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Response of Long Lake sediments to Antarctic climate: A perspective gained from sedimentary organic geochemistry and particle size analysis

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A B S T R A C T

Sediments from the pristine lakes of ice-free regions of Antarctica are a great source for proxies to reconstruct the effect of past-climate on the lake evolution and its response to Antarctic climate. A 50 cm long sediment core retrieved from Long Lake, a periglacial lake of Schirmacher Oasis in Dronning Maud Land was measured for elemental (C%, N% and C/N), isotopic ($\delta^{13}C$, $\delta^{15}N$) and particle size (sand-silt-clay percent) variation. The radiocarbon dated core spanning the last 48 cal ka BP has been deciphered for the lake's response to Antarctic climate. The C/N ratio (atomic ratio) predominantly indicates that the productivity has been autochthonous for majority of the down-core while the top 0–3 cm indicates that there has been addition of terrestrial organic matter into the lake system owing to longer ice-free conditions. The organic carbon shows significantly lower values (0.2%) throughout the glacial period and major part of the Holocene while the core-top values are consistent with the presence of a microbial mat which is reflected as higher organic carbon (12%). The $\delta^{13}C$ and $\delta^{15}N$ range from −33 to −9‰ and 2 −18‰, respectively. The isotopic signals vary marginally for the entire glacial period (48–8 cal ka BP) suggesting an intense cold period. The gradual increase in C/N ratio, sand content and $\delta^{13}C$ and decrease in $\delta^{15}N$ beginning at about 6 cal ka BP suggest that the Long Lake experienced longer ice-free conditions owing to sustained warmer Holocene conditions suggesting that the ice-cover over the Long Lake persisted well through early-Holocene. The sand and silt percent shows inverse correlation likely reflecting the warmer and colder conditions. The Holocene is characterised by higher sand content owing to melting of ice due to warmer conditions. The Long Lake's response to Antarctic climate is reflected in its response to the ice-cover conditions which regulates the productivity and sedimentation in the lake system.

1. Introduction

Past-climate reconstruction in Antarctica has been a forte of ice-cores and marine sediments. However, in the recent decades, paleoclimate reconstruction using lake sediments has gained much importance due to its easy accessibility in the lakes of the ice-free regions of Antarctica and also owing to its pristine conditions. These ice-free regions (e.g., McMurdo Dry Valleys, Larsemann Hills, Schirmacher Oasis etc.), which occupies about two percent of Antarctic land mass are marked with numerous lakes and hence act as a source for paleo-archives. The lakes are well established as “sentinels of change” (Williamson et al., 2009) as they are sensitive and respond rapidly to changes in climate and integrating these information in their sediments (Adrian et al., 2009). Various techniques have been successfully used to decipher the past-climatic history from lake sediments, for example, organic geochemistry

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(Smith et al., 2006; Hodgson et al., 2009a,b; Verleyen et al., 2011), particle-size (Kashiwaya et al., 2001; Holz et al., 2007; Fagel et al., 2007) and environmental magnetism (Shen et al., 2008; Phartiyal, 2014; Warrier et al., 2014).

The source and accumulation of organic matter in sediments can be identified by studying the abundance and isotopic composition of carbon and nitrogen. The type and amount of sedimentary organic matter can be used to reflect the past fluctuations in lake's productivity and terrestrial inputs which are influenced by climate-induced environmental changes (Talbot and Johannessen, 1992; Meyers, 1997; Leng and Marshall, 2004). Elemental analysis (e.g., carbon, nitrogen, phosphorus) and stable isotope geochemistry ($\delta^{13}C$ and $\delta^{15}N$) are the primary archives that can be extracted from lake sedimentary organic matter. These proxies are indicators of the provenance of organic matter, the type and amount of organic matter that has been deposited in the lake over a period of time (Talbot and Johannessen, 1992; Meyers, 1997; Leng and Marshall, 2004). The C/N ratios of organic matter is also a widely used indicator of the provenance of organic matter (Talbot, 2001; Meyers, 2003). Past-changes in the lacustrine systems due to change in climate can be deciphered from the $\delta^{13}C$ and $\delta^{15}N$ of bulk sedimentary organic matter (e.g., Talbot and Johannessen, 1992; Engel and Macko, 1993). The particle size in lake sediments are principally controlled by hydraulic conditions (Sly, 1978; Håkanson and Jansson, 1983). The down-core variations in particle size reflect general trends of warming versus cooling per se in Antarctic lake sediments. Large amount of coarser particles generally indicate warmer period while higher content of fine particles indicate cooler period (Wang et al., 2001; Chen et al., 2004; Yanhong et al., 2006; Xiao et al., 2009).

Even though applications of lake sediments to past-climate is highly significant, studies on Antarctic lakes are rare. Majority of paleoclimate data generated from the ice-free regions of Antarctica are from Ross Sea region, Wilkes Land, Princes Elizabeth Land and Mac Robertson Land (e.g., Adamson and Colhoun, 1992; Cremer et al., 2003; Hodgson et al., 2006; Verleyen et al., 2011) and significant studies have been carried out in the Soya Kaigan of East Antarctica (eg., Matsumoto et al., 2010, 2013, 2014; Takano et al., 2012; Takano et al., 2015). Past-climate records for East Antarctica i.e., Schirmacher Oasis are few (Krause et al., 1997; Bera, 2004; Singh and Tiwari, 2004; Matsumoto et al., 2006; Warrier et al., 2014).

In this study, we have used multi-proxy data (e.g., C_{org}, N%, $\delta^{13}C$, $\delta^{15}N$, C/N and particle size measurements) from a sediment core of Long Lake of Schirmacher Oasis with an aim to reconstruct the past-climate variations in the Schirmacher Oasis.

2. Site description

Schirmacher Oasis is an ice-free area covering about 35 km^2, located in East Antarctica on the Princess Astrid Coast of Dronning Maud Land (Fig. 1). The oasis is about 20 km in its length and 3 km at its maximum width. Located 100 m above mean sea level, it is situated between the edge of the continental ice sheet and the Novolazarevskaya Nivl Ice Shelf. The oasis is a recent periglacial region that is unaffected by anthropogenic activity (Krause et al., 1997). Schirmacher Oasis consists of a number of low-lying hills and has 118 lakes (Ravindra et al., 2004) which can be differentiated as periglacial, proglacial and epishelf lakes. The size of the lakes vary from few hectares to a few km^2 and its maximum depth varies from a couple of meters to a few meters. All major lakes of oasis are localized along the glacial valleys (Ravindra et al., 2004). The lakes in the oases are generally under ice-cover only during winter and receive significant precipitation (Walton, 1984). The region is marked with debris cover, valley systems which are dotted with lakes which are either in glacially eroded bedrock or dammed by moraines or ice (Bormann and Fritzsche, 1995).

The general climate in Schirmacher Oasis is milder as compared to the Antarctic climate. The air temperatures range from −7.7 to +8.2 °C during mid-summer (December–January) resulting in abundant melt-water. January is the warmest month (monthly mean air temperature of 0.7 °C, maximum +8.2 °C) while August is the coldest (monthly mean air temperature of −16.3 °C, minimum −35.5 °C) with an average wind velocity of about 9.7 m/s and 264.5 mm in annual precipitation usually in the form of snow (Lal, 2006). Lichens and mosses grow on the rocky soils of Schirmacher Oasis (Verlecar et al., 1996; Lal, 2004; Rai et al., 2011). Dominant faunal group such as protozoans, nematode tuatis, turbillaria are very few which results in low organic carbon content in sediment ranging from 0.05 to 1.8%.

The Long Lake, located in Schirmacher Oasis (see Fig. 1) is a landlocked lake or a periglacial lake, primarily fed by glacier melt-water during the austral summer (Heywood, 1972). This is located towards the western side of the Priyadarshini Lake or Zub Lake. The structure of this lake is elongated and hence the name Long Lake which has a water depth of about 5 m. The periglacial lakes in the Schirmacher Oasis are ice-covered during the austral winter for a period of around eight months and become ice-free during the austral summer for a period of 3–5 months (Ravindra and Chaturvedi, 2011).

3. Materials and methods

A 50 cm long sediment core was retrieved from Long Lake from a water depth of 7 m during the 28th Indian Scientific Expedition to Antarctica. This core was raised using percussion method of coring and stored under −20 °C. The core was sub-sampled at 1 cm interval. Each 1 cm slice was labelled appropriately and stored in heavy, transparent, non-toxic, sterilized HDPE (High Density Polyethylene) whirl pack.

3.1. Radiocarbon dates

Six samples at different depths (see Table 1) were selected for radiocarbon dating. Bulk sedimentary organic matter were used for the measurement of radiocarbon dates. The AMS-^{14}C ages for the core was measured at the National Science Foundation-Accelerator Mass Spectrometer facility, University of Arizona, USA. The ^{14}C dates were converted to calendar ages by using CLAM 6 (Blaauw, 2010) program along with the age-depth model. Though a reservoir age of approximately 1000 years was reported (Schwab, 1998), due to considerable variability between lakes this was not used. We have subtracted the core-top age to account for local reservoir effect from the measured ages before calibration.

3.2. Elemental and isotope measurements

We measured bulk organic carbon (%C_{org}) and carbon isotope ($\delta^{13}C$) for both untreated and treated (with 2N HCl) samples while nitrogen ($\delta^{15}N$) isotope analysis was carried out for untreated samples. The sample aliquots were treated with excess 2N HCl acid to remove carbonate. After 24 h, the samples were rinsed in distilled water five times and dried in an oven at 40 °C. The dried samples were crushed, finely ground and homogenized using a planetary ball mill. We followed the standard procedure of rinse method (e.g., Ostle et al., 1999; Schubert and Nielsen, 2000; Galy et al., 2007) for preparing samples materials for C_{org}%, N%, $\delta^{13}C$ and $\delta^{15}N$ analysis, which involved weighing an acid-treated sample aliquot (90–95 mg) into a tin capsule. The analysis of elemental concentrations and isotopic ratios was carried out at the Marine Stable Isotope Lab (MASTIL) of National Centre for Antarctic and Ocean Research, Goa, India using an Isoprime Stable Isotope Ratio Mass