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Artikel: The terminal Eocene and Early Oligocene events in Hungary and the separation of anoxic, cold Paratethys

Autor: Báldi, Tamás

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The terminal Eocene and Early Oligocene events in Hungary and the separation of an anoxic, cold Paratethys[1])

By TAMÁS BÁLDI[2])

ABSTRACT

Based on paleontologic and magnetostratigraphic evidence, the stratigraphy of the Eocene and Oligocene sections in Hungary are discussed as a means for recognizing major events effecting the area. They include the Eocene/Oligocene boundary at 37 My, the first indications of the Paratethys isolation at 36–35 My, whereon increasing cooling took place and the first total separation of the Paratethys from the Tethys between 35 and 33 My. Between 36 and 31 My the Paratethys was affected by a number of anoxic phases. The separation of the Paratethys from the Tethys was caused by the Late Eocene subductions and overthrustings in the Eastern Alps and Dinarids, which were followed by isostatic readjustments of the Internids and the formation of a land barrier. The Kiscellian is proposed as a Paratethys regional stage. Its base is equated with the Eocene/Oligocene boundary, its top with the lower boundary of the Egerian stage, within zone NP24.

ZUSAMMENFASSUNG

Basierend auf paläontologischen und magnetostratigraphischen Methoden, wird die Stratigraphie der Eozän- und Oligozän-Ablagerungen von Ungarn besprochen mit dem Zweck, bedeutende Ereignisse im Untersuchungsgebiet während dieser Zeitspanne zu erkennen. Dazu gehören neben der Eozän/Oligozän-Grenze vor 37 Mio. Jahren die ersten Anzeichen einer Isolation der Paratethys vor 36–35 Mio. Jahren, mit der eine zunehmende Abkühlung einsetzte, sowie die erste totale Abtrennung der Paratethys von der Tethys zwischen 35 und 33 Mio. Jahren. Zwischen 36 und 31 Mio. Jahren erfuhr die Paratethys eine Reihe von anoxischen Phasen. Zur Trennung der Paratethys von der Tethys führten die späteozänen Subduktionen und Gebirgsbildungen in den Ostalpen und Dinariden, welche ihrerseits isostatische Kompensationen der Interniden und die Bildung einer Landbarriere zur Folge hatten. Das Kiscellian wird als regionale Stufe vorgeschlagen. Seine Basis fällt mit der Eozän/Oligozän-Grenze zusammen; seine Obergrenze entspricht der Basis der Egerian-Stufe und liegt innerhalb der Zone P24.

Introduction

The Eocene/Oligocene boundary has been a very old, most debated question of the Hungarian geology since its beginnings. After BEYRICH had introduced the Oligocene in 1854, the grand old men of the Hungarian geology, HANTKEN & HOFMANN, who were mapping the Buda Hills, laid down the foundation of the lithostratigraphy and

[1]) Presented at the "Terminal Eocene Event Meeting" at Visegrád, Hungary, 1983.

[2]) Department of Geology, Eötvös Loránd University, Budapest, Muzeum krt. 4/a, H–1088.

correlation of the Late Eocene–Early Oligocene sequence in Hungary. A violent debate developed between them about the position of this boundary already more than a century ago.

HANTKEN described as "*Clavulina szabói*-Schichten" the Bryozoa Marl, the Buda Marl and the Kiscell Clay, and placed the whole series into the Oligocene. On the other hand, the Bryozoa Marl ("Bryozoen-Mergel") was recognized by HOFMANN as Upper Eocene, while the Buda Marl ("Ofner Mergel") and the Kiscell Clay ("Klein-Zeller Tegel") were placed also by him into the Oligocene. The dispute of the two geologists, and the pioneering work of HANTKEN in the field of micropaleontology, attracted attention throughout Europe. No lesser personalities than HÉBERT, MUNIER-CHALMAS in 1876, BEYRICH in 1877, OPPENHEIM, FUCHS and others visited the Hungarian type localities in the classical area of the Szép-völgy ("Schön-Tal") near the Kiscell Plateau in Budapest. Today this area is entirely built up and the best profiles are now obtained by cores from drill holes.

Figure 1 demonstrates the general setting of the Late Eocene–Early Oligocene sedimentary area of Hungary within the Alpine–Carpathian–Dinaric system.

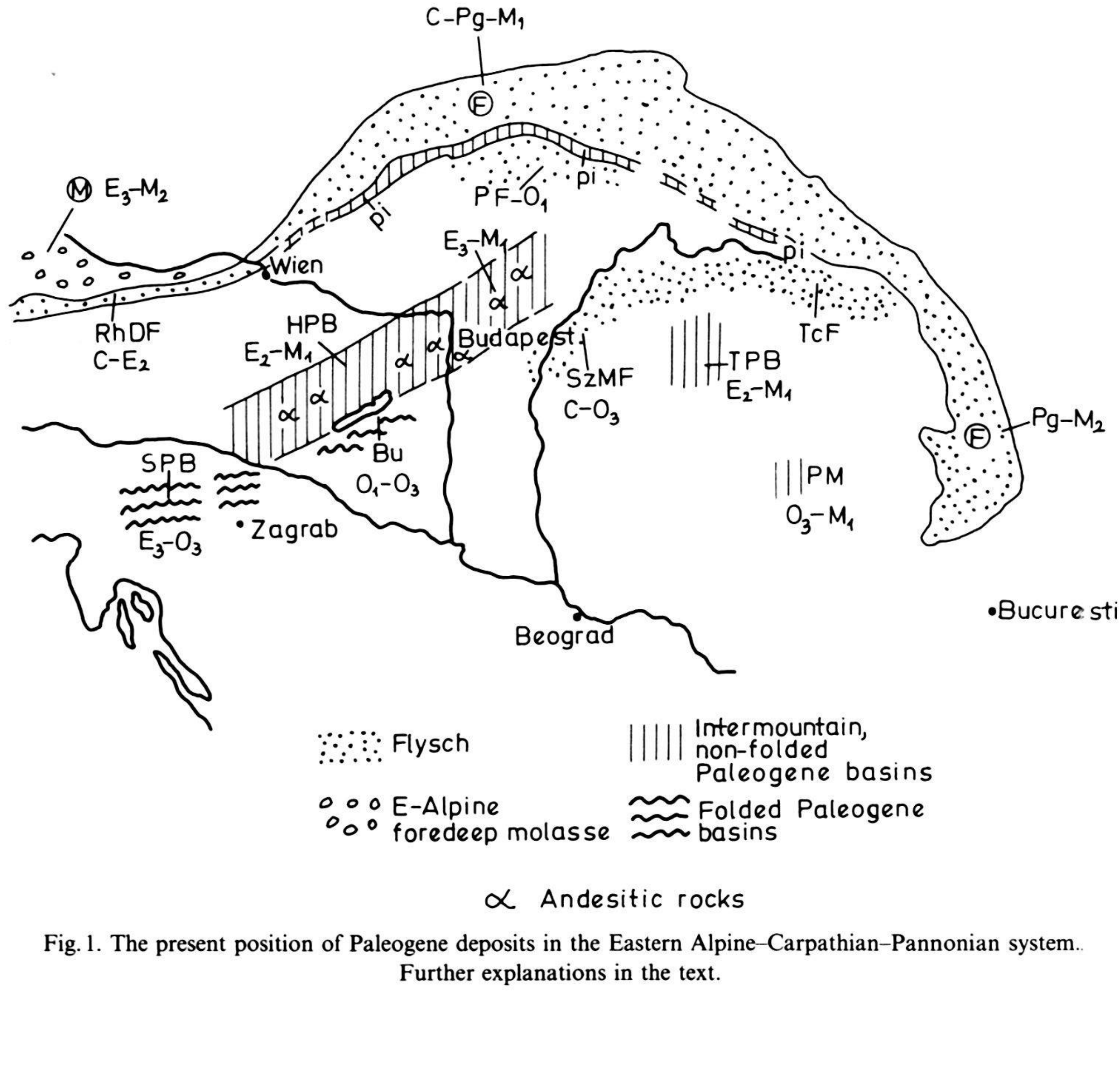

Fig. 1. The present position of Paleogene deposits in the Eastern Alpine–Carpathian–Pannonian system. Further explanations in the text.

M = Austrian Molasse; sedimentation from Late Eocene to Middle Miocene.
RhDF = Rhenodanubian Flysch; age of the sediments from Cretaceous through Middle Eocene, overthrusting and folding in Late Eocene.
pi = Pienides; age of the sediments from Jurassic through Late Paleogene, folding in Neogene.
F = Outer Carpathian Flysch; age of sediments from Cretaceous through Early Miocene, overthrusting and folding in Middle and Late Miocene.
PF = Inner Carpathian (Podhale) Flysch; sedimentation from Cretaceous till the end of Early Oligocene, no strong folding.
SzMF = Szolnok Flysch; sedimentation from Cretaceous through Latest Oligocene, folded in Neogene (known from borings).
TcF = Trans-Carpathian Flysch; sedimentation from Cretaceous until the end of Oligocene, folding in Neogene.
HPB = Hungarian Paleogene Basin; sedimentation from Lutetian until the end of Early Miocene, not folded, only block-faulted. This is our area of interest now.
TPB = Transylvanian Paleogene Basin; sedimentation from Middle Eocene through Early Miocene, not folded, only slightly faulted.
PM = Petrosani Basin; Egerian–Eggenburgian (Late Oligocene–Early Miocene).
SPB = Slovenian Paleogene Basin; Late Eocene–Egerian (Oligocene) sediments strongly folded at the end of Oligocene (Savian folds).
Bu = Buzsák Oligocene; Early through Late Oligocene, strongly folded, known only from cores. It is a supposed continuation of the Slovenian Paleogene.

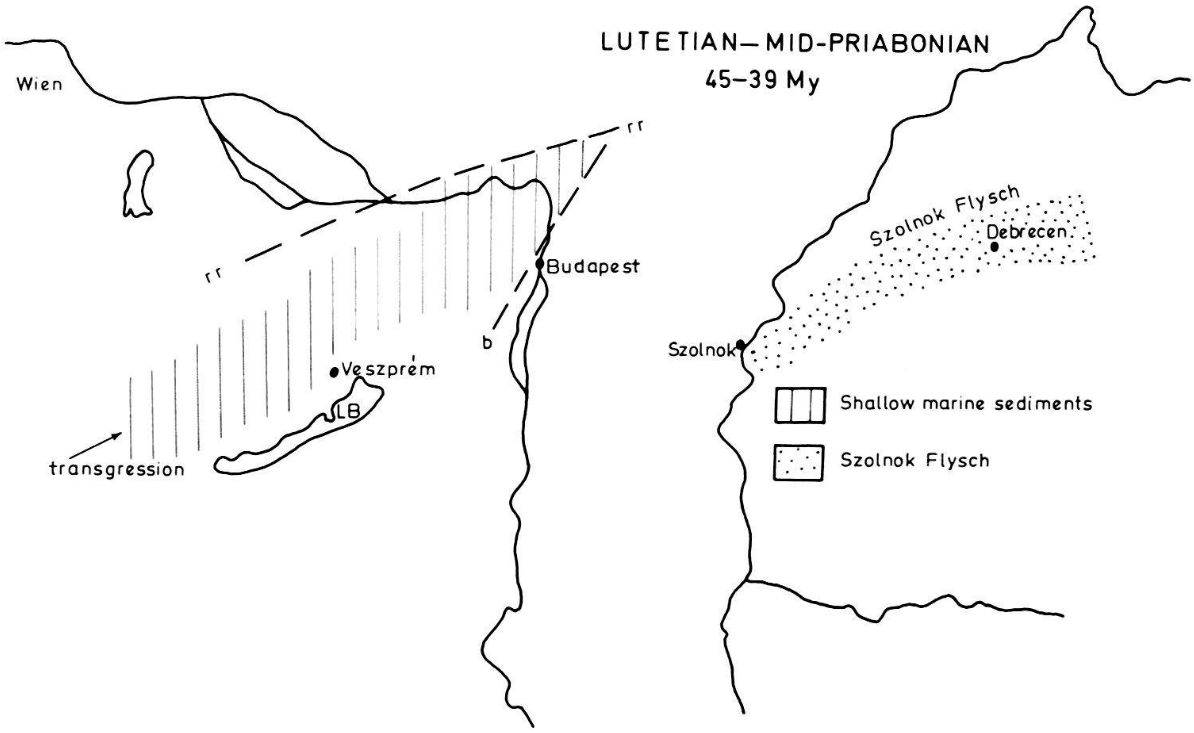

Fig. 2. The present distribution of Lutetian–Mid-Priabonian sediments (vertical hatching) in Hungary, as related to the Szolnok Flysch.
rr = Rába–Rozsnyó lineament; b = Buda lineament.

Figure 2 schematically demonstrates the distribution of the Middle Eocene (Lutetian–Bartonian) and earliest Priabonian of Hungary. The transgression arrived from southwest. A sequence of a few hundred meters includes a brackish-paralic formation with coal seams in the deeper part and shallow marine marls and limestones in the upper part. In some sections this sequence is overlain by Early Priabonian *Globigerina* marls which escaped the intra-Priabonian denudation. The sediments are tectonically limited in distribution, namely by the Rába–Rozsnyó line (rr) and by the Buda line (b). These lines are supposed to be big strike slip faults which changed the relative position to the Szolnok Flysch considerably (see below).

Figure 3 shows the recent position of the Late Priabonian–Oligocene sedimentary basin of Hungary. Areas of continuous sedimentation (Buda Marl–Tard Clay–thick Kiscell Clay–Egerian) are indicated by the latticed symbol. They are the basin centres. Areas with transgressing Kiscell Clay are symbolized by vertical lines, and dots indicate where the Kiscell Clay is underlain by the Hárshegy Sandstone. The direction of transgression is from the northeast. Lateral movements have changed the relative position of the Szolnok Flysch also in this case.

The general stratigraphy of the Eocene/Oligocene sections in Hungary

Figure 4 indicates the locations of the most significant Late Eocene–Early Oligocene sections of Hungary. West of the Buda line the general succession is the following: Mesozoic or Upper Eocene limestones are unconformably overlain by the Hárshegy Sandstone Formation (NP24 Zone), which in turn grades upwards into the Kiscell Clay (NP24). This type of succession is typical for the areas of Tokod, Sárisáp, Esztergom, Solymár, Berkenye, Szendehely (Báldi et al. 1976). The hiatus No. IV (named earlier "infra-Oligocene denudation") may cover 7 million years and include at least three nannozones. This area is therefore of little interest for the designation of the Eocene/Oligocene boundary.

There are, however, two exceptions. In the section of the boring Alcsútdoboz-3, quite a thick portion of the Buda Marl and Tard Clay somehow escaped the "infra-Oligocene denudation". Underlying unconformity No. IV, a continuous Late Eocene–Early Oligocene section is available with the characteristic zones.

The other exception is the Felsőpetény–Romhány area, where, in a surface section (Romhány–Délhegy) and in a dozen core-hole sections, we can recognize unconformity No. III, covered by the lowermost horizon of the Tard Clay with the *Spiratella* Zone. The Tard Clay is here unconformably underlain either by the Triassic Dachstein Limestone (Délhegy) or by Priabonian biogenic limestones. It grades upwards with alternations into the Hárshegy Sandstone. Because of the absence of the Buda Marl (the III. unconformity), this area is not suitable for designating a "golden spike", but it is interesting to note that the Tardian Sea or the *Spiratella* sea had a transgression here soon after the turn of the Eocene/Oligocene.

East of the Buda line, in the central area of the basin, a continuous sequence developed and has been preserved. The classic succession of the Priabonian Limestone, Bryozoa Marl (Hofmann 1871), Buda Marl (Hofmann 1871, Hantken 1871), the Oligocene Tard Clay (Majzon 1940), and the Kiscell Clay (Peters 1859) can be studied here in continuous sections. The continuity of sedimentation provides a good oppor-

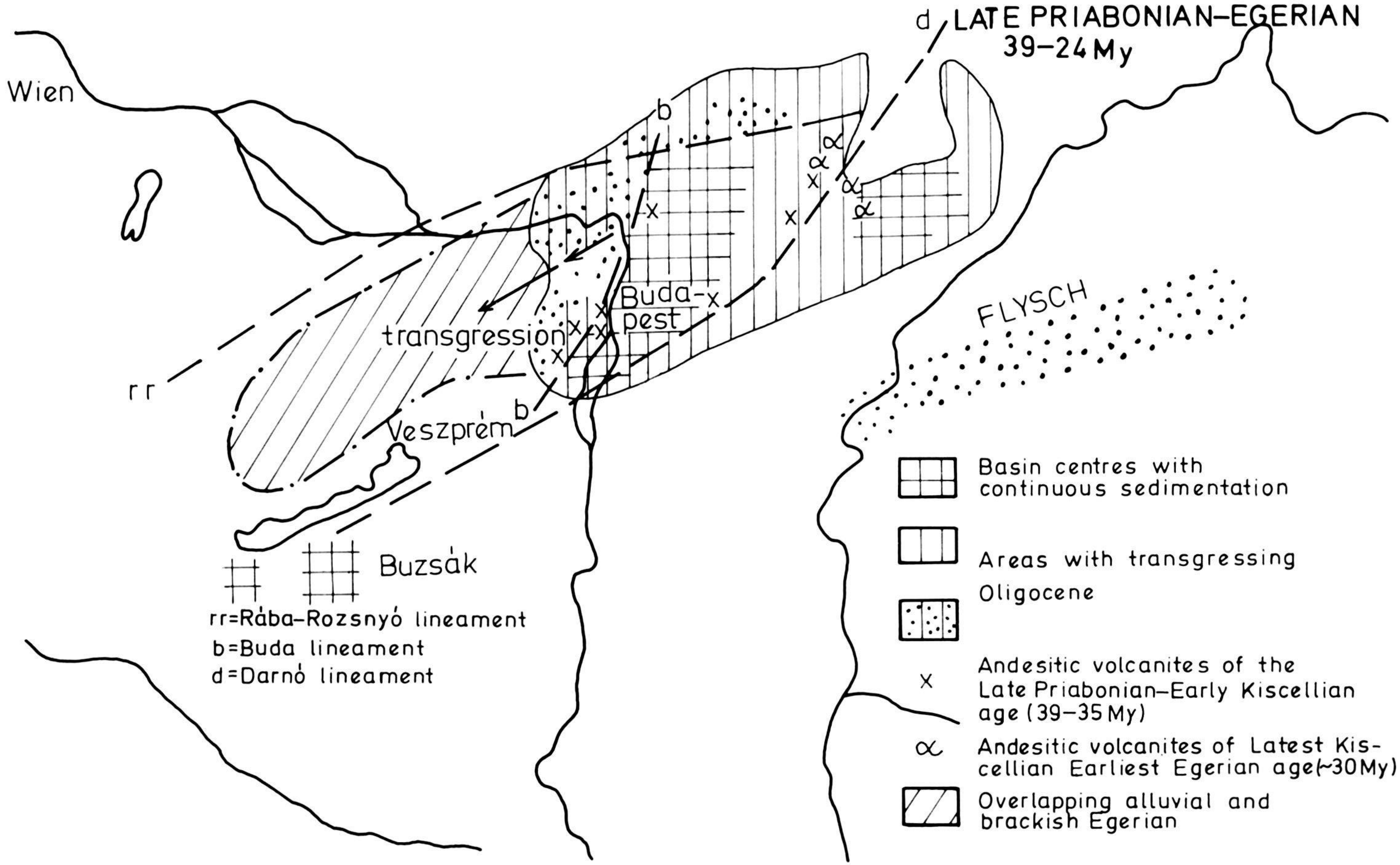

Fig. 3. The present distribution of the Late Priabonian to Egerian sediments in Hungary. Further explanations in the text.

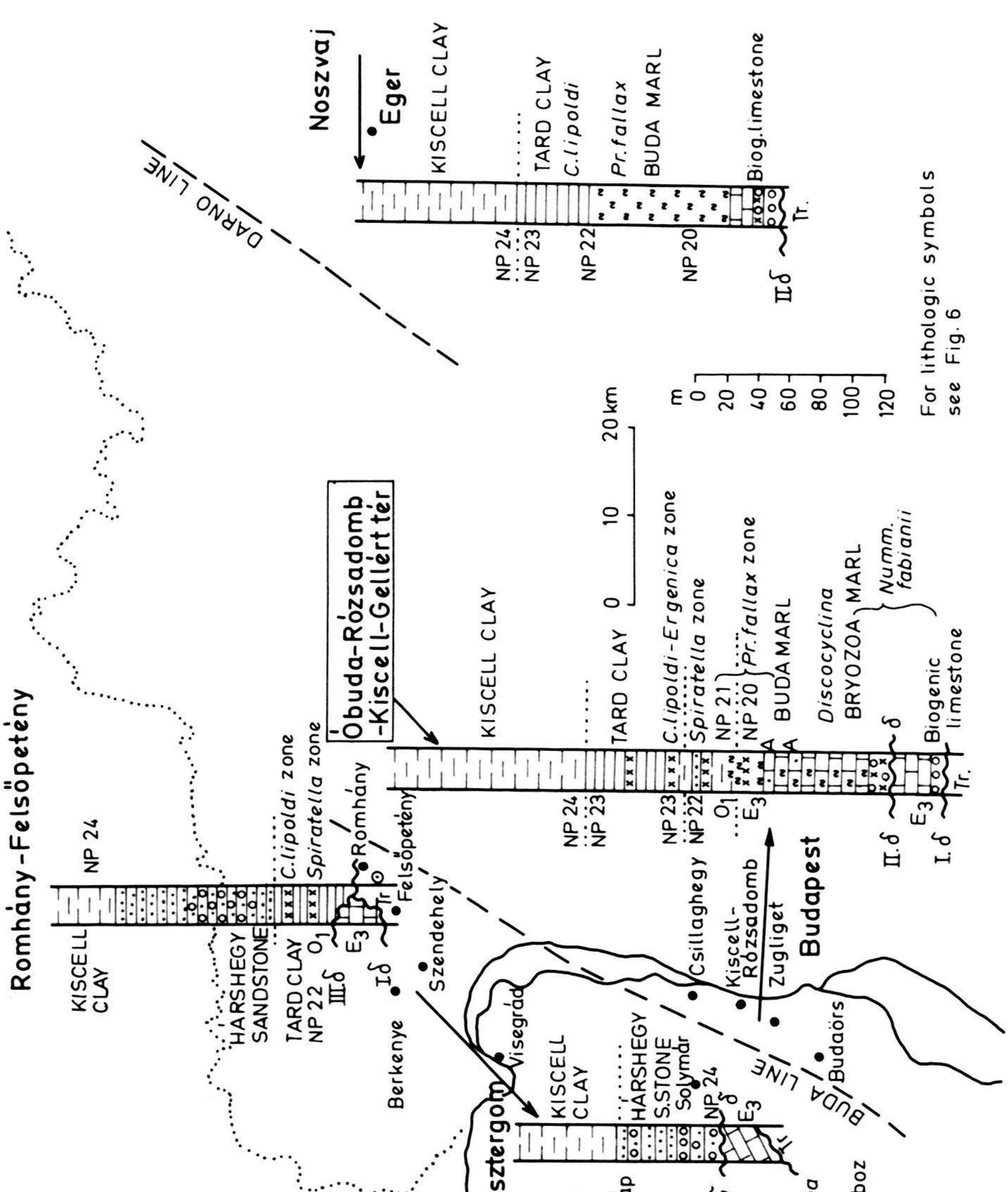

Fig. 4. Selected (generalized) profiles of the Late Eocene–Early Oligocene sequences of the Hungarian Paleogene Basin. Further comments in the text.

tunity in this area for a closer study of the terminal Eocene events. Because good surface sections are very rare, most of the new results had to be obtained from studies on cores. The differences between the Budapest and Eger area are not significant.

The following core-hole sections in the Budapest area were studied, in which the Eocene/Oligocene boundary was drilled: in Kiscell (Óbuda) the boring Kiscell-1 (drilled for the stratotype section by the Hungarian Geological Survey) and H 11/a, H 12, H 13 borings; in József-hegy-Rózsadomb the FTV 8/3 (Fillér utca), FTV 6/3 (Borbolya utca), FTV 4 (Mandula utca), FTV 2, FTV 3; in Angyalföld the H 3; south of the Gellért-hegy (Gellért Hill) the M 299, M 300, M 302 sites; in Zugliget, the Zug.-2, drilled for the stratotype section. In the Eger area, only the Cserépváralja-1 boring, drilled by the Geological Survey (HÁMOR) was investigated. The most important outcrops studied are Csillaghegy-Ibolya utca, Pusztaszeri út, Mátyás-hegy, Martinovics-hegy, Zugliget-Gim utca, Budaörs in the Buda Hills and Eger–Kis-Eged, Noszvaj-Síkfőkút, Kisgyőr, etc. in the Eger area.

Figure 5 provides information on the Late Eocene–Early Oligocene of the Budapest area. The Buda line crosses the Buda Hills, and west of it (dotted lines) the Solymár type succession with unconformity No. IV can be found. The classic area of HANTKEN and HOFMANN is located around Kiscell, Rózsadomb and Szép-völgy (Schön-Tal). The full succession is present here (area marked by fine dots) without unconformities around the Eocene/Oligocene boundary.

The stratigraphy of this area is as follows: The Priabonian overlies transgressively the Mesozoic with a biogenic limestone, formed by *Nummulites fabianii*, corals, bryozoans, echinids, calcareous algae, molluscs, discocyclinids, etc. (KÁZMÉR 1983). After a short erosional interval, the Bryozoa Marl was deposited, unconformably covering either the Triassic or the Priabonian biogenic limestone (No. II unconformity). The Bryozoa Marl is formed of basal conglomerates, calcareous *Discocyclina* and Bryozoa Marls, *Gypsina* and echinid limestones. Those parts of the shelf where the *Discocyclina* and/or Bryozoa facies developed may indicate a depth up to 100 m.

The Buda Marl evolves gradually out of the Bryozoa Marl. The change in sedimentation was caused by the collapse of the calcareous submarine platform of the Bryozoa Marl. The high ratio of planktonics (Globigerinids, pteropods) and the dominance of *Propeamussium* and *Cyclopecten* or *Palliolum* among the molluscs indicates the considerable depth of the Buda Marl sea. The depth of this basin was more than 200 m, but could have reached even 1000 m. This depression was formed by a rather rapid tensional process. From the neighbouring seafloor which remained shallow, calcareous detritus was transported again and again into the depression by turbidity currents. Therefore, the lower part of the Buda Marl contains several turbiditic limestone intercalations ("allodapische Kalke"), which include coarse bioclasts of shallow marine molluscs *(Ostrea, Chlamys)*, calcareous algae and *Nummulites fabianii*. The intercalations show in most cases normal gradation, and their thickness is generally less than 1 m (BÁLDI 1983). The upper portion of the Buda Marl is more clayey, and no turbiditic intercalations can be found. The whole formation measures 30–60 m in thickness.

In the Eger area the succession is similar, except that the typical Bryozoa Marl is here substituted by biogenic limestones.

The Buda Marl grades upwards into the Tard Clay. The lower 20 m of the Tard Clay is not or only slightly laminated. It abounds in planktonics, and *Propeamussium*

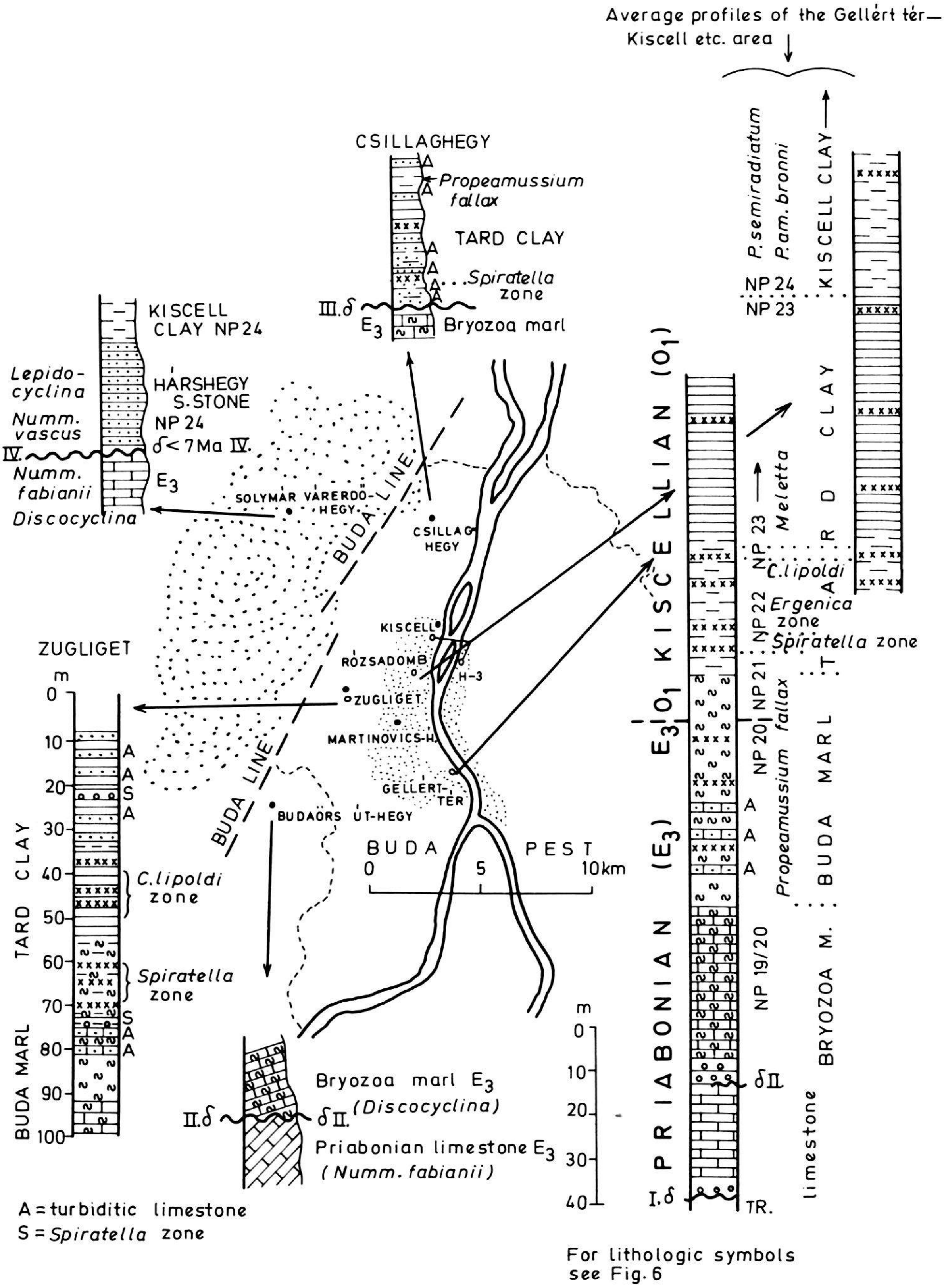

Fig. 5. Late Eocene–Oligocene sequences of the Budapest area. Further explanations in the text.

fallax still occurs. This indicates an essentially unchanged bathyal, marine environment. Therefore, the lithostratigraphic boundary between the two formations is in some cases uncertain and not sharp.

In this lowermost part of the Tard Clay, immediately above the last occurrence of *Propeamussium fallax*, two *Spiratella* zones occur. The thickness of each zone varies between some centimeters and some meters. It is literally full of the compressed, poorly preserved shells of the almost planispirally coiled Pteropod *Spiratella* BLAINVILLE 1817 (= *Limacina* BOSC 1817; = *Planorbella* GABB 1872) and of fish scales.

Some meters above the *Spiratella* horizon, the 10 m thick zone of *Cardium lipoldi* ROLLE, *Ergenica cimlanica* POPOV and *Janschinella melitopolitana* NOSSOVSKI follows (BÁLDI 1979, 1980). The rich but poorly preserved benthic mollusc association is accompanied by large sized ostracods. Though the species diversity is low, the number of individuals is high.

The *C. lipoldi* Zone is overlain by more and more strongly laminated sediments of the Tard Clay, which contain no benthos but only fish scales and remains of whole marine and brackish fishes (WEILER 1933, 1938). Furthermore, a rich macroflora of excellently preserved leaf imprints (HABLY 1979) is found.

This upper part of the Tard Clay is very poor in $CaCO_3$. On the other hand, it is very rich in pyrite (2–7%) bound to framboids and in organic matter of sapropelic origin (BÁLDI-BEKE 1977, VETŐ in BRUCKNER-WEIN et al. 1983).

The Tard Clay is conformably overlain by the nonlaminated Kiscell Clay, which is rich in planktic and benthic foraminifera and in molluscs. *Propeamussium* reoccurs with more taxa. The depth of the Kiscell Clay sea was well below 200 m and could have reached even 1000 m. Comparing the Kiscell Clay mollusc fauna with KNUDSEN'S (1970) Galathea report on the recent abyssal malakofauna, I have found that 38% of the Holocene abyssal genera are common in the Kiscell Clay. Furthermore, bathyal decapods (*Thaumastocheles rupeliensis* BEURLEN 1939) and bathyal cirripeds (*Scalpellum* SZÖRÉNYI 1934) occur beside 7 pteropod and 4 nautiloid taxa (BÁLDI 1983). On the basis of the foraminiferal fauna W. Berggren (pers. comm.) estimates the depositional depth of the Kiscell Clay at 800 m.

The typical sediment of the Kiscell Clay is a silty clayey marl; sandy turbiditic intercalations are rare (BÁLDI 1983).

An andesitic–dacitic, subordinately rhyolitic volcanic activity is indicated by the sandy tuff intercalations in the Buda Marl and by the andesite pebbles in the conglomerates in the Bryozoa Marl. In the Tard Clay, thin laminae of andesite tuffs are often intercalated, mainly in the deeper part of the formation. While the volcanic material in the Bryozoa and Buda marls seems to be reworked, the intercalations of the Tard Clay indicate aerial transport before deposition into the sea (SZABÓ & BALOGH 1983). The upper part of the Tard Clay is already poor in tuff intercalations and they are almost absent from the Kiscell Clay. The tuffaceous intercalations are marked on Figures 5 and 6 by the symbol "x".

To the west of the classic Kiscell area, close to the Buda line, but still in its eastern flank, one finds successions which more or less deviate from those of the classical area. In the outcrop Csillaghegy-Ibolya utca, the Buda Marl is either lacking or is substituted by the Bryozoa Marl. In the first case, which is the more probable, the Bryozoa Marl is overlain unconformably by the Tard Clay with its *Spiratella* Zone at the base.

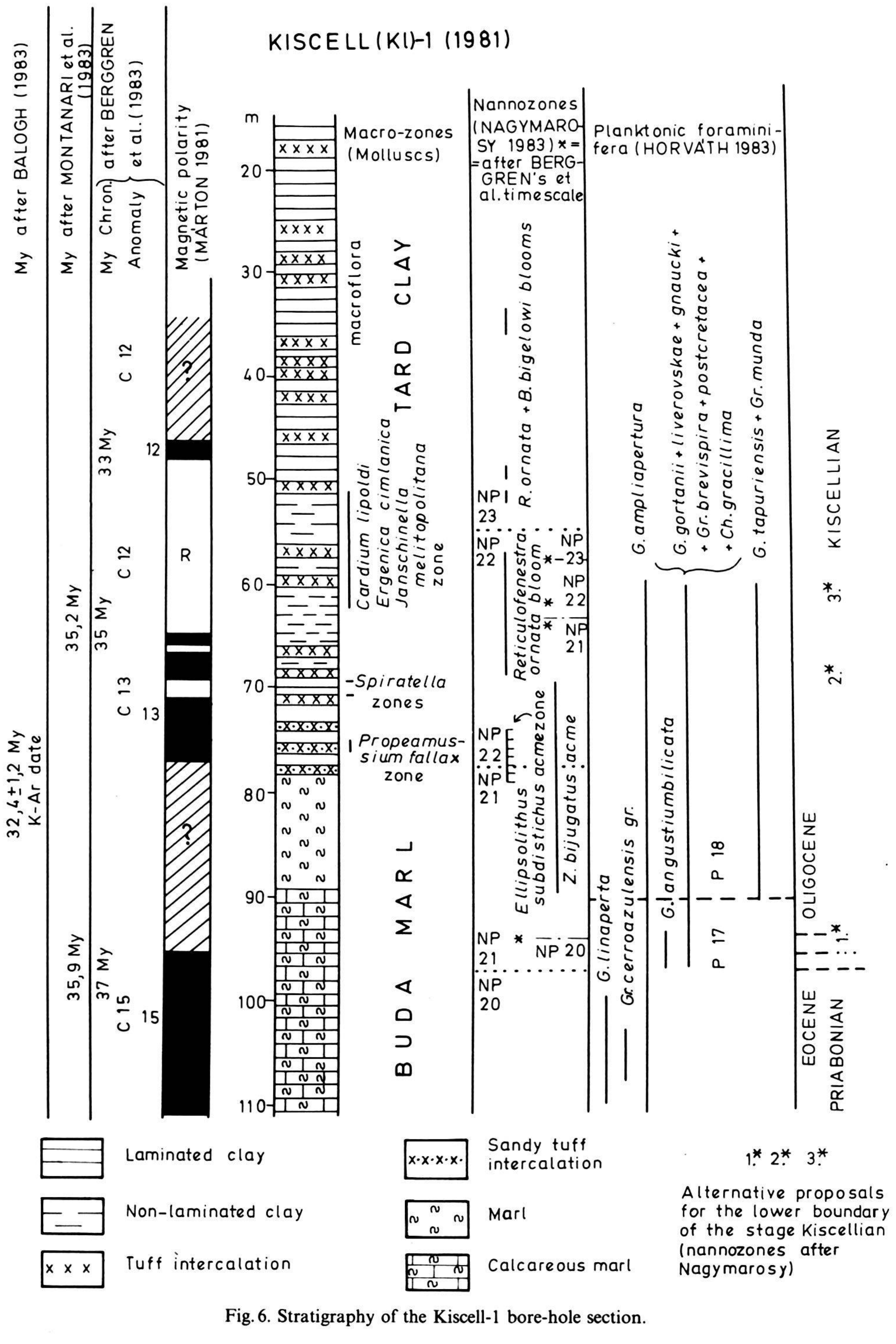

Fig. 6. Stratigraphy of the Kiscell-1 bore-hole section.

This would be the No. III unconformity, known so far only from the Felsőpetény-Romhány area. The Tard Clay itself is also different: frequent turbiditic limestone intercalations and some thin olistolite (fluxoturbiditic) layers of pebbly mudstone are intercalated. Many of the fossils found in these beds are redeposited. The discocyclinids, for example, were first abraded in a shallow sea; afterwards they were transported by submarine slumps, slides or turbidity currents in to the deep basin of the Tard Clay. The planktonic foraminifera (HORVÁTH 1983, NAGYMAROSY 1983) and the *Palliolum–Propeamussium* fauna of the autochthonous clay in this section indicate an Oligocene age and a considerable depth of deposition. It is interesting to note, however, that all the larger foraminifera which occur in the turbiditic and olistolithic intercalations are restricted to the Priabonian. No Oligocene larger foraminifera (as e.g. *Nummulites vascus*) were found (VARGA 1983). Because of the Oligocene age of the planktonics and the *Spiratella* Zone, the larger foraminifera seem to belong to an older fauna.

Two explanations are possible:

1. The larger foraminifera were eroded from a semi-consolidated Priabonian sediment and transported by slump and/or turbidity currents into the depression. No favourable environment existed in the shallow sea for an Early Oligocene larger foraminiferal population.
2. The autochthonous and redeposited fossils were living contemporaneously; this could prove the coexistence of an Early Oligocene planktonic assemblage with a shallow shelf assemblage believed so far to be restricted to the Eocene *(Discocyclina, Nummulites fabianii)*.

The second solution seems to be more probable, since we studied a section near Eger (Noszvaj–Síkfőkút), in which the last *N. fabianii* are followed by the first *N. vascus* assemblages (KECSKEMÉTI & VARGA 1983), but – after the planktonics – the age of the whole section is already Early Oligocene (NAGYMAROSY 1983, HORVÁTH 1983).

The Zugliget profile is again different, both in the boring and in the outcrop. The Tard Clay here also contains several turbiditic limestone intercalations, even nonturbiditic calcareous sandstone interbeddings. However, the Buda Marl is present in Zugliget.

Very close to the Buda line, the sharp angular and erosional unconformity No. II can be seen in the Budaörs–Úthegy outcrop.

The Eocene/Oligocene Boundary and the Kiscellian in the Kiscell-1 core-hole section

This is the most elaborately studied section so far. It has a continuous, rather condensed sedimentary sequence ranging from the Tard Clay down to a very calcareous Buda Marl (Fig. 6). Therefore, I would propose the Kiscell-1 site for the lower boundary stratotype of the stage Kiscellian and also for a good reference section of the "Terminal Eocene Events". The full core material is available at the Szépvizér storing station of the Hungarian Geological Survey.

The lithostratigraphy is as follows:

0–52 m well-laminated Tard Clay with leaf imprints and fish scales;

52–72 m slightly laminated or nonlaminated Tard Clay with thin laminitic intercalations and with tuff laminae;

72–90 m nonlaminated clayey marl (Buda Marl or Tard Clay) with thin sandy tuff intercalations;

90–110 m calcareous marl (Buda Marl) with turbiditic limestone intercalations.

At 75 m *Propeamussium fallax* indicates this zone; the two *Spiratella* zones were found at 69.6 and 70.4 m, respectively. The *Cardium lipoldi* Zone with its characteristic fauna was recognized between 51 and 63 m.

The magnetic polarity was measured by Márton (1981). Planktonic foraminifera were studied by Horváth (1983). After her, the Eocene/Oligocene boundary would be placed at 98 m in the bore-hole section.

Nannoplankton studies were carried out by Nagymarosy (1983). The *C. lipoldi* Zone overlaps part of NP22 and NP23. *Reticulofenestra ornata, R. lockeri* and *Braarudosphaera bigelowi* blooms are common in and above this interval (as shown already by Báldi-Beke 1977). The *Spiratella* zones are included in NP22. The nannozones are, however, very indistinct in this section, because of the reworking (for example, reworked *Discoaster saipanensis* still occurs in the *C. lipoldi* Zone). They are conflicting also with the global time scale of Berggren et al. (1983). The only reliable nannodatum seems to be the *Ellipsolithus subdistichus* Acme zone, recognized by Nagymarosy between 75.0 and 79.0 m (NP21–22).

Based on all data above and furthermore on the time scale of Berggren et al. (1983), we can correlate Márton's (1981) normal polarity zone at 34.5–47.1 m with anomaly 12, and the underlying reversed zone at 48.5–65.0 m would fit also into chron C12. Since the *C. lipoldi* Zone is bound to C12 reversed, I estimate the duration of the *C. lipoldi* Zone after Berggren et al. (1983) at two million years, between 33 and 35 My.

The *Spiratella* zones should be included in a reversed interval of C13; their age is around 36 My, but 35 My in the Montanari et al. (1983) time scale.

The Eocene/Oligocene boundary, as proposed by Berggren et al. (1983), can be placed of around 37 My, within a reversed zone between anomaly 13 and 15. Recently, Márton (1983, communication in the Hungarian Geological Society) withdrew his results obtained on samples from the 77.9, 79.70 and 80.40 m. Reliable normal polarity was found from 94.60 m downwards, and this portion belongs to anomaly 15. The Eocene/Oligocene boundary is in the Kiscell-1 section somewhere between 78 and 95 m. More accurate proposals have resulted from the studies of planktonics (Horváth 1983, Nagymarosy 1983). The Eocene/Oligocene boundary lies within the upper part of the Buda Marl, and within the *Propeamussium fallax* Zone. It can also be near the base of the *Ellipsolithus subdistichus* Acme zone, which indicates part of nannozone NP21.

As to position of the lower boundary of the Kiscellian stage, three possibilities can be considered:

1. At the Eocene/Oligocene boundary.
2. At the lower *Spiratella* level where the first Paratethyan features occur (around 36 My, at 70 m in this boring).
3. At the base of the first real Paratethyan endemic macrofaunal zone (*C. lipoldi;* around 35 My, at 63 m in the section).

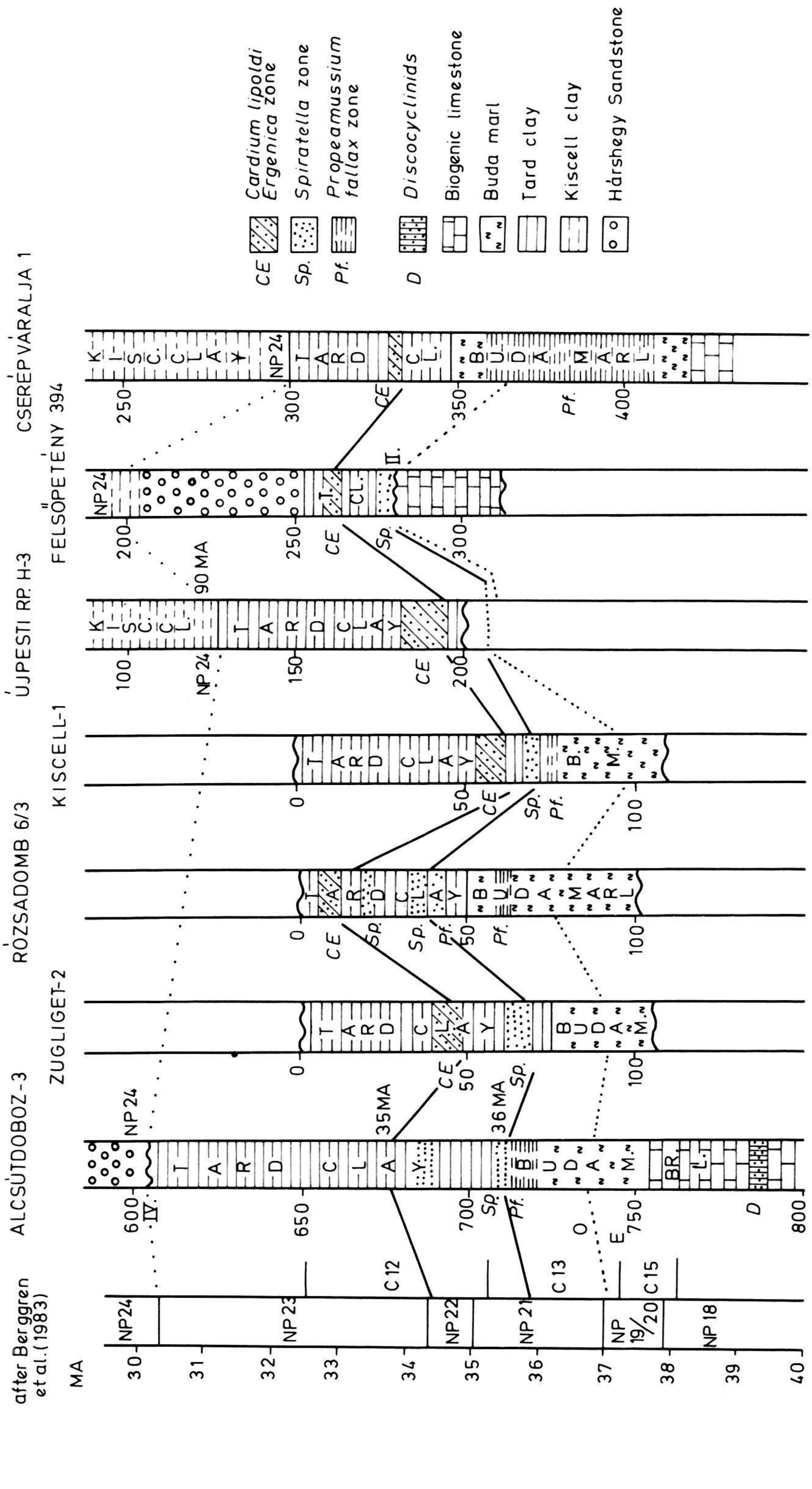

Fig. 7. Correlation of some selected Hungarian profiles.

A strong argument for the first solution is the fact that no gap would be left between the top of the Priabonian and the base of the Kiscellian. On the other hand, it would be rather difficult to recognize this boundary in practice, and its datum still precedes the first tendencies of the Paratethyan isolation by one million or half a million years. According to the second and third proposals, a gap of 0.5 or 1–2 million years would be left between the end of the Priabonian and the beginning of the Kiscellian.

Finally, it is interesting to note that there is a K/Ar date from the boring, obtained on biotites from 79 to 82 m. This is 32.4 ± 1.2 My after BALOGH (1983), who himself doubts the reliability of this date. This datum is conflicting both with the magnetostratigraphic and biostratigraphic date as well as those of with BERGGREN et al. (1983) and stands close to the datings of WOLFE, GLASS & CROSBIE, ODIN & CURRY, etc. (see in BERGGREN et al. 1983).

Correlation of selected Late Eocene–Early Oligocene profiles of Hungary

Our most important sections penetrating the continuous Eocene/Oligocene boundary are figured on Figure 7. The *Propeamussium fallax* Zone, the *Spiratella* zones and the *C. lipoldi* Zone can be recognized all over the basin area. Since they are always confined to the same planktonic zones throughout the area, it can be assumed that they are coeval. In Alcsútdoboz-3 and in Rózsadomb 6/3 the lower *Spiratella* Zone overlies directly the top of the *Propeamussium fallax* Zone. This zone boundary is 35–36 My old, as it was proven on the Kiscell-1 section. The Eocene/Oligocene boundary, as proposed by BERGGREN et al. (1983), lies below this level in the Buda Marl.

The lithostratigraphic boundary between the Buda Marl and the Tard Clay is not distinct because of the undisturbed transition. The designation of this boundary can be subjected to different personal judgements. Also it can be a diachronous level. On the average, the base of the Tard Clay seems to be very close to the *Spiratella* horizon, which is always within the Tard Clay. In some cases, the *Propeamussium fallax* Zone reaches into the lowermost Tard Clay.

The *C. lipoldi–Ergenica cimlanica* Zone covers the time span 33–35 My, within the reversed zone of the C 12 chron. The base of nannozone NP 24 is around 30 My old, and the Kiscell Clay deposition starts at this datum. This is not contradicting the K/Ar date on glauconite from the Kiscell Clay, determined by BALOGH (in BÁLDI et al. 1975) as 33 ± 3 My. It is conflicting with his latest results on the Buda Marl (BALOGH 1983). In our opinion, the possibility of placing the lower boundary of NP 24 1–2 million years deeper in BERGGREN'S otherwise good time scale would deserve consideration.

Correlation with South and East Europe

Figure 8 shows the correlation of the Hungarian profiles with the Austrian molasse, Transylvania, Slovenia, the Outer Carpathian Flysch, southern USSR, Bulgaria and northern Italy (southern Alpine foreland). The *C. lipoldi–Ergenica* Zone is here regarded synchronous throughout the region studied, covering the time span 33–35 My. This is in good accordance with the results obtained on nannoplankton, which everywhere indicate the nannozone NP 23 within the *C. lipoldi* horizon, as it was shown in

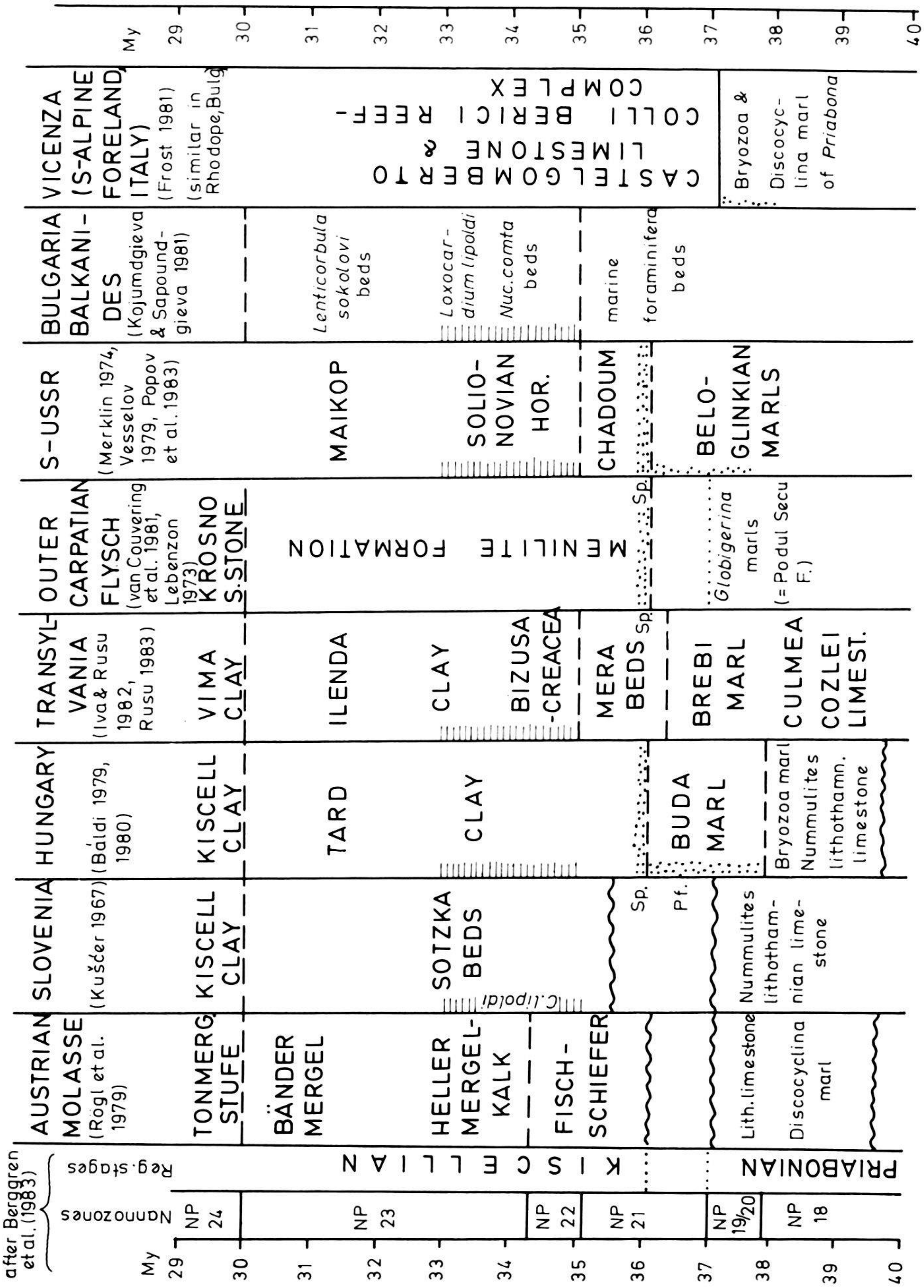

Fig. 8. Correlation of some Tethyan and Paratethyan areas for the Late Eocene and Early Oligocene. Sp = *Spiratella* Zone; Pf = *Propeamussium fallax* Zone.

Transylvania (Mészáros & Ianoliu 1977) and in the southern USSR (Vesselov 1979). Based on the synchroneity of the *C. lipoldi* Zone, the Sotzka beds (Slovenia), the Bizusa, Creaca and Ileanda formations (Transylvania), the Solionovian and Serogozian horizons (southern USSR) and the beds with *C. lipoldi* described by Kojumdgieva & Sapoundgieva (1981) from the Balkanides (Bulgaria) are coeval with the Tard Clay. The "Fischschiefer" and especially the "Heller Mergelkalk" – a pelagic fossilized nannochalk – in the Austrian Molasse were deposited in a deeper marine environment than the Tard Clay; therefore, the *C. lipoldi* Zone can be absent. But after the studies by Rögl et al. (1979), we can establish a reliable correlation, based mainly on the nannoplankton and planktonic foraminifera. The same is valid for the Carpathian Menilites of pelagic, oceanic origin, where plankton foraminifera and nannoplankton as well as the *Spiratella* (= *Planorbella*) Zone make the correlation possible (Lebenzon 1973, Martini & Lebenzon 1971, Van Couvering et al. 1981).

The *Spiratella* Zone is well-known from the southern USSR in the northern Caucasus as far as Lake Aral. Its stratigraphic position in the Chadoum Formation seems to be similar, probably identical with the Hungarian occurrence.

Both in Hungary and in the southern USSR the *Spiratella* Zone is underlain by the *Propeamussium fallax* Zone. We can place the Eocene/Oligocene boundary below the *Spiratella* Zone (which is around 35–36 My old) into the upper *Propeamussium fallax* Zone (37 My).

The sedimentologic and faunistic evolution of the areas discussed above is very similar; there are similar formations and the same faunal zones. In sharp contrast, the South-Alpine foreland around Vicenza, northern Italy, had a radically different evolution. Until the end of the Priabonian, the fossil content and the depositional facies were very similar to the Carpathian–Alpine region (Bryozoa and *Discocyclina* marls with *Nummulites fabianii,* as in Budapest). But from the beginning of the Oligocene one of the world's most beautiful Tertiary coral-reef complexes (Colli Berici) and barrier-lagoon facies (Castelgomberto Limestone) were built up here (Frost 1981). The area south of the Alps demonstrates a totally different geological evolution. A similar difference is seen in Bulgaria between the Balkanides, the Varna area and the southern Rhodope. The Balkanides and the Varna area have a sedimentological history and fauna, regarding the Oligocene, which is similar to that of the North Alpine–Carpathian–Caucasian region. On the other hand, the southern Rhodope, with its thick Oligocene coral limestone formations, stands much nearer to northern Italy (Bontchev 1960, Kojumdgieva & Sapoundgieva 1981, Báldi 1980).

The Late Eocene–Early Oligocene events

Figure 9 summarizes the chronology of events in the Alpine–Carpathian area.

The Priabonian and the Early Oligocene were tectonical unrest periods. During this interval unconformities No. I, II and III came into existence, each covering a duration of around half or one million years. Between unconformities I and II, several smaller unconformities exist after M. Kázmér (pers. comm.). Around 38 My ago, extensional stresses led to the formation of a deep basin, where the Buda Marl was deposited. At the same time calcareous sedimentation persisted in shallow parts of the sea which escaped subsidence. Turbidity current activity was strong at this time and reoccurred

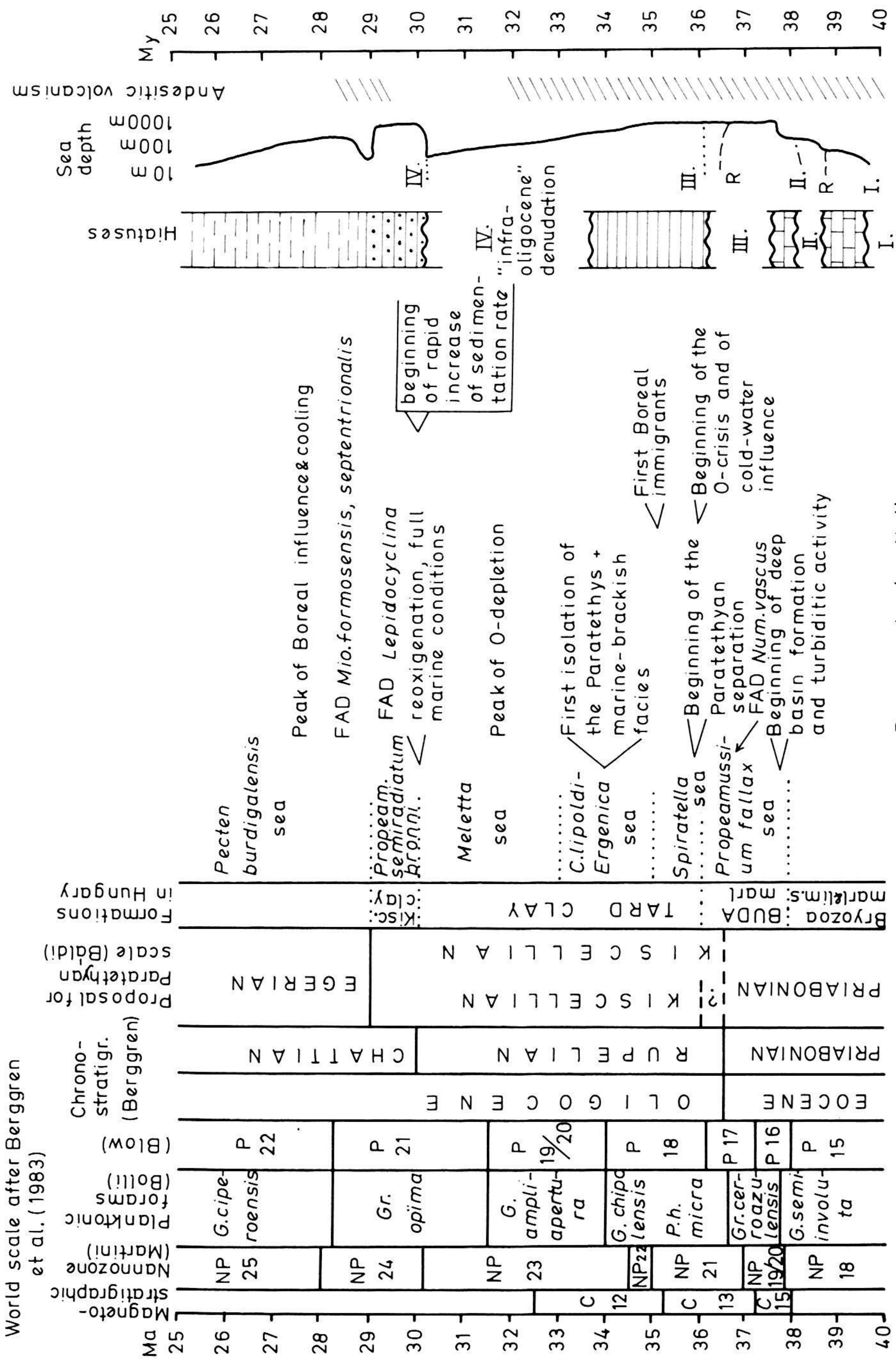

Fig. 9. Most important events in Late Eocene–Early Oligocene times. See also comments in the text.

later, as indicated by turbiditic intercalations found in the Tard Clay and Kiscell Clay. Olistolithic intercalations (fluxoturbidites) in the same formations also indicate rather steep parts of the seafloor. The andesite pebbles in the Bryozoa Marl and the tuff intercalations in the Buda Marl and Tard Clay can have a connection with those crustal movements, which caused the unconformities. The centres of the andesitic volcanism are known from south and southwest of Budapest (in strongly denudated patches, dykes, etc. known from bore holes), and from the Recsk area (eastern Mátra Hills).

These tectonic and magmatic events are coeval with the overthrusting of the Austro-Alpine nappes (the Alpine Internides) on the Rheno-Danubian Flysch, which event took place during Late Eocene times (Tollmann 1980).

Upwards there is a normal Tethyan sequence and fauna in the sedimentary column until the *Spiratella* Zone (36 My), which is located in the lowermost Tard Clay. The Eocene/Oligocene boundary, as proposed by Berggren et al. (1983) would underlie the lower boundary of the Tard Clay.

In the lowermost Tard Clay, the *Spiratella* Zone is always confined to a strongly laminated intercalation, which is already of Early oligocene age.

What is the paleoecological meaning of the mass occurrence of *Spiratella*? This is a crucial question, since the *Spiratella* Zone is the first evidence of a process, which led one million years later to the separation of a Paratethys from the Tethyan province.

Scattered occurrences of large and small *Spiratella* shells are known throughout the Buda Marl, Tard Clay and Kiscell Clay (observed also by M. Horváth, pers. comm.), but the mass occurrence is limited to the *Spiratella* Zone.

Our fossil *Spiratella* shells are very poorly preserved and compressed. All shells of the *Spiratella* Zone seem to belong to one species. This form – in comparison with Recent Spiratellas – stands very close to *Spiratella helicina* Phipps, but its size is larger. Another Recent close relative can be *Spiratella helicoides* Jeffreys.

Our knowledge about the ecology of the Pteropods is rather scanty (Kennett 1982). After Bé & Gilmer (1977), all living Spiratellas are restricted to normal salinity seawater. "The low species diversity of the Cold-water Region contrasts sharply with the high diversity of the Warm-water Region" (Bé & Gilmer 1977). The only thecosomateaous pteropod living in the Arctic Ocean is *Limacina (= Spiratella) helicina* Phipps, which is a typical polar epiplanktonic species, not extending in major quantity in equatorial direction beyond the 50° S and 45° N latitudes, respectively (Bé & Gilmer 1977). *Spiratella helicoides* Jeffreys is a bathypelagic form, found between 500 and 1500 m depth, recorded mainly from the middle latitudes of the Atlantic.

The very probable relationship between the Spiratellas of the Tard Clay and the two living species indicates a cold-water influence during the deposition of the *Spiratella* Zone. The low diversity pteropod fauna could have been transported by cold currents which arrived from the North Sea or from the Arctic through the East European epicontinental sea, or through the Rhinegraben, which opened at this time into the North Alpine Molasse sea. The low diversity of the pteropod fauna is also a strong argument for the cold-water influence. In the same horizon the planktonic foraminifera are represented by low diversity assemblages of small sized taxa, as *Globigerina postcretacra, Globorotalia liverovskae,* etc. (M. Horváth, pers. comm.). The cold-water coccolith *Zygrablithus bijugatus* is common in this part of the section (M. Báldi-Beke, pers. comm.). One more evidence for cold-water influence are diatom oozes, which are deposited today in high latitude oceans (KENNETT 1982). Diatom oozes and cherts originating from it are common in the Carpathian Menilites. Deposition of Menilites began about at the same time, as that of the *Spiratella* clay.

We can take into consideration also the climatic deterioration of Early Oligocene times, recognized on a O-isotopic and paleobotanical basis (SAVIN et al. 1975, FRAKES 1979, KENNETT 1982). However, this process – a general cooling of the seawater – would have been gradual. The rather abrupt and synchronous occurrence of the *Spiratella* sea suggests an instantaneous cold-current break-in from the north. The Spiratellas could have been bathypelagic; this is not conflicting with other data (*Propeamussium*, turbidites, etc.), and would indicate a considerable depth of the Tard Sea.

The sedimentological change, the first appearance of laminated clay intercalations, is almost coeval with the development of the *Spiratella* clay and indicates the first tendencies towards temporary breakdowns of the vertical water exchange, leading to a temporary depletion of oxygen in the lower water layers and on the sea bottom.

The explanation of the development of an intermittently anoxic sea bottom for this time (36 My) is rather difficult, since no fresh- or brackish-water influence can be proved for the *Spiratella* sea.

Two possible causes may be considered:

1. Cold, dense water masses entered the basin from the north, filling the depressions and, in lack of a vertical exchange, were losing their O-content. This process was recurring whenever the cold currents from the north became stronger.
2. Brines were built up in the deep basin by evaporative, hypersaline shallow waters descending into the depressions. The example of the Rhinegraben, where evaporites are intercalated into the Fish Shales of the same age (DOEBL 1970), indicates the possibility of such an environmental development. FRAKES (1979) has summarized paleobotanical data indicating that around the turn Eocene/Oligocene the climate became not only cooler, but also dryer, after a warm humid Eocene. HABLY (1979, and pers. comm.) found that the fossil flora of the Tard Clay lived under a relatively dry climate, though the paleotropical character of this flora still persisted, but xerophilous marks could be proven on the basis of epidermis investigations. Abundant dolomite in the Tard Clay (Bognár, pers. comm.) could have been chemically precipitated, but an extrabasinal, erosional origin cannot be excluded.

During the time of the *C. lipoldi–Ergenica* Zone (35–33 My) freshwater influx became significant, and water stratification could develop by the recurring occurrences of a brackish surface water layer. The low diversity of this mollusc fauna and the occurrence of the Rzehakiid (= Oncophoridae) *Ergenica* indicate unstable salinity and brackish influences. Blooms of *Reticulofenestra ornata* and *R. lockeri*, and blooms of *Braarudosphaera bigelowi* somewhat higher, indicate a similar environment (BÁLDI-BEKE 1977, NAGYMAROSY 1983), as the ostracods also do after MONOSTORI (1983). Even freshwater forms were recognized among the ostracods (MONOSTORI 1983) and among the dinoflagellates (RÁKOSI 1983). This environmental situation can best be characterized by KENNETT'S (1982) words for the Black Sea: "The sediment sequence is controlled by changing history and balances between freshwater, mixed freshwater, marine and true marine conditions" (p. 487).

Similar conditions prevailed, on the basis of marine and brackish nectonic fishes, until the end of nannozone NP23 or the beginning of NP24, when the deposition of the Kiscell Clay began around 31–30 My ago and a reoxygenation occurred in the whole Paratethys.

One of the preconditions of the development of an O-depleted basin is isolation. Isolation is responsible also for the evolution of an endemic fauna such as the *Cardium lipoldi–Ergenica cimlanica–Janschinella melitopolitana* assemblage. The isolation was widespread, affecting the whole northern portion of the Tethys from the Western Alps through the Carpathian as far east, as Lake Aral. This isolated part of the Tethys is interpreted here as the Paratethys. This concept was originally introduced only for the Neogene isolations, but there is no reason for not extending it to the Oligocene, as long as the paleogeography and the conditions in general were quite similar to those occurring later in the Neogene.

We are now in a position to exactly date the process of the first isolation of the Paratethys. The first signs of isolation occurred at 35–36 My with the *Spiratella* sea and with the first occurrence of an anoxic facies. The isolation from the Tethys became more and more definite about 35 My ago with the appearance of the endemic mollusc association. The isolation was again suspended 31–30 My ago (zone NP24).

Paleogeography

Looking for the possible geodynamic causes of a Paratethyan separation in the Early Oligocene, the northward directed overthrustings in the Eastern Alps (Tollmann 1980) and the southwestward directed overthrustings in the Dinarides (Burchfiel 1980) could play a role. These crustal movements resulted in the isostatic uplift of the central part of the Alpine–Dinaric Internides, which became a flat mainland area. This mainland separated the newly born Paratethys from the rest of the Tethys. While on the northern active margin of this mobile mainland the anoxic, cold-water influenced Paratethyan sedimentation and fauna evolved during the Oligocene, south of this mainland the reef facies of Vicenza and Rhodope were built up in a warm-water environment. The barrier became active around 35–36 My ago, when north of it the *Spiratella* sea expanded, standing under intermittent or constant Boreal and Arctic influence. Boreal immigration can be recorded from the whole Paratethyan Oligocene (Báldi 1973, 1980 and others), except for intervals of total isolation such as the *C. lipoldi* chron. The Kiscell Clay mollusc fauna contains beside Boreal taxa many Tethyan ("Mediterranean") species. This indicates the opening of a marine strait at 30–31 My between the Tethys and the Paratethys. Slovenia is suggested as the place of this marine strait (Báldi 1973, 1980). The general climatic deterioration was not favourable for northward migration (Cavelier 1979); therefore, many Tethyan molluscs, as well as larger foraminifera *(Nummulites vascus, Lepidocyclina, Miogypsina),* could reach only the Central Paratethys area (Slovenia, Hungary, southern Slovakia, Austrian molasse). Quite a few northern species appeared at the same time in North Italy (Molare Formation, Piedmont; Báldi 1980).

Figure 10 shows the palinspastic paleogeography of the Carpathian area for the Lutetian to Mid-Priabonian and Mid-Priabonian to Late Kiscellian intervals, respec-

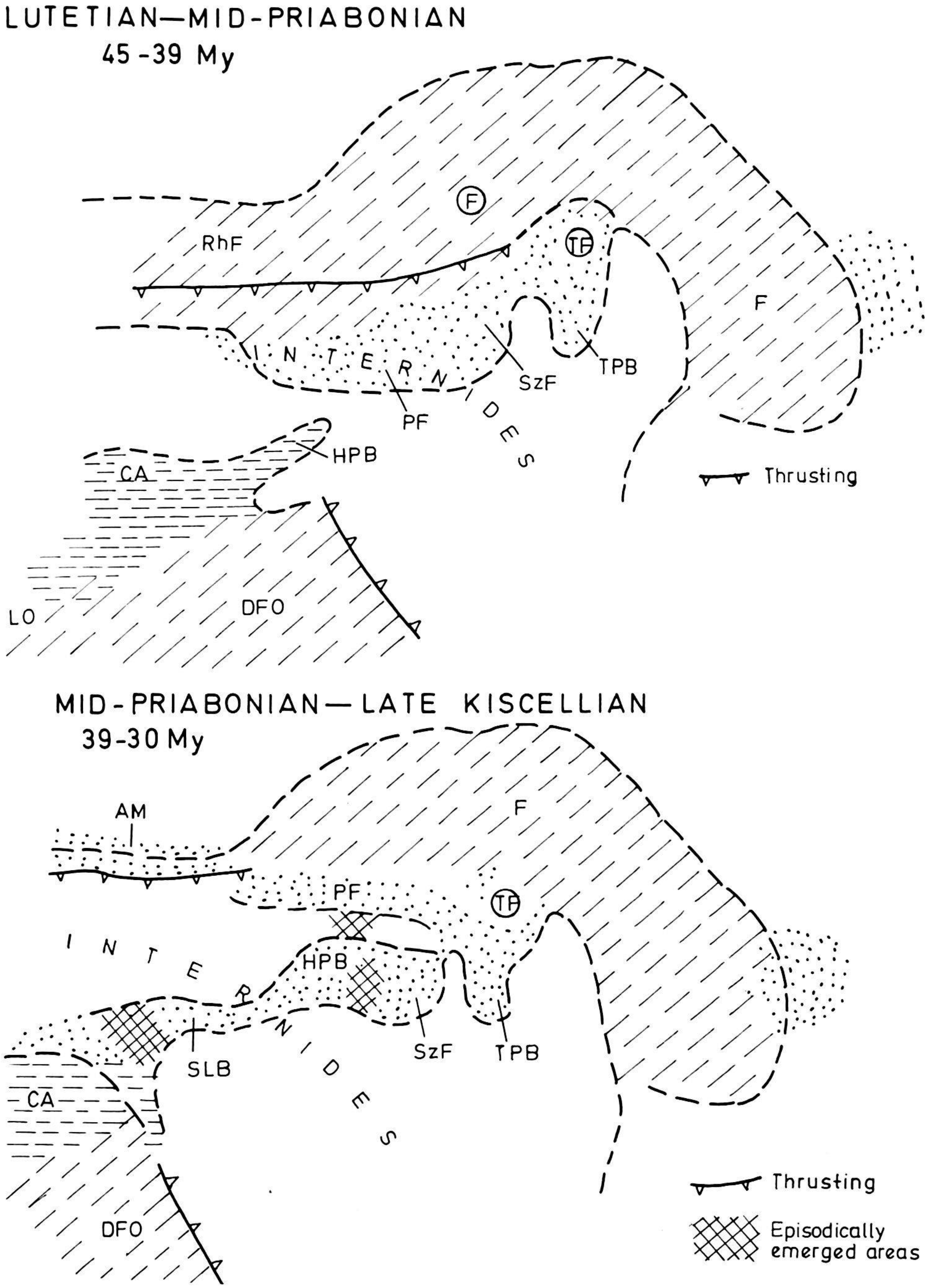

Fig. 10. Paleogeography of the Eastern Alpine–Carpathian–Dinaric system in Lutetian to Mid-Oligocene times.
CA = Carinthia; HPB = Hungarian Paleogene Basin; DFO = Dinaric Flysch sea; LO = Ligurian Ocean; F = Flysch sea; RhF = Rhenodanubian Flysch sea; TF = Transcarpathian Flysch sea; SzF = Szolnok Flysch sea; PF = Podhale Flysch sea; TPB = Transylvanian Paleogene Basin; AM = Alpine Molasse; SLB = Slovenian Basin.

tively. The basic method of the reconstruction was the unfolding into their original position of those Alpine and Carpathian nappes which had been overthrusted in the Late Eocene (Eastern Alps) or in the Miocene (Carpathian Flysch: BÁLDI 1982, 1983). On the other hand, the Internides are built up of structures which had come into existence already in Mid-Cretaceous time and which were located in a much more south and west position than today. Estimates of the Paleogene width of the Flysch ocean vary between 200 and 600 km (KSIAZKIEWICZ 1960, SWIDZINSKY 1971, UNRUG 1979, BURCHFIEL 1976). During Lutetian–Bartonian times, the Hungarian Paleogene Basin was a bay of the Ligurian–Dinaric ocean, while the Transylvanian Paleogene Basin was formed on the southern margin of the Carpathian Flysch ocean. This paleogeographic pattern is reflected also in the bioprovincial differences of the two areas at this time (in the nummulite and mollusc faunas, as summarized by BÁLDI 1982). In Mid-Priabonian through Late Kiscellian times, a new Hungarian Paleogene Basin was formed in North Hungary, extending eastward of the Buda line. This basin was in contact both with the Carpathian Flysch ocean and with the Dinaric–North Italian marine area. Northern influences could reach this basin through the Flysch ocean, while an isthmus between Slovenia and North Italy could have caused separation from the Tethys when it emerged above sea level in *C. lipoldi* Zone.

The Lutetian to Mid-Priabonian paleogeography of a large part of Europe, right before the isolation of the Paratethys is shown on Figure 11. Because of the warm-subtropical climate, the Boreal bioprovince is limited to the North Sea region, while the Tethys extends into the Alpine–Carpathian area. In the earliest Oligocene, a Paratethyan bioprovince was formed between the Boreal and Tethyan ones (Fig. 12), which was strongly influenced by the North Sea, because of the southward shift of the climatic belts in the Early Oligocene (CAVELIER 1979). In *C. lipoldi* times, the whole Paratethys became isolated from the Tethys, and partially also from the Boreal province. In NP24 the connection with the Tethys was restored through Slovenia, and also the northward marine straits became again wider and deeper.

Conclusions and proposals

1. The timing of events in the Alpine–Carpathian region is based on the magnetostratigraphically calibrated global time scale of BERGGREN et al. (1983). The Eocene/Oligocene boundary of 37 My is placed within the *Propeamussium fallax* Zone, which belongs to the uppermost part of the Buda Marl. This Eocene/Oligocene boundary lies between anomalies 13 and 15.
2. The first indications of the Paratethyan isolation can be recorded at the level of the *Spiratella* Zone (35–36 My) in the Tard Clay and Chadoum formations, 1 My after the turn Eocene/Oligocene. From this time onwards an increasing cold-water, boreal-arctic influence is recognized. This is in sharp contrast with the Oligocene reefal limestone sedimentation south of the Alps and of the Balkanides.
3. The *Cardium lipoldi–Ergenica cimlanica* Zone covers the interval between 35 and 33 My. During this time, the first total isolation of the Paratethys from the Tethys occurred, resulting in the evolution of an endemic mollusc fauna.
4. First anoxic events occurred in the *Spiratella* sea (36 My). From that time until

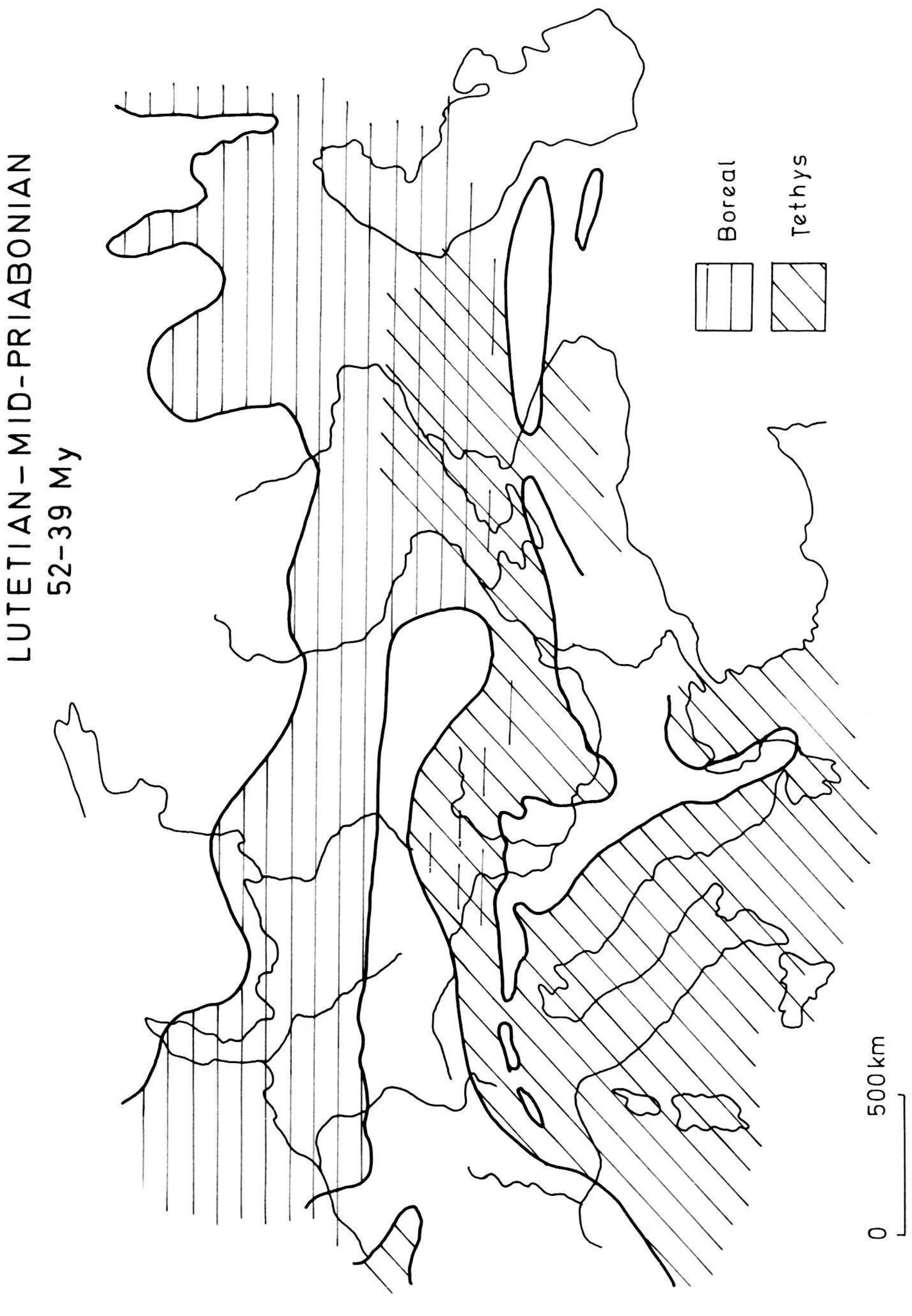

Fig. 11. Paleogeographic map of Central and Southeast Europe for the Eocene.

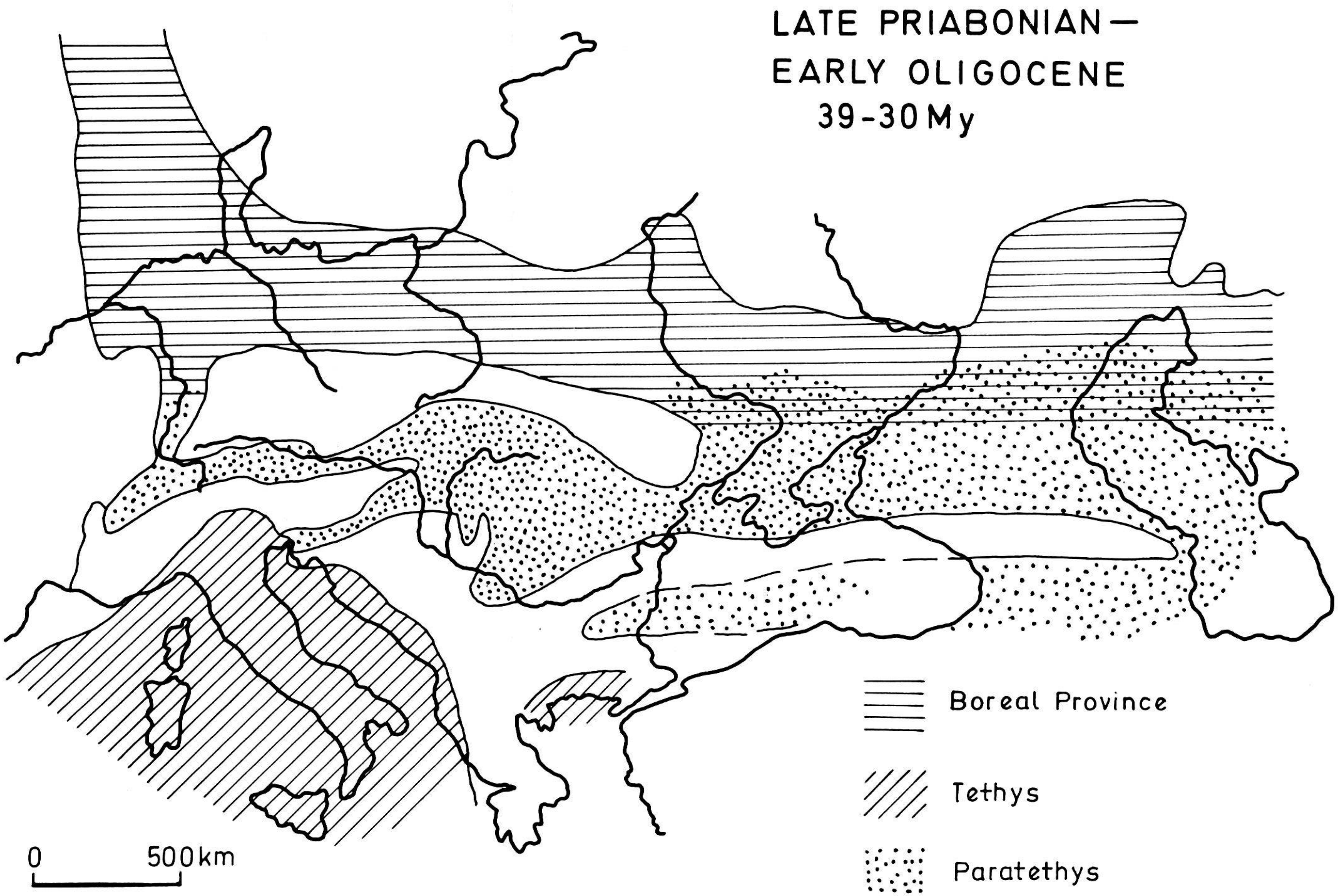

Fig. 12. Paleogeographic map of Central and Southeast Europe showing the Early Oligocene Paratethys.

zone NP24, between 36 and 31 My, the Paratethys was intermittently O-depleted due to stratification of water layers of different salinity and/or temperature. Reoxygenation occurred at the beginning of nannozone NP24.

5. The separation of the Paratethys from the Tethys was a consequence of subduction processes and overthrustings of Late Eocene age in the Eastern Alps and Dinarides, causing isostatic readjustments of the Internides, which emerged forming a mainland barrier.
6. The lower boundary of the Kiscellian stage (BÁLDI 1969, 1979) is proposed here to be placed at the Eocene/Oligocene boundary, but the base of the *Spiratella* Zone can be taken into consideration as the Kiscellian lower boundary. The upper boundary of the Kiscellian equals the lower boundary of the Egerian (BÁLDI & SENEŠ 1975), within the NP24 zone. The Kiscellian is proposed as a Paratethyan regional stage.

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