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The Cenozoic Cooling – continental signals from the Atlantic and Pacific side of Eurasia

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ABSTRACT

The evolution of Cenozoic continental climate signals from the Atlantic and Pacific side of Eurasia can be assessed for the first time by comparing climate records obtained for two mid-latitudinal regions. For the West, a detailed climate record over the past 45 Ma, based on palaeofloras from two Northern German Cenozoic basins (Mosbrugger et al., 2005) revealed major trends and shorter-term events throughout the Cenozoic Cooling, thus testifying the close correlation of continental and marine temperature evolution as derived from oxygen isotopes (Zachos et al., 2008). Using the same methodology, we analyze a total of 14 floral horizons originating from continental strata of Southern Primory'e (Russia) in order to study the evolution at the eastern side of the continent. The Primory'e record spans the middle Eocene to early Pleistocene. As the coeval record for the Atlantic side, it reflects major global signals of Cenozoic climate change such as the temperature decline throughout the late Eocene, coinciding with the growth of Antarctic Ice-sheets, warming during the Mid-Miocene Climatic Optimum, and step-wise cooling throughout the later Neogene. The comparison of both records reveals differing regional patterns. The considerable longitudinal temperature gradient, currently existing between both study areas, already began to evolve during the Aquitanian, and was very significant during the Mid-Miocene Climatic Optimum. The temperature offset between East and West is likely attributable to an effective North Atlantic Current, already operational from the late early Miocene onwards bringing about mild winters and low seasonality in Western Europe, while in Primory'e, seasonality steadily increased from the late Oligocene on. The strong late Pliocene decline of cold month mean temperatures recorded in Primory'e is supposed to coincide with the establishment of the Siberian High as semi-permanent structure of the Northern Hemisphere circulation pattern. When comparing the precipitation records obtained for both study areas, an unexpected co-variability at the longer-term (in the order of 5–20 Ma) is noted, pointing to continent-wide hydrological changes. The steady decline of mean annual precipitation in the Primory'e record, beginning in the Bartonian and culminating in the Aquitanian, coincides with an aridity increase reported from coeval Chinese inland localities of the mid-latitudes. The seasonality patterns of rainfall point to progressive intensification of the East Asian Summer Monsoon in Primory'e since the later Tortonian while the post-Zanclean decline of the precipitation of the dry season can be related to an increasing impact of the winter monsoon.

1. Introduction

Eurasian climate is characterized today by a distinct contrast between the western (Atlantic) side and the eastern (Pacific) side with a central region marked by strong seasonality typical of continental interiors (Rhines and Hakinnen, 2003; Takaya and Nakamura, 2005). The presently observed gradients largely result from prevailing global and regional circulation patterns of the atmosphere and oceans and their variability. On the Atlantic side, the presently effective Gulf Stream, including its eastern extension, the North Atlantic Current (NAC), bring about oceanic climate conditions in northwestern Europe. The northward energy transport by ocean and atmosphere causes a displacement of the January isotherms by up to 20° northern latitude when compared to the Pacific side as evident from climatological data (New et al., 2002),

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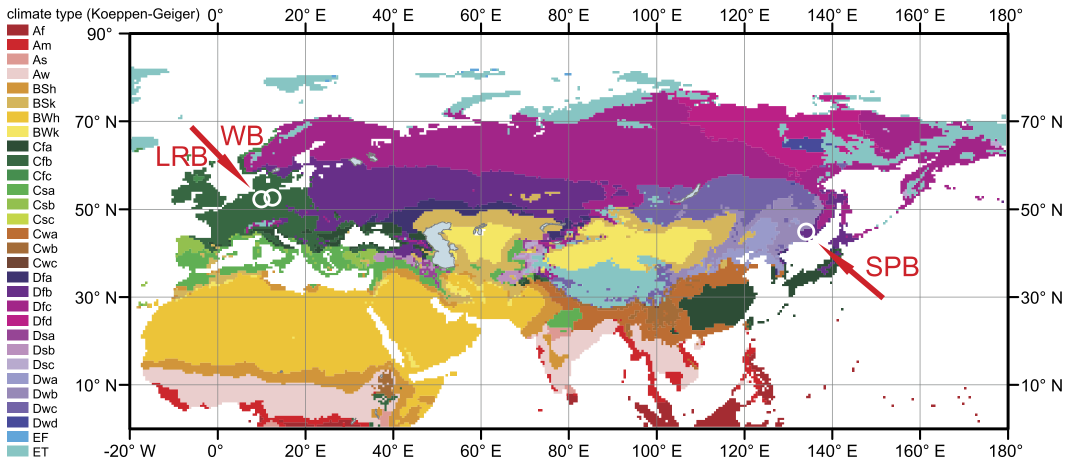

Fig. 1. Study areas at the Atlantic and Pacific sides of Eurasia in the context of modern Koeppen–Geiger type climates. A: tropical; B: dry; C: megathermal; D: microthermal; E: polar; w: winterdry; s: summerdry; f: fully humid; m: monsoon. White circles mark the approximate position of the studied Cenozoic basins. LRB: Lower Rhine Basin; WB: Weisselster Basin; SPB: Cenozoic basins of southern Primory'e.

and the asymmetric distribution of Koeppen–Geiger climate types over Eurasia (Fig. 1). Past climates of Eurasia are supposed to reflect various states of the North Atlantic ocean circulation system in the West (e.g., Via and Thomas, 2006; Steppuhn et al., 2007; Krapp and Jungclaus, 2011) and the varying intensity of the warm Kuroshio and cold, subarctic currents in the eastern coastal regions (e.g., Gallagher et al., 2009; Matthiessen et al., 2009). Moreover, the climatic evolution in eastern Eurasia is tied to the history of the East Asian Monsoon System and is complicated by tectonic events such as uplift of the Tibetan Plateau, and the Japan Sea back-arc opening (e.g., An et al., 2001; Liu and Yin, 2002; Sato et al., 2006; Yamamoto and Hoang, 2009). Thus, the comparison of continental climate records from both sides of the continent can provide valuable insights into the evolution of past continental climate anomalies throughout the Cenozoic cooling, and their underlying processes.

For the Atlantic side of Eurasia, detailed, quantitative climate records for Cenozoic time-spans were reconstructed based on palaeobotanical records from various, mid-latitudinal regions such as the Central Paratethys (Mosbrugger et al., 2005), Eastern Paratethys (Syabryaj et al., 2007; Bozukov et al., 2009; Ivanov et al., 2011), and Cenozoic North Sea realm (Mosbrugger et al., 2005; Utescher et al., 2009). This last area provided the most comprehensive record, reconstructed based on megafloras from two continental to marginal marine Cenozoic basins, the Lower Rhine Basin and the Weisselster Basin, both located in Northern Germany, which together document Cenozoic climate history throughout the past 45 Ma. This record reflects global climatic trends and events such as the late Eocene temperature decline during the buildup of the Antarctic ice-sheets, the Mid-Miocene Climatic Optimum (MMCO), and the Late Neogene Cooling, and testifies the close correlation of continental and marine temperature evolution as evident from benthic foraminiferal oxygen isotopes on million-year time scales (Mosbrugger et al., 2005; Zachos et al., 2001, 2008), and even at orbital time-scales (Utescher et al., 2012).

As regards the Cenozoic climate evolution on the Pacific side of Eurasia, our knowledge is still more fragmentary. Palaeoclimate studies based on Miocene sites in several regions of Northern China considering three different Miocene levels show a general cooling trend (Liu et al., 2011). For the earlier part of the Paleogene, Quan et al. (2012) present a more detailed record for Liaoning Province, Northern China, based on palynofloras from the Fushun Mine (coordinates: 41.84°N; 123.88°E) that partly correlates with the benthic foraminiferal oxygen-isotope curve (Zachos et al., 2008). Although these studies give valuable details there is still no comprehensive, quantitative record showing Cenozoic climate evolution of a region in a typical "East Coast Setting".

In order to obtain a longer, quantitative climate record for the mid-latitudes of the Pacific side of Eurasia, we selected the rich palaeobotanical record of Primory'e, Russian Federation, located at ca. 43°N and thus about comparable with the German study area (ca. 50°N) addressed in Mosbrugger et al. (2005). The Cenozoic continental deposits of Primory'e are well exposed in open cast mines exploiting browncoal in several basins, and have a reasonable time control based on regional stratigraphy (see Section 2.1). The current state of taxonomic resolution in the palaeobotanical record allows for the analysis of 14 different floral horizons in total, representing warm temperate broadleaved forests with evergreens to temperate mixed deciduous-conifer forests (cf. Table 1 for references), and covering the time-span from the middle Eocene to the early Pleistocene. The climate records of Primory'e presented in this study for the first time allows for direct comparison of two mid-latitude regions of the Atlantic and Pacific side of Eurasia representing the characteristic west and east coast climate situation. All the climate data for the 14 floral assemblages considered are reconstructed using the Coexistence Approach, a method of quantitative palaeoclimate reconstruction applicable on Cenozoic floras of every organ type (Mosbrugger and Utescher, 1997; Utescher et al., 2014), and thus are directly comparable with published records from the Atlantic side (Mosbrugger et al., 2005; Utescher et al., 2009).

2. Materials and methods

2.1. Study areas and floral records

2.1.1. Primory'e

The palaeobotanical record of Primory'e studied here with respect to palaeoclimate originates from 6 Cenozoic basins, all located in Southern Primory'e, within a distance of ca. 100–200 km from Vladivostok, except the Turérogskii Basin west of Khanka Lake, which is situated ca. 600 km to the north of the city (Fig. 2). Because of the closeness of the sites we consider spatial gradients as negligible. The Cenozoic of South Primory'e is represented by a series of volcanic and sedimentary deposits, unconformably lying on Mesozoic strata. The sedimentary facies includes fine to coarse-grained continental clastics and intercalated lignites excavated in several active open cast mines. For some of the basins, mainly generated by extensional tectonics (Pavlovskoe,