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Late Miocene vegetation of the Pannonian Basin

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A B S T R A C T

The Pannonian Basin system provides sufficient data to study local and regional vegetation in the context of palaeoclimate and palaeogeography. The present study attempts to make use of the latest results in stratigraphy and track vegetation change throughout the Late Miocene. Vegetation layers are reconstructed for five time slices, from 10.8 Ma to 6.5 Ma, and placed in a palaeogeographic context. Plant functional types and their distribution, frequently applied in ecological studies and biome modelling, serve as a tool for reconstructing palaeovegetation units. A classification system is introduced considering non-zonal elements as well, in order to represent the Neogene floral record. The PFT spectra obtained from fossil leaf assemblages indicate the presence of mainly broadleaved deciduous vegetation throughout the regarded time span, with variable diversities of conifers and broadleaved evergreen vegetation components. During the Late Miocene, the lowland vegetation of the Pannonian realm seemed to be more homogeneous than reported in other reconstructions, which is in line with the persistence of overall warm and humid climate conditions. The existence of distinctly dry periods as partly suggested by other proxies is not supported. At the same time, data suggest the coeval declining trend of the broadleaved evergreen component in the study area, and its final complete disappearance from the north of the Pannonian Basin. In the younger time slices, constantly humid conditions might have existed along the northern border of the lake, possibly connected to uplift pulses of the Alps and Carpathians.

1. Introduction

Regional vegetation patterns and their evolution through time potentially reflect continental climate and its change and are impacted by palaeogeographic settings. Having a relatively abundant palaeobotanical record with a number of well-dated sites and a detailed palaeogeographic model (Magyar et al., 1999a), the Pannonian Basin system provides sufficient data to study local and regional vegetation in the context of palaeoclimate and palaeogeography, e.g. regional response to Neogene global cooling, migration of shoreline and extent of inundated areas. Recent detailed stratigraphic investigations by Magyar (2013) enable us to access a temporal framework of the Late Miocene floras in the Pannonian Basin. Late Miocene Pannonian Basin floras have so far been discussed mainly as an entity, although spanning more than 6 million years. The present study is an attempt to make use of the latest results in stratigraphy and track vegetation change through this time interval in a higher temporal resolution compared to earlier works (e.g. Kvaček et al., 2006). In these studies most of the Pannonian Basin floras have not been included, since mainly representing non-zonal vegetation supposed to reflect neither regional climatic conditions nor related zonal biomes. Based on the approach selected for the present study it can be shown that many elements of these floras may provide information on the zonal conditions as well as on regional climate. The method used here focuses on the track of more informative elements of these floras by interpreting vegetation at the level of plant functional types (PFTs).

PFTs and their distribution, frequently applied in ecological studies and biome modelling, serve as a tool for tracing ecological gradients and reconstructing palaeovegetation units. First quantitative studies focusing on distribution patterns of PFTs and designed to put forward data–model comparisons were carried out recently on well-dated Late Miocene floras by Utescher et al. (2007) and François et al. (2011). These studies are based on a classification system using 14 arboreal and 2 herbaceous classes, and included a biome modelling study for the European Tortonian (CARAIB/CARbon Assimilation In the Biosphere/dynamic vegetation model). Recent model studies with CARAIB on global Mid-Miocene biome distribution, including proxy–model data inter-comparison and validation of model data use a PFT classification system comprising 26 classes allowing for a further subdivision of arboreal types and for the first time including several types of shrubs (cf. Henrot et al., 2017). Although various PFTs play a subordinate role in model-based biome reconstructions or are not represented at all (e.g. salt marsh and other azonal vegetation types), PFT classification of the complete palaeobotanical record is considered worthwhile when making proxy data-based reconstructions. To achieve this, we

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introduce here a classification system comprising a total of 40 types. The new classification system for the first time allows representing as well azonal vegetational components that may have a considerable diversity in the Neogene floral record of the Pannonian.

In the present study, we reconstruct vegetation layers for five time slices and place them in a palaeogeographic context. The palaeogeographic background is set by a series of detailed maps published by Magyar et al. (1999a). The maps represent configurations at 10.8, 9.5, 9.0, 8.0, and 6.5 Ma, respectively, and thus document the extension and shrinkage of Lake Pannon during the Late Miocene (Tortonian–Messinian/Pannonian). In order to complement vegetation data, marginal–extramarginal megafossil localities are also included. The observed vegetation patterns are discussed in the context of relevant palaeogeography, regional climate and its global change. The vegetation analysis is based on a total of 35 fossil plant assemblages, located nearshore or in the closer neighbourhood of the lake, which are assigned to one of the time slices within reasonable accuracy. Floras considered from Hungary have recently been studied or reinvestigated (Hably, 2013).

In detail, we address the following questions:

- To what degree do the megafloral data reflect zonal biomes or local vegetation? Is it possible to use leaf flora in order to obtain meaningful information on vegetation cover?
- How homogeneous/inhomogeneous was the vegetation in the Pannonian realm throughout the regarded time span?
- How useful is the new PFT classification comprising 40 classes to resolve ecological gradients and describe Late Miocene vegetation?
- Are the PFT-based vegetation data consistent with earlier reconstructions based on other methods?
- To what degree can the PFT data be referred to regional climate patterns and global climate change?

2. General remarks on geology

The Pannonian stage (standard chronostratigraphy: Tortonian/Messinian) comprises one of the thickest, non-marine Late Neogene sedimentary sequences in Europe (Rasser and Harzhauser, 2008). The sequence of the Pannonian Basin was deposited in Lake Pannon and in adjacent deltaic, fluvial, and, subordinately, lacustrine environments. The basin was part of the Miocene Central Paratethys; however, marine gateways closed by the Late Miocene. The brackish water body of Lake Pannon existed with continuously changing shoreline and surface area from the beginning of the Late Miocene until ca. the beginning of the Late Pliocene (Magyar, 2013). The closed and subsiding Pannonian Basin trapped the sediments derived from the emerging Alps and Carpathians (Horváth et al., 2006). Sedimentation in Lake Pannon took place in several hundred meters-deep water in the basin proper and in its slopes. River deltas, prograding across the extended shelf of Lake Pannon, however, included a variety of shallow water environments (Magyar, 2013).

At the onset of the Late Miocene, extensional tectonics prevailed in the Pannonian backarc basin system. Therefore, it is assumed that the Pannonian archipelago had a low relief differing from modern basement topography. The modern elevated blocks within the Pannonian Basin system primarily refer to compressional tectonics postdating the Miocene (Magyar et al., 1999a).

In the lack of marine fossils, the chronostratigraphic subdivision and correlation of the sedimentary succession is based on cross-correlations between regional aquatic biostratigraphy based on endemic Lake Pannon fauna and flora, European mammal stratigraphy, magnetostratigraphy, regional seismic stratigraphy, and radioisotopic age determinations from interbedded volcanic layers (Magyar et al., 1999b; Harzhauser et al., 2004). These correlations have demonstrated that boundaries between the lithological units are diachronous, and progradation and resulting shift of the environments from the basin margins towards the centre, dominantly from N–NW to S–SE, persisted for several million years (Pogácsás et al., 1994; Vakarcs et al., 1994; Magyar et al., 2007).

For the present study five Pannonian time slices are differentiated (Fig. 1). The stratigraphic correlation of the Lake Pannon biozones (Magyar et al., 1999b) serves as a basis for delineating these time slices. Based on recent studies, a total of 15 individual floras from the Hungarian Pannonian can be assigned to these time slices (Fig. 1). Detailed explanations on the cross-correlations and dating of the localities from Hungary are given by Magyar (2013). These 15 floras providing the stratigraphic frame for the present study are complemented by 21 localities from the Pannonian Basin and nearer surroundings, for which literature data allow a clear allocation to the here defined time slices. When inferring the stratigraphic position and age of these sites, mollusc biozonation, mammal biostratigraphy, magnetostratigraphy and seismic stratigraphy were extensively used. Three of the studied localities represent younger (Gérce–Pliocene, Dacian) and older (Erdőbénye, Pančevo Bridge–Late Middle Miocene, Sarmatian) time slices, which are included here in order to have a comparison with the vegetation cover before and after the main phases of Lake Pannon formation.

3. Climatic background

After the Mid-Miocene Climatic Optimum, diverse sets of evidence suggest a Late Miocene cooling (Zachos et al., 2001; Mosbrugger et al., 2005; Bruch et al., 2007; Darby, 2008; Utescher et al., 2009; etc.). As part of these evidences, the climate analyses of macrofloras (Erdei et al., 2007) spanning most of the Neogene of the Pannonian Basin seem to reflect this trend as well. Various proxy data, like plant and mammal fossil records and related quantitative palaeoclimate reconstructions, suggest that Late Miocene mid- and high-latitude climate was definitely warmer and more humid on average than today coupled with a shallower latitudinal climate gradient (e.g. Bruch et al., 2007, 2011; Fauquette et al., 2007; Utescher et al., 2009, 2011; Böhme et al., 2011). It is presumed based on palaeobotanical proxies that Late Miocene mean annual temperatures in Central Europe were higher by nearly 5 °C when compared to present (e.g. Mosbrugger et al., 2005).

Various recent studies based on the palaeoflora record provide the framework to analyse regional vegetation patterns of the Pannonian Basin in the Late Miocene (Mosbrugger et al., 2005; Bruch et al., 2007, 2011; Erdei et al., 2007; Liu et al., 2011; Ivanov et al., 2011; Utescher et al., 2007, 2009, 2011, 2012).

The application of the coexistence approach (CA) (Mosbrugger and Utescher, 1997; Utescher et al., 2014) on a revised palaeobotanical record of Neogene fossil plant assemblages in the Pannonian Basin provided data for the "pre- and post-Lake Pannon" climatic conditions (Erdei et al., 2007). MAT inferred from Late Middle Miocene (Sarmatian) and Early Pliocene (Dacian) megafloras ranges between 14 °C and 16.6 °C and 10 °C–15.7 °C, respectively. Intervals for CMT are estimated between 4.5 °C and 7 °C for Late Middle Miocene and 0.2 °C to 5 °C for Early Pliocene floras. Values of MAP for Late Middle Miocene and Early Pliocene floras are 759–1179 mm and 619–1,160 mm, respectively, indicating a comparable level of humidity. The calculations are based on fossil floras of comparable facies bound to a volcanic environment both during the Late Middle Miocene and the Early Pliocene. The comparison of climate data suggests a slight climate cooling by the Pliocene, which is more pronounced when considering the lower CMT values during the Early Pliocene. This correlates well with relevant data of the Cenozoic continental climate record for Central Europe (Mosbrugger et al., 2005). Flora lists indicate a lower taxa diversity of the Early Pliocene floras than during the Late Middle Miocene. Elements of the zonal Sarmatian (Late Middle Miocene) vegetation (Erdei and Hír, 2003) appeared during the Pliocene again attested by fossil floras from crater lake sediments but with less thermophilous taxa (Hably and Kvaček, 1997; Erdei et al., 2007).

Precipitation and humidity data for the Late Miocene of Europe (Central-Eastern Europe) show a diversified picture and results from