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Biogeochemical processes and response to climate change recorded in the isotopes of lacustrine organic matter, southeastern Qinghai-Tibetan Plateau, China

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A B S T R A C T

Large amount of labile organic matter sequestered in Qinghai–Tibetan Plateau (QTP), the highest plateau in the world. However, large uncertainties remained in the response of biogeochemical cycling to climate change due to the lack of spatial and temporal resolution of climatic and ecosystem records in the plateau. Here, we present the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope records from Muge Co, a lake in the southeastern QTP, in order to investigate the response of biogeochemical processes to climate change. In this record, changes in $\delta^{13}C$ and $\delta^{15}N$ values were more likely to reflect the rate of organic matter decomposition in the catchment and within the lake, while early diagenesis, changes in organic matter sources and aquatic primary productivity may only play an insignificant role. The trend of the greenhouse gases efflux index (GGEI) based on the $\delta^{13}C$ and $\delta^{15}N$ records is similar to that of other archives which record the organic matter mineralization, and that of climate change records from the eastern QTP and the adjacent regions, with higher GGEI values indicating a higher degree of decomposition of organic matter is associated with a warmer and wetter climate, and vice versa.

1. Introduction

The Qinghai–Tibetan Plateau (QTP), with a total area of more than 2.5 million km^2 and an average altitude above 4000 m above sea level, is one of the most sensitive and fragile regions to global climate change (Rockstrom et al., 2009). Due to the prevailing low temperatures and low turnover rates, large amount of labile organic matter stocks in the high-cold alpine regions, including more than 33.5 Pg of carbon stored in the meadow and steppe soils of the plateau which accounts for about 2.5% of the global soil carbon pool (Dörfer et al. 2013; Wang et al., 2002). At present, the margin of the QTP is primarily controlled by the warm–humid Asian monsoon system in the summer and by the cold–dry Northern Hemispheric middle latitude westerlies in the winter, however, the interior of the QTP is less influenced by the Asian monsoon system and dominated by continental climate due to the block effect of the huge topographic landform (Yao et al., 2012). The mean temperature has increased by 0.2 °C per decade on the QTP during the past five decades and is predicted to rise an additional 2.6–5.2 °C by the end of this century, similar to other high elevation and high latitude areas and much greater than the world as a whole (Chen et al., 2013; Liu and Chen, 2000). Elevated temperatures would largely affect the biogeochemical processes in these plateau ecosystems, such as decomposition of soil organic matter and fluxes of greenhouse gases, assuming no changes in other components of climate such as rainfall (Chen et al., 2014; Davidson and Janssens, 2006; Fang et al., 2005). Great efforts have been made to investigate the response of greenhouse gas fluxes to climate warming from different ecosystem on the QTP, based on seasonal field observations or controlled warming experiment (Chen et al., 2010a; Du et al., 2008; Hu et al., 2010; Li et al., 2015; Qin et al., 2015; Saito et al., 2009; Yang et al., 2014; Zhao et al., 2006; Zheng et al., 2012), and the QTP will become an increasing source of CO_2, CH_4 and N_2O (Chen et al., 2013). Large uncertainties remained, however, due to the lack of spatial and temporal resolution of climatic and ecosystem parameters describing the heterogeneous landscape and vegetation communities of the plateau. Gaining a deeper understanding of the long-term biogeochemical processes on the QTP in response to climate change is therefore essential.

The sediments of high-elevation alpine lakes are well-suited to studies of environmental changes because of the sensitivity of these lakes to climate change and the fact that they are relatively undisturbed by human activity (Catalan et al., 2013). Lacustrine organic matter serves as a useful archive of lake internal processes and external terrestrial influx entering the lake (Leng and Marshall, 2004). The variations in carbon and nitrogen cycling in lakes and their catchments associated with climate change can be reflected by stable carbon ($\delta^{13}C$) and nitrogen isotope ($\delta^{15}N$) data obtained from lake sediments (Meyers, 1997; Talbot, 2001; Wolfe et al., 1999). In the present study, we present the

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stratigraphic variations in the elemental and stable isotopic signatures of C and N in the sediments of Muge Co, southeastern QTP, in order to investigate the response of the plateau's biogeochemical cycles to climate change in the monsoonal area.

2. Study site

Muge Co (30°08′ N, 101°50′ E, Fig. 1a) is located at a NW–SE oriented mountain valley, 3780 m above sea level in the Gongga Mountains, which are part of the larger Hengduan Range in the southwestern China. During the field investigation in 2011, hydrochemical parameters were measured from a single sample. The open freshwater lake (specific conductivity of 121 μS/cm) has a surface area of about 3.0 km^2, a catchment area of 75 km^2 and a maximum water depth of 31.4 m. The lake has a pH of 8.4 and is classified as oligotrophic water body (total phosphorus concentration is 10 μg/L and total nitrogen concentration is 230 μg/L). Muge Co is fed by seasonal snow melt derived from the higher altitude areas of the lake catchment, and by precipitation. There is one outlet on the northeast side of the lake, which flows into the Yala River. The regional bedrock geology is mainly composed of granite. Muge Co is near the local tree line, the catchment vegetation is dominated by subalpine meadow on the western banks, with forest across the upper areas of the catchment rich in *Pinus*, *Picea*, *Abies*, *Cyclobalanopsis* and *Taxoidiaceae*, *Betula*, *Rhododendron*, *Salix*, *Ribes* and *Sorbus* are also common in the catchment, along with a range of herbaceous taxa including *Artemisia*.

The study area is mainly influenced by the Asian monsoon system (Wang et al., 2003). During summer it transports warm and moist air masses to the QTP leading to a comparatively warm and humid climate. In winter, dry and cold continental air masses prevail in the study area, driven by the anticyclone over Siberia and Mongolia. Mean annual temperature is 7.2 °C and mean July temperature is 15.6 °C, the mean annual precipitation is ~830 mm, and most (77%) of the annual rainfall occurs during the rainy season between May and September (measured at the nearest meteorological station Kangding Station, 30°1′48″N, 101°34′48″E, at 2615 m above sea level). Based on the observed temperature gradient of 0.5 °C decrease per 100 m increase in altitude, the mean annual and July temperatures at Muge Co are about 1.4 °C and 9.8 °C, respectively (Sun et al., 2015).

3. Material and methods

3.1. Coring, sampling and sediment dating

A 383 cm long sediment core (MG1) from the deepest part (about 30-m depth) of Muge Co was collected in 2011 using a Kullenberg Uwitech Coring Platform System (Fig. 1b). In addition, 20 samples of common terrestrial plant species around Muge Co were also collected. The core sections were split, photographed, and described in the laboratory, and continuously subsampled at 1-cm intervals for laboratory analysis, except the interval between 331 and 323 cm, which may be disturbed by sediment slipped down before the section was drilled (Sun et al., 2015). The core chronology is based on ^{137}Cs dating of the surface sediments at 0.5-cm intervals and 8 accelerator mass spectrometry (AMS) ^{14}C radiocarbon dating, including 7 bulk sediment samples and one sample of concentrated pollen (Sun et al., 2015). ^{137}Cs dating was conducted using the EG and G Ortec well-type, coaxial, low background, intrinsic germanium detectors (HPGe GWL-120-15) at the State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences. The bulk sediment samples were dated by Beta Analytic Inc., Miami, USA, and the pollen sample was dated at the Oxford Radiocarbon Accelerator Unit. All of the 8 AMS ^{14}C dates obtained were calibrated to calendar years before present (0 BP = 1950 AD) using the IntCal13 calibration dataset (Reimer et al., 2013). The relationship between age and depth is interpolated by Bayesian model utilizing the Bacon program with default settings for lake sediments (Blaauw and Andres Christen, 2011; R Development Core Team, 2013) (Fig. 2). The basal age of the core is ~12 cal ka BP and the average sedimentation rate is about 33 cm ka^{-1}.

3.2. Analytical methods

Samples of modern terrestrial plants were washed with distilled water and freeze-dried. Samples of the sediment were obtained every 2-cm for total organic carbon (TOC), total nitrogen (TN) content, and stable isotopic analysis of the bulk organic matter. Sample aliquots were treated with 5% HCl to remove possible trace amounts of carbonates and oven-dried at 40 °C. The dried samples were then crushed in an agate mortar to homogenize them and reduce the grain size. The TOC and TN contents were determined using an elemental analyzer

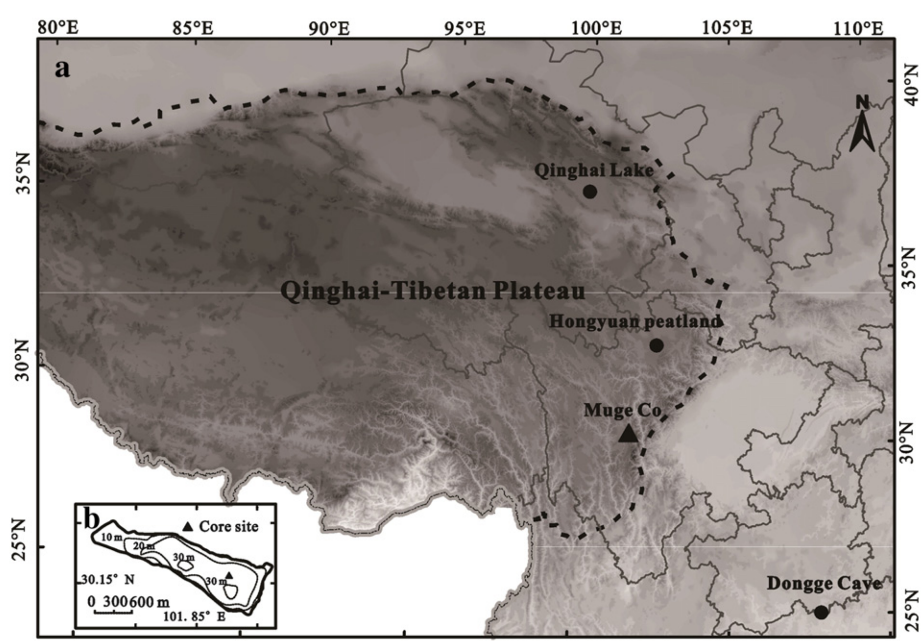

Fig. 1. (a) Location of the study site and paleoclimatic sites referenced in Fig. 6. Triangle indicates the location of Muge Co, and the circles indicate the location of Dongge Cave (Dykoski et al., 2005), Hongyuan peatland (Yu et al., 2006), and Qinghai Lake (Ji et al., 2005). (b) Bathymetric chart of Muge Co with coring site indicated by the triangle.