Twenty Sixth Indian Antarctic Expedition 2006-2008
Ministry of Earth Sciences, Technical Publication No. 24, pp 289-303

Limnological Investigation of Antarctic Lakes and their Paleoclimatic Implications

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ABSTRACT

A short 78 cm sediment core (L2) from a fresh water lake in Larsemann Hills, East Antarctica was obtained during 26th Indian Scientific Expedition to Antarctica in austral summer (January to March, 2007). The sediment core samples was analyzed for grain size distribution and biological productivity indicator such as Total Organic Carbon (TOC) and Biogenic Silica (BSi %). The sediment core represented the time period of ~8.3 cal ka BP. The values of BSi from the core showed prominent high productivity from ~8.3 to ~6 cal ka BP in comparison to less productivity in mid-late Holocene (~6 cal ka BP to recent). Moreover, high sand (%) infers the glacio-fluvial deposition from ~8.3 to ~5 cal ka BP. TOC showed little variation throughout the core, except in the upper ~ 10 cm (~4 cal ka BP) part wherein it was comparatively high. The increased TOC in the upper part of the core possibly indicates presence of algal mat due to exposure of the lake to the ice free (glacier free) conditions. Furthermore, grain size distribution showed major influence on the preservation of the TOC and BSi%. The increased TOC in the upper part of the core indicates good preservation of algal mat due to decrease in sand % and increase in silt %. The BSi% shows positive correlation with the higher % of sand during ~8.3 to ~5 cal ka BP and comparatively low values from ~ 5 cal ka to recent time which can be described with the high and low ratios of Al/SiO_2.

Keywords: Climate, Sediment Core, Freshwater lake, Holocene, Larsemann Hills.

INTRODUCTION

Antarctic continent along with its surrounding ocean influences the climate not just in the high latitudes but across the entire planet. The

Polar Regions are the first to be affected by changes in climate than other parts of the world both in terms of rapidity and intensity. Therefore this region is considered the best site in order to get the early signals of climate change. Antarctic lake sediments assume a pivotal role in paleoclimatic and global change investigation. The lakes of Antarctica are the major feature of the Antarctic landscapes. It is well known that the sediments and fauna contained therein are influenced by climatic changes to which the Antarctic lakes are subjected to. The cores retrieved from the lakes are used for sedimentological, geochemical and biological studies to decipher the climatic changes that have occurred in the immediate past in Antarctica.

In general, Antarctic lakes in the coastal areas are ice free for 3- 4 months in a year and are exposed to the sun which influences the biological productivity as characterized by the presence of diatom and moss. Ice cover greatly influences both the physical and biological processes occurring within the lakes. The extent of ice thickness of ice cover is an extremely important parameter in the biogeochemistry of Antarctic lakes (Wharton et al., 1993). To understand the biogeochemistry, productivity and environmental behavior of the Antarctic lakes and surrounding ocean, proxies such as Total Organic Carbon (TOC) and Biogenic Silica (BSi) have been used from both lake and oceanic sediments in the paleoclimatic studies (Yoon et al., 2006; Kaplan et al., 2002; Colman et al., 1995; Mortlock and Froelich, 1989). There are numerous factors which control the productivity which are linked to seasonal temperature variations in the Antarctic region due to the glacier retreat and exposure of the area to the sun (ice free) in summer and/or the ice sheet extension in winter (Hodgson et al., 2004).

The sediment core has been collected from the small lake (L2) of Larsemann Hills area to understand the environmental behavior and climatic variation within the Holocene based on BSi, Sand (%) and TOC parameters. This area was chosen because previous studies from Larsemann Hills area indicate that it was not heavily glaciated during the Last Glacial Maxima (LGM) (Burgess et al., 1994) and recent work by Hodgson et al., (2001) has also described that during LGM the valley on western side i.e. Stornes peninsula was filled withsoft snow and ice while the eastern side (Broknes peninsula) was not covered by the ice.

Previous Work

Core logging and grain size analyses of two sediment cores have been done by GSI from Schirmacher Oasis. Anna University and GSI have carried out a detailed geochemical investigation, grain size analysis and AMS dating of selected cores (L – 49 / 29 and L – 49 / 20 having 242 cm and 194 cm core length, respectively) (Achyuthan et al., 2008). Mineral magnetic observations by IIG along with other parameters with Anna University and GSI for two sediment cores (L – 49 & L – 26) have been reconstructed showing the paleoclimatic variation.

The sedimentological and radio carbon dates (AMS) pertaining to two sediment cores have been determined. The oldest radiocarbon date of organic carbon at 170 – 172 cm horizon of the core from lake L – 49 has been computed to be 32,655 yrs. BP. Based on the radiocarbon dates of organic carbon, the rate of sedimentation and algal growth have been postulated. The rate of sedimentation and algal matt growth have been very low varying from 0.005mm/year between 30,640 yr BP and 21,685 yr BP and 0.015mm/year between 32,655 yr BP and 30,640 yr BP (warm period);and was about 0.09 mm/yr between 29,920 and 28,890 yrs BP (wet period) (Achyuthan et al., 2008). It is noted that during the overall warm period between the Mid MIS 2 (25,000 yrs BP) and beginning of MIS 3 (28,000 onwards), there have been brief periods of warmer and wetter interludes. This inference is supported by the stable isotope data of $\delta^{13}C$ values which exhibit -5.8% differences between 30,000 yr BP and 21000 yr BP (Achyuthan et al., 2008). Furthermore, multiproxy biological data (pollen, diatom, other alga) generated from sediments although in low value, have been used for paleoclimatic interpretation over polar region (Bera, 2004a, b; Bera and Sinha, 2005; Bera, 2006; Bera et al., 2007; Phartiyal and Bera, 2007) by BSIP.

After analyzing and comparing temperature, pH, oxidation-reduction potential, TDS (total dissolved solids), conductivity and Salinity, of water samples over a period of six years data it has been demonstrated by Tiwari and Kulkarni (2005), that there is an increase in pH and decrease in the conductivity in the Zub (Priyadarshini Lake) lake. Lakes which are near the research stations (Maitri and Novo) have a threat of being polluted by anthropogenic activity throughout the year as per studies on 34 lakes in the eastern part which need more investigation. The present study pertains to the sediment core from Larsemann Hills.

OBJECTIVES

The main objectives of this study are to reconstruct paleoclimatic variation and to understand the biogeochemical behavior of the lake during late Quaternary period.

Materials and Methods

The L2 Lake (Lat: 69°24.427’ S and Long: 76°11.293’ E) is situated in Larsemann Hills area in East Antarctica at ~25m above mean sea level (Fig. 1). A core of 78 cm length was obtained by a sediment corer during the austral summer of 2006-2007. The full length core was further sub sampled at 2 cm interval in the field lab. The entire core was mainly composed of sand except the top 10 cm which contained sand, silt and algal mat.

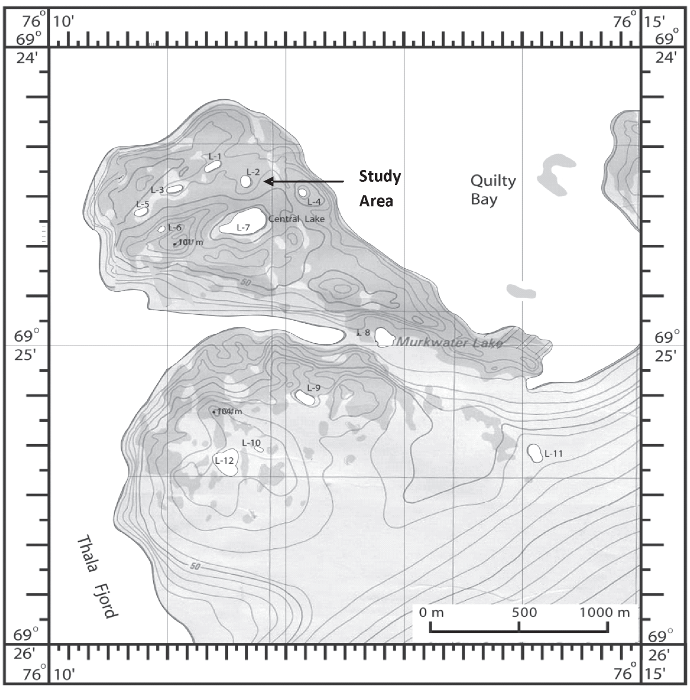

Fig. 1: Study area and location of sedimentary core from L2 lake in Larsemann Hills, East Antarctica. (Modified Base Map after the Australian Antarctic Division and Geological Survey of India)

The samples were oven dried at 50°C for geochemical analysis and powdered for TOC analysis. The powdered samples were treated with 2N HCL to remove the inorganic carbon. The Total Inorganic Carbon (TIC) analysis requires no pre-treatment of the powdered samples. Total Carbon (TC) and TIC were measured using the Shimadzu TOC-VCPN analyzer. The precision for IC/$CaCO_3$ is 0.5% and that for TOC is 0.1%. TC precision can be reported as 0.5%.

Grain size analysis was performed after taking sufficient amount of sample (1gm), which was further kept for oven drying. The dried sample was soaked in water for 24 hours. The water was decanted next day, then sodium hexametaphosphate was added and further kept overnight. The next day hydrogen peroxide was added and again kept overnight. Sieving was performed after 24 hours using a 63µm sieve in order to separate the coarser sand fraction from finer silt and clay. The sand (>63 µm) was collected in an empty beaker and weighed after drying. The residue (<63 µm) was collected in 1000 ml cylinder and stirred vigorously according to the method described by Krumbein and Pettijohn (1938). Accordingly the percentage of sand, silt and clay was calculated.

Biogenic silica was measured by wet alkaline extraction, modified from Mortlock and Froelich (1989) and Muller and Schneider (1993). Approximately 10 mg of powdered sediment was dissolved in 30 ml of 1N NaOH solution in a 50 ml polypropylene tube. The tubes were oven dried at 85°C for 5 hours. At every two hours interval, 0.1 ml solution was taken in a 10 ml vial tube containing 2 ml 0.1N HCL. Dissolved silica in diluted samples was measured using molybdate blue spectrophotometric method. In the processed samples, aluminum (Al) was determined by Thermo Solar M6 Atomic Absorption Spectrometer. Calibration standards were prepared through Merck (Germany) AAS Al standard, traceable to SRM from National Institute of Standards and Technology, USA. The RSD of the calibration standards (five different concentrations) varied from 0.5 to 3.1% where as the RSD of total 39 samples varied from 0.4 to 3.8 %. Total Al was used to correct the Si concentrations for contributions from clay mineral dissolution. Total Al was multiplied by 2 (the average molar ratio Si : Al in most clays; Eggimann et al., 1980) and then subtracted from the total measured Si. Duplicate measurements were conducted on each sample and relative error in sediment samples was noticed less than 1%.

Accelerator Mass Spectrometer (AMS) radiocarbon (^{14}C) ages of the organic carbon from 4 sediment samples were obtained from the University of Arizona, Physics Department, Tucson, AZ. The radiocarbon ages were calibrated to calendar years before present by using CALIB version 5.0 (Stuiver et al., 1998; McCormac et al., 2004). Means and uncertainties of the calendar ages were calculated from the upper and lower boundaries of the probability distribution at the 2σ level.

RESULT

The AMS radiocarbon dating shows that the total core represents 8.3 cal ka BP. The age-depth relationship (Fig. 2) shows that the sedimentary rate varied from minimum 3.36 cm/ka (modern Holocene) to maximum 26.92 cm/ka (early to mid Holocene) in the study area.

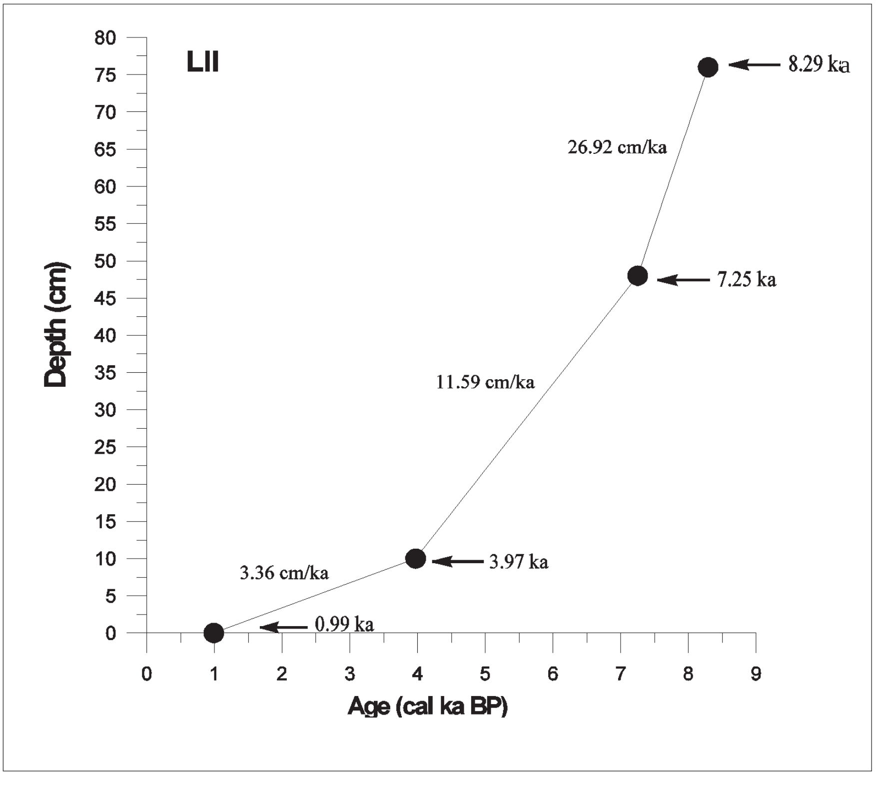

Fig. 2: Chronology of the L2 sediment core. Age-Depth relationship showing the sedimentation rate

The grain size distribution shows dominance of the sand over silt and clay throughout the Holocene (Fig. 3). Interestingly, decrease in sand percentage was noticed from~6 cal ka BP to late Holocene. The sand content varied from 66.53 to 97.44 %, whereas silt content varied from 0 to 22.83 % and clay content varied from 0 to 3.13 % (Fig. 3). The lower part of the core consisted of large amount of sand with very less

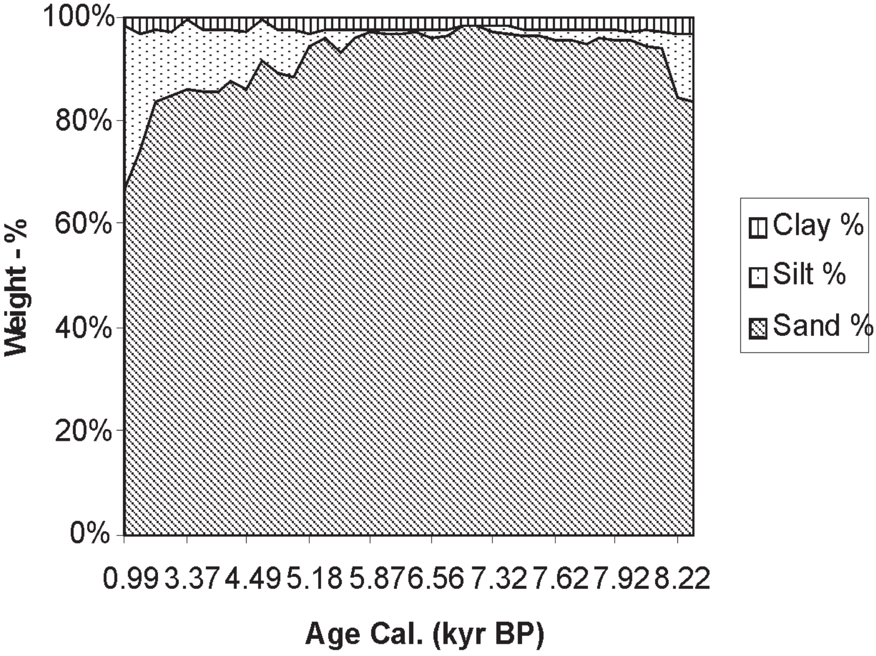

Fig. 3: Chronological variation of sand, silt and clay %

amount of silt and clay which corresponds to fluvio-glacial deposit formed, before ~6 cal ka BP, as reported by others (Tatur et al., 2004; Yoon et al., 2006).

The BSi varied from 1.57 to 3.06 %, which shows a very low abundance of silicate microfossils. The BSi remained low (1.57 % to 2.49%) from recent to ~6 cal ka BP and comparatively higher values were found (1.96% to 3.06%) from ~6 to ~8.3 cal ka BP. Overall the BSi showed occurrence of very low concentration (Fig. 4). The TOC values were found higher in upper part of core (12.6 to 0.1 %) up to ~4 cal ka BP and 0.1 to 0.03 % during ~4 to ~8.3 cal ka BP (Fig. 4).

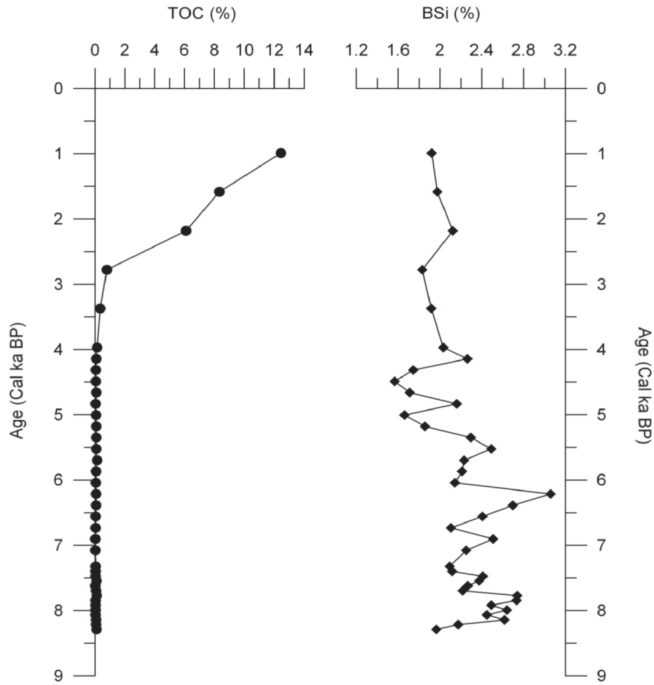

Fig. 4: Chronological variation of Total Organic Carbon (TOC) and Biogenic silica (BSi)

DISCUSSION

The radiocarbon dating of the present core showed that the maximum sedimentation rate of 26.92 and 11.59 cm/ka occurred in early-mid Holocene which supports the evidence that the lake was open in the polar summers (3 to 4 months) and have got deposition of high sand compared to silt and clay due to the glacio-fluvial deposition.

Grain Size Distribution and Influence on Paleoproductivity

The grain size can provide an insight in to the preservation of TOC and BSi. The higher TOC in the upper part of core corresponds to high silt and low sedimentation rate during ~4 cal ka BP. Low TOC in the lower part of the core corresponds with increasing sand content and high sedimentation rate during ~4 to ~8.3 cal ka BP.

The present study showed that the high TOC values are due to the presence of algal mat in the upper part of the core. This high TOC concentration also correlates with silt size grain indicating the poorly oxygenated environment. The finer particles did not allow penetration of oxygen in to the deposited sediment for decomposing the organic matter. As compared to this, the TOC was low or negligible in the lower part of core wherein sand was high which means TOC got decomposed in the lower part of core or was poorly preserved and indicate the oxic environment. In the coarse fraction oxygen had penetrated and caused the decomposition of organic matter. In general, the environmental conditions which enhance the preservation of carbon content in sediments include high productivity in the overlying water column, low oxygen bottom water and high sedimentation rate, which restrict the remineralization (Summerhayes, 1983). Studies by Keil et al. (1994) and Mayer (1994) suggested that in marine sediment grain size sustain a high relationship between surface area and preservation of Organic Carbon. The study (Bergamaschi et al., 1997) discussed a mechanism of the coastal sediments which shows that organic material was rapidly degraded by aerobic bacteria in oxic condition. Similarly, sediments from Peru Margin inferred that grain size variation is a principal determinant for the distribution of the organic carbon, total nitrogen, biogenic opal, carbohydrates and lignin within sediments. As stated earlier, the TOC

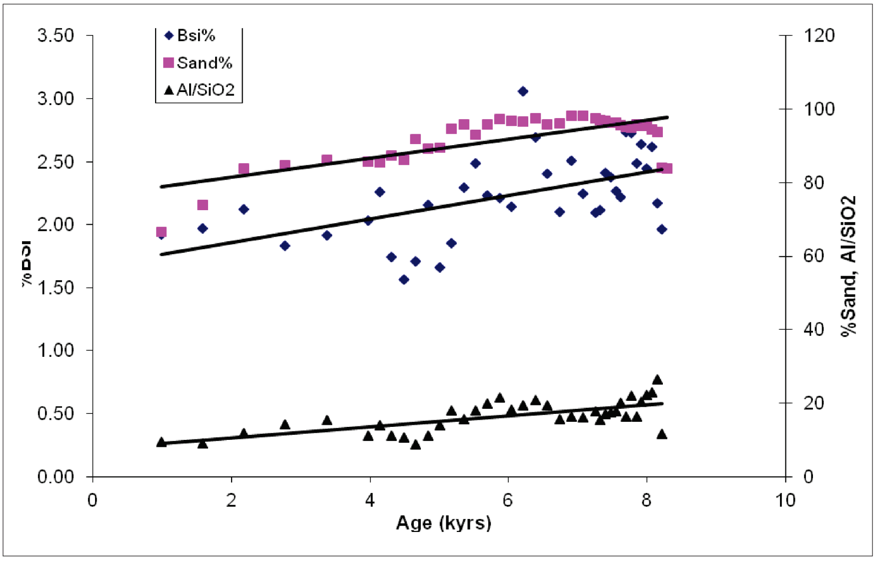

Fig. 5: Chronological Variation of Sand %, Al/SiO$_2$ ratio and BSi%

and BSi theoretically are in direct correlation as for the biological productivity in any area. However, in this study TOC and BSi showed opposite trend, which may have another explanation for the BSi shows more concentration with high sand content (Fig. 4).

BSi in the present study evidenced positive correlation with the grain size distribution and Al/SiO_2 ratio (Fig. 5). These three parameters increase with depth of deposited sediment. In this core, BSi varied from 1.57 to 3.06%, which shows an absence of silicate microfossils. The BSi percentage remained low (1.57 to 2.49%) from recent to ~6 cal ka BP and comparatively higher values (1.96 to 3.06%) were found during ~6 to ~8.3 cal ka BP. Though the concentration of BSi was very low throughout, but BSi shows significant variation. Study from other areas show that dissolved silica concentrations in marine sediments and interstitial waters are highly variable and low values are explained by the incorporation of aluminum in diatom frustules. Dissolution in the surface sediments was 3 times higher than the burial. The dissolution of silica however, declined with increasing water depth and the high content of Al in sedimentary BSi was most likely caused by precipitation of dissolved silica with Al dissolved from minerals in sediment (Rickert et al., 2002). Temperature dependence of silica solubility means at low temperature, silica solubility will be low and vice versa may also explain the observed BSi trends. If the solubility of silica is low in water column due to low temperature in Antarctic lake system, it may decipher that the precipitation of dissolved silica in sediment BSi increased with high dissolved Al content in sediment. Furthermore, high Al/SiO_2 ratio and high sediment BSi shows the positively correlation with the grain size variation in the present core. However, these are the preliminary results from the fresh water lake system in Antarctica and a future challenge to extend further for generating the database which will be helpful to understand the biological-geochemical behavior of Antarctic lake environment.

Holocene Climate Variation in Larsemann Hills

The high TOC during the late Holocene is attributed to the presence of algal mat in the top ~10 cm part of the core, which indicates ice free conditions in the study area during last ~4 cal ka BP. Earlier studies in other parts of Antarctica have reported that the Holocene warming (Hypsithermal) started at ~4 cal ka BP (Hodgson et al. 2004). Low TOC in the lower part of the core, down the depth, may indicate that the algal, mat throughout the time period might have been decayed. Another explanation could be seen in work of Yoon et al. (2006), in King Georges Island, West Antarctica where low TOC values have been ascribed to the existence of grounded glaciers in the core site before the formation of post glacial lake environment. In general, the biological productivity in the lake sediment is characterized by the diatom production (Birnie 1990; Roberts et al., 2001). But in present study, diatoms were absent throughout the length of the core. Therefore, the overall the values of BSi varied less but showed significant variation from ~8.3 to ~6 cal ka BP and ~6 to recent cal ka BP. It infers the presence of better productivity from ~8.3 to ~6 cal ka BP as compared to that in mid-late Holocene. The supporting evidence from the earlier study of Larsemann Hills also suggests a period of warming and more productivity during the interval of ~7.4 to ~5.2 cal ka BP (Verleyen et al., 2004).

The presence of algal mat in the top of the core indicates the warming and exposure of the lake to the ice free conditions, rather than being covered by the ice for most part of the year. Similarly, the upper part of the core consists of relatively low sand with high silt and clay fractions (Fig. 3), with abundant moss remains, showing that the study area was ice free which started at ~5 cal ka BP. The fine grained sediments of late Holocene were deposited due to the supply of ice melt water. Lower part of the core contains high sand with low silt and clay which implies that fluvio-glacial deposit formed before ~6 cal ka BP. Over all, the lower part of the core describes the modest productivity with the absence of moss. Thus, the record of paleoproductivity and environmental variation from the study area of last ~8.3 cal ka BP shows the shifting from warm to thermal maximum warmth stability until ~6 cal ka BP based on BSi results (Fig. 4). At~4 cal ka BP, the lake was ice free and opened to environment, and therefore, the productivity might have got enhanced due to direct exposure to sunlight. The recent studies from elsewhere in Antarctica shows that the early-mid Holocene was continuing with the warmer phase but at a slower rate while mid-late Holocene may possibly be indicated as a period of high organic productivity in lake sediments and suggest more warmer period (Björck et al., 1996; Bentley et al., 2009). In addition, the consideration of high and low productivity due to ice free conditions and extension of ice was related to local glacier retreat and re-advance during the Holocene which also can be influenced by the relative sea level rise and fall and isostatic uplift in and around the Larsemann Hills, East Antarctica (Domack et al., 1991; Verleyen et al., 2005). However, the correlation between TOC and BSi content generally indicates a positive relationship. On the contrary, it did not show any significant relationship in this core. From available data analysis, it may be stated that the results indicate multifaceted findings for the Holocene environment in study area in Larsemann Hills, which can also be further validated and may be conclusive with additional study including supportive parameters.

ACKNOWLEDGEMENTS

Author wishes to thank the Directors of Birbal Sahni Institute of Palaeobotany, Lucknow and National Centre for Antarctic and Ocean Research, Goa for providing permission to publish these results and is grateful to NCAOR for providing logistic support. The assistance by Dr. A. Bhattacharya and Dr. A. Sharma of Birbal Sahni Institute of Palaeobotany in collection of core at Larsemann Hills is gratefully acknowledged. Thanks are also due to the 26th Indian Scientific Expedition to Antarctica summer team members for their immense help.

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