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Palynological implications for Late Glacial to middle Holocene vegetation and environmental history of the Lop Nur Xinjiang Uygur Autonomous Region, northwestern China

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ABSTRACT

Lop Nur is located in the northeastern area of the Tarim Basin, in the Xinjiang Uygur Autonomous Region, northwestern China. A 210-cm-deep trench section was collected from the center of the lake. Five accelerator mass spectrometry (AMS) ^{14}C dating results indicate that the studied section encompasses the Late Glacial to middle Holocene periods (12.8–5.5 cal ka BP). Vegetation and environmental changes in the Lop Nur region can be divided into three stages and six sub-stages, based on significant changes in the pollen assemblages. Dry conditions and desert steppe or steppe vegetation dominated this region from 12.8 to 11.4 cal ka BP. The climate became warmer and wetter at the beginning of the Holocene, and steppe vegetation replaced the previous flora. Steppe vegetation continued to dominate until the middle Holocene (8.7–6.7 cal ka BP), which had the wettest moisture conditions. Increased winter temperatures from 6.7 to 5.5 cal ka BP triggered more evaporation, causing shrinkage of the lowland wetlands. Climate events such as the Allerød oscillation, the Younger Dryas, and events at 9.4 cal ka BP, 8.4cal ka BP, 7.5 cal ka BP, and 7.0 cal ka BP, were recognized in the Lop Nur section. The evidence indicates that climate oscillations in the Lop Nur area were influenced and controlled by changes in global climate.

1. Introduction

The formulation of hypotheses about the causes of climatic change requires the synthesis of global and regional climate information from all available sources. Studies performed in northwestern China have aided our understanding of changes in vegetation and climate during the late Pleistocene and Holocene (Mischke and Wünnermann, 2006; Huang et al., 2009; Zhao et al., 2009; Wang N. et al., 2013; Wang W. et al., 2013; Lyu et al., 2015; Ran et al., 2015). However, some issues remain unresolved, including a) whether different stages of the Holocene were wet or dry and b) the nature of prevailing hydrothermal regimes and climate change patterns in the Xinjiang Uygur Autonomous Region during the late Pleistocene and Holocene.

Previous studies have yielded conflicting humidity results from the same core sampled from Wulungu Lake. Some authors have divided the climate into four stages (Xiao et al., 2006), whereas others have divided it into three (Jiang et al., 2006, 2007; Liu et al., 2008). Xiao et al. (2006), Jiang et al. (2006), and Liu et al. (2008) reported evidence for a dry early Holocene and a moderately dry or wet middle Holocene. Using the same core, Jiang et al. (2007) determined that 9985–5250 cal BP was the wettest phase and 5250–1255 cal BP was the driest phase. Studies of Aibi Lake have also produced contradictory results; the temperature was higher from 11.5 to 10.6 cal ka BP, accompanied by increased precipitation (Jiang and Wu, 2003). The climate was cool and dry prior to 8 ka BP, 8.0–3.5 ka BP was a warmer moist climate stage, and 3.5 ka BP–present has been warm and dry (Jiang and Wu, 2003; Wu et al., 1996). In contrast, Wang N. et al. (2013); Wang W. et al. (2013) determined that the Aibi Lake area was subject to increased basinwide moisture conditions between 13,870 and 7430 cal BP. The water level of Aibi Lake increased from approximately

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7430–3620 cal BP. Moisture levels have increased continuously from about 3620 cal BP onward, leading to further lake transgression. A dry interval from about 1400 to 1150 cal BP interrupted the late Holocene wet conditions of the previous 3600 years. Studies of several other lakes (Balikun Lake, Bosten Lake, and Sayram Lake) have shown evidence for a dry early Holocene (An et al., 2011; Huang et al., 2009; Jiang et al., 2013). In contrast, palynological records from the Yili Valley show that the early Holocene (10.6–7.6 cal ka BP) was the wettest time (Li et al., 2011).

Interpretations of hydrothermal regimes are also contradictory. Some researchers have suggested cold-humid and warm-dry westerly regimes (Han and Li, 1994; Zhong and Han, 1998; Luo et al., 2008), whereas others have proposed warm-humid and cooling-drying monsoon regimes (Sun et al., 1994). Research from Balikun Lake indicates that various combinations of regimes, including cold-dry, wet-warm, wet-cold, and dry-temperate regimes, have occurred (Xue and Zhong, 2008).

Some researchers have suggested a westerly pattern of climate change, with a dry early Holocene and a gradual wetting of the climate dominating the middle–late Holocene in the Xinjiang area (Chen et al., 2008; Huang et al., 2009; Tao et al., 2010; An et al., 2011; Jiang et al., 2013). Other proxy data from Manas Lake indicate that the Holocene climatic changes in Xinjiang have been similar to those in eastern China (Sun et al., 1994; Rhodes et al., 1996; Lin et al., 1996; Lin and Wei, 1998; Wei and Gasse, 1999), with a warm and humid early–middle Holocene and cooling and drying conditions in the late Holocene.

Lop Nur is situated in the continental interior of northwestern China; as the terminal lake of the Tarim Basin, it is a climatically sensitive region (Luo et al., 2009). Several studies of Quaternary deposits in Lop Nur have been conducted (Yan et al., 1983, 1998; Wu, 1994; Wang et al., 2000, 2004; Wang and Zhao, 2001; Ma et al., 2008; Luo et al., 2008, 2009; Wang et al., 2009; Zhu et al., 2009; Hua et al., 2009; Yang et al., 2013). However, conditions in the region during the Late Glacial to middle Holocene phases remain unresolved due to limitations of temporal resolution and chronology. An understanding of the regional paleovegetation and environmental variability of Lop Nur will provide insight into the westerly and Asian monsoon climatic systems, and will improve prediction of future climate change. In this study, we focused on reconstruction of the paleovegetation and paleoclimate variation in Lop Nur from 12.8 to 5.5 cal ka BP.

2. Study area

Lop Nur is located in the northeastern part of the Tarim Basin. It is an inland playa lake that historically received fluvial input from the Tarim, Kongque, and Cheerchen rivers, which are supplied by mountain precipitation and glacial meltwater. In the mid-20th century, water input to Lop Nur ceased as a result of excessive animal husbandry and agriculture in the upper and middle reaches of the rivers, which accelerated the ongoing desertification of the area. Today, Lop Nur is a large dry lake with a salt crust 30–100-cm-thick.

The present climate is temperate continental, and mean monthly temperatures range from −8–28 °C at the nearby Ruoqiang station. Annual rainfall is approximately 22 mm, but the potential evaporation is about 3000 mm (Xia, 1987).

The Lop Nur region contains approximately 1% of the extant vascular plant species in Xinjiang, and is the most plant species-poor area in China (Xia et al., 2007). It contains almost no vegetation in the salt crust, gravel desert, and Yadan areas. The vegetation in the salt desert consists of *Halocnemum* Bieb., *Halostachys* C.A. Mey, *Kalidium* Moq, *Tamarix*, and *Phragmites* Adans. The gravel desert is dotted with *Ephedra* and *Sarcozygium* Bunge. The desert near the Kuluke riverbed contains *Tamarix*, *Populus euphratica*, *Karelinia*, *Scorzonera*, *Apocynum venetum* L., *Poacynum* Baill, *Lycium*, *Alhagi* Gagneb, *Nitraria*, *Glycyrrhiza* L., *Kalidium* Moq, and *Phragmites* Adans. The dominant species in the Kumu Tucker desert are *Tamarix*, *Calligonum* L., and *Salsola ruthenica*.

3. Materials and methods

A 2.2-m trench profile (the DHX section) comprising the Late Glacial to the middle Holocene was collected in May 2013 from the center of Lop Nur, Xinjiang Uyghur Autonomous Region, China (Fig. 1). To eliminate surface and bottom impacts, the top 6 cm and bottom 4 cm were not analyzed.

The chronology of the section was determined based on accelerator mass spectrometry (AMS) ^{14}C dating of five bulk sediment samples (Fig. 2) taken at depths of 42, 102, 158, 178, and 218 cm. Samples were dated at Beta Analytic Inc. (Florida, USA). Radiocarbon dates were calibrated to BP calendar dates according to Talma and Vogel (1993) and Reimer et al. (2013). Age–depth models were constructed for the section using available AMS ^{14}C radiocarbon dates, which provide a mean for sample age estimation. Sample ages were derived through linear interpolation of the AMS ^{14}C dates. Age was linearly interpolated using the central point of the 2σ values of the five calibrated ages. The interpolation formula used was $y = 0.0283x - 147.34$, where y is depth and x is age (correlation coefficient $R^2 = 0.9445$; Fig. 2). We prepared 105 pollen samples following standard techniques for analysis of pollen succession throughout the sediment profile. After drying at 60 °C for 48 h, samples were weighed and treated using an HCl–KOH–HF method. A 10-g soil sample was mixed with two *Lycopodium* spore tablets (55,274 grains) as a standard marker. Samples were then decalcified with cold 36% HCl and rinsed with distilled water. Neutral samples were treated with 10% KOH and rinsed with distilled water. Cold 40% HF (50 mL) was added and left overnight to remove silicate particles. After rinsing with distilled water, another 36% HCl treatment was applied to eliminate silicate fluoride. The residues were then sieved using a 10-μm mesh, and the larger fraction was retained. Water was then removed from the samples using glacial acetic acid, and the samples were acetolyzed to remove protoplasm. Samples were then mounted in glycerin jelly for microscopic identification. A minimum of 400 grains was counted. Identification was performed using the authors' collection and pollen morphological descriptions (Xi and Ning, 1994; Wang et al., 1995). Pollen assemblages of particular species/taxa were presented as relative abundances (%) on a stratigraphic diagram using Tilia software (Grimm, 1991, 1993). Cluster analysis was performed using CONISS software (Grimm, 1987). The resulting pollen diagram (Fig. 3) is composed of 105 samples and presents the most abundant (>1%) taxa. The remaining taxa are listed as "other."

4. Results

A total of 77 pollen taxa were identified. The pollen diagrams (Fig. 3) are divided into three pollen zones and six sub-zones based on significant changes in the pollen assemblages and changes in the *Artemisia*/Chenopodiaceae (A/C) ratio, the (*Artemisia* + Gramineae + Asteraceae)/(*Nitraria* + *Ephedra* + Chenopodiaceae) [(A + G + A)/(N + E + C)] ratio, and the non-arboreal pollen/arboreal pollen (NAP/AP) ratio. In the Xinjiang desert area, *Artemisia* is known to grow in warm-moist conditions, whereas Chenopodiaceae thrive in cold-dry desert environments. The A/C ratio is used to determine changes in regional moisture (El-Mosilimany, 1990; Sun et al., 1994; Luo et al., 2006, 2007). The (A + G + A)/(N + E + C) ratio can also be used as an indicator of aridity level (Shu et al., 2009). The zones are described from the