Palynological analysis of the Late Miocene sediments from the Sofia Basin (SW Bulgaria)

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Abstract. The article presents the results of a palynological zonation of the Late Miocene sediments from the Sofia Basin (Southwest Bulgaria). The age of the 6.00–262.40 m interval of core C-14, Katina has been determined as Middle and Upper Pontian on the basis of mollusks and mammals. A rich and diversified fossil flora has been discovered too, comprising 104 spore and pollen types referred to 76 genera of 59 families. A palynological zonation of the sediments has been carried out on the basis of the most characteristic changes in the percentage abundance of the basic pollen types in the pollen spectra and with the help of cluster analysis. The pollen diagram was divided into three local pollen zones and four subzones. The described local pollen zones reflect the changes in the fossil flora at the end of the Miocene and the beginning of the Pliocene.

Key words: Bulgaria, Late Miocene, palynology, Sofia Basin

Introduction

The sediments from the Neogene basins in Bulgaria contain important floristic information about the character and evolution of the local and regional flora. The Late Miocene Sofia Basin has an important place within the system of lake-marsh sedimentary complexes on the Balkan Peninsula. It represents the main geological structure in the region during the Miocene and its development directly influenced the geological evolution of the nearby situated Belobrezhki, Aldomirovski and Stanyanski basins. Data on the fossil content of the sediments from the Sofia Basin have been presented in a number of paleobotanical studies dedicated to the composition of the macroflora and its dynamics: Stefanov & Jordanov (1935), Kitanov (1940, 1956, 1960), Kitanov & Nikolova (1956), Kitanov (1972, 1982), Palamarev (1991) and Palamarev & al. (2002). Diatom flora of the sediments from the Sofia Basin has also been studied (Ognjanova-Rumenova & al. 2008).

Pollen-analytical studies of the fossil flora have been carried out mainly for biostratigraphic purposes aiming to precise the age of sediments previously determined with the help of other fossil groups (Kamenov & Kojumdjieva 1983). Some fragmentary information on the pollen flora was published by Drivaliari (1992), Drivaliari & al. (1999) and Jiménez-Moreno & al. (2007). More detailed information on the composition of the microflora and tracing out of its dynamics has been published recently by Hristova & Ivanov (2009). In this study, palynological zonation of the Upper Miocene sediments of the Sofia Basin is made on the basis of the interpretation of palynological data.

Geological notes

The Sofia Basin is a graben structure located southwards of the Balkan Range, approximately 80 km long and over 20 km wide (Nakov & al. 2001). The substrate and coastline of the Basin is formed of Paleosoic, Triassic, Jurassic, Cretaceous and Paleogene rocks (Kortenski & Zdravkov 2007). The Basin is filled with Neogene sediments (Fig. 1) differentiated into four lithostratigraphic units: a Variegated terrigenous Formation, Gnilyane Formation, Novi Iskar Formation and Lozenets Formation. The three latter Formations have been united into the so-called Sofia Group (Kamenov & Kojumdjieva 1983) (Fig. 1).

The Gnilyane Formation extends as a narrow strip along the northern rim of the Basin, in the deeper eroded sections near Novi Iskar town with its residential districts Gnilyane and Katina, and Balsha village. According to the data from coring, the depth of this Formation is about 100–150 m. The Gnilyane Formation occurs transgressively and discordantly on the folded sediments of the Mesosoic and pre-Mesosoic substrate and in some places in the central part of the Basin on the Variegated Terrigenous Formation. Conglomerates, sandstones, silts and silty clays with lignite layers (Balsha Member of the Gnilyane Formation) are the most frequent components of the Gnilyane Formation. They are chiefly alluvial and more seldom marsh sediments.

The Novi Iskar Formation unfolds as a broken strip along the northern rim of the Basin. Its depth varies from 100 m in the southern parts of the Basin to 400 m in its central and northern parts. It is formed of lake sediments represented by monotonous grey and grey-bluish clays, diatomaceous clays and silty clays (Angelova & Yaneva 1998, Ognjanova-Rumenova & al. 2008). On the basis of mollusk and mammal finds, the age of the Formation in the southern and central parts of the Sofia Basin was determined as middle and late Pontian, and in the northern parts of the Basin the age scope extends to the beginning of the Dacian (Kamenov & Kojumdjieva 1983; Nikolov 1985). The late Pontian to early Dacian age was also suggested by data from the diatom analysis of these sediments (Ognjanova-Rumenova & al. 2008).

The Lozenets Formation develops across the Basin, occurring chiefly along the rim of the Basin, between the towns of Slivnitsa and Sofia, and in its central part is covered with Quaternary deposits. Its depth varies from 94 m to 158 m. It is represented by irregular horizontal and vertical alternation of sandy clays, silts, sands and often rubble. Lignite coal layers occur in the lower parts of the Formation, distinguished as the Novi Han Member of the Lozenets Formation. The Pliocene (Dacian – Romanian) age is supposed for this Formation (Kamenov & Kojumdjieva 1983).

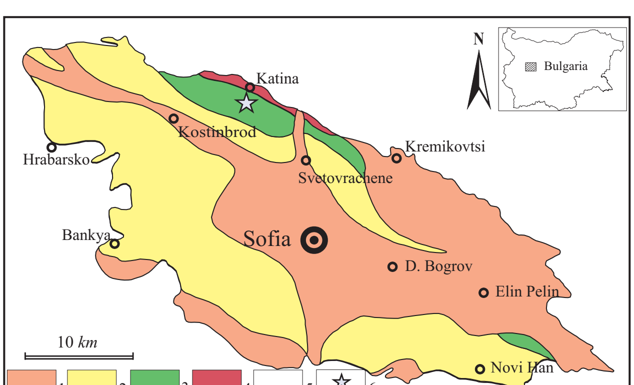

Fig. 1. Geological map of the Sofia Basin:
1, Quaternary; **2**, Lozenets formation; **3**, Novi-Iskar formation; **4**, Gnilyane formation; **5**, pre-Neogene rocks; **6**, core C-14 (redrawn from Palamarev & al. 2002).

Material and methods

Materials from the C-14 core near Katina village (42°50'01"N, 23°14'13"E, Google Earth 5.0), 15 km northwards from Sofia City, are the object of this study (Fig. 1). The sediments occurring between 262.40 m and 199.00 m belong to the Gnilyane Formation, those between 199.00 m and 20.00 m to the Novi Iskar Formation and those between 6.00 m and 20.00 m to the Lozenets Formation. They consist of sands, sandy clays, silty stratified clays, diatom clays, lignite coal, and limestone. Seventy-five pollen samples from the 6.00 m to 262.40 m interval have been studied palynologically out (Fig. 2). The samples were processed according to the standard procedure for pollen exraction, namely treatment in 5 % solution of $Na_4P_2O_7$, 10 % KOH, heavy liquid, and acetolysis according to Erdtman (1966).

The abundance of occurrence of the different pollen types and spores is presented in percentage from the pollen amount (ΣP), which includes the amount of arboreal and shrub taxa (AP) and of herbal taxa (NAP): $\Sigma P = AP + NAP = 100\,\%$. Percentages of the local elements have been calculated in relation to the total pollen amount: $AP + NAP + L = 100\,\%$, where L includes the spores of the fern plants and the pollen of aquatic vegetation.

Data from the performed analysis have been processed with TILIA 2.0.b.4 software (Grimm 1991–1993) and TGView 2.0.2 (Grimm 2004). The results of the palynological research are presented in a percentage spore-and-pollen diagram (Fig. 3). The diagram does not include the samples from the 260.00 m to 262.40 m interval which had poor pollen content and lacked the necessary number of pollen grains and spores for correct calculation of the percentage relationships.

While differentiating the zones, the authors clung to the definition of pollen zone provided by Gordon & Briks (1972): "A sedimentary body with constant and homogeneous content of fossil spores and pollen", and the boundaries of the zones have been set according to the characteristic changes in the individual curves of the established pollen types (Moore & al. 1991). Numerical zonation of pollen diagrams was used for differentiation of the local pollen zones (Briks 1974; Briks & Briks 2006), with the help of cluster analysis for grouping out the obtained palynological data. Mathematical processing and cluster analysis were carried out using CONISS software (Grimm 1987). The Square Root Transformation method (Edwards and Cavalli-Sforza's chord distance) was used for evaluation of the similarity degree between the compared objects, while the sum total of quadratic deviations was used as a measure of distance. The result of the cluster analysis is presented as a dendrogram, graphically depicted within the respective pollen diagram.

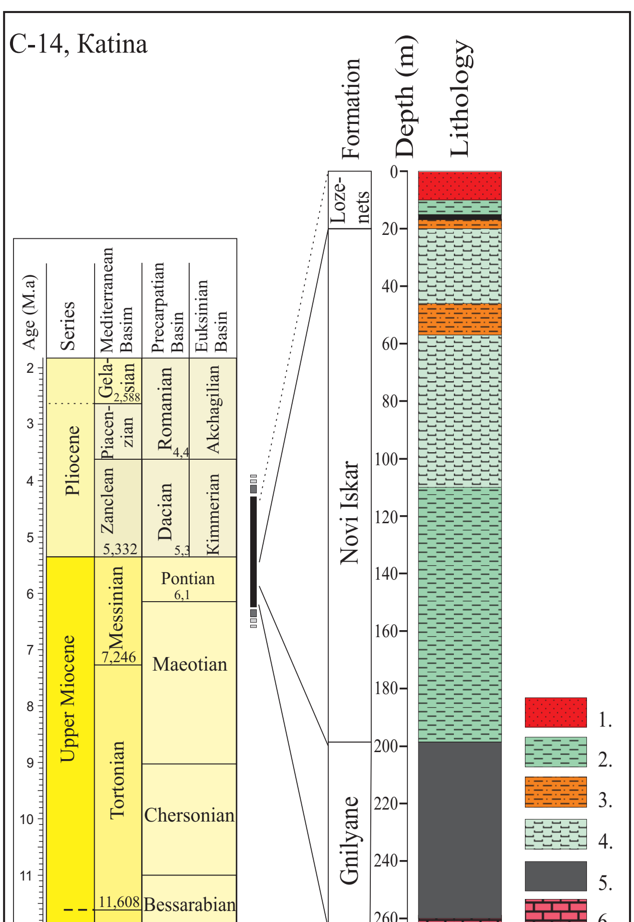

Fig. 2. Litological column of the core C-14, Katina: **1**, sands; **2**, silty clayshale; **3**, sandy silty clayshale; **4**, diatomiceous clayshale; **5**, lignite; **6**, chalk.

Results

A rich and diverse fossil flora was identified, consisting of a total of 104 spore and pollen types, belonging to 76 genera and 59 families.

On the basis of the most characteristic changes in the relationships between the basic pollen types in the pollen spectra, three local pollen zones (LPZ) and four subzones were differentiated in the pollen diagram of the C-14 core (Fig. 3).

Local pollen zone **KT-1 (198.0–150.0 m)**: *Carya-Pterocarya-Taxodiaceae*.

Stratigraphic range: Early and Middle Pontian.

The *Pinus dyploxylon* type showed the highest percentage, with a maximum of 35.2 % and a second peak of 29.8 %. The values of the representatives of genus *Picea* in this zone reached 1.8 %, which stands for their maximum for the entire profile. This zone is characterized in the pollen diagram by the considerable abundance of *Taxodiaceae*, varying up to 20.9 %. Of the arboreal taxa, the following pollen types have been registered in this zone, with their maximum values for the entire profile: *Castanea* (up to 20.4 %), *Ulmus* (from 2.3 % up to 14.0 %), *Quercus* (from 6.9 % up to 12.3 %), *Pterocarya* (from 1.9 % up to 12.0 %), *Carya* (from 1 % up to 8.8 %), *Alnus* (from 1 % up to 8.3 %), *Nyssa* (6.6 %), *Fraxinus* (6.5 %), *Glyptostrobus* (up to 6.2 %), *Populus* (5.7 %), *Liquidambar* (up to 4.6 %), *Oleaceae* (up to 4.5 %), *Fagus* (up to 3.6 %), and *Salix* (3.5 %). The herbal taxa were represented by *Chenopodiaceae*, with values varying from 2.4 % to 8.8 %; and *Poaceae* from 1.4 % to 4.2 %. The pollen of *Asteroideae* (1.9 %) and *Apiaceae* (1.9 %) was also present in the pollen spectra. Present were too some palaeotropical elements, such as *Platycarya* (up

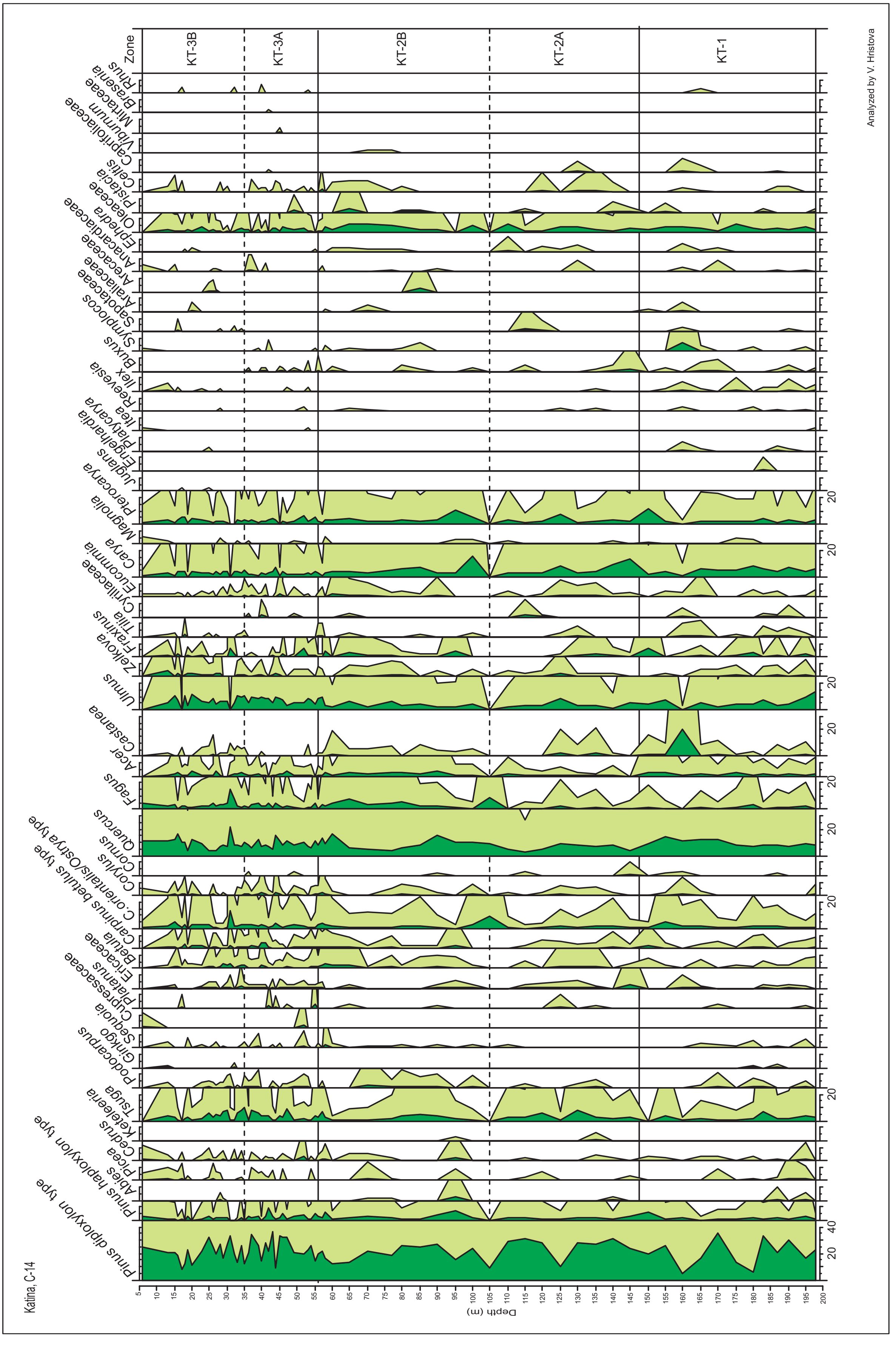

Fig. 3. Percentage spore-pollen diagram of the core C-14, Sofia Neogene Basin, with exaggerated factor 10.

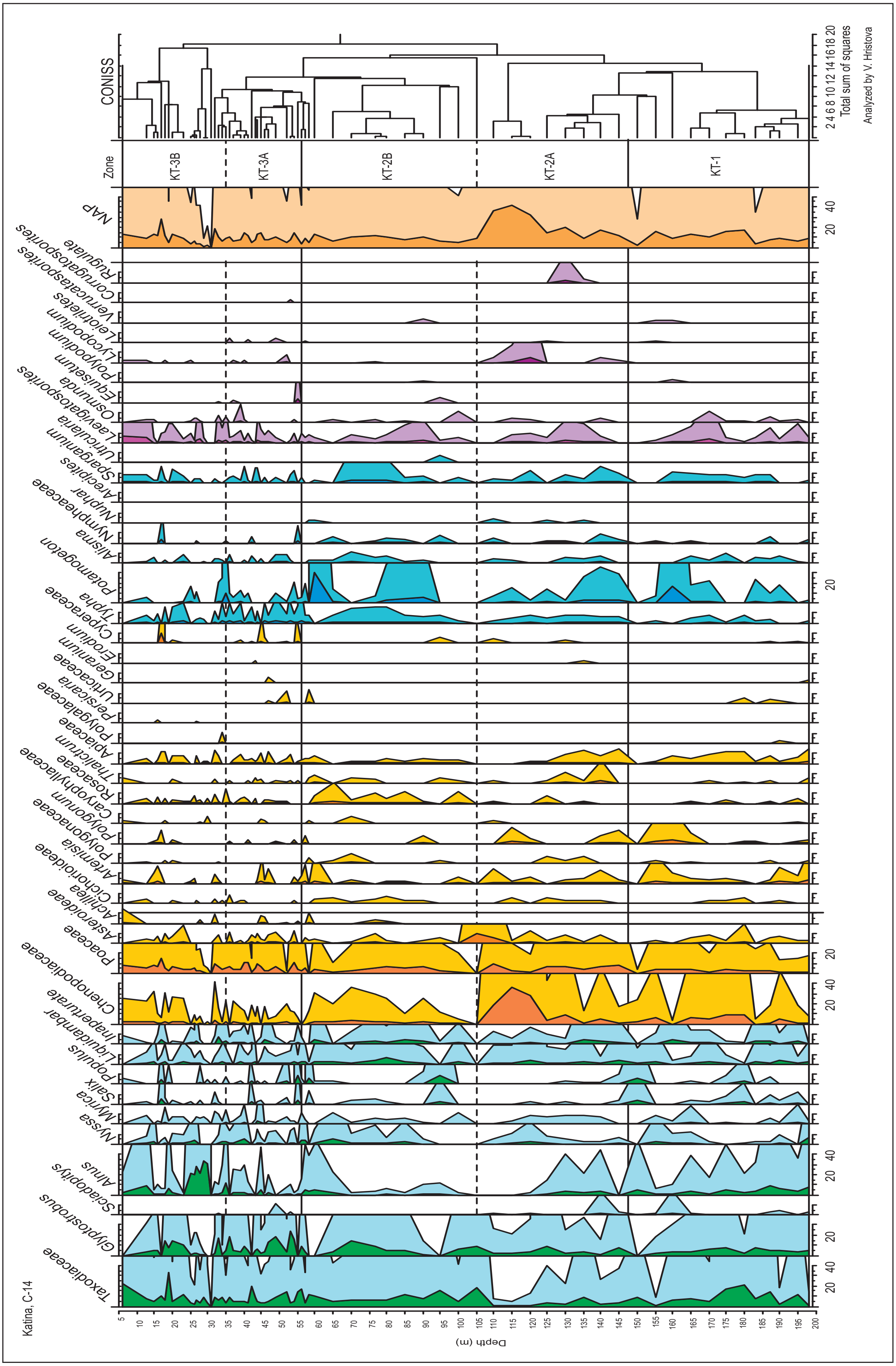

Fig. 3. Percentage spore-pollen diagram of the core C-14, Sofia Neogene Basin – continuation.

to 0.7 %), *Reevesia* (up to 0.4 %) and *Engelhardia* (up to 1.1 %). *Symplocos* (up to 6.9 %) showed the highest values, as compared to other zones.

Potamogeton (up to 16.5 %), *Laevigatosporites* (cf. *Polypodiaceae*) (up to 3.5 %), *Sparganium* (up to 1.6 %), *Osmunda* (up to 1.1 %), and *Typha* (up to 0.8 %) here recorded the highest percentages.

Local pollen zone **KT-2 (140.0–60.0 m)**: *Pinus dyploxylon* type-*Tsuga*-*Quercus*-NAP.

Stratigraphic range: Pontian.

In this zone NAP registered the maximum values: 35.5 %. This was due to the maximum values recorded in the pollen spectra by *Chenopodiaceae* (27.9 %), *Poaceae* (9.2 %), *Asteroideae* (5.3 %), and *Thalictrum* (2.3 %). The pollen of *Artemisia* (2.6 %) also showed the maximum percentage value for the entire profile. The values of *Taxodiaceae* (from 0.7 % up to 9.8 %), *Alnus* (up to 5.3 %), *Nyssa* (up to 2.1 %), *Myrica* (up to 0.9 %), and *Salix* (up to 0.3 %) recorded a slight lowering. The curves of *Ulmus* and *Zelkova* did not show any significant change. The percentage values of *Castanea* and *Symplocos* (0.7 %) were lower, as compared to those in the pollen zone KT-1. Of the other arboreal taxa, the highest percentage was registered by *Pinus dyploxylon* type (from 12.8 % up to 30.9 %). *Carya* (from 3.1 % up to 16 %), *Quercus* (from 5.1 % up to 16.6 %), *Oleaceae* (from 1.3 % up to 6.5 %), *Tsuga* (7.9 %), *Fagus* (5.4 %), and *Acer* (4.0 %) were represented by their maximums in the diagram. In that zone, *Nymphaeaceae* marked the highest values, as compared to the other zones (0.9 %). Of the local aquatic elements, *Potamogeton* (up to 29.9 %), *Sparganium* (up to 3.0 %) and *Lycopodium* (up to 5.0 %) also showed the maximum values for the entire profile.

Two subzones were differentiated within this zone:

KT-2A (140.0–100.0 m):

Stratigraphic range: Pontian.

The pollen records from that subzone registered maximum values for *Chenopodiaceae* (27.9 %), *Asteroideae* (5.3 %) and *Thalictrum* (2.3 %). Of the herbal taxa, *Artemisia* (up to 1.4 %) and *Poaceae* (up to 9.2 %) were presented. High values were also recorded for *Carya* (3.1–16 %), *Pterocarya* (up to 7.5 %), *Quercus* (5.1–16.6 %), and *Pinus dyploxylon* type (12.8–30.9 %). The curve of *Salix* dipped down (up to 0.3 %), as well as that of *Taxodiaceae* (0.7–9.8 %). *Glyptostrobus* (9.1 %) showed a lower percenage too. Representatives of *Tilia* (1.3 %), *Sciadopitys* (2.3 %), *Sapotaceae* (1.9 %), *Caprifoliaceae* (0.9 %), and *Cyperaceae* (0.5 %) also occured in this subzone. Pollen from *Ephedra* (1.3 %) and *Celtis* (1.9 %) was registered too. The spore of *Lycopodium* (5.0 %) showed a more significant occurance.

KT-2B (90.0–60.0 m):

Stratigraphic range: Pontian.

Characteristic feature of this subzone was the higher values of *Taxodiaceae* (up to 15.1 %), *Glyptostrobus* (up to 14.2 %), *Oleaceae* (6.5 %), *Fagus* (7.8 %), *Quercus* (16.6 %), and *Eucommia* (1.9 %). The individual curves of *Carya* (7.2 %) and the *Pinus dyploxylon* type (27.4 %) decreased. Representatives of *Symplocos* (0.7 %) were present in this subzone. Contrary to the previous subzone, *Chenopodiaceae* manifested a lesser participation (up to 3.6 %). The herbal taxa are characterized by *Poaceae* (up to 6.5 %), *Cichorioideae* (0.7 %), *Artemisia* (with a maximum of 2.6 % for the profile), and *Rosaceae* (2.0 %).

The local aquatics, such as *Potamogeton* (29.9 %) and *Sparganium* (3.0 %) were represented with their maximum values. Participation of *Typha* marked an increase (up to 1.6 %), as compared to subzone KT-2A.

Local pollen zone **KT-3 (50.0–6.0 m)**: *Ulmus*-*Taxodiaceae*-*Glyptostrobus*.

Stratigraphic range: Pontian – Dacian.

The pollen of *Glyptostrobus* (14.6 %) and *Alnus* (21.5 %) showed their maxima and there was a second maximum of the pollen of *Taxodiaceae* (22.3 %). This zone was characterized by a drop in the percentage of *Chenopodiaceae* (up to 3 %) and *Asteroideae* (up to 1.8 %), while the values of *Poaceae* increased from 2.4 % to 11.4 %. The NAP values were also lower (up to 15 %). In this zone the pollen curve of *Ulmus* went up (to 10.7 %), and that of *Oleaceae* decreased (0.8 %-4.1 %). The *Pinus dyploxylon* type showed a triple increase. The pollen of *Quercus* varied without any significant changes in its percentage with values from 6.8 % to 15 %.

Of the local elements, *Sparganim* were best represented in this pollen zone (up to 1.4 %) and *Typha* showed maximum values for the entire profile, up to 2.3 %.

Two subzones were differentiated in this zone:

KT-3A (50.0–30.0 m): *Ulmus-Poaceae*

Stratigraphic range: Pontian.

Specific for this subzone was the high percentage in *Poaceae* (up to 11.4 %) and *Ulmus* (up to 10.7 %) (Fig. 4). The pollen spectra also registered occurance of *Buxus* (0.4 %). The values of *Nyssa* (5.2 %) and *Sparganium* (1.6 %) marked a slight increase. The local elements were represented by *Laevigatosporites* (up to 3.0 %) and *Osmunda* (1.8 %).

KT-3B (30.0–6.0 m): *Taxodiaceae-Alnus-Glyptostrobus-Laevigatosporites.*

Stratigraphic range: Upper Pontian – Dacian

This subzone was characterizes by with the high percentage of *Alnus* (up to 21.5 %). The representatives of *Taxodiaceae* (up to 22.3 %) and *Glyptostrobus* (up to 14.6 %) also showed high values. The values of *Zelkova* showed a slight increase (up to 4.2 %). The pollen spectra of this subzone registered *Ilex* (up to 0.6 %), *Itea* (up to 0.3 %), *Anacardiaceae* (0.6 %), *Sapotaceae* (1.0 %), and *Tilia* (1.6 %). There was also a slight increase in *Castanea* (up to 1.6 %), *Carpinus betulus* (up to 2.8 %) and *Picea* (up to 1.4 %), as compared to the pervious subzone. In comparison to subzone KT-3A, the representatives of *Laevigatosporites* showed higher values (up to 6.9 %).

The pollen of *Pinus* registered high percentages participation in all pollen spectra. The *Pinus dyploxylon* type prevailed over *P. haploxylon*. *Abies, Sequoia, Ericaceae*, *Cyrillaceae*, *Araliaceae*, *Pistacia, Caryophillaceae*, and *Erodium* showed sporadic occurrences with single pollen grains in the pollen diagram spectra.

Discussion

Vegetation dynamics and climate changes in the investigated region were analysed on the basis of the different local pollen zones.

The sediments of the local pollen zone KT-1 reflect a period characterized by the prevalence of hygrophytic forest communities: *Taxodiaceae*, *Glyptostrobus*, *Alnus*, *Nyssa, Myrica, Salix, Liquidambar,* and *Osmunda.* Their development was directly related to changes in the paleogeographic situation and water level of the basin. The representatives of these communities were also identified during the paleobotanic investigations of the vegetation of the Sofia plain by Stefanov & Jordanov (1935). These plants inhabited the lower parts along the periphery of the water level and the marshy spots. Presumably, the high humidity in the region at that time had contributed to their wide distribution.

Judging by the abundant non-riparian pollen types also represented in that zone such as *Quercus, Ulmus, Carya, Pterocarya*, *Fraxinus*, *Castanea*, *Fagus*, and *Carpinus orientalis/Ostrya, Tilia* we can infer the occurrence in this area of a mixed mesophytic forest communities, with undergrowth of broadleaved and evergreen representatives of *Corylus, Cornus, Ilex,* and *Ericaceae*. The high diversity of these forests is mainly due to the floristic elements developing under a warm temperate climate. Such is the character of the floras from the Karlovo and Stanyantsi Basins (Ivanov & Slavomirova 2004; Ivanov & al. 2008). Some thermophilous taxa, such as *Engelhardia, Ilex*, *Reevesia*, *Sapotaceae*, and *Araliaceae* are present in the composition of the mesophytic forest communities. Probably, the greater humidity around the basin had favoured their survival as relicts from the subtropical middle Miocene flora. Their presence could be interpreted as a proof that the past climate in this area was warmer and of higher humidity, as compared to the present climate.

Herbaceous vegetation was abundant in the LPZ KT-2. It probably coverly the flatlands and open places along the basin's coastal parts. The main role in the herbaceous paleocoenoses went to the representatives of *Chenopodiaceae*, *Poaceae* and *Artemisia*. This was clearly reflected in the pollen records of subzone KT-2A. The higher values of herbal taxa were probably connected to a change in the paleogeographic situation: shrinking of the marshland areas, emergence of open habitats, etc., as well as reduction of the annual precipitations.

While tracing out the percentages of *Taxodiaceae*, *Alnus*, *Nyssa, Myrica,* and *Salix* in this zone, a reduction of their participation in subzone KT-2A has been noticed in relation to LPZ KT-1. Along with this, the pollen spectra registered a presence of some plants developing under drier conditions in their habitats (for instance, *Ephedra, Celtis, Pistacia*). *Ulmus* and *Salix* also recorded a slight decrease in their percentage participation. These data could be interpreted as an indication of the onset of a drier climatic regime. The values of the representatives of *Corylus, Acer* and *Fagus* recorded a slight increase. There were no occurrences

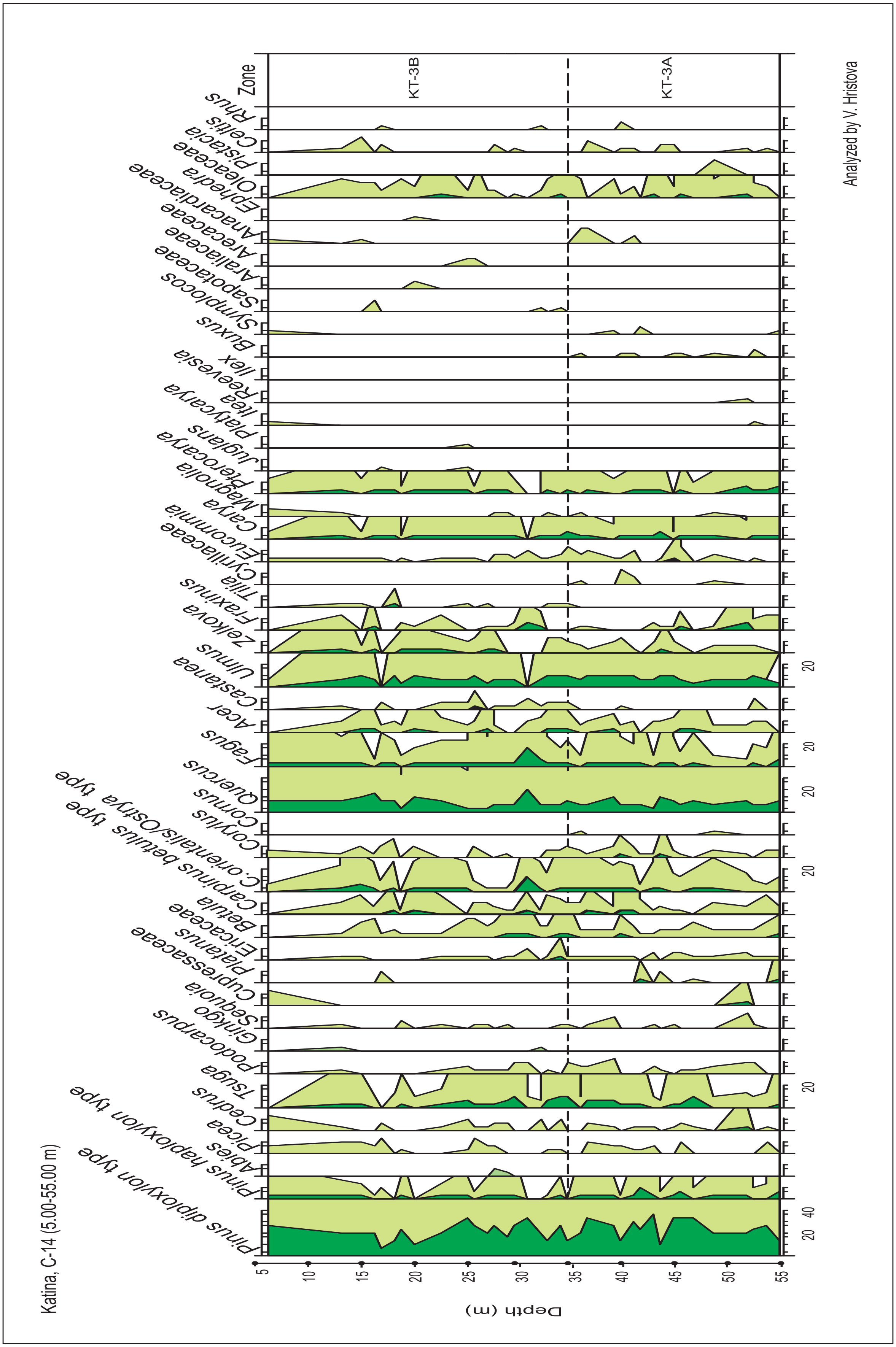

Fig. 4. Percentage spore-pollen diagram of the core C-14 (Katina): 5.00–55.00 m.

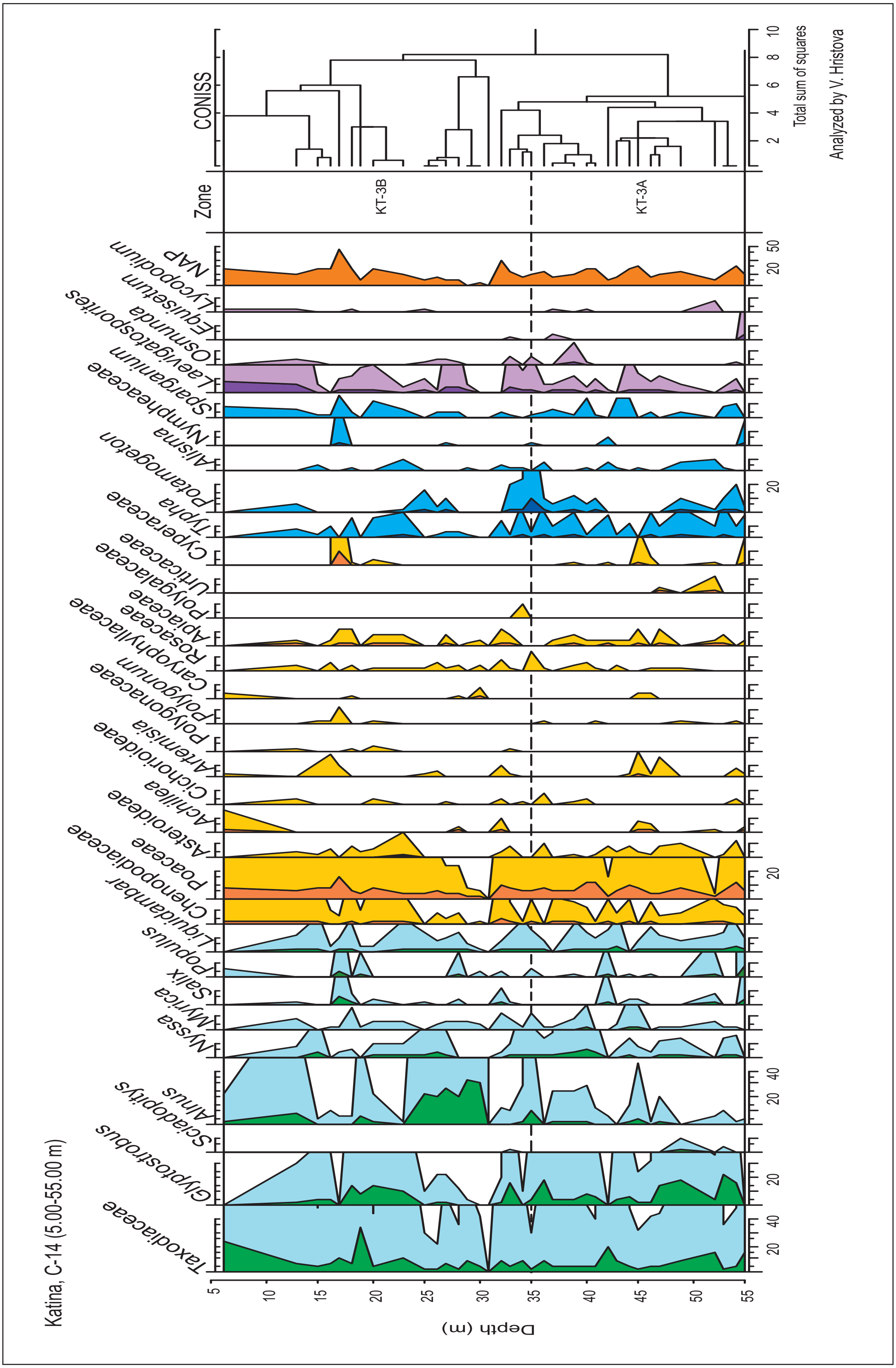

Fig. 4. Percentage spore-pollen diagram of the core C-14 (Katina): 5.00–55.00 m – continuation.

of the pollen of *Engelhardia, Ilex*, *Reevesia*, *Sapotaceae*, and *Araliaceae* in the pollen spectra.

In this zone, and particularly in the subzone KT-2B, aquatic vegetation was very well represented, with maximum values for the entire profile. This vegetation was closely connected to the wetland and shallow water stretches of the water basin. The pollen spectra registered pollen of *Potamogeton, Sparganium, Typha,* and *Nymphaeaceae.*

The LPZ KT-3 marked a significant increase of the components of the hygrophytic forest communities: *Taxodiaceae*, *Alnus* and *Glyptostrobus* (Fig. 4: LPZ KT-3B). They were widely distributed and testify to a humid climate and permanently inundated territories. This zone corresponds to the Upper Pontian and Early Dacian, when intensive faulting processes took place and the basin was lowered, especially in its central and eastern parts, which continued into the Pliocene (Kamenov & Kojumdjieva 1983). The greater presence of hygrophytic communities coincided with reduction trend in herbaceous vegetation such as *Chenopodiaceae* and *Asteroideae*, which again supports the assumption that the climate was more humid.

The results of the pollen analysis have shown that *Quercus, Ulmus, Fagus, Carpinus orientalis/Ostrya*, and *Liquidambar* were still the major components of the mesophytic forest communities, with relatively stable values. Data from other paleobotanical investigations of the Miocene flora from the Sofia Basin (Kitanov & Nikolova 1956, Kitanov 1982) testified that their floristic composition was richer and was characterized by the presence of *Platanus, Ginkgo* and *Magnolia*. A slight drop in the individual curve of *Oleaceae* was registered, as compared to KT-2 zone.

The presence of the thermophylous elements *Ilex*, *Itea*, *Anacardiaceae*, *Sapotaceae*, and *Tilia* in the pollen spectra could be explained with the onset of a warmer climate.

This study agrees results correlated with the conclusions of Palamarev & al. (1999). On the basis of the rich macroflora established in the Upper Pontian sediments from freshwater basins in South Bulgaria (including the Sofia Basin) and the performed paleoecological analysis, the authors drew the conclusion that a warm and humid climate had existed in the Pontian, with average annual temperatures of 13–14 °C and average annual precipitations from 800 mm/m² to 1200 mm/m².

Conclusion

As a result from the palynological investigations of the Late Miocene sediments from the Sofia Basin (Southwest Bulgaria), a palynological zonation of these sediments was made. Tracing out of the percentage participation values of the pollen types made possible the differentiation and description of three local pollen zones with four subzones: KT-1, KT-2A, KT-2B, KT-3A and KT-3B. The floristic records of the pollen zones KT-1 and KT-3B showed high values of the hygrophytic forest communities component, presumably conditioned by a humid climate, contrary to the pollen zone KT-2A with a considerable participation of herbaceous vegetation. The pollen zones KT-1 and KT-2B illustrate the wide distribution and diversity of the mixed mesophytic forests. The pollen zones KT-2B and KT-3B reflect the presence of thermophilous floristic elements in the pollen spectra.

The palynological data and the conducted analysis give grounds to the assumption that the climate which influenced the development of the fossil flora of the Sofia Basin in the Late Miocene was warm-temperate and humid, without any distinctly dry period.A

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