Role of global teleconnections and moistures sources in triggering extreme events in ISM realm: comparing a modern and 2K perspective

Pranshu Kalson

A dissertation submitted for the partial fulfilment

of BS-MS dual degree in Science

Indian Institute of Science Education and Research *Mohali*

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MS14082

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Certificate of Examination

This is to certify that the dissertation titled “Role of global teleconnections and moistures sources in triggering extreme events in ISM realm: comparing a modern and 2K perspective” submitted by Pranshu Kalson (Reg. No. MS14082) for the partial fulfilment of BS-MS dual degree programme of the Institute, has been examined by the thesis committee duly appointed by the Institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted.

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Thesis Supervisor

Date: April 26, 2019

Declaration

The work presented in this dissertation has been carried out by me under the guidance of Dr. Anoop Ambili at the Indian Institute of Science Education and Research Mohali. This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contribution of others are involved, every effort is made to indicate this clearly, with due acknowledgment of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have been detailed in the bibliography.

Pranshu Kalson

Date: April 26, 2019

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Dr. Anoop Ambili

Thesis Supervisor

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Abstract

We aim to develop comprehensive picture of late Holocene climate variability over the North-Eastern India to address the existing large spatial gaps in paleoclimate data coverage in Indian subcontinent. This region receives precipitation only from the Indian Summer Monsoon (ISM) and lies in the region sensitive to the impact of various teleconnections (e.g., El-Niño, North Atlantic oscillations and Indian Ocean Dipole). A multi-proxy approach involving elemental concentration, isotopic geochemistry ($\delta^{13}C$, $\delta^{15}N$) and pollen studies have been performed on short sediment cores (ca. 1.0 m long) retrieved from Shilloi Lake, Nagaland, NE India (25°35′44″ N, 94°47′33″ E) to decipher climate vis-à-vis vegetation dynamics in the region. The chronology of the core sediment is based on the eight ^{14}C dates derived from bulk organics, charcoal and organic fragments spanning over 2000 cal yr BP. The $\delta^{13}C$ values from the core sediments ranges from -34h to -23h with a sharp excursion of ~8h observed during 1000 cal yr BP. The grain size parameters (D [4,3]-De Brouckere Mean Diameter) also demonstrate enhanced ISM precipitation from 1000 cal yr BP. Furthermore, pollen and *n*-alkanes indices also provide evidences of vegetational shift corresponding to the changes in the rainfall variability. The present work will provide an improved picture of the ISM variability and helps to identify the possible teleconnections responsible for the changes in regional paleoclimate during the late Holocene.

Chapter 1

Introduction

1. Introduction

The dominant portion (ca. 80%) of the annual precipitation on most regions of the Indian subcontinent is contributed by the Indian Summer Monsoon (ISM). The differential heating of the landmass and ocean resulting in the retreat of the Inter Tropical Convergence Zone (ITCZ) along the equator drives the kinetics of the ISM (Wang et al., 2002). The shift of the ITCZ is influenced by many factors such as distance of the earth from the sun, amount of solar radiation received, positioning of the continental and oceanic masses (e.g. Kale et al., 2007 and references therein). This in turn affects the dynamics of ISM bringing about periods of humid and dry conditions over the Indian subcontinent. Also, the monsoon rainfall is not evenly distributed over the subcontinent (Kale et al., 2006, Singhvi et al., 2004). Even around the recent time frame, the dynamics of the ISM keeps changing spatially and temporally (Zhisheng et al., 2011). Therefore, it is reasonable to assume that such fluctuations or even more intense deviations in the climatic conditions operated by the ISM might have also occurred in the past. Instrumental and satellite records can give us information of last few decades only. In order to unravel the mystery of the past beyond few decades, a different approach has to been considered.

The precipitation in Northeastern (NE) part of the Indian subcontinent is majorly contributed by the ISM. The sedimentary deposits and lacustrine sediments from the region can be utilized as archives for understanding the paleoclimatic conditions of the region. The interpretation of the conditions and mechanisms involved in these depositions can help us understand the climate undulations that the region might have experienced. The Shilloi Lake present in the Phek district of Nagaland preserves the records of the climatic fluctuations that the region went through for a time period beyond instrumental records. However, in order to disentangle these records preserved in lacustrine sediments, different proxies must be applied . For our study, we adopted a multi-proxy approach in which core sediments were collected and analyzed. Also a robust chronology of the core sediments was obtained by C-14 dating method. Since, each proxy has its own limitations application of a single proxy approach for paleo-climatic interpretation can be debatable. Therefore, multi-proxy approach is being utilized to get a more resolved idea about the climatic variations in the past 2 millenia. The various proxies used in our study include grain size analysis, stable isotope and palynological investigations.

Grain size analysis helps us understand the energy of the system during which the deposition might have occurred (Holz et al., 2004; Folk, 1980; Friedman and Sanders, 1978). As suggested by the Hjulstrom model, the grain size range deposited in a particular environment is directly dependent on the velocity of the transporting medium. Hence, obtaining knowledge about the dominant grain size of a particular time period can help us understand the energy condition and the transportation medium. Therefore, grain size analysis can serve as an ideal proxy for paleo-climatic reconstruction (McManus., 1988; Stanley-Wood and Lines, 1992).

Organic matter is a very minute yet crucial constituent of lake sediments. The primary source of organic matter is the vegetation surrounding the lake setting. Therefore, they act as a "geochemical fossil" for paleo-climatic analysis (Meyers et al., 1995). The type of vegetation dominating in a region and the shift it undergoes are governed by the climatic conditions of the region. Stable isotope data can help us understand the quality of the past environment i.e., the kind of paleo-vegetation and paleo-productivity of the region. For the study, stable isotopes of carbon and nitrogen are analyzed (Liu et al., 2005, Waser et al., 1999, Schulze et al., 1994). The fluctuations in the isotopic ratios can help us differentiate the wet phases from the dry phases and also understand the shift in vegetation dynamics. Also analyzing the Total Organic Carbon (TOC) and Total Nitrogen (TN) in the sediment core (Watanabe et al., 2004) can help us interpret and correlate the distribution with the periods of transition from cold to warm.

Similarly, pollen data can be used for reconstructing vegetational history of the region and it helps to deduce the paleoenvironmental changes that might have resulted in the vegetational shift (Moreno et al., 2010). Pollens have a coating of complex lipid and fatty acids combinations which preserves the soft, more prone to decay organic matter and thus, retains the shape. This can be analyzed to learn about the taxa to which a particular pollen belongs to from an already developed database containing information about the different taxa and their respective pollen shapes (Bessedik, 1984; Diniz, 1984 a, b; Suc et al., 1992, 1995a,b; Fauquette et al., 1998a, 1999). The taxa identification of a given time period can tell about the vegetational shift and the climatic conditions can be correlated to it.

1.1 Objectives

The major objectives of the present work are understanding the below mentioned processes;

- Changes in precipitation seasonality and precipitation pathways of ISM during late Holocene.
- Regional impact of large-scale climate changes e.g., Little Ice Age (LIA) and Medieval Warming Period (MWP) and the rate and duration of climate change and their impact on ecosystem.
- Changes in the frequency of extreme events during late Holocene. A multi-proxy approach will allow to determine sensitivities and thresholds of the different components of the ecosystem with respect to monsoonal forcing.
- Compare the amplitude, duration, and spatial heterogeneity of modern extreme events with that during the Holocene in NE India.
- Land cover changes over the Holocene: human impact vs climate changes using compound specific isotope analyses.

1.2 Study Area

1.2.1 Climate

The present study is focused on the Shilloi Lake (250 -37'-37" to 250-39'-47" N (LT), 940-35'- 18" to 940- 38'-09" E (L), height) situated in the southern fringe of Nagaland (Figure 1). The foot shaped freshwater lake lies in Patkai range, near Latsum village in Nagaland. The lake is smaller in size (0.25 to 0.30 sq km) and the water depth varies between 3 to 5 m with an average depth of 4. The limited human activity in the region makes the lake as an ideal location to understand the natural climate variability in the region. The lake is surrounded by dense terrestrial vegetation. The hydrology of the lake is controlled by the 1 perennial and 2 or 3 ephemeral streams. The region is characterized by complex topography with sharp altitudinal gradient and variety of vegetation that influence local weather condition (Chatterjee et al., 2006).

Climatically, because of the sharp altitudinal variation and complex topography, the region has distinct rainfall variation as compared to the ISM rainfall from the core monsoon zone. The precipitation data from Climate Research Unit (CRU TS3.10) data for the period of 1901 to 2017 (from June to September) interpolated into 0.5° latitude/longitude gridded cell suggests that the mean annual precipitation is 1527 mm approximately. However, the mean annual temperature ranges between 27°C and 8°C.

1.2.2 Geology

Geologically, the lake lies in the ophiolite complex and is sandwiched between low grade Naga metamorphic in the east and the Disang group in the west (Fareeduddin et al., 2015). The ophiolite complex along the Nagalang-Myanmar border predominantly consists of serpentinites and volcanics (e.g., dunite, harzburgite, peridotite and basalt which are associated with radiolariena chert and limestones) (Acharyya et al., 2008). The Naga metamorphic is characterised by the dominance of quartzite, phyllite, mica schist and sheared granite. The sharp change in the litho unit between the ophiolite complex and naga metamorphic and presence of folds suggest thrusting of Naga metamorphic over the ophiolite complex. The Disang group consists of flysch sediments, which constitute thick sequence of grey shale interbedded with fine-grained sandstone and siltstone (Mathur and Evans., 1964).

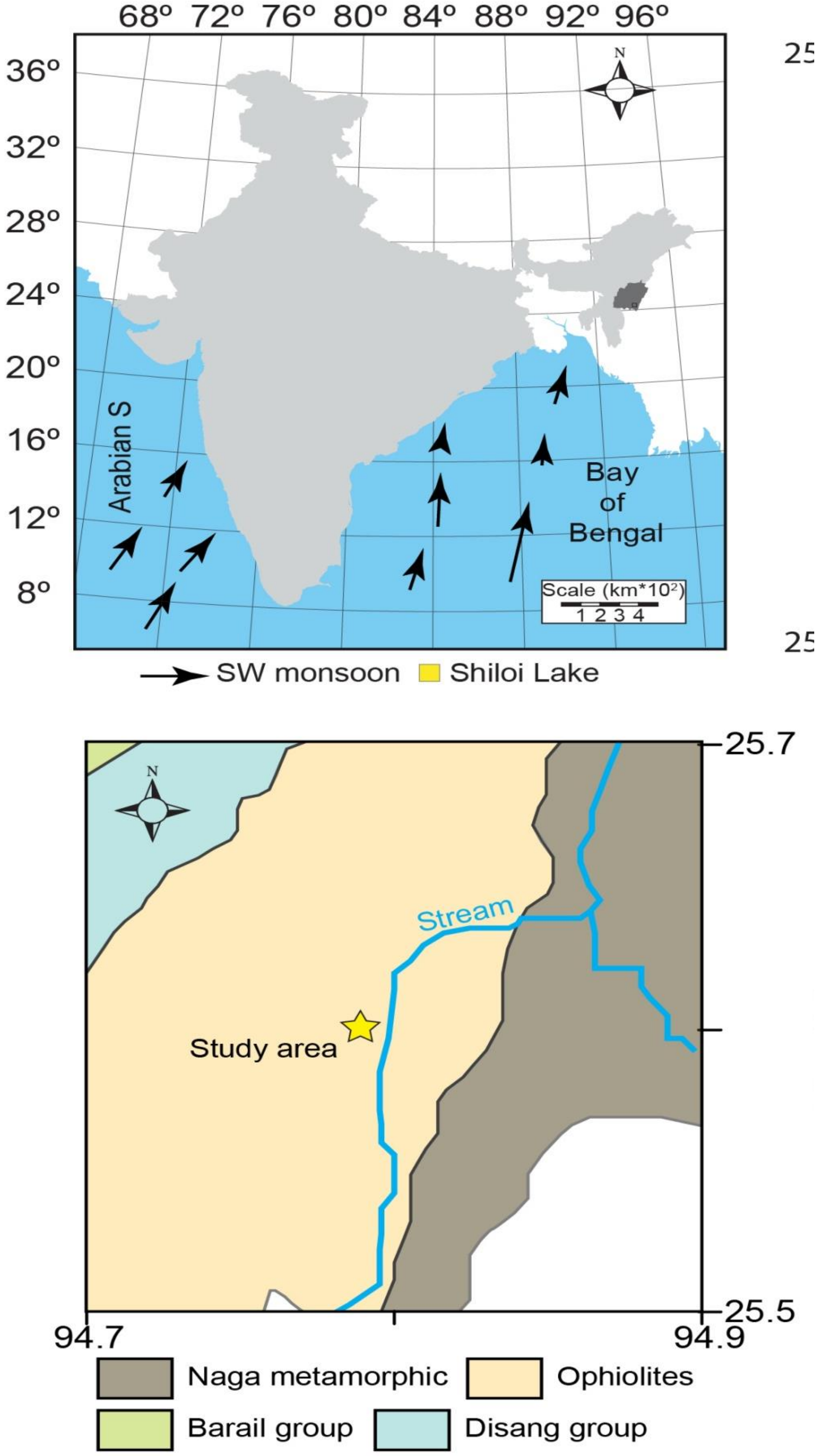


Figure 1: Map of study area

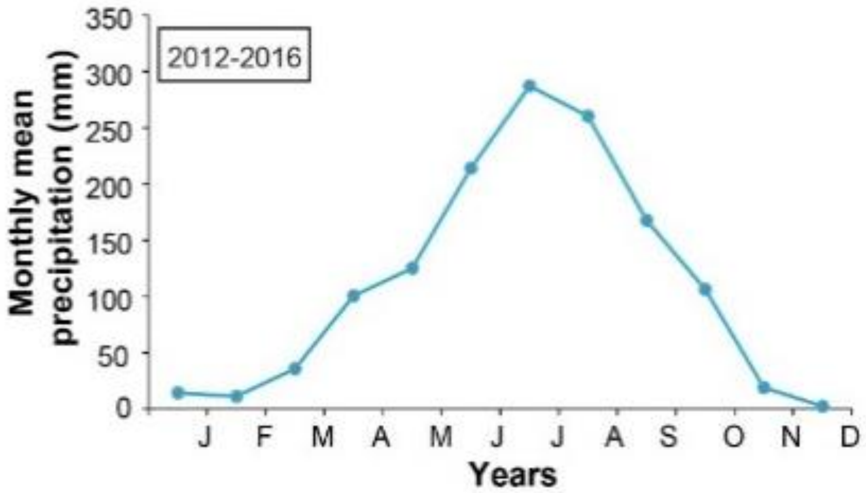


Figure 2: IMD Rainfall trend

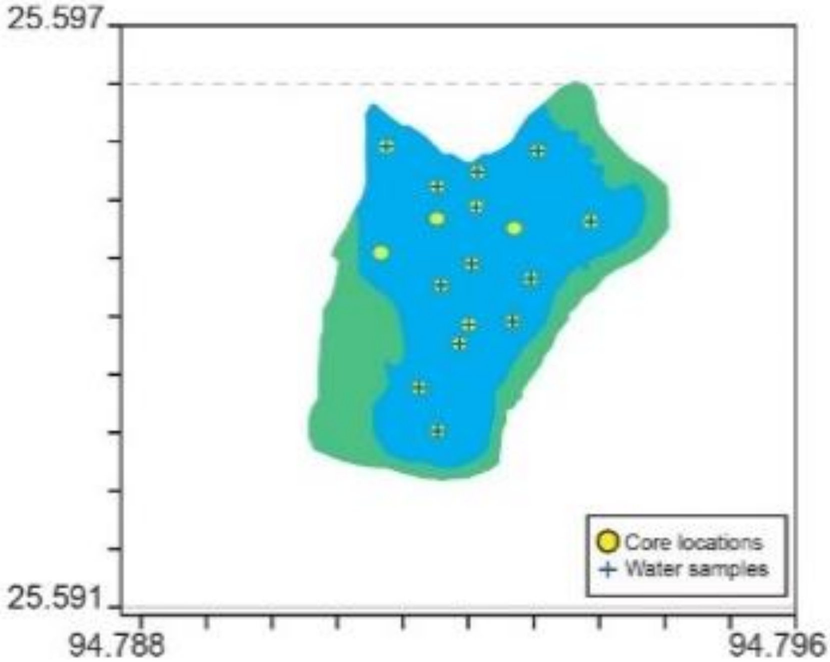


Figure 3: Map of the lake denoting the location from which samples were taken.

Chapter 2

Methodology

2. Methodology

2.1 Field investigation and samples collections

During the field investigation in 2017, several short cores ranging from 90 to 105 cm were retrieved using UWITEC gravity corer from variable depths in Shilloi Lake (Figure 3 & 4). Additionally, 13 lake surface sediments were recovered using van veen grab sampler and, modern terrestrial and aquatic vegetation were also collected from in and around the lake basin. Furthermore, the lake surface water and the spring samples were also collected to decipher the physico-chemical condition of the lacustrine system.

For the present study, the core SHC-02 from the deepest (~5 m) water depth was selected for the detailed study. Core samples at 1cm intervals were measured for stable isotopes ($\delta^{13}C$ and $\delta^{15}N$), grain size and pollen analysis.

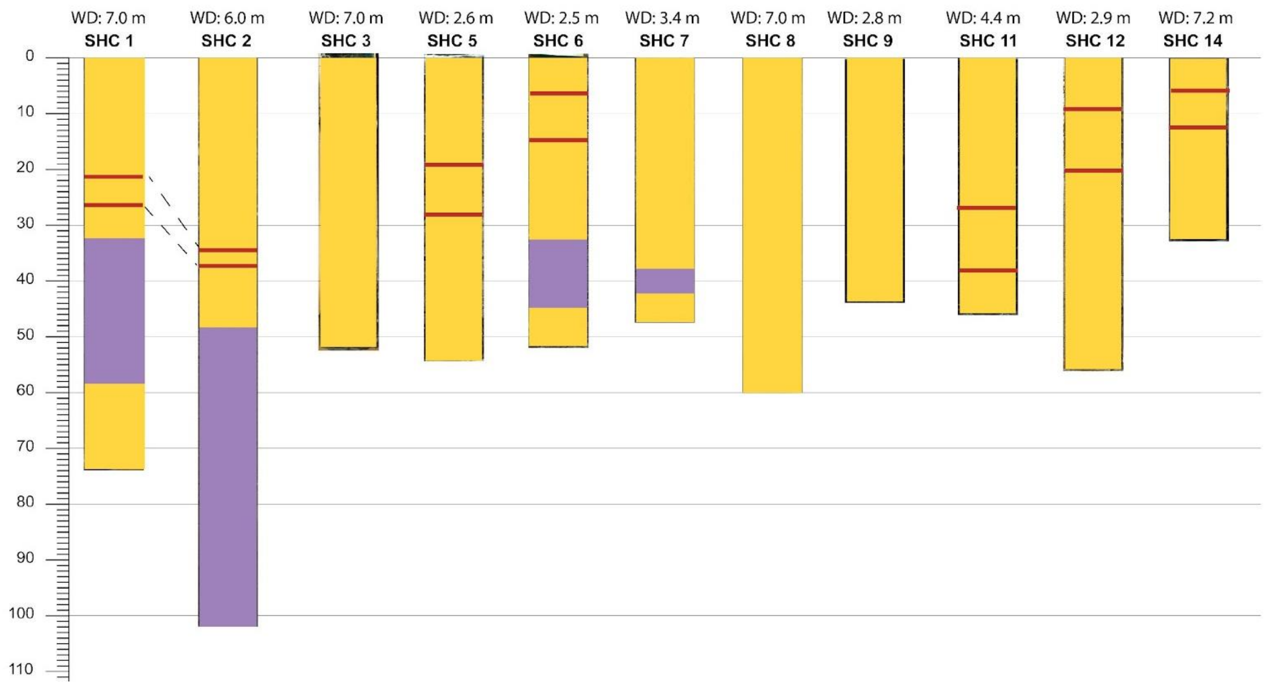


Figure 4:Litho-log of the cores retrieved from the site.

2.2 Chronology

The chronology of the core SHC-02 has been established based on the four organicfragments and one charcoal sample. The dating of the sediments was carried out at Laval University, Canada. The calibration of radiocarbon dates to calendar years before present (0 BP= 1950 CE) and reconstruction of age-depth relationship were carried out using Clam 2.2 (clam 2.3.2) (Blaauw et al., 2010) in R language (R version 3.5.1) based environment. The Clam package use IntCal13xx calibration dataset for the calibration of the radiocarbon age. The interpolation of the calibrated age were done assuming that the modern age of the top of the core (0 cm) is -67 years BP, considering the fact the core was retrieved during 2017. For the age-depth model reconstruction, input settings were adapted from Crann et al., 2015 which is being used for the typical lake settings.

In Clam, the memory strength 20 and mem. Mean =1 because of the highly dynamic rate of sedimentation in the lake (Crann et al., 2015).

2.3 Stable Isotopes ($\delta^{13}C$ and $\delta^{15}N$)

The carbon and nitrogen isotopic analysis of the sediment were carried out using Flash 2000 HT elemental analyzer coupled with conflow IV in continues flow mode of Isotope Ratio Mass Spectrometer (CF-IRMS) at Wadia Institute of Himalayan Geology, Dehradun. These isotopic measurements were carried out one by one separately using single reactor method. The single reactor setup have two sections, one for combustion (chromium oxide; Cr_2O_3) and one for reduction (reduced copper; Cu), adjusted to the temperature profile of the furnace. The lower section is filled with cobaltic oxide to remove halogens and sulfur. The reactor packed with quartz wool at the top and bottom and regents separated from each other using quartz wool. The packed reactor gradually heated step by step to rise the temperature upto 1050 °C for the analysis of carbon and nitrogen isotopes. Leak test were performed at every step of increasing or decreasing the temperature. After acquiring the temperature, samples were analyzed using the bracketing of blank, Tin/silver capsules and standards at the interval of each 10 samples. The instrument and gas were calibrated using the international standard 'IAEA-CH3' (for carbon isotope) and atm-N_2 (for nitrogen isotope), whereas in-house standards (WIHG-CH3 and WIHG-US2) were used for quality control and cross verification of the instrument and results. The standard deviation (SD) of the samples and standard is ±0.2‰. The R 2 value for the reported and measured standard is 1.

The sample and standard were compactly packed in dry Pre-treated (with Methanol) Tin/Silver capsules. The packed capsules were put in the reactor at 1050°C through auto sampler. The samples were combusted at 1050°C in the presence of oxidizing regent (Cr_2O_3) and O_2 dosing. During combustion of samples with addition of oxygen, the sample gets converted to CO_2 and NO_2 among other gases. Nitrous oxides which may be formed during combustion are reduced by copper (in reactor) to N_2. After removal of H_2O, the CO_2 and N_2 are separated using GC column and the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ isotope ratios are measured with CF-IRMS.

Figure 5: IRMS coupled with element analyzer

2.4 Pollen study

In sedimentary records, the pollen data is utilized to understand the vegetational shift and associated paleo climatic variations. Pollen extraction was carried out by a series of acid treatments. (Hydrochloric acid (HCl) and hydrofluoric acid (HF) and acetolysis (a mixture of acetic anhydride and sulphuric acid) (Erdtman., 1943). After chemical extraction, pollen slides were prepared in glycerine jelly and scanned under a compound light microscope at 500x. Rarefaction technique was used to estimate the minimum number of pollen grains that had to be counted per sediment layer to account for most of the pollen taxa richness (Birks and Line, 1992).

Figure 6: Pollens of Pinus under microscopic view (500X)

(Source:https://www.nps.gov/romo/microscopic_pine_pollen.htm)

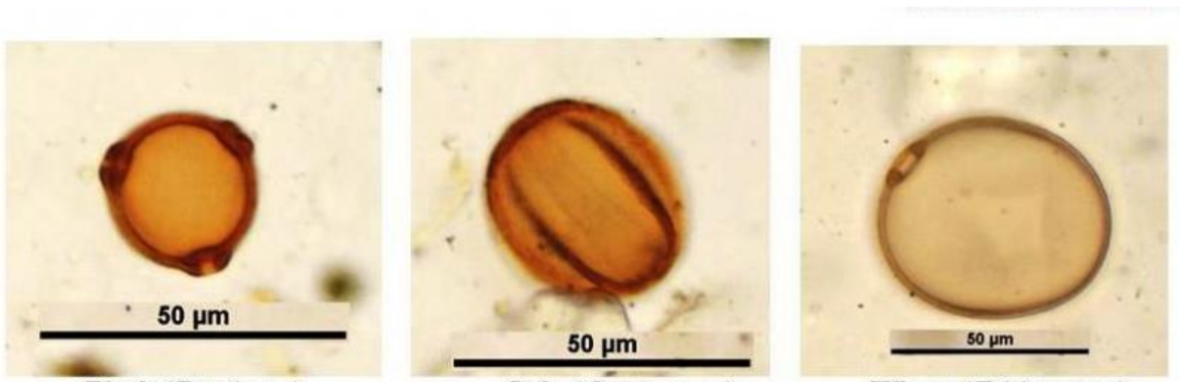


Figure 7: Pollen database

(http://www.mpov.uw.edu.pl/en/thesaurus/paleobotany/palynology)

2.5 Grain size

The grain size analysis was performed at 3 cm intervals using the wet sediment analysis in Malvern Mastersizer (3000E) at Indian Institute of Science and Education Research (IISER)-Mohali (India). For its analysis, the samples were pre-treated with 30% H_2O_2 to remove the organic carbon. The treated solution was then further washed with milli-Q water and centrifuged several times to remove excess H_2O_2 solution. The samples were measured for the grain size between 0.02 to 100 μm. Before analysis, the samples were kept in an ultrasonic bath for atleast 15 minutes to disperse the sediments. The instrument measured each sample for five times, and the average values were used for the interpretation (Lopez, 2016).

Figure 8: Grain Size Analyzer (Malvern Mastersizer)

2.6 Biomarker Analysis

Biomarker analyses were carried at PRISM Lab, IISER Mohali. The sediment samples were powdered using agate mortar pestle and were extracted using pressurized solvent extraction (Buchi speed extractor E-914 (Figure 9) with Dichloromethane/Methanol (93:7) at 100°C and 100 bar for 2 cycles. The TLE fraction was concentrated in a Multivapour (P-6, Buchi (Figure 10)) and aliphatic hydrocarbon fraction (*n*-alkane) was separated from the TLE using deactivated silica gel (100-200 mesh) column eluted with *n*-hexane. The detailed method for the lipid extraction has been discussed elsewhere (Sayak et al., 2016). Then *n*-alkane fraction has been concentrated up to 0.5 ml under a stream of dry N_2.

The concentration and identification of *n*-alkanes were performed in a gas chromatograph (Agilent 7890B, GC system (Figure 11)) equipped with a split/splitless injector, non-polar capillary column (HP5-MS, 30 m × 250 µm × 0.25 µm) and quadrupole mass spectrometer (MS). Samples were injected in a splitless mode with an initial inlet temperature of 320 °C. The GC oven temperature was started at 40 °C (held 2 min) and then increased to 320 °C at 4 °C/min (held 10 min). The individual *n*-alkanes were identified using NIST library (version?) and further supported by matching with the characteristic retention time obtained from the external *n*-alkane standard mixture (SUPELCO C_8–C_{20} and C_{21}–C_{40}alkanes).

Figure 9: Pressurized Solvent Extracter (Buchi E-914)

Figure 10: Multivapor (Buchi P-6)

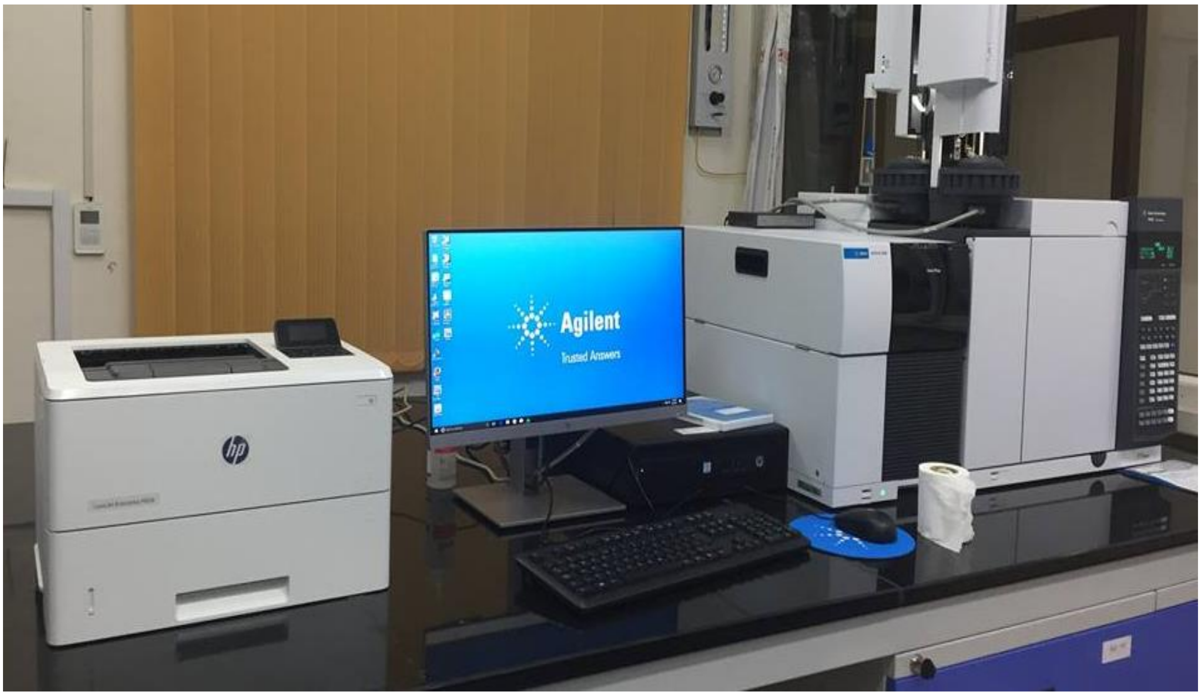


Figure 11: Gas Chromatography Mass Spectrometry (Agilent)

Chapter 3

Results

3. Results

3.1 Chronology and sedimentation rate:

The radiocarbon ages are presented in the age-depth model as shown in the Figure 12. The chronology of the core ranges between 1903 to -67 cal BP. Red mark in the figure denote an outlier. The sedimentation rate (SR) varies between 0.073 and 0.040 cm/yr with an average value of 0.054 cm/yr. The sedimentation rate was maximum during ~750 to ~530 cal BP ($SR_{avg.}$ = 0.073 cm/yr), whereas minimum value is witnessed from ~1880 to 1550 cal BP.

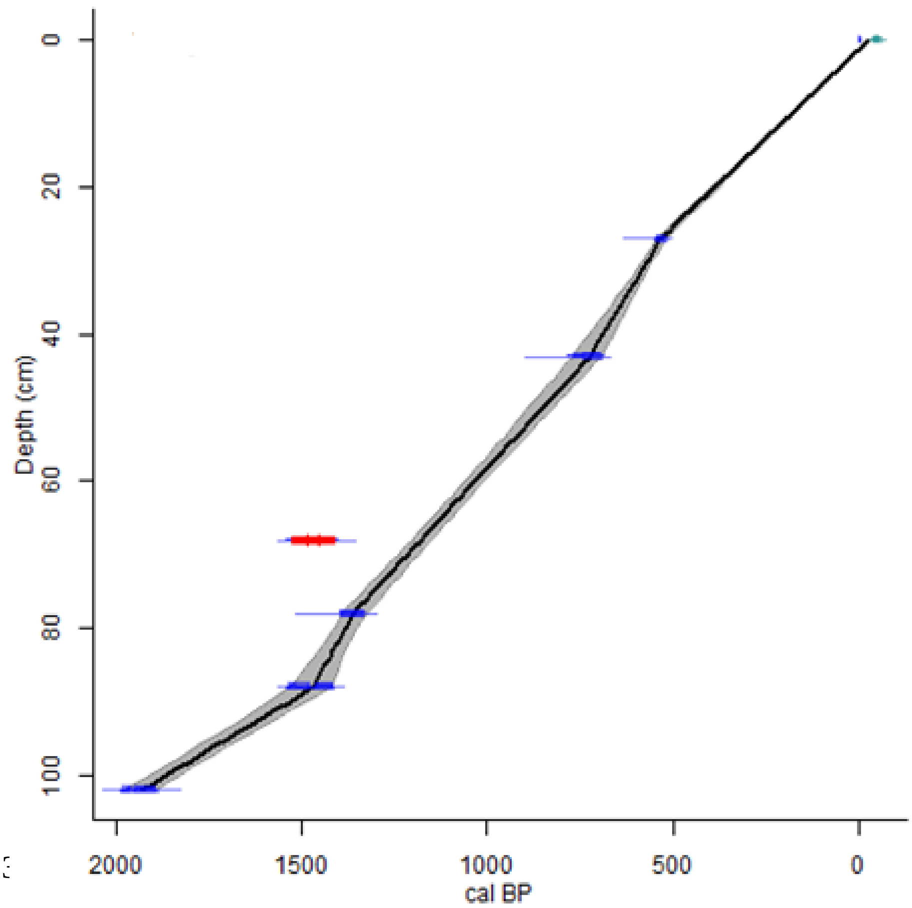
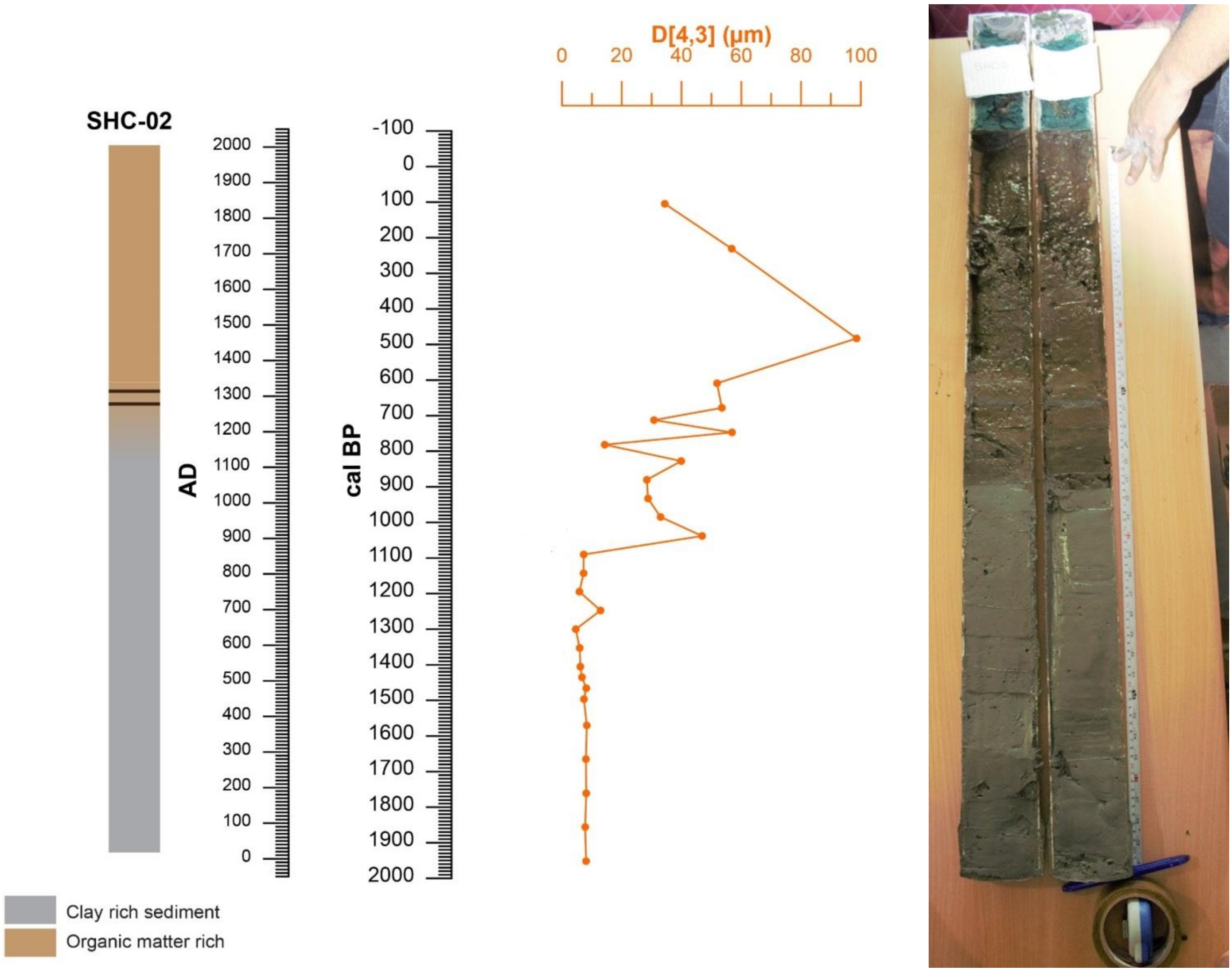


Figure 12: Chronology (Carbon-14 dating)

The representative sediment core retrieved from the lake basin (water depth= ~6 m), is 102 cm long with dominance of silt sized fractions. Based on the sediment characteristics (grain size), and presence of the organic matter, the core has been divided into three parts: (i) Zone-I (102-56 cm)- dominance of clay material and presence of shell fragments; (ii) Zone-II (56-33 cm)- gradational decrease in clay size fraction, fragments of organic matter increased relative to the preceding stage; and (iii) Zone-III (33-0 cm)- dark brown, organic rich material. The grain size variability shows coarsening upward from Zone I ($Sand_{avg.}$= 1.9%; $Clay_{avg.}$= 27.5%) to Zone II ($Sand_{avg.}$= 26.1; $Clay_{avg.}$=6.8%).



(a) (b)

Figure 13: (a) Grain Size distribution along the core. (b)Image of the retrieved SHC-02 core

3.3 Multiproxy characteristics (Stable isotopes, organic matter, pollen and biomarkers)

The total organic carbon (and nitrogen) of the SHC core sediment ranges between 1 and 30 (0.1 and 1.3) with highest values in the unit-I (Figure 14). The significant correlation between TOC and TN (r= 0.96) indicating that the presence of inorganic nitrogen in the lake sediments are minimal. The C/N ratio of the SHC core sequence varies between 10 and 31. Furthermore, the $\delta^{13}C$ and $\delta^{15}N$ shows significant high correlation (r=0.90) and the values ranges between -34 and -23 ‰ for $\delta^{13}C$ and 0.6 to 6 ‰ for $\delta^{15}N$. In the core sequence, $\delta^{13}C$ and $\delta^{15}N$ both show decreasing trend from unit-I to unit-II, with a transitional phase at around 1000 cal yr BP (Figure 15).

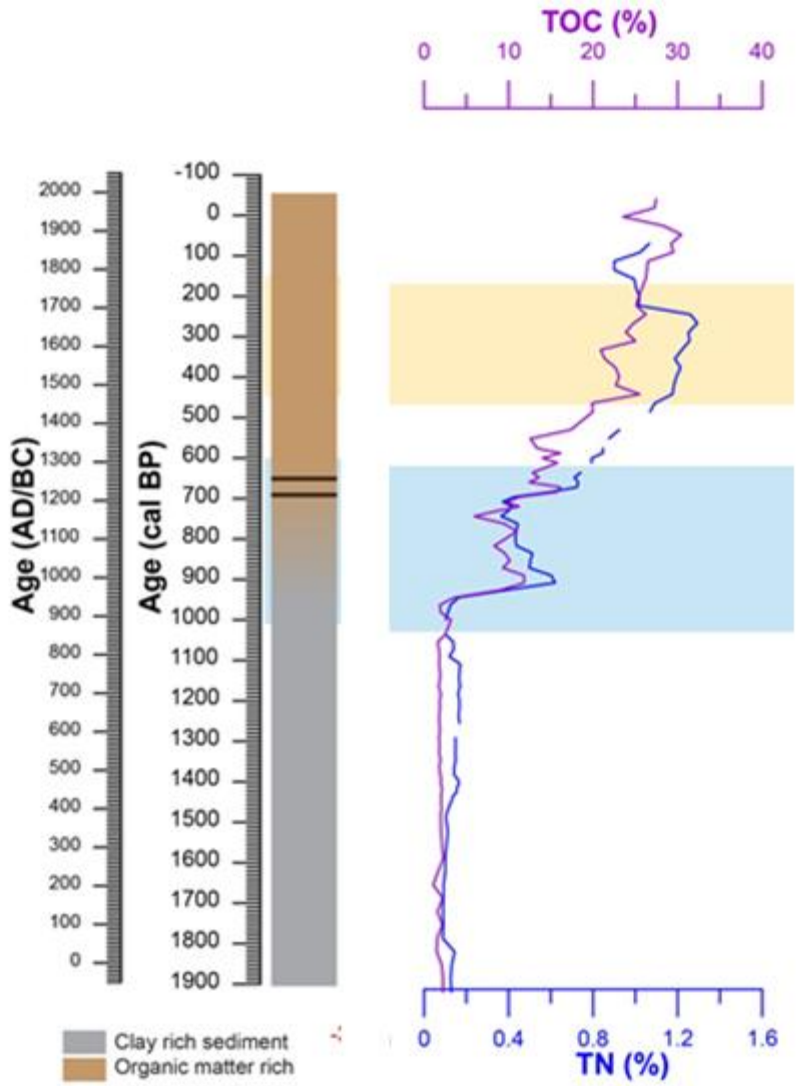


Figure 14: TOC and TN trend along the core

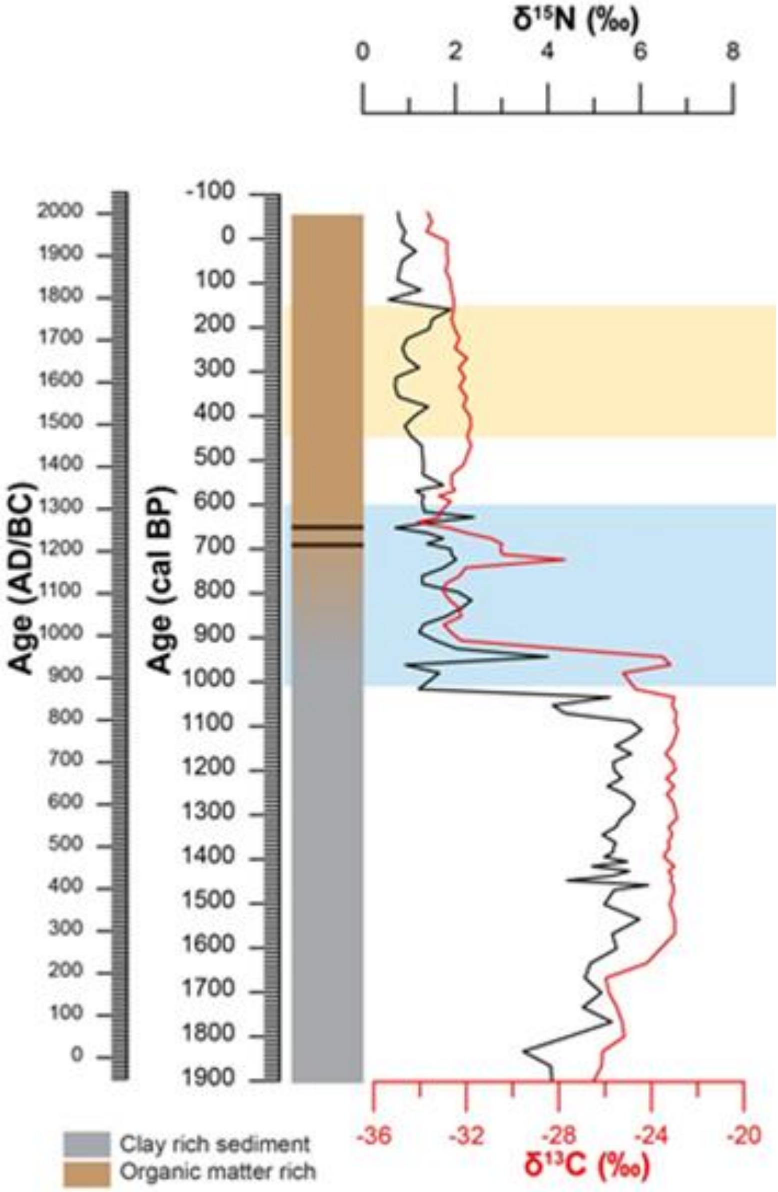


Figure 15: δ13C and δ15N excursion along the core

The major portion of the pollen count was contributed from the tress, particularly in the upper part of the sediment core. The most frequently occurring plant taxa in the Shilloi core were *Alnus, Pinus, Betula, Quercus* and *Acanthaceae* type (Figure 16, 17 & 18). *Pinus* pollens were dominant from ca. 1000 cal yr BP to present. Similarly, *Alnus* and *Quercus* were present in depths from ca. 1000 cal yr BP to present.

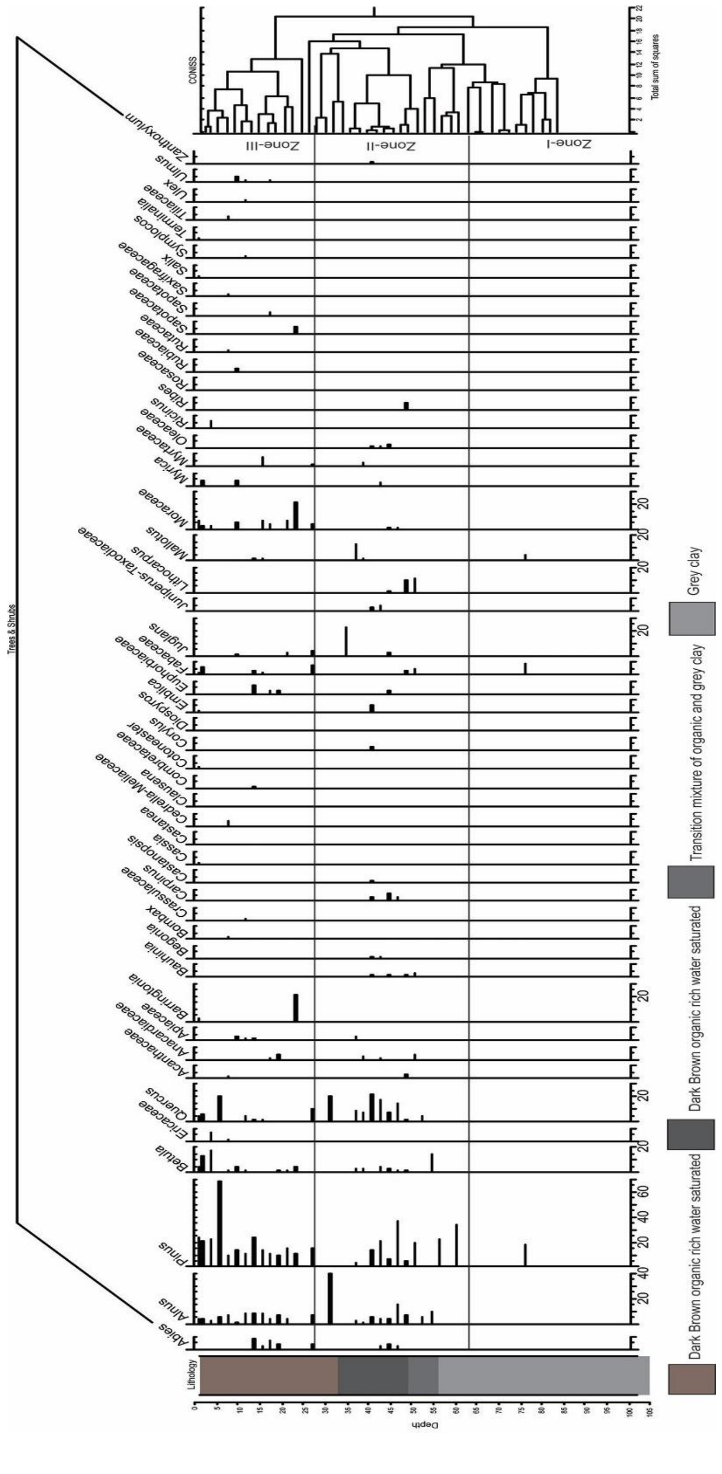


Figure 16: Spatial distribution of pollen data (trees and shrubs)

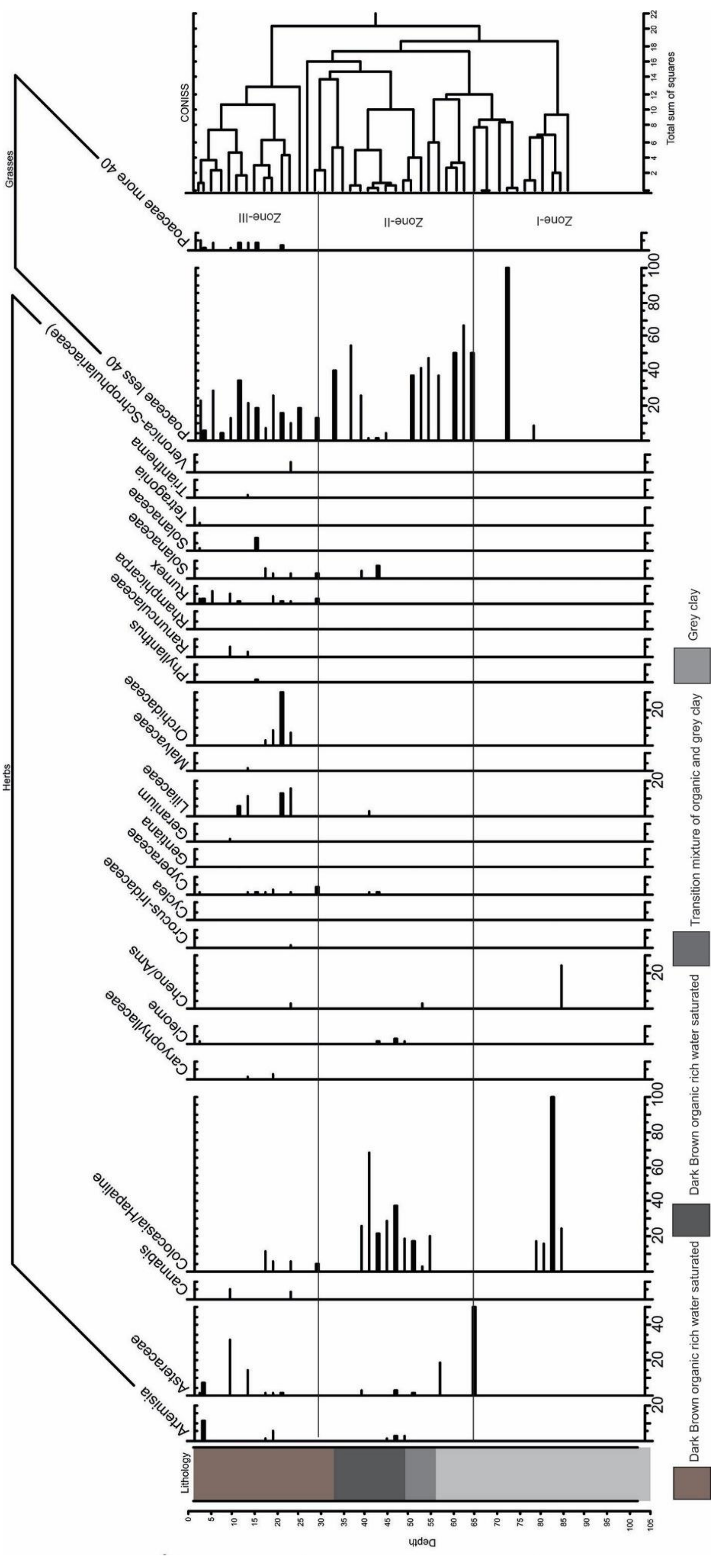


Figure 17: Spatial distribution of pollen data (ferns, aquatics and algal remains).

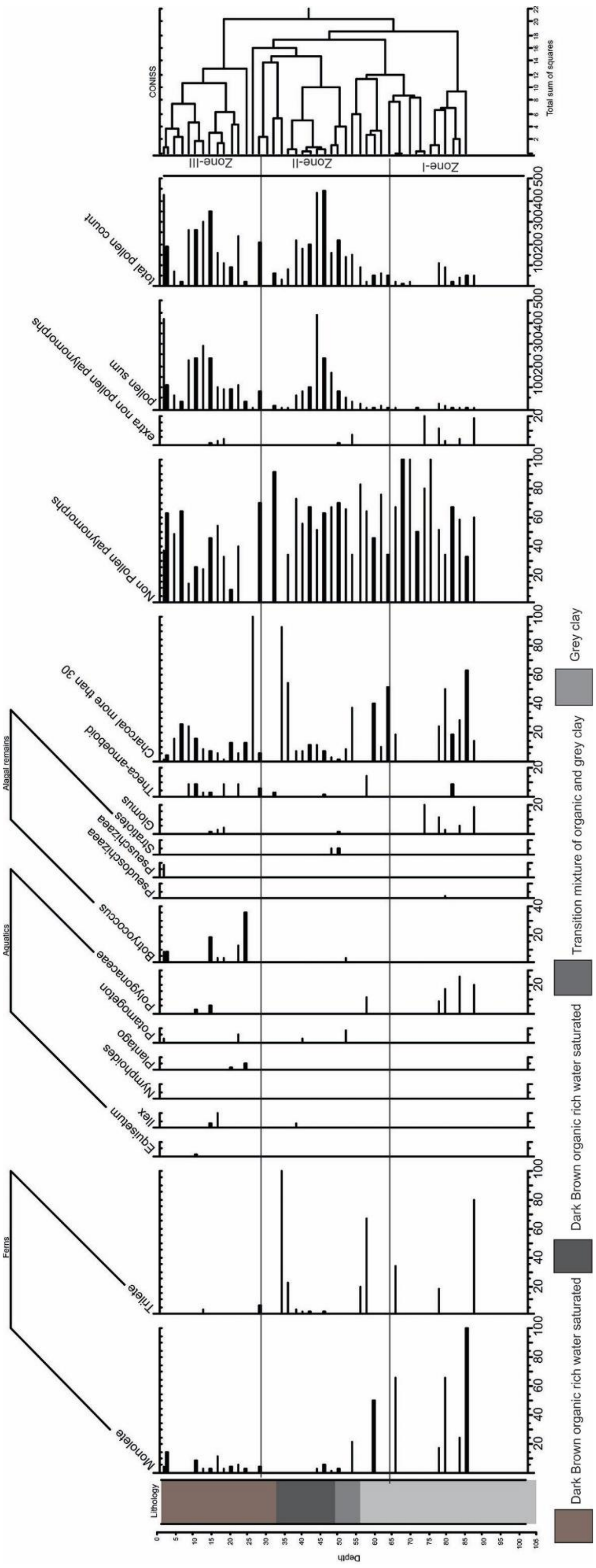


Figure 18: Spatial distribution of pollen data (Herbs)

Chapter 4

Discussions

4. Discussions

4.1. Grain Size

The dominance of coarse grains in the upper part of the core suggests a high-energy environment prevailing in the lake system from ca.1000 cal yr BP. The lower part of the core is characterized by finer grain sediments. This indicates a low energy environment, suggesting a relatively dryer period around ca. 2000 cal yr BP to 1000 cal yr BP.

4.2. Carbon stable isotopic composition:

To assess the organic matter (OM) sources (proportions of C3 and C4 plants, algal productivity) and concerning depositional processes of OM in a lacustrine environment is investigated using the carbon isotopic composition of OM in lake sediments (Meyers 1994, Meyers 1997, Talbot and Johanessen 1992, Hodell and Schelske 1998). The characteristic isotopic values correspondent to various vegetation types consisting C3, C4 and CAM are very well attributed to different physiological processes comprising photosynthetic pathways (Carbon assimilation), precipitation amount and gas exchange dynamics (Fractionation) (Kohn 2010, Hayes 1993).

Our work provides preliminary information for more accurate paleovegatation reconstruction in the region with isotopic values fluctuating from -23‰to -34‰ indicating the change in C3/C4 vegetation ratio. The vegetation cover over the region was covered with the mixed vegetation type in the zone 2 and later it was predominently dominated by C3 type of vegetation having an average isotopic value of -34‰. Subsequently, the highly depleted values of $\delta^{13}C$ in the zone 1 (1000cal yr BP- present) can be interpreted with high stomatal conductance, particularly to C3 plants. An increase in stomatal conductance that in turn results in the depletion of $\delta^{13}C$ (Farquhar et al, 1989, Feng & Epstein 1995, Anderson et al.1996, Schulze et al.1996, Korol et al.1999, Moore et al.1999, Miller et al.2001, Van de Water et al.2002, Swap et al.2004). Furthermore a change in the isotopic values is evidentially characterised with a change in climate conditions as well. C3 plants show $\delta^{13}C$ values of -23‰ to -35‰, whereas C4 plants have $\delta^{13}C$ values of -10 to - 16‰ (O'Leary, 1988). C3 plants are more abundant during wet conditions whereas C4 plants usually spread during phases of dry climate (Tieszen et al. 1979).

4.3. Nitrogen stable isotopic composition:

The nitrogen isotopic composition of OM in lake sediments are investigated to identify OM sources and for the reconstruction of trophic status (Meyers1997, Hodell and Schelske 1998, Herczeg et al. 2001, Meyers 2003, Ogrinc et al.2005). The $\delta^{15}N$ values of inorganic nitrogen varies from +7‰ to +10‰ (Meyers 1997), while Peters et al. (1978) demonstrated that the distinctive isotopic composition of the OM sources (Aquatic and land plants) to inorganic nitrogen and marine environment differs. The isotopic differences between these nitrogen sources is characterized with $\delta^{15}N$ values from algae (+8‰) and land plants (+0.5‰) (Peterson and Howarth 1987, Peterson and Fry 1987). Additionally, an isotopic increase also reflects constricted input of isotopically light land-plant detritus carried by the inflow streams. The shift therefore marks the source change with a change in the fraction of algal and land-plant contributions to the lake sediments. However, additional factors such as denitrification, nitrogen fixation and algal discrimination complicate interpretation or nitrogen isotopic composition of OM sources in a lacustrine environment (Teranes and Bernasconi 2000, Hodell and Schelske 1998, Fogel and Cifuentes 1993, Talbot and Laerdal 2000).

Here we hypothesize that the changes in isotopic values of nitrogen are because of changes in the organic matter contributions to the lake sediments. An increase in primary productivity is marked with the discrimination effect triggering an increase in $\delta^{15}N$ in the lake sediments (Hodell and Schelske 1998) supported with the strong correlation of $\delta^{13}C$ and $\delta^{15}N$ eliminating the presence of N_2 fixing algae component in the lake.

4.4. Pollen:

The interpretation of pollen diagram in terms of the extant vegetation vis-à-vis climatic change is very complex. The presence of good amount of diversified tress such as *Pinus*, *Quercus*, *Alnus* and others throughout ca. 1000 cal yr BP to present are suggestive of high moisture availability. The upper part of the pollen diagram (Figure 16, 17 & 18) shows pollen enrichment of *pinus* than its lower part which perhaps indicates drastic shift in vegetation pattern in the region. This in turn suggests a sudden switch from dry and cold environment to humid and warm environment.

Chapter 5

Conclusions

5. Conclusions

- Multi-proxy high resolution paleoclimatic records of Shilloi core sediments provide evidence for vegetational shift and rainfall variability in NE India during past ca. 2000 cal yr BP.
- The grain size variability and pollen data of Shilloi core sediments demonstrate increased ISM precipitation from ca. 1000 cal yr BP.
- The isotope data coupled with grain size parameters from the Shilloi core sediments will provide evidence of "Medieval Warm Period (MWP)"/ ‘Little Climatic Optimum’ (An epoch experiencing high temperature regime and considered to be warmest millennium of post-glacial times.) from NE India.

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