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High-resolution OSL dating of a late Quaternary sequence from Xingkai Lake (NE Asia): Chronological challenge of the "MIS 3a Mega-paleolake" hypothesis in China

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ABSTRACT

In this paper a combined OSL (49 samples) and ^{14}C (14 samples) dating study was conducted on a sediment core from Xingkai Lake, NE Asia. A single-aliquot regenerative-dose protocol was used to determine the equivalent dose (D_e) of the extracted fine-grained (FG) quartz fraction; the suitability of the measurement procedure was confirmed by a set of luminescence tests (e.g., preheat plateau and dose recovery measurements). In addition, a post-IR infrared stimulated luminescence protocol at 290 °C ($pIRIR_{290}$) was applied to the polymineral FG fraction of seven samples. Our results can be summarized as follows: (1) The uppermost sample was dated to ~110 a, indicating that the OSL signal of FG quartz has been well bleached. This has been further confirmed by the consistency of OSL ages and $pIRIR_{290}$ ages within <80 ka. The resulting OSL ages generally increased with depth, and the lowermost samples of core XK08 reached back to the last interglacial, although the $pIRIR_{290}$ dating suggested that the quartz OSL ages likely begin to be underestimated beyond 80 ka; (2) The comparison of OSL and ^{14}C ages suggested that the radiocarbon dating technique may significantly underestimate the age of sediments for samples older than 30 cal ka BP (corresponding to ~25 ^{14}C ka BP), and thus it is necessary to pay attention when using such old ^{14}C dates for paleoclimatic/archaeological interpretation; (3) This study challenges the radiocarbon-based chronology of the "MIS 3a Mega-paleolake" hypothesis, which had been reiterated for many years and extensively reported across northern and western China; and (4) The current high-resolution OSL dating record (one-age/5–10 cm) showed clear sedimentation rate changes down the core. The identified variations in the sedimentation processes at the orbital timescale may be related to regional/global climatic changes during the past 130 ka, and the high sedimentation rate during the last ~0.4 ka has probably been caused by intensified human activities in the Xingkai Lake catchment.

1. Introduction

Robust geochronological constraint is of crucial importance in interpreting and correlating the late Quaternary paleoenvironmental events derived from fragmentary terrestrial sequences (Briant and Bateman, 2009). For lake archives, chronological control often relies only upon radiocarbon dating of organic matter with its accompanying problems of scarcity of available material (e.g., Long et al., 2011), and methodological problems such as varying hard water effects during burial time (e.g., Sikes et al., 2000), as well as saturation effects due to the upper age limit for dating relatively old materials (e.g., Groot et al., 2014). In particular, geochronologists have widely recognized that the reliability of ^{14}C dating quickly degrades towards the end of its dating range, and that radiocarbon ages older than 40 ^{14}C ka BP (~45 cal ka BP) are often inaccurate (Pigati et al., 2007). Nevertheless, some important paleoenvironmental implications from lake archives have still been deduced based on ^{14}C dating of old materials whose ages might be close to or even beyond the dating limit of such techniques. For example, across the whole northern and western China (including the Tibetan Plateau), there is considerable evidence for significant variability of lake levels during the late Pleistocene, and the timing

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of these lake highstands were coincidently placed between 40 and 30 cal ka BP (equal to the late period of marine isotope stage 3, i.e., MIS 3a), mostly based on ^{14}C dating of fragmentary shorelines and terraces around lakes (e.g., reviews by Shi et al., 2001, and Yang et al., 2004). These previous studies then claimed that lakes were markedly enlarged during MIS 3a, and then the hypothesis of a "Mega-paleolake" period during the last interstadial was proposed. This notion of a "MIS 3a Mega-paleolake" was also supported by Li (2000) and reiterated for many lakes throughout the entire western and northern China (e.g., Lehmkuhl and Haselein, 2000; Yu et al., 2003; Zhang et al., 2004; Herzschuh, 2006; Yang and Scuderi, 2010). Subsequently, the ^{14}C-based mega-lake hypothesis was even incorporated into modeling work to interpret regional climate dynamics (e.g., Yu et al., 2003, 2007; Jiang et al., 2015) and trace its links to atmospheric circulation systems such as Asian monsoons (Shi et al., 2001) and Westerlies (Yang et al., 2004; Jiang et al., 2011).

In theory, radiocarbon techniques could provide a way to date material that contains carbon with an age of up to ~50,000 yr (Walker, 2006). Nevertheless, the reliability of radiocarbon dates around ~40–30 cal ka BP might be problematic, as they are at or just over the limits of what is considered to be reliable for conventionally pre-treated radiocarbon ages (Pigati et al., 2007; Briant and Bateman, 2009). The major hypothesis of the "MIS 3a Mega-paleolake" has been challenged by alternative dating methods that have wider age ranges. A set of recent studies reported that the lake highstands of the late Pleistocene were dated back to the MIS 5 interglacial period according to non-radiocarbon dating methods (e.g., Madsen et al., 2008, 2014; Liu et al., 2010; Rhode et al., 2010; Long et al., 2012). More recently, Long and Shen (2015) compiled those dates constraining the timing of high lake levels and showed different high-lake-level periods inferred by different dating methods. They argued that the timing of the high-lake-level event in the late Pleistocene is likely to be underestimated by ^{14}C dating and in reality is dated to older than 80 ka, making a correlation with MIS 3a unlikely. However, whether the discrepancy of the high-lake-level periods results from different dating methods or an inherent difference of lake evolution between different regions requires further examination. A direct comparison between different dating techniques for the same lacustrine sequence would help to answer this question.

The optically stimulated luminescence (OSL) dating method is an alternative for dating the whole period from the late Pleistocene to the Holocene (Murray and Olley, 2002), and it also provides the opportunity to independently test radiocarbon-based chronologies (e.g., Briant and Bateman, 2009; Long et al., 2012; Long and Shen, 2015). In particular, the development of the single-aliquot regenerative (SAR) protocol (Murray and Wintle, 2000) allowed the application of OSL dating to lacustrine sediments, which are often associated with lake cores or shoreline sediments (Long et al., 2011, 2012; Lukas et al., 2012; Shanahan et al., 2013). In the current study, a Quaternary lacustrine sediment sequence from Xingkai Lake (NE Asia) was chosen for dating using both the OSL and ^{14}C techniques. The robustness of OSL dates was confirmed in a series of tests, and the subsequent dating results allow us to determine whether ^{14}C-based chronologies are suitable for dating relatively old samples (e.g., beyond 30 cal ka BP).

2. Regional setting and research materials

Xingkai Lake (44°32″–45°21″N, 131°58″–132°51″E), situated at the border between China and Russia (Fig. 1a), is the largest freshwater lake in NE Asia. The present lake covers an area of 4190 km^2 with a catchment area of 16,890 km^2. The average water depth is ~4.5 m, the maximum water depth is ~10 m, and the elevation of the modern lake level is ~65 m above sea level. The

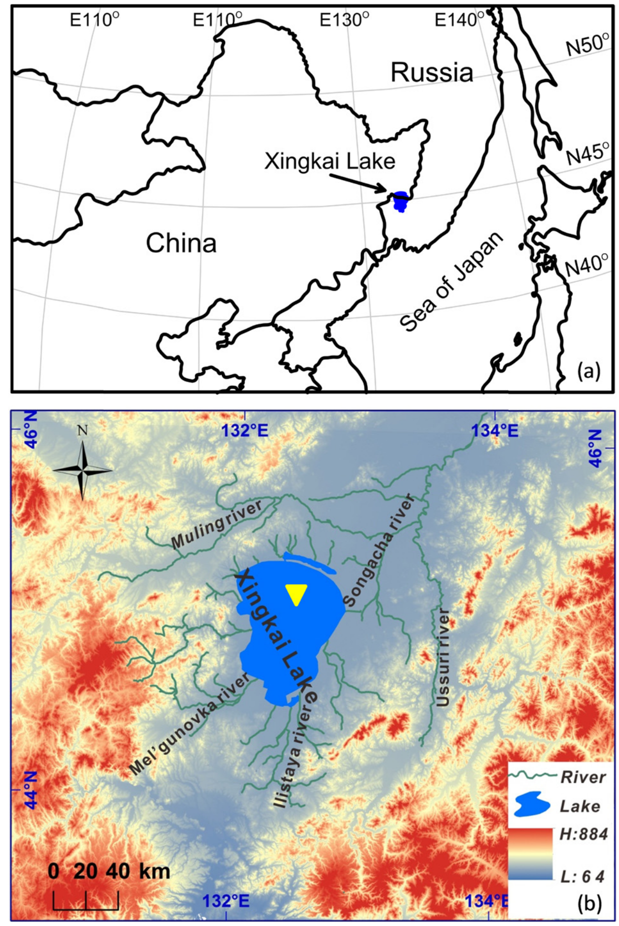

Fig. 1. (a) The location of Xingkai Lake in NE Asia; (b) Digital elevation model (DEM) map of the Xingkai Lake catchment (downloaded from http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp); Filled triangle denotes the drilling location of core XK08.

maximum monthly mean temperature is ~21 °C in summer, while the minimum monthly mean temperature is approximately −19 °C in winter. Rainfall occurs mainly in summer, reaching ~750 mm annually. Xingkai Lake is a Cenozoic formation basin that is filled by Quaternary silt and clay and bounded by uplifted elongated mountain ridges in the west and east.

A 308-cm-long core (XK08) was retrieved using a UWITEC piston corer from the central part (water depth: ~7 m) of Xingkai Lake (Fig. 1b). The core lithology consisted of homogeneous lacustrine sediment, mainly grayish silty clay. Under subdued red light, the core was split into two halves, and one entire half was sectioned at 5–10-cm intervals to collect the sediments for OSL dating. Care was taken to sample the inner non-light-exposed part and to avoid any influence of smearing by the core barrel; separate samples were taken for dose rate measurements. A total of 49 OSL samples were obtained. In addition, we collected 14 samples (including one terrestrial fossil sample and 13 bulk organic matter samples) for accelerator mass spectrometry (AMS) ^{14}C dating.

3. Methods

3.1. OSL dating

Sample preparation and OSL measurements were carried out in the Luminescence Dating Laboratory of NIGLAS (Nanjing, China). For each sample, the fine-grained (FG, 4–11 μm) quartz fraction was isolated for D_e measurements. Bulk materials were first treated with 30% H_2O_2 and 10% HCl to remove organic matter