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New evidence on deglacial climatic variability from an alpine lacustrine record in northwestern Yunnan Province, southwestern China

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ABSTRACT

New deglacial pollen and conifer stoma records from Tiancai Lake, northwestern Yunnan Province, southwestern China, an alpine lake in the southwest monsoon region, are presented in this study. Based on these records, the lithology of core TCYL1, and PCA analysis of pollen data between ~21 and 11.5 ka BP (calibrated ^{14}C years), the deglacial vegetation and climate changes are discussed in detail. The results show that Tiancai Lake was above the upper limit of *Picea*/*Abies* forest (a treeline in the study area) between ~21 and 11.5 ka BP, and the climate was colder and drier than that of the Holocene. During this period eight significant vegetation changes are recorded that are considered to be responses to changing temperatures and variations in the southwest monsoon in southwestern China. The Heinrich Event 1 (H1), the Bølling/Allerød warm period (BA) and the Younger Dryas cold event (YD) are all clearly detected in this record. In addition, this study finds that the initial late glacial warming in northwestern Yunnan Province was at ~18.7 ka BP, which is coincident with the climate records in monsoonal Central Asia, the Indian Ocean, the tropical and subtropical Pacific Ocean, and Antarctica, and is a response to solar insolation changes. A noted temperature increase between 15.8 and 14.4 ka BP occurred at the end of the H1 and before the BA, which indicates a strong pre-Bølling warming. Based on the study, we consider that the hypothesis about a slowdown of the ocean's thermohaline circulation is sufficient to explain these late glacial abrupt events.

1. Introduction

The last deglaciation in the Northern Hemisphere is not a smooth transition from one climate state to another and is punctuated by some abrupt climate events. The most prominent deglacial events in the Northern Hemisphere are the Heinrich Event 1 (H1, ~17.5 to 16 ka) and the associated Oldest Dryas cold period (~18 to 14.7 ka), the Bølling/Allerød warm period (BA, ~14.7 to 12.9 ka) and the Younger Dryas cold event (YD, ~12.9 to 11.7 ka) (Alley and Clark, 1999). The global extent of these events is not yet clearly established (Clark et al., 2002) as the geographic distribution of high resolution last deglaciation records is largely focused on high-latitude regions such as Greenland, North Atlantic Ocean and Antarctica (Johnsen et al., 1972; Duplessy et al., 1992; Blunier et al., 1998; Stuiver and Grootes, 2000; Blunier and Brook, 2001; Jouzel et al., 2001; Waelbroeck et al., 2001; Knorr and Lohmann, 2003; EPICA Project Members, 2004; McManus et al., 2004; NGRIP members, 2004; Brook et al., 2005; EPICA Community Members, 2006; Gherardi et al, 2009; Barker et al., 2010; Thornalley et al., 2010; Pedro et al., 2011; Ritz et al., 2013).

Southwestern China, especially northwestern Yunnan Province, is a region affected strongly by the southwest summer monsoon (Indian summer monsoon). At the same time, it is adjacent to the Tibetan Plateau, which makes southwestern China a key region for reconstruction of paleoclimate changes and past southwest monsoon dynamics. However, paleoenvironmental records spanning the whole last deglaciation are relatively few in southwestern China (Wu et al., 1991; Tang, 1992; Liu et al., 1995; Jiang et al., 1998; Hodell et al., 1999; Qin et al., 2001, 2004; Yin et al., 2002; Zhang et al., 2002, 2004a, 2004b; Zhang and Mischke, 2009; Yang et al., 2010; Cook et al., 2011). Because of low temporal sampling resolution, age uncertainties and/or regional sensitivity, there are large differences between the results of these published studies. Some studies suggest that the climate was cold and wet during the whole last deglaciation (Wu et al., 1991; Tang, 1992). A majority of studies detect the Last Glacial Maximum (LGM) and YD (Liu et al., 1995; Jiang et al., 1998; Hodell et al., 1999; Yin et al., 2002). Only a few studies detect H1 (Qin et al., 2004; Zhang et al., 2004a) and the BA (Kramer et al., 2010; Yang et al., 2010), and the timing and paleoclimatic interpretations vary across these records. Consequently, it is necessary to develop more precise, high-resolution studies in southwestern China, which can help clarify regional climate dynamics and detect possible teleconnections between the southwest monsoon and the global climate system.

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High-elevation alpine lake sediments have been shown to be sensitive to climate change, recording changes in subalpine treeline vegetation since the late glacial and early Holocene (Pellatt and Mathewes, 1997; Barnett et al., 2001; Jiménez-Moreno et al., 2008). In many regions, alpine environments present the additional advantage for paleoclimate reconstruction by being less disturbed by humans than low elevation sites. Tiancai Lake is an alpine lake in the southwest monsoon region, little disturbed by human activities, which makes the lake more sensitive to natural processes. At the same time, sedimentation in Tiancai Lake is continuous and provides the possibility for a high-resolution study. Thus, Tiancai Lake is an ideal area to study paleoclimate changes in the southwest monsoon region (Xiao et al., 2014).

Here we present a new centennial scale paleolimnological record from Tiancai Lake, which provides new evidence on the last deglacial regional climate variability and southwest monsoon dynamics. This study is an extension of the record presented in Xiao et al. (2014) that focused on vegetation and climate changes since 12.2 ka BP from Tiancai Lake.

2. Regional setting

Tiancai Lake is an alpine ice-scoured lake in northwestern Yunnan Province, southwestern China. The lake is located on the southeast edge of the Qinghai–Tibet Plateau, a transition zone from the Hengduan Mountains to the Yunnan–Guizhou Plateau. The elevation of Tiancai Lake is 3898 m a.s.l. with a maximum water depth of 7 m, surrounded on three sides by mountains rising to 4100–4200 m a.s.l. with a stream outlet in the northeast of the lake (Xiao et al., 2014) (Fig. 1).

The study region is characterized by a highland cold temperate humid monsoon climate. It is mainly determined by warm–humid airflow from the Indian Ocean and Bengal Bay in summer and by the south-branch westerly winds in winter and is also affected by the local climate of the Qinghai–Tibet Plateau. Due to the monsoon, the lake region is characterized by distinct wet (summer) and dry (winter) seasons. There is no weather station around the lake at present. The mean annual temperature and mean annual precipitation for the lake region have been obtained by interpolation using a gradient-plus-inverse distance squared (GIDS) method, which combines multiple linear regression and distance weighting (Nalder and Wein, 1998) according to the climatic data of the 46 weather stations around the study area. The result shows that the mean annual temperature around the lake is 2.5 °C and the average annual precipitation is about 910 mm (Xiao et al., 2011).

Because of marked altitudinal gradients and complex topography in northwestern Yunnan Province, altitudinally controlled vegetation belts in the region are distinct (Xiao et al., 2008, 2010). Tiancai Lake is located about 200 m below the treeline. Primary forest around the lake appears to be undisturbed in the historic past, with cold-temperate old-growth conifer forest composed of *Abies* and *Picea* covering the catchment (Xiao et al., 2014).

3. Materials and methods

3.1. Coring and sampling

Sediment of core TCK1 collected in October 2008 from Tiancai Lake using a UWITEC piston corer was found to be continuous and was analyzed at high-resolution (Xiao et al., 2014), though the core did not reach the basal sediments of the lake. In November 2010, another core (26°38′3.8″ N, 99°43′0.5″ E) was collected that reached the bottom of the sediments near core TCK1 using the same piston corer (Fig. 1). The second core (TCYL1) is an 865-cm-long sediment core, and was sectioned at 1 cm intervals. Samples were stored at 4 °C until analyzed. Core correlation between TCK1 and TCYL1 was carried out using surface scanning magnetic susceptibility (Anderson, 1986). There is a very good correlation between cores TCK1 and TCYL1 (Fig. 2), and by comparing peaks in the magnetic susceptibility records, it is shown that core TCYL1 is older than core TCK1 as the lowest peak at 820 cm in core TCK1 corresponds to the peak at 678 cm in core TCYL1. Thus, the date at 678 cm in core TCYL1 equals the date at 820 cm in core TCK1, which is 10,527 cal. yr BP (Table 1). Based on the date obtained by core correlation and 12 AMS ^{14}C dates in the lower part of core TCYL1, the time series of the lower part of core TCYL1 is established (see Section 4.1 for detail). According to the ages of cores TCK1 and TCYL1, the stratum at 707 cm of core TCYL1 can be joined to the bottom of core TCK1. Consequently, the integrated core in Tiancai Lake consists of core TCK1 and the strata between 707 and 865 cm of core TCYL1. Core TCK1 has been discussed in detail in Xiao et al. (2014). In this study, we focus on the lower part of core TCYL1, namely, the sediment between 693 and 865 cm. The sediment is almost continuous lacustrine sediment except for 24-cm-long ground moraine with poor psephicity in the lowest part of core TCYL1 (841 to 865 cm). The lithology of the lower part of core TCYL1 consists of black fine detritus mud between

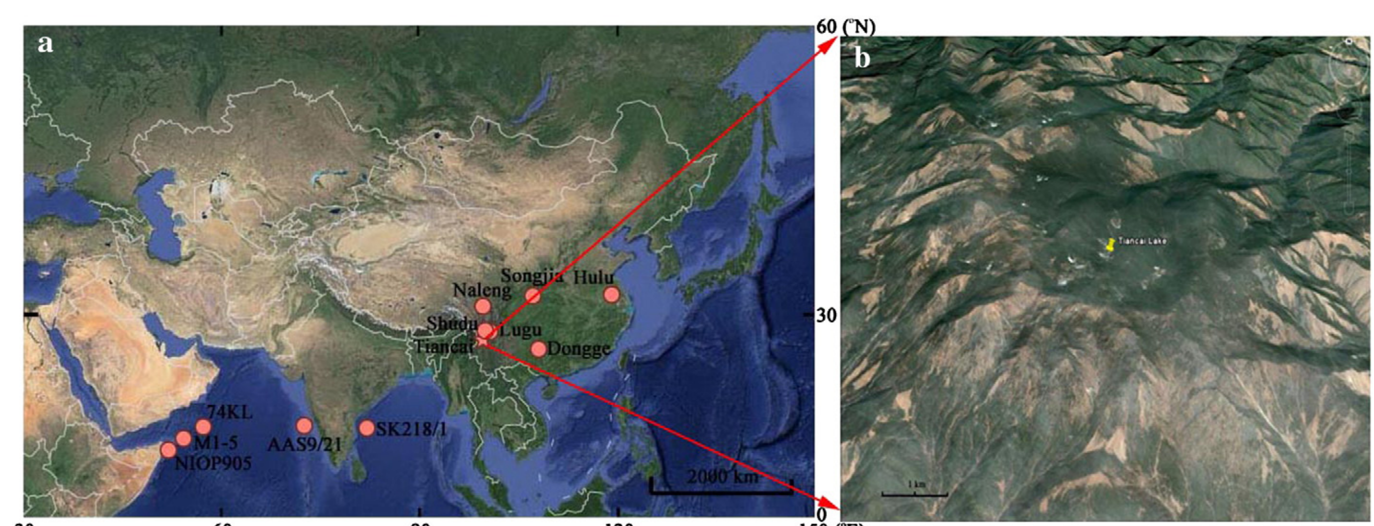

Fig. 1. (a) Location map of Tiancai Lake, northwestern Yunnan Province, China. Other sites mentioned in Section 5.2 are also shown. (b) Topography of Tiancai Lake surrounded on three sides by mountains.