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Late Miocene "washhouse" climate in Europe

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ABSTRACT

We present two eight-million year long proxy records of precipitation for Southwest and Central Europe, covering the middle to late Miocene (5.3–13 Ma) at a temporal resolution of about 60 kyr and 150 kyr, respectively. The estimates of precipitation are based on the ecophysiological structure of herpetological assemblages (amphibians and reptiles). From 13.0 Ma until about 9 Ma, both records show a similar trend, evolving from a long dry period (13–11 Ma) into a "washhouse climate" (10.2–9.8 Ma), characterized by global warm conditions and several times more precipitation than present. The transition from washhouse to a dryer climate between 9.7 and 9.5 Ma and the concomitant cooling episode appear to have triggered a severe biotic event known as the Vallesian crisis, which included the extinction of hominoids in Western Europe. A second washhouse period (9.0–8.5 Ma), coeval with a global warm episode, was unprecedentedly intense in Southwest Europe, but less pronounced in Central Europe. From 8 Ma onward, a divergence in the two precipitation records is observed, with Southwest Europe staying wetter and Central Europe becoming dryer than present. Both precipitation records are combined into a common run-off curve as a measure of the relative intensity of the hydrological cycle for moderate latitudes of continental Europe. The run-off curve shows a remarkable positive correlation with Atlantic deep-water temperatures from Ceará Rise by Lear et al. (2003), which are significantly higher (up to +3 °C) during the two washhouse periods and show no other positive excursion of comparable magnitude. We discuss potential links and the role of the coeval temporary restriction of the Central American Seaway on ocean and atmosphere circulation.

1. Introduction

The late Miocene has attracted recent interest as a potential model system for testing future climate change scenarios (Lunt et al., 2008a). Model predictions for future global warming (IPPC, 2007) project an increase in global mean precipitation with substantial spatial variations, e.g. between northern Europe (wetter than present) and southern Europe (drier than present). Climate proxy data for the Tortonian (11.6–7 Ma) indicate warmer and more humid conditions than today in continental Europe (e.g., Mosbrugger et al., 2005; Bruch et al., 2006), an already well-developed Antarctic ice cap, and a mostly ice-free Greenland (Thiede et al., 1998). The land–sea distribution was similar to present, but probably with less pronounced topography and still open oceanic gateways that now are either completely closed (Isthmus of Panama) or at least restricted for large-scale oceanic interexchange (Indonesian seaway). Overall warmer ocean temperatures have been deduced from deep-sea proxy records (Zachos et al., 2001; Lear et al., 2003). For such a scenario, it is reasonable to expect higher sea-surface temperatures in the North Atlantic and an enhanced northward heat transport and moisture supply from low to high latitudes, leading to an intensified hydrological cycle in Europe. This is also suggested by a paleoprecipitation map for Europe reconstructed from paleoflora analysis (Fig. 6 in Bruch et al., 2006). Because of the less accurate dating of many palaeobotanical sites such maps typically contain data with low temporal resolution (in this case from 11–7 Ma). However, the late middle and late Miocene are characterized by several cooling and warming events (Mudie and Helgason, 1983; Thiede et al., 1998; Winkler et al., 2002; Billups and Schrag, 2002), which underline the need for higher temporal resolution of palaeoprecipitation data.

To learn more about the long-term variations of the hydrological cycle in the late middle and late Miocene, we have constructed two eight-million year long paleoprecipitation proxy records for two European regions, with characteristic time resolution of ~100 kyr. The stratigraphic–chronologic framework is provided by cyclostratigraphic, magnetostratigraphic and/or small mammal based biostratigraphic methods. A precipitation database was established using the ecophysiological structure of herpetological (amphibians and reptiles) assemblages (Böhme et al., 2006) stemming from two regions in the European sector of the North Atlantic catchment area (Fig. 1): the Calatayud–Teruel Basin in Southwest Europe (13.56 to 5.36 Ma) and the Paratethys region in Central–Eastern Europe (13.27 to 5.75 Ma). The median temporal resolution of each record is ~60 kyr and ~150 kyr, respectively. Since the regions investigated have a different spatial extent, we will later express the precipitation in terms of an

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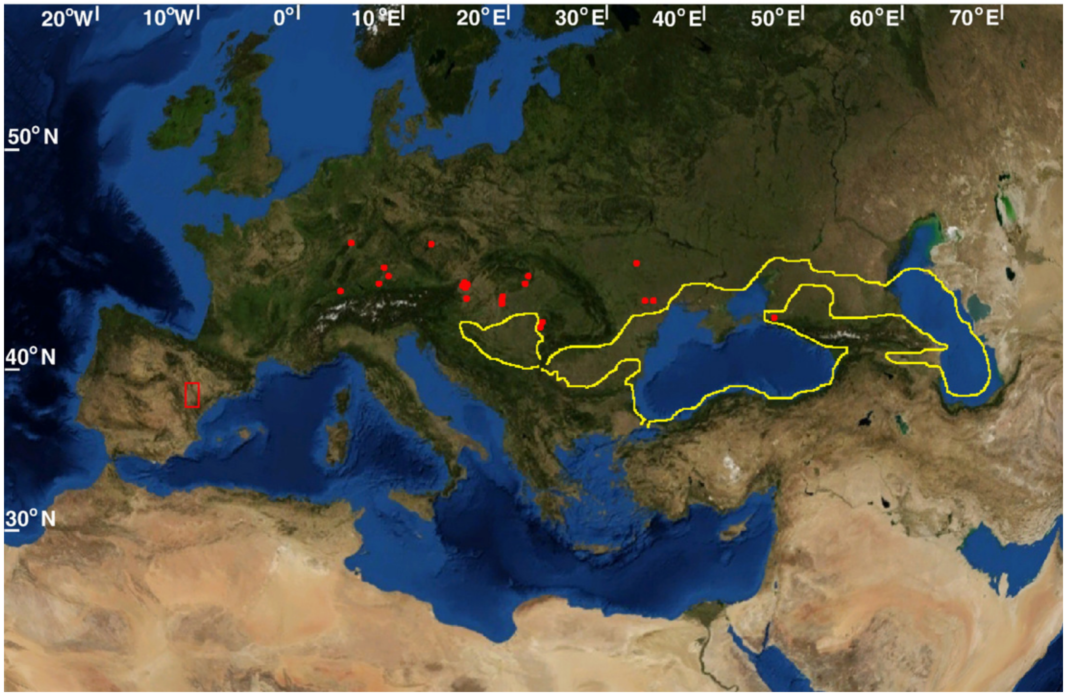

Fig. 1. Map of western Eurasia showing the coastline (yellow) of the Central and Eastern Paratethys Sea around 8 Ma, according to Popov et al., 2004, 2006), the position of localities used for reconstructing the Central and Eastern European precipitation curve (red dots), and the South-West European precipitation curve (red rectangular; Calatayud–Teruel Basin).

area-weighted continental run-off as an indicator of the intensity of the hydrological cycle.

2. Methods

2.1. Stratigraphic–chronological framework

2.1.1. Southwest Europe

The fossil record of amphibian and reptilian communities comes from two continental sequences of NE Spain (Calatayud–Daroca and Teruel Basin), both representing endorheic basins. Fossils were found in alluvial and lacustrine facies of the basin margins which may laterally grade into evaporites.

18 fossil-bearing horizons from the Calatayud–Daroca Basin were sampled from an area of few square kilometres east of the Villafeliche village, (see Fig. 2 in Daams et al., 1999). The composite section comprises over 200 m sediments of alluvial and lacustrine origin.

52 fossil-bearing horizons from the Teruel Basin were sampled from an area of up to 100 km^2 between the Teruel and Alfambra villages (Van Dam et al., 2001) and south of Teruel (Abdul Aziz et al., 2004). The composite section comprises over 200 m sediments of alluvial and lacustrine origin.

The age model for the 70 horizons (localities) is according to the one established by Van Dam et al. (2006), which is based on correlation to local magnetostratigraphically dated sections, cyclo- and lithostratigraphic extrapolation, and biostratigraphic correlation. For details see Van Dam et al. (2006). The fossil amphibians and reptiles we used for the estimation of paleoprecipitation were picked out from exactly the same sediment samples from which Van Dam et al. (2006) derived their small mammal record.

2.1.2. Central- and Eastern Europe

The fossil record of amphibian and reptilian communities was obtained from several locations of the Paratethys region (Western Paratethys: North Alpine Foreland Basin, Central Paratethys: Vienna, Pannonian, Transylvanian Basins, Eastern Paratethys region, see Fig. 1 for sampling sites). The sites contributing to the Paratethys precipitation record range from 46.5°N to 49.5°N in latitude and 8°E (Switzerland) to 28°E (Moldova) in longitude; a single locality is from 40°E (Southern Russia). Combining data from such a wide geographic band may appear difficult because of possible regional precipitation gradients. However, fossil sites of similar age are located close to each other and the general age trend is such that older sites are from the Western Paratethys and younger sites are from the Eastern part of the region covered. To overcome remaining spatial uncertainties we calculate the paleoprecipitation relative to the present-day values (see below). According to the IPCC, 2007 report, precipitation (relative to recent values) predicted for Europe shows a meridional trend over most of Europe, with little regional variation in the zonal band studied here (Fig. 11.5 in Christensen et al., 2007). Therefore we are confident that our approach of combining data from this area is fairly robust and provides a spatio-temporally coherent record, which is also corroborated by independent coeval proxy data, as discussed further below.

Fossils were derived from a variety of depositional and environmental regimes, like near shore, fluvial, lacustrine and swamp facies and karstic fissure fillings (Supplementary Table 1).

The stratigraphic–chronological framework for the 29 localities (Supplementary Table 1) is based on correlation to local magnetostratigraphically dated sections, sequence- and lithostratigraphic extrapolation, and biostratigraphic correlation.

2.2. Estimation of paleoprecipitation based on herpetofaunal composition

The distribution and spatial occurrence of amphibians and reptiles depend on environmental conditions at various scales, ranging from habitat to global scale (Zug et al., 2001). It is assumed that distribution of species at a given spatial scale is in equilibrium with their environment (Guisan and Theurillat, 2000). Several investigations found a strong positive correlation between annual precipitation and amphibian species richness (e.g. Duellmann, 1999; Duellmann and Sweet, 1999; Tyler, 1994; Crowe, 1990). For reptiles it has been documented that climate (precipitation and temperature) more closely matches their distribution than any other environmental factors such as topography (Guisan and Hofer, 2003; Owen, 1989).