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Major changes in East Asian climate in the mid-Pliocene: Triggered by the uplift of the Tibetan Plateau or global cooling?

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ABSTRACT

Since the mid-Pliocene, East Asian climates have experienced significant changes. One view suggests that significant uplift of the Tibetan Plateau during this period could have been responsible for these dramatic changes in the strength of the East Asian monsoon and for Asian interior aridification, while some other authors attribute these changes to the ongoing global cooling and rapid growth of the Arctic ice-sheet. Up to the present, which factor dominates the major changes of East Asian climate in the mid-Pliocene is still a contentious issue. This study presents an analysis of several climate proxies including grain-size, $(CaO^{*} + Na_2O + MgO)/TiO_2$ ratio, Na/Ka ratio and dust accumulation rates of the Xifeng Red Clay sequence in the eastern Chinese Loess Plateau and the Xihe Pliocene loess-soil sequence in West Qinling. They reveal that aridity in the continental interior and winter monsoon circulation both intensified, whereas the East Asian summer monsoon showed a weakening rather than intensifying trend since the mid-Pliocene. These changes are also supported by the other multi-proxy records from various regions in East Asia. Previous numerical modeling studies have demonstrated that uplift of the Tibetan Plateau would have simultaneously enhanced continental-scale summer and winter monsoon strength as well as central Asian aridity. The mid-Pliocene climate changes in East Asia are therefore unlikely to be a response to Plateau uplift. On the contrary, our recent modeling results give support to the view that ongoing cooling could have intensified both the aridity of the interior and the strength of the winter monsoon, but weakened the summer monsoon in East Asia.

1. Introduction

The mid-Pliocene was a critical period, during which both the East Asian and global climates experienced major changes. In this period, the Earth's climate underwent a significant cooling with rapid expansion of the Northern Hemisphere ice-sheets (Shackleton et al., 1995), and a significant intensification of Asian interior aridity (Rea et al., 1998; An et al., 2001; Guo et al., 2004). At the same time, in the Chinese Loess Plateau (CLP), the grain-size of eolian deposits coarsened remarkably, suggesting continuous strengthening of the East Asian monsoon circulation at ~3.6 Ma ago (An et al., 2001). Meanwhile, the mid-Pliocene was also considered to be a period with strong tectonic activity over the Tibetan Plateau (TP). Enhanced TP uplift after ~3.6 Ma was inferred from the rapid accumulation of widely distributed conglomerates and the sharp increase in sediment fluxes in many basins along the northeastern and eastern margins of the TP (Li and Fang, 1999; Zheng et al., 2000; Fang et al., 2005), from the strengthened activities of some faults in the northeastern margin of TP (Yuan, 2003; Hough et al., 2011), and from rapid exhumation on the Plateau (Wang et al., 2011).

On the basis of abundant observational evidence of the tectonic movements, some authors have suggested that significant uplift of the TP occurred in the mid-Pliocene and led to dramatic changes in the strength of the East Asian monsoon and in Asian interior aridification (e.g., Li and Fang, 1999; An et al., 2001). Others have argued that the conglomerate deposits and the increased

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sedimentation rates were both possibly caused by climatic changes rather than tectonic uplift (Zhang et al., 2001; Molnar, 2004; Heermance et al., 2007), and that the strengthened interior aridity and winter monsoon intensity could be attributed to the rapid growth of the Arctic ice-sheet (Guo, 2003; Lu et al., 2010). Whether these changes in the East Asian environment were mainly induced by tectonic uplift or by climatic changes, and the extent to which the TP uplift influenced the Asian climates during the Mid-Pliocene, are still issues in debate.

Over the past decades, a number of numerical modeling experiments have been performed to investigate the climatic effects of Cenozoic TP uplift. It was found that TP uplift can give rise simultaneously to several linked climatic consequences, i.e., intensification of both the East Asian winter monsoon (EAWM) circulation and East Asian summer monsoon (EASM) precipitation, as well as increased aridity of the continental interior (e.g., Kutzbach et al., 1989; Broccoli and Manabe, 1992; An et al., 2001; Liu and Yin, 2002; Abe et al., 2003). Thus, reconstructing the history of the East Asian monsoon and interior aridity using geological records, and comparing the results with numerical model simulations may provide critical information regarding TP uplift and the mechanism responsible for East Asian climate changes during the mid-Pliocene.

The widespread eolian deposits on the Eurasian continent, covering a time from the early Miocene to the Holocene, are considered to be some of the most detailed and long-term records of late Cenozoic climate change (Liu, 1985; Markovic et al., 2011; Guo et al., 2002), and are of particular value for providing insight into the history of continental interior aridification. They also record changes in regional atmospheric systems (Markovic et al.,

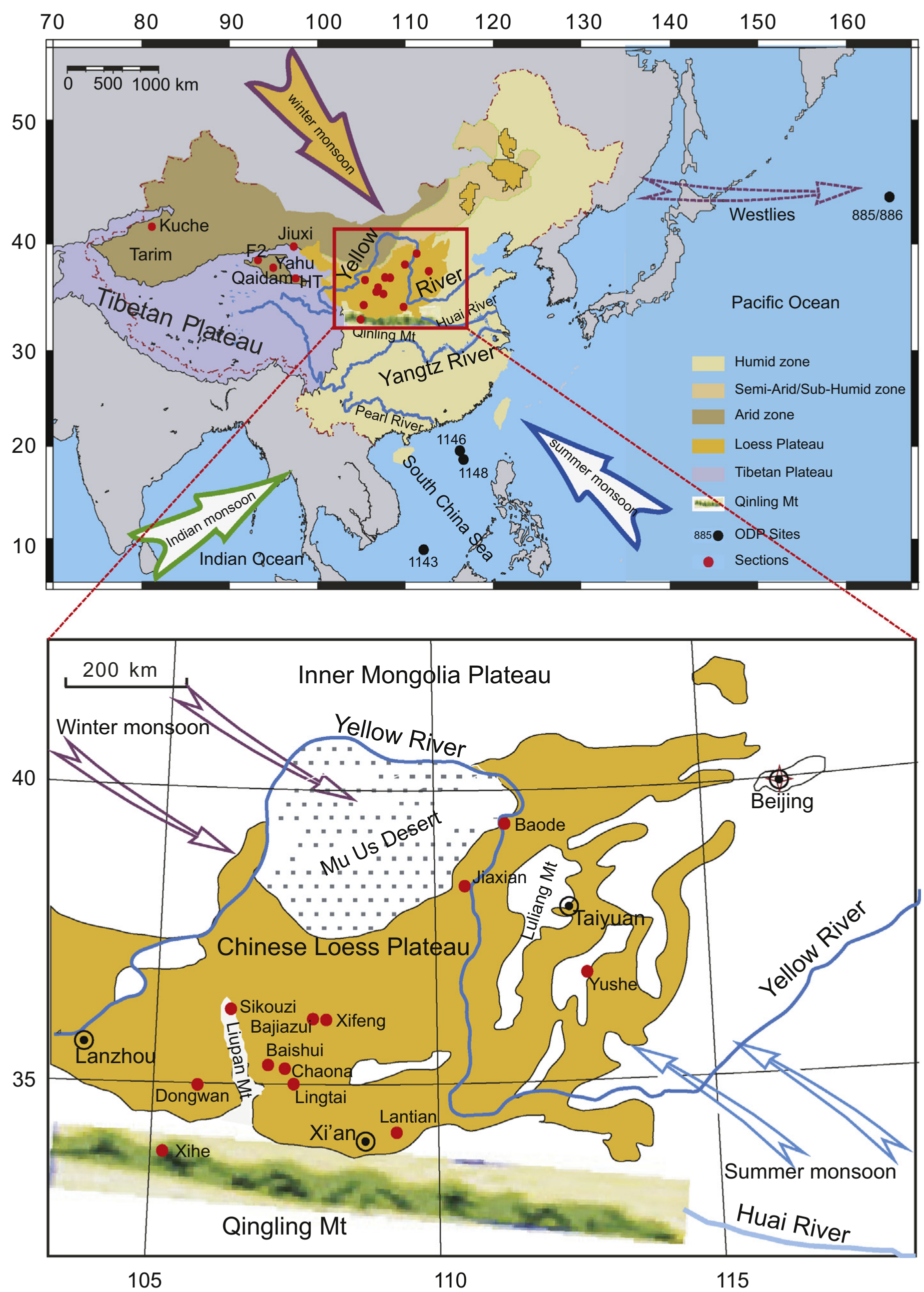

Fig. 1. Map showing the location of the multi-proxy records in the Northwest Arid areas including the Baikal, Qaidam, Tarim and Jiuxi Basins, in the Chinese Loess Plateau, in the Pacific Ocean and in the South China Sea.