrogressive stage of basin evolution. Nevertheless, the vitrinite reflectance data from the near-surface sediments of the Levoeské vrchy Mts. point out, that up to 2 km of this sequence is missing (Kotulová et al. 1998). So that, the last third-order cycle of deep-sea fan deposition in the Central Carpathian Paleogene kept on for about 7 Ma (29 - 22.5 Ma) giving a high accumulation rate of sandy-rich deposits (320 - 370 m/Ma). The time-equivalent sedimentation in the Outer Flysch Carpathians took also place in lowstand setting, recorded by the Krosno Facies (incl. Ždánice-Hustopeče event - Krhovský & Djurasinovič 1993).

The sequence stratigraphy approach allows to subdivide the basin-fill sequence in more detail - Fig. 4 (according to predictive approach of Ciner et al. 1996). The main depositional sequences (DS) can be divided into particular cyclic units such as progradational sequence of lobes, lithosome sequence of suprafan, channelized sequence of the upper fan zone, etc. (each having a thickness of 300 - 600 m). Although, the BS development can easily be explained by autocyclic factors (compensation cycles levelled deep-sea fan relief - Mutti & Sonnino 1981), we cannot exclude even their origin in the sea-level fluctuations (cf. Mutti 1992, Posamentier et al. 1988 etc.). These BSs are comparable with forth-order cycles, which correspond to parasequence sets spanning the time between 0.1 - 1 Ma. The BS can be further subdivided into the basic units (BU). The BUs are developed as a small-scale cyclic units of lobes, channels, levees, etc. The thickness of these BUs in the Levoča Mts. ranges from 5 to 20 m. For example, in a complete 13 m thick lobe unit there are about 115 individual turbidites. Considering the recurrence time for one turbidite event about 300 - 400 years (Rupke & Stanley 1974) the duration of this unit may be calculated for 35 to 46 Ka. In this case, the BUs might correspond to fifth-order cycles developing over intervals between 10 and 100 Ka (i.e. Milankovitch cycles). Using BU data to calculate the BS (cca 20 BUs), a time span of about 700 Ka to 1 Ma appears to be reasonable for the forth-order cycles.

Conclusions

The Central Carpathian Paleogene basin accommodates the destructive plate-margin domain. The basin-fill formations began to develop from continental footplain sediments, shoreface sands and carbonate platform deposits (Nummulitic banks) related to Lutetian -Bartonian transgressive cycles 3.5 and 3.6 sensu Haq et al., 1988 (cf. Bartholdy 1997). In the Priabonian, the carbonate platforms were subsequently drowned by sea-level rising, which reached an early highstand with dominance of hemipelagic deposition and high productivity of the Globigerina Marls. Afterwards, the Central Carpathian Paleogene basin occurred under dominancy of turbidite fan deposition. The turbidite sediments of the Central Carpathian Paleogene can be divided into three depositional sequences (DS) comparable to third-order cycles. Lower cycle of turbidite lowstand deposition is represented by the Šambron Beds (Priabonian - Early Rupelian), which are considered to be synrift sediments of the marginal slope fans accumulated along scarps in tilted-fault-block situation (cf. Surlyk 1978). Next depositional sequence reveals the maximum rate of eustatic rise in the Central Carpathian Paleogene basin, which during the Lower Oli-



Order	Eslimated duration	Comparable to	Causes
2nd	5 to 50My	Transgressive-Regresive Cycles Supercycles	Plate motions
3rd	DS	Depositional Sequences	Glacio-eustatism and intraplate stresses
4th	BS	Parasequence sets PACs sequences	
5th	BU	Progradational events Transgressive-Regressive Units Genetic stratigraphic sequences Genetic sequences 5th order sequences	Milankovitch cycles

Fig. 4 Turbidite systems of the Central Carpathian Paleogene and their possible subdivision to depositional sequences (DS) and cyclic units (BS - basic sequences, BU - basic units). A - correlation with cyclic sequences proposed in literature, see Ciner et al. 1996.

gocene starved in highstand deposition of the mud-rich fans (Huty Fm.). Maximum flooding of this highstand formation falls into the horizon of manganese layers (condensed sections of MFS). Early Oligocene highstand sedimentation of the Central Carpathian Paleogene correspods to the so-called Menilite event of the Outer Flysch Carpathians. The last third-order cycle of the Central Carpathian Paleogene reflects an abrupt sea-level fall near time of 30 Ma which introduced the Late Oligocene deep-sea fan deposition. Upper Oligocene sediments were deposited as a prograding lowstand wedge with complex deep-sea zones. Higher up, the sequence grades up to sandy-rich deposits of suprafan, which terminated to the Early Miocene, as is evidenced by the backish event (small gastropods, etc.) indicating the maximum lowstand on the base of the NN2 zone. The time-equivalent sedimentation in the Outer Flysch Carpathians took also place in lowstand conditions recorded by the Krosno Facies. Such correlations indicate a narrower range of the Central and Outer Carpathian basins and their Paleogene (Early Miocene) sedimentation driven by global eustasy.

The turbidite systems of the Central Carpathian Paleogene can be subdivided into more particular up to small-scale units comparable with the forth-order cycles (basic sequences - BS, time duration 0.1 - 1 Ma) and fifth-order cycles (basic units - BU, with time duration of 10 - 100 Ka). The development of these units could have been controlled by autocyclic or allocyclic factors.

The implication of sequence stratigraphy to basin history of the Central Carpathian Paleogene reveals an integrated effects of tectonism and eustasy. The basin began to develop with initial collapse and rapid subsidence, induced probably by tectonics (gravitational collapse due to tectonic erosion - cf. Wagreich 1993). Initial subsidence pattern of the Central Carpathian Paleogene basin reflects a trenchward tilting with a fault-controlled accumulation of marginal slope fans (Šambron Beds). The accommodation space of the Central Carpathian Paleogene basin was enlarged by landward aggradation progressed through alluvial aprons, shoreface banks and shelfal deposits. Landward migration of the basin was driven by a highstand eustasy inferred from overall of pelagic sedimentation. The accumulation of sandy-rich deposits during the Upper Oligocene does not exhibit a tectonic subsidence record (flexural loading). Therefore, the sediment input of deep-sea fans should be initiated by allocyclic (external) factors. Besides of source tectonics, which was a major control of the the deep-sea fan accumulation, the deposition seems also to be accelerated by eustasy (its onset coincides with the abrupt sea-level fall near 30 Ma - Krosno event in the Outer Carpathians). Under the lowstand accumulation of the deep-sea fan clastics the Central Carpathian Paleogene basin became gradually uncompensated with rate of subsidence and overfilled. The sandy-rich submarine wedge grew to form an elevated bulge with a convex-upward relief (suprafan). The sedimentation in the Central Carpathian Paleogene ceased under a tectonic shortening and gradual uplift recorded by the mollase-like sediments of retrogradational cycle (Early Miocene). This paper is a contrib. to VEGA grant no 4077.

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