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A new approach for reconstruction of the Holocene climate in the Mongolian Altai: The high-resolution $\delta^{13}C$ records of TOC and pollen complexes in Hoton-Nur Lake sediments

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ABSTRACT

$\delta^{13}C$ of total organic carbon (TOC) and pollen grain, TOC, C/N ratio, and $\delta^{15}N$ of total organic nitrogen (TON) in a 2.57-m long core from Hoton-Nur Lake in Mongolian Altai have been measured for reconstruction of the Holocene climates. The $\delta^{13}C$ values of TOC and pollen carbon have similar average values but different ranges. Pollen $\delta^{13}C$ has negative correlation with %AP (arboreal taxa pollen) and positive correlation with %NAP (herbaceous pollen and spores) that are connected with conditions of humidity in the area. Taiga-biome has lighter $\delta^{13}C$ than steppe-biome. Hence, pollen $\delta^{13}C$ composition is more sensitive to changes of humidity in the analogous spectra than palynotaxonomical structure and $\delta^{13}C$ of TOC. Based on our results, the Holocene climates in Mongolian Altai are: (1) dry conditions prior to 11.5 kyr BP; (2) wet conditions between 11.5 and 6.0 kyr BP; (3) a relatively dry/cool episode during 6–4 kyr BP; (4) stable cool and semiarid conditions with moderately effective moisture during the past 4000 years. Two abrupt climatic changes occurred at ~7.45 kyr BP and ~11.5 kyr BP might be related to glacial activities. The Holocene climatic trend in Mongolian Altai which is controlled by the Westerlies is similar to the trend of monsoonal climate shown by the Chinese speleothem records as well as the lake/sand dune evidence in the deserts of NW China. The contact of the two climatic systems and shift of the monsoonal boundary during the past need to be further studied.

1. Introduction

Located in the central Asia and bounded with Russia to the north and China to the south, Mongolia is an extremely continental territory. Its climatic setting is strongly influenced by the Siberian–Mongolian High (SMH) pressure cell, with cold and semi-arid climatic conditions in general. The variation of SMH affects strongly the strength of Asian Winter Monsoon (AWM) and average position of northern limit of the East Asian Summer Monsoon (EASM) on different time scales during Quaternary (Ding et al., 1995; An et al., 2000). In a review paper, An et al. (2008) interpreted that the climate changes of Mongolia are influenced by Westerlies and the EASM. Yang et al. (2002, 2003) described the influence of changes in Westerlies and monsoons on precipitation variability in the Tarim Basin of Xinjiang and in the Alashan Plateau of western Inner Mongolia during the late Quaternary. According to the modern meteorological observation, however, the EASM northern limit does not cross the boundary between Mongolia and China, and no maritime moisture source reaches Mongolia in general (Wang et al., 2010). Even during the early Holocene (10–9 kyr BP) when the solar insolation at mid-latitudes of N. Hemisphere reached the highest of the entire Holocene, the northern limit of the EASM boundary did not reach the southern boundary of Mongolia according to the reported geological evidence (Winkler and Wang, 1993). On the other hand, the influence of the Westerlies on paleoclimate and environmental changes of Central Asia is still unclear and controversial (Chen et al., 2008; Schwanghart et al., 2009). Therefore, how did the SMH, Westerlies and Asian monsoon affect the Holocene climate of Mongolian Altai, and what were the connections among these climatic systems during Holocene? We need more paleoclimate records to address the above questions.

Based on modern climatic settings and vegetation features, five bioclimatic zones in Mongolia can be identified (An et al., 2008; Wang et al., 2011). Thus, the temporal variations of the Holocene climate in Mongolia may have spatial difference. Furthermore, according to the summary of previous studies on paleoclimate changes during the late Quaternary in the drylands of China, interpretations of climatic conditions in the same area might not be consistent depending on time resolution and meanings of climatic

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proxies (Yang and Scuderi, 2010; Yang et al., 2011). For instance, Schwanghart et al. (2009) interpreted that a warm and wet mid Holocene (ca. 8–4 kyr BP) was prevailing in Ugii Nuur basin of central Mongolia. In contrast, Wang et al. (2011) reported a persistently warm and dry mid-Holocene (5830–3080 ^{14}C yr BP) climate recorded in the same lake basin. Obviously, more high-resolution, continuous and multi-proxy records of the Holocene climates in Mongolia are needed in order to understand the mechanisms that control climatic changes of this large and variable continental region.

In this study, we report the first carbon isotopic records of total organic carbon and pollen grains extracted from the lake sediments of Hoton-Nur Lake in Mongolian Altai which had previously been carried out pollen analysis and climate reconstruction (Rudaya et al., 2009). Up to date, rare available literatures examine the δ^{13}C of pollen assemblages and compare the pollen δ^{13}C with δ^{13}C of TOC in the same core. If pollen δ^{13}C provides a meaningful proxy of changes in vegetation and climate, this method will develop another fast and semi-quantitatively geochemical approach for lake study. Here, we establish the connection between the δ^{13}C of pollen complexes and climate dynamics, and compare the pollen δ^{13}C, $\delta^{13}C_{TOC}$, TOC and C/N, and refine the history of climate and vegetation in Mongolian Altai during the Holocene.

2. Background of the studying area and sample description

Hoton-Nur Lake (48°35–42′N, 88°10–24′E, 2083 m a.s.l.) is located on the eastern slope in the northern high-elevated part of the Mongolian Altai (Fig. 1A), with a surface area of 50 km^2 and maximum depth of 58 m. This region is bounded by Altai Mountains, Tannu-Ola Mountains (part of Sailughem Mountains), and Hangayn Mountains. The peak of Huytan Orgil with an elevation of 4082 m (a.s.l.) is on the west side of the lake valley (Fig. 1A). The lake region is characterized by continental climate with cold and dry winters (Cold season $T_c = -20{\sim}-25$ °C) and cool summers (Warm season $T_w = 12{\sim}15$ °C). The annual mean precipitation is ca 250 mm at the lake level and ca 300 mm at the elevations above 3000 m with maximum precipitation (60–70% of annual rainfall) in the late summer (July–August). However, the summer rains are mainly short-duration thunderstorms due to the cool westerly winds to meet with warm air mass from local summer heating. Period with snow cover is about 100–140 days in high mountains and 50–100 days in intermountain basins (Volkova, 1994; Gunin et al., 1999).

Modern vegetation of the high-mountain belt is represented by different types of alpine tundra, and kobresian and sedge meadows. Steppe belt is formed by cold-tolerant dry grass steppes in the upper part, and semi-desert communities in the intermountain basins. Although tree taxa are not of importance in the region today, they are represented by Siberian larch (*Larix sibirica*) and Siberian spruce (*Picea obovata*) in the river valleys (Volkova, 1994). The most important climatic factor controlling vegetation distribution in Mongolian Altai is amount of annually atmospheric precipitation (Gunin et al., 1999). The prevailing photosynthetic pathway in vegetation communities over the studying area is C_3 carbon fixation (Pyankov et al., 2000).

Quantitative reconstruction of the Holocene vegetation and climate dynamics of the Mongolian Altai based on the pollen data obtained from the sediment cores of Hoton-Nur Lake (Tarasov et al., 2000; Rudaya et al., 2009), suggested that the regional climate was relatively dry prior to ca 10.7 kyr BP. Cold and dry steppe communities dominated in the region in the beginning of Holocene. Coniferous forest with *P. obovata* replaced partly the open landscape about 10 kyr BP in response to an increase in precipitation from 200–250 mm/yr to 450–550 mm/yr (Rudaya et al., 2009). Those pollen complexes and climatic conditions remained until the middle Holocene. A decline of the woodland and a return to a predominance of open steppe vegetation occurred after 5 kyr BP when precipitation decreased to modern level of 250–300 mm/yr (Rudaya et al., 2009).

Although detailed pollen analysis had been done on the lake sediments in this region, few geochemical studies have conducted on the lake sediments. The 2.57-m long gravity core was obtained from the 32 m depth in the southeastern part of Hoton-Nur Lake in 2004 (Fig. 1B). Age-depth model was worked out by the seven radiocarbon dates from two Hoton-Nur Lake cores. These AMS ^{14}C dates were measured on the plant remains found from two adjacent cores. Using the distinguished lithological stratigraphy and pollen assemblages of the two cores, all seven AMS ^{14}C dates were applied to this 2.57-m long core (see the details in Rudaya et al., 2009). A best fitting of the seven AMS ^{14}C dates provided the depth-age relationship: Age (a) = $1086.5 + 10.376 * D - 0.004065 * D^2 + 7.1056 \times 10^{-7} * D^3$, whereas D is the core depth (mm). The upper unit of the core (205–0 cm) consists of striate gray clay and silt sediment with touch of organic matter, whereas the lower part

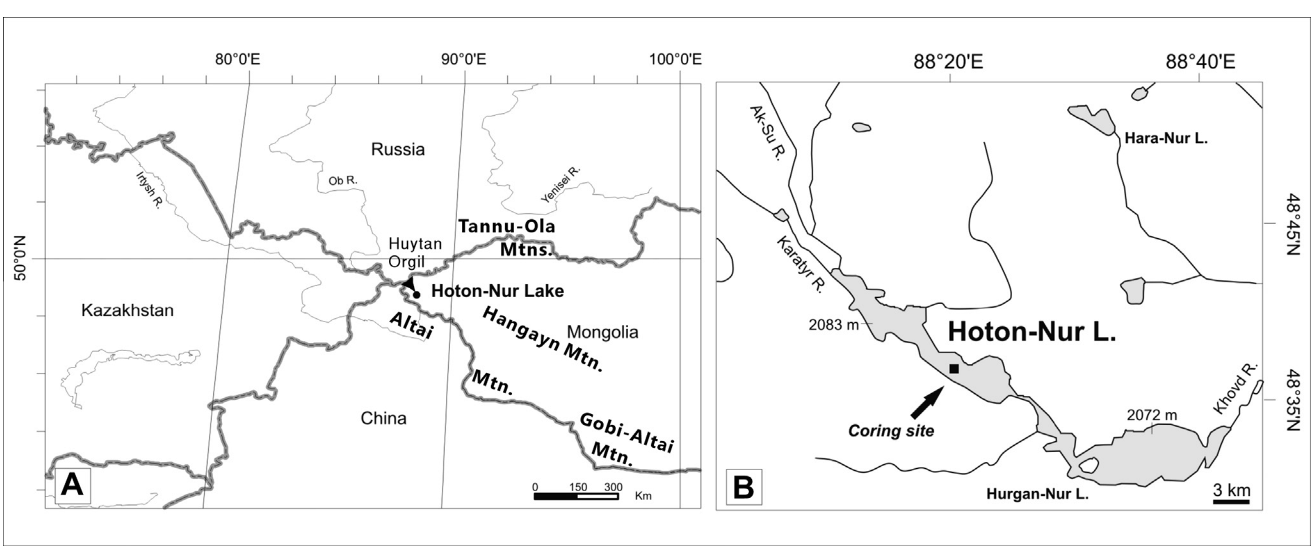

Fig. 1. Map of studied part of Asia (A) and Hoton-Nur Lake region (B).