The stable isotope archive of Lake Pannon as a mirror of Late Miocene climate change

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Stable isotope analysis of Lake Pannon mollusc aragonite reveals a quickly changing hydrologic regime throughout the late Miocene. The lake originated at about 11.6 ma as a heritage of the alkaline, carbonate-oversaturated Paratethys Sea. It soon developed into an alkaline, probably strongly stratified lake with highly endemic mollusc fauna. The alkaline legacy is expressed by strongly elevated $\delta^{13}C$ values. Salinity remnants, as predicted from the fauna to range around 15‰, are indicated by the similarly high $\delta^{18}O$ values. At that time, even coastal areas are hardly affected by light isotopes from fluvial discharge, resulting in very stable isotope fields in the $\delta^{18}O/\delta^{13}C$ cross-plots and correspondingly low variation in the data. The absence of any notable freshwater signal supports the interpretation of a reduced humidity during the early Pannonian, as also suggested by Lueger (1978) based on aridity adaptations of land gastropods. Further evidence is provided by the global curve of Zachos et al. (2001), which displays a short warming phase at the end of the Middle Miocene. This warming and dry spell is reflected in the Paratethys by a highly productive Sarmatian carbonate factory in a subtropical climate (Piller and Harzhauser, 2005). The early Pannonian was thus the phase-out interval of that low-humidity system, which allowed a tremendous radiation and increase in disparity of *Melanopsis*.

The lack of any carbon peaks with low $\delta^{13}C$ values suggests that no recycling of depleted waters from the hypolimnion took place. Throughout the Pannonian, the occurrence of unbioturbated dark blue-grey clays with high amounts of pyrite and marcasite document the existence of such dysoxic bottom conditions.
With the onset of the middle Pannonian, conditions changed and a very humid warm climate allowed the establishment of vast wetlands in the hinterland of the lake, which now reached its maximum extension. The generally warm and humid Cfa-type climate with annual precipitation of about 1200 mm (Bernor et al., 2003; Bruch et al. 2004) coincides with the Vallesian optimum of mammal diversity with its oversaturated communities (Fortelius et al., 1996).

The isotope patterns indicate that elevated summer precipitation in the Lake Pannon catchment area caused an increase of freshwater discharge, reflected by light $\delta^{18}O$ values in nearshore taxa. Input of light carbon by rivers due to decaying plant material or soil weathering shifted the carbon regime towards light values as well. In addition, the extremely low $\delta^{13}C$ values in *Congeria* and *Unio* might have been caused by the uptake of light carbon due to periodic recirculation of depleted water from the hypolimnion. Such mixing events have already been postulated based on short-lived dreissenid settlement episodes in deeper lake settings (Harzhauser and Mandic, 2004). The seasonally changing precipitation loads are also reflected in a sudden increase of data variability. These conditions substantially suppressed the radiation of *Melanopsis*, probably because this gastropod lived in deltaic-coastal areas that were maximally exposed to such runoff events. The coinciding increase in nutrient supply, however, might have been an important factor for the onset of dreissenid radiation.
The late Pannonian is characterised by a quite simple isotope pattern reflecting a predictable succession from riverine freshwater, estuarine mixing zone to open lake; this is also reflected by the sequence from *Margaritifera* via *Melanopsis* towards *Mytilopsis* and *Congeria*. The high carbon regime remains typical for an alkaline lake, but the movement of the isotope field along the mixing line towards freshwater indicates a reduced salinity.

Our data suggest that the prevailing Cfa-type climate of the central European Late Miocene was accentuated by a low-humidity phase in the early Pannonian persisting from the latest Middle Miocene. During the middle Pannonian a considerable summer precipitation peak within an overall humid climate prevailed. The coincidence of that phase with the Vallesian optimum in mammal communities, and the abrupt change of isotope patterns in the subsequent late Pannonian (coinciding with the Vallesian crises and the early Turolian), indicate a strong climate control on the terrestrial ecosystem. A comparable link between climatically driven changes of isotope patterns and radiation pulses of the lake molluscs proves an at least equally strong climate control on the aquatic system.