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Variability of the ^{14}C reservoir effects in Lake Tangra Yumco, Central Tibet (China), determined from recent sedimentation rates and dating of plant fossils

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ABSTRACT

Sediments from lakes provide one of the most important archives for past environmental changes on the Tibetan Plateau. The recent sedimentation rate of modern lakes is widely used as an independent method to calibrate ^{14}C-derived chronologies because ^{14}C values are often affected by a reservoir effect. Terrestrial plant residues in lake sediments are believed to be the ideal material for ^{14}C dating because they normally provide the true ages of the sediments. In this study, we present the spatial and temporal variations in modern sedimentation rates over the past ~150 years and evaluate the reservoir effects of ^{14}C ages determined from bulk sediments and plant residues from Lake Tangra Yumco on the central Tibetan Plateau. The results show that ages determined from plant residues are systematically younger than those of the bulk sediments. However, the reservoir effects associated with the bulk sediments are much more constant than those of the plant residues, highlighting the complicated composition of these macro-remains and the fact that they might not be the best dating materials in Tangra Yumco, especially in southern part. A similar reservoir effect of ~2200 years is observed in the southern and northern parts of Tangra Yumco, based on the dating of modern surface sediments and aquatic plants. This study demonstrates the complexity of the reservoir effect in a closed lake on the Tibetan Plateau, and careful consideration must be paid to the use of different approaches to date different materials in order to establish a reliable chronology.

1. Introduction

Lakes are one of the most important archives for studying past environmental changes, especially in areas where other archives, such as glaciers (ice cores) or trees, are scarce. The Tibetan Plateau (TP), also called “The Third Pole”, is characterized by (semi)-arid climatic conditions with high evaporation rates. However, a large number of closed lakes are widely distributed on the TP. For paleoenvironmental studies using lake sediments, chronology is the most basic and crucial issue. Concerning the temporal coverage of most Tibetan lake sediment records, radio-isotopic analysis (^{210}Pb, ^{137}Cs) for the very young (<150 years) and AMS ^{14}C dating for the past max. 50 ka cal BP are the most valuable and commonly used methods to determine the ages of the deposits. Recently, optical dating has been used more frequently on lake sediments, especially for lake level terraces.

Carbon reservoir effects (R) are common in lacustrine environments all over the world and have also been reported on the TP (e.g., Wu et al., 2010;Hou et al., 2012; Mischke et al., 2013). Different approaches have been used to determine the R and overcome this hurdle in establishing reliable and robust chronologies in

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individual lakes. However, a uniform and effective method has not yet been established. For Lake Nam Co, Zhu et al. (2008) calculated an R between 2476 and 1230 a using modern sediment accumulation rates determined via ^{210}Pb and ^{137}Cs analyses. In Lake Qinghai, Hou et al. (2010) measured ^{14}C ages of lignin phenols and determined an R between 700 and 1600 a in a sediment core. OSL dating was used to evaluate the R in Qingtu Lake in arid northern China and yielded a generally very small reservoir effect (Long et al., 2011). Watanabe et al. (2010) used plant residues separated from lake sediment as dating material and retrieved an R of ~2300 a in Pumoyum Co. Recently, radiocarbon-based chronologies for the late Holocene (max. 4000 cal BP) have been produced using paleomagnetic secular variation data from lake sediments (Kasper et al., 2012; Ahlborn et al., 2015a; Haberzettl et al., 2015).

OSL and cosmogenic nuclide (^{10}Be and ^{26}Al) dating of lake level terraces have been conducted in the basin of Lake Tangra Yumco, and the results indicate high lake levels occurred during different stages in this area (e.g., Kong et al., 2011; Long et al., 2012; Rades et al., 2013, 2015). An investigations of a remnant lake on a former lake level terrace of Tangra Yumco, ~160 m above the present level, revealed environmental and hydrological changes during the Holocene (Miehe et al., 2014). That study addressed a potential carbon reservoir effect by rejecting carbonate lake marl samples from their chronology, instead using bulk organic samples from peat sections in the core. Long et al. (2015) tested post-IR IRSL (pIRIR) signals from polymineral grains from Tangra Yumco to validate a possible hard water effect in ^{14}C ages from bulk organic matter and showed a 2 ka age difference between the two approaches. This difference agreed with radiocarbon ages obtained from an aquatic plant and the sediment–water-interfaces of two sediment cores from the northern part of Tangra Yumco, which were used for reservoir corrections of sediment records covering the past 3 ka. Magnetostratigraphic analyses confirmed this approach for the northern basin (Haberzettl et al., 2015). However, a reliable ^{14}C chronology sequence from lake sediments and a continuous paleoenvironmental record from Tangra Yumco covering more than the past 3 ka are still lacking.

For lacustrine records, multiple dating approaches have been shown to be best suited for establishing robust chronologies (e.g., Hall and Henderson, 2001; Shanahan et al., 2013; Haberzettl et al., 2015; Long et al., 2015). In this paper, we present new results from Tangra Yumco concerning (1) modern sedimentation rates based on ^{210}Pb measurements and (2) AMS ^{14}C chronologies of two sediment cores retrieved from the northern and southern parts of this lake. Furthermore, (3) we determine the Rs by comparing ^{14}C ages of plant residues and bulk sediments from surface sediments and sediment cores, and (4) we evaluate the variability in the ^{14}C ages determined from plant residues in different sediment cores.

2. Materials and methods

2.1. Regional setting

Tangra Yumco is located on the northern flank of the central section of the Gangdise mountain range (central Transhimalaya), within a north–south trending graben that consists of three subbasins (Xu et al., 2006; Cao et al., 2009). Quaternary deposits, which are widely distributed on the lake shore, are mostly of alluvial and lacustrine origin. Magmatic rocks, e.g., 'Rapakivi' granite, are exposed on both sides of the lake as well but cover only small areas (Chen et al., 2006).

Lake Tangra Yumco is located at an altitude of 4550 m a.s.l. at 86°23′–86°49′ E and 30°45′–31°22′ N and has a maximum N–S extent of 72 km and a maximum W–E extent of 19 km. The lake itself is shaped as an "eight"; it is divided into two parts by a bottle-neck-like structure only 3 km in width (Fig. 1). The southern part has a maximum water depth of 110 m and is characterized by rather gentle slopes (Fig. 1). The northern part is deeper, with a maximum depth of 230 m, making Tangra Yumco the deepest lake on the TP (Wang et al., 2010). The connection between these two parts possesses water depths of up to 130 m with steep slopes typical of a graben structure (Akita et al., 2015). The total lake area of Tangra Yumco has been relatively stable since 1972, with a minimum of 831.2 km^2 in 1989 (Landsat 5 TM, Jan. 24, 1989) and a maximum of 846.5 km^2 in 2013 (Landsat 8 OLI, Nov. 18, 2013). However, there has been a continuous increase in lake area since 1989. Based on the bathymetric data, the water volume of Tangra Yumco is estimated to be 708.9×10^8 m^3; thus, the present mean depth of this lake is 83.7 m.

The lake's water is characterized as brackish and alkaline, with a conductivity of 12,200 μS cm^{-1} and a pH of 10.2 in June, 2012. In late summer (September 2009), during the thermal stratification period, a thermocline appeared between 24 and 40 m water depth. During this phase, the water body had a minimum temperature of 1.6 °C in the hypolimnion (Wang et al., 2010).

The recent water balance of Tangra Yumco is mainly driven by precipitation and surface runoff delivered to the lake by more than 10 intermittent tributaries that are only active during the summer. Two large perennial rivers in the northwest and southeast of the southern part also provide water to Tangra Yumco (Fig. 1). The remaining inflows are small, short, and intermittent streams.

2.2. Sampling

Four sediment cores were retrieved from the northern and southern parts of Tangra Yumco (Fig. 1). Two cores, DCG09-1 (length: 60 cm; water depth: 80 m) and TAN10-5 (length: 140 cm, water depth: 180 m) were recovered from the northern part, using a modified ETH-gravity corer (Kelts et al., 1986). From the southern lake part, the cores DCG10-2 (length: 77 cm, water depth: 80 m) and DCLC10-1 (length: 260 cm, water depth: 80 m) were retrieved close to each other using a gravity and a piston corer, respectively (Fig. 1). Surface sediments were collected using a Van Veen grab sampler in different areas of the lake. The upper portions (<2 cm section) of all samples were used in further analyses. All the samples were collected during two field campaigns in September of 2009 and 2010. Gravity cores DCG09-1 and DCG10-2 were sliced at 0.5 cm intervals for the upper 20 cm during the field work for ^{210}Pb and ^{137}Cs measurements. The other cores were closed tightly with flower foam and tapes for safe transportation to the laboratory in Lhasa; there, they were sliced at 1 cm intervals.

2.3. Laboratory analysis

The ^{210}Pb and ^{137}Cs activities of the uppermost core sediments were measured by a well-type high-purity germanium gamma spectrometer (ORTEC GWL-120-15) at an interval of 0.5 cm. Samples were placed into a cylindrical centrifugal tube and sealed with Parafilm® for at least three weeks to allow radioactive equilibration prior to the measurement (Appleby, 2001). Each sample was measured for 22.2 h (i.e., 80,000 s) and excess ^{210}Pb activity (^{210}Pb$_{ex}$, unsupported ^{210}Pb) was calculated from total ^{210}Pb minus the ^{226}Ra activity.

The samples selected for AMS ^{14}C dating (2-cm-thick samples) were wet-sieved through 63 and 125 μm meshes. The fraction >125 μm was treated with 1.2 mol l^{-1} HCl and NaOH to remove carbonates and humic acid matter (AAA treatment). The remaining material was regarded as the plant residue concentration (PRC) of the sediments. The fraction <63 μm was treated with 1.2 mol l^{-1} HCl to remove carbonates. The remaining carbon content was then regarded as the total organic carbon (TOC) fraction of the sediment. The treated samples were combusted and purified to obtain CO_2 and

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