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Holocene Climate Variability from Lake Sediment Core in Larsemann Hills, Antarctica

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Abstract: A sediment core (L2) from Larsemann Hills, Antarctica was analyzed for Biogenic Silica (BSi), Sand (%) and Total Organic Carbon (TOC). The 78 cm core length represents the time span of ~8.3 cal ka BP. The values of BSi from the core show 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 shows little variation through out the core, except in the upper ~10 cm (~4 cal ka BP) part wherein it is 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.

Keywords: Climate, Sediment core, Holocene, Larsemann hills.

INTRODUCTION

Antarctica and its surrounding Southern Ocean, play an important role in long-term climatic evolution (Li et al. 2000). In Antarctica, the ice cores have been studied to infer Quaternary climatic changes over past 740,000 years (EPICA, 2004), but these climatic variations have to be studies from marine and lake-sediment cores by using the various proxies. It is understood that Holocene climate variations are more stable compared to the late Pleistocene climate variations. Furthermore, less impacted from the human activity, lake sediments from Antarctica have been especially useful to elucidate the Holocene climate variations. The understanding of Holocene climate variations has increasingly attracted the attention of many workers towards Larsemann Hills, East Antarctica to understand the physical and biological mechanism on terrestrial environment, which influences the environmental behaviour in the area (Roberts and McMinn, 1999; Hodgson et al. 2005).

In general, Antarctica lakes in 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; Fristen and Priscu 1999). To understand the biogeochemistry, productivity and environmental behaviour of the Antarctica lakes and surrounding ocean, there are proxies, such as TOC and BSi used from both lake and oceanic sediments in the paleoclimatic studies (Colman et al. 1995; Yoon et al. 2006; Kaplan et al. 2002; Kamatani and Oku, 2000; Muller and Schneider, 1993; Mortlock and Froelich, 1989). There are numerous factors which control the productivity which are linked to seasonal temperature variation in 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 behaviour and climatic variation within the Holocene depending on BSi, Sand (%) and TOC parameters studies. This area was chosen because previous studies of 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 by soft snow and ice while the eastern side (Broknes peninsula) was not covered by the ice.

MATERIAL 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

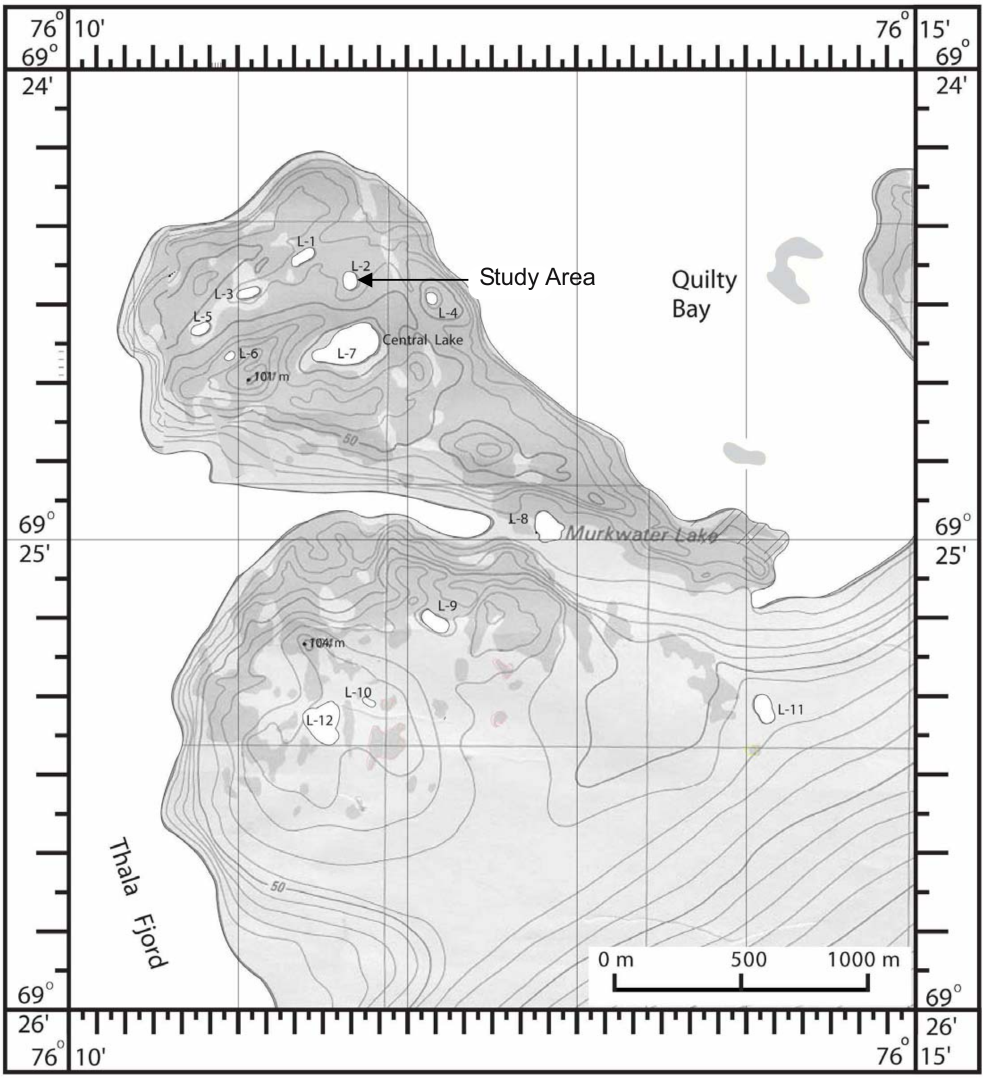

Fig.1. Study area and location of sedimentary core L2 from the L2 lake in Larsemann Hills, East Antarctica. (Modified Base Map after the Australian Antarctic Division and Geological Survey of India).

~25 m 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 mainly composed of sand except the top 10 cm which contains the sand, silt and algal mat.

The samples were oven dried at 50ºC 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 hexa-metaphosphate was added and further kept over night. 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 using 30 ml of 1N NaOH solution in a 50 ml polypropylene tube. The tubes were oven dried at 85^{0}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, aluminium (Al) was determined by Thermo Solar M6 Atomic Absorption Spectrometer. Calibration standards were prepared through Merck (Germany) AAS aluminium 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 (Table 1) by using CALIB version 5.0 (Stuiver et al. 1998; McCarmac 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.

Table 1. Radiocarbon (AMS ^{14}C) chronology of Lake L2

Depth (cm)	Conventional Radiocarbon Age (^{14}C yr BP ± 1σ)	$\delta^{13}C_{PDB}$‰ ±0.1	Calibrated age (cal yr BP) 2σ	Relative area under probability distribution
0-2	1,103±37	-14.7	915-1056	1.000
10-12	3,705±41	-15.1	3843-4090	0.996
48-50	6,380±47	-20.1	7161-7336	0.904
76-78	7,525±50	-19.1	8184-8381	1.000

RESULTS

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

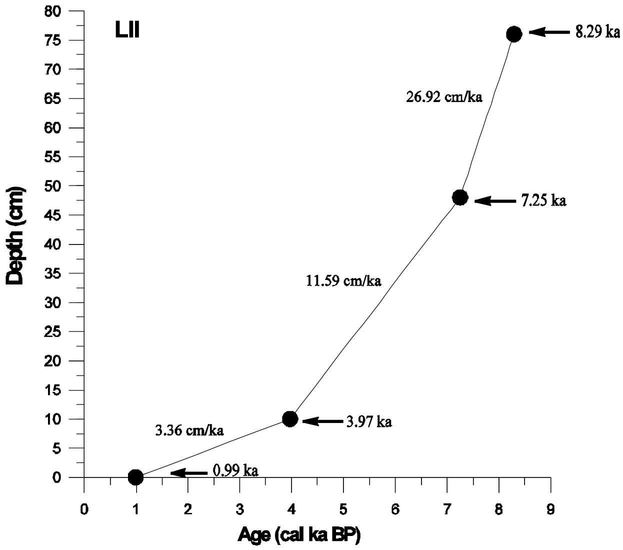

Fig.2. Chronology of the L2 sediment core. Age-Depth relationship showing the sedimentation rate.

The BSi varied from 1.57 to 3.06 %, which shows a very low abundance of silicate microfossils. The BSi remains 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 shows occurrence of very low concentration (Fig.3). The TOC values 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.3).

The grain size distribution shows dominance of the sand over silt and clay throughout the Holocene (Fig.4). Interestingly, decrease in sand percentage is noticed from ~6 cal ka BP to late Holocene. The sand values varied from 66.53 to 97.44 %, whereas silt values varied from 0 to 22.83 % and clay values varied from 0 to 3.13 % (Fig.4). The lower part of the core consists of large amount of sand with very less amount of silt and clay which corresponds to fluvioglacial deposit formed, before ~6 cal ka BP, as reported by studies conducted by others (Tatur et al. 2004; Yoon et al. 2006).

DISCUSSION

BSi documents direct measure of biological production from the siliceous algae and diatoms which can be used as a proxy of aquatic origin (Conely 1988; Kaplan et al. 2002). However, siliceous and calcareous microfossils in the core is absent and therefore, overall the values of BSi varied less but shows significant variation from ~8.3 to ~6 cal ka BP and ~6 to recent cal ka BP. It infers the presence of high productivity from ~8.3 to ~6 cal ka BP in compare to less

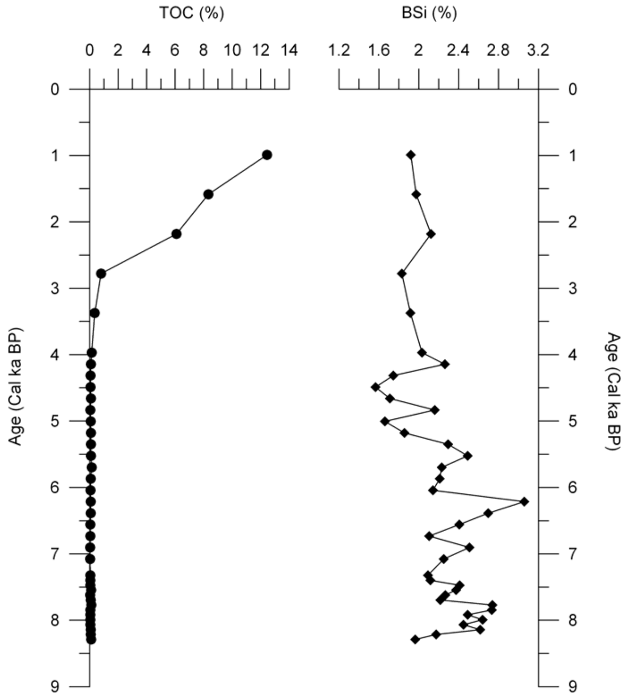

Fig.3. Chronological variation of Total Organic Carbon (TOC) and Biogenic silica (BSi).

productivity in mid-late Holocene. The supporting evidence from the earlier study of Larsemann Hills also suggests that a period of warming and more productive during the interval of ~7.4 to ~5.2 cal ka BP (Verleyen et al. 2004).

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 reported 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 indicates that the algal

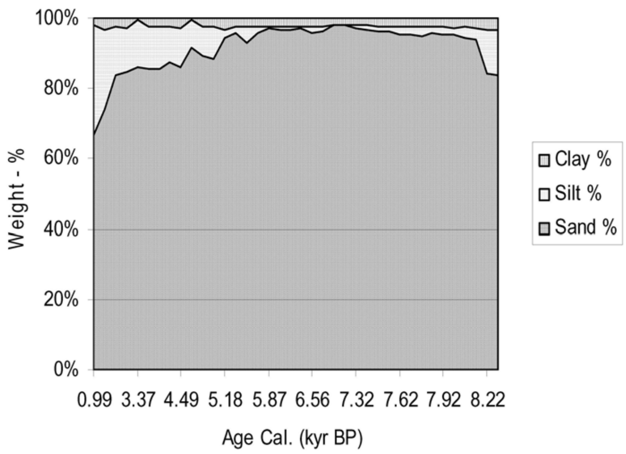

Fig.4. Chronological variation of sand, silt and clay %.

mat through out 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 postglacial 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 are absent through out the length of the core. 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 of the time of the year. Similarly, the upper part of the core consists of relatively low sand with high silt and clay fractions (Fig.4), 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 fluvioglacial 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.3). At the time of ice free conditions at ~4 cal ka BP shows the initial stage of lake formation and therefore, may enhanced the productivity, geochemical behaviour of the fresh water lakes of study area. 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 (Schmidt et al. 1990; 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 readvance 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; Zwartz et al. 1998; Miura et al. 1998; Verleyen et al. 2005; Hodgson et al. 2006). However, the correlation between the TOC and BSi content generally indicates a positive relationship, on the contrary it does not show any significant relationship in this core. From available data analysis, it may be stated that 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.

CONCLUSION

The L2 core sediment samples have been analyzed for different parameters in chronological sequences. Most of the values of TOC, BSi, and sand show quite low concentrations and indicate no major evolution in paleoproductivity within the Holocene climate variations in the study area. TOC values show the algal mat presence in the upper part of the core and indicate the ice free conditions of the lake from ~4 cal ka BP in the study area. Similarly, the sand, silt and clay values in upper part of the core indicate that the transport of the fine grained composition by ice melt water started at ~ 5 cal ka BP. The high sand value concludes the fluvioglacial deposit formed before ~6 cal ka BP. The siliceous and calcareous microfossils from the core are absent. Therefore, overall the values of BSi and TOC are found very less but show significant variation from ~8.3 to ~6 cal ka BP and ~4 cal ka BP to recent respectively. Furthermore, the inferences drawn on the basis of preliminary data within the Holocene retrieved through the sedimentological and geochemical proxies provide the basic idea of the Holocene climatic variation in study area. Therefore, it is recommended to continue study from the other lake sediment cores on advanced proxies in future to validate these conclusions.

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