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A palynological insight into the Miocene aridification in the Eurasian interior

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Abstract

Monsoonal systems have gained dominance in East Eurasia since the latest Oligocene, evidenced by eolian deposits in North China. Consequently, the central Eurasia became a middle-latitude inland arid area, and in the Late Miocene finally formed a pattern like that of modern day. But the timing, extent, and forcing of the aridification remain poorly understood. Here we gathered palynological sequences from the continental interior and divide them into four chronological parts to reconstruct the development of the central Eurasian aridity during the Miocene. The oldest known aridification record shows the rise of xerophytes observed in the fluviolacustrine Jingou River section at the south margin of the Junggar Basin, suggesting a latest Oligocene drying. Compared with the well-dated records from the inland, the available palynological records reveal two stepwise expansions of arid conditions from the Junggar Basin to its adjacent regions, which occurred in late Middle Miocene and Late Miocene, respectively. The two major expansions are roughly synchronous with the development of North American steppe and call for a global forcing explanation. We discuss various possible explanations for the inland aridity expansions, including regional uplift, land-sea redistribution, global changes in CO_2 concentration, and conclude that none of these are fully consistent with the available data. The most likely explanation for the northern mid-latitude drying is global cooling during the Miocene. For eastern Eurasia, cooling weakens monsoon circulation, and consequently drying conditions expand following retreat of the monsoonal rain belt, while in the west, cooling reduces water vapor pressure and therefore reduces the moisture mass transported into the continental interior.
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1. Introduction

Earth's arid regions are distributed broadly in sub-tropical zones where precipitation is reduced due largely to stable descending air and high pressure. Outside the subtropical zone, the largest mid-latitude arid region can be found in the Eurasian interior. In the Köppen-Geiger world map on climate classification (Kottek et al., 2006), the arid region (Fig. 1a) with the climate types of BSk and BWk stretches across the inland from the western Caspian to the eastern Mongolian Plateau, forming a dominant source of mineral dust in the northern mid-latitudes (Prospero et al., 2002). The earliest known eolian deposits in the Chinese Loess Plateau (Guo et al., 2002; Qiang et al., 2011) and Asian inland (Sun et al., 2010) implied that the mid-latitude Eurasian aridification initiated as early as the latest Oligocene–earliest Miocene. These records, however, do not constrain directly the timing and process of the drying.

Evaporites are regarded as an effective indicator of arid climate for long time (Green, 1961). Even back to the 1960s, evaporite-based reconstruction of arid regions suggested that the mid-latitude arid belt during the Paleogene shifted to a modern-day-like pattern during the Neogene on the Eurasian continent (Lotze, 1964). Supported by biotic evidence, this major reorganization of climate pattern has been corroborated repeatedly in recent decades (Gordon, 1975; Zhou, 1982; Wang, 1990; Sun and Wang, 2005). Recently, based on palynological data, there have been attempts to summarize the Neogene vegetation evolution for the Eurasia or its parts (Wang, 2006b; Jiang and Ding, 2009; Miao et al., 2012; Utescher et al., 2011). These efforts have described for us the developing environmental patterns of the continent; however, partly due to the poorly dated materials, and partly due to lack of critical examination of the data, the evolutionary sequence is out of focus.

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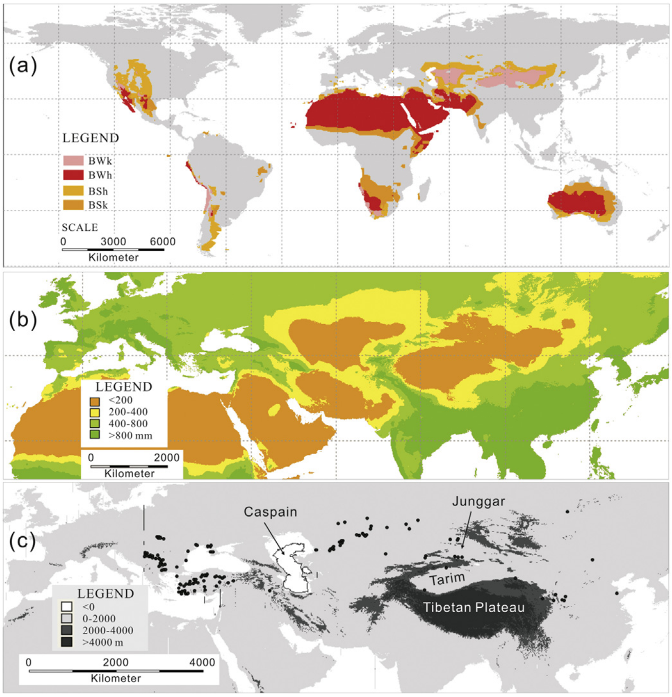

Fig. 1. (a) World map of dry climates, the group B of the Köppen climate classification (Kotteck et al., 2006); (b) current precipitation (1950–2000) of central Eurasia (Hijmans et al., 2005); (c) simplified topography of central Eurasia. Dots represent the palynological sites collected.

Over the past score years, numerous palynological sequences from separated locations within the continental interior provide scattered direct records on the processes of the aridification, and finally facilitate a global vegetation database that suggests the Late Miocene precipitation in the central Eurasia very close to that of present day (Pound et al., 2011, 2012). Unfortunately, the timing and extent of the Miocene aridification of central Eurasia is still unclear.

Here we compile the chronological and palynological sequences from the Eurasian inland and attempt to clarify the timing, extent, and forcing of aridity in Eurasia during the Miocene.

2. Background and materials

Low precipitation characterizes the Eurasian interior (Fig. 1b). Water isotopic observations show most modern precipitation on this region originates from recycled moisture over Aral–Caspian region, with some minor moisture directly from the North Atlantic (Aizen et al., 2001; Tian et al., 2007). During the Miocene the predecessor of the Aral–Caspian, the Paratethys, occupied central Eurasia (Rögl, 1999; Popov et al., 2004), which is presumably a potential moisture source for its surroundings. If greater coverage of the intracontinental sea were considered, the recycled moisture could have delivered a higher proportion of precipitation to central Eurasia during the Miocene. This rationale means that the environmental history of central Eurasia is different from the rest of the continent.

Our data (Fig. 1c) were acquired mainly from recent publications. The collected records are selected based on the following criteria: (1) the record should be well dated. The records constrained solely on lithological correlations or pollen chronologies are removed from consideration, and the remaining records are dated mainly by detailed biostratigraphy, magnetostratigraphic ages, and isotope analyses; (2) palynological assemblages should be able to be replicated. Among the available dataset, very few records challenge the vegetation contexts of their location and cannot be repeated by other researchers. We rejected these records to ensure the internal consistency of the compiled dataset. Moreover, we preferred quantitative reconstructions of paleoclimate parameters and continuous sequences.

All selected data sources are listed in Table 1. For the eastern part of the central Eurasia, the Cenozoic sediments are mainly terrestrial and in most cases Miocene pollen data are dated by paleomagnetism with the constraint of vertebrate fossils. For the paleo-Paratethys areas in the west, the chronologies of pollen records are based mainly on a detailed biostratigraphy, such as planktonic foraminifers, ostracods, and calcareous nannofossils (Harzhauser and Piller, 2007, and references therein), with rare records constrained by paleomagnetism or radioactive dating. The applied data clearly reflected the differences in the dating method: on the eastern part the data mainly come from sequential records in sedimentary basins, whereas on the western part the data are combined from numerous samples of various localities, representing an average for stratigraphic stages and substages.

Based on the chronology of the applied palynological data and the development of the Eurasian aridity, the dataset was organized chronologically into four time units: (1) ca. 23–20 Ma, (2) ca. 17–15 Ma, (3) ca. 14–11 Ma, and (4) ca. 9–6 Ma. For convenience, we define the drying or aridification as vegetation degradation to modern-day-like open vegetation, and/or achievements of present-day mean annual precipitation (MAP, Fig. 1b).

3. Development of the central Eurasian aridity during the Miocene

3.1. Stage 1 (∼23–20 Ma)

The earliest identified drying event occurred in the latest Oligocene as evidenced by a palynological sequence from the Jingou River section located at the northern Tian Shan Mountain (Tang et al., 2011). At ∼23.8 Ma, broadleaf arboreal pollen abundance gradually decreased and was replaced by previously sporadic Chenopodiaceae and *Artemisia* at ca. 23.3 Ma. Correspondingly, the pollen concentration and influx decreased by 1–2 orders of magnitude. This arid condition prevailed in the southern Junggar Basin throughout the Early Miocene.

In a depression of the northern Kazakhstan Tian Shan, hyperarid conditions with high summer temperatures prevailed during the Early Miocene, as evidenced by evaporites such as gypsum, halite, and thenardite (Akhmetyev et al., 2005). Meanwhile, the plains of Kazakhstan, ∼1000 km west of the Jingou River section, formed a widespread lacustrine deposits, and the Early and Middle Miocene were called “the great lacustrine stage” (Akhmetyev et al., 2005). Palynological evidence suggested that during the Oligocene and Early Miocene this area was

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