Peatland responses to Holocene climate change in a temperate poor fen, northeastern Pennsylvania

Shanshan Cai
Lehigh University

Follow this and additional works at: https://preserve.lehigh.edu/etd

Part of the Physical Sciences and Mathematics Commons

Recommended Citation
https://preserve.lehigh.edu/etd/1013

This Thesis is brought to you for free and open access by Lehigh Preserve. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of Lehigh Preserve. For more information, please contact preserve@lehigh.edu.
Peatland Responses to Holocene Climate Change in a Temperate Poor Fen, Northeastern Pennsylvania

September 2008
PEATLAND RESPONSES TO HOLOCENE CLIMATE CHANGE IN A TEMPERATE POOR FEN, NORTHEASTERN PENNSYLVANIA

by

Shanshan Cai

A Thesis

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Department of Earth and Environmental Sciences

Lehigh University

August 2008
Approved and recommended for acceptance as a thesis in partial fulfillment of the requirements for the degree of Master of Science

Date

7-17-08

---

Dr. Zicheng Yu (Thesis Advisor)

Dr. Robert K. Booth (Committee Member)

Dr. Dark Sahagian (Committee Member)

Dr. Joan M. Ramage (Committee Member)

Dr. Frank J. Panzarella (Department Chairperson)
ACKNOWLEDGEMENTS

I wish to thank my supervisor Dr. Zicheng Yu (Zic) for his tremendous patience and guidance throughout this work. Zic has given quite much of his time, energy, and thought to this thesis that I am very grateful. I also wish to thank my advisory committee Dr. Robert K. Booth for his great help on sample collecting and his professional and nice teaching and discussion on testate amoebae and humification analysis, Dr. Dork Sahagian and Dr. Joan M. Ramage for their insights and encouragement.

I wish to extend my sincere thanks to many people who have supported and encouraged me in this work. I thank my colleague Ms. Valerie Sousa for her help on testate amoebae analysis, Ms. Paula Zelanko and Spring 2007 class of EES 396 Wetlands for their help on coring, Mr. Michael Flanagan for his help on humification analysis, and Mr. Cheng Zhao for his help on lab and graph techniques. I thank Fall 2006 class of EES250 Terrestrial Ecosystem for their sharing data with me. I also thank all my graduate colleagues in the Department of Earth and Environmental Sciences for their always kind assistance and encouragement.

The project was supported by a grant to Zicheng Yu from Natural Science Foundation – Carbon and Water in the Earth System program.

Finally, I wish to give my particular thanks to my parents for their support and understanding on my study abroad. This thesis could not have been completed without the tremendous support of my husband, Heng Chiat Tai, throughout my program.
# CONTENTS

ABSTRACT .................................................................................................................. 1

1 INTRODUCTION ................................................................................................. 3
  1.1 HOLOCENE CLIMATE CHANGE ................................................................. 4
  1.2 PEATLANDS AND PEATLAND CARBON DYNAMICS ................................... 6
  1.3 CONCEPTUAL MODELS OF PEAT ACCUMULATION ................................. 9
  1.4 RESEARCH OBJECTIVES AND QUESTIONS .............................................. 11
  1.5 RESEARCH APPROACH .............................................................................. 13

2 STUDY REGION AND STUDY SITE ................................................................. 14
  2.1 PHYSIOGRAPHY ........................................................................................ 15
  2.2 CLIMATOLOGY .......................................................................................... 16
  2.3 HYDROLOGY ................................................................................................ 17
  2.4 VEGETATION ............................................................................................. 17
  2.5 SITE HISTORY ............................................................................................ 18

3 METHODS ........................................................................................................... 21
  3.1 SAMPLE COLLECTING ............................................................................... 21
  3.2 RADIOCARBON DATING .............................................................................. 21
  3.3 LOSS ON IGNITION ANALYSIS .................................................................. 22
  3.4 HUMIFICATION AND C/N ANALYSIS ...................................................... 22
  3.5 PLANT MACROFOSSIL ANALYSIS ............................................................. 24
  3.6 POLLEN ANALYSIS ................................................................................... 25
  3.7 TESTATE AMOEBAE ANALYSIS .................................................................. 26
  3.8 DIATOM ANALYSIS .................................................................................... 27
  3.9 PEAT ACCUMULATION ANALYSIS ............................................................ 28

4 RESULTS .............................................................................................................. 31
  4.1 RADIOCARBON DATES AND CHRONOLOGY .............................................. 31
  4.2 SEDIMENT LITHOLOGY .............................................................................. 32
  4.3 HUMIFICATION .......................................................................................... 34
  4.4 MACROFOSSIL RECORD .......................................................................... 35
  4.5 POLLEN RECORD ..................................................................................... 37
  4.6 TESTATE AMOEBAE AND WATER TABLE DEPTH RECONSTRUCTION .... 42
  4.7 DIATOM ABUNDANCE .............................................................................. 45
  4.8 CONCEPTUAL MODELING RESULTS ......................................................... 46
  4.9 SECOND CORE (TB06-2) .......................................................................... 48

5 DISCUSSION ......................................................................................................... 49
LIST OF TABLES

Table 1 AMS radiocarbon dates obtained from core TB07-1 at Tannersville Bog............31

Table 2 Pollen concentration and accumulation rates from each pollen zone at Tannersville Bog.................................................................41

Table 3 Testate amoeba zone descriptions for core TB07-1 at Tannersville Bog........42

Table 4 Estimates of long-term peat accumulation parameters.................................47

Table 5 Comparison of long-term rates of carbon accumulation (LORCA) at Tannersville Bog and other peatlands. .................................................................54

Table 6 Comparison of peat addition rate and decomposition rate at Tannersville Bog with boreal peatlands, and net annual primary production in temperate and boreal regions. ...........................................................................................................55
LIST OF FIGURES

Figure 1 Main boundary conditions and selected climate records for the last 12000 years ........................................ 5
Figure 2 Classification of functional levels of ecosystem and criteria that define the major boreal wetland types .................................................. 7
Figure 3 Generalized trajectories of the long term carbon accumulation in peatlands ........................................ 11
Figure 4 Flow chart and research design for the study at Tannersville Bog .................................................. 14
Figure 5 The location map of Tannersville Bog, Pennsylvania .................................................. 15
Figure 6 Climate Normal of monthly average air temperature and precipitation of the study area .................................................. 16
Figure 7 Cross-section of the Cranberry Creek Valley .................................................. 19
Figure 8 Topographic map and Google image of Tannersville Bog .................................................. 20
Figure 9 Age-depth model for core TB07-1 .................................................. 32
Figure 10 Sediment lithology of core TB07-1 .................................................. 33
Figure 11 Humification for peat samples from the top 400 cm .................................................. 35
Figure 12 Plant macrofossil diagram of core TB07-1 from Tannersville Bog .................................................. 37
Figure 13 Pollen diagram of core TB07-1 at Tannersville Bog .................................................. 39
Figure 14 Total pollen concentrations at Tannersville Bog .................................................. 41
Figure 15 Testate amoebae diagram of core TB07-1 from Tannersville Bog .................................................. 43
Figure 16 Testate amoeba-inferred water-table depth and peat humification-inferred paleohydrology of the upper 3.4-m section of core TB07-1 .................................................. 45
Figure 17 Diatom concentration counted from pollen/testate amoebae slides for the upper 3.4-m section of core TB07-1 .................................................. 46
Figure 18 Cumulative peat mass-age profile and fitting curves for Tannersville Bog .................................................. 47
Figure 19 Lithology, C/N ratio, and plant macrofossil of core TB06-2 from Tannersville Bog .................................................. 48
Figure 20 Correlation of lithology, plant macrofossil and pollen results core TB07-1 from Tannersville Bog .................................................. 51
Figure 21 Comparison of apparent carbon accumulation rates at Tannersville Bog and long term apparent rates of carbon accumulation (LORCA) from other peatlands .................................................. 53
Figure 22 Summary graph of lithology, apparent rate of carbon accumulation, plant macrofossil results, diatom concentration, humification, testate amoeba-inferred water-table depth, and zonation over the last 3500 years .................................................. 61
Abstract

Climate change can significantly affect the carbon balance of peatlands by influencing production and decomposition. Studying boreal peatlands along the edge of their southern limit can provide insight into responses of boreal peatlands to warmer climates. In this study, I derived multi-proxy data through loss-on-ignition, humification, plant macrofossil, pollen, testate amoebae and diatom analysis from Tannersville Bog in northeastern Pennsylvania. The aim was to test the hypothesis that a boreal-type poor fen associated with a temperate climate has a different peat accumulation pattern and higher peat accumulation rate compared to northern continental peatlands.

Plant macrofossil data indicate peat accumulation at Tannersville Bog was initiated by terrestrialization of a glacial lake at ~9000 cal years BP as a rich fen dominated by brown mosses. It changed to a poor fen dominated by Cyperaceae (sedge) and *Sphagnum* at ~1400 cal years BP and to a *Sphagnum*-dominated poor fen at ~200 cal years BP (1750 AD). The association of decline in hemlock (*Tsuga canadensis*) pollen at 5500-3000 years BP with decrease in brown moss macrofossils and increase in fine debris at 5000-2700 years BP appears to support the argument that the hemlock decline in mid-Holocene might have been caused by a dry climate, as documented in other studies. The transition to a poor fen was associated with major changes in lithology and hydrologic conditions, which was probably triggered by a dry climate event documented in a lake-level study in northern New Jersey.
A concave peat-age pattern over the last ~9000 years derived from \( 8^{14} \text{C} \) dates and 240 bulk density measurements is similar to patterns of oceanic bogs but different from those of continental fens. The peat-addition rate of \( \approx 170 \text{ gm}^{-2} \text{yr}^{-1} \) during the last 8000 years with a time-averaged mean of 27 gCm\(^{-2}\)yr\(^{-1}\) were higher than most boreal peatlands, although deep-peat decomposition rate was similar (0.0004 yr\(^{-1}\)). The relatively high accumulation rate may have been caused by high primary production (and possibly low acrotelm decomposition) associated with temperate climate. The results imply that some boreal peatlands can behave as carbon sinks under a warmer and wetter climate in the future.
1 Introduction

Northern peatlands contain a carbon pool of ~455 Gt (1 Gt = 10^{15} g) which is about 30% of the world’s terrestrial soil carbon, although they cover only about 2-3% of the earth’s land surface (Gorham 1991). Changes of peatlands between carbon source (peat degradation) and carbon sink (peat accumulation) can significantly affect the global carbon cycle especially in response to climate change. Peatlands have originated mostly by the processes of paludification (on previously drier, vegetated mineral soils due to water table rise) and terrestrialization (lake infilling). For example, peat may form directly on fresh, moist, nonvegetated mineral soils exposed from isostatic rebound, and/or be deposited on shallow basins once occupied by early Holocene lakes (Vitt 2006). The term peatland, commonly used in the North American literature, is used interchangeably with the European term mire.

Variations in climate (temperature and precipitation) have significant impact on carbon dynamics in peatlands through their influences on water table, photosynthesis, decomposition, and CH₄ and CO₂ fluxes. Climatic warming can cause substantial water table drawdown, due to increasing evapotranspiration, and subsequent peat oxidation in northern peatlands (Gorham 1991). However, as most carbon cycling studies have been focused on peatlands in boreal and subarctic regions, such as Canada, Siberia and northern Europe (Ovenden 1990; Gorham 1991; Warner et al. 1993; Charman et al. 1994; Botch et al. 1995; Tolonen and Turunen 1996; Walter 1997; Vitt et al. 2000; Yu et al.
2003; Belyea and Malmer 2004; Belyea and Baird 2006; Frolking et al. 2006; Roulet et al. 2007), responses of peatland carbon dynamics to climatic variations under a warmer climate have been poorly understood.

The research project of this study is focused on the climatic impact on peat accumulation at Tannersville Bog, located in northeastern Pennsylvania. Tannersville Bog is a southerly (41°N) low altitude (277 m above sea level) poor fen dominated by Sphagnum moss. This allows to study the impact of Holocene climate change on a boreal-like peatland in a generally warmer climate as a possible analogue of future warm climate, and to evaluate differences in peat accumulation between southern and northern Sphagnum peatlands.

1.1 Holocene Climate Change

The Holocene is the present interglacial period, spanning the last 11,600 years. The most pronounced radiative changes in the Holocene were a gradual decrease in the summer insolation (June-July-August) of more than 30 W/m² accompanied by an increase of about 15 W/m² in the winter insolation (December-January-February) (Figure 1a). The seasonal distribution of solar radiation at the top of the atmosphere primarily influences heat distribution on the Earth. The variation of insolation during the Holocene represents half of a 22,000-year precession cycle.
Figure 1 Main boundary conditions and selected climate records for the last 12000 years (the Holocene): a, insolation at 40°N (summer, winter, and annual) (Berger 1978); b, the area of the Laurentide ice sheet (LIS) as a fraction of its area during the last glacial maximum (LGM) (Shuman and Donnelly 2006); c, atmospheric CO2 concentration from Taylor Dome, Antarctic (Indermuhle et al. 1999); d, δ18O from Agassiz Ice Cap, Arctic Canada as a proxy of air temperature (Fisher et al. 1995); e, abundance of hematite-stained grains (HSG) from the North Atlantic as a proxy of ice bergs and temperature (Bond et al. 2001); f, SIRM from White Lake, New Jersey, North America as an indicator of lake-level changes (Li et al. 2007).

The Holocene started at 11.6 ka (1 ka = 1000 cal yr BP) associated with a marked climatic warming from 11 to 8 ka (Holocene Thermal Maximum) (Ritchie et al. 1983; Haug et al. 2001). A cold event at ca. 8.2 ka was documented by stable oxygen isotopes from Greenland ice cores (Johnsen et al. 2001). A warming period in the mid-Holocene between 8.6 and 4.3 ka was characterized with 0.5-2°C warmer than today (Fisher et al. 1995; Johnsen et al. 2001). The Little Ice Age started from 0.6-0.5 ka to 0.1 ka with a
significant cooling (COHMAP 1988). A ~1500 year climate cycle has been observed to characterize Holocene climate variability. Bond et al. (2001) showed that a solar forcing mechanism may influence the climate cycle in variations of oceanic thermohaline circulation in the North Atlantic.

The Holocene climate evolution in North America follows the same pattern. The millennial-scale climate cycle has also been observed in North America. For example, low lake levels have been documented at 1.3, 3.0, 4.4 and 6.1 ka for the past 6000 years (Li et al. 2007), likely corresponding to cold periods of North Atlantic Ocean documented in Bond et al. (2001). Studies on vegetation history reveal an abrupt decline of *Tsuga canadensis* (eastern hemlock) from 5.5 to 3 ka from pollen records in eastern North America, which may be related to a dry climatic interval that induced regional-to-continental changes in vegetation and water levels during this period (Foster et al. 2006).

### 1.2 Peatlands and Peatland Carbon Dynamics

Peatland ecosystems can be simply defined as “terrestrial environments where over the long term, on an areal basis, net primary production exceeds organic matter decomposition, leading to the substantial accumulation of a deposit rich in incompletely decomposed organic matter, or peat” (Wieder et al. 2006). Three major types of peatlands are rich fens, poor fens, and bogs (Figure 2). Fens are peatlands characterized by the presence of surface and ground water which also transports nutrients to peatlands (Vitt
Rich fens are often dominated by true mosses (i.e. brown mosses) and sedges, with high amounts of base cations and alkalinity, high pH, and high nutrient availability. Poor fens are often dominated by peat mosses (i.e. *Sphagnum*), low base cations and little or no alkalinity, low pH, and low nutrient availability. Bogs, especially raised bogs, are peatlands with precipitation as the only source of nutrient and water, and are typically characterized by abundant *Sphagnum* species, decreased amounts of base cations and no alkalinity, increased acidity, and decreased nutrient availability (oligotrophy).

![Classification of functional levels of ecosystem](image)

**Figure 2** Classification of functional levels of ecosystem (top) and criteria (bars with hierarchy clusters) that define the major boreal wetland types. Modified from Vitt (2006).
Peat accumulates whenever the rate of organic matter production exceeds the rate of decay. Though net primary production in boreal peatlands is lower than in many other ecosystems, peat accumulates as decay rates are extremely low in peatlands due to water-logged environment and anoxic conditions (Gorham 1991). The peat accumulation rate varies among peatlands owing to differences in geographical location (south greater than north), age (young greater than old), and type (Vasander and Kettunen 2006).

The peat growth rate in peatlands is in some degree regulated by *Sphagnum* moss which is the most dominant species in bogs and poor fens (Rydin et al. 2006). The refractory nature of *Sphagnum* causes the high acidity of soil and low decomposition of *Sphagnum* litter in the soil (e.g., decay rate of *Sphagnum* is 1/4 of that in other plants) (van Breemen 1995). *Sphagnum* peat conducts heat poorly, causing a short growing season for vascular plants on boreal peat, whereas the shallow euphotic zone of the *Sphagnum* carpet tends to be relatively warm (van Breemen 1995). The presence of *Sphagnum* also reduces supply of nutrients to vascular plants by effective interception of nutrients from the atmosphere and by slow mineralization and recycling (Maimer et al. 1994). Finally, depressed growth of vascular plants increases light availability and moisture by decreased evapotranspiration, which reinforces *Sphagnum* growth, and therefore peat growth. By building peat out of its own dead tissue, *Sphagnum* moss changes the supply of resources to other plants as the ecosystem engineer in bogs and poor fens (Rydin and Jeglum 2006).
1.3 Conceptual Models of Peat Accumulation

Dynamics of peat accumulation are determined by the processes of production and decay of organic matter. Based on different functional behaviors of production and decay, two or three layers can be distinguished in peat forming systems: litter, acrotelm, and catotelm (Clymo 1984; Yu et al. 2001a; Belyea and Baird 2006). In the litter layer, or living plants layer, production is the major process of carbon input, while rapid initial decomposition removes about 20% of the litter mass including leaching of soluble organic materials (Heal et al. 1978), before the litter enters the underlying layer as a new source of peat. The product of this initial decay is most likely in the form of dissolved organic carbon rather than CO₂ or CH₄, and the decomposition rates of litter are influenced by mean temperatures and temperature fluctuations (Clymo 1984; Yu et al. 2001b). Below the litter layer is the acrotelm, which is a layer with fluctuating water table, variable water content, periodically aerobic, high decomposition rate with both aerobic and anaerobic bacteria, and relatively fast water movement. Catotelm is the layer permanently saturated with water, and therefore only comprises low anaerobic decomposition. The boundary between the acrotelm and catotelm is approximately the average water table below the vegetated surface (Ingram 1983; Clymo 1984). The bulk density becomes higher when plant mass decay and collapse, so the hydraulic conductivity is much lower in the catotelm than in the acrotelm.

Peat accumulation in the catotelm can have three general trajectories as shown in
the age-depth (cumulative mass) plots: linear, concave, and convex patterns (Figure 3). A linear relationship (Figure 3: curve II) between cumulative peat mass and time could occur if change in mass over time were constant (constant apparent accumulation rates). This assumption seems implausible in most peatlands, and the generally accepted assumptions are that the rate of decay is directly proportional to the amount of mass left (Jenny et al. 1949; Clymo 1984). Two other trajectories have been observed in various peatland types. The concave curve (Figure 3: curve I) developed by Clymo (1984) for cumulative mass vs. age indicates higher apparent accumulation rates in younger peat and lower rates in older peat, which is the general pattern of peat accumulation in bogs under oceanic climate. The convex curve (Figure 3: curve III) developed by Yu et al (2003) has been observed in continental fens in western Canada, which implies lower apparent accumulation rates in younger peat and higher rates in older peat. The convex shaped pattern implies that peatlands will reach their growth limit sooner and that their carbon sequestration capacity will decline faster than would be expected in the concave shaped pattern (Figure 3), disregarding climatic change (Yu et al. 2003).

Climatic change (variations in temperature and precipitation) and induced changes in moisture and vegetation would have significant effects on the rate of peat decay, the rate of peat addition into the catotelm (the mass input from the bottom of acrotelm per unit time), and therefore the peat accumulation pattern. Based on the concave model, Clymo (1998) suggested that the value of rate of peat addition was
related to the degree-days above 0°C and proportional decay rate was exponentially related to mean annual temperature. The ranges of average long-term carbon accumulation (g C m⁻² yr⁻¹) estimated in individual cores from Finnish peatlands were much higher in bogs than in fens and almost double in southern peatlands as compared with those in the northern Boreal zone (Tolonen and Turunen 1996).

**Figure 3** Generalized trajectories of the long term carbon accumulation in peatlands: I: higher apparent accumulation rates in younger peat and lower rates in older peat (concave pattern); II: constant apparent accumulation rates; and III: lower apparent accumulation rates in younger peat and higher rates in older peat (convex pattern). Modified from Yu (2006).

### 1.4 Research Objectives and Questions

Peat accumulates whenever the rate of organic matter production exceeds the rate of decay. Higher peat accumulation rates can be attributed to two reasons: higher production at the peat surface, or a lower decomposition rate. Warmer climate with a
longer growing season and/or higher moisture conditions can favor primary production in peatlands (Belyea and Malmer 2004). A longer growing season and/or higher temperature may result in greater evaporation and a longer seasonal drawdown of water table, which exposes more peat to be oxidized; meanwhile, the decomposition rate is positively correlated with soil temperature (the higher the soil temperature, the higher the decomposition rate) (Carroll and Crill 1997; Frolking et al. 2001). Conversely, wetter climate or higher precipitation would affect the dynamics of hydrology in peat, likely increasing primary productivity and water table which impedes decomposition of peat.

The aim of this research is to test the hypothesis that a boreal-type poor fen associated with a temperate climate, such as Tannersville Bog, has a different peat accumulation pattern and higher peat accumulation rate during the Holocene compared to northern continental peatlands. The temperate climate is characterized by warm climate with an average high temperature of about 10°C and annual precipitation greater than 1000 mm, while the climate of northern continental peatlands is characterized by a mean annual temperature of 0°C and annual precipitation less than 600 mm. Climate, therefore, must have a significant effect on carbon accumulation by influencing primary production and decomposition. To evaluate this idea, I will address the following questions:

1) What is the peat accumulation pattern of Tannersville Bog during the Holocene? Is this pattern different from the pattern observed in northern continental peatlands of different types in boreal and subarctic regions? What is the reason for the difference?
2) What is the peat accumulation rate at Tannersville Bog? Is the rate higher or lower than the rates of northern peatlands of different types? What caused the higher/lower rates compared to the rates of northern peatlands?

3) How have the local vegetation, substrate moisture conditions and regional vegetation changed at Tannersville Bog during the Holocene? Were the changes in local vegetation succession influenced by climate change?

4) How has peat accumulation of Tannersville Bog responded to the variations of local vegetation, substrate moisture condition and regional vegetation during the Holocene?

1.5 Research Approach

I used multi-proxy data derived from peat cores to document the peat accumulation pattern and accumulation rate, climate variations, and decomposition at Tannersville Bog. Proposed analyses are illustrated in a flow chart (Figure 4). Loss-on-ignition (LOI) analysis was used to estimate organic matter content, to calculate bulk density, and to quantify the accumulation of organic matter. AMS radiocarbon dating was used to derive chronology and to calculate peat accumulation rates during the Holocene. A simple conceptual model was used to estimate long-term peat-addition rate (PAR) and decomposition coefficients by curve fitting analysis. Humification and C/N ratio analyses were conducted to examine the variations of the degree of decomposition and the carbon loss along the peat profile, which would help me to understand the relative roles of production and decomposition processes in determining peat accumulation.
These results will be compared with data from Alaskan peatlands and other northern peatlands to investigate the differences between temperate and boreal peatlands, and to understand the effects of warmer climate on peat accumulation at Tannersville Bog.

![Flow chart and research design for the study at Tannersville Bog.](image)

**Figure 4** Flow chart and research design for the study at Tannersville Bog.

Climate change and variability can be inferred from regional vegetation, local vegetation and moisture conditions at Tannersville Bog. Pollen analysis was conducted to reconstruct regional vegetation, and macrofossil analysis was utilized to reconstruct local vegetation. Testate amoebae analysis was conducted to reconstruct surface moisture condition. The reconstructed paleoclimate was used to study the impact of climatic variability on local vegetation change and peat accumulation.

2 Study Region and Study Site
2.1 Physiography

Tannersville Bog is located at the edge of the Pocono Mountains in Monroe County, Pennsylvania (75° 16’W, 41° 02’N, Figure 5) with a current size of the 3 km². Bedrock in the region consists of gently dipping Paleozoic age (570-225 million years, or ma) strata consisting of sandstones and shales. During the Pleistocene (1.8 ma - 10 ka) the rocks were eroded by advancing glaciers and covered by glacial deposits (Hirsch 1977). Tannersville Bog was once a glacial lake before the Holocene and developed by the lake-infilling (terrestrialization) process (Watts 1979).

Figure 5 The location map of Tannersville Bog, Pennsylvania.
2.1 Physiography

Tannersville Bog is located at the edge of the Pocono Mountains in Monroe County, Pennsylvania (75° 16’W, 41° 02’N, Figure 5) with a current size of the 3 km². Bedrock in the region consists of gently dipping Paleozoic age (570-225 million years, or ma) strata consisting of sandstones and shales. During the Pleistocene (1.8 ma - 10 ka) the rocks were eroded by advancing glaciers and covered by glacial deposits (Hirsch 1977). Tannersville Bog was once a glacial lake before the Holocene and developed by the lake-infilling (terrestrialization) process (Watts 1979).

Figure 5 The location map of Tannersville Bog, Pennsylvania.
2.2 Climatology

The study area is characterized by temperate climate with a mean maximum air temperature of 16°C, a mean minimum air temperature of 3°C, and a mean annual temperature of ~10°C (Stroudsburg station 2005 NOAA, 10 km from Tannersville Bog). The mean annual precipitation is around 1256 mm (Stroudsburg station 2005 NOAA). In 2006, 1570 mm of precipitation was reported at Tannersville station (Tannersville 2e, NOAA). Figure 6 shows the monthly average air temperature and precipitation in the study area based on the normal climate from 1971 to 2000.

**Figure 6** Climate Normal (1971-2000) of monthly average air temperature (line with markers) and precipitation (bars) of the study area (Data from the weather station of Tobyhanna Pocono Mountain which is 11 km northwest of Tannersville Bog).
2.3 Hydrology

Tannersville Bog is fed mainly through precipitation and surface water (Luebbe 2007). Although it is called a bog, it is actually an acidic poor fen also fed by groundwater coming from the uplands, with a pH of \( \sim 5.1 \). A first-order stream, Cranberry Creek, flows through Tannersville Bog. The discharge and flux of dissolved organic carbon (DOC) in Cranberry Creek are greatest from the summer into early-fall and generally varied with average temperature (Luebbe 2007). In 2006, the DOC concentration ranged from 3 to 23 mg/L in Cranberry Creek with an annual DOC flux of 12.18 g/m\(^2\)/yr (Luebbe 2007).

2.4 Vegetation

The upland vegetation is mostly secondary oak forest. *Pinus rigida* (pitch pine) is present locally, and large *Fagus* (beech) occur in the Pocono Mountains (Gehris 1964; Watts 1979). Tannersville Bog is dominated by peat moss (*Sphagnum*). Open areas in the middle of the poor fen are dominated by *Sphagnum* with patches of *Vaccinium macrocarpon* (cranberry), *Ledum groenlandicum* (Labrador tea), and *Chamaedaphne calyculata* (leather leaf). Dominant trees are *Picea mariana* (black spruce) and *Larix laricina* (tamarack) rooted in hummocks of *Sphagnum* moss. Tannersville Bog is one of the southern-most (41°N) low altitude (277 m) *Sphagnum* dominated poor fens along the eastern seaboard, and one of the Nature Conservancy's first preserves.
2.5 Site History

Tannersville Bog was first investigated by Gehris (1964), who analyzed pollen grains from a 10.5-m peat profile from a site close to the creek, in the central open area of the peatland which was believed to be deepest (Figure 7). He noted two watery pockets at 1.5-1.8 m and at 5.8-6.1 m below the peat surface, attributed to floating mats. Above 1.5 m, the peat was relatively coarse and dark brown in color. From 1.8 to 8.1 m, it was peaty brown (except for watery pocket). From 8.1 to 10.2 m, the gritty content of peat gradually increased. Below 10.2 meters, the sediment is bluish-gray clay having a unique purplish tint in the sunlight. In the report to the Nature Conservancy, Hirsch (1977) indicated (Figure 7) that the peat is deepest at the central part of the bedrock valley with a maximum depth of ~11 m; the peat is underlain by a dark brown peaty clay that ranges in thickness from 0 to 5.5 m wherever the peat is more than 3 m; beneath the peat, the basal sediment is a layer of pink, gray, or white silty clay (>0.6 m thick) extending over the top of bedrock that forms an impermeable layer between the bedrock and overlying peat where the depth is over 6 m.
Figure 7 Cross-section of the Cranberry Creek Valley. The Tannersville Bog section is based on borings that were proximal to the line of section (Hirsch 1977).

Watts (1979) analyzed pollen and macrofossils from a 13-m sedimentary core from Tannersville Bog (Figure 8) spanning 13,300 $^{14}$C years to investigate the earliest vegetation after deglaciation. He calculated an average sedimentation rate of 12.2 yr/cm which did not distinguish the sedimentation of peat and lake sediments. Watts’ (1979) pollen diagram illustrated the decline of white pine and a rise in oak that is accompanied by a steep rise in hemlock shortly after 9800 $^{14}$C yr BP; oak has been continuously predominant through the Holocene to the present day while hemlock declined before 4600 $^{14}$C yr BP. Sphagnum spores and aquatic taxa were present throughout the Holocene but became dominant in the late Holocene. Macrofossil results suggest that Tannersville Bog was a lake until the middle Holocene when Larix appeared in the profile after 8000 $^{14}$C yr BP.
Figure 8 Topographic map and Google image of Tannersville Bog (also called Cranberry Swamp, or Tannersville Cranberry Bog), with previous coring sites and our three coring sites (solid dots). Light-colored linear features are boardwalk.
3 Methods

3.1 Sample Collecting

A 1073-cm sediment core (TB07-1) was collected on 24 March 2007 at Tannersville Bog (41.03817° N, 75.26582°W), about 10 meters away from boardwalk west of the Cranberry Creek (Figure 8). The top 183 cm were recovered using a 10.2-cm-diameter modified Livingstone piston corer (Wright et al. 1984), and lower sediments were collected using a 5-cm-diameter modified Livingstone piston corer. Core segments of 100 cm long were extruded in the field and wrapped in plastic wrap and stored in polyvinylchloride pipe during transportation to the laboratory, where they were stored at 4°C in a cold room.

3.2 Radiocarbon Dating

AMS radiocarbon analysis on hand-picked plant macrofossils was used to date the peat core. Only the macrofossils from non-aquatic plants (e.g., Sphagnum moss, Ericaceae leaves, charcoal, or ligneous plant fragments) are used for dating to avoid hard-water effect (some aquatic plants absorb bicarbonate formed from limestone). AMS samples were analyzed at the W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory (KCCAMS) in the Department of Earth System Science at the University of California, Irvine. Thirteen peat samples from selected 1-cm-thick slices at approximately 100-cm intervals were submitted for AMS radiocarbon dating, of which 12 radiocarbon dates were obtained. Radiocarbon dates were calibrated with IntCal04 calibration data set.
(Reimer et al. 2004) using the program Calib v5.01 (Stuiver et al. 1998). Age-depth model was reconstructed with a cubic polynomial regression on the median probability age within ~95% possibility range (2 standard deviation).

3.3 Loss on Ignition Analysis

Sequential loss on ignition (LOI) analysis is a commonly used method to estimate the moisture, organic and carbonate contents of sediments (Dean 1974; Heiri et al. 2001). Moisture content is estimated by the weight loss at 100°C; organic matter content can be calculated by the weight loss at 550°C; and carbonate content is calculated by the weight loss at 1000 °C. LOI provides a fast and inexpensive method of determining organic content and carbonate of clay-poor calcareous sediments with precision and accuracy (Dean 1974). Volumetric samples (1.4 cm$^3$) were selected from 1-cm-thick slices at 2-cm interval for the upper 4-m peat core and at 10-cm interval for the lower 6.73-m peat core from Tannersville Bog. Bulk density measurements were calculated using sample volume and dry weight.

3.4 Humification and C/N Analysis

Humic acids are produced by the decomposition of organic material. They are dark brown in solution. The proportion of humic acid increases as peat decomposes. This principle has been used to estimate the quantities of humic acid in peat, based on the assumption that the color of the extracts are indicative of the degree of humification and therefore the degree of decomposition (Caseldine et al. 2000). Since decomposition is
primarily a function of the degree of surface wetness of a peatland, the humification record represents a paleohydrological proxy, although it is influenced by the botanical composition of the peat. The sodium hydroxide (NaOH) extracts are most widely used in this technique. The standard colorimetric technique has been used to reconstruct peatland surface wetness in several recent studies (Booth and Jackson 2003; Langdon and Barber 2005).

Fossil C/N ratios of bulk peat and *Sphagnum* fossils provide an index to represent the degree of carbon losses through anaerobic decay in the catotelm (Kuhry and Vitt 1996). Slow anaerobic decomposition in the catotelm results in continuous carbon loss through processes such as sulphate reduction and methanogenesis (Mitsch and Gosselink 2000). Nitrogen is lost mainly by becoming immobilized in the catotelm in spite of the small amount lost from the acrotelm through denitrification, grazing, burning, surficial runoff, and erosion (Mitsch and Gosselink 2000). About 95-98% of the nitrogen in the moss and other components of the peat is recycled while 80-90% of the carbon is lost through aerobic decomposition (Kuhry and Vitt 1996). Due to the preferential loss of carbon in the catotelm, nitrogen is consequently relatively enriched and carbon/nitrogen ratios gradually decrease moving down along the peat profile (Malmer and Holm 1984; Kuhry and Vitt 1996). Study on fossil C/N ratios by Kuhry and Vitt (1996) shows that the decrease of C/N ratios corresponds to carbon loss when nitrogen losses in the catotelm of bog ecosystems can be considered negligible, and that net carbon accumulation rates are
significantly correlated with the nitrogen accumulation rate gradient.

Humification and C/N analysis were conducted on peat samples from Tannersville Bog. A Genesys™ 10 series spectrophotometer (Thermo Electron Corporation) was used to measure the percentage of light transmittance at wavelengths of 400-1000 nm. Measurement was conducted on 0.2 g powdered peat from 1-cm-thick slices at 10-cm sampling interval. The percentage of light transmittance at 540 nm was used in the paleo-hydrology reconstruction. The higher percent of transmittance means lower degree of peat decomposition, indicating a wet condition (Booth and Jackson 2003). C/N ratio measurements for the short core were obtained by measuring carbon and nitrogen content in samples at the same resolution with humification analysis, using total organic carbon and nitrogen analyzer (Shimadzu TOC-Vcph and TNM-1).

3.5 Plant Macrofossil Analysis

Plant macrofossils preserved in peat profiles are indicative of local vegetation changes (Barber et al. 1994). Variations of local vegetation could represent a sequence of autogenic change or could be in response to climate change (allogenic effect). I used a semi-quantitative method for macrofossil analysis following Yu et al. (2003). Peat subsamples of approximately 1 cm³ were taken every other centimeter for the upper 4-m section and every 20-cm for the lower 6.73-m section and dispersed into a custom-designed picking tray with channels (“channeled plexiglass template”) without chemical treatment and sieving. The macroscopic components are usually composed by
recognizable plant remains and unrecognizable debris (Yu et al. 2003). The relative abundance of unrecognizable debris independently reflects the degree of decomposition of each measured sample. The subsamples were examined under a dissecting stereomicroscope to identify and estimate relative abundance of different macroscopic components, including *Sphagnum*, brown mosses, herbs (Cyperaceae), ligneous (woody materials from shrubs or trees and charcoals), and unrecognizable debris. Identification was aided by Lévesque et al. (1988) and online identification key by Dale Vitt (http://www.peatnet.siu.edu/PeatGuide.html). The sampling resolution of plant macrofossil analysis is the same as for LOI analysis.

### 3.6 Pollen Analysis

Pollen as a proxy of regional vegetation and climate change at Tannersville Bog allow me to address the possible connection between climate, upland vegetation, and peatland ecosystem changes. The hemlock (*Tsuga*) decline at ~5.5 ka is a widespread palynological event in eastern North America and has been attributed to a dry climate (Yu et al. 1997; Foster et al. 2006). To study the peatland responses to this event, the pollen record provides the information of climate change that is used to investigate the association with other independent records, such as plant macrofossil-inferred peatland vegetation dynamic and testate amoeba-inferred water table depth. Also, in northeastern United States *Ambrosia* (Ragweed) pollen increased rapidly, corresponding to the European settlement and forest clearance for agriculture at ~250 years BP (Russell 1980;
Willard et al. 2003). This pollen horizon can be used for dating the recent peat profile.

Pollen analysis was conducted on 1-cm-thick slices from Tannersville Bog at 10-cm interval for the upper 3.4-m by using the same sample preparation for testate amoebae analysis as described in the following section. The lower 7.3-m peat was analyzed at 20 cm intervals with a modified standard method for pollen sample preparation (Fægri and Iversen 1989). One Lycopodium spore tablet (batch No. 938934, mean = 10679 spores) was added during sample preparation as spike used in the calculation of pollen concentration. Pollen and spores were identified and counted under a compound microscope at 400× magnification following the illustrated key by McAndrews et al. (1973). The percentages of pollen, spore and aquatics were calculated based on the total pollen sum which includes trees and shrubs, upland herbs, Pteridophytes, unknowns and indeterminable types. The pollen diagram was plotted using TGView v 2.0.2 with cluster analysis conducted by CONISS (Grimm 1987).

3.7 Testate Amoebae Analysis

Testate amoebae (Protozoa: Rhizopoda) assemblages provide quantitative estimates of water table and soil moisture in Sphagnum peatlands (Woodland et al. 1998; Charman et al. 1999; Booth 2002; Booth and Jackson 2003; Charman et al. 2004). Testate amoebae are microscopic Protists, typically between 20 and 250 μm in size, which inhabit the surface layers of peatlands and other moist soils and the benthic environment of freshwater lakes (Charman et al. 2000). Testate amoebae live within thin water films
around soil particles and on Sphagnum leaves and stems. In Sphagnum peatlands, testate amoebae are a major component of the microfauna (Woodland et al. 1998). The sensitivity of testate amoebae to moisture has been documented in several paleoecological studies by comparison with other independent proxies, including peat humification and plant macrofossils (Charman et al. 1999; Booth and Jackson 2003; Langdon and Barber 2005). Charman (2004) examined the relationships between a 200-year record of reconstructed water table change from testate amoebae, instrumental water table and climate data in Europe, and showed that ombrotrophic peatland surface wetness records primarily reflected summer moisture balance.

At Tannersville Bog testate amoebae analysis was carried out at 10-cm intervals using 3 cm$^3$ of peat samples from selected 1-cm-thick slices using the method described in Booth (2007). Taxonomy follows Charman et al. (2000) and Booth (2007). A Lycopodium spore tablet was added to each sample for the calculation of testate amoeba concentration. The count total is the sum of all identified testate amoeba types and indeterminables. The testate amoebae diagram was plotted in TGView v 2.0.2 with CONISS for zonation. Water-table depths were reconstructed by weighted averaging partial least squares transfer function model based on a calibration datasets developed from North American peatland samples (Booth 2008).

3.8 Diatom Analysis
Diatoms represent a group of algae whose siliceous valves are usually well preserved in sedimentary deposits. They are usually typical of clean-water environments (Cushing and Allan 2001). Diatom growth is optimal in open water and in low acidity environments, so its abundance indicates the moisture conditions and types of peatlands (Smol 1990). I estimated the abundance of diatoms on pollen and testate amoebae slides for the samples from the upper 340-cm section of core TB07-1, without identifying to specific taxa. The calculation of diatom concentration is based on the same spike as described in section 3.7.

3.9 Peat Accumulation Analysis

Peat accumulation in the catotelm can have three general trajectories as shown in Figure 3 (subsection 1.2). The rate of decay is directly proportional to the amount of mass left (Jenny et al. 1949; Clymo 1984):

\[ \frac{dm}{dt} = -\alpha m, \]

where \( m \) is the mass at time \( t \), \( \alpha \) is the decay parameter.

The solution is:

\[ m = m_0 e^{-\alpha t}. \]

where \( m_0 \) is the original mass.

This equation implies that there is always some of the plant material left, and a plot of logarithmically scaled \( m \) vs. \( t \) is a straight line (Clymo 1984).

Clymo’s concave curve was originally based on Ingram’s (1982) hydrological
model. Water flows laterally in the acrotelm but there is almost no lateral flow in the water-saturated catotelm. The average water table or the boundary therefore rises at the same rate at which peat accumulates. Based on the exponential decay model (equation 1), a more specific model for the peat accumulation in the catotelm can be described with a constant peat addition rate, $p$ (the rate of peat mass input from the bottom of the acrotelm), and decay at a rate ($\alpha$) proportional to the amount of mass ($x$) at any time ($t$):

\[
\frac{dx}{dt} = p - \alpha x .
\]

The solution is:

\[
x = \frac{p}{\alpha} (1 - e^{-\alpha t}) .
\]

In this equation, the present surface of the catotelm can be arbitrarily set at any depth and the other values of mass and age are expressed relative to that depth, and $p$ and $\alpha$ have been constant over the time under consideration. Equation 3 generates an age-depth (or cumulative mass) curve in a concave shape. The concavity indicates a long-term trend which cannot be explained by change in bulk density only; it is suggested there is decay ($\alpha > 0$) in the catotelm (Clymo 1984). Most of the mass loss in the catotelm is attributed to the fact that the decayed organic matter leaves the system through diffusion, by mass flow in solution, and by gas bubbles of methane (Gorham 1991).

For core TB07-1 from Tannersville Bog, I applied the calibrated radiocarbon ages obtained from the peat core and the ash-free bulk density to calculate cumulative peat mass and apparent peat accumulation rates. Based on the calculation, I used the Clymo
concave model (equation 4) to estimate parameters including long-term peat-addition rates and catotelm decomposition rate in Tannersville Bog. Exponential regressions have been conducted on different continuous periods of time to explore the variations of peat addition rate ($p$) and decomposition rate ($a$) with time.
4 Results

4.1 Radiocarbon Dates and Chronology

One of twelve radiocarbon dates (Table 1) were rejected: the date at depth of 375-376 cm is reversed (Figure 9). The 11 accepted calibrated ages were used in the age-depth model using a cubic polynomial regression curve (Figure 9). The square of the correlation coefficient \( R^2 \) is 0.9991. The p-values of all regression coefficients are less than 0.0001, which means all the regression coefficients are statistically significant. Based on this age model, the temporal sampling resolution ranges from 4 to 18 years for each contiguous 1-cm interval. A time scale based on this age model is used in this study.

Table 1 AMS radiocarbon dates obtained from core TB07-1 at Tannersville Bog.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Material dated</th>
<th>AMS No.*</th>
<th>14C yr BP</th>
<th>Calibration year BP** (95% range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-100</td>
<td>Needles, Ericaceae leaves, woody fragments</td>
<td>38081</td>
<td>340±30</td>
<td>394.5 (326-473)</td>
</tr>
<tr>
<td>199-200</td>
<td>Ericaceae leaves, woody fragments</td>
<td>38082</td>
<td>1250±30</td>
<td>1217.5 (1170-1265)</td>
</tr>
<tr>
<td>235-236</td>
<td>Ericaceae leaves, woody fragments, seed</td>
<td>42064</td>
<td>1540±25</td>
<td>1439 (1370-1519)</td>
</tr>
<tr>
<td>299-300</td>
<td>Ericaceae leaves</td>
<td>38083</td>
<td>2010±30</td>
<td>1959 (1923-1995)</td>
</tr>
<tr>
<td>375-376</td>
<td>Ericaceae leaves, needles, woody fragments, sedge s</td>
<td>42065</td>
<td>1535±25</td>
<td>1420 (1381-1509)</td>
</tr>
<tr>
<td>498-500</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38084</td>
<td>4305±40</td>
<td>4856.5 (4836-4877)</td>
</tr>
<tr>
<td>598-600</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38085</td>
<td>5555±50</td>
<td>6348.5 (6299-6398)</td>
</tr>
<tr>
<td>698-700</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38086</td>
<td>7320±80</td>
<td>8107 (8018-8196)</td>
</tr>
<tr>
<td>711-713</td>
<td>Peat</td>
<td>42066</td>
<td>7365±25</td>
<td>8183 (8046-8307)</td>
</tr>
<tr>
<td>799-800</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38087</td>
<td>7420±60</td>
<td>8251.5 (8185-8318)</td>
</tr>
<tr>
<td>898-900</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38088</td>
<td>8910±50</td>
<td>10047 (9916-10178)</td>
</tr>
<tr>
<td>1013-1014</td>
<td>Ericaceae leaves, woody fragments, sedge leaves</td>
<td>38089</td>
<td>9565±40</td>
<td>10912.5 (10745-11080)</td>
</tr>
</tbody>
</table>

*: AMS \(^{14}\)C dates were measured in KCCAMS UCI.
**: calibrated ages are the median of 95% probability;
***: date at depth of 375-376 cm was rejected and not used in the age model.
Figure 9 Age-depth model for core TB07-1 using cubic polynomial regression on calibrated AMS $^{14}$C dates.

4.2 Sediment Lithology

The peat moisture content of the core TB07-1 ranges from 90% (top 8 m) to 75% (Figure 10a). The organic matter (OM) content of the dry material is highest (~96%) for the upper 2 m (0-1.4 ka), which decreases to ~50% below 2 m (from ~1.4 to 9 ka), and further declines to <30% at the base of the core (Figure 10b). The remaining dry material consists of carbonate and non-carbonate silicate minerals. The carbonate content of the dry material is lowest in the upper 2 m, and has an excursion up to 10% at the middle part (1.4-3.4 ka) of the peat core, while the value declines to ~5% for the lower part from ~3.2
ka toward the base part (Figure 10c). Non-carbonate material (mostly silicate) is lowest in the upper 2 m, which increases to a high content of \( \sim 50\% \) before 1.4 ka and reaches \( \sim 80\% \) in the base (Figure 10d). The ash-free (OM) bulk density ranges from 0.03 to 0.11 g/cm\(^3\), with an average of 0.065 g/cm\(^3\) (Figure 10e). The basal peat has relatively lower moisture and ash-free bulk density due to low organic matter content, and high non-carbonate minerals. The whole core shows clear variations of mineral composition with depth.

**Figure 10** Sediment lithology of core TB07-1. a, moisture content; b, organic matter.
content; c, carbonate content; d, non-carbonate (silicate) content; e, ash-free bulk density.

4.3 Humification

The peat humification measurements on samples for the last 3500 years from Tannersville Bog demonstrate that the transmission at 540 nm ranges from 51.7% to 68.8% (Figure 11). Compared to other North American peatlands (Sousa 2008), the results suggest that the peat appears to be less humified and presumably under relatively stable hydrological conditions. Four humification zones were defined by visual inspection (Figure 11). Zone H-1 (3.4-1.5 ka) has relatively high transmittance of ~62-68% with moderate variability, suggesting low decomposition and wet conditions. Zone H-2 (1.5-0.9 ka) has the lowest transmittance of 52% with values fluctuated between 50% and 60%. Except for one data point, H-2 represents relatively high peat decomposition and dry conditions. H-3 (0.9-0.4 ka) is characterized by intermediate humification with relatively small variability, which represents a period with relatively stable moist conditions. In contrast to the other zones, H-4 (0.45 ka-present) has the largest variations in transmittance with relatively low values on average, which suggest frequently changed moisture availability under generally dry conditions in the last 500 years.
Figure 11 Humification for peat samples from the top 400 cm at 10-cm sampling interval measured as percent of transmission at 540 nm. The horizontal line (x̄) is the numerical average of humification (61.5%) in the last 3500 years.

4.4 Macrofossil Record

Five plant macrofossil zones have been identified by visual inspection of dominant components (Figure 12). The macrofossil results show that the basal “peat” (11-9 ka) is dominated by filamentous green alga, woody material and charcoal with low brown moss leaves, suggesting an open water environment (zone M-1, Figure 12). Zone M-2 (9-5 ka) is dominated by brown moss leaves and stems with low abundance of woody materials and Cyperaceae leaves, which indicates a characteristic of rich fen vegetation. Zone M-3 (5-2.7 ka) is characterized by decline of brown moss, prevailing absence of Cyperaceae, and high abundance of fine debris, indicating a dry condition.
Zone M-4 (2.7-1.4 ka) shows a recovery of brown moss abundance with a decrease of detritus component toward the top of the zone. There is a major shift of dominant plant macrofossil from M-4 to M-5. Zone M-5 (1.4-0.2 ka) is characterized by the high abundance in Cyperaceae leaves and roots, increased abundance of *Larix* needles, Ericaceae leaves and roots, and woody fragments, presence of low abundant *Sphagnum* leaves, and the absence of brown moss. Zone M-6 (0.2 ka - present) is dominated by *Sphagnum* leaves and stems, *Picea* and *Larix* needles, Ericaceae leaves and roots, and decreased Cyperaceae leaves and roots. In this zone, brown moss leaves are only present in a few samples at ~250-200 years BP and may indicate a wet event during this time period. Microscopic charcoal pieces are present in all five zones, but tend to be more abundant before 3 ka. Filamentous green alga was present before 10 ka, indicating a lake or pond environment. Insect remains (e.g., chitin) were most abundant in zone M-2 and zone M-3.
4.5 Pollen Record

Pollen diagram for core TB07-1 is divided to six pollen zones based on CONISS dendrogram using the pollen types with a maximum abundance $>2\%$ (Figure 13). The basal zone P-1 (11.1-11 ka) has 50% Pinus, 30% Betula, $\sim$5% Picea, <10% Quercus, and low amounts of Tsuga, Alnus, Fraxinus, Populus, and other herbs and ferns. This zone represents the end of the spruce-dominated woodland before the Holocene (Deevey 1939; Watts 1979). Zone P-2 (11-9.8 ka) has 20-60% Pinus, 10-40% Quercus, 10% Tsuga, <5% Picea and Betula, and other herbs and ferns. This zone represents a mixed forest at
the very early Holocene. Zone P-3 (9.8-4.9 ka) is dominated by *Quercus* (50-60%) and *Tsuga* (~20%), with <10% of *Pinus, Betula, Fagus* and others, representing a mixed oak forest during the early Holocene. Compared with zone P-3, zone P-4 (4.9-2.9 ka) is characterized by the low *Tsuga* pollen to 0-2% and more *Pinus* (10-20%) and *Picea* (~5%) pollen and the presence of *Osmunda* spores. This zone represents a dry climate. In zone P-5 (2.9-0.22 ka), *Tsuga* pollen recovered to 10%, associated with an increase in *Picea, Carya, Fagus, Ericaceae, Nuphar, Salix, Poaceae* pollen and *Sphagnum* spores. The very top zone P-6 (0.22 ka-present) is characterized by a sudden increase in *Ambrosia, Ericaceae* and *Cyperaceae* pollen. *Sphagnum* spores are present almost throughout the profile but increase in the last 3000 years (to 15%).

The pollen concentration calculated for each zone at Tannersville Bog ranges from 20,000 to 500,000 grains/cm³ (Figure 14 and Table 2). The age-depth model and chronology in Figure 9 were used to calculate sedimentation rates and pollen accumulation rates ranging from 8,000 to 117,000 grains/cm²/yr (Table 2).
Figure 13. Pollen diagram of core TB07-1 at Tannersville Bog.
Table 2 Pollen concentration and accumulation rates from each pollen zone at Tannersville Bog.

<table>
<thead>
<tr>
<th>Pollen zone (this study)</th>
<th>New England pollen Zone (Deevey 1939)</th>
<th>Pollen concentration ($\times 10^3$ grains/cm$^3$)</th>
<th>Pollen accumulation rate ($\times 10^3$ grains/cm$^2$/yr)</th>
<th>Pollen accumulation rate at equivalent zones in Watts (1979) ($\times 10^3$ grains/cm$^2$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-6 (last 200 years)</td>
<td>Present</td>
<td>40</td>
<td>9</td>
<td>n/d</td>
</tr>
<tr>
<td>P-5 (mixed oak)</td>
<td>C3 (oak forest)</td>
<td>50-450</td>
<td>8</td>
<td>n/d</td>
</tr>
<tr>
<td>P-4 (hemlock decline)</td>
<td>C2 (hemlock minimum)</td>
<td>150</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>P-3 (pine minimum)</td>
<td>C1 (oak forest)</td>
<td>50-400</td>
<td>13</td>
<td>10-16</td>
</tr>
<tr>
<td>P-2 (pine peak)</td>
<td>B (mixed forest)</td>
<td>100-500</td>
<td>34</td>
<td>22</td>
</tr>
<tr>
<td>P-1 (mixed forest)</td>
<td>A (spruce woodland)</td>
<td>300</td>
<td>117</td>
<td>17</td>
</tr>
</tbody>
</table>
4.6 Testate Amoebae and Water Table Depth Reconstruction

Twenty-six testate amoebae taxa have been identified in the upper 3.4-m section (the last 2700 years) of Tannersville Bog core TB07-1 (Figure 15). The maximum abundance of each identified taxa is larger than 5%, though their abundance varied widely. Four zones were defined by stratigraphically constrained cluster analysis using CONISS, and descriptions of these zones are presented in Table 3.

Table 3 Testate amoeba zone descriptions for core TB07-1 at Tannersville Bog.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth (cm)</th>
<th>Age range (cal BP)</th>
<th>Dominant taxa</th>
<th>Zone description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-4</td>
<td>0-58</td>
<td>80 to -57</td>
<td><em>Hyalosphenia subflava</em>, <em>Nebela militaris/minor</em></td>
<td>Cyclopyxis-Phryganella, <em>Arcella discoides</em>, <em>Difflugia pulex</em>, <em>Euglypha</em> spp. and <em>Trigonopyxis arcula</em> are variably abundant in this zone.</td>
</tr>
<tr>
<td>A-3</td>
<td>58-85</td>
<td>200-80</td>
<td><em>Centropyxis aculeate</em>, <em>Hyalosphenia papilio</em></td>
<td><em>Amphitrema flavum</em> and <em>Hyalosphenia papilio</em> and <em>H. elegans</em> all increase, <em>Arcella discoides</em> decreases in abundance toward the top of the zone.</td>
</tr>
<tr>
<td>A-2</td>
<td>85-235</td>
<td>1400-200</td>
<td><em>Amphitrema flavum</em>, <em>Centropyxis aculeate</em>, <em>Hyalosphenia sphagni</em></td>
<td><em>Arcella discoides</em>, <em>Hyalosphenia papilio</em>, <em>H. subflava</em>, and <em>Nebela militaris/minor</em> are variably abundant in this zone. Taxa diversity increased while several species were present for short time period.</td>
</tr>
<tr>
<td>A-1</td>
<td>235-340</td>
<td>2670-1400</td>
<td><em>Centropyxis aculeate</em></td>
<td>The abundance of <em>Nebela griseola</em> is variable. Sixteen species present.</td>
</tr>
</tbody>
</table>
Figure 15 Testate amoebae diagram of core TB07-1 from Tannersville Bog.
The reconstructed water-table depth is shown in Figure 16. Zone A-1 (2670-1400 years BP) has a low water-table depth (5 cm), suggesting wet conditions. Zone A-2 (1400-200 years BP) has a low and fluctuated water-table depth (5-25 cm) compared to zone A-1. Zone A-3 (200-80 years BP) has an intermediate to low water-table depth of 16-7 cm. Zone A-4 (80 years BP – present) has the largest water-table depth of ~27 cm, suggesting the driest condition during the last 2700 years.

The water-table depths and the degree of peat humification show similar patterns although humification is more sensitive to the variation of substrate moisture conditions than testate amoebae is (Figure 16). Pollen, humification, and testate amoebae zones are also summarized in Figure 16. Pollen zone P-5 generally corresponds to testate amoeba zone A-1 and A-2 and hydrologic zone B-1 to B-3. Testate amoebae and humification both indicate that H-1 and A-1 (2300-1450 years BP) was the wettest time period in the last 2700 years, while pollen zone P-5 represents a recover of Tsuga abundance during this time period. Testate amoebae zone A-2 approximately includes hydrologic zones H-2, H-3 and part of zone H-4, except that H-2 (1460-960 years BP) started a few decades ahead of A-2. The major shift from wet to dry conditions from 1400 to 900 BP was recorded by both humification and testate amoebae. Zone H-4 (400 BP-present), corresponding to P-6 and A-3 & A-4, is characterized by fluctuating moisture conditions which is also indicated by testate amoebae-inferred water-table depth.
Figure 16 Testate amoeba-inferred water-table depth ($r^2 = 0.76$, RMSEP = 7.7) and peat humification-inferred paleohydrology of the upper 3.4-m section of core TB07-1. Gaps in testate amoeba-inferred water-table depth represent the intervals that reliable reconstructions can not be obtained due to low abundance of testate amoebae (amoebae sum < 50).

4.7 Diatom Abundance

The diatom concentration from the upper 340 cm peat core (the last 2700 years) shows large variations (Figure 17). Diatom has the highest concentrations up to $8 \times 10^6$ valves/cm$^3$ in the lower part of this section (2700-1400 years BP). From 1400 to 340 years BP, the concentrations are lower than 2000 valves/cm$^3$ or absent. From 340 to 230 years BP, diatom increased to high concentrations of 4000-8000 valves/cm$^3$. In the upper part of the sediment spanning the last 230 years, diatom valves are absent. The high abundance of diatom corresponded with the high abundance of brown moss macrofossils.
and the high carbonate content at 2700-1400 years BP and at 340-230 years BP, suggesting wet or open water environments.

![Diatom concentration counted from pollen/testate amoebae slides for the upper 3.4-m section of core TB07-1 (the last 2700 years).](image)

**Figure 17** Diatom concentration counted from pollen/testate amoebae slides for the upper 3.4-m section of core TB07-1 (the last 2700 years).

### 4.8 Conceptual Modeling Results

The cumulative peat mass-age profile over the last ~11 ka based on 11 calibrated $^{14}$C dates and 268 ash-free bulk density measurements shows a concave curve, similar to the patterns of oceanic bogs rather than continental fens (Figure 18). Fitted curves from different intervals and estimated parameters are shown in Table 4. Both peat-addition rates ($p$) and catotelm decomposition rates ($\alpha$) increased with shorter length of records analyzed, from 129 g m$^{-2}$ yr$^{-1}$ and 0.00023 yr$^{-1}$ (for the last 10 ka) to 233 g m$^{-2}$ yr$^{-1}$ and 0.00079 yr$^{-1}$ (for the last 2 ka).
**Figure 18** Cumulative peat mass-age profile and fitting curves for Tannersville Bog. The values of corresponded parameters are listed in Table 4.

**Table 4** Estimates of long-term peat accumulation parameters (peat-addition rate and decomposition rate) by using a curve fitting analysis.

<table>
<thead>
<tr>
<th>Age range (ka BP)</th>
<th>( p ) (g m(^2) yr(^{-1}))</th>
<th>( \alpha ) (yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-0</td>
<td>129.2</td>
<td>2.3 \times 10^{-4}</td>
</tr>
<tr>
<td>10-0</td>
<td>152.2</td>
<td>3.1 \times 10^{-4}</td>
</tr>
<tr>
<td>8.1-0</td>
<td>174.4</td>
<td>4.0 \times 10^{-4}</td>
</tr>
<tr>
<td>4.8-0</td>
<td>198.9</td>
<td>5.4 \times 10^{-4}</td>
</tr>
<tr>
<td>2-0</td>
<td>232.6</td>
<td>7.9 \times 10^{-4}</td>
</tr>
</tbody>
</table>
4.9 Second Core (TB06-2)

The results of the 4-m core TB06-2 illustrate similar shifts in peat composition and bulk density in the upper 4-m section (the last ~4000 years) of the core TB07-1 (Figure 19: a-c). The C/N ratio is relatively low for the lower ~250 cm and becomes higher in the top 150 cm when *Sphagnum* moss became dominant (Figure 19: d, e). This implies the degree of decomposition became lower as the dominant vegetation changed from brown moss to *Sphagnum* moss, or the young peat experienced less decomposition. The macrofossil result also indicates the same vegetation transition from a rich fen to a poor fen at 2 m depth (~1.4 ka) associated with the shift of bulk density from high to low values (Figure 19e).

![Figure 19](image-url)  
*Figure 19* Lithology (moisture content, organic matter content, ash-free bulk density), C/N ratio, and plant macrofossil of core TB06-2 from Tannersville Bog (analyzed by the EES250 Terrestrial Ecosystem class in fall 2006).
5 Discussion

5.1 Peatland Development at Tannersville Bog

Tannersville Bog was initiated by the terrestrialization (lake infilling) of a glacial lake, as suggested by the abundance of non-carbonate minerals (i.e., silicate) (Figure 20) and the presence of aquatic fossils (e.g., green algae) and pollen (e.g., *Nuphar*) (Figure 12 and Figure 13). Gehris (1964) and Hirsch (1977) described the silty clay layer deposited beneath the peat in detail (see section 2). Both of the authors indicated that the peat is underlain by gray silty clay over bedrock at Tannersville Bog. Watts (1979) suggested that the lake-filling process started shortly after 8 ka and the "bog" (poor fen) environment had been established at about 4 ka. Peat initiation at Tannersville Bog might have responded to a warm climate in the early Holocene (Fisher et al. 1995). A gradual increase in organic matter content and presence of brown mosses from 11 to 9 ka (Figure 20) suggests increasing primary productivity of aquatic plants. Brown moss started to increase in abundance at 9 ka, probably extending laterally around the coring site.

During the period of 9 to 5 ka, the brown moss leaves and stems dominated the macrofossil records at Tannersville Bog, while oak and hemlock pollen reached their highest values (Figure 20). Organic matter content increased slowly with a gradual decrease in carbonate and silicate contents in the sediments, which suggests the establishment of a stable rich fen environment during this time period. Brown moss macrofossils decline and fine debris (detritus) increase (to >90%) from 5 to 2.7 ka
(Figure 20), suggesting high decomposition during a dry climate interval. This time period corresponded with the decline of hemlock pollen from 5.5 to 3 ka, the slight increase in organic matter content and decrease in silicate content at Tannersville Bog. The decline of hemlock pollen has been documented in many studies (e.g., Foster et al. 2006), which corresponded with a dry time period inferred from low lake levels in northeastern North America (e.g., Yu et al. 1997). For example, it has been argued that this dry event was affected a dry climate at mid-Holocene which was driven by the change in atmospheric circulation patterns in North America. After 2.7 ka, brown moss recovered to become the dominant plant, along with a slightly increased abundance of sedges.

The transition from a rich fen to a poor fen at ~1.4 ka was characterized by decreased brown mosses, increased sedges and Sphagnum, as well as decreased input of ground water, suggested by decreased carbonate content (Figure 20). The increased organic matter content and decreased bulk density during the transition were the result of decreased carbonate content and silicate content, as well as the slow decomposition of Sphagnum liters (van Breemen 1995; Verhoeven and Liefveld 1997). A decrease in hemlock at the same time implied a dry condition (Figure 20). Watts (1979) illustrated a very similar shift of organic matter content and an increase in oak pollen percentage at a comparable time around 1.4 ka at Tannersville Bog.
Figure 20 Correlation of lithology, plant macrofossil and pollen results core TB07-1 from Tannersville Bog.
5.2 Rates and Pattern of Carbon Accumulation

Long-term apparent rates of carbon accumulation range from 13.4 to 101.2 g C m$^{-1}$ yr$^{-1}$ (Figure 21), which were calculated from 268 ash-free bulk density measurements (Figure 10e) and peat vertical growth rates (Figure 9) using the average carbon content of peat organic matter (51.8%) derived from peatlands in continental western Canada (Vitt et al. 2000). The apparent rates at Tannersville Bog started an increasing trend from ~8 ka and reached the highest value in the last 400 years. The long-term (time weighted) average rate of carbon accumulation for core TB07-1 from Tannersville Bog is 27.2 g C m$^{-1}$ yr$^{-1}$ for the last 11.1 ka or 27.3 g C m$^{-1}$ yr$^{-1}$ for the last 8.2 ka. This value is higher than the rates of subarctic and boreal peatlands (Figure 21, Table 5), such as peatlands in western Canada (Vitt et al. 2000), eastern Canada (Roulet et al. 2007), Alaska (Cai and Yu unpublished data), northwestern Canada (Vardy et al. 2000), and Finland (Makila 1997; Makila et al. 2001).
Figure 21 Comparison of apparent carbon accumulation rates at Tannersville Bog and long term apparent rates of carbon accumulation (LORCA) from other peatlands. See Table 5 for details and references.
Table 5 Comparison of long-term rates of carbon accumulation (LORCA) at Tannersville Bog and other peatlands.

<table>
<thead>
<tr>
<th>Type</th>
<th>Site</th>
<th>Peatland Type</th>
<th>LORCA (gC/m²/yr)</th>
<th>Period (ka)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elev. (a.m.s.l.)</th>
<th>MAT (°C)</th>
<th>Precip. (mm)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical</td>
<td>Kalimantan, Indonesia</td>
<td>n/d</td>
<td>56.2</td>
<td>8.6-9.5</td>
<td>2°19'S</td>
<td>113°54'E</td>
<td>15</td>
<td>25-27</td>
<td>2700</td>
<td>Page et al. 2004</td>
</tr>
<tr>
<td>Temperate</td>
<td>Tannersville Bog, PA</td>
<td>Poor Fen</td>
<td>27.2</td>
<td>0.4-8.3</td>
<td>41°2'N</td>
<td>75°16'W</td>
<td>227</td>
<td>10.7</td>
<td>1256</td>
<td>This study</td>
</tr>
<tr>
<td>Boreal</td>
<td>Mer Bleue, ON</td>
<td>Bog</td>
<td>21.9</td>
<td>0.4-3</td>
<td>45°25'N</td>
<td>75°29'W</td>
<td>69</td>
<td>6</td>
<td>943</td>
<td>Roulet et al. 2007</td>
</tr>
<tr>
<td>Subarctic</td>
<td>Western Nunavut</td>
<td>Fen</td>
<td>14.5</td>
<td>8-0</td>
<td>64°43'N</td>
<td>105°35'W</td>
<td>n/d</td>
<td>-4</td>
<td>150</td>
<td>Vardy et al. 2000</td>
</tr>
<tr>
<td>Rich fen</td>
<td>Goldeye Lake, AB</td>
<td>Rich fen</td>
<td>25.5</td>
<td>0-10</td>
<td>52°27'N</td>
<td>116°12'W</td>
<td>427</td>
<td>3</td>
<td>540</td>
<td>Yu et al. 2006</td>
</tr>
<tr>
<td>Poor fen</td>
<td>Peatland Island, AK</td>
<td>Poor fen</td>
<td>32.3</td>
<td>0-9.3</td>
<td>58°21'N</td>
<td>135°40'W</td>
<td>n/d</td>
<td>5.2</td>
<td>2940</td>
<td>Gorham et al. 2003</td>
</tr>
<tr>
<td>Bog</td>
<td>Haukkasuo, Finland</td>
<td>Bog</td>
<td>22.3</td>
<td>0-10.4</td>
<td>60°49'N</td>
<td>26°57'E</td>
<td>54-59</td>
<td>4</td>
<td>600</td>
<td>Makila 1997</td>
</tr>
<tr>
<td>Canadian</td>
<td>Western CA</td>
<td>Fens</td>
<td>19.4</td>
<td>0-1</td>
<td>51-59°N</td>
<td>98-119°W</td>
<td>n/d</td>
<td>0-2</td>
<td>600</td>
<td>Vitt et al. 2000</td>
</tr>
<tr>
<td>Alaska</td>
<td>No Name Creek, AK</td>
<td>Poor fen</td>
<td>23.2</td>
<td>0-11</td>
<td>60°38'N</td>
<td>151°04'W</td>
<td>23</td>
<td>-2</td>
<td>431.8</td>
<td>This study</td>
</tr>
<tr>
<td>Siberian</td>
<td>Plotnikovo</td>
<td>Bog</td>
<td>40</td>
<td>0-9.7</td>
<td>56°50'N</td>
<td>78°25'E</td>
<td>130</td>
<td>0</td>
<td>500</td>
<td>Borren et al. 2004</td>
</tr>
<tr>
<td>Finland</td>
<td>Ruosuo mire</td>
<td>Mire</td>
<td>8</td>
<td>0-9.6</td>
<td>65°39'N</td>
<td>27°19'E</td>
<td>176</td>
<td>1</td>
<td>650</td>
<td>Makila et al. 2001</td>
</tr>
</tbody>
</table>

Notes: n/d = no data; Elev. = elevation; a.m.s.l. = meter above sea level; MAT = mean annual temperature; precip. = mean annual precipitation.
The high rate of carbon accumulation at Tannersville Bog could result from high primary production or low peat decomposition or both. The significant higher peat addition rate \((p)\) and similar peat decomposition rate \((a)\) at Tannersville Bog, compared to those in boreal peatlands (Table 6) (Clymo 1984; Yu et al. 2003), indicate that the higher primary production have more likely contributed to the high rate of carbon accumulation at Tannersville Bog, because of warmer and wetter climate characterizing temperate regions than that in boreal regions. Table 6 also shows that the net primary production of peatlands in temperate regions is around four times of the production of peatlands in boreal regions (Carroll and Crill 1997; Wieder et al. 2006).

Table 6 Comparison of peat addition rate and decomposition rate at Tannersville Bog with boreal peatlands, and net annual primary production in temperate and boreal regions.

<table>
<thead>
<tr>
<th>Peatland</th>
<th>Region</th>
<th>Peat addition rate ((p, \text{g m}^{-2} \text{yr}^{-1}))</th>
<th>Decomposition rate ((a, \text{yr}^{-1}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tannersville</td>
<td>Temperate</td>
<td>174</td>
<td>(4 \times 10^{-4})</td>
<td>This study</td>
</tr>
<tr>
<td>Bog, PA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Pinto</td>
<td>Boreal</td>
<td>26</td>
<td>(3.7 \times 10^{-4})</td>
<td>Yu et al. 2003</td>
</tr>
<tr>
<td>Fen, AB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>Boreal</td>
<td>(~50)</td>
<td>(10^4)</td>
<td>Clymo 1984</td>
</tr>
<tr>
<td>Siberian</td>
<td>Boreal</td>
<td>42</td>
<td>(10^{-5})</td>
<td>Borren et al. 2004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Net annual primary production of peatlands</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g m(^{-2}) yr(^{-1})</td>
<td>g C m(^{-2}) yr(^{-1})</td>
</tr>
<tr>
<td>Temperate</td>
<td>(~1800)</td>
<td>(~900)</td>
</tr>
<tr>
<td>Boreal</td>
<td>(~500)</td>
<td>(~250)</td>
</tr>
</tbody>
</table>
Temperature and moisture are the most important factors influencing the rates of carbon accumulation and decomposition. Temperature can affect carbon sequestration through controlling the processes of photosynthesis and respiration (Carroll and Crill 1997). The mean annual temperature at Tannersville Bog is much higher than all the boreal regions (Table 5), which may provide a favorable environment for plant growth under a longer growing season and shorter freezing season compared to boreal regions. Although higher decomposition rates have been expected under higher temperature in temperate region (Davidson and Janssens 2006), inferred decomposition rate at Tannersville Bog is similar to those of boreal peatlands (Table 6) which may be the result of a high and stable water table maintained by significantly higher and evenly distributed precipitation among seasons in northeastern Pennsylvania, and by the beneficial hydrology at Tannersville Bog such as the nearby stream and the partially floating property.

Precipitation controls the moisture available to vegetation and the water-table depth of peatlands which affects the anoxic decomposition and therefore carbon accumulation. Northeastern Pennsylvania has a mean annual precipitation of 1200-1600 mm (NOAA data), which is almost double of the precipitation at most of the boreal peatlands (Table 5). Gorham et al. (2003) reported a higher LORCA value of a poor fen from Peatland Island, Alaska (32.3 g C m\(^{-1}\) yr\(^{-1}\)) associated with a high annual precipitation of 2940 mm. A tropical peatland studied by Page et al. (2004) also has a
great value of annual precipitation (2700 mm) and a high LORCA of 56.2 g C m\(^{-1}\) yr\(^{-1}\), which appears to support the significant influence of precipitation on primary production and further the rate of carbon accumulation. Borren et al. (2004) reported a high LORCA of 40 g C m\(^{-1}\) yr\(^{-1}\) from a Siberian peatland (Table 5), with a peat addition rate similar to those for boreal peatlands (Table 6); but the peat-addition rate is 10 times lower than Tannersville Bog, probably due to low annual precipitation.

Besides the environmental controls of temperature and precipitation regimes on primary production and decomposition, some other environmental factors should also be considered during the processes of peat accumulation, including hydrology, microbial communities, nutrients, and light. Tannersville Bog has a watery pocket at the depth of 1.5-2 m which varies in thickness during the year (Maura Sullivan, 2008 personal communication). The floating character tends to have a high rate of peat accumulation due to the special hydrology (Campbell et al. 1997; Asada et al. 2005), which further influence the microbial communities and decomposition of the upper part of the peatland (Dickinson 1983). Nutrient availability is generally higher at minerotrophic fens than bogs, while competition for light tends to be high at sites with high productivity and low in peatlands lack of nutrients (Rydin and Jeglum 2006). The floating property of Tannersville Bog is suggested to contribute to the low decomposition indicated by the low humification (high transmittance) during the last 2000 years, comparing with other similar floating peatlands and non-floating peatlands in North America (Sousa 2008).
Therefore, the low decomposition during the late Holocene might also have contributed to the high carbon accumulation rates at this study site.

5.3 Autogenic and Allogenic Controls of Peatland Succession

It has been suggested that autogenic processes play a major role in the development of peatlands (hydroseral succession: aquatic $\rightarrow$ rich fen $\rightarrow$ poor fen $\rightarrow$ bog), such that the establishment of *Sphagnum* follows the transition to a bog eventually (Tansley 1939; Rydin and Jeglum 2006). However, many paleoecological studies on peatlands show that allogenic factors, such as climate change and human impact, can affect the pattern of change and the timing of the transitions along the classic pathway of peatland development (Walker 1970; Foster 1984; Campbell et al. 1997; Huber and Markgraf 2003; Booth et al. 2004). The transition at Tannersville Bog from a rich fen to a poor fen at $\sim$1.4 ka (Figure 22) was associated with the transition of testate amoebae and humification zones from A-1 to A-2 and H-1 to H-2, respectively. The association between plant macrofossil-inferred local vegetation change and testate amoebae and humification-inferred hydrologic change indicates that the transition of vegetation succession might have been triggered by allogenic factor such as hydrologic change at the study area. The decreased carbonate content might have resulted from a decreasing groundwater input to the peatland, which is also supported by the suppressed diatom frequency and the shift from wet to dry in humification-inferred moisture conditions (Figure 22).
A dry event at \(~1.3\) ka was inferred from a low lake level time period based on paleomagnetic records at White Lake in New Jersey (Li et al. 2007). This dry event might have corresponded with the hydrologic change (\(~1.4\) ka) at Tannersville Bog. Slight age offsets between these two records are probably within the uncertainties of radiocarbon dating at both sites. Li et al. (2007) suggested that the dry event with the other three low lake level records at about 3.0, 4.4 and 6.1 ka are likely a response to the cold periods in the North Atlantic Ocean occurred every 1500 years during the Holocene (Bond et al. 2001). Bond et al. (2001) observed this millennial-scale cycle from changes in proxies of drift ice measured in deep-sea sediments. They argued that a solar forcing mechanism may underlie at least the Holocene segment of the North Atlantic’s 1500-year cycle (Bond et al. 2001).

The spike of brown moss abundance at \(~200\) year BP (1750 AD) was associated with presence of diatoms and humification-inferred wet conditions (Figure 22). This spike simultaneously corresponded to the rise of *Ambrosia* (ragweed) pollen abundance during this time period (P-6) that marks the start of the European settlement of North America (Russell 1980; Willard et al. 2003). This short time period of wetness probably reflected the peatland response to the change in hydrology and surface water regimes that were induced by human activities such as deforestation (e.g., Campbell et al. 1997; e.g., Bunting et al. 1998; Lamentowicz et al. 2007). The study by Bunting et al. (1998) on Oil Well Bog in southern Ontario showed that when the upland forest was cleared by
European settlers (ca. AD 1830-1845), trees that colonized parts of the wetland was replaced by low shrub communities that dominated the area during wet periods before 500 BP, which suggested initially the wetland surface became wetter.
Figure 22 Summary graph of lithology (organic matter and carbonate content), apparent rate of carbon accumulation, plant macrofossil results, diatom concentration, humification, testate amoeba-inferred water-table depth, and zonation of macrofossil (M), humification (H), testate amoebae (A), and pollen (P), over the last 3500 years.
6 Conclusions and Implication

Peat accumulation at Tannersville Bog was initiated by the terrestrialization (lake infilling) of a glacial lake at ~9 ka with establishment of brown mosses in a rich fen. It shifted to a poor fen with abundant Cyperaceae and Sphagnum at ~1.4 ka and a Sphagnum-dominated poor fen at ~200 years BP.

As a boreal-type poor fen associated with a temperate climate, Tannersville Bog possesses a concave peat accumulation pattern, which is similar to the patterns of most oceanic bogs and different with those of most continental fens in boreal region, due to the warmer and wetter climate in temperate region. Apparent rates of carbon accumulation at Tannersville Bog range from 13.4 to 101.2 g C m\(^{-1}\) yr\(^{-1}\), in the last 10 ka, with a long term average rate of carbon accumulation of 27.2 g C m\(^{-1}\) yr\(^{-1}\). This value is higher than the rates of most northern peatlands in boreal and subarctic regions. The significant higher peat-addition rate (174 g m\(^{-2}\) yr\(^{-1}\)) and similar modeled peat decomposition rate (0.0004 yr\(^{-1}\)) at Tannersville Bog, compared to those in boreal peatlands, suggest that the high rate of carbon accumulation may have been caused by higher primary production. However, humification data is not consistent with this interpretation, and suggests that local hydrology (partially the floating condition) has maintained decomposition rates low at Tannersville Bog. Maybe both high production and low decomposition would explain the pattern best. More studies are needed on the same type of peatland to better understand the environmental controls on peat accumulation.
The dry event inferred by the decline of brown mosses and increase in fine organic debris from 5 to 2.7 ka suggest that the decline of hemlock pollen from 5.5-3 ka at Tannersville Bog might have been driven by a dry climate in North America, as documented elsewhere. The transition from a brown moss-dominated rich fen to a sedge and Sphagnum-dominated poor fen at Tannersville Bog at ~1.4 ka was characterized by i) increased organic matter content and decrease in diatoms; ii) low water table and high decomposition rates as inferred by testate amoebae and humification data; and iii) decrease in groundwater input suggested by low carbonate content. The timing of the transition is coincident with a low lake level event and a dry climate at nearby White Lake in northeastern New Jersey at ~1.3 ka (Li et al. 2007).

The high primary production at Tannersville Bog is likely due to the warmer and wetter climate in temperate regions compared to boreal regions, despite the possibilities of higher decomposition under a warmer climate and other possible environmental factors. This study implies that some types of northern peatlands can behave as carbon sinks under a warmer and wetter climate in the future. Based on observation and climatic modeling, projected warming in the 21st century is expected to be greatest at most high northern latitudes, and the increases in the amount of precipitation are very likely in high-latitudes (IPCC 2007 Synthesis Report). Under this scenario, northern peatlands that are similar to the carbon accumulation at Tannersville Bog are expected to behave as carbon sinks.
References


Foster, D. R. 1984. The dynamics of *Sphagnum* in forest and peatland communities in southeastern Labrador, Canada. *Arctic* 37, 133-140.


Langdon, P. G. and Barber, K. E. 2005. The climate of Scotland over the last 5000 years inferred from multiproxy peatland records: inter-site correlations and regional variability. *Journal of Quaternary Science* 20, 549-566.


Rydin, H., Gunnarsson, U. and Sundberg, S. 2006: The role of *Sphagnum* in peatland


Appendixes

1. Loss-on-ignition analysis results of core TB07-1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>H2O %</th>
<th>LOI@550%</th>
<th>Dry Bulk Density (g/cm³)</th>
<th>CaCO3 %</th>
<th>Silicates %</th>
<th>Ash-free Bulk Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>95.84</td>
<td>99.03</td>
<td>0.066</td>
<td>0.00</td>
<td>0.97</td>
<td>0.066</td>
</tr>
<tr>
<td>2</td>
<td>93.45</td>
<td>97.56</td>
<td>0.070</td>
<td>0.69</td>
<td>1.74</td>
<td>0.059</td>
</tr>
<tr>
<td>4</td>
<td>93.94</td>
<td>98.24</td>
<td>0.049</td>
<td>0.33</td>
<td>1.43</td>
<td>0.048</td>
</tr>
<tr>
<td>6</td>
<td>93.93</td>
<td>97.19</td>
<td>0.081</td>
<td>0.53</td>
<td>2.28</td>
<td>0.059</td>
</tr>
<tr>
<td>8</td>
<td>94.11</td>
<td>97.69</td>
<td>0.056</td>
<td>0.00</td>
<td>2.31</td>
<td>0.054</td>
</tr>
<tr>
<td>10</td>
<td>94.04</td>
<td>96.97</td>
<td>0.066</td>
<td>0.00</td>
<td>3.03</td>
<td>0.064</td>
</tr>
<tr>
<td>12</td>
<td>94.08</td>
<td>96.93</td>
<td>0.077</td>
<td>0.00</td>
<td>3.07</td>
<td>0.074</td>
</tr>
<tr>
<td>14</td>
<td>93.51</td>
<td>96.63</td>
<td>0.081</td>
<td>0.81</td>
<td>2.56</td>
<td>0.078</td>
</tr>
<tr>
<td>16</td>
<td>93.09</td>
<td>97.00</td>
<td>0.074</td>
<td>0.66</td>
<td>2.34</td>
<td>0.072</td>
</tr>
<tr>
<td>18</td>
<td>91.78</td>
<td>96.84</td>
<td>0.075</td>
<td>0.00</td>
<td>3.16</td>
<td>0.072</td>
</tr>
<tr>
<td>20</td>
<td>93.35</td>
<td>94.43</td>
<td>0.068</td>
<td>1.19</td>
<td>4.37</td>
<td>0.064</td>
</tr>
<tr>
<td>22</td>
<td>93.34</td>
<td>95.49</td>
<td>0.082</td>
<td>0.79</td>
<td>3.72</td>
<td>0.079</td>
</tr>
<tr>
<td>24</td>
<td>91.36</td>
<td>95.36</td>
<td>0.091</td>
<td>1.61</td>
<td>3.03</td>
<td>0.087</td>
</tr>
<tr>
<td>26</td>
<td>91.87</td>
<td>94.20</td>
<td>0.101</td>
<td>2.09</td>
<td>3.71</td>
<td>0.095</td>
</tr>
<tr>
<td>28</td>
<td>92.60</td>
<td>95.12</td>
<td>0.078</td>
<td>2.51</td>
<td>2.37</td>
<td>0.074</td>
</tr>
<tr>
<td>30</td>
<td>92.93</td>
<td>95.41</td>
<td>0.070</td>
<td>1.62</td>
<td>2.97</td>
<td>0.067</td>
</tr>
<tr>
<td>32</td>
<td>94.16</td>
<td>94.67</td>
<td>0.059</td>
<td>2.75</td>
<td>2.57</td>
<td>0.056</td>
</tr>
<tr>
<td>34</td>
<td>92.61</td>
<td>94.41</td>
<td>0.087</td>
<td>2.62</td>
<td>2.97</td>
<td>0.082</td>
</tr>
<tr>
<td>36</td>
<td>93.16</td>
<td>95.35</td>
<td>0.063</td>
<td>2.64</td>
<td>1.81</td>
<td>0.060</td>
</tr>
<tr>
<td>38</td>
<td>91.46</td>
<td>97.40</td>
<td>0.080</td>
<td>1.43</td>
<td>1.17</td>
<td>0.078</td>
</tr>
<tr>
<td>40</td>
<td>91.17</td>
<td>95.22</td>
<td>0.120</td>
<td>1.63</td>
<td>3.15</td>
<td>0.114</td>
</tr>
<tr>
<td>42</td>
<td>91.64</td>
<td>94.12</td>
<td>0.092</td>
<td>2.81</td>
<td>3.06</td>
<td>0.087</td>
</tr>
<tr>
<td>44</td>
<td>92.26</td>
<td>95.35</td>
<td>0.089</td>
<td>2.37</td>
<td>2.28</td>
<td>0.085</td>
</tr>
<tr>
<td>46</td>
<td>91.13</td>
<td>94.93</td>
<td>0.101</td>
<td>2.56</td>
<td>2.51</td>
<td>0.096</td>
</tr>
<tr>
<td>48</td>
<td>90.93</td>
<td>95.54</td>
<td>0.112</td>
<td>3.05</td>
<td>1.42</td>
<td>0.107</td>
</tr>
<tr>
<td>50</td>
<td>90.98</td>
<td>95.69</td>
<td>0.113</td>
<td>2.31</td>
<td>2.00</td>
<td>0.108</td>
</tr>
<tr>
<td>52</td>
<td>90.66</td>
<td>95.75</td>
<td>0.101</td>
<td>2.58</td>
<td>1.67</td>
<td>0.097</td>
</tr>
<tr>
<td>54</td>
<td>90.93</td>
<td>97.07</td>
<td>0.078</td>
<td>1.87</td>
<td>1.06</td>
<td>0.076</td>
</tr>
<tr>
<td>56</td>
<td>91.15</td>
<td>98.82</td>
<td>0.092</td>
<td>2.47</td>
<td>0.71</td>
<td>0.089</td>
</tr>
<tr>
<td>58</td>
<td>91.40</td>
<td>96.52</td>
<td>0.101</td>
<td>2.26</td>
<td>1.22</td>
<td>0.097</td>
</tr>
<tr>
<td>60</td>
<td>93.13</td>
<td>96.23</td>
<td>0.088</td>
<td>1.90</td>
<td>1.88</td>
<td>0.096</td>
</tr>
<tr>
<td>62</td>
<td>92.03</td>
<td>97.09</td>
<td>0.088</td>
<td>2.20</td>
<td>0.70</td>
<td>0.086</td>
</tr>
<tr>
<td>64</td>
<td>92.20</td>
<td>96.56</td>
<td>0.083</td>
<td>2.35</td>
<td>1.09</td>
<td>0.080</td>
</tr>
<tr>
<td>66</td>
<td>93.36</td>
<td>97.60</td>
<td>0.062</td>
<td>2.60</td>
<td>-0.20</td>
<td>0.081</td>
</tr>
<tr>
<td>68</td>
<td>93.20</td>
<td>97.29</td>
<td>0.069</td>
<td>1.89</td>
<td>0.81</td>
<td>0.087</td>
</tr>
<tr>
<td>70</td>
<td>92.92</td>
<td>97.97</td>
<td>0.077</td>
<td>1.26</td>
<td>0.77</td>
<td>0.076</td>
</tr>
<tr>
<td>72</td>
<td>91.39</td>
<td>97.27</td>
<td>0.084</td>
<td>1.55</td>
<td>1.18</td>
<td>0.082</td>
</tr>
<tr>
<td>74</td>
<td>92.01</td>
<td>96.15</td>
<td>0.093</td>
<td>1.75</td>
<td>2.10</td>
<td>0.089</td>
</tr>
<tr>
<td>76</td>
<td>90.38</td>
<td>96.40</td>
<td>0.101</td>
<td>1.45</td>
<td>2.16</td>
<td>0.097</td>
</tr>
<tr>
<td>78</td>
<td>90.63</td>
<td>96.29</td>
<td>0.100</td>
<td>1.14</td>
<td>2.58</td>
<td>0.096</td>
</tr>
<tr>
<td>80</td>
<td>90.85</td>
<td>98.26</td>
<td>0.107</td>
<td>1.06</td>
<td>0.67</td>
<td>0.105</td>
</tr>
<tr>
<td>82</td>
<td>91.63</td>
<td>98.61</td>
<td>0.087</td>
<td>0.75</td>
<td>0.65</td>
<td>0.086</td>
</tr>
<tr>
<td>84</td>
<td>92.62</td>
<td>98.12</td>
<td>0.091</td>
<td>1.07</td>
<td>0.81</td>
<td>0.089</td>
</tr>
<tr>
<td>86</td>
<td>91.80</td>
<td>96.14</td>
<td>0.093</td>
<td>1.40</td>
<td>2.45</td>
<td>0.089</td>
</tr>
<tr>
<td>88</td>
<td>89.23</td>
<td>94.49</td>
<td>0.122</td>
<td>1.33</td>
<td>4.17</td>
<td>0.115</td>
</tr>
<tr>
<td>90</td>
<td>88.55</td>
<td>93.65</td>
<td>0.118</td>
<td>1.24</td>
<td>5.11</td>
<td>0.111</td>
</tr>
<tr>
<td>92</td>
<td>90.19</td>
<td>95.25</td>
<td>0.086</td>
<td>1.14</td>
<td>3.62</td>
<td>0.082</td>
</tr>
<tr>
<td>94</td>
<td>88.73</td>
<td>93.38</td>
<td>0.114</td>
<td>1.70</td>
<td>4.91</td>
<td>0.107</td>
</tr>
<tr>
<td>96</td>
<td>90.40</td>
<td>96.37</td>
<td>0.108</td>
<td>1.35</td>
<td>2.28</td>
<td>0.104</td>
</tr>
<tr>
<td>98</td>
<td>89.01</td>
<td>95.19</td>
<td>0.114</td>
<td>1.71</td>
<td>3.11</td>
<td>0.109</td>
</tr>
<tr>
<td>100</td>
<td>90.35</td>
<td>95.50</td>
<td>0.108</td>
<td>1.20</td>
<td>3.30</td>
<td>0.103</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>102</td>
<td>89.45</td>
<td>95.35</td>
<td>0.102</td>
<td>1.28</td>
<td>3.36</td>
<td>0.097</td>
</tr>
<tr>
<td>104</td>
<td>90.00</td>
<td>96.85</td>
<td>0.095</td>
<td>1.71</td>
<td>1.45</td>
<td>0.092</td>
</tr>
<tr>
<td>106</td>
<td>90.28</td>
<td>94.95</td>
<td>0.089</td>
<td>2.55</td>
<td>2.50</td>
<td>0.085</td>
</tr>
<tr>
<td>108</td>
<td>90.67</td>
<td>96.14</td>
<td>0.088</td>
<td>0.50</td>
<td>3.36</td>
<td>0.094</td>
</tr>
<tr>
<td>110</td>
<td>91.15</td>
<td>95.48</td>
<td>0.104</td>
<td>0.93</td>
<td>3.59</td>
<td>0.100</td>
</tr>
<tr>
<td>112</td>
<td>91.64</td>
<td>96.87</td>
<td>0.089</td>
<td>0.73</td>
<td>2.40</td>
<td>0.086</td>
</tr>
<tr>
<td>114</td>
<td>91.64</td>
<td>96.29</td>
<td>0.091</td>
<td>0.54</td>
<td>3.17</td>
<td>0.087</td>
</tr>
<tr>
<td>116</td>
<td>92.26</td>
<td>97.04</td>
<td>0.075</td>
<td>1.30</td>
<td>1.66</td>
<td>0.073</td>
</tr>
<tr>
<td>118</td>
<td>91.99</td>
<td>96.78</td>
<td>0.080</td>
<td>2.44</td>
<td>0.78</td>
<td>0.077</td>
</tr>
<tr>
<td>120</td>
<td>92.62</td>
<td>96.55</td>
<td>0.087</td>
<td>0.93</td>
<td>2.51</td>
<td>0.084</td>
</tr>
<tr>
<td>122</td>
<td>92.23</td>
<td>97.11</td>
<td>0.086</td>
<td>1.13</td>
<td>1.76</td>
<td>0.084</td>
</tr>
<tr>
<td>124</td>
<td>91.83</td>
<td>96.66</td>
<td>0.100</td>
<td>0.97</td>
<td>2.37</td>
<td>0.097</td>
</tr>
<tr>
<td>126</td>
<td>90.92</td>
<td>97.33</td>
<td>0.088</td>
<td>1.29</td>
<td>1.38</td>
<td>0.086</td>
</tr>
<tr>
<td>128</td>
<td>91.53</td>
<td>97.23</td>
<td>0.085</td>
<td>0.19</td>
<td>2.58</td>
<td>0.083</td>
</tr>
<tr>
<td>130</td>
<td>91.74</td>
<td>97.57</td>
<td>0.088</td>
<td>1.29</td>
<td>1.14</td>
<td>0.086</td>
</tr>
<tr>
<td>132</td>
<td>91.62</td>
<td>97.23</td>
<td>0.090</td>
<td>1.08</td>
<td>1.69</td>
<td>0.088</td>
</tr>
<tr>
<td>134</td>
<td>91.13</td>
<td>97.61</td>
<td>0.105</td>
<td>0.47</td>
<td>1.92</td>
<td>0.102</td>
</tr>
<tr>
<td>136</td>
<td>91.43</td>
<td>97.73</td>
<td>0.076</td>
<td>1.07</td>
<td>1.19</td>
<td>0.074</td>
</tr>
<tr>
<td>138</td>
<td>92.04</td>
<td>98.09</td>
<td>0.086</td>
<td>1.88</td>
<td>0.02</td>
<td>0.085</td>
</tr>
<tr>
<td>140</td>
<td>92.80</td>
<td>96.46</td>
<td>0.089</td>
<td>0.91</td>
<td>2.63</td>
<td>0.086</td>
</tr>
<tr>
<td>142</td>
<td>92.67</td>
<td>97.39</td>
<td>0.090</td>
<td>0.72</td>
<td>1.89</td>
<td>0.088</td>
</tr>
<tr>
<td>144</td>
<td>92.26</td>
<td>97.31</td>
<td>0.093</td>
<td>1.75</td>
<td>0.94</td>
<td>0.091</td>
</tr>
<tr>
<td>146</td>
<td>91.53</td>
<td>97.08</td>
<td>0.095</td>
<td>1.53</td>
<td>1.39</td>
<td>0.093</td>
</tr>
<tr>
<td>148</td>
<td>90.52</td>
<td>96.78</td>
<td>0.104</td>
<td>1.87</td>
<td>1.35</td>
<td>0.101</td>
</tr>
<tr>
<td>150</td>
<td>92.33</td>
<td>96.19</td>
<td>0.112</td>
<td>0.87</td>
<td>2.95</td>
<td>0.108</td>
</tr>
<tr>
<td>152</td>
<td>91.38</td>
<td>97.24</td>
<td>0.096</td>
<td>2.21</td>
<td>0.56</td>
<td>0.093</td>
</tr>
<tr>
<td>154</td>
<td>91.83</td>
<td>97.67</td>
<td>0.089</td>
<td>0.55</td>
<td>1.79</td>
<td>0.087</td>
</tr>
<tr>
<td>156</td>
<td>91.70</td>
<td>97.38</td>
<td>0.096</td>
<td>0.68</td>
<td>1.94</td>
<td>0.093</td>
</tr>
<tr>
<td>158</td>
<td>91.92</td>
<td>97.70</td>
<td>0.084</td>
<td>0.78</td>
<td>1.53</td>
<td>0.082</td>
</tr>
<tr>
<td>160</td>
<td>92.05</td>
<td>94.78</td>
<td>0.094</td>
<td>1.03</td>
<td>4.19</td>
<td>0.089</td>
</tr>
<tr>
<td>162</td>
<td>91.99</td>
<td>97.24</td>
<td>0.098</td>
<td>0.66</td>
<td>2.10</td>
<td>0.096</td>
</tr>
<tr>
<td>164</td>
<td>92.09</td>
<td>97.58</td>
<td>0.080</td>
<td>0.61</td>
<td>1.81</td>
<td>0.078</td>
</tr>
<tr>
<td>166</td>
<td>91.56</td>
<td>97.05</td>
<td>0.092</td>
<td>1.06</td>
<td>1.89</td>
<td>0.089</td>
</tr>
<tr>
<td>168</td>
<td>92.14</td>
<td>97.11</td>
<td>0.106</td>
<td>0.76</td>
<td>2.12</td>
<td>0.103</td>
</tr>
<tr>
<td>170</td>
<td>91.75</td>
<td>95.06</td>
<td>0.113</td>
<td>1.01</td>
<td>3.93</td>
<td>0.107</td>
</tr>
<tr>
<td>172</td>
<td>92.51</td>
<td>97.47</td>
<td>0.085</td>
<td>0.77</td>
<td>1.76</td>
<td>0.083</td>
</tr>
<tr>
<td>174</td>
<td>93.14</td>
<td>97.17</td>
<td>0.088</td>
<td>3.68</td>
<td>-0.85</td>
<td>0.086</td>
</tr>
<tr>
<td>176</td>
<td>92.20</td>
<td>97.15</td>
<td>0.093</td>
<td>2.98</td>
<td>-0.13</td>
<td>0.090</td>
</tr>
<tr>
<td>178</td>
<td>91.71</td>
<td>96.50</td>
<td>0.092</td>
<td>1.95</td>
<td>1.55</td>
<td>0.089</td>
</tr>
<tr>
<td>180</td>
<td>91.87</td>
<td>95.03</td>
<td>0.101</td>
<td>1.29</td>
<td>3.68</td>
<td>0.096</td>
</tr>
<tr>
<td>182</td>
<td>91.93</td>
<td>96.15</td>
<td>0.095</td>
<td>2.23</td>
<td>1.62</td>
<td>0.091</td>
</tr>
<tr>
<td>184</td>
<td>93.42</td>
<td>96.19</td>
<td>0.073</td>
<td>2.00</td>
<td>1.81</td>
<td>0.070</td>
</tr>
<tr>
<td>186</td>
<td>93.52</td>
<td>95.76</td>
<td>0.074</td>
<td>2.63</td>
<td>1.61</td>
<td>0.071</td>
</tr>
<tr>
<td>188</td>
<td>93.48</td>
<td>95.93</td>
<td>0.072</td>
<td>3.38</td>
<td>0.68</td>
<td>0.069</td>
</tr>
<tr>
<td>190</td>
<td>93.41</td>
<td>96.25</td>
<td>0.083</td>
<td>3.34</td>
<td>1.41</td>
<td>0.079</td>
</tr>
<tr>
<td>192</td>
<td>92.67</td>
<td>96.12</td>
<td>0.085</td>
<td>3.07</td>
<td>0.81</td>
<td>0.081</td>
</tr>
<tr>
<td>194</td>
<td>92.80</td>
<td>95.78</td>
<td>0.078</td>
<td>3.34</td>
<td>0.88</td>
<td>0.075</td>
</tr>
<tr>
<td>196</td>
<td>92.81</td>
<td>96.63</td>
<td>0.078</td>
<td>3.11</td>
<td>0.26</td>
<td>0.076</td>
</tr>
<tr>
<td>198</td>
<td>91.93</td>
<td>96.29</td>
<td>0.102</td>
<td>2.71</td>
<td>1.00</td>
<td>0.098</td>
</tr>
<tr>
<td>200</td>
<td>92.10</td>
<td>95.93</td>
<td>0.095</td>
<td>1.20</td>
<td>2.87</td>
<td>0.091</td>
</tr>
<tr>
<td>202</td>
<td>91.54</td>
<td>95.96</td>
<td>0.097</td>
<td>0.33</td>
<td>3.70</td>
<td>0.093</td>
</tr>
<tr>
<td>204</td>
<td>92.28</td>
<td>96.33</td>
<td>0.093</td>
<td>0.00</td>
<td>3.67</td>
<td>0.090</td>
</tr>
<tr>
<td>206</td>
<td>93.12</td>
<td>97.44</td>
<td>0.092</td>
<td>0.00</td>
<td>2.56</td>
<td>0.090</td>
</tr>
<tr>
<td>208</td>
<td>92.65</td>
<td>96.72</td>
<td>0.092</td>
<td>0.00</td>
<td>3.28</td>
<td>0.089</td>
</tr>
<tr>
<td>210</td>
<td>93.43</td>
<td>96.23</td>
<td>0.081</td>
<td>2.19</td>
<td>1.58</td>
<td>0.078</td>
</tr>
<tr>
<td>212</td>
<td>93.04</td>
<td>97.08</td>
<td>0.088</td>
<td>0.00</td>
<td>2.92</td>
<td>0.086</td>
</tr>
<tr>
<td>214</td>
<td>92.39</td>
<td>96.85</td>
<td>0.084</td>
<td>0.39</td>
<td>2.77</td>
<td>0.081</td>
</tr>
<tr>
<td>216</td>
<td>93.36</td>
<td>96.08</td>
<td>0.086</td>
<td>0.38</td>
<td>3.54</td>
<td>0.082</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>218</td>
<td>93.72</td>
<td>97.74</td>
<td>0.076</td>
<td>0.00</td>
<td>2.26</td>
<td>0.074</td>
</tr>
<tr>
<td>220</td>
<td>94.50</td>
<td>96.80</td>
<td>0.060</td>
<td>2.16</td>
<td>1.04</td>
<td>0.058</td>
</tr>
<tr>
<td>222</td>
<td>93.54</td>
<td>97.70</td>
<td>0.076</td>
<td>1.25</td>
<td>1.04</td>
<td>0.076</td>
</tr>
<tr>
<td>224</td>
<td>93.91</td>
<td>96.45</td>
<td>0.066</td>
<td>0.49</td>
<td>3.06</td>
<td>0.064</td>
</tr>
<tr>
<td>226</td>
<td>94.47</td>
<td>96.56</td>
<td>0.062</td>
<td>0.26</td>
<td>3.18</td>
<td>0.060</td>
</tr>
<tr>
<td>228</td>
<td>93.83</td>
<td>96.35</td>
<td>0.073</td>
<td>0.00</td>
<td>3.65</td>
<td>0.070</td>
</tr>
<tr>
<td>230</td>
<td>93.14</td>
<td>95.35</td>
<td>0.088</td>
<td>1.30</td>
<td>3.35</td>
<td>0.084</td>
</tr>
<tr>
<td>232</td>
<td>93.33</td>
<td>96.32</td>
<td>0.089</td>
<td>0.00</td>
<td>3.68</td>
<td>0.086</td>
</tr>
<tr>
<td>234</td>
<td>93.64</td>
<td>95.72</td>
<td>0.073</td>
<td>0.22</td>
<td>4.06</td>
<td>0.070</td>
</tr>
<tr>
<td>236</td>
<td>92.87</td>
<td>95.30</td>
<td>0.067</td>
<td>0.19</td>
<td>4.51</td>
<td>0.063</td>
</tr>
<tr>
<td>238</td>
<td>94.14</td>
<td>88.73</td>
<td>0.069</td>
<td>0.24</td>
<td>11.04</td>
<td>0.061</td>
</tr>
<tr>
<td>240</td>
<td>94.18</td>
<td>84.42</td>
<td>0.063</td>
<td>2.82</td>
<td>12.75</td>
<td>0.053</td>
</tr>
<tr>
<td>242</td>
<td>93.90</td>
<td>79.04</td>
<td>0.071</td>
<td>0.68</td>
<td>20.28</td>
<td>0.056</td>
</tr>
<tr>
<td>244</td>
<td>94.89</td>
<td>79.38</td>
<td>0.071</td>
<td>1.14</td>
<td>19.48</td>
<td>0.056</td>
</tr>
<tr>
<td>246</td>
<td>92.80</td>
<td>65.20</td>
<td>0.084</td>
<td>3.28</td>
<td>31.52</td>
<td>0.055</td>
</tr>
<tr>
<td>248</td>
<td>93.16</td>
<td>65.64</td>
<td>0.079</td>
<td>3.72</td>
<td>30.64</td>
<td>0.052</td>
</tr>
<tr>
<td>250</td>
<td>93.03</td>
<td>64.21</td>
<td>0.079</td>
<td>4.34</td>
<td>31.45</td>
<td>0.051</td>
</tr>
<tr>
<td>252</td>
<td>92.73</td>
<td>65.58</td>
<td>0.086</td>
<td>4.33</td>
<td>32.09</td>
<td>0.055</td>
</tr>
<tr>
<td>254</td>
<td>92.73</td>
<td>64.36</td>
<td>0.087</td>
<td>4.32</td>
<td>31.33</td>
<td>0.056</td>
</tr>
<tr>
<td>256</td>
<td>92.85</td>
<td>62.50</td>
<td>0.082</td>
<td>4.57</td>
<td>32.93</td>
<td>0.051</td>
</tr>
<tr>
<td>258</td>
<td>91.54</td>
<td>55.31</td>
<td>0.107</td>
<td>5.16</td>
<td>39.52</td>
<td>0.059</td>
</tr>
<tr>
<td>260</td>
<td>91.71</td>
<td>56.11</td>
<td>0.066</td>
<td>8.36</td>
<td>35.53</td>
<td>0.037</td>
</tr>
<tr>
<td>262</td>
<td>91.94</td>
<td>64.01</td>
<td>0.097</td>
<td>4.87</td>
<td>31.12</td>
<td>0.062</td>
</tr>
<tr>
<td>264</td>
<td>91.89</td>
<td>60.30</td>
<td>0.094</td>
<td>4.32</td>
<td>35.37</td>
<td>0.057</td>
</tr>
<tr>
<td>266</td>
<td>92.01</td>
<td>61.04</td>
<td>0.098</td>
<td>4.65</td>
<td>34.31</td>
<td>0.060</td>
</tr>
<tr>
<td>268</td>
<td>91.61</td>
<td>60.23</td>
<td>0.091</td>
<td>5.15</td>
<td>34.61</td>
<td>0.055</td>
</tr>
<tr>
<td>270</td>
<td>91.88</td>
<td>60.74</td>
<td>0.077</td>
<td>7.16</td>
<td>32.10</td>
<td>0.047</td>
</tr>
<tr>
<td>272</td>
<td>91.56</td>
<td>64.29</td>
<td>0.097</td>
<td>5.85</td>
<td>29.86</td>
<td>0.063</td>
</tr>
<tr>
<td>274</td>
<td>92.86</td>
<td>67.04</td>
<td>0.084</td>
<td>4.08</td>
<td>28.89</td>
<td>0.056</td>
</tr>
<tr>
<td>276</td>
<td>92.35</td>
<td>56.00</td>
<td>0.081</td>
<td>5.41</td>
<td>38.59</td>
<td>0.045</td>
</tr>
<tr>
<td>278</td>
<td>92.09</td>
<td>58.95</td>
<td>0.090</td>
<td>5.43</td>
<td>35.62</td>
<td>0.053</td>
</tr>
<tr>
<td>280</td>
<td>91.63</td>
<td>58.26</td>
<td>0.094</td>
<td>8.66</td>
<td>33.08</td>
<td>0.055</td>
</tr>
<tr>
<td>282</td>
<td>92.72</td>
<td>57.87</td>
<td>0.096</td>
<td>6.10</td>
<td>36.03</td>
<td>0.055</td>
</tr>
<tr>
<td>284</td>
<td>91.81</td>
<td>55.98</td>
<td>0.094</td>
<td>6.75</td>
<td>37.27</td>
<td>0.053</td>
</tr>
<tr>
<td>286</td>
<td>91.51</td>
<td>57.74</td>
<td>0.105</td>
<td>6.49</td>
<td>35.77</td>
<td>0.061</td>
</tr>
<tr>
<td>288</td>
<td>91.82</td>
<td>55.90</td>
<td>0.103</td>
<td>7.74</td>
<td>36.36</td>
<td>0.058</td>
</tr>
<tr>
<td>290</td>
<td>92.40</td>
<td>59.66</td>
<td>0.104</td>
<td>7.97</td>
<td>32.37</td>
<td>0.062</td>
</tr>
<tr>
<td>292</td>
<td>91.85</td>
<td>57.46</td>
<td>0.096</td>
<td>6.96</td>
<td>35.88</td>
<td>0.055</td>
</tr>
<tr>
<td>294</td>
<td>92.04</td>
<td>55.64</td>
<td>0.101</td>
<td>7.54</td>
<td>36.82</td>
<td>0.056</td>
</tr>
<tr>
<td>296</td>
<td>91.68</td>
<td>53.58</td>
<td>0.112</td>
<td>7.56</td>
<td>38.86</td>
<td>0.060</td>
</tr>
<tr>
<td>298</td>
<td>92.15</td>
<td>54.70</td>
<td>0.096</td>
<td>7.69</td>
<td>37.62</td>
<td>0.052</td>
</tr>
<tr>
<td>300</td>
<td>91.92</td>
<td>52.03</td>
<td>0.100</td>
<td>8.09</td>
<td>39.88</td>
<td>0.052</td>
</tr>
<tr>
<td>302</td>
<td>91.78</td>
<td>53.74</td>
<td>0.099</td>
<td>8.17</td>
<td>38.10</td>
<td>0.053</td>
</tr>
<tr>
<td>304</td>
<td>91.50</td>
<td>53.67</td>
<td>0.109</td>
<td>7.31</td>
<td>39.01</td>
<td>0.058</td>
</tr>
<tr>
<td>306</td>
<td>91.77</td>
<td>54.31</td>
<td>0.109</td>
<td>7.48</td>
<td>38.22</td>
<td>0.059</td>
</tr>
<tr>
<td>308</td>
<td>91.60</td>
<td>54.28</td>
<td>0.102</td>
<td>6.87</td>
<td>38.86</td>
<td>0.055</td>
</tr>
<tr>
<td>310</td>
<td>91.45</td>
<td>56.09</td>
<td>0.094</td>
<td>5.16</td>
<td>38.74</td>
<td>0.053</td>
</tr>
<tr>
<td>312</td>
<td>91.55</td>
<td>55.95</td>
<td>0.102</td>
<td>6.72</td>
<td>37.33</td>
<td>0.057</td>
</tr>
<tr>
<td>314</td>
<td>91.46</td>
<td>54.43</td>
<td>0.106</td>
<td>7.48</td>
<td>38.09</td>
<td>0.058</td>
</tr>
<tr>
<td>316</td>
<td>91.69</td>
<td>54.71</td>
<td>0.112</td>
<td>6.95</td>
<td>38.33</td>
<td>0.081</td>
</tr>
<tr>
<td>318</td>
<td>91.28</td>
<td>57.18</td>
<td>0.097</td>
<td>7.17</td>
<td>35.65</td>
<td>0.056</td>
</tr>
<tr>
<td>320</td>
<td>91.47</td>
<td>57.47</td>
<td>0.088</td>
<td>5.01</td>
<td>37.52</td>
<td>0.050</td>
</tr>
<tr>
<td>322</td>
<td>91.74</td>
<td>75.31</td>
<td>0.100</td>
<td>11.92</td>
<td>12.78</td>
<td>0.075</td>
</tr>
<tr>
<td>324</td>
<td>91.58</td>
<td>54.86</td>
<td>0.109</td>
<td>7.76</td>
<td>37.39</td>
<td>0.060</td>
</tr>
<tr>
<td>326</td>
<td>91.42</td>
<td>56.44</td>
<td>0.106</td>
<td>7.36</td>
<td>36.20</td>
<td>0.060</td>
</tr>
<tr>
<td>328</td>
<td>91.74</td>
<td>53.86</td>
<td>0.104</td>
<td>7.99</td>
<td>38.16</td>
<td>0.056</td>
</tr>
<tr>
<td>330</td>
<td>91.57</td>
<td>55.88</td>
<td>0.092</td>
<td>5.10</td>
<td>39.01</td>
<td>0.052</td>
</tr>
<tr>
<td>332</td>
<td>91.42</td>
<td>54.69</td>
<td>0.119</td>
<td>7.71</td>
<td>37.60</td>
<td>0.060</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>334</td>
<td>91.27</td>
<td>54.77</td>
<td>0.098</td>
<td>8.61</td>
<td>36.62</td>
<td>0.054</td>
</tr>
<tr>
<td>336</td>
<td>91.29</td>
<td>54.17</td>
<td>0.110</td>
<td>8.60</td>
<td>37.23</td>
<td>0.059</td>
</tr>
<tr>
<td>338</td>
<td>91.14</td>
<td>53.30</td>
<td>0.108</td>
<td>8.26</td>
<td>38.44</td>
<td>0.058</td>
</tr>
<tr>
<td>340</td>
<td>91.03</td>
<td>55.13</td>
<td>0.090</td>
<td>5.03</td>
<td>39.84</td>
<td>0.050</td>
</tr>
<tr>
<td>342</td>
<td>91.14</td>
<td>50.98</td>
<td>0.106</td>
<td>8.61</td>
<td>40.41</td>
<td>0.054</td>
</tr>
<tr>
<td>344</td>
<td>91.35</td>
<td>51.45</td>
<td>0.113</td>
<td>8.61</td>
<td>39.93</td>
<td>0.058</td>
</tr>
<tr>
<td>346</td>
<td>91.34</td>
<td>50.49</td>
<td>0.090</td>
<td>8.03</td>
<td>37.31</td>
<td>0.052</td>
</tr>
<tr>
<td>348</td>
<td>91.03</td>
<td>55.13</td>
<td>0.090</td>
<td>5.03</td>
<td>39.84</td>
<td>0.050</td>
</tr>
<tr>
<td>350</td>
<td>91.66</td>
<td>53.52</td>
<td>0.102</td>
<td>8.09</td>
<td>38.38</td>
<td>0.055</td>
</tr>
<tr>
<td>352</td>
<td>91.14</td>
<td>50.98</td>
<td>0.106</td>
<td>8.61</td>
<td>40.41</td>
<td>0.054</td>
</tr>
<tr>
<td>354</td>
<td>91.14</td>
<td>50.98</td>
<td>0.106</td>
<td>8.61</td>
<td>40.41</td>
<td>0.054</td>
</tr>
<tr>
<td>356</td>
<td>91.35</td>
<td>51.45</td>
<td>0.113</td>
<td>8.61</td>
<td>39.93</td>
<td>0.058</td>
</tr>
<tr>
<td>358</td>
<td>91.34</td>
<td>50.49</td>
<td>0.090</td>
<td>8.03</td>
<td>37.31</td>
<td>0.052</td>
</tr>
<tr>
<td>360</td>
<td>91.43</td>
<td>55.24</td>
<td>0.082</td>
<td>6.16</td>
<td>38.59</td>
<td>0.045</td>
</tr>
<tr>
<td>362</td>
<td>91.70</td>
<td>55.02</td>
<td>0.095</td>
<td>7.67</td>
<td>38.01</td>
<td>0.056</td>
</tr>
<tr>
<td>364</td>
<td>91.44</td>
<td>54.02</td>
<td>0.104</td>
<td>7.97</td>
<td>38.01</td>
<td>0.049</td>
</tr>
<tr>
<td>366</td>
<td>91.76</td>
<td>54.34</td>
<td>0.090</td>
<td>8.70</td>
<td>38.26</td>
<td>0.057</td>
</tr>
<tr>
<td>368</td>
<td>91.42</td>
<td>53.77</td>
<td>0.106</td>
<td>7.97</td>
<td>38.26</td>
<td>0.057</td>
</tr>
<tr>
<td>370</td>
<td>91.45</td>
<td>52.89</td>
<td>0.109</td>
<td>6.58</td>
<td>40.52</td>
<td>0.057</td>
</tr>
<tr>
<td>372</td>
<td>91.15</td>
<td>52.97</td>
<td>0.105</td>
<td>8.55</td>
<td>38.48</td>
<td>0.055</td>
</tr>
<tr>
<td>374</td>
<td>91.28</td>
<td>66.93</td>
<td>0.099</td>
<td>7.70</td>
<td>25.37</td>
<td>0.066</td>
</tr>
<tr>
<td>376</td>
<td>91.96</td>
<td>64.31</td>
<td>0.096</td>
<td>8.13</td>
<td>27.56</td>
<td>0.062</td>
</tr>
<tr>
<td>378</td>
<td>91.18</td>
<td>53.53</td>
<td>0.111</td>
<td>9.62</td>
<td>36.85</td>
<td>0.060</td>
</tr>
<tr>
<td>380</td>
<td>91.92</td>
<td>52.31</td>
<td>0.096</td>
<td>9.81</td>
<td>37.88</td>
<td>0.050</td>
</tr>
<tr>
<td>382</td>
<td>91.06</td>
<td>52.72</td>
<td>0.110</td>
<td>9.56</td>
<td>37.72</td>
<td>0.058</td>
</tr>
<tr>
<td>384</td>
<td>91.70</td>
<td>52.22</td>
<td>0.111</td>
<td>9.21</td>
<td>38.57</td>
<td>0.058</td>
</tr>
<tr>
<td>386</td>
<td>91.11</td>
<td>52.60</td>
<td>0.109</td>
<td>9.42</td>
<td>37.98</td>
<td>0.057</td>
</tr>
<tr>
<td>388</td>
<td>91.61</td>
<td>50.05</td>
<td>0.110</td>
<td>8.68</td>
<td>37.27</td>
<td>0.060</td>
</tr>
<tr>
<td>390</td>
<td>91.96</td>
<td>54.10</td>
<td>0.096</td>
<td>9.49</td>
<td>36.41</td>
<td>0.052</td>
</tr>
<tr>
<td>392</td>
<td>92.01</td>
<td>54.80</td>
<td>0.101</td>
<td>8.51</td>
<td>36.69</td>
<td>0.055</td>
</tr>
<tr>
<td>394</td>
<td>92.25</td>
<td>58.63</td>
<td>0.092</td>
<td>8.66</td>
<td>32.70</td>
<td>0.054</td>
</tr>
<tr>
<td>396</td>
<td>92.38</td>
<td>58.85</td>
<td>0.097</td>
<td>9.06</td>
<td>32.09</td>
<td>0.057</td>
</tr>
<tr>
<td>398</td>
<td>92.83</td>
<td>61.74</td>
<td>0.098</td>
<td>9.15</td>
<td>29.11</td>
<td>0.060</td>
</tr>
<tr>
<td>400</td>
<td>92.02</td>
<td>61.05</td>
<td>0.091</td>
<td>5.35</td>
<td>33.60</td>
<td>0.056</td>
</tr>
<tr>
<td>410</td>
<td>92.43</td>
<td>67.85</td>
<td>0.075</td>
<td>3.48</td>
<td>28.87</td>
<td>0.051</td>
</tr>
<tr>
<td>420</td>
<td>92.22</td>
<td>64.02</td>
<td>0.073</td>
<td>4.68</td>
<td>31.30</td>
<td>0.047</td>
</tr>
<tr>
<td>430</td>
<td>92.13</td>
<td>65.56</td>
<td>0.073</td>
<td>4.42</td>
<td>30.01</td>
<td>0.048</td>
</tr>
<tr>
<td>440</td>
<td>92.44</td>
<td>66.50</td>
<td>0.073</td>
<td>2.67</td>
<td>30.82</td>
<td>0.049</td>
</tr>
<tr>
<td>450</td>
<td>93.47</td>
<td>68.14</td>
<td>0.074</td>
<td>4.36</td>
<td>27.50</td>
<td>0.051</td>
</tr>
<tr>
<td>460</td>
<td>93.24</td>
<td>67.05</td>
<td>0.081</td>
<td>4.43</td>
<td>28.52</td>
<td>0.054</td>
</tr>
<tr>
<td>470</td>
<td>91.68</td>
<td>55.40</td>
<td>0.093</td>
<td>6.14</td>
<td>38.46</td>
<td>0.051</td>
</tr>
<tr>
<td>480</td>
<td>92.96</td>
<td>55.17</td>
<td>0.067</td>
<td>3.15</td>
<td>41.89</td>
<td>0.037</td>
</tr>
<tr>
<td>490</td>
<td>93.05</td>
<td>54.02</td>
<td>0.073</td>
<td>2.68</td>
<td>43.31</td>
<td>0.039</td>
</tr>
<tr>
<td>500</td>
<td>92.68</td>
<td>52.93</td>
<td>0.079</td>
<td>2.67</td>
<td>44.40</td>
<td>0.042</td>
</tr>
<tr>
<td>510</td>
<td>93.00</td>
<td>51.96</td>
<td>0.084</td>
<td>3.10</td>
<td>44.93</td>
<td>0.044</td>
</tr>
<tr>
<td>520</td>
<td>92.38</td>
<td>45.53</td>
<td>0.073</td>
<td>4.65</td>
<td>49.83</td>
<td>0.033</td>
</tr>
<tr>
<td>530</td>
<td>92.69</td>
<td>48.33</td>
<td>0.079</td>
<td>4.71</td>
<td>46.96</td>
<td>0.038</td>
</tr>
<tr>
<td>540</td>
<td>92.66</td>
<td>48.57</td>
<td>0.070</td>
<td>4.87</td>
<td>46.56</td>
<td>0.034</td>
</tr>
<tr>
<td>550</td>
<td>92.19</td>
<td>48.61</td>
<td>0.085</td>
<td>4.22</td>
<td>47.17</td>
<td>0.041</td>
</tr>
<tr>
<td>560</td>
<td>92.28</td>
<td>54.58</td>
<td>0.081</td>
<td>3.60</td>
<td>41.62</td>
<td>0.044</td>
</tr>
<tr>
<td>570</td>
<td>92.58</td>
<td>54.57</td>
<td>0.084</td>
<td>6.21</td>
<td>39.22</td>
<td>0.046</td>
</tr>
<tr>
<td>580</td>
<td>91.91</td>
<td>48.23</td>
<td>0.087</td>
<td>4.87</td>
<td>46.90</td>
<td>0.042</td>
</tr>
<tr>
<td>590</td>
<td>91.42</td>
<td>46.66</td>
<td>0.090</td>
<td>5.07</td>
<td>48.27</td>
<td>0.042</td>
</tr>
<tr>
<td>600</td>
<td>91.82</td>
<td>49.89</td>
<td>0.098</td>
<td>5.28</td>
<td>44.82</td>
<td>0.049</td>
</tr>
<tr>
<td>610</td>
<td>91.25</td>
<td>45.86</td>
<td>0.092</td>
<td>5.28</td>
<td>48.86</td>
<td>0.042</td>
</tr>
<tr>
<td>620</td>
<td>91.11</td>
<td>48.14</td>
<td>0.092</td>
<td>5.98</td>
<td>45.87</td>
<td>0.044</td>
</tr>
<tr>
<td>630</td>
<td>91.54</td>
<td>52.74</td>
<td>0.098</td>
<td>3.83</td>
<td>43.43</td>
<td>0.052</td>
</tr>
<tr>
<td>640</td>
<td>91.00</td>
<td>50.23</td>
<td>0.078</td>
<td>4.35</td>
<td>46.42</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>-----</td>
<td>-----</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>---</td>
</tr>
<tr>
<td>650</td>
<td>91.53</td>
<td>48.44</td>
<td>0.101</td>
<td>5.17</td>
<td>46.39</td>
<td>0.049</td>
</tr>
<tr>
<td>660</td>
<td>91.64</td>
<td>47.09</td>
<td>0.087</td>
<td>5.22</td>
<td>47.69</td>
<td>0.041</td>
</tr>
<tr>
<td>670</td>
<td>91.43</td>
<td>51.00</td>
<td>0.090</td>
<td>5.44</td>
<td>43.57</td>
<td>0.046</td>
</tr>
<tr>
<td>680</td>
<td>91.78</td>
<td>52.57</td>
<td>0.081</td>
<td>5.03</td>
<td>42.40</td>
<td>0.042</td>
</tr>
<tr>
<td>690</td>
<td>91.22</td>
<td>52.58</td>
<td>0.101</td>
<td>5.15</td>
<td>42.27</td>
<td>0.053</td>
</tr>
<tr>
<td>700</td>
<td>90.27</td>
<td>47.71</td>
<td>0.100</td>
<td>4.72</td>
<td>47.57</td>
<td>0.048</td>
</tr>
<tr>
<td>710</td>
<td>89.98</td>
<td>41.01</td>
<td>0.097</td>
<td>5.51</td>
<td>53.48</td>
<td>0.040</td>
</tr>
<tr>
<td>720</td>
<td>90.30</td>
<td>42.14</td>
<td>0.102</td>
<td>4.93</td>
<td>52.94</td>
<td>0.043</td>
</tr>
<tr>
<td>730</td>
<td>90.01</td>
<td>45.40</td>
<td>0.119</td>
<td>5.06</td>
<td>49.54</td>
<td>0.054</td>
</tr>
<tr>
<td>740</td>
<td>89.65</td>
<td>43.04</td>
<td>0.122</td>
<td>4.85</td>
<td>52.30</td>
<td>0.053</td>
</tr>
<tr>
<td>750</td>
<td>90.22</td>
<td>48.37</td>
<td>0.101</td>
<td>4.50</td>
<td>47.12</td>
<td>0.049</td>
</tr>
<tr>
<td>760</td>
<td>90.54</td>
<td>48.63</td>
<td>0.094</td>
<td>3.63</td>
<td>47.74</td>
<td>0.046</td>
</tr>
<tr>
<td>770</td>
<td>91.19</td>
<td>41.35</td>
<td>0.093</td>
<td>5.22</td>
<td>53.43</td>
<td>0.039</td>
</tr>
<tr>
<td>780</td>
<td>91.27</td>
<td>44.51</td>
<td>0.096</td>
<td>5.26</td>
<td>50.22</td>
<td>0.043</td>
</tr>
<tr>
<td>790</td>
<td>89.96</td>
<td>48.80</td>
<td>0.104</td>
<td>4.70</td>
<td>46.51</td>
<td>0.051</td>
</tr>
<tr>
<td>800</td>
<td>90.23</td>
<td>44.35</td>
<td>0.105</td>
<td>5.11</td>
<td>50.54</td>
<td>0.047</td>
</tr>
<tr>
<td>810</td>
<td>89.49</td>
<td>46.67</td>
<td>0.106</td>
<td>3.52</td>
<td>49.81</td>
<td>0.050</td>
</tr>
<tr>
<td>820</td>
<td>89.69</td>
<td>47.11</td>
<td>0.106</td>
<td>3.67</td>
<td>49.22</td>
<td>0.050</td>
</tr>
<tr>
<td>830</td>
<td>89.21</td>
<td>48.56</td>
<td>0.114</td>
<td>4.27</td>
<td>47.17</td>
<td>0.055</td>
</tr>
<tr>
<td>840</td>
<td>89.06</td>
<td>46.41</td>
<td>0.104</td>
<td>4.39</td>
<td>49.20</td>
<td>0.048</td>
</tr>
<tr>
<td>850</td>
<td>87.33</td>
<td>35.25</td>
<td>0.127</td>
<td>4.82</td>
<td>60.13</td>
<td>0.045</td>
</tr>
<tr>
<td>860</td>
<td>87.68</td>
<td>33.81</td>
<td>0.111</td>
<td>5.13</td>
<td>61.06</td>
<td>0.037</td>
</tr>
<tr>
<td>870</td>
<td>88.00</td>
<td>36.07</td>
<td>0.113</td>
<td>4.60</td>
<td>59.33</td>
<td>0.041</td>
</tr>
<tr>
<td>880</td>
<td>89.39</td>
<td>42.17</td>
<td>0.104</td>
<td>4.71</td>
<td>53.12</td>
<td>0.044</td>
</tr>
<tr>
<td>890</td>
<td>87.54</td>
<td>31.44</td>
<td>0.132</td>
<td>5.16</td>
<td>63.40</td>
<td>0.042</td>
</tr>
<tr>
<td>900</td>
<td>88.09</td>
<td>30.25</td>
<td>0.147</td>
<td>5.21</td>
<td>64.55</td>
<td>0.044</td>
</tr>
<tr>
<td>910</td>
<td>85.27</td>
<td>28.06</td>
<td>0.171</td>
<td>4.85</td>
<td>67.09</td>
<td>0.048</td>
</tr>
<tr>
<td>920</td>
<td>83.18</td>
<td>24.73</td>
<td>0.146</td>
<td>4.57</td>
<td>70.70</td>
<td>0.036</td>
</tr>
<tr>
<td>930</td>
<td>84.84</td>
<td>26.29</td>
<td>0.155</td>
<td>5.76</td>
<td>67.95</td>
<td>0.041</td>
</tr>
<tr>
<td>940</td>
<td>84.29</td>
<td>27.46</td>
<td>0.160</td>
<td>5.89</td>
<td>66.66</td>
<td>0.044</td>
</tr>
<tr>
<td>950</td>
<td>85.28</td>
<td>28.81</td>
<td>0.152</td>
<td>6.00</td>
<td>65.19</td>
<td>0.044</td>
</tr>
<tr>
<td>960</td>
<td>85.49</td>
<td>27.98</td>
<td>0.172</td>
<td>5.77</td>
<td>66.25</td>
<td>0.048</td>
</tr>
<tr>
<td>970</td>
<td>84.03</td>
<td>24.87</td>
<td>0.199</td>
<td>6.13</td>
<td>69.00</td>
<td>0.049</td>
</tr>
<tr>
<td>980</td>
<td>83.69</td>
<td>22.39</td>
<td>0.150</td>
<td>6.81</td>
<td>70.81</td>
<td>0.034</td>
</tr>
<tr>
<td>990</td>
<td>82.51</td>
<td>22.77</td>
<td>0.196</td>
<td>6.06</td>
<td>71.18</td>
<td>0.045</td>
</tr>
<tr>
<td>1000</td>
<td>78.96</td>
<td>19.59</td>
<td>0.197</td>
<td>4.69</td>
<td>75.72</td>
<td>0.039</td>
</tr>
<tr>
<td>1010</td>
<td>82.77</td>
<td>24.13</td>
<td>0.159</td>
<td>6.63</td>
<td>69.25</td>
<td>0.038</td>
</tr>
<tr>
<td>1020</td>
<td>83.33</td>
<td>25.81</td>
<td>0.150</td>
<td>6.81</td>
<td>67.38</td>
<td>0.039</td>
</tr>
<tr>
<td>1030</td>
<td>82.05</td>
<td>24.36</td>
<td>0.174</td>
<td>5.33</td>
<td>70.30</td>
<td>0.042</td>
</tr>
<tr>
<td>1040</td>
<td>79.83</td>
<td>18.91</td>
<td>0.196</td>
<td>5.22</td>
<td>75.87</td>
<td>0.037</td>
</tr>
<tr>
<td>1050</td>
<td>76.49</td>
<td>18.16</td>
<td>0.209</td>
<td>4.81</td>
<td>77.02</td>
<td>0.038</td>
</tr>
<tr>
<td>1060</td>
<td>76.74</td>
<td>18.15</td>
<td>0.224</td>
<td>5.09</td>
<td>76.77</td>
<td>0.041</td>
</tr>
<tr>
<td>1070</td>
<td>74.77</td>
<td>15.97</td>
<td>0.271</td>
<td>4.98</td>
<td>79.05</td>
<td>0.043</td>
</tr>
</tbody>
</table>
## 2. Plant macrofossil percentage data for core TB07-1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Detritus</th>
<th>Moss</th>
<th>Sphagnum Brown</th>
<th>Cyperacea Ligneous Wood</th>
<th>Picea Needle</th>
<th>Larix Needle</th>
<th>Leaves Ericaceae</th>
<th>Charcoal</th>
<th>Algae</th>
<th>Chitin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>85</td>
<td>0</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>80</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>45</td>
<td>45</td>
<td>0</td>
<td>5</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>80</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>45</td>
<td>30</td>
<td></td>
<td></td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>60</td>
<td>35</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>20</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>80</td>
<td>80</td>
<td>0</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>40</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>5</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>10</td>
<td>30</td>
<td>25</td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>60</td>
<td>10</td>
<td>25</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>22</td>
<td>20</td>
<td>60</td>
<td>60</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>24</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>20</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>26</td>
<td>20</td>
<td>65</td>
<td>65</td>
<td>0</td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>28</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>40</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>40</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>32</td>
<td>20</td>
<td>60</td>
<td>60</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>34</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>0</td>
<td>5</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>36</td>
<td>10</td>
<td>60</td>
<td>60</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>38</td>
<td>10</td>
<td>60</td>
<td>60</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>40</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>42</td>
<td>10</td>
<td>45</td>
<td>45</td>
<td>0</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>44</td>
<td>10</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>20</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>46</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>48</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>50</td>
<td>15</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>52</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>54</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>45</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>56</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>58</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>60</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>60</td>
<td>20</td>
<td>40</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>62</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>30</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>64</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>66</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>68</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>70</td>
<td>10</td>
<td>10</td>
<td>75</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>72</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>20</td>
<td>18</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>20</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>25</td>
<td>35</td>
<td>30</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>50</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>60</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>0</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>50</td>
<td>20</td>
<td>25</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>40</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>45</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>45</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>15</td>
<td>25</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>25</td>
<td>20</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>30</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>40</td>
<td>15</td>
<td>25</td>
<td>20</td>
<td>2.5</td>
<td>2.5</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>30</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>30</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>50</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>25</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>126</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>10</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>134</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>136</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>138</td>
<td>50</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>35</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>142</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>146</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>30</td>
<td>20</td>
<td>40</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>232</td>
<td>50</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>234</td>
<td>50</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>50</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>238</td>
<td>50</td>
<td>25</td>
<td>5</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>50</td>
<td>25</td>
<td>5</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>242</td>
<td>50</td>
<td>25</td>
<td>5</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>244</td>
<td>60</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>60</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>60</td>
<td>25</td>
<td>5</td>
<td>20</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>60</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>252</td>
<td>60</td>
<td>15</td>
<td>0</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>254</td>
<td>60</td>
<td>20</td>
<td>10</td>
<td>19</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>60</td>
<td>25</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>258</td>
<td>70</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>70</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>262</td>
<td>60</td>
<td>15</td>
<td>0</td>
<td>15</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>264</td>
<td>60</td>
<td>15</td>
<td>0</td>
<td>15</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>266</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>268</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>272</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>274</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>276</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>278</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>282</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>284</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>286</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>288</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>292</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>294</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>296</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>298</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>302</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>306</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>308</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>60</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

81
<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>312</td>
<td>80</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>314</td>
<td>80</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>316</td>
<td>80</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>318</td>
<td>80</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>320</td>
<td>70</td>
<td>15</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>322</td>
<td>80</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>324</td>
<td>80</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>326</td>
<td>80</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>328</td>
<td>80</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>330</td>
<td>85</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>332</td>
<td>80</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>334</td>
<td>80</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>336</td>
<td>85</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>338</td>
<td>85</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>340</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>342</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>344</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>346</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>348</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>350</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>352</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>354</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>356</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>358</td>
<td>85</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>360</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>362</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>364</td>
<td>85</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>366</td>
<td>90</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>368</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>370</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>372</td>
<td>90</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>374</td>
<td>85</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>376</td>
<td>90</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>378</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>380</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>382</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>384</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>386</td>
<td>90</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>388</td>
<td>95</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>390</td>
<td>95</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

82
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>760</td>
<td>80</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>770</td>
<td>85</td>
<td>2</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>780</td>
<td>90</td>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>790</td>
<td>90</td>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>800</td>
<td>90</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>810</td>
<td>90</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>820</td>
<td>95</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>830</td>
<td>95</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>840</td>
<td>95</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>850</td>
<td>90</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>860</td>
<td>95</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>870</td>
<td>95</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>880</td>
<td>95</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>890</td>
<td>90</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>900</td>
<td>80</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>910</td>
<td>70</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>920</td>
<td>70</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>930</td>
<td>80</td>
<td>5</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>940</td>
<td>85</td>
<td>6</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>950</td>
<td>90</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>960</td>
<td>95</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>970</td>
<td>95</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>980</td>
<td>95</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>990</td>
<td>95</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1000</td>
<td>98</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1010</td>
<td>98</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1020</td>
<td>97</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1030</td>
<td>98</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1040</td>
<td>96</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1050</td>
<td>95</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1060</td>
<td>98</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1070</td>
<td>98</td>
<td>0.5</td>
<td>1.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
4. Pollen count data for core TB07-1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Age (kcalBP)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td>30</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>40</td>
<td>46</td>
<td>7</td>
</tr>
<tr>
<td>50</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>60</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>70</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>80</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>90</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>110</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>120</td>
<td>37</td>
<td>19</td>
</tr>
<tr>
<td>130</td>
<td>47</td>
<td>13</td>
</tr>
<tr>
<td>140</td>
<td>54</td>
<td>18</td>
</tr>
<tr>
<td>150</td>
<td>63</td>
<td>15</td>
</tr>
<tr>
<td>160</td>
<td>70</td>
<td>17</td>
</tr>
<tr>
<td>170</td>
<td>78</td>
<td>20</td>
</tr>
<tr>
<td>180</td>
<td>87</td>
<td>15</td>
</tr>
<tr>
<td>190</td>
<td>96</td>
<td>16</td>
</tr>
<tr>
<td>200</td>
<td>105</td>
<td>18</td>
</tr>
<tr>
<td>210</td>
<td>114</td>
<td>25</td>
</tr>
<tr>
<td>220</td>
<td>125</td>
<td>7</td>
</tr>
<tr>
<td>230</td>
<td>134</td>
<td>42</td>
</tr>
<tr>
<td>240</td>
<td>143</td>
<td>23</td>
</tr>
<tr>
<td>250</td>
<td>152</td>
<td>21</td>
</tr>
<tr>
<td>260</td>
<td>161</td>
<td>22</td>
</tr>
<tr>
<td>270</td>
<td>170</td>
<td>23</td>
</tr>
<tr>
<td>280</td>
<td>180</td>
<td>18</td>
</tr>
<tr>
<td>290</td>
<td>190</td>
<td>24</td>
</tr>
<tr>
<td>300</td>
<td>200</td>
<td>19</td>
</tr>
<tr>
<td>310</td>
<td>210</td>
<td>24</td>
</tr>
<tr>
<td>320</td>
<td>220</td>
<td>29</td>
</tr>
<tr>
<td>330</td>
<td>230</td>
<td>29</td>
</tr>
<tr>
<td>340</td>
<td>240</td>
<td>18</td>
</tr>
<tr>
<td>350</td>
<td>250</td>
<td>24</td>
</tr>
<tr>
<td>360</td>
<td>260</td>
<td>19</td>
</tr>
<tr>
<td>370</td>
<td>270</td>
<td>15</td>
</tr>
<tr>
<td>380</td>
<td>280</td>
<td>21</td>
</tr>
<tr>
<td>390</td>
<td>290</td>
<td>14</td>
</tr>
<tr>
<td>400</td>
<td>300</td>
<td>10</td>
</tr>
<tr>
<td>410</td>
<td>310</td>
<td>16</td>
</tr>
<tr>
<td>420</td>
<td>320</td>
<td>19</td>
</tr>
<tr>
<td>430</td>
<td>330</td>
<td>24</td>
</tr>
<tr>
<td>440</td>
<td>340</td>
<td>27</td>
</tr>
<tr>
<td>450</td>
<td>350</td>
<td>13</td>
</tr>
<tr>
<td>460</td>
<td>360</td>
<td>17</td>
</tr>
<tr>
<td>470</td>
<td>370</td>
<td>11</td>
</tr>
<tr>
<td>480</td>
<td>380</td>
<td>7</td>
</tr>
<tr>
<td>490</td>
<td>390</td>
<td>4</td>
</tr>
<tr>
<td>500</td>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>510</td>
<td>410</td>
<td>5</td>
</tr>
<tr>
<td>520</td>
<td>420</td>
<td>2</td>
</tr>
<tr>
<td>530</td>
<td>430</td>
<td>7</td>
</tr>
<tr>
<td>540</td>
<td>440</td>
<td>9</td>
</tr>
<tr>
<td>550</td>
<td>450</td>
<td>2</td>
</tr>
<tr>
<td>560</td>
<td>460</td>
<td>7</td>
</tr>
<tr>
<td>570</td>
<td>470</td>
<td>11</td>
</tr>
<tr>
<td>580</td>
<td>480</td>
<td>17</td>
</tr>
<tr>
<td>590</td>
<td>490</td>
<td>1</td>
</tr>
<tr>
<td>600</td>
<td>500</td>
<td>7</td>
</tr>
<tr>
<td>610</td>
<td>510</td>
<td>4</td>
</tr>
<tr>
<td>620</td>
<td>520</td>
<td>9</td>
</tr>
<tr>
<td>630</td>
<td>530</td>
<td>16</td>
</tr>
<tr>
<td>640</td>
<td>540</td>
<td>13</td>
</tr>
<tr>
<td>650</td>
<td>550</td>
<td>17</td>
</tr>
<tr>
<td>660</td>
<td>560</td>
<td>10</td>
</tr>
<tr>
<td>670</td>
<td>570</td>
<td>12</td>
</tr>
<tr>
<td>680</td>
<td>580</td>
<td>13</td>
</tr>
<tr>
<td>690</td>
<td>590</td>
<td>9</td>
</tr>
<tr>
<td>700</td>
<td>600</td>
<td>16</td>
</tr>
<tr>
<td>710</td>
<td>610</td>
<td>15</td>
</tr>
<tr>
<td>720</td>
<td>620</td>
<td>18</td>
</tr>
<tr>
<td>730</td>
<td>630</td>
<td>19</td>
</tr>
<tr>
<td>740</td>
<td>640</td>
<td>17</td>
</tr>
<tr>
<td>750</td>
<td>650</td>
<td>14</td>
</tr>
<tr>
<td>760</td>
<td>660</td>
<td>12</td>
</tr>
<tr>
<td>770</td>
<td>670</td>
<td>13</td>
</tr>
<tr>
<td>780</td>
<td>680</td>
<td>18</td>
</tr>
<tr>
<td>790</td>
<td>690</td>
<td>20</td>
</tr>
<tr>
<td>800</td>
<td>700</td>
<td>12</td>
</tr>
<tr>
<td>810</td>
<td>710</td>
<td>24</td>
</tr>
<tr>
<td>820</td>
<td>720</td>
<td>15</td>
</tr>
<tr>
<td>830</td>
<td>730</td>
<td>20</td>
</tr>
<tr>
<td>840</td>
<td>740</td>
<td>14</td>
</tr>
<tr>
<td>850</td>
<td>750</td>
<td>15</td>
</tr>
<tr>
<td>860</td>
<td>760</td>
<td>24</td>
</tr>
<tr>
<td>870</td>
<td>770</td>
<td>15</td>
</tr>
<tr>
<td>880</td>
<td>780</td>
<td>18</td>
</tr>
<tr>
<td>890</td>
<td>790</td>
<td>13</td>
</tr>
<tr>
<td>900</td>
<td>800</td>
<td>12</td>
</tr>
<tr>
<td>910</td>
<td>810</td>
<td>19</td>
</tr>
<tr>
<td>920</td>
<td>820</td>
<td>24</td>
</tr>
<tr>
<td>930</td>
<td>830</td>
<td>15</td>
</tr>
<tr>
<td>940</td>
<td>840</td>
<td>18</td>
</tr>
<tr>
<td>950</td>
<td>850</td>
<td>12</td>
</tr>
<tr>
<td>960</td>
<td>860</td>
<td>13</td>
</tr>
<tr>
<td>970</td>
<td>870</td>
<td>15</td>
</tr>
<tr>
<td>980</td>
<td>880</td>
<td>18</td>
</tr>
<tr>
<td>990</td>
<td>890</td>
<td>13</td>
</tr>
<tr>
<td>1000</td>
<td>900</td>
<td>11</td>
</tr>
</tbody>
</table>

Note: The data is presented in a tabular format with Depth (cm) on the left and Age (kcalBP) on the top, with values in the middle.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Age (cal BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>0</td>
</tr>
<tr>
<td>1-2</td>
<td>0</td>
</tr>
<tr>
<td>2-3</td>
<td>0</td>
</tr>
<tr>
<td>3-4</td>
<td>0</td>
</tr>
<tr>
<td>4-5</td>
<td>0</td>
</tr>
<tr>
<td>5-6</td>
<td>0</td>
</tr>
<tr>
<td>6-7</td>
<td>0</td>
</tr>
<tr>
<td>7-8</td>
<td>0</td>
</tr>
<tr>
<td>8-9</td>
<td>0</td>
</tr>
<tr>
<td>9-10</td>
<td>0</td>
</tr>
<tr>
<td>10-11</td>
<td>0</td>
</tr>
<tr>
<td>11-12</td>
<td>0</td>
</tr>
<tr>
<td>12-13</td>
<td>0</td>
</tr>
<tr>
<td>13-14</td>
<td>0</td>
</tr>
<tr>
<td>14-15</td>
<td>0</td>
</tr>
<tr>
<td>15-16</td>
<td>0</td>
</tr>
<tr>
<td>16-17</td>
<td>0</td>
</tr>
<tr>
<td>17-18</td>
<td>0</td>
</tr>
<tr>
<td>18-19</td>
<td>0</td>
</tr>
<tr>
<td>19-20</td>
<td>0</td>
</tr>
<tr>
<td>20-21</td>
<td>0</td>
</tr>
<tr>
<td>21-22</td>
<td>0</td>
</tr>
<tr>
<td>22-23</td>
<td>0</td>
</tr>
<tr>
<td>23-24</td>
<td>0</td>
</tr>
<tr>
<td>24-25</td>
<td>0</td>
</tr>
<tr>
<td>25-26</td>
<td>0</td>
</tr>
<tr>
<td>26-27</td>
<td>0</td>
</tr>
<tr>
<td>27-28</td>
<td>0</td>
</tr>
<tr>
<td>28-29</td>
<td>0</td>
</tr>
<tr>
<td>29-30</td>
<td>0</td>
</tr>
<tr>
<td>30-31</td>
<td>0</td>
</tr>
<tr>
<td>31-32</td>
<td>0</td>
</tr>
<tr>
<td>32-33</td>
<td>0</td>
</tr>
<tr>
<td>33-34</td>
<td>0</td>
</tr>
<tr>
<td>34-35</td>
<td>0</td>
</tr>
<tr>
<td>35-36</td>
<td>0</td>
</tr>
<tr>
<td>36-37</td>
<td>0</td>
</tr>
<tr>
<td>37-38</td>
<td>0</td>
</tr>
<tr>
<td>38-39</td>
<td>0</td>
</tr>
<tr>
<td>39-40</td>
<td>0</td>
</tr>
</tbody>
</table>

**Testate amoeba count data for core TTB07-1**

- *Amphitretum flavum*  
- *A. pинтерum*  
- *Arcella arboresc*  
- *A. calinnus*  
- *A. discoides type*  
- *Assulina micoorum/semilunum*  
- *Buliminaria indica*  
- *Centropyxis aculeata*  
- *C. cassis type*  
- *Coryphton-Trinema type*  
- *Cyclopyxis-Phryganeia type*  
- *Difflugia pulex*  
- *D. oblonga*  
- *Euglypha spp.*  
- *Heliopera spp.*  
- *Hyalophasis elegans*  
- *H. papillo*  
- *H. subflava*  
- *Nebela carinata/marginata*  
- *N. fibulum*  
- *N. griseola*  
- *N. miliaris*  
- *N. tincta*  
- *Pseudodiffugia fascicularis*  
- *Trygonopyxis arcula*  

**Indeterminate**  

**Total**
6. Diatom count data for core TB07-1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Age (cal BP)</th>
<th>Diatom</th>
<th>Lycopodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-43</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>20</td>
<td>-26</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>30</td>
<td>-5</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>22</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>50</td>
<td>54</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>60</td>
<td>91</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>70</td>
<td>132</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>80</td>
<td>178</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>90</td>
<td>229</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>100</td>
<td>284</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>110</td>
<td>343</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>120</td>
<td>406</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>130</td>
<td>474</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>140</td>
<td>545</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>150</td>
<td>621</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>160</td>
<td>700</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>170</td>
<td>783</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>180</td>
<td>870</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>190</td>
<td>960</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>1054</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>210</td>
<td>1150</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>220</td>
<td>1251</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>230</td>
<td>1354</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>240</td>
<td>1460</td>
<td>133</td>
<td>9</td>
</tr>
<tr>
<td>250</td>
<td>1570</td>
<td>565</td>
<td>5</td>
</tr>
<tr>
<td>260</td>
<td>1682</td>
<td>781</td>
<td>12</td>
</tr>
<tr>
<td>270</td>
<td>1797</td>
<td>752</td>
<td>21</td>
</tr>
<tr>
<td>280</td>
<td>1914</td>
<td>1634</td>
<td>8</td>
</tr>
<tr>
<td>290</td>
<td>2034</td>
<td>685</td>
<td>14</td>
</tr>
<tr>
<td>300</td>
<td>2157</td>
<td>539</td>
<td>11</td>
</tr>
<tr>
<td>340</td>
<td>2669</td>
<td>85</td>
<td>2</td>
</tr>
</tbody>
</table>
Vita

Personal Information
Born: December 9th, 1979, Beijing, China
Parents: Cai, Jiming (Father) Zhang, Jing (Mother)

Education
Lehigh University, Bethlehem PA
M.S. Earth and Environmental Sciences, September 2008

University of Saskatchewan, Saskatoon, SK
M.S. Physical Geography, April 2006

Peking University, Beijing, China
B.S. Natural Resource & Environmental Ecology, July 2002

Research Experience
Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA
Teaching Assistant of an undergraduate course “earth system science”, January 2008 – May 2008;
Research Assistant, January 2007 – June 2008;
Department of Geography, University of Saskatchewan, Saskatoon, SK

Conferences Attended
October 1st - 2nd, 2004 Annual Meeting the Prairie Division of the Canadian Association of Geographers, St. Peter’s College, Muenster, Saskatchewan, Canada.

Professional Affiliations
Member of The American Association of Geographers, 2007- present
Member of the Canadian Association of Geographers, 2003 – 2006
END OF TITLE