Polar Science 10 (2016) 89–100

Contents lists available at ScienceDirect

Polar Science

journal homepage: http://ees.elsevier.com/polar/

Sediment grain size and surface textural observations of quartz grains in late quaternary lacustrine sediments from Schirmacher Oasis, East Antarctica: Paleoenvironmental significance

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A R T I C L E I N F O

Article history:
Received 16 April 2015
Received in revised form
1 December 2015
Accepted 25 December 2015
Available online 30 December 2015

Keywords:
Quartz
Surface texture
Aeolian
Weathering
Climate
Schirmacher oasis
East Antarctica

A B S T R A C T

In this study we report the sediment grain size parameters and surface textural observations (using scanning electron microscopy (SEM)) of quartz grains from sediments of Sandy Lake, Schirmacher Oasis, East Antarctica. The sediment core spans the last 43 cal ka B.P. The statistical parameters of grain size data (sorting, skewness, kurtosis, mean grain size, D_{10}, D_{50}, D_{90} and SPAN index) indicate that the sediments are primarily transported by melt-water streams and glaciers. However, during the last glacial period, sediments seem to be transported due to wind activity as evident by the good correlation between rounded quartz data and dust flux data from EPICA ice-core data. The mean grain size values are low during the last glacial period indicating colder climatic conditions and the values increase after the last glacial maximum suggesting an increase in the energy of the transporting medium, i.e., melt-water streams. The sediments are poorly sorted and finely skewed and show different modes of grain size distribution throughout the last 43 cal ka B.P. SEM studies of selected quartz grains and analyses of various surface textures indicate that glacigenic conditions must have prevailed at the time of their transport. Semi-quantitative analyses of mineral (quartz, feldspar, mica, garnet and rock fragments & other minerals) counts suggest a mixed population of minerals with quartz being the dominant mineral. Higher concentration of quartz grains over other minerals indicates that the sediments are compositionally mature. The study reveals the different types of physical weathering, erosive signatures, and chemical precipitation most of them characteristic of glacial environment which affected these quartz grains before final deposition as lake sediments. The palaeoclimatic signals obtained from this study show similarities with ice-core and lake sediment records from Schirmacher Oasis and other ice-free regions in East Antarctica.

1. Introduction

Sediments deposited in the lakes and oceans surrounding Antarctica offer tremendous potential to understand the different sedimentary processes under harsh climatic conditions (Damiani et al., 2006; Mahesh et al., 2015). These sediments are made up of organic and inorganic materials which can be classified as *allogenic*, *endogenic* and *authigenic*. This classification is made purely on their mode of genesis (Engstrom and Wright, 1984). *Allogenic* (also known as detrital) minerals are brought into the lake basin with the help of surface streams, shoreline erosion, mass movement, wind activity, sheet flood etc. Minerals that originate within the lake water column due to inorganic or biological processes are termed as *endogenic* and those formed due to diagenetic alteration are known as *authigenic*. Detrital mineral grains give a true reflection of the interaction between different geological processes such as tectonic framework of the depositional basin, provenance of sediments, type and intensity of weathering processes in the catchment, and/or transportation processes responsible for the delivery of sediments into the lake (Last, 2001). These detrital grains can therefore be used to infer past changes in drainage basin size and morphology (Henderson and Last, 1998; Olsen, 1990) and fluctuations in the climatic regime within the catchment (Schütt,

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http://dx.doi.org/10.1016/j.polar.2015.12.005
1873-9652/

1998; Dean, 1997; Menking, 1997). In the Polar Regions, quartz, feldspars, mica, garnet etc. are few important examples of detrital minerals that have been widely used for paleoclimate reconstruction, as they are products of physical weathering processes (Pistolato et al., 2006; Chamley, 1989). According to the Bowen's reaction series, the mineral quartz (SiO_2) crystallizes at the end at lower temperature and is the most stable and commonly found rock mineral on the earth's surface. It has a lower tendency to weather compared to other minerals and therefore has high preservation potential in lake/marine sediments (Krinsley and Doornkamp, 1973; Mahaney, 1995b, 2002). It provides an ideal substrate for micro-textural study because of its durability, hardness and lack of cleavage. Surface micro features, angularity, chemical features, and grain-size analysis of quartz grains, collectively reveal the sedimentary and physicochemical processes that acted on the grains during different stages of their geological history. Quartz grains in lake sediments can have different sources i.e., locally derived quartz grains due to mechanical and chemical weathering of catchment rocks, aeolian quartz, that has been transported by wind and dropped within the lake catchment or onto the lake, and biogenic silica which comprises the remains of siliceous organisms such as diatoms (Stanley and DeDeckker, 2002). Several studies have underlined the importance of scanning electron microscopic (SEM) observations of sand-sized quartz grains. The results from these studies have established that sediments affected by different geological processes, transport and deposition display distinct grain surface features and micro textural characteristics (Helland and Holmes, 1997; Mahaney, 1995a, b; Strand et al., 2003).

In this study, we present the results of a preliminary investigation of sedimentary grain size studies and morphological features of quartz grains and semi-quantitative analysis of minerals deposited in the sediments of Sandy Lake, Schirmacher Oasis (SO), East Antarctica, with an aim to evaluate the modes of transport, weathering characteristics, maturity of sediments and effect of regional climate on these sediments.

2. Study area

Schirmacher Oasis (SO) is a 35 km^2 ice-free area and is located in the Queen Maud Land, East Antarctica (Fig. 1a). It lies between the margins of the ice-shelf and the continental ice sheet (Fig. 1a). It is made up of several hills of low elevation (~200 m; Srivastava and Khare, 2009). There are about 120 lakes and depending on their geomorphic evolution are classified as epishelf, proglacial and landlocked (Ravindra, 2001). Sandy Lake ($70^0$45′45.9″S; $11^0$47′34.7″E) is one of the small, land-locked lake (Fig. 1a) situated ~2.5 km in the east-north-east direction from the Indian Research Station – *Maitri*. Rocks in the Schirmacher Oasis are predominantly gneissic with the felsic variety making up > 85% of the exposed bed rocks (Rao, 2000). Pyroxene granulites, enderbites, calc-granulites and khondalites are the other rock types found in SO (Bose and Sengupta, 2003).

The weather conditions in SO are harsh with a dry climate and extremely low temperatures and strong winds. The summer season lasts from November to February. During this period, the maximum and minimum temperature varies from 0.4 to −2.6 °C and from −2.7 to −8.8 °C, respectively. During winter (March to October), the maximum temperature dips between −4.5 and −12.9 °C and the minimum temperature varies from −10.4 to −20.9 °C (Lal, 2006). The annual average wind speed is 17.5 knots and they blow mainly from the southeast direction (Lal, 2006). Precipitation is scanty and is frequently received between April and September in the form of snowfall.

3. Materials and methodology

3.1. Sampling

A 68-cm long sediment core was raised during the 28th Indian Scientific Expedition to Antarctica. The core was retrieved by manually hammering an acrylic pipe into the lake bed from its periphery when it was ice-free. The sediment core was neatly labelled, packed and stored in a deep-freeze at −18 °C. The core was transported to the laboratory and sub-sampled at 1 cm interval to obtain high resolution paleoenvironmental data. The sub-samples were packed in labelled polythene covers, stored in a deep-freeze and used for laboratory studies.

3.2. Geochronology

The chronology of the Sandy Lake sediments was established using accelerated mass spectrometry (AMS) ^{14}C dates obtained on the bulk organic matter in the sediments. The dates were calibrated using CALIB 6.0 (Stuiver and Reimer, 1993) software. The age-depth model obtained suggests a mean sedimentation rate of 0.015 mm/year with a low of 0.013 mm/year during marine isotopic stage (MIS) 3 and a high of 0.019 mm/year during MIS 2. The youngest age of the sediment core is 1116 cal. years B.P. (0–2 cm depth) and the oldest age is 42,357 cal. years B.P. Further details of AMS ^{14}C dating, calibration and age-depth model are given by Warrier et al. (2014).

3.3. Petrographic studies

Thirty five samples from the sediment core were selected for this study. Approximately 2 g of the sediment samples were oven-dried at 50 °C and treated with 10 ml of 30% H_2O_2 to eliminate the organic matter. The samples were thoroughly rinsed with deionised water and were oven-dried. Ten ml of sodium hexametaphosphate (calgon) solution was added to every sample to separate the clay coatings and fine-grained particles adhered to quartz grains (Lewis and Armstrong, 1994; Helland and Holmes, 1997). The samples solutions were then wet-sieved using 125 μ sieve. The >125 μ fraction was transferred to a pre-weighed beaker and oven-dried. Representative samples were prepared by sub-sampling the >125 μ fractions with the help of a Rifle sample divider (McManus, 1988). Each sample was split five times into representative portions until a sample of desired quantity was obtained. The individual grains from these split samples were observed and counted under a stereo zoom magnifying microscope (Nikon SMZ-1500). Detrital minerals like quartz, feldspar, micas, garnet, rock fragments (RF) and other minerals were observed and counted.

3.4. Sediment grain size analysis

Sediment samples were pre-treated with hydrogen peroxide and glacial acetic acid to eliminate organic matter and carbonate, respectively (Schumacher, 2002). The biogenic silica content in the sediments was quite negligible and hence no pre-treatment was carried out to eliminate the effect of the same. Ten ml of calgon (sodium hexametaphosphate) solution was added to the sample. The sand fraction was separated using a 63 μ sieve. The >63 μ fraction was transferred to a pre-weighed beaker and oven-dried. The silt + clay fractions were later analysed with a Beckman-Coulter LS-13320 (0.04–2000 mm). The data output was processed using the Gradistat software for sediment parameters (Blott and Pye, 2001). Apart from the basic statistical parameters (Folk and Ward, 1957) such as mean grain size, sorting, skewness and kurtosis, the 10th (D_{10}), 50th (D_{50}) and 90th (D_{90}) percentile particle size data was also extracted. The parameter SPAN (a