Palynological subdivision of Late Miocene sediments from Karlovo Basin (Central Bulgaria)

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Abstract. The results of palynological subdivision of sediments from four drilling cores in the Karlovo Basin (Central Bulgaria) are presented in the article. Spore and pollen zones of local character have been differentiated in each of the drilling cores. They are based on the characteristic changes in the percentage participation of the main pollen types obtained by the group hierarchical analysis as a method of numerical zonation. On the basis of definitive characters of the Local Pollen Zones (LPZ) and their stratigraphic location in the investigated drilling profiles, they have been divided into three groups. The first LPZ group has been differentiated in the sediments under the main coal layer and reflects the character of vegetation before the establishment of swampy environments. The next group of pollen zones corresponds to the period of vegetation development after rising of the water level and resumption of the lake regime. The pollen zones in the uppermost levels of the cores correspond to the latest stage of development of the vegetation in the area of Karlovo Basin registered in the fossil records. The thus differentiated three LPZ groups correspond to the vegetation dynamics, changes in the hydrological regime of the water basin and local climatic conditions, and could be regarded as regional character zones for the Karlovo Late Miocene Basin (Central Bulgaria).

Key words: Late Miocene, palynology, pollen zones, Karlovo Basin, Bulgaria

Introduction

Sediments of the Neogene Basins in Bulgaria contain important floristic information about the character and evolution of the local and regional flora. The Karlovo Late Miocene Basin occupies an important place in the system of lake-swampy sedimentary complexes on the Balkan Peninsula. Its specific location between the Balkan Range and Mt Sredna Gora determines its unique character. Irrespective of this, paleobotanical data about the basin are extremely scanty owing to the lack of natural outcrops of the Neogene Basin. Actually, from the system of continental basins of the so-called Sub Balkan Graben System of Central Bulgaria (Tzankov & al. 1996), there are palynological data only on the Karlovo Basin (Ivanov & Slavomirova 2004; Ivanov 2009), which permit the determination of pollen and spore zones. Indirect data on vegetation are also available from the petrographic and geochemical researches of the lignite coal (Zdravkov & al. 2006; Stefanova & al. in press).

The first attempt at palynological zonation was made for Middle and Late Miocene sediments from a drilling in the Pre-Carpathian Basin (Ivanov 1994). Subsequent palynological zonation of the sediments from that basin was made on the basis of three extra drilling cores (Ivanov 1997, 2002; Palamarev & Ivanov 1998). The recent studies of fossil palynomorphs from Sofia Basin (W Bulgaria) (Hristova & Ivanov 2009b) have contributed to differentiation of three zones and four subzones (Hristova & Ivanov 2009a). The present study is a further palynological subdivision of the different Neogene fresh-water basins and a step towards the creation of a palynostratigraphic scheme for the Late Miocene in Bulgaria.

Notes on the geology of Karlovo Basin

Karlovo Basin (Fig. 1) is a narrow graben structure filled in with Neogene sediments. It borders on the Troyan and Kalofer divide of the Balkan Range in the north, Mt Sredna Gora Proper in south-southwest, Sarnena Gora in the southeast, Koznitsa in the west and Strazha in the east. For a long time the presence of Late Miocene sediments in the Karlovo Basin remained unproved, owing to their limited and deficient outcrops. The idea of Pliocene sediments in the graben belonged to Yaranov (1961) and was subsequently proved by numerous drillings and studies (Chounev & al. 1966; Brunkin 1973; Cholakov & al. 1984).

The lithostratigraphic division of the sediments in Karlovo Basin was introduced by Angelova & al. (1991) and adopted in the geological map of Bulgaria, Karlovo map sheet, 1:100000 (Russeva & al. 1991). It comprises two Formations and one Member.

The Iganovo Formation is mainly built of grey-bluish and bluish-green oily, often sandy clays, alternating irregularly with clayey sands, silts and gravels, with a sheaf of diatomites, diatome clays and layers of lignite coal in its uppermost part. The lower boundary is transgressive and the upper boundary has a generally eroded surface with the Karavelovo Formation. Iganovo formation reaches a total depth of 250 m (Angelova & al. 1991).

The Moskovets Member of Iganovo Formation includes the sheaf of diatomites, diatome clays and layers of lignite coal. Its lower boundary is marked by the level where the grey-greenish sandy clays and associated sands disappear and are replaced by carbonized phytogenic detritus, diatomites and lignite coal. The upper boundary has characteristically eroded surface. The sediments reach 50 m in total depth (Angelova & al. 1991). According to the data of the diatom analysis (Temniskova & al. 1996; Temniskova & Valeva 1996), their age was determined as Mio-Pliocene.

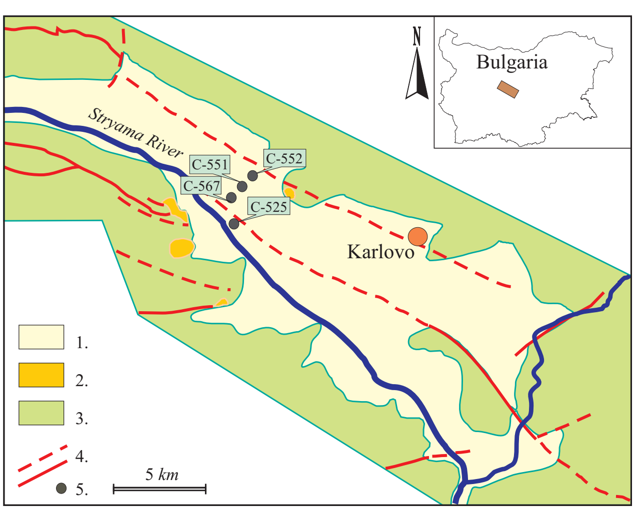

Fig. 1. A geological map of the Karlovo Neogene Basin and location of the investigated cores (after Temniskova & Valeva 1996). **Legend: 1**. Pleistocene sediments cover; **2**. Karavelovo formation; **3**. Pre-Neogene rocks; **4**. An assumed and proved faults; **5**. Core.

The Karavelovo Formation comprises sands with different grain size, gravels, silts, and light-grey to grey-white clays alternating irregularly. Its lower boundary borders on the Iganovo formation and its upper boundary on Quaternary sediments. The total depth of the formation is up to 70 m. According to regional and lateral lithological correlations, the age was determined as Late Pliocene (Angelova & al. 1991).

Karlovo Basin had probably emerged at the end of the Maeotian, some 6.5 Ma ago, as a result of rupturing and plate displacement (Angelova & al. 1991). The structure of the basin shaped out rather quickly and the deposit of the powerful sediments of Iganovo Formation began under the conditions of lake and lake-marsh type of sedimentation. Several thin coal layers were formed during the transition from river delta to lake conditions and only the upper one reached 10–11 m. The lignite coal deposits were formed under the reotrophic conditions of a swamp basin, with a lake basin connected to it (Zdravkov & al. 2006). During the period of peat accumulation there was an open water area in the middle of the basin. The end of peat accumulation indicated dryer conditions, with subsequent flooding of the peat bog and the sedimentation continued under lake conditions. The rough terrigenous sediments of Karlovo Formation were deposited in the Pliocene, probably under drier climatic conditions, according to Angelova & al. (1991). The contemporary outlook of Karlovo Valley had taken shape somewhere between 750 ka to 25 ka BP.

Material and methods

Materials of four cores drilled in the western part of Karlovo Basin were investigated (Figs 1 & 2): C-525 (in the interval from 64.5 m up to 109.0 m), C-551 (58.0 m – 120.0 m and a sample from 40.0 m, barren), C-552 (88.0 m – 139.0 m), and C-567 (64.0 m – 110.3 m). The four cores intersected the sediments of Iganovo Formation and Moskovets Member. The investigated materials originated from the grey-bluish and grey-greenish clays, as well as from the diatomite clays below and above the main coal layer, and from the contact spots of the clays with the lignite coal. The samples were taken at every 0.5 m to 1.0 m, depending on the lithological changes. A total of 143 samples were investigated, 12 poor in pollen and three barren, distributed between the cores as follows: C-525 – 25 samples (six pollen-poor and two barren), C-551 – 32 samples (one barren), C-552 –32 samples, and C-567 – 54 samples (five pollen-poor). That is, the analysis of the fossil flora of Karlovo Basin is based on 129 spore and pollen complexes (Table 1).

Table 1. Distribution of the investigated samples by cores: total number, analysed, pollen-poor and barren.

Core number	Number of samples	Number of analyzed samples	Samples with low pollen content	Samples without pollen
C-525	25	17	6	2
C-551	32	31		1
C-552	32	32		
C-567	54	49	5	
Total	143	129	12	3

The investigated materials were processed by standard methods for disintegration of Neogene sediments (Erdtman 1966; Kaiser & Ashraf 1974; Faegri & Iversen 1975). The main stages of processing included in succession: a treatment with hydrochloric acid (in the presence of a carbonate substance), hydrogen fluoride processing, processing with potassium base, heavy liquid separation, acetolysis, and making preparations for light microscopy. The laboratory processing of the materials was carried out at the Palynological Laboratory of the Institute of Botany, BAS.

Interim glycerine microscope slides and durable glycerine-gelly slides were used in the light microscopic research. The microscopic investigations were carried out with Docuval, Amplival and Olympus BX 51 microscopes.

The results of the spore and pollen analyses are presented as percentage spore and pollen diagrams. Computer data processing and plotting of the pollen diagrams was made with the help of TILIA software: Tilia 2.0.b.4 (Grimm 1991–93) and TGView 2.0.2 (Grimm 2004).

Percentage participation (F) of the arboreal (AP) and nonarboreal (NAP) pollen types is calculated on the basis of the pollen sum ΣP, which included ΣP = AP + NAP = 100 %; and of the local elements (L) as a percentage of the total sum AP + NAP + L = 100 % for each pollen spectrum. Percentage participation of the other palynomorphs (algal cysts, fungal spores, etc.) is calculated as a super sum above the total pollen sum.

Tracing out the changes in the percentage values of the different pollen type curves made possible the distinguishing of pollen zones in the investigated cores. Differentiation of the pollen zones is based on sediments with a specified fossil content, or specific paleontological characters (characteristic pollen complexes, type and frequency of palynomorphs), which distinguish them from the neighbouring sediments (Gordon & Birks 1972; Nikolov 1977; Nikolov & Sapunov 2002). Thus the differentiated biostratigraphic units were in themselves assemblage zones (coenozones). The boundaries of the zones were determined by the characteristic changes in the different curves of the established pollen types (Moore & al. 1991). The presented pollen zones for each core were regarded as Local Pollen Zones (LPZ) indexed by letters and digits.

Numerical zonation of the pollen diagrams is used as an auxiliary means for differentiation of LPZs (Birks 1974; Birks & Birks 2006), with the help of cluster analysis for grouping the palynological data obtained in the course of research. The mathematical processing and cluster analysis were carried out with the help of CONISS software (Grimm 1987). The matrix used in the respective calculations included the values of the pollen types expressed in percentage from the pollen sum (ΣP). The method of Square Root Transformation (Edwards and Cavalli-Sforza's chord distance) is used for determining the degree of similarity between the compared objects, and the total sum of square deviations is used as a measure of distance. The method of similarity evaluation by Edwards and Cavalli-Sforza has been known for a long time and widely applied in the comparisons of biological objects and in ecological and genetic researches. The results of the cluster analysis are presented as dendrograms, graphically offered in the respective pollen diagrams.

This study follows the stratigraphic scheme approved by the 14th and 15th International Geology Congress (Gradstein & al. 2004; Ogg & al. 2008). The boundary between Pontian/Dacian Stage is accepted at 5.3±0.1 Ma (Popov & al. 2004; Snel & al. 2001, 2006; Steenbrink & al. 2000, 2006), and the boundary between the Meotian and Pontian is assumed at 6.15±0.11 Ma (Fig. 2). This means that the duration of Pontian was 0.86 million years and corresponds approximately to the second half of the Messinian.

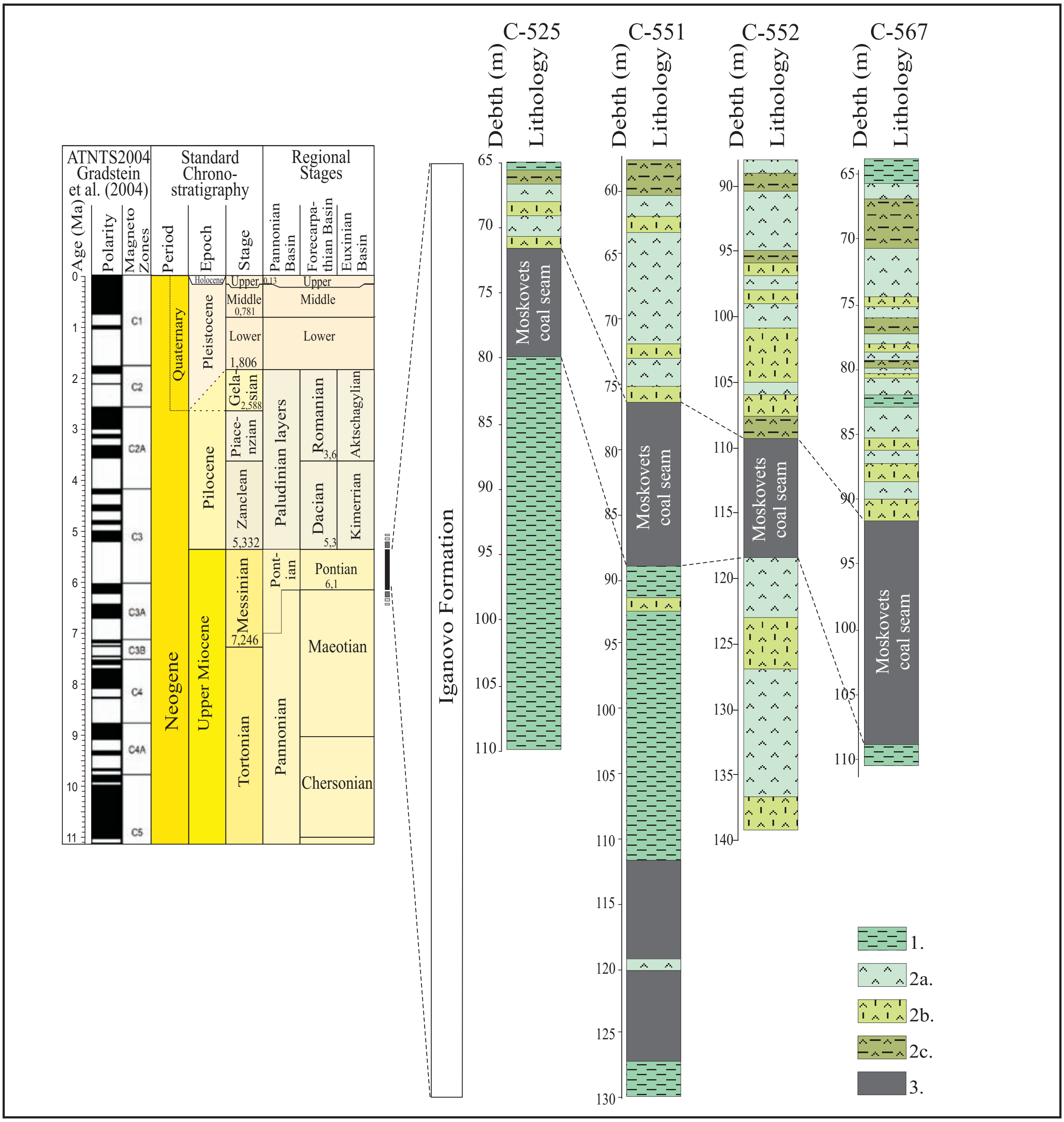

Fig. 2. Lithological columns of the investigated cores from Karlovo Basin.
Legend: 1. Clays; **2**. Diatomic layers with the following dominating genera: **2a**. *Aulacosira*, **2b**. *Actinocyclus*, **2c**. *Fragilaria*; **3**. Lignite coal and black clays.

Results

Core C-525 (Figs 3A & 3B)
Local pollen zone **Kar 525-1**
Alnus – Betula – Poaceae
Stratigraphic Range: Late Miocene
Distribution: 109.00 m –80.00 m

This zone had characteristically high values of the pollen of genus *Alnus,* represented mainly by values from 20 % to 32 %, occasionally higher, up to 48.8 % and 56.2 %, respectively at 82.50 m and 94.50 m, or lower values of 11.3 % and 13.5 %, respectively at 80.00 m and 81.50 m. The pollen of *Betula* registered values of 3–4 % in the lower part of the zone, and between 5 % and 7 % in the upper part.

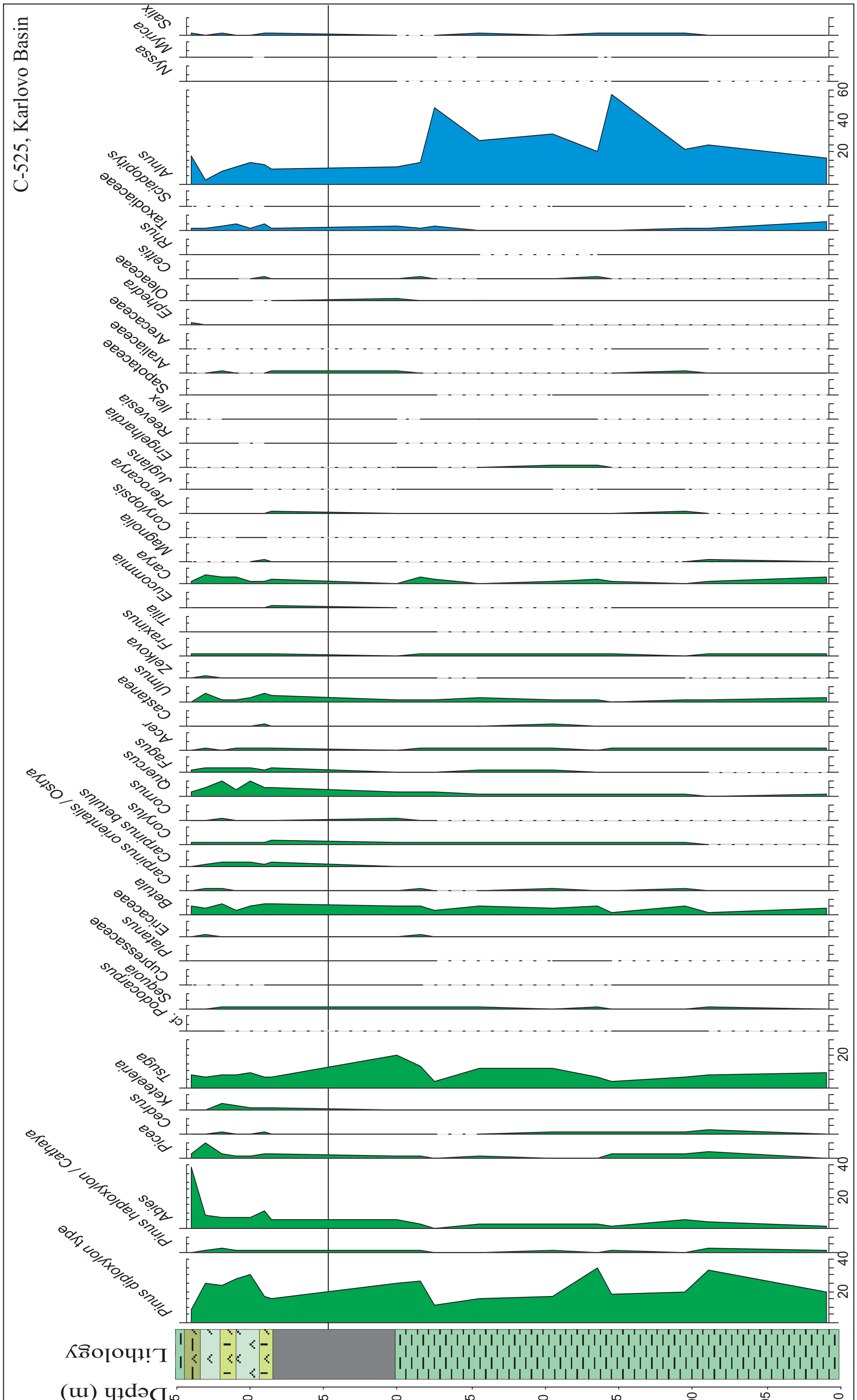

Fig. 3A. Percentage spore and pollen diagram of Core C-525, Karlovo Basin.

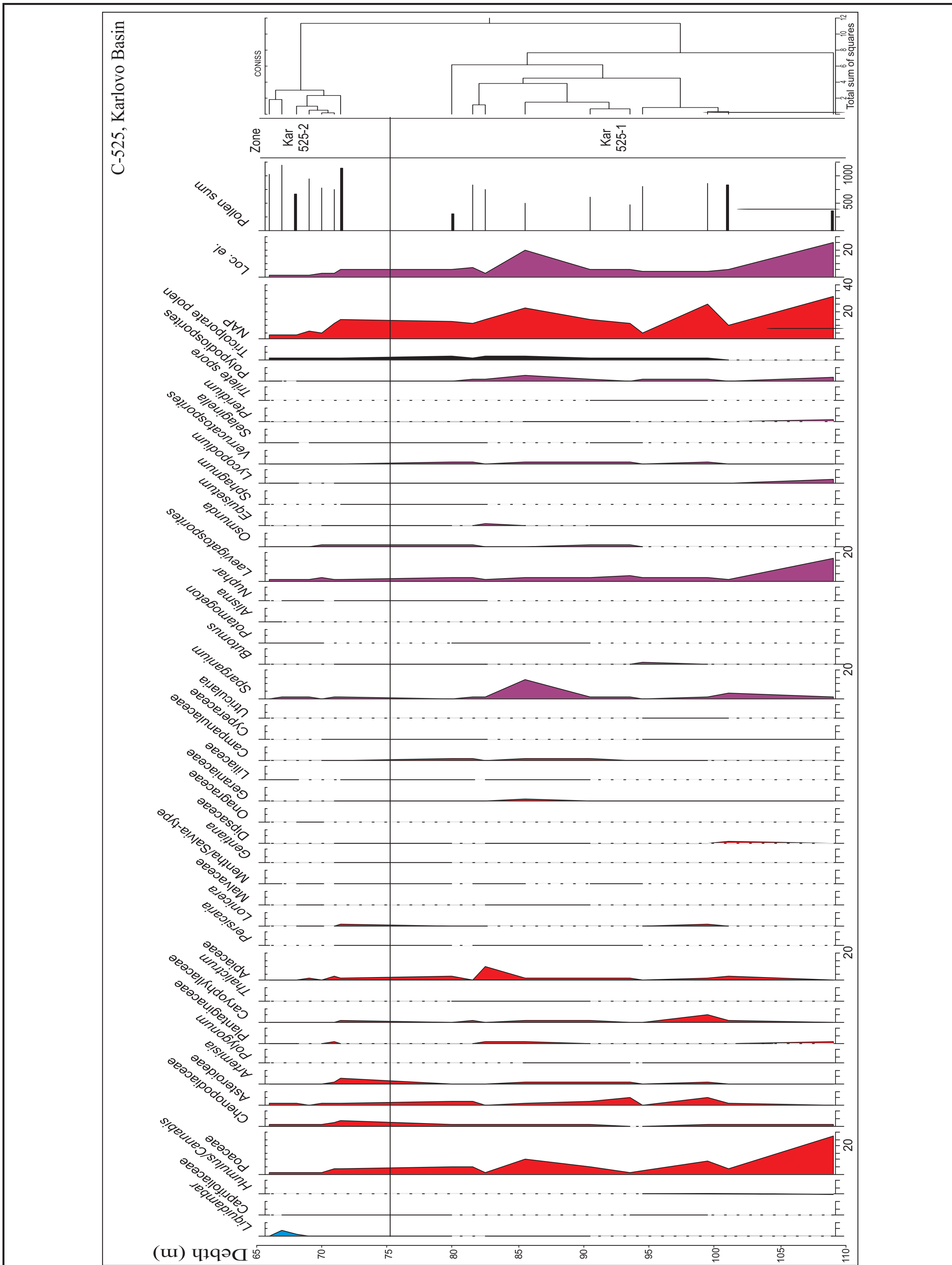

Fig. 3B. Percentage spore and pollen diagram of Core C-525, Karlovo Basin (Continuation).

The pollen of the family *Poaceae* occurred with higher values than in the rest of the core: 5 % and 8.6 % and an absolute maximum of 28 % at 109.0 m. Dynamics of *Carya* values varied mainly between 3–5 %, with some slight deviations. The pollen of *Quercus, Ulmus* and *Fagus* was presented with lower values, as compared to the rest of the core, 1.0–3.0 %, 1.0–2.0 % and 0.5–1.5 % for the three genera respectively. The pollen of *Picea* recorded higher values in the lower part of the zone (2.1–3.8 %), with a subsequent drop below 1.0 %. Local elements in that zone were represented with higher values than in the following zone, exceeding occasionally 20 %, although there were also lower values too. These values were mainly due to the representatives of *Laevigatosporites* (*Thelypteridaceae/Polypodiaceae*), *Polypodiaceae*, *Sparganium,* and *Osmunda*. The pollen of *Cedrus* had variable participation, mainly with 2–3 % in the lower part and a drop below 1 % in the upper. The representatives of genus *Tsuga* also showed higher values, between 8 % and 12 %, with an absolute maximum of 20.2 % for the entire profile at 80.00 m.

Local pollen zone **Kar 525-2**
Quercus – Ulmus – Abies
Stratigraphic Range: Late Miocene
Distribution: 71.50 m –66.00 m

This zone was characteristic with increased values of the pollen of genus *Quercus,* within the range 5.1 %–9.8 %. The pollen of genus *Ulmus* registered even higher values: 3.15 % up to 6.2 %. A slight increase was observed in *Zelkova*, but owing to the low pollen values of this genus in the entire profile (usually with single pollen grains), it could be hardly used as an indicator of change. Contrary to the preceding zone, the pollen of genus *Alnus* showed lower values and ranged between 7.55–13.6 %. The pollen of *Betula* retained its values from the upper part of the preceding zone and even marked a slight increase (within the range of 1 %–2 %). The representatives of *Carpinus betulus* and *Fagus* registered a slight increase of their values in the pollen spectra of this zone. *Acer*, *Fraxinus, Salix, Corylopsis, Araliaceae*, and *Oleaceae* kept almost steady values of their percentage participation in the analysed pollen spectra in the entire profile. The pollen of *Abies* marked higher values of 6.8 %–10.6 % and a maximum of 38.6 % at 66.00 m, but this increase started already at the end of the LPZ Kar 525-1 (from the pollen spectra at 81.50 m and 80.00 m). The pollen of *Tsuga* showed a slight tendency to decrease in this zone, while that of *Carya* marked a slight increase. Among the other pollen types mention deserved the reduction in percentage participation of the pollen of *Chenopodiaceae*, *Asteraceae*, *Apiaceae*, and the general NAP values. The curve of the local elements also showed a reduction, with lower values in the highest levels of the profile.

Comparison of the differentiated pollen zones with the clusters determined during the group hierarchical analysis (numerical zonation, Fig. 3B) (LPZ Kar 525-1) has shown complete correspondence of zonal differentiation with the statistically defined groups. The pollen spectrum at 109.0 m could be mentioned as an exception with its greater distance from the other pollen spectra in the group.

Core C-551 (Figs 4A & 4B)
Local pollen zone **Kar 551-1**
Alnus – Betula – Ulmus
Stratigraphic Range: Late Miocene
Distribution: 127.60 m –89.00 m

This zone was characteristic with high values of the pollen of genus *Alnus,* represented mainly within the range from 15.7 % to 28.2 %, with two deviations, of 62.7 % at 127.60 m and 6.3 % at 89.00 m. The values of the pollen of *Betula* varied mainly within the boundaries up to 3–5 %, but some higher values also occurred, for instance, 8.6 %. The percentage participation of the pollen of *Ulmus* was from 4 % up to 8 % in the most of pollen spectra and with a maximum of 11.9 % reached in this zone. The pollen of representatives of family *Taxodiaceae* occurred with higher values than in the rest of the core, mainly from 2.8 % to 8.7 %, and occasionally up to 11.3 %. Dynamics of the values of *Carya* pollen was more varied and ranged chiefly between 3–6 % in the lower part of the zone and, after a peak of 11.6 % at 93.00 m, there was drop in the values up to 1–2 %. *Juglans* was represented with higher values, as compared to the rest of the profile, which ranged between 3–5 %. The pollen of *Quercus* was represented with low values, although in some pollen spectra it could reach 8 % (in the lower part of the zone). As compared to the rest of the profile, genus *Fagus* showed very low values and was even missing in some of the pollen spectra. The pollen of *Picea* registered lower values in the lower part of the zone (7–8 %), which subsequently rose to 21 %. The local elements in this zone were represented with higher values than in the following zones, occasionally exceeding 10 %. These values were mainly due to the representatives of genus *Osmunda* and to a lesser extent to the participation of *Laevigatosporites* (*Thelypteridaceae/Polypodiaceae*), *Lycopodium* and *Selaginella*.

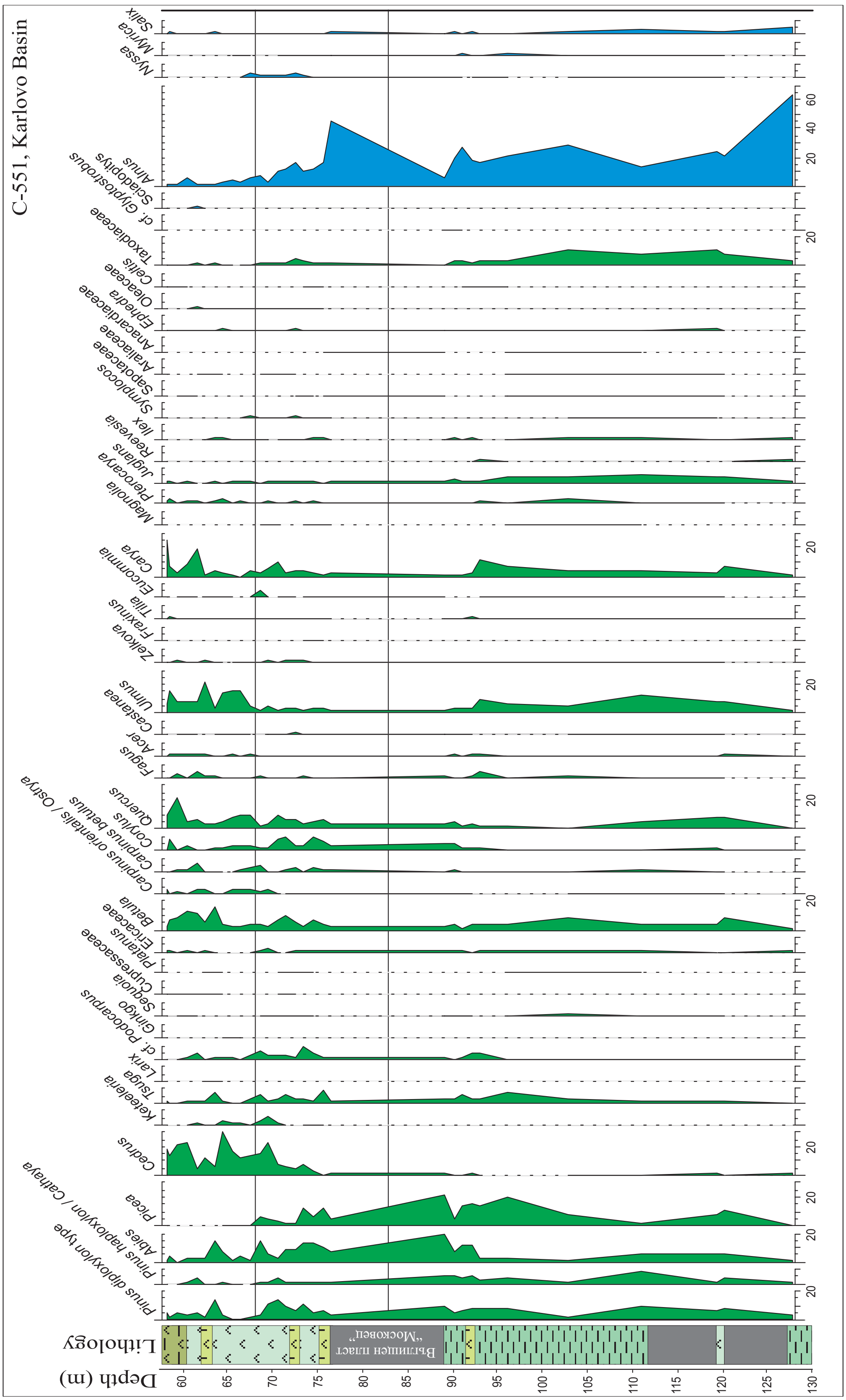

Fig. 4A. Percentage spore and pollen diagram of Core C-552, Karlovo Basin.

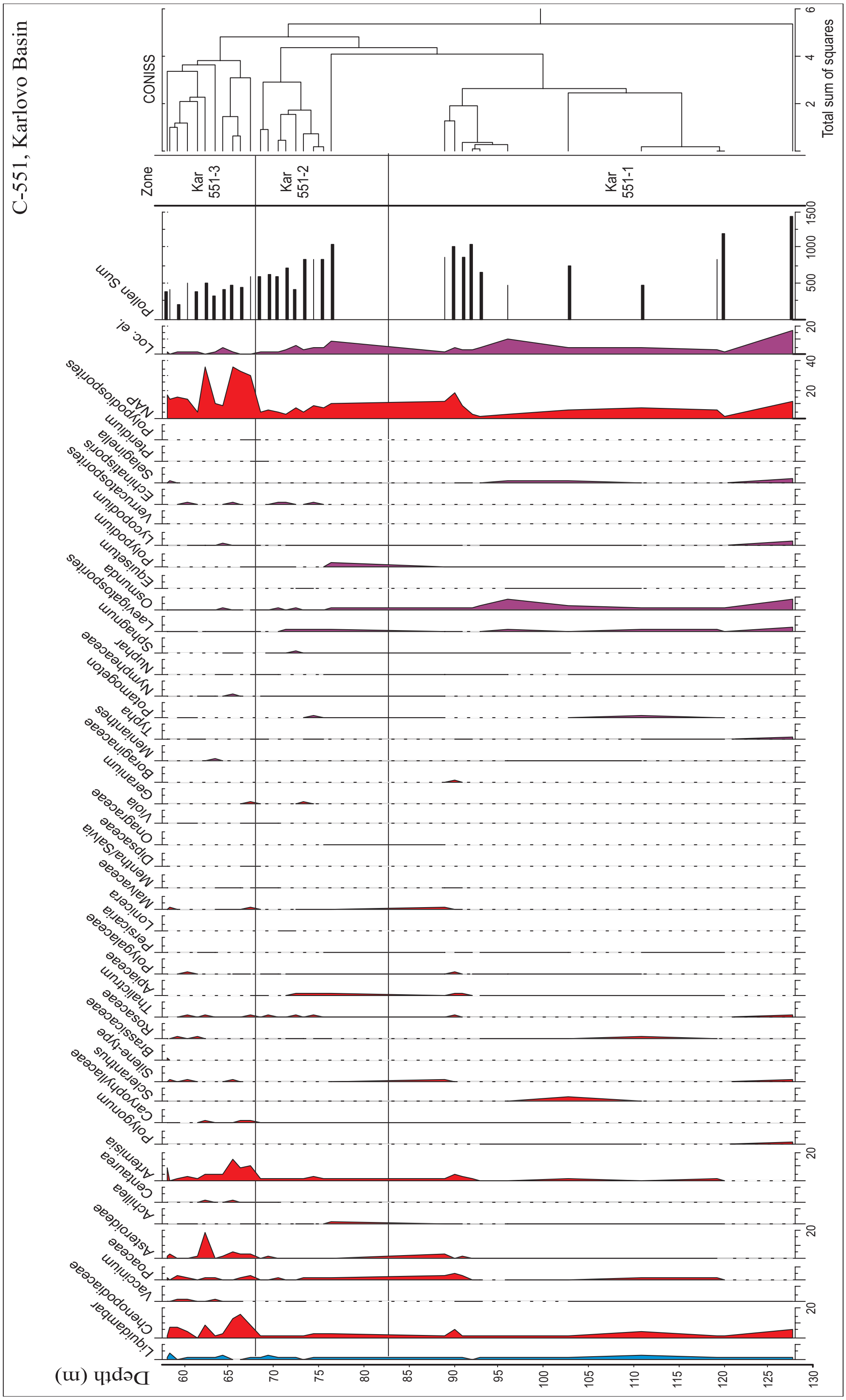

Fig. 4B. Percentage spore and pollen diagram of Core C-552, Karlovo Basin (Continuation).

Local pollen zone **Kar 551-2**
Pinus diploxylon – Tsuga – Corylus
Stratigraphic Range: Late Miocene
Distribution: 76.40 m –68.40 m

This zone was characteristic with an increase of the quantitative values of the pollen of *Pinus diploxylon* type, reaching up to 14.2 %, despite the more dynamic changes manifested by them as compared with the preceding zone, where their maximum values did not exceed 9 %. The pollen of genus *Tsuga* was represented by higher values, reaching up to 8.4 %. *Abies* also manifested higher values, but also a minimum in the upper part of the zone. In the upper part of the zone an increase was marked by *Cedrus* (up to 22.7 %) and *Keteleeria* (up to 5.5 %), while *Picea* marked a drop. Within this zone the pollen of *Corylus* showed the highest participation within the entire profile, exceeding 9 %. The curves of percentage participation of the representatives of the genera *Ulmus, Carya, Juglans,* and the family *Taxodiaceae* marked a sharp drop and low values in this zone. The pollen of genus *Alnus,* after a maximum of 45 % in the pollen spectrum at 76.40 m, showed a reduction of its percentage participation below 10 %. At the end of the preceding zone (LPZ Kar 551-1) there was observed a slight increase of the values of some herbaceous plants –*Poaceae*, *Asteroideae*, *Artemisia* – which was retained also in this zone. The local elements were represented by lower values, as compared to LPZ Kar 551-1.

Local pollen zone **Kar 551-3**
Quercus – Ulmus – NAP
Stratigraphic Range: Late Miocene
Distribution: 67.40 m –58.00 m

This zone was characteristic with an increase of the quantitative values of the pollen of genus *Quercus:* mainly within the range 7.4 % to 12.7 % and with a maximum of 21.6 %. The pollen of genus *Ulmus* also registered higher values, between 8.5 % and 16.4 %, and with an absolute maximum of 22.0 % for the entire profile (in the pollen spectrum of 62.40 m). The pollen of *Betula* also marked an increase, but mainly in the upper part of the zone, where it reached 11 %–12 % and even 16.5 %. The curve of percentage participation of *Carya* showed similar characteristics: with two peaks of 19.0 % at 61.40 m and 24.9 % at 58.00 m. *Carpinus betulus* type, *C. orientalis/Ostrya* type, *Fagus*, *Acer,* and *Pterocarya* similarly marked a trend towards higher values, although not so strong. The pollen of coniferous species showed a reduction for all their representatives, with the exception of *Cedrus,* which retained the high values reached in the upper part of the preceding zone (LPZ Kar 551-1). The pollen of genus *Alnus* continued the trend for reduction of its percentage participation from the preceding zone, registering here merely 1 % to 3 %. An important change characteristic for this zone was the rapid increase of the pollen of herbaceous species. Here NAP reached values above 30 %, maintaining 12–16 % in most pollen spectra. These high values were mainly due to the increased participation of *Chenopodiaceae*, *Asteroideae* and *Artemisia*. The curve of local elements showed characteristically reduced participation and they almost disappeared from the pollen spectra.

The dendrogram obtained from the cluster analysis confirmed the good differentiation of the different zones (Fig. 4B.). Three major clusters were differentiated corresponding to the three zones. More distinct was LPZ Kar 551-1. Both clusters in the upper part of the diagram showed the well differentiated LPZ Kar 551-2 and LPZ Kar 551-3. An exception was the pollen spectrum at 76.40. it was very distant from the clusters of LPZ Kar 551-1 and LPZ Kar 551-2, which was due to the specific character of the spore and pollen complex.

Core C-552 (Figs 5A & 5B)
Local pollen zone **Kar 552-1**
Alnus – Betula – Picea
Stratigraphic Range: Late Miocene
Distribution: 139.00 m –119.00 m

This zone was characteristic with high values of the pollen of genus *Alnus,* reaching 55–56 %, but with a trend to reduction in the upper part of the zone (9.8 % at 119.00 m). The values of the pollen of *Betula* varied between 7 % and 12 %, but showed lower values of 2–4 % for some pollen spectra. *Picea* registered percentage participation of 9.7 % up to 17.9 %, but only in the central part of the zone, while in the lowermost and uppermost samples it was represented by single pollen grains. Similar characteristics showed the curves of genus *Tsuga*, *Pinus diploxylon* type and *P. haploxylon/Cathaya* type, with maximum values in the central part of the zone. Of the other pollen types, similar distribution of the percentage values and maximum values for the central part of the zone were observed in *Fagus, Acer, Castanea, Fraxinus, Carya, Poaceae*, and *Apiaceae.*

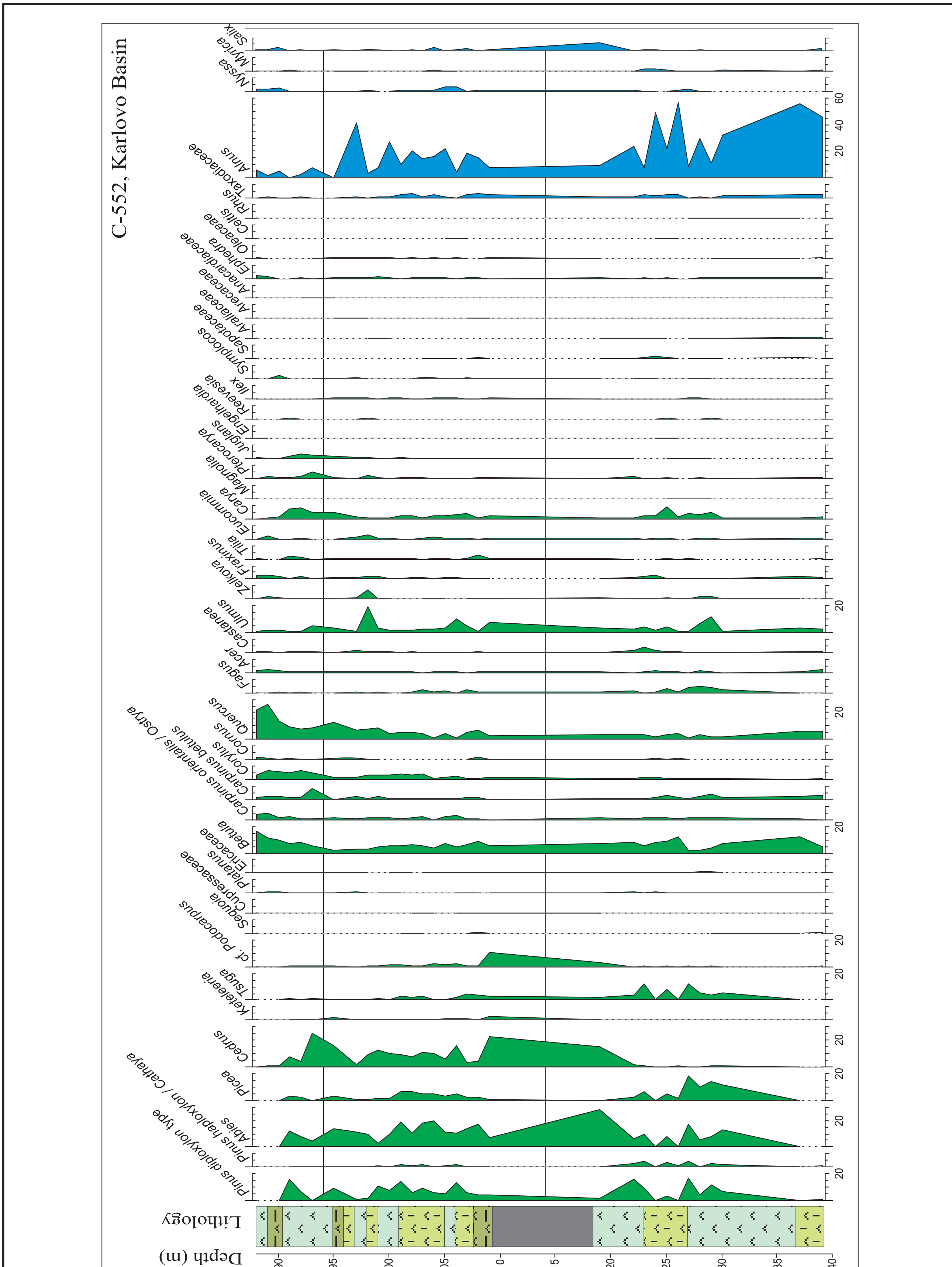

Fig. 5A. Percentage spore and pollen diagram of Core C-551, Karlovo Basin.

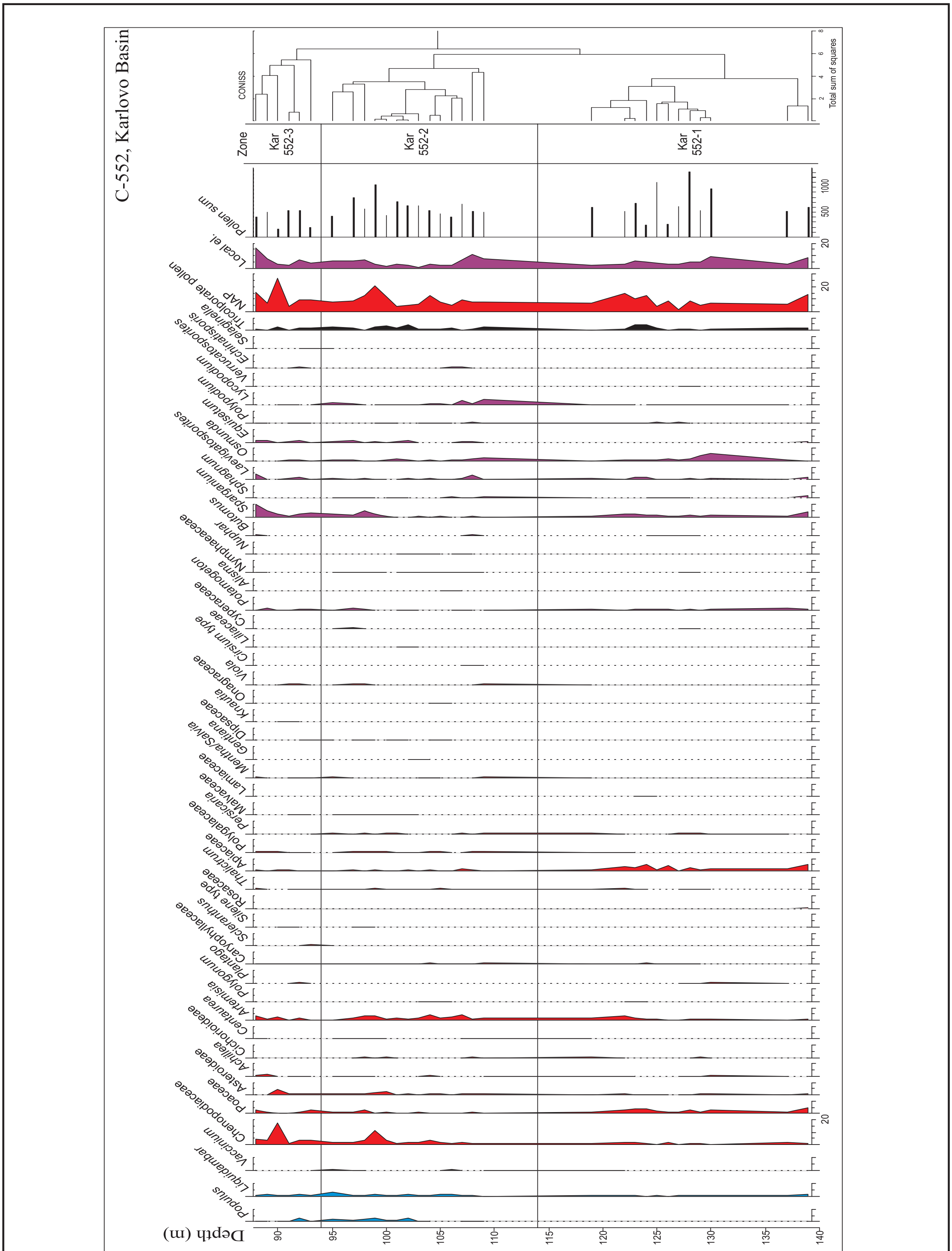

Fig. 5B. Percentage spore and pollen diagram of Core C-551, Karlovo Basin (Continuation).

The local elements in this zone were represented by approximately low values (3–5 %), which only in the lower part reached 8 %. Of these, greater participation showed the spores of genus *Osmunda,* while the participation of *Sparganium*, *Laevigatosporites* (*Thelypteridaceae*/*Polypodiaceae*), *Lycopodium,* and *Polypodium* was sporadic. The pollen of the herbaceous species registered approximately constant vales (6 % to 10 %), with some deviations, especially in the central part of the zone.

Local pollen zone **Kar 552-2**
Pinus diploxylon – Abies – Ulmus
Stratigraphic Range: Late Miocene
Distribution: 109.00 m –95.00 m

This zone was characteristic with an increase of the quantitative values of the pollen of *Pinus diploxylon* type, reaching 14.2 %, but mainly ranging between 7 % and 11 %. Although in the preceding zone (LPZ Kar 552-1) the values of that pollen type had reached such values in some pollen spectra, this was in isolated cases and they did not show stability as in the local pollen zone discussed here. The pollen of genus *Abies* was represented by higher values, steadily above 9 %, and often reaching up to 17–19.5 %. This pollen type was represented in the preceding pollen zone by lower values and a maximum of 29 % in the boundary pollen spectrum at 119.00 m. This zone also marked an increase of the percentage participation of the pollen of genus *Cedrus,* with values between 11 % and 17 %. Actually, the increased presence of *Cedrus* started at the end of LPZ Kar 552-1 (119.00 m) and continued until the beginning LPZ Kar 552-3 (93.00 m). Within the boundaries of this zone, the pollen of *Ulmus* registered a higher quantitative participation, with a maximum of 19.3 % for the entire profile, but usually within the range 3–5 %, and occasionally up to 10 %. A drop in the percentage participation was marked by *Betula,* while *Corylus, Quercus, Tilia, Eucommia,* and *Ilex* showed a slight increase. *Alnus* some higher values in the upper part of the zone, after a drop at the end of the preceding zone. The presence of local elements did not show any significant changes.

Local pollen zone **Kar 552-3**
Quercus – Betula – Corylus
Stratigraphic Range: Late Miocene
Distribution: 93.00 m –88.00 m

This zone was characteristic with the rapid increase of the quantitative values of *Quercus*, *Betula* and *Corylus.* The pollen of genus *Quercus* had increased from 9.0 % in the beginning of the zone to 26.5 % in its upper part. The pollen of *Betula* also marked an increase, mainly in the upper part of the zone, where it reached 16.4 %. Within the boundaries of this zone, the pollen of *Corylus* showed the highest percentage participation for the entire profile. It registered steady values, which varied within some rather narrow margins of 5.0 % to 6.9 %. A slight increase in the upper part of the zone was registered by the pollen curves of *Carpinus orientalis/Ostrya* type, *Acer*, *Fraxinus,* and *Eucommia*. The curves of percentage participation of the representatives of *Carpinus betulus* type, *Ulmus, Carya, Pterocarya, Juglans,* and *Cedrus* showed higher values in the beginning of the zone and marked a drop in its upper part. In the uppermost parts of the zone the pollen of coniferous representatives disappeared from the pollen spectra. After its latest maximum of 41 % in the preceding LPZ, the pollen of genus *Alnus* recorded a reduction in its percentage participation, up to 3–7 %. Changes were observed in the pollen of the herbaceous species. NAP registered slightly higher values, as compared to the preceding zone: with a maximum up to 26.5 %. These higher values were mainly due to the increased participation of *Artemisia, Achilea, Asteroideae*, and *Chenopodiaceae*. The curve of local elements was characteristic with certain increase of the percentage values, but only in the uppermost levels of the zone (increased values of *Sparganium* and *Laevigatosporites*).

A comparison of the differentiated pollen zones in core C-552 (Fig. 5B.) with the cluster differentiated with the help of the group hierarchical analysis (numerical zonation) showed full correspondence of the zonal differentiation achieved by both methods. The statistically defined groups corresponded without exception to the zones differentiated by the classic methods.

Core C-567 (Figs 6A & 6B)
Local pollen zone **Kar 567-1**
Pinus diploxylon – Alnus – Poaceae
Stratigraphic Range: Late Miocene
Distribution: 110.30 m – 108.80 m

This zone was characteristic with higher quantitative values of the pollen of *Pinus diploxylon* type, which

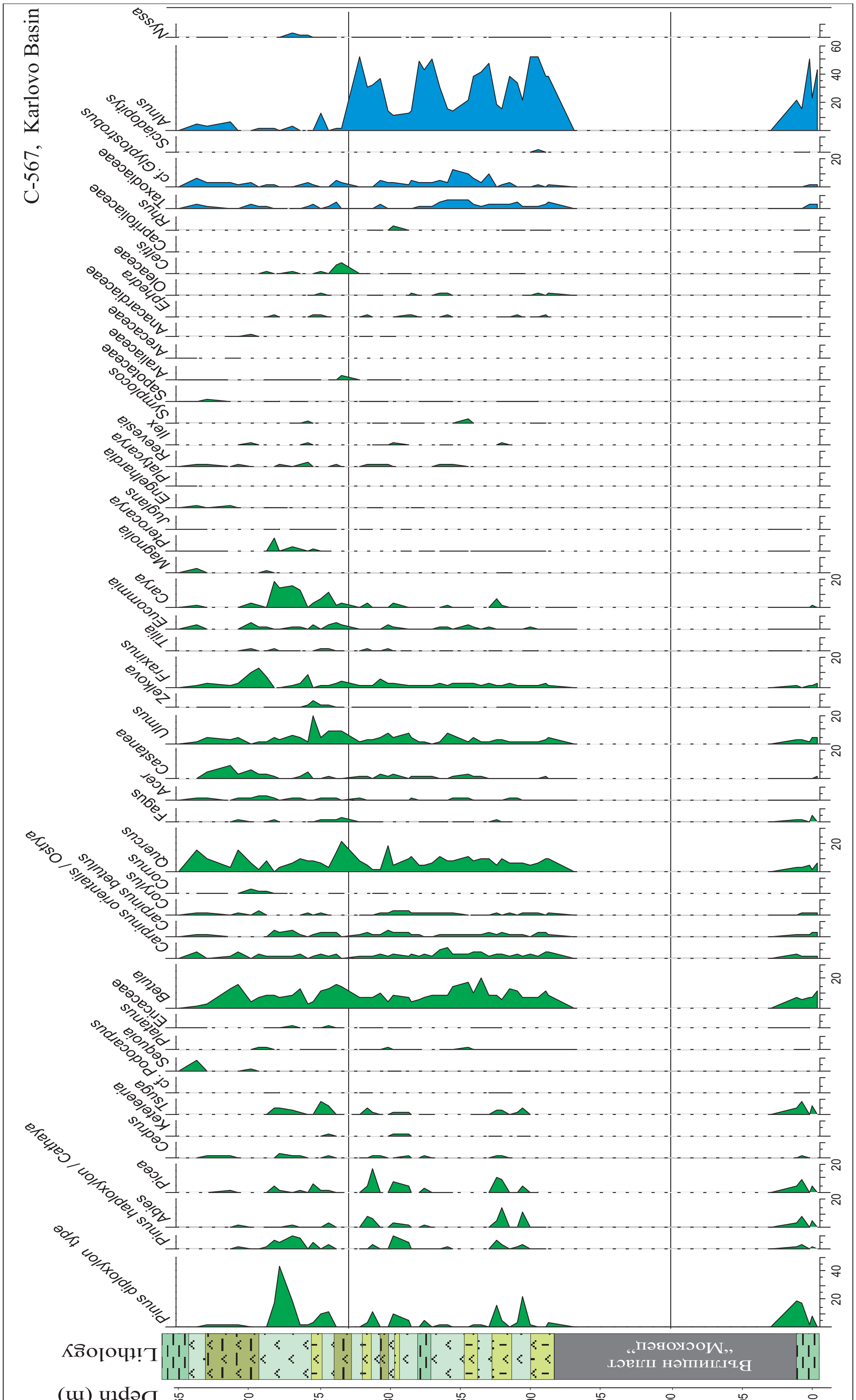

Fig. 6A. Percentage spore and pollen diagram of Core C-567, Karlovo Basin.

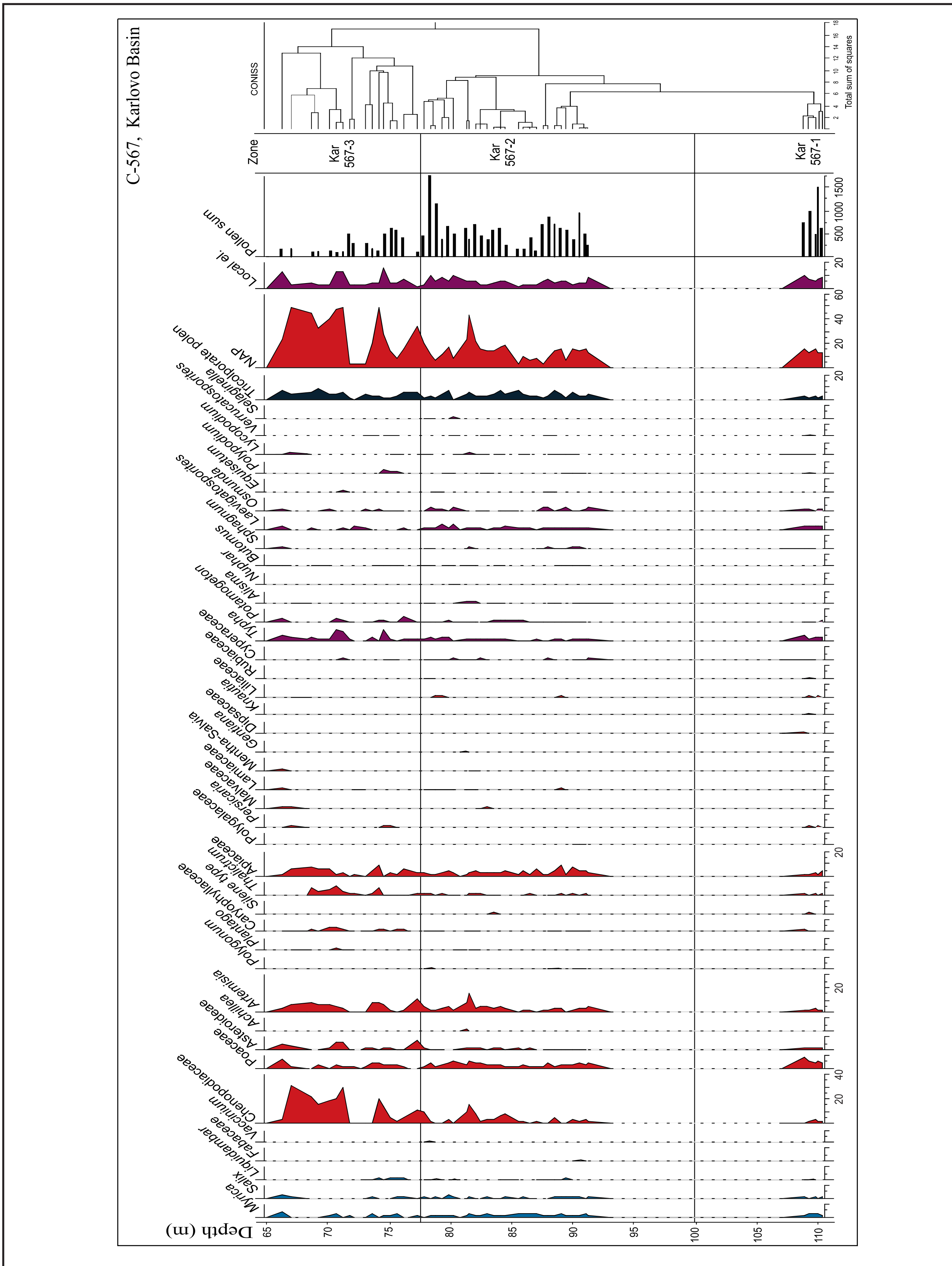

Fig. 6B. Percentage spore and pollen diagram of Core C-567, Karlovo Basin (Continuation).

reached 14.2 % and stood out as some of the highest in that core. Other representatives of the coniferous plants were also registered with higher values: *Picea* and *Tsuga*, up to 9.2 % and 8.9 % respectively. The pollen of genus *Alnus* showed dynamic and comparatively high values, reaching 50.8 % at 109.80 m. More distinct taxa in this zone were those of *Poaceae* (up to 8.0 %) and the group of local elements represented mainly by *Typha*, *Laevigatosporites* and *Osmunda*. The pollen of *Betula* ranged mainly within 5–8 %, but some higher values occurred too, for instance of 12 %. The percentage participation of *Ulmus* was 3–4 %. Similar values registered *Quercus, Carpinus, Fagus, Corylus, Fraxinus,* and *Myrica*. A number of pollen types were represented by single pollen grains: *Eucommia, Carya, Pterocarya, Juglans,* etc.

Local pollen zone **Kar 567-2**
Quercus – Corylus – Alnus
Stratigraphic Range: Late Miocene
Distribution: 91.20 m –77.80 m

This zone was characteristic with an increase of the quantitative values of the pollen of genus *Quercus,* ranging mainly within 6–10 %, but reaching also higher values (for instance, 18.6 %) in some cases. The pollen of genus *Corylus* was represented by higher values, reaching 2–3 %. *Alnus* showed very dynamic values, retaining the variable character of the pollen curve from the preceding zone (LPZ Kar 567-1). As compared to LPZ Kar 567-1, slight increase registered the values of *Castanea* and *Ulmus*. *Carpinus orientalis/Ostrya* type also registered a slight increase in its percentage participation. A more significant and mention-deserving change was the increased values of *Taxodiaceae* and *Glyptostrobus*. The pollen of these two types reached a maximum in the central part of the zone, recording the highest values for the entire profile: 6.9 % and 12.4 %. *Myrica* also registered the highest values in this zone, as compared to the pollen spectra from the rest of the core. The pollen curves of all coniferous plants were varied strongly and some conifers were missing from a number of the analysed samples. The herbaceous plants were represented too, with *Chenopodiaceae*, *Poaceae*, *Artemisia,* and *Apiaceae* as the most expressed pollen types. The curve of the local elements did not show any drastic deviations and, in total, did not exceed 10 %.

Local pollen zone **Kar 567-3**
Quercus – Castanea – NAP
Stratigraphic Range: Late Miocene
Distribution: 77.30 m –66.20 m

This zone was characteristic with a certain increase of quantitative values of the pollen of genus *Quercus,* mainly within the 8 %–10 % range, but considerably higher values were registered in a number of samples: 16.0 %, 14,9 %, 14,3 %, or 19,5 %. The pollen of *Castanea* also marked an increase, but mainly in the upper part of the zone, where it reached 5–7 % and even 10.1 %. The same trend obtained for *Fraxinus*, with a more significant presence in the upper part of the zone. *Carya, Pterocarya* and *Ulmus* marked just the opposite trend: higher percentage values in the lower part of the zone and a trend to reduction of their importance in the pollen complexes in the upper part. The pollen of coniferous plants registered an even more limited presence (with the exception of a peak in the values of *Pinus diploxylon* type), and this trend was especially distinct in the upper part of the zone. The pollen of *Alnus* showed strongly reduced percentage participation, as compared to the previous zones, marking here merely 2 % to 5 %. An important characteristic change of this zone was the rapid increase of the herbaceous plants pollen. Here NAP reached values above 40 %, and in some pollen spectra even above 48 %. These high values were mainly due to the increased participation of *Chenopodiaceae*, *Asteroideae* and *Artemisia*, and to a lesser extent to *Poaceae*, *Thalictrum* and *Apiaceae*. The curve of local elements characteristically retained their percentage values without significant changes.

The dendrogram obtained from the cluster analysis confirmed the distinct differentiation of the different zones in the upper part of the profile: LPZ Kar 567-2 and LPZ Kar 567-3 (Fig. 6B.). The different clusters in the lower part of LPZ Kar 567-2 had shown similarity to the pollen spectra of LPZ Kar 567-1. This could be explained, on the one hand, with the relatively small number of the pollen spectra differentiating LPZ Kar 567-1 and, on the other, with the comparatively close ecological conditions immediately prior to and after the depositing of coal, which conditioned respectively the similarity of vegetation.

Discussion

A comparison of the differentiated pollen zones had shown similarity of their characteristics, depending on their stratigraphic location in the cores. Thus, for example, LPZ Kar 525-1, LPZ Kar 551-1 and LPZ Kar 552-1, situated under the main Moskovets coal layer, were very similar in composition and quantitative participation of palynomorphs. The differences concerned chiefly some local and individual specificities of the flora. LPZ Kar 567-1 corresponded to the uppermost layers of LPZ Kar 525-1, LPZ Kar 551-1 and LPZ Kar 552-1, i.e. it represented the final stage of development of the vegetation prior to the transition from lake to bog type of sedimentation and the formation of the main Moskovets coal layer. LPZ Kar 525-2, LPZ Kar 551-2, LPZ Kar 552-2 and LPZ Kar 567-2 corresponded to the period of development of the vegetation after the rising of the water level and restoration of the lake regime. Of the pollen zones in the upper part of the cores, best developed was LPZ Kar 567-3 in the C-567 core. LPZ Kar 551-3 corresponded to lower part of LPZ Kar 567-3, while LPZ Kar 552-3 corresponded to the outset of the vegetation changes reflected in that zone. The LPZ Kar 567-3 corresponded to the opening of vegetation (NAP reached values above 40 %), spread of open landscapes, and reduction of woody vegetation.

The palynological data provided by Ivanov & al. (2008) and Utesher & al. (2009) from the Stanyantsi Basin, Western Bulgaria (Late Miocene) registered a sharp increase of the herbaceous component at the top of section. A high values of the herbaceous component was established for the pollen spectra from the Late Miocene-Pliocene sediments of the outcrop Sinapovska River, Tundzha Basin (Ivanov & al. 2007.) An increase of the herbaceous component and the steppe/forest index (SFI) in the Late Miocene-Pliocene was registered also by Popescu (2006) in the sediments from hole 380A, drilled in the southwestern part of the Black Sea. These data corresponded to the high NAP values established in the present study and testified to a large-scale change in the vegetation during that time period.

Conclusion

A detailed pollen analysis of the Late Miocene sediments of Karlovo Basin has permitted differentiation of local pollen zones for each of the four investigated cores. The differentiated pollen zones have local character for each of the cores. They are based on the characteristic changes in the percentage participation of the main pollen types. Numerical zonation with the help of the group hierarchical analysis (cluster analysis) has confirmed the distinct differentiation of the different zones with the help of the classic pollen analysis, i.e. there is complete correspondence of the zone differentiation achieved by both methods. Deviations of the different pollen spectra from the differentiated zones are rare and are explained by the individual character of the spore and pollen complexes formed under specific local conditions.

A comparison of the characteristics and principles of definition of the various local pollen zones has made possible their correlation into three distinct groups in the investigated cores, allowing for their respective stratigraphic location in the local pollen zones of the cores (Fig. 7). The first LPZ group is established in three of the investigated cores (C-525, C-551, C-552) and only partially in core C-567. Stratigraphically, they are situated below the main Moskovets coal layer. Their palynological characteristics are very similar and reflect the character of the vegetation prior to the establishment of swampy environments in the Karlovo Basin. The next group of pollen zones correspond to the period of development of the vegetation after the rising of water level and resumption of the lake regime, and are well represented in all four cores. The pollen zones from the upper levels of the cores correspond to the latest stage of development of the vegetation in the region of Karlovo Basin, registered in the fossil records. Best developed is LPZ in core C-567 (Kar 567-3), while in the other cores (Fig. 7) the local pollen spectra register smaller scopes and correspond to the lower part of that zone (C-551 and C-552), or are altogether absent (C-525).

Thus determined, the LPZ groups correspond to the dynamics of vegetation, changes in the hydrological regime of the water basin and local climatic conditions, and could be accepted as zones of regional character for Karlovo Basin (Central Bulgaria)

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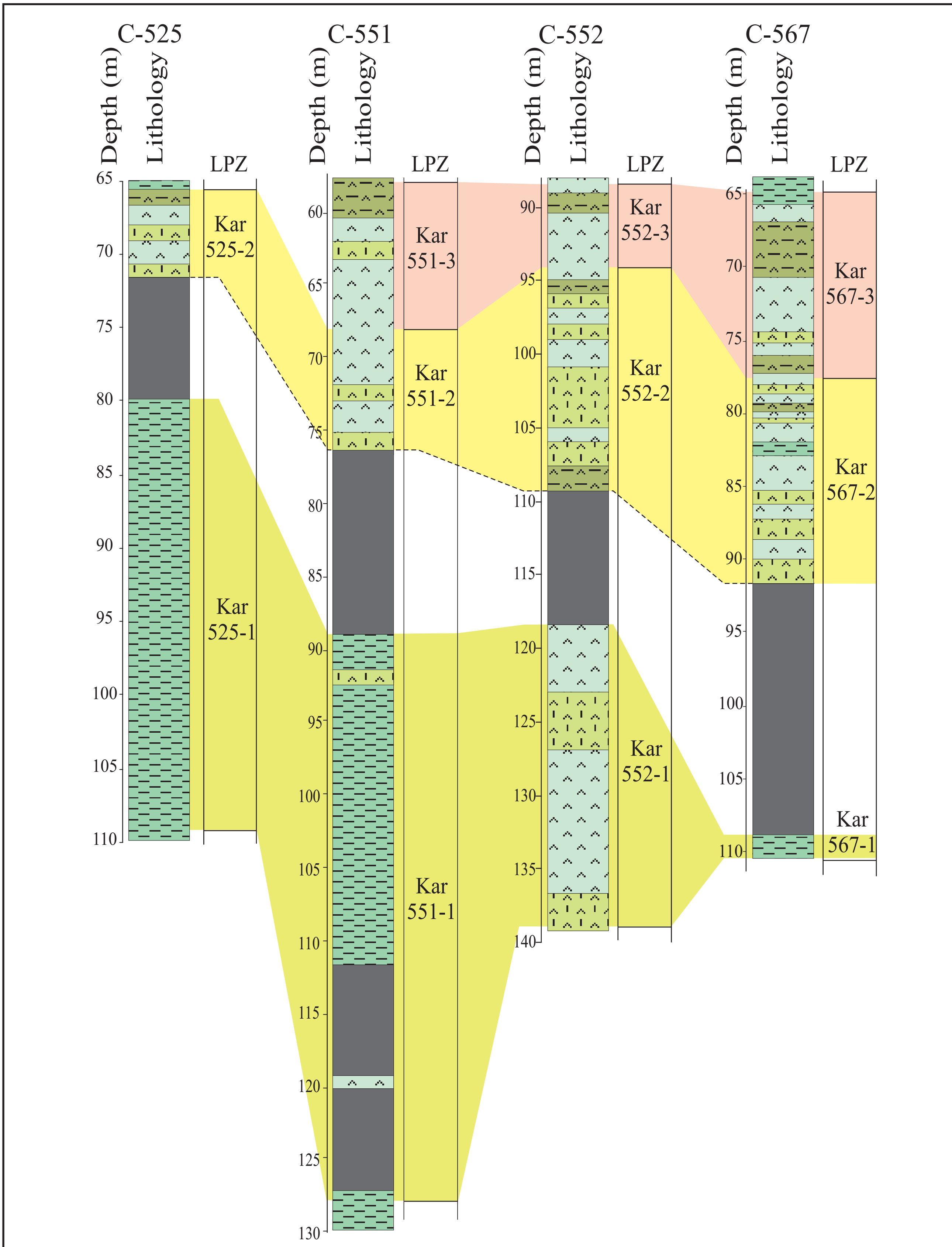

Fig. 7. Relationships between the Local Pollen Zones (LPZ) in the investigated cores from Karlovo Basin. Characteristic features and stratigraphic position have made possible their correlation into three distinct groups.

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