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Holocene climate changes in the central Asia mountain region inferred from a peat sequence from the Altai Mountains, Xinjiang, northwestern China

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A B S T R A C T

A continuous peat sequence collected in the Altai Mountains, Xinjiang Province, northwestern China, provides a new opportunity to reconstruct the Holocene climate history in the arid central mountain region of Asia. Based on AMS ^{14}C dating, high resolution records of the humification degree and *n*-alkane distributions reveal that the region experienced a relatively warm and dry early Holocene (10.0–8.0 ka) and a cold and wet early mid-Holocene (8.0–6.3 ka), followed by a warm and dry mid-Holocene (6.3–5.5 ka). A shift to cold and wet conditions occurred between 5.5 and 4.0 ka, and then the climate entered into a warmer period from 4.0 to 2.5 ka. In the late Holocene (2.5–1.0 ka), the region experienced a colder and wetter climate. A gradual shift to warm and dry conditions occurred during the last 1.0 ky in this region.

The regional climate patterns have been generally dominated by alternations of warm-dry and cold-wet episodes during the Holocene that were quite different from the warm-wet and cool-dry episodes in the Asian summer monsoon region. Regional comparisons indicate that the climate changes in arid central Asia have been mainly influenced by the North Atlantic Ocean sea surface temperatures (SSTs) via the westerlies. However, owing to the mountainous character of the study areas, glacial meltwater, and other local factors, the climate changes in the Altai Mountains region have not always been concordant with variations of North Atlantic Ocean SSTs. We postulate that the history of moisture balance between regional precipitation, glacier and snow meltwater, and evaporation has been modulated by air temperatures that were mainly influenced by changes in the summer insolation of the Northern Hemisphere.

1. Introduction

Peat sequences are composed of the remains of plant communities that reflect climate conditions, and the peat itself is sensitive to microbial alterations and degradation in response to changes in climate. The sequences therefore can serve as high resolution archives recording past environment conditions (Blackford, 2000). As examples, macrofossils (Mauquoy et al., 2010; Aarnes et al., 2012) and pollen (Wen et al., 2010; Hayashibara et al., 2011; Guo et al., 2013) from peat and sediments have successfully been used to reconstruct local vegetation types, thereby reflecting regional climate changes. However, use of these paleoclimate proxies has been limited by the decomposition of organic matter (OM) brought about by microbial diagenesis and other environmental factors (Nott et al., 2000; Zhang et al., 2014). Lipid biomarkers that originate from the waxes of vascular plants and are found in different geological sequences have the important characteristics of relative source specificity and recalcitrance to decomposition (e.g. Eglinton and Hamilton, 1967; Meyers, 1997, 2003). They have been recognized as being promising proxies for providing valuable information on the production and preservation of OM and thereby being especially valuable for recording climate changes of the past in peat sequences (Seki et al., 2012; Zech et al., 2012; Street et al., 2013; Zhang et al., 2014).

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The Asian monsoon and westerly winds play important interactive roles in affecting changes in the climate of Asia. Regional climates can consequently have sensitive responses to the global climate system (Li et al., 2011; An et al., 2011). Many studies have been carried out over the past decades that report records of paleoclimate changes and that reconstruct the evolution of mechanisms of changes in the climate system of the Asian-Pacific monsoon region. However, there is yet no consensus on the climate evolutionary patterns and mechanisms in arid central Asia (Chen et al., 2008). Xinjiang Province in northwestern China, owing to its central Eurasian continental position and arid environment, is particularly sensitive to climate changes and therefore has attracted the attention of many environmental scientists. Although progressively more paleodata have been obtained from Xinjiang region for reconstructing the changes in vegetation and climate during the Holocene, most of the studied archives have been restricted to lake sediments (Li et al., 2011). Climate change reconstructions from peat records remain rare in this region. Previous studies on regional paleoenvironments have focused mainly on pollen analysis (Luo et al., 2009), whereas the use of lipid biomarkers for reconstructing paleoclimate in China has concentrated largely on the Asian monsoon region (Xie et al., 2004; Zhou et al., 2005, 2010; Zhang et al., 2006, 2014; Zheng et al., 2007). Few studies have been done that assess biomarkers as proxies for identifying past climate changes in northwestern China.

Some environmental scientists have mainly used pollen records from the lakes in the Jungar and Tarim basins as proxies to reconstruct the vegetation changes that reflect regional past climates in Xinjiang province, and Cheng et al. (2012) employed high-resolution $\delta^{18}O$ records of stalagmites from Kesang Cave in the Tianshan region, northern Xinjiang, to describe a dynamic precipitation history in central Asia. Also, Yang et al. (2002, 2006 and 2011) have done some work to emphasize the histories and potential mechanisms of Quaternary environmental changes in the Taklamakan Desert, southern Xinjiang. However, information from well-dated peat records has not existed that would allow reconstruction of the paleoclimate history in the arid mountain regions. The Altai Mountains, stretching across China, Kazakhstan and Mongolia, are characterized by a terraced topography and occupy a central position in the mid-latitude Asian interior. The mountains are far from oceans, and the regional climate is consequently mainly controlled by the westerlies. Ample water resources and mountain hollows in the mountains result in development of thriving marsh and aquatic plants, thereby providing good settings for the development of peatlands within this generally dry part of Asia. Consequently, this region can yield valuable geological archives for providing evidence for climate changes in northwestern China.

The Tielishahan peat sequence in the study area has had an apparently continuous accumulation throughout the Holocene. It therefore can provide new perspectives on climate changes in the mountain region of central Asia, especially on effective moisture changes during the Holocene. Meteorological data show that modern precipitation in central Asia is controlled by the westerlies; monsoon rainfall does not extend to this region (Li, 1991). However, controversy remains about the temperature-moisture patterns and the factors influencing climate changes during the Holocene in Central Asia. As examples, Jiang et al. (2007) concluded that the monsoon extended as far north as Wulungu Lake at ca. 6.0 ka. Similarly, other studies have documented the appearance of the monsoon imprint in Bosten Lake (Mischke and Wünnemann, 2006) and Hoton Nuur Lake (Rudaya et al., 2009) in the early and mid-Holocene, corresponding to a humid phase when the Asian monsoon strengthened. However, Chen et al. (2008) pointed out the effective moisture changes in arid central Asia could be mainly controlled by the westerlies and hence hardly influenced by the Asian monsoon. Liu et al. (2008) suggested that the westerlies were the dominant factor in determining the moisture changes in Wulungu Lake and that the Asian monsoon did not extend to the region during the Holocene. Li et al. (2011) documented that moisture changes in Yili Valley were mainly influenced by the North Atlantic Ocean SSTs through teleconnection by the westerlies. Moreover, based on the review of Holocene climate changes mainly inferred from pollen data from the Mongolian Plateau and its surrounding areas, Wang and Feng (2013) postulated that the moisture index from the northern Xinjiang has had a trend of persistent increase during the Holocene that may be related to cold-season temperatures in northern Europe and the Holocene trend of increasing winter insolation.

To provide more information on the paleoclimate history of arid central Asia, our study employs high temporal resolution analyses of the Humification Degree (HD) and *n*-alkane biomarker paleoclimate proxies in a peat sequence from the Altai Mountains in northwestern China. By comparison with other paleoclimate records, we offer new perspectives on Holocene climate changes and their possible driving mechanisms in the mountain region of arid central Asia.

2. Material and methods

2.1. Study area

The Tielishahan peat bog (48° 48′ 31″ N, 86° 55′ 10″ E; elevation ca. 1770 m) is located in an intermontane depression in the Khanas National Nature Reserve, northernmost Altai Mountains of Xinjiang Province, China (Fig. 1). The main modern orography of the area has typical horst structure mountain relief features that originated from Miocene-Pliocene uplifts. The mountainous relief can consequently intercept much of the water vapor carried by the westerlies from the North Atlantic Ocean to the uplifted areas. Moreover, the study area lies in a typical intermontane depression that is characterized by poor drainage, which provides good geological conditions for peat development. Water supply in the peat bog comes mainly from surface runoff of glacier and snow meltwater with a subequal admixture of rainfall. The peat bog is managed by the Nature Reserve and is not much affected by human activities. Well-preserved modern vegetation on the peat bog is dominated by *Carex* and *Sphagnum* spp. The distance from the top of the peat to the water surface in the peat bog on August 13, 2014, was measured as 20–30 cm.

The climate around the peat bog is characterized by long cold winters with perpetual snow, and short cool and wet summers. Mean temperatures vary between −12 and −16 °C in January and are less than 16 °C in July. The mean annual air temperature in the region is −3.6–1.8 °C. The Altai Mountains in their mid-continent position are far from oceans. The mean annual precipitation in the study region is 500–600 mm and is mostly concentrated in the period from June to August. This amount is far less than the mean annual evaporation capacity, which is 1844 mm/y at nearby Wulungu Lake (Liu et al., 2008). The structure and composition of modern vegetation around the study area is categorized as taiga and meadow steppe, which are distributed in the elevation belt between 1500 and 2600 m in the Altai Mountains. The taiga belt is dominated by larch (*Larix sibirica*) and spruce (*Picea obovata*), and the meadow steppe belt is characterized by mixed grasses and sedges (Forestry Bureau of Altai Mountains in Xinjiang, 2003).

2.2. Sample collection and stratigraphy

A 391 cm peat sequence was collected by drilling with an