ГОДИШНИК НА СОФИЙСКИЯ УНИВЕРСИТЕТ „СВ. КЛИМЕНТ ОХРИДСКИ“
БИОЛОГИЧЕСКИ ФАКУЛТЕТ
Книга 2 – Ботаника
Том 104, 2020

ANNUAL OF SOFIA UNIVERSITY "ST. KLIMENT OHRIDSKI"
FACULTY OF BIOLOGY
Book 2 – Botany
Volume 104, 2020

MACRO- AND MICROPALAEOBOTANICAL EVIDENCES FOR LATE MIDDLE MIOCENE CLIMATE CHANGE IN BULGARIA

DIMITER A. IVANOV*

Department of Plant and Fungal Diversity and Resources, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, 23 Acad. G. Bonchev Str., BG-1113 Sofia, Bulgaria

Abstract. An analysis of selected macrofloras (leaves, fruits and seeds) from NW Bulgaria using the Coexistence approach method was applied to obtain quantitative data about Volhynian and Bessarabian climate in studied area. The aim of the study is to compare the climate data derived from the analysis of macrofloras and palynological data. The Middle Miocene was a period of a subtropical/warm temperate humid climate with mean annual temperature between 16 and 18 °C and mean annual precipitation between 1,100 and 1,300 mm. Comparison of all data, received from different floras we can observed, showed that nevertheless some differences, in all cases there was a good relation between climate and vegetation dynamics. We observed some deviations in quantities, but they varied in small limits. The climate data derived from macro- and microfloras coincided well in regard to all parameters, nevertheless that different taxa determined coexistence intervals. In some cases, the macropalaeobotanical data provide narrow climate interval, that is explained by better taxonomic resolution and better identification of nearest living relatives (NLRs). The application of both methods has the advantage of obtaining both more accurate climate data and tracking climate change in more detail throughout the study period.

Key words: Volhynian, Bessarabian, macroflora, pollen, Coexistence approach, climate reconstruction

**corresponding author*: D. A. Ivanov – Department of Plant and Fungal Diversity and Resources, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, 23 Acad. G. Bonchev Str., BG-1113 Sofia, Bulgaria; dimiter@bio.bas.bg.

INTRODUCTION

The history of vegetation change in Northwestern Bulgaria (Forecarpathian Basin) has been studied last few decades on the basis of both macrofossil and microfossil records. The well-preserved leaf imprints, seeds/fruits, dispersed cuticles and palynomorphs (Palamarev & Petkova 1987 and Ivanov et al. 2002, and references therein) provide a good ground for vegetation and climate reconstructions. Because of the specific geographic position of the Balkan Penninsula in the Miocene between two vast marine basins – Mediterranean to the south and Parathetyan to the north (Rögl 1998; Meulencamp & Sissingh 2003), it plays a major role in the evolution plants in the Neogene of Europe. This area appears as a land bridge and a main migration route between Asia minor and Central Europe, and apparently it also plays a major role in the evolution of Mediterranean vegetation (Palamarev 1989). It is also important in understanding the evolution of climate system in this area.

Palaeoclimatic research is an important tool for the correct interpretation of modern climate change and for the correct understanding of how the climate system works. Data on terrestrial climate usually come from two main proxies - analysis of fossil land animals (mainly mammals) and mainly from the data on fossil flora and vegetation. The latter is widespread for reconstructions because of different techniques developed for climate analysis of fossil plant data. There are two approaches to extract climate data from plant fossils - leaf physiognomy and nearest living relatives (NLR) approach. Recently a study comparing these two approaches based on leaf-floras was published (Ivanov et al. 2019) and the results clearly showed the advantages and preciseness of the NLR's using Coexistence approach (CA) method. The present study uses the possibilities of the NLR's approach comparing palaeofloristic data obtained by macro- and micro-floristic studies.

Geological settings

The palaeogeography of the Forecarpathian Basin and its variations during the Neogene are relatively well known. A shallow brackish basin covered wide territories in the NW Bulgaria in the Middle Miocene. The age of sediments is well dated by characteristic mollusk associations, as well as by ostracods and foraminifers (Ivanov et al. 2002). The longitudinal depression was active in the Volhynian (Kojumdgieva & Popov 1986, 1989; Kojumdjieva et al. 1989; Ivanov et al. 2019), and in the peripheral parts of the basin (the so called Marginal stable area: **Fig. 1**) a lot of swamps and almost freshwater ponds existed. This study is based on macrofloristic analysis of several localities of Volhynian and Bessrabian ages situated south of the Forecarpathian Basin (**Fig. 1**). The studied sediment successions are presented by sandy clays and clays, which contained well preserved macroremains and palynomorphs. Stratigraphically they belong to the

Krivodol Formation assigned to the Middle Miocene (Kojumdjieva et al. 1989).

MATERIAL AND METHODS

About 32 fossil macrofloras are known from NW Bulgaria (Palamarev 1988, 1990, 1993; Palamarev & Petkova 1987). The revised taxonomy of fossil flora (Palamarev et al. 2005) is used in this study. For the present study four floras of Volhynian and three of Bessrabian age were chosen. The choice of flora for analysis was based on the sufficient completeness of the fossil record. Most local floras contains 4-5 fossil species. In order to obtain reliable data, flora with a sufficiently rich floristic composition were selected, namely Tsar Shishmanovo-Tolovitsa, Ruzhintsi, Kladorub-Ostrokarptsi and Pelovo of Volhynian age, and Drenovets,

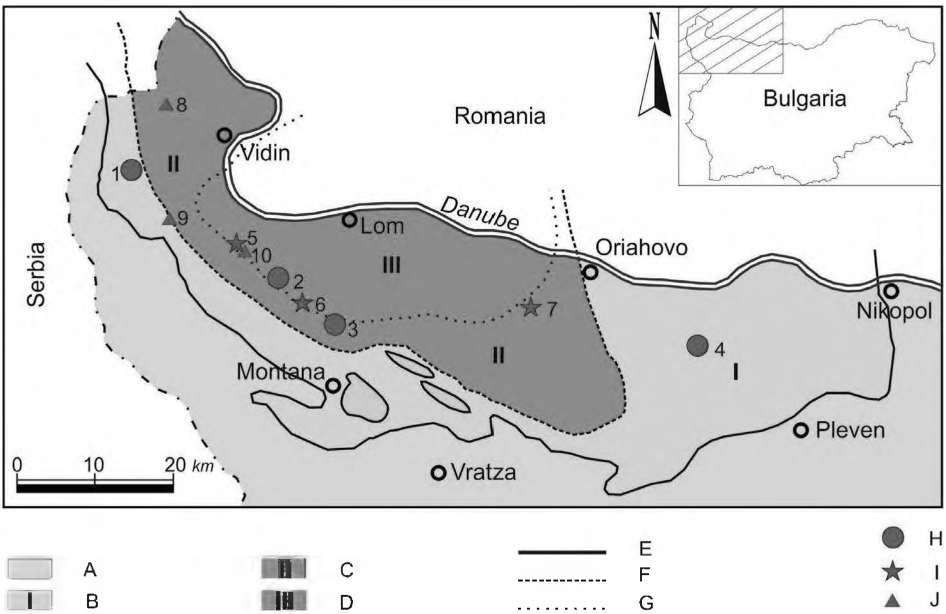

Fig. 1. Sketch map showing the structural-palaeogeographical areas in Northwest Bulgaria during the Miocene, and the localities of the studied profiles (after Ivanov et al. 2002). Legend: A - Areas outside the Forecarpathian Basin (land); B - Marginal stable area; C - Miocene longitudinal depression; D - Lom depression; E - Boundaries of the basin; F - Boundaries of the Miocene longitudinal depression; G - Boundaries of the Lom depression; H - Localities with Volhynian macroflora: 1. Tsar Shishmanovo-Tolovitsa; 2. Ruzhintsi; 3. Kladorub-Ostrokarptsi; 4. Pelovo; I - Localities with Bessranian macroflora: 5. Drenovets; 6. Belo Pole-Cherno Pole; 7. Hairedin; J – Localities with pollen flora: 8. Deleina; 9. Makresh; 10. Drenovets.

Belo Pole-Cherno Pole, and Hairedin of Bessarabian age. Pollen flora used in this study came from cores C-12 Deleina, C- Drenovets and C-37 Makresh (**Fig. 1**).

The NLR approach is a widely applied technique for palaeoclimate estimates with the help of fossil plants. It is based on comparisons of fossil taxa with recent species and it is assumed that the climatic requirements of fossil species are more or less similar to those of their nearest living relatives. In this study the CA method (MOSBRUGGER & UTESCHER 1997; UTESCHER ET AL. 2014) was applied to obtain quantitative climatic data. This technique is straightforward and uses climatic tolerances of nearest living relatives of fossil taxa with respect to various climatic parameters to reconstruct past climates. The interval of possible coexistence of all taxa is calculated for the various climate parameters, within which all nearest living relatives of the fossil flora can exist. This coexistence interval is regarded as representing a reasonable estimator of the past climate under which the fossil flora lived. Such approach can be used with all kinds of plant remains (*e.g.* leaves, fruits/seeds, pollen/spores) for which the NLRs can be reliably identified. The method was recently applied for palaeoclimate reconstructions in Europe and Asia (*e.g.* PROSS ET AL. 1998; UTESCHER ET AL. 2000; UHL ET AL. 2003; IVANOV ET AL. 2002, 2011; BILTEKIN ET AL. 2015; DURAK & AKKIRAZ 2016; IVANOV & WOROBIEC 2017; KAYSERI-ÖZER 2017; KAYSERI-ÖZER ET AL. 2017; YAVUZ ET AL. 2017; IVANOV & LAZAROVA 2019). For a given fossil flora, the CA method determines the nearest living relatives of fossil taxa and their climatic tolerances and calculates the coexistence intervals (minimum and maximum values) for various climate parameters (for details see MOSBRUGGER & UTESCHER 1997 and UTESCHER ET AL. 2014) within which all living relatives of fossil species can coexist. The climate data were obtained with the help of Palaeoflora database (UTESCHER & MOSBRUGGER 2015). The following climate parameters were considered as presenting the main climate characteristics: MAT - mean annual temperature (°C), TCM - mean temperature of the coldest month (°C), TWM - mean temperature of the warmest month (°C), MAP - mean annual precipitation (mm). In addition, a brief description of fossil vegetation is also presented based on autecological analysis (IVANOV 2015; IVANOV & WOROBIEC 2017; IVANOV & LAZAROVA 2019).

The present-day climate of Northwest Bulgaria is characterised by MAT 11.2-11.5 °C, TCM -2.1 to -0.9 °C, TWM 22.6-23.6 °C and MAP 536-586 mm (VELEV 1997).

RESULTS AND DISCUSSION

The Volhynian

We analyzed four floras of Volhynian age located near the villages of Tsar Shishmanovo-Tolovitsa, Ruzhintsi, Kladorub-Ostrokarptsi and Pelovo. These floras are enough rich with taxa to provide reliable palaeoclimate date.

The Volhynian palaeoflora contains 154 species belonging to 114 genera and 69 families of the whole macroflora. In addition, 139 palynomorphs have been discovered. This flora is systematically very rich in representatives of Algae, Bryophyta, Lycopodiophyta, Equisetophyta, Polypodiophyta, Pinophyta and Magnoliophyta. The largest families are Lauraceae, Fagaceae, Fabaceae, Betulaceae, Juglandaceae, Rhamnaceae and Magnoliaceae. Among the genera, the most diversified were *Quercus*, *Magnolia*, *Myrica*, *Persea*, *Rhamnus* and *Pinus*.

Specific feature of the studied flora is the mixture of different floristic elements. As many other Tertiary floras, it comprises taxa which for the most part do not grow together today, being a unique combination of refugial-geographic elements. Among all, the East Asian and North American elements are better presented, thus pointing to closeness and relationship of the fossil flora to recent ones from East Asia and North America (**Fig. 2**). The East Asian element clearly dominates with 31.7%. An important feature is the considerable presence of Mediterranean elements (8.5%).

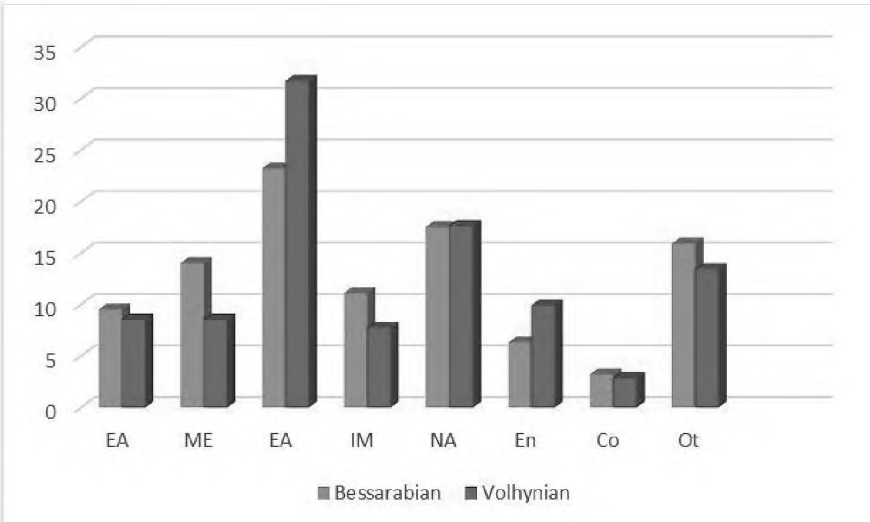

Fig. 2. Ratios between refugial-geographic elements in Sarmatian macroflora. Legend: EU – Eurasian; ME – Mediterranian; EA – East Asian; IM – Indo-Malaysian; NA – North American; En – endemic; Co – cosmopolitan; Ot – others (after Palamarev & Ivanov 2001).

A very important phytogeographical characteristic of the flora discussed is the high value of endemism - 9.9%. With fourteen new taxa the Volhynian flora acted as a significant centre of speciation (for details see Palamarev et al. 1999). The ratio between the genetic genera categories is: allochthonous taxa - 48.2%, autochthonous taxa - 43.9%, extinct taxa - 4.4% and form genera - 3.5%. In addition, participation in arctotertiary elements has increased compared to Badenian flora, although the dominance of the thermophilous palaeotropic components is still provable.

From palaeoecological point of view, the following plant communities were described (**Fig. 3**): hygro-hydrophytic grassy paleocoenoses, euhydrophytic grassy paleocoenoses, hygrophytic forest paleocoenoses, riparian forests, mesophytic to hygromesophytic forests, mesoxerophytic to sclerophyllous forests, and herbaceous communities (Palamarev & Ivanov 2001).

The results obtained for Volhynian climate (**Table 1; Fig. 4**) shows CA-

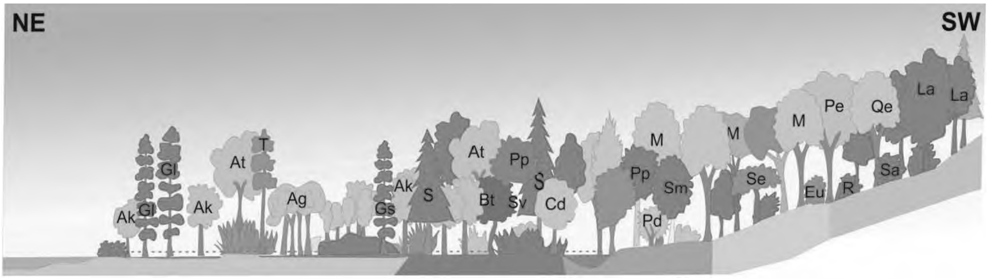

Fig. 3. Reconstructed vegetation profile for the Middle Miocene (Volhynian) in NW Bulgaria. Vegetation Structure includes: Mesophytic to hygromesophytic forests – polydominant and multispecies communities composed by species of *Pteris*, *Pteridium*, *Woodwardia*, *Sequoia*, *Magnolia*, *Liriodendron*, *Persea*, *Ocotea*, *Daphnogene*, *Litsea*, *Laurus*, *Corylopsis*, *Arbutus*, *Berchemia*, *Fagus*, *Quercus*, *Castanea*, *Zelkova*, *Carpinus*, *Engelhardia*, *Eurya*, *Sassafras*, *Schefflera*, *Adinandra*, *Hartia*, *Symplocos*, *Diospyros*, *Rubus*, *Prunus*, *Skimmia*, *Staphylea*, *Thevetia*, *Sapindus*, *Meliosma*, *Cornus*, *Aralia*, *Sambucus*, *Cedrela*, *Trigonobalanopsis*, *Sabal*, *Lygodium*, *Actinidia*, *Humulus*, *Berchemia*, *Carya*, *Pterocarya*, *Ampelopsis* and *Pathenocissus*.

intervals for mean annual temperature (MAT) 16.0-16.5 °C (narrowest climatic interval derived from Ruzhintsi paleoflora). Slightly lower left borders of intervals (14.4 °C) concerning Kladorub-Ostrokaptsi and Pelovo could be due to the incompleteness of the flora and the lower number of species in coexistence. The right border of the intervals of MAT could be also at 16.9 or 17.4 °C as derived by data from Pelovo, Kladorub-Ostrocarptsi and Tsar Shishmanovo-Tolovitsa. The temperature of the coldest month (TCM) is in the frame 5.6-5.8 °C. The temperature of the warmest month (TWM) is almost equal from all 4 sites – 25.7-26.4 °C. As regard the precipitation the CA-intervals for mean annual precipitation (MAP) is well above 1,000 mm (1,090-1,230 mm), but some wide intervals were obtained – between 843 and 1297 mm. This is in agreement with results from CA-analysis

Table 1. Climate data for Volhynian and Bessarabian derived from macro-paleobotanical record.

Age	Locality	MAT (°C)	TCM (°C)	TWM (°C)	MAP (mm)
Bessrabian	Drenovets	14.7-18.0	3.8-13.3	25.4-27.1	1096-1189
	Belo Pole-Cherno Pole	13.8-16.9	3.1-8.1	24.7-25.3	816-1297
	Hairedin	9.1-15.7	2.9-9.1	21.9-27.9	963-1362
Volhynian	Tsar Shishmanovo-Tolovitsa	16.0-17.4	5.6-5.8	24.5-27.0	840-1230
	Ruzhintsi	16.0-16.5	5.6-5.8	25.7-26.4	1090-1230
	Kladorub-Ostrokarptsi	14.4-17.4	5.6-5.8	25.7-26.4	867-1230
	Pelovo	14.4-16.9	3.7-5.8	25.4-26.4	1035-1356

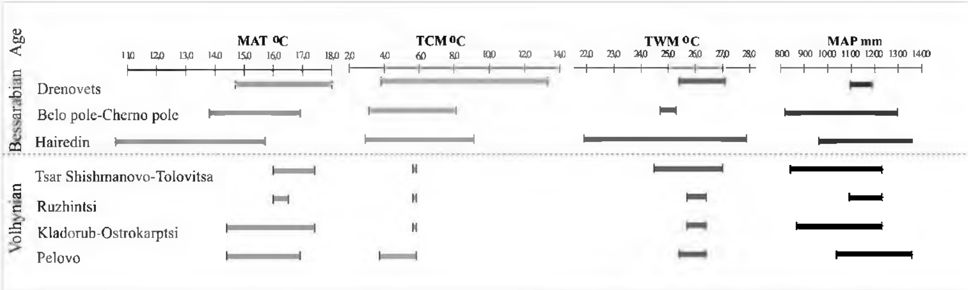

Fig. 4. Reconstruction of the paleoclimatic parameters for the Forecarpathian basin on the basis of the macropaleobotanical data.

of palynological data which suggest drying at very late Bessarabian and early Chersonian (Ivanov 1998).

In the Volhynian the climatic conditions derived from pollen data (**Table 2; Fig. 5**) show relatively stable climate. MAT is between 15.6 and 17.2 °C (but some samples give higher temperatures, *e. g.* 17.2-18.4 °C) and a second coexistence interval may. TCM is mainly between 5 and 7 °C, temperatures of the warmest month lie within 24.6-27.8 °C and both TCM and TWM show small oscillations of the upper limit. As regards the fluctuations of MAP, the narrowest coexistence intervals occur during the upper part of the Volhynian with 1,187-1,322 and 1,076-1,322 mm. this corresponds to the high precipitation rate in the Volhynian obtained from macropalaeobotanical data.

The Bessarabian

Three floras of the Bessrabian age located near the villages of Drenovets, Belo pole-Cherno pole, and Hairedin were analyzed. In terms of quality of data these floras are poorer in species, and provide less reliable data.

Bessarabian paleoflora is relatively poorer in genera and species compared to Volhynian complex. It contains ca. 60 species from the macroflora, which belong to 53 genera and 33 families. The microflora has become known through 119 taxa (Ivanov 1998). The Fagaceae, Betulaceae and Juglandaceae are characterized by greater variety at the genus level. The species diversification is weak. In this type of flora one can observe the sharp decrease in Lauraceae, Magnoliaceae and ferns, as well as a general floristic impoverishment. Obviously, during this period, there is a phase of degradation in the development of the Neogene vegetation. The endemic element is relatively high (6.3%) because most endemic species with Volhynian origin continue to develop in Bessarabian. The high value is also due to the low taxonomic diversity of the flora.

The autochthonous elements (50.0%) predominate over allochtonous ones (44.2%). Compared to the Volhynian paleoflora, shrub and liana components have dropped significantly here. The herbs had also become somewhat higher at the

Table 2. Climate data for Volhynian and Bessarabian derived from pollen record from core Deleina.

Age	Depth (m)	MAT (ºC)	TCM (ºC)	TWM (ºC)	MAP (mm)
Bessrabian	78	14,7-17,2	1,7-6,6	23,0-27,8	740-740
	80,5	11,6-18,4	1,7-8,1	23,6-27,8	652-759
	83,5	15,6-17,2	5,0-6,6	24,7-27,3	897-1308
	106	17,2-18,4	5,0-8,1	24,7-27,8	1187-1322
	110	15,6-17,2	5,0-7,0	24,7-27,3	823-1380
	114	15,6-17,2	5,0-7,0	24,7-27,8	897-1322
	120	17,2-17,2	5,0-6,6	24,7-27,8	1187-1308
Volhynian	143,5	15,6-17,2	5,0-6,6	24,7-27,3	1076-1281
	150,5	15,6-17,2	5,0-6,6	24,7-27,8	897-1281
	185	15,6-17,2	5,0-7,0	24,7-27,8	1187-1281
	194	15,6-17,2	5,0-7,0	24,7-27,3	1187-1281
	220	15,6-17,2	5,0-6,6	24,7-27,8	1187-1322
	234	15,6-17,2	5,0-6,6	24,7-27,8	823-1322
	245	15,6-17,2	5,0-6,6	24,7-27,1	1076-1380
	258	15,6-17,2	5,0-6,6	24,7-27,8	1187-1281
	260	15,6-17,2	5,0-7,0	24,7-27,8	1187-1308
	262	15,6-17,2	5,0-7,0	24,7-27,8	897-1281
	264	15,6-17,2	5,0-7,0	24,7-27,8	1187-1281
	268	15,6-17,2	5,0-7,0	24,7-27,8	740-1281
	273,5	15,6-17,2	5,0-7,0	24,7-27,8	1187-1281
	281,5	15,6-17,2	5,0-7,0	24,7-27,1	823-1281
	285	15,6-18,4	5,0-8,1	24,7-27,8	1076-1308
	349	15,6-17,2	5,0-6,6	24,7-27,8	823-1308
	353	15,6-17,2	5,0-6,6	24,7	1076-1281

same time. This time interval (the end of Bessarabian) corresponds to the beginning of Tortonian in Mediterranean area and the beginning of the so-called *Vallesian crisis* - sequence of mammal events, changes in lower vertebrate record.

With regard to the ecological requirements, the paleoflora type consists of the following components: hydrophytes (8.3%), hygrophytes (5.0%), hygromesophytes (15.0%), mesophytes (51.7%) and hemixerophytes to xerophytes (20.0%). The greatest change occurred in the group of hygromesophytes. Numerous macro- and mesothermal ferns, laurel and magnolia species have fallen off. The number of arctotertiary elements is significantly increased and this change is particularly

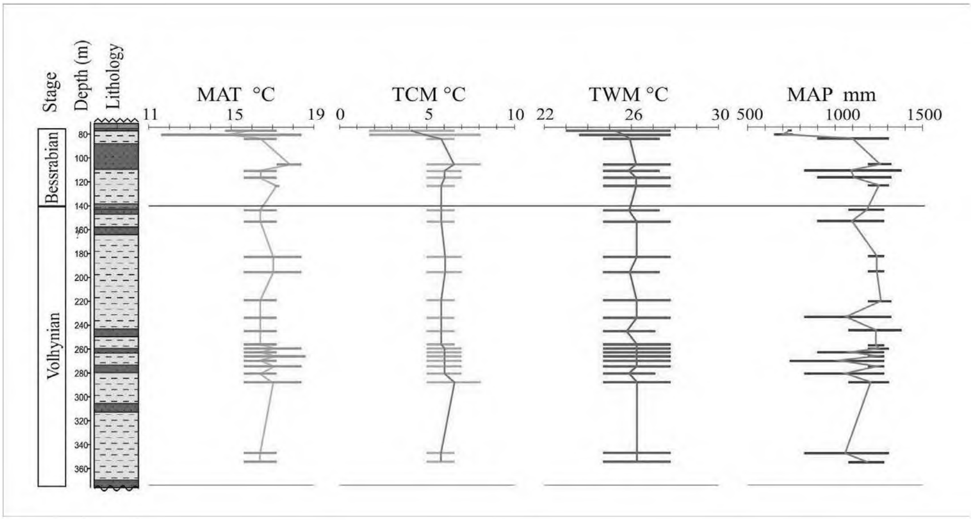

Fig. 5. Reconstruction of the paleoclimatic parameters for the Forecarpathian basin on the basis of the palynological data from drilling profile C-12 Deleina.

visible in the pollen spectra (Ivanov et al. 2011). This trend is valid also for the involvement of the herb component (**Fig. 6**). The phytogeographic analysis (**Fig. 2**) shows a relatively monotonous picture. The East Asian and Atlantic North American elements are in first place with 23.2% and 17.5%. Then comes the Mediterranean element with 14.3%, which is an important increase.

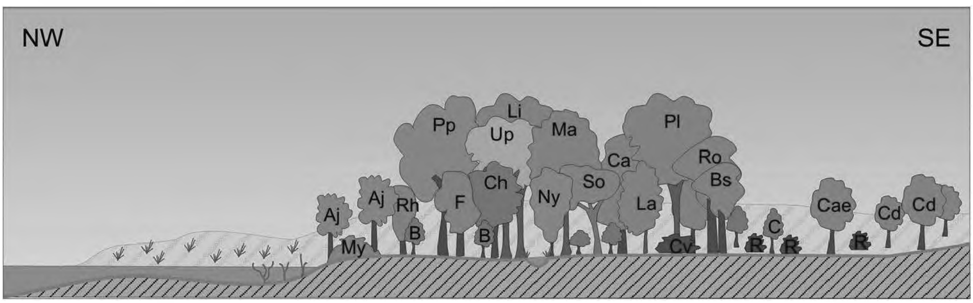

Fig. 6. Reconstructed vegetation profile for the latest Bessarabian - early Khersonian in NW Bulgaria. The most significant event are: appearance of open landscapes and development of herbaceous xerophytic communities – Chenopodiaceae-Artemisia-Caryophyllaceae-Asteraceae; Subxerophytic shrubs – *Celtis*, *Anagyris*, *Caesalpinites*, *Robinia*, *Sophora*, *Paliurus* etc.; Restricted distribution of thermophyllous elements in the mesophytic forests; Changes of dominant species in forest communities; Restriction in the distribution of the swamp forests.

The results obtained for Bessarabian climatic parameters show similar values, slightly lower CA-intervals concerning annual temperature (left border at 13.8 and 14.7 °C) and temperature of the coldest month (2.0-9.1 and 3.1-8.1 °C), which could due both to climate change or incompleteness of fossil record. As regard the precipitation the CA-intervals are wider – between 843 and 1,297 mm. It is worth to note that the Besserabian macroflora comprise more xeric and semi-xeric floristic elements that could suggest some drying of the climate during that period. This is in agreement with results from CA-analysis of palynological data which suggest drying at very late Bessarabian and early Chersonian (IVANOV ET AL. 2002).

The pollen data for Bessarabian shows that the palaeoclimate is most similar to the Volhynian (**Table 2; Fig. 5**). However, at the end of this stage a slight decrease in MAT is indicated in cores C-12 Deleina and and C-1 Drenovets. Thus the end of the Bessarabian represents the starting point for the climatic changes occurring in the Chersonian. This latter substage is characterised by lower values in almost all climate parameters (**Fig. 5**). MAT coexistence intervals are 13.3 (14.4) to 17.2 °C, corresponding to a decrease of the lower boundary of about 2 °C as compared to the Bessarabian and Volhynian. A similar cooling is observed for the TCM with the lower boundary of the coexistence intervals changing from 5 °C in the Volhynian/ Bessarabian to 1.7 °C in the Bessarabian/Khersonian (IVANOV ET AL. 2002). The lower boundary of the coexistence interval for the summer temperature (TWM) also decreases by about 2 °C. But the most significant change occurs in the mean annual precipitation. The climatic estimates for the end Bessarabian (**Fig. 5**) indicate that the climate was slightly cooler (particularly in winter) and significantly drier. This could mean a greater seasonality and probably more or less pronounced dry period in the summer.

Comparison of all data, received from different observed floras showed, that nevertheless some differences, in all cases there was a good relation between climate and plants. We observed some of deviations in quantities, but they varied in small limits. These deviations could due to several factors, in our case more appropriate is to suggest that completeness of paleofloristic data, and the applied paleobotanical method, which discloses different floristic components, influenced in major part the preciseness and correctness of results.

CONCLUSION

The Volhynian and Bessarabian in Northwest Bulgaria were periods of subtropical or warm-temperate and humid climate, with small fluctuations in palaeoclimatic parameters as evidence from bouth macropaleobotanical and palynological data. The correlation between climate data derived from macro- and microfloras shows coincidence as regard all parameters, nevertheless that different taxa determine coexistence intervals. In some cases, the macropaleobotanical data provide narrow climate interval, that is explain by better taxonomic resolution and better identification of NLRs (*e.g.* at species level). The recognition of NLRs for pollen taxa is usually at genus level. The application of both palaeoclimate recovery methods has the advantage of obtaining both more accurate climate data and tracking climate change in more detail throughout the study period.

CONFLICT OF INTERESTS

The author declares that there is no conflict of interest regarding the publication of this article.

ACKNOWLEDGEMENTS

This work was supported by the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01- 230/06.12.2018 and № DO1-322/18.12.2019). It is a contribution to the International Network Program NECLIME (www.neclime.de).

References

Biltekin D., Popescu S.-M., Suc J.-P., Quézel P., Jiménez-Moreno G., Yavuz N. & Çağatay M. N. 2015. Anatolia: A long-time plant refuge area documented by pollen records over the last 23 million years. - Review Palaeobotany Palynology 215: 1-22.

Durak S. D. Ü. & Akkiraz M. S. 2016. Late Oligocene–Early Miocene palaeoecology based on pollen data from the Kalkım-Gönen Basin (Northwest Turkey). - Geodinamica Acta 28: 295-310.

Ivanov D. & Lazarova M. 2019. Past climate and vegetation in Southeast Bulgaria — a study based on the late Miocene pollen record from the Tundzha Basin. – Journal of Palaeogeography 8: 3-25.

Ivanov D., Ashraf A. R., Mosbrugger V. & Palamarev E. 2002. Palynological evidence for Miocene climate change in the Forecarpatian Basin (Central Paratethys, NW Bulgaria). – Palaeogeography, Palaeoclimatology, Palaeoecology 178 (1-2): 19-37.

Ivanov D., Tsenov B., Utescher T., Kováčová M., Mosbrugger V. & Ashraf A. R. 2019. Climate reconstructions based on Miocene leaf flora from NW Bulgaria: Comparing leaf physiognomy and nearest living relative approach. - Phytologia Balcanica 25 (2): 137-146.

Ivanov D., Utescher T., Mosbrugger V., Syabryaj S., Djordjevic-Milutinovic D. & Molchanoff S. 2011. Miocene Vegetation and Climate dynamics in Eastern and Central Paratethys (Southeastern Europe). – Palaeogeography, Palaeoclimatology, Palaeoecology 304: 262-275.

Ivanov D. & Worobiec E. 2017. Middle Miocene (Badenian) vegetation and climate dynamics in Bulgaria and Poland based on pollen data. – Palaeogeography,

Palaeoclimatology, Palaeoecology 467: 83-94.
KAYSERI-ÖZER M. S. 2017. Cenozoic vegetation and climate change in Anatolia — A study based on the IPR-vegetation analysis. - Palaeogeography, Palaeoclimatology, Palaeoecology 467: 37–68.
KAYSERI-ÖZER M. S., KARADENIZLI L., AKGÜN F., OYAL N., SARAÇ G., ŞEN Ş., TUNOĞLU C., & TUNCER A. 2017. Palaeoclimatic and palaeoenvironmental interpretations of the Late Oligocene, Late Miocene-Early Pliocene in the Çankırı-Çorum Basin. - Palaeogeography, Palaeoclimatology, Palaeoecology 467: 16-36.
KOJUMDGIEVA E. & POPOV N. 1986. Stratigraphy and correlation of the Neogene in Mediterranean area: results and discussion (in Bulgarian). - Review of the Bulgarian Geological Society 47 (3): 124-126.
KOJUMDGIEVA E. & POPOV N. 1989. Paleogeographie et evolution geodynamique de la Bulgarie Septentrionale au Neogene. - Geologica Balcanica 19 (1): 73-92.
KOJUMDGIEVA E., POPOV N., STANCHEVA N. & DARAKCHIEVA S. 1989. Correlation of the biostratigraphic subdivision of the Neogene in Bulgaria after mollusks, foraminifers and ostracods. - Geologica Balcanica 19 (3): 9-22 (In Russian, English abstract).
MEULENKAMP J. E. & SISSINGH W. 2003. Tertiary palaeogeography and tectonostratigraphic evolution of the Northern and Southern Peri-Tethys platforms and the intermediate domains of the African-Eurasian convergent plate boundary zone. – Palaeogeography, Palaeoclimatology, Palaeoecology 196 (1-2): 209-228.
MOSBRUGGER V. & UTESCHER T. 1997. The coexistence approach – a method for quantitative reconstructions of Tertiary terrestrial palaeoclimate data using plant fossils. – Palaeogeography, Palaeoclimatology, Palaeoecology 134: 61-86.
PALAMAREV E. & IVANOV D. 2001. Charakterzüge der Vegetation des Sarmatien (Mittel- bis Obermiozän) im südlichen Teil des Dazischen Beckens (Südost Europa). - Palaeontographica Abteilung B 259: 209-220.
PALAMAREV E. & PETKOVA A. 1987. Sarmatian macroflora. – In: TZANKOV V. (Ed.), Fossils of Bulgaria. Bulgarian Academy of Sciences Publishing House, Sofia, 8 (1): 3-275 (In Bulgarian with French summary).
PALAMAREV E. 1988. *Schefflera chandlerae* sp. nov., a new subtropical element in the Bulgarian Neogene Flora. – Tertiary Research 9 (1-4): 97-106.
PALAMAREV E. 1989. Palaeobotanical evidences of the Tertiary history and origin of the Mediterranean sclerophyll dendroflora. - Plant Systematics and Evolution 162: 93-107.
PALAMAREV E. 1990. Grundzüge der paläofloristischen Paläosukzessionen im Spätmiozän (Sarmatien-Pontien) Bulgariens. – In: Proceedings of the Symposium Paleofloristic and Paleoclimatic Changes in the Cretaceous and

Tertiary, Prague, August 28th - September 1st, 1989, 257-263.

Palamarev E. 1993. Über die Tetriäre Geschichte der Gattung *Juglans* L. in Bulgarien. - Acta Palaeobotanica 33 (1): 299-307.

Palamarev E., Bozukov V., Uzunova K., Petkova A. & Kitanov G. 2005. Catalogue of the Cenozoic plants of Bulgaria (Eocene to Pliocene). - Phytologia Balcanica 11(3): 215-364.

Pross J., Bruch A. & Kvacek Z. 1998. Paläoklima-Rekonstruktionen für den Mittleren Rupelton (Unter-Oligozän) des Mainzer Beckens auf der Basis mikro- und makrobotanischer Befunde. – Mainzer geowissenschaftliche Mitteilungen 27: 79-92.

Rögl F. 1998. Palaeogeographic considerations for Mediterranean and Paratethis Seaways (Oligocene to Miocene). – Annalen des Naturhistorischen Museums in Wien, Serie A für Mineralogie und Petrographie, Geologie und Paläontologie, Anthropologie und Prähistorie 99: 279-310.

Uhl D., Mosbrugger V., Bruch A. & Utescher T. 2003. Reconstructing palaeotemperatures using leaf floras – case studies for a comparison of leaf margin analysis and the coexistence approach. - Review of Palaeobotany and Palynology 126 (1-2): 49-64.

Utescher T., Mosbrugger V. & Ashraf A. R. 2000. Terrestrial climate evolution in Northwest Germany over the last 25 million years. - Palaios, 15: 430-449.

Utescher T. & Mosbrugger V. 2015. The Palaeoflora Database. Last accessed on 21st April 2020 at: http://www.palaeoflora.de/

Utescher T., Utescher T., Bruch A.A., Erdei B., Francois L., Ivanov D., Jacques F. M. B., Kern A. K., Liu Y.-S. C., Mosbrugger V. & Spicer R. A. 2014. The Coexistence Approach-Theoretical background and practical considerations of using plant fossils for climate quantification. - Palaeogeography, Palaeoclimatology, Palaeoecology 410: 58-73.

Yavuz N., Culha G., Demirer Ş.S., Utescher T. & Aydin A. 2017. Pollen, ostracod and stable isotope records of palaeoenvironment and climate: Upper Miocene and Pliocene of the Çankırı Basin (Central Anatolia, Turkey). - Palaeogeography, Palaeoclimatology, Palaeoecology 467: 149-165.

Received 21st April 2020
Accepted 7th May 2020